

ABSTRACT

FELTNER, DAVID TRAVIS. Effect of Interface Design on User Performance and Cognitive Workload in Unmanned Aerial Vehicle Control Tasks. (Under the direction of Dr. David B. Kaber).

Unmanned Aerial Vehicles (UAVs) are becoming more prevalent in civilian and military applications, from delivering online shopping parcels to executing top-secret missions. Given their broad scope of application, UAVs present a unique set of human factors issues and considerations different than those applied to conventional manned flight systems. Interface control screens are complex, and convey a significant amount of important information to pilots. However, the human pilot has finite cognitive capabilities to process this information and display formats.

Piloting an UAV is a difficult task and can cause a significant workload, but a properly designed interface can moderate this workload and potentially improve performance. Researchers and designers need to evaluate and develop control interfaces that minimize operator workload, improve performance, and promote safe airspace. The present research evaluated an objective UAV interface evaluation tool for addressing the identified design need. Using the Modified Ergonomic Guideline for Supervisory Control Interface Design – Unmanned Aerial Vehicles (M-GEDIS-UAV), “baseline” and “enhanced” UAV control interfaces were prototyped and evaluated in experimental trials. Each of the interfaces yielded different M-GEDIS-UAV scores and were expected to produce different workload and performance outcomes.

Twenty-four participants took part in the experiment to determine the performance and workload implications of the two different interface designs across two vehicle speeds or scenario event rate conditions. The experiment followed a mixed factor design in which the two interface variations (Baseline and Enhanced) served as a between-subject factor and the two

speed levels (Fast and Slow) served as a within-subject factor. Exposure to the speed conditions was replicated to assess within-subject performance variability. The Enhanced Interface was created with optimal conformance to human factors and UAV domain specific standards while the Baseline Interface mimicked current commercial UAV interfaces. Each participant performed two slow and two fast scenarios with their assigned interface. A subjective workload rating was completed after each trial using the NASA-TLX (Task Load index). Objective response measures included accuracy and completion time for determining distance between objects in the airspace environment, fixing alarms, and identifying flight parameter deviations.

Results revealed interface type to be significant for all time measurements with the Enhanced Interface yielding faster completion times. Interface type was also significant for the Distance and Coordinate estimation tasks, but was negligible in alarm fixes. Interface type was not significant in workload, and speed was not significant for any Dependent Variable (DV). There was also a consistent trial number effect across multiple DVs, indicating a learning effect for participants throughout the experiment (despite extensive advance training).

These findings indicate that the M-GEDIS-UAV is sensitive to UAV control interface feature manipulations. The findings also indicate that the M-GEDIS-UAV can be used as a tool for selecting among interfaces to identify an alternative imposing lower cognitive workload. This finding was anecdotally supported by participant comments on interface usability but is confounded by the fact that neither interface was more robust across vehicle speed conditions. It is possible that the speed manipulation was not sufficient to reveal potential performance advantages of the enhanced control interface.

Overall, it was concluded that performance increased in use of the Enhanced Interface, which the M-GEDIS-UAV predicted by assigning it a higher evaluation score. The M-GEDIS-UAV tool shows promise for UAV interface workload prediction and additional research should be conducted to assess the tool with additional workload measures on expert UAV operators in high fidelity testing.

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Effect of Interface Design on User Performance and Cognitive Workload in Unmanned
Aerial Vehicle Control Tasks

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DEDICATION

I would like to take the time to dedicate this work to my Family, Friends, and fellow Soldiers whom all have supported me in different ways. To my Mom and Dad, thank you for instilling me the work ethic and drive I leaned on so often. Specifically, I would like to dedicate this work to Lisa, the love of my life, and my two little boys, Ryan and Josh, whom never fail to bring a smile to my face. I strive to set an example of lifelong learning, humility, and hard work – I work to make ya’ll proud.

BIOGRAPHY

David Feltner was born in Bamberg, SC on October 11, 1986. He grew up in Summerville, SC then moved to Puyallup, WA when he was ten years old. In 2004, he started his undergraduate degree at the United States Military Academy at West Point. He graduated with a Bachelor's of Science with Honors in Engineering Psychology from West Point in 2008. After graduation, he commissioned as an Infantry Officer with follow on assignments at Joint Base Lewis-McCord, Fort Benning, and Fort Campbell; during his service, he deployed in support of Operation Iraqi Freedom and twice in support of Operation Enduring Freedom / Operation Freedom's Sentinel. Given the opportunity to serve as a professor at West Point, he enrolled in the master's program at North Carolina State University's Edward P. Fitts Industrial & Systems Engineering Department with a focus on Human Factors and Ergonomics. He will graduate with a M.S.I.E. in May 2017 with a follow-on assignment as a professor in the Engineering Psychology Department at West Point.

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List of Abbreviations

ANOVA	Analysis of Variance
AOI	Area of Interest
CRD	Completely Randomized Design
DV	Dependent Variable
DOF	Degrees of Freedom
FAA	Federal Aviation Administration
ICC	Intra-class Correlation Coefficient
IV	Independent Variable
LP	Launch Point
MCDU	Multi-Control Display Unit
MCH UVD	Modified Cooper Harper – Unmanned Vehicle Device
M-GEDIS-UAV	Modified Ergonomic Guideline for Supervisory Control Interface Design – Unmanned Aerial Vehicles
NAI	Named Area of Interest
NAS	National Airspace System
NASA-TLX	NASA Task Load Index
NextGen	Next Generation Air Transportation System
PFD	Primary Flight Display
RCBD	Randomized Complete Block Design
SPD	Split Plot Design
UAV	Unmanned Aerial Vehicles

UAS Unmanned Aircraft Systems

WP Waypoint

1. Introduction

1.1 UAV State of the Art

In the 1990s, UAVs became a key component of high-tech military arsenals ranging from the U.S. and Europe, to Asia and the Middle East. UAVs have played key roles for US military forces deployed in many countries (Tvaryanas, Thompson, & Constable, 2006).

Currently, military and government agencies represent the major users of UAVs. There is a large call for the expansion of UAVs into a variety of domestic and commercial operations. With the potential for increased task efficiency and safety, unoccupied aircraft are growing in use to support a broad range of operations, including aerial photography, surveying land and crops, monitoring forest fires and other environmental conditions, and protecting borders and ports against intruders (Dorr & Duquette, 2010). With these applications in mind, the Federal Aviation Administration (FAA), along with many private agencies, is extensively investigating the integration of UASs into the National Airspace System (NAS), with safety at the forefront of the research. The Next Generation Air Transportation System (NextGen) is a major FAA initiative combining increased aviation automation with new procedures to achieve increased economic, safety, and security benefits by 2025 (Prevot, Lee, Smith, & Palmer, 2005). The NextGen system and the US Army's UAV System Roadmap 2010-2035 (US Army, 2010) have major implications for UAV operation and, as such, users have high expectations for UAV usability and mission accomplishment.

UAVs present a unique set of human factors issues and considerations different than those associated with conventional manned flight (Hobbs, 2010; Kaliardos & Lyall, 2014). Just like manned aircraft, UAVs require human interaction for negotiating unexpected

situations and decision making but operators are remote to the technology. Pilots rely entirely on visual displays to understand the state of the aircraft and the surrounding environment (Hobbs, Cardoza, & Null, 2015). Display interfaces represent critical interaction links between the human operator and machine. Supervisory control interfaces are a key technology for pilots to efficiently control vehicles. Interface screens are complex, and convey a significant amount of important information to pilots. However, the human pilot has finite cognitive capabilities to process the information being displayed. These human-machine systems are only as effective as the pilot's ability to process the information being presented at the control interface, despite the cutting edge technology enabling unmanned aviation. Therefore, it is imperative that UAV interfaces effectively support pilot information processing and control task performance.

Given the state-of-the-art in UAV technology, several research questions were formulated as a basis for a literature review. The questions included: (1) What are the current issues UAV pilots have with supervisory control interfaces? (2) What impact has control interface design had on UAV operation? (3) What studies have been completed on UAV interface design features in relation to cognitive workload? (4) What interface evaluation methods are currently used in UAV domains, and what are the benefits and limitations of each? These questions and their implications will be examined in the next section.

2. Literature Review

2.1 UAV Accident Data

Although UAV technology is continuously improving, the frequency of system failures is expected to rise due to increases in system complexity and opportunities for human and mechanical failures (Booher, 2003). Since 1986, the accident rate for unmanned aircraft has been significantly higher than for manned aircraft. In the period from 1986-2002, three types of unmanned aircraft operated by the US Military – Predator, Hunter, and Pioneer – were lost with accident rates of 32, 55, and 334 per 100,000 hours respectively (Department of Defense, 2003). This compares unfavorably with the rate for general aviation of approximately one accident per 100,000 hours. The accident rate for Predators has reduced significantly since 2002, but remains at about 10 times the general aviation rate (Nullmeyer & Montijo, 2009).

Williams (2004) reviewed all current information on US Military UAV accidents to determine to what extent human error contributed to those accidents, and to identify specific human factors involved in accidents. Personnel from the Safety Centers of the Army, Navy, and Air Force were contacted and they analyzed UAV operations, including Hunter, Shadow, Pioneer, Predator, and Global Hawk deployments. Accidents were classified into broad categories, based on whether the accident was related to human factors or was a failure of an aircraft component, and then further stratified within human factors issues. Accidents classified as being human factors-related were broken down into (a) human factors issues of alerts/alarms, (b) display design, (c) procedural error, (d) skill-based error, or (e) other. The percentage of involvement of human factors issues varied across aircraft from 21 % to 68 %,

and Williams (2004) postulated that many of the accidents could have been anticipated through an analysis of the interfaces used to control the vehicles and operating procedures. Most UAV control interfaces were not developed based on established aviation display concepts, and many of the mishaps reported involved a problem with the command interface to the system. Williams did not discuss further the specific issues found in interfaces, alluding only to a lack of adherence to current domain convention.

Related to the Williams (2004) study, Tvaryanas, Thompson, and Constable (2006) analyzed 10 years of unmanned aircraft mishaps in the US Military. A mishap was defined as an unplanned occurrence or series of occurrences, resulting in damage or injury (Tvaryanas & Thompson, 2008). In total, just over 60 % of mishaps were judged to involve human factors in one form or another, with slight differences occurring within each of the armed services. The Air Force UAS accidents included automation problems, inadequate instrumentation or feedback to the operator, and channelized attention. The primary human factors issues that the Army identified were lack of situation awareness, communication during alarm states, and cognitive overload, described as operators being unable to process pertinent information leading to errors. Tvaryanas et al. showed that pilots exhibited an over-reliance on textual information when experiencing cognitive overload, accompanied by underutilization to other interface features and mediums. Across all services, there were issues involving control interfaces that contributed to operator error. Specific issues, included poor decision support systems, poor workstation design, lack of interface enhancements, and absence of memory aids (Tvaryanas et al., 2006). These problems were

also identified as being prevalent across UAV platforms, across military branches, and to represent opportunities for UAV design improvements.

Yesilbas and Cotter (2014) reviewed over 300 US Air Force and Accident Investigation Board accident reports of UAV accident reports from 2000 to 2013. In line with Williams (2004) and Tvaryanas et al. (2006), the researchers suggested that about 60 % of the remotely piloted aircraft mishaps involved operation-related human casual factors. Based on the relatively stable accident rate over the years, and consistent identification of accident causal factors, this paper reinforced that the point that researchers and designers have data to use as a basis for improving UAV design and potentially preventing user errors. However, even though data may exist, the tools to help designers create the most effective interfaces and systems have either not been created, validated, or utilized when designing and fielding systems.

Giese, Carr, and Chahl (2014) conducted an analysis of all Air Force Predator mishaps over the past 15 years, attempting to determine the impact of human factors issues within these mishaps. Researchers used the official investigation reports from the US Air Force Accident Investigation Board and reviewed accidents that resulted in a fatality, loss of an aircraft, or property damage greater than \$2 million (Giese et al., 2014). Among 52 events reviewed, Giese et al. documented that 42 % of those mishaps involved human error as the main or a contributing cause. Moreover, 30 % of mishaps involving human error identified system design of technology (interfaces, guidance material, etc.) as a contributing factor in the accident. Endsley (2000) has previously observed that poor aviation system design has led to errors as a result of overloading operators with information, data presented in an

ineffective way, and excessive attention demands. For the Predator mishaps, in which poor technology design contributed to operational problems, two major areas of concern were the design of heads-up displays, along with warnings and cautions (Giese et al., 2014). This suggests that the interfaces between humans, computers, and aircrafts are not optimally designed for the tasks to be performed, especially in terms of accommodating user limitations. Giese et al.'s analysis did not further investigate pilot needs, or make any specific suggestions for optimizing interface designs.

Not surprisingly, operator flight experience has been shown to be an advantage when controlling an unmanned aircraft that requires stick and rudder inputs (Schreiber, Lyon, Martin & Confer, 2002). However, a lack of traditional flight experience may be less relevant for systems that are largely controlled via a computer interface (Barnes, Knapp, Tillman, Walters, & Velicky, 2000). Most UAV pilots do not have manned piloting experience, and teleoperate – remotely pilot – the UAV from afar using a computer-based interface (Cahillane, Baber, & Morin, 2012). The control interfaces are, therefore, intended to communicate all vehicle information to the pilot. This design intention places a significant burden on the designer and emphasizes the need for interface design tools.

A challenge common to all pilots teleoperating UAVs is the reduced set of perceptual cues available through control interfaces, as compared to an out-of-cockpit view in a manned aircraft. The pilot of a UAV is limited to perceiving information as presented by control interfaces and in the defined format of the interface; they are often deprived of rich surrounding environment cues as used by conventional pilots. The perceptual gulf between the operator and remote aircraft is illustrated by reports from US Military UAV pilots, who

were unaware they were receiving direct small arms fire until they saw fuel splash on the lens of an on-board camera (indicating a gross failure in pilot situation awareness). UAV interfaces need to provide system-state information and control action feedback to operators in order to support performance (Lam, Mulder, & Van Passen, 2007). The vehicle attack situation further illustrates the limitation of operator understanding of vehicle and environment states in terms of interface content as well as the necessity to design displays to reduce operator workload and maximize situation awareness.

Despite being referred to as “unmanned,” many of the major challenges facing UAVs relate to human factors and human limitations. For example, what information do UAV pilots need and how can it be presented in a cogent manner that does not overload pilot information processing capabilities? These are human factors issues that can provide an opportunity to optimize interface features or functions in order to facilitate high pilot performance. In the next section, UAV human factors studies are reviewed with a focus on how to properly design interfaces to moderate workload and reduce errors.

2.2 Current Human Factors Studies

The mounting interest for unmanned aviation is a direct result of demonstrated vehicle capabilities and potential in many fields. As existing unmanned aircraft automation technological has been fine-tuned for reliability, human factors issues in vehicle control have come to the forefront of systems design. Over the past 15 years, the human factors field has conducted a significant number of studies on UAV interfaces that have attempted to identify how control interfaces can be enhanced. These efforts have been aimed at improving performance and minimizing cognitive workload for operators.

Olson and Wuennenberg (2001) proposed that UAV interface design requirements must be developed for each level of autonomy, given that there is no one standard appropriate for all UAVs. With this in mind, they proposed a set of user interface design guidelines for supervisory control of UAVs. Automation behavior, such as system status and flight control functions, need to be highly visible to the operator to facilitate situation awareness. Users should find it easy to extract meaning from displays quickly; designers should minimize information access costs by highlighting relevant information and displaying information in appropriate formats (Olson & Wuennenberg, 2001). Designers should direct user attention to changes in system status by highlighting changes in relevant areas of displays and reducing time to detect a change by making the data more salient. Lastly, Olson and Wuennenberg (2001) recommended easy protocols for pilots to re-instruct an automated system or make it quick to change UAV actions as necessary. Olson and Wunnenberg's recommendations highlight the need for effective interface designs for users regardless of the specific UAV control task or level of automation.

Pedersen, Cooke, Pringle, and Connor (2006) documented the perspectives of two UAV operators, including vehicle piloting issues. There was no empirical work as part of this research; however, the identified issues represent expert opinions. The pilots identified some problematic interface designs, which could be easily fixed. The Predator interface was identified as causing eye fatigue by including red graphics on blue background or black lettering on a red background – this display led to extra stress and fatigue for the operator. Additionally, the interface symbology was not intuitive and caused operator reliance on knowledge in the head rather than knowledge in the world. This situation also created extra

stress for pilots in terms of the need to use working memory. Unfortunately, such interface designs have been tested, approved and fielded by the US Army with unresolved issues that compromised pilot performance. As seen from the perspective of expert users, there is a need to continue to iteratively improve the Predator system design. By addressing established human factors design standards in interfaces, such as that used to control the Predator, designers can decrease user workload and improve mission performance.

Calhoun and Draper (2006) conducted studies that hypothesized multisensory interfaces would improve UAV operator performance, and that awareness could be improved through sensory stimulation akin to that experienced by pilots in non-remote control settings. The researchers determined that visual interfaces could be augmented with synthetic views, effectively overlaying information on camera feeds. These synthetic views increased pilot situation awareness, reduced search time, and reduced workload. Moreover, tactile feedback on the control stick was used to cue pilots to the presence of turbulence. This tactile feedback improved landing accuracy, increased situation awareness, and reduced pilot workload. Calhoun and Draper (2006) showed that there are specific features of visual interfaces and physical controls that can be manipulated to increase performance and decrease operator workload.

Williams (2006) conducted an in-depth review of unmanned vehicle accidents, solely focusing on accidents that involved flight control. In a study of the Global Hawk UAV, Williams explained how the system was not designed to receive inputs from a pilot, as the design was intended to automate the user out of the system. The lack of capability for a pilot to set vehicle speed between waypoints led to infeasible aerial maneuvers and crashes of the

Global Hawk on runways. Similarly, Williams reviewed a Helios accident, another large scale UAV, where the control panel was not designed for pilots to input commands during exigent circumstances. The pilot was not able to navigate and prevent the loss of the vehicle during off-nominal conditions, resulting in the loss of multimillion-dollar aircraft. Williams concluded that improvements to the control interface – specifically the inputs and system feedback - could be used to decrease errors during use.

Drury, Richer, Rackliffe, and Goodrich (2006) compared situation awareness for two UAV interfaces in an attempt to mitigate shortcomings in pilot awareness due to a limited display field-of-view or “soda-straw” effect. The “soda-straw” effect is when the pilot loses an understanding of what is going on around them because they are only receiving inputs from a small view of the environment, as would be the case in viewing the world through a soda-straw. While doing a search and rescue task with an augmented interface, pilots felt they had a better understanding of their location in the environment and were able to more quickly and accurately execute tasks with the augmented visual interface. When provided contextual information via pre-loaded terrain data, pilots were better able to comprehend 3D spatial relationships between the UAV and points on a map. This increased spatial understanding significantly improved pilot performance in the search and rescue tasks, and simultaneously increased situation awareness and decreased mental workload.

Chen, Barnes, and Harper-Sciarini (2010) reviewed research pertaining to human performance issues in supervisory control of unmanned vehicles. Chen et al. determined that augmented reality, or synthetic vision, was an effective means by which to enhance pilot situation awareness, by portraying a more veridical view of the environment. Additional

contextual information about the surrounding terrain enhanced user spatial understanding and improved performance on search tasks across multiple platforms. Additionally, the researchers validated the recommendations set forth by Olson and Wunnenberg (2001) that interfaces should highlight changes and direct user attention to relevant areas of displays. Many UAV systems are highly automated and it is difficult for users to detect system state changes. By making system status abnormalities salient, interfaces can decrease operator workload under off-nominal situations when more resources need to be directed towards decision-making.

Neville, Blickensderfer, Archer, Kaste, and Luxion (2012) conducted a cognitive work analysis to identify human machine interface design requirements aimed at improving challenges unique to UAV pilots. The researchers adopted a multi-pronged approach to understand pilot difficulties in vehicle control. They conducted critical event interviews with 10 expert UAV pilots where the pilots ‘walked through’ the event from beginning to end; after completing the walkthrough, the researchers followed up with specific questions to better understand pilot actions and interactions with the vehicle. Additionally, the researchers observed operations at a Predator ground control station, analyzed mishap summaries and reviews, and had two UAV subject matter experts consult during the process. Through these methods, Neville et al. (2012) identified six overarching areas where human-machine interfaces could be improved, including: (a) better communication of status and environment information, (b) reduced demand on memory, (c) support for attention management, (d) more robust feedback-control loops, (e) improved error avoidance, detection, and recovery aids, and (f) support for information synthesis. Neville et al. also

identified what information should be available to users but did not provide specific design suggestions on how interfaces should deliver such information.

Lu et al. (2013) assessed the effect of a UAV situation-augmented display on pilot Level 3 situation awareness as compared to a conventional control display. The planned trajectory of the UAV was diagramed in a Cartesian space formed by two axes: altitude (vertical) and velocity (horizontal). The researchers hypothesized that if an abnormality occurred, the deviation could be more easily detected in the augmented display. Participants using the situation-augmented display were 2.67 seconds faster in detecting abnormalities than those using the conventional display. The effects of the situation-augmented display on abnormality detection were robust across different workload and noise levels. Detection of signal noise was not different for the two display types, suggesting the situation-augmented display gained its benefit in UAV performance without any extra cost to the secondary task.

Fuchs, Borst, de Groot, Van Paassen, and Mulder (2014) contended that most UAV studies focused on increasing the level of vehicle automation, and overlooked potential positive influences of visual interface information presentation. Fuchs et al. performed a work domain analysis and summarized the findings in an abstraction hierarchy model. Using this analysis, they created a set of visualization enhancements to help UAV operators identify deviations from mission, trace causes of deviations, and formulate alternative solutions. The researchers observed users in problem-solving activities and assessed the effectiveness of the enhancements. Through a post-test questionnaire, users considered coloring of flightpath waypoints, and the coloring of lines connecting waypoints to be useful (Fuchs et al., 2014). The work domain analysis and abstraction hierarchy model were considered to be powerful

tools for deciding what information to display on a interface – however, these tools did not inform the researchers of how to visualize the information on the interface.

Similar to Fuchs et al. (2014) disposition on UAV studies, Hobbs and Lyall (2016) offered that, despite advances in unmanned aviation, control station and interface design guidelines have not addressed some of the unique challenges faced by unmanned vehicle operators. From a review of existing technologies, the following design problems were identified across control interfaces: (a) a reliance on textual information, (b) complicated menu sequences to perform tasks, (c) unguarded safety-critical controls that could be accidentally activated, and (d) pop-up windows that could obscure pilot view of critical displays. Based off these design issues, they advocated for an augmentation of existing system design guidelines to address unique operational requirements. Hobbs and Lyall (2016) identified five types of information needed for expanding UAV guidelines, including: (a) task descriptions, (b) display requirements, (c) control requirements, (d) properties of the interface, and (e) general human factors principles. By developing and grouping guidelines in such a manner, UAV designers can be provided with a compiled source of domain-specific and generalizable criteria. There is a significant need in both commercial and military domains for a comprehensive set of UAV interface design guidelines.

Table 2.1 provides a summary of the findings of the above human factors studies identifying UAV interface deficiencies as well as their impact on pilot performance. These studies discussed overall design standards and some provided recommendations based on specific experiments and targeted at certain domains. One limitation of these studies is that there is no formalized and accepted process to quantitatively evaluate and compare different

UAV interface designs. The studies provide an empirical basis/approach for determining which interface may be better for operator performance and workload than another, but there is no comprehensive quantitative method that integrates the results of all these studies to justify the design of an UAV interface.

Table 2.1: Constrained Review of UAV Interface Design Deficiencies

Constrained Review of UAV Interface Design Deficiencies	Reference
Interfaces should highlight changes to the user.	Olson & Wunnenberg, 2001
Lack of design consistency across controls and displays as they were not designed off of established aviation principles.	Williams, 2004
Complicated multi-step sequences required to perform routine or time-critical tasks.	Williams, 2006
Non intuitive symbology; Improper color combinations; Physical implements that were not sized for a human hand.	Pedersen et al., 2006
Lack of feedback on pilot control inputs or system states.	Tvaryanas et al., 2006; Williams, 2006; Neville et al., 2012
Difficult to detect and correct errors.	Neville et al., 2012
Heavy reliance on memory to keep track of system status and flight plan details.	Neville et al., 2012; Pedersen et al., 2006
Waypoints not colored.	Fuchs et al., 2014
Reliance on text displays to the exclusion of other sources of information.	Hobbs & Lyall, 2016; Tvaraynas et al., 2006
Use of non-standard language in messages; Poor hierarchy of presentation; Complicated menus to perform critical or frequent tasks.	Hobbs & Lyall, 2016

2.3 Mental Workload Measures

Mental workload is an idea with which many are familiar and consider to be fundamentally complex; however, there are few clear definitions of the construct (Hancock & Meshkati, 1988). Humans have limited mental resources, and because of this fact, mental workload can be defined as the difference between the amount of available mental processing resources and cognitive task demands (Hart & Staveland, 1988). For instance, a routine task may require only 10% of a person's available resources; whereas, a very difficult task might require 90% of the same person's mental resources. Mental overload occurs when there are too few resources available to allocate to required tasks, increasing stress and errors; whereas, underload occurs when tasks consume too few available resources, increasing boredom. Both overload and underload can hinder overall performance (Nachreiner, 1995).

Mental workload can be measured using both subjective and objective measures. Subjective measures include self-report surveys, such as the Multiple Resource Questionnaire (Boles, Bursk, Phillips, & Perdelwitz, 2007) and the NASA Task Load Index (Hart & Staveland, 1988). Subjective measures are useful for determining how much workload a person "feels." Some research has also demonstrated utility of multidimensional rating scales to gain more information on the types of task demands that people perceive. The most common subjective measure of workload is the NASA-TLX. Although the measure requires substantial time to complete, it has been shown to be highly accurate (Miller, 2001). The NASA-TLX uses six dimensions to assess workload: (a) mental demand, (b) physical demand, (c) temporal demand, (d) performance, (e) effort, and (f) frustration. A respondent assigns a rating from 0-100 to each dimension (Hill et al., 1992). The ratings are

weighted based on paired comparisons of the various workload dimensions. Respondents choose which dimension is more relevant to workload for a particular task across all pairs of the six dimensions. The overall workload measure is obtained for a task by multiplying the weights by the individual dimension scale ratings, summing across scales, and dividing by the total weights. Generally, the NASA-TLX is useful multidimensional scale for measuring mental workload (Hill et al., 1992).

Within the UAV domain, Lu, Horng, and Chao (2013) demonstrated the effectiveness of the NASA-TLX. They used the NASA-TLX to compare workload responses in using a situation-augmented display for UAV monitoring task performance. They concluded that the new interface improved performance without increasing operator cognitive workload. Subjective mental workload measurements, like those collected by Lu et al., can provide insight into how respondents perceive demand, but typically must occur after completing a task or subtask. By taking the measurement after a task is complete, there is a gap in understanding of how mental workload may fluctuate during a task.

Objective metrics include measures of performance, spare mental capacity and physiological responses. Task performance represents how well a person accomplishes a task and is measured objectively by gauging error, efficiency, and/or accuracy when completing a task (Gawron, 2008). One of the problems associated with strictly using task performance as an indicator of workload is that it does not take into account spare mental capacity (Sirevaag et al., 1993). For example, two tasks may be performed equally, but one person's mental capacity may be pushed to its limits while another person's mental capacity is not pushed at all (De Waard, 1996). Another problem with using primary performance measures to

estimate workload is variation in motivation. When people are more motivated, their workload may increase, but their performance might not increase to the same extent (Vidulich & Wickens, 1986). Examples of task performance measures include how many times a person accomplishes a task or subtask, how long it takes, whether or not the task was successful, or how close the method of completion was to the correct method. It is also hard to measure changes to performance due to workload, unless the workload is high; changing from a “low” to “medium” level of workload probably will not produce a change in performance even though workload is increasing.

Spare mental capacity can be measured through secondary task performance (Gawron, 2008). Secondary tasks are separate from the primary work task and associated metrics, such as accuracy and speed of response, can be used to indicate levels of participant performance and mental workload. Secondary tasks can include activities such as memorization, simple math, counting, or answering questions while also performing the primary work task. Physiological metrics, such as heart rate, heart rate variability, and respiration rate have also been identified as indicators of mental workload or demand capacity (Miller, 2001). Although these measures can provide an indication of how workload may fluctuate over time, they are influenced by a broad range of demands, including both physical and cognitive activities, and, therefore, may not have the same level of diagnosticity as subjective measures.

2.4 Existing Interface Evaluation Methods

2.4.1 *Usability Testing*

Usability testing is broadly defined as focusing on user needs and using empirical measures to iteratively improve an interface (Nielsen, 1999). Usability testing is a highly-used method to assess whether an interface presents users with adequate functional features and whether they are easy to use (Dix, 2004). Usability testing involves a number of steps, including: (a) engaging real users in testing; (b) giving users real tasks to accomplish; (c) enabling testers to observe and record actions of users; (d) enabling testers to analyze data and make changes to interface designs; and (e) improving product usability. There are many different methods for testing usability, including heuristic analysis, cognitive walkthroughs, design experiments, etc. Methods measure learnability, efficiency, memorability, errors, and user satisfaction (Nielsen, 1999). Methods also vary in terms of using novices vs. experts. However, testing has proven to be powerful when applied iteratively to interface designs.

Cavett, Coker, Jimenez, and Yaacoubi (2007) leveraged persons with no manned or unmanned piloting experience to evaluate UAV interface designs. Eight participants conducted usability tests by performing missions and accomplishing discrete tasks with two different interfaces. Researchers watched and listened as the participants provided verbal protocols during the experiment. Cavett et al. measured how long it took to train participants to become proficient on the interface, the time to complete the tasks, number of errors for each task, and the level of satisfaction with the interface. Researchers also collected user preferences and comments on the interfaces. Although Cavett et al. did not re-design the

UAV interfaces, they developed information necessary to improve functions and features. They also proposed a follow-on experiment to test design revisions.

Experts are often relied upon to complete usability testing. Experts understand the tasks required to accomplish a mission and they have experience with nominal and off-nominal performance conditions. They can leverage these experiences to comment on potential system usability issues. Within the manned aviation domain, Kaber, Riley, and Tan (2002) conducted a usability inspection of commercial aircraft flight management system with expert pilots. The pilots assessed a multifunction control display unit interface in terms of usability principles. The expert pilot observations and assessments resulted in design recommendations that increased consistency among interface screens, thereby reducing pilot working memory requirements and cognitive workload.

Another common way that experts evaluate a system is through a heuristic evaluation. A heuristic evaluation requires examination of every aspect of an interface to ensure that it meets usability standards (Nielsen, 1993). Nielsen recommended having at least 3 evaluators perform an evaluation in isolation from each other using design heuristics, such as: (a) simple and natural dialogue, (b) speak the user's language, (c) minimize the user's memory load, (d) be consistent, (e) provide feedback, (f) provide clearly marked exits, (g) provide shortcuts, (h) provide good error messages, and (i) prevent errors. Each heuristic can be evaluated with ratings of "satisfied", "partially satisfied", and "not satisfied". Once complete, evaluators should come together and aggregate their findings. From these evaluations, a usability expert can predict performance – typically, the greater an interface adheres to design heuristics, the greater performance will be during use.

2.4.2 *Modified Cooper Harper – Unmanned Vehicle Device (MCH-UVD)*

The Modified Cooper-Harper (MCH) scale is a 10-point rating scale of workload (Hill et al., 1992). The MCH scale has been used to measure perceptual, cognitive, and communications workload. Generally, the MCH has been found to be a reliable estimator of overall mental workload. Currently, the FAA and the manned aviation domain accept the MCH as a valid measure of cognitive workload.

Cummings, Meyers, and Scott (2006) extended the MCH as a usability evaluation tool for application to unmanned vehicle devices (UVD), creating the MCH-UVD. The researchers used the same general approach to administration of the MCH but applied domain specific questions, shifting the emphasis away from evaluating physical controls of an aircraft, to evaluating how well displays support basic operator information processing. As shown in Figure 2.1, the MCH-UVD has 10 ratings separated into four distinct blocks. These ratings address stages of a human information processing model and acceptable display designs. Acceptable displays include two ratings: “good displays with negligible deficiencies”, and “excellent and highly desired displays”. A display receives a rating of 1 when the operator is not compensating for any deficient display properties. Displays receive a rating of 2 when they are considered to support information processing but have very minor preference issues that do not hinder pilot performance (Cummings et al., 2006). In their pilot study, Cummings et al. (2006) found that the MCH-UVD helped to identify what level of information processing and decision support interfaces provide to UAV operators – activities critical to most UAV missions.

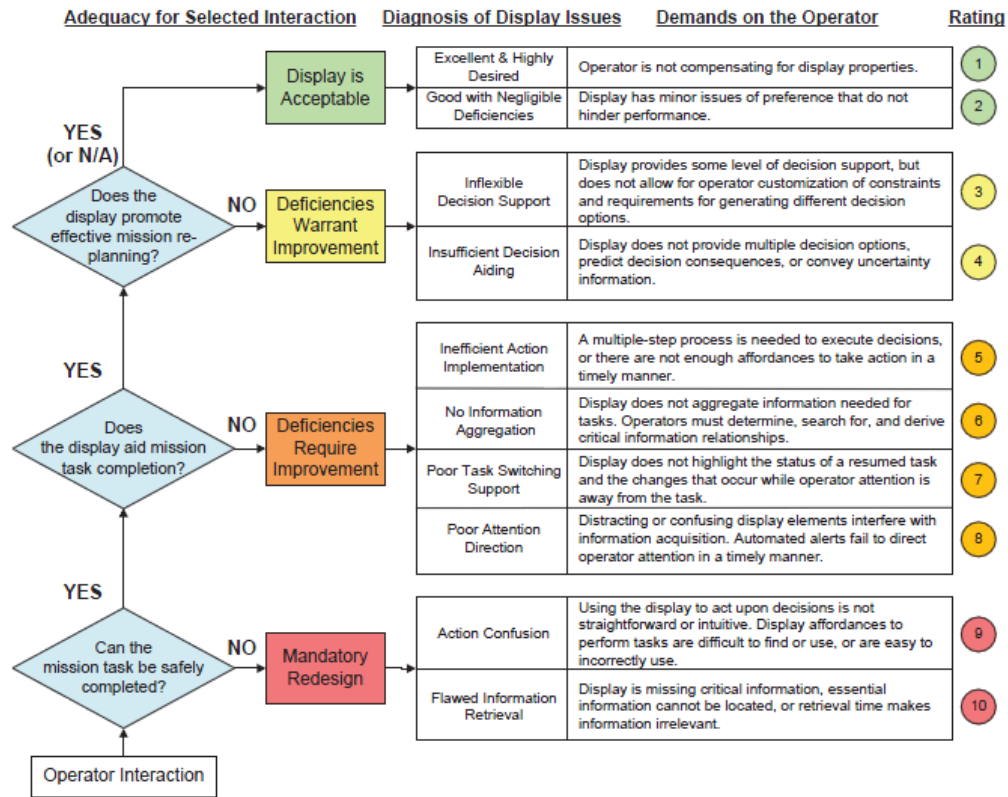


Figure 2.1: Modified Cooper Harper Scale for Unmanned Vehicle Displays

Donmez, Cummings, Brzezinski, and Graham (2010) empirically assessed the validity of the MCH-UVD by having 60 participants use the tool as a post-test survey in evaluation of two unmanned aerial and ground vehicle displays for performing multiple missions. Most participants (86 %) found the MCH-UVD to help them identify display deficiencies, and 32 % said they could not have identified deficiencies without the tool (Donmez et al., 2010). The tool provides UAV users with a higher level cognitive framework for evaluating an interface and is effective for identifying display issues. However, the MCH-UVD’s subjectivity leaves room for discrepancies between raters, and

fails to address the sensitivity and selectivity of the tool when used by experts and novices. Moreover, the MCH-UVD does not provide a designer with concrete criteria as a basis for either creating or re-configuring an interface to ensure that the design conforms to with established domain norms and findings of previous empirical studies.

2.4.3 *GEDIS-UAV*

Lorite, Munoz, Torner, Ponsa, and Pastor (2013) created the Ergonomic Guideline for Supervisory Control Interface Design – Unmanned Aerial Vehicles (GEDIS-UAV), which was intended to evaluate the usability of an UAV interface in an objective manner and to establish a “pedigree” for interface designs in terms of guidelines. Based on a set of industrial and domain specific guidelines, 10 design indicators (features) were identified to comprehensively evaluate interfaces, including: (a) architecture, (b) distribution, (c) navigation, (d) color, (e) text font, (f) status and devices, (g) process values, (h) graphs and tables, (i) data entry commands, and (j) alarms. Within each indicator, sub-indicators (feature characteristics) were identified to address domain specific resources as shown in Table 2.2. These indicators and sub-indicators are meant to provide a basis for comprehensively evaluating every aspect of a UAV interface by applying domain conventions and established HCI principles. The goal for the GEDIS-UAV evaluation tool is to help identify and correct common sub-optimal UAV interface designs for improving performance.

Table 2.2: GEDIS-UAV's Indicators and Sub-Indicators

A: Architecture		A	M	N.A	Specific Criteria
A1:	Division in areas	5	3	0	---
A2:	Screens number "sn"	---	---	---	$3 < sn < 9 = 5; n < 4 = 0$
B: Distribution		A	M	N.A	Specific Criteria
B1:	Model comparison	5	3	0	---
B2:	Flow process	5	3	0	---
B3:	Density	5	3	0	---
C: Navigation		A	M	N.A	Specific Criteria
C1:	Navigation between screens	5	3	0	---
D: Color		A	M	N.A	Specific Criteria
D1:	Absence of non-appropriate	---	---	---	Yes=5; No=0
D2:	Colors number "cn"	---	---	---	$cn < 4 = 5; cn > 4 = 0$
D3:	Blink absence	---	---	---	Yes=5; No=0
D4:	Screen contrast versus graphics	5	3	0	---
D5:	Colors number "cn"	5	3	0	---
E: Text Font		A	M	N.A	Specific Criteria
E1:	Font number "fn"	---	---	---	$fn < 4 = 5; fn > 4 = 0$
E2:	Absence of small fonts	---	---	---	Yes=5; No=0
E3:	Absence of non-appropriate	---	---	---	Yes=5; No=0
E4:	Abbreviation use	5	3	0	---
F: Status of the devices		A	M	N.A	Specific Criteria
F1:	Uniform icons and symbols	---	---	---	Yes=5; No=0
F2:	Status team representativeness	---	---	---	$lc < 4 = 5; lc > 4 = 0$
G: Process Values		A	M	N.A	Specific Criteria
G1:	Visibility	5	3	0	---
G2:	Location	5	3	0	---
H: Graphs and Tables		A	M	N.A	Specific Criteria
H1:	Format	5	3	0	---
H2:	Visibility	5	3	0	---
H3:	Location	5	3	0	---
H4:	Grouping	5	3	0	---
I: Data Entry Commands		A	M	N.A	Specific Criteria
I1:	Visibility	5	3	0	---
I2:	Usability	5	3	0	---
I3:	Feedback	5	3	0	---
J: Alarms		A	M	N.A	Specific Criteria
J1:	Visibility of alarms	5	3	0	---
J2:	Location	5	3	0	---
J3:	Situation awareness	---	---	---	Yes=5; No=0
J4:	Alarms grouping	5	3	0	---
J5:	Information to the operator	5	3	0	---

The GEDIS-UAV involves expert ratings of interface design conformance for each sub-indicator on a scale from 0 (inappropriate) to 5 (appropriate). An evaluation index for each indicator can be calculated based on the extent of interface conformance to sub-

indicators. Aggregate indicator scores can be used for a comparison of competing UAV interfaces. An overall score of 4 or more points for interface is considered as a criterion for “positive” design; designs with global scores of 3 or less should be considered “unacceptable” and re-designed to improve attributes yielding “inappropriate” scores. The global GEDIS-UAV score, along with the various indicator and sub-indicator scores, provides designers with specific feedback on where to focus design changes and interventions to promote usability (Lorite et al., 2013).

The GEDIS-UAV does, however, have some limitations that detract from its goal of objectively evaluating UAV interfaces. Zhang, Feltner, Shirley, Swangnetr, and Kaber (2016) observed limited justification for usage of the various design indicators, as they were directly taken from the industrial process control realm and failed to account for UAV domain specific interface features. Additionally, the sub-indicators (or interface characteristics) were not supported by detailed references to existing literature, making selection appear arbitrary in nature. Lastly, the scoring criteria was subjective and provided no justification for (or details on) the various levels of design conformance/deviation from guidelines. The determination of “Appropriate,” “Medium,” and “Non-Appropriate” ratings are subject to analyst personal preference (Zhang et al., 2016).

2.4.4 *Modified GEDIS-UAV (M-GEDIS-UAV)*

Zhang et al. (2016) used the concept of the GEDIS-UAV and addressed the above identified limitations (lack of justification of design indicators, sub-indicators, and scoring system) to create a new UAV interface usability evaluation method. The Modified GEDIS-UAV (M-GEDIS-UAV) was developed based on reference to UAV domain specific design

guidelines and general interface usability principles. The researchers identified required interface functions and necessary usability features as a comprehensive basis for evaluating UAV supervisory control interfaces. Zhang et al. followed a “bottom-up” approach to identifying interface design indicators/features by grouping established human factors and domain specific design criteria. They also used a “top-down” approach for organizing all indicators according to established usability heuristics. They ensured that all indicators were clearly defined and uniquely classified by heuristic without overlap among heuristics. The revised set of M-GEDIS-UAV macro-indicators include: (a) Display Layout, (b) Information Presentation, (c) Color, (d) Text, (e) Map and Navigation, (f) Status and Devices, (g) Data Entry Command, (h) Alarm, and (i) Physical Control (Zhang et al., 2016).

In order to develop a revised set of sub-indicators as part of the interface evaluation tool, the researchers leveraged knowledge within the UAV domain and combined that with other established human factors guidelines. Zhang et al. referenced: (a) the Human Factors Design Standard (HFDS), (b) Man Systems Integration Standard (NASA-STD 3000), (c) Nuclear Regulatory Guide (NUREG) 0700, (e) Military-Standard-1472, (f) Unmanned Aerial System Ground Control System Human-Machine Interaction (UAS GCS HMI) guide, (g) Joint Architecture for Unmanned Systems Human Machine Interaction (JAUS HMI) guide, and (h) Norwegian Technology Centre’s (NORSOK) guidelines. Some prior research has shown that established human factors standards for computer workstations and visual display terminals can be applied as bases for effective design of UAV control stations and interfaces (Waraich, Mazzuchi, Sarkani, and Rico, 2013). Therefore, Zhang et al. aligned these seven established human factors design guidelines within the overarching macro-indicators to

create sub-indicators for detailed assessment of interface design conformance. Related to this approach, Donmez et al. (2010) indicated that 15 % of users of the MCH-UVD suggested using a checklist to grade displays. Zhang et al. (2016) used the criteria from established guidelines to create a conformance checklist. Table 2.3 presents the set of sub-indicators, or design criteria, targeting color features of an interface along with the source reference for each criteria. Every other indicator (beyond color) has a separate spreadsheet and provides the evaluator with source material identification, in case further research is desired.

Table 2.3: M-GEDIS-UAV Color Indicator Score Sheet

Subindicator score	Subindicators	Conformance	ID	Criteria related to this sub-indicator	Reference
50%	Color Discrimination (CD)	NA	CD1	Colored symbols differ from their color background by an E distance (CIE Yu'v') of 100 units or more.	HFDS 8.6.2.2
		1	CD2	Users do not have to discriminate among colors in small areas.	HFDS 8.6.2.1.9
		0	CD3	Similar colors are used to convey similarity among items.	HFDS 8.6.2.5
NA	Color Luminance (CL)	NA	CL1	Luminance does not vary by more than 50% from the center to the edge of the display.	HFDS 5.2.2.1
		NA	CL2	Either characters or their background, whichever has higher luminance, has a luminance of at least 35 cd/m ² (10 fL).	HFDS 5.2.2.2
		NA	CL3	A control is provided for adjusting luminance from 10% of minimum ambient luminance to full luminance.	HFDS 5.2.2.1.4
NA	Color Contrast (CCT)	NA	CCT1	The contrast between the lowest intensity symbol and its background is a ratio from 1:1 to at least 16:1.	NASA-STD-3000 9.4.2.3.3.9
		NA	CCT2	For low ambient illumination applications, contrast is at least 90%.	NASA-STD-3000 9.4.2.3.1.2
		NA	CCT3	For low ambient illumination applications, the background luminance is less than the figure (text) luminance.	NASA-STD-3000 9.4.2.3.1.2
		NA	CCT4	The foreground color (and any embedded text) has a contrast ratio of at least 7:1 with the background color (e.g., a medium achromatic background like dark or medium grey should be used).	HFDS 8.6.2.6
62%	Color Use (CU)	1	CU1	Blue is not used as the foreground color.	HFDS 8.6.2.2.7
		1	CU2	When green, yellow, and red are used, they are used in combination with other visual cues, such as brightness or saturation.	HFDS 8.6.2.2.10
		0	CU3	When light images on a dark background are viewed extensively, the images are amber or green rather than white.	HFDS 8.6.2.2.11
		0	CU4	When colors are used for items in peripheral vision, blue, yellow, black, or white are used.	HFDS 8.6.2.3
		0	CU5	Red and green are not used for items located in peripheral vision.	HFDS 8.6.2.3
		0	CU6	The total number of colors used does not exceed four (4) for a single alphanumeric screen.	HFDS 8.6.2.7
		0	CU7	More than four (4) colors on a single alphanumeric screen are only used in special circumstances (e.g., map displays).	HFDS 8.6.2.7
		1	CU8	Any set of related alphanumeric screens does not use more than seven (7) total colors.	HFDS 8.6.2.7
		1	CU9	The use of color does not reduce screen readability.	HFDS 8.6.2.1.7
		NA	CU10	In case of an unknown target, color is not used if multiple other items in the display might be the same color as the target.	HFDS 8.6.2.1.12
		1	CU11	Colors used to present static information are not bright or highlighted.	HFDS 8.6.2.1 & NORSOK 4.4.4.2.4
		1	CU12	No more than six (6) distinct colors or shades of gray are used if the user must recall the meanings of colors or shades.	HFDS 8.6.2.7
		1	CU13	No more than six (6) distinct colors or shades of gray are used if the user must perform rapid visual searching based on color discrimination.	HFDS 8.6.2.7
		1	CU14	Either the background or foreground is achromatic.	UAS_GCS_HMI 3.2.3.6
33%	Brightness (B)	0	B1	The number of brightness intensity levels used as codes does not exceed three (3).	HFDS 8.6.3
		1	B2	When color is used to emphasize information, the brightest color should be used for the most important information.	HFDS 8.6.2.2.2
		0	B3	Each level of brightness is separated from an adjacent level by a 2:1 ratio.	HFDS 8.6.3
		0	B4	High brightness is used to call attention to errors in data-entry fields.	HFDS 8.6.3
		1	B5	High brightness is used to highlight answer fields on question and answer screens.	HFDS 8.6.3
		0	B6	A control for video display terminal brightness is provided.	HFDS 5.2.2.5

The checklists for each indicator are applied in a binary manner; that is, an evaluator determines whether an interface conforms to guidelines (1), does not conform (0), or the guideline (sub-indicator) does not apply (N/A). Aggregation of sub-indicator scores leads to indicator scores, and aggregation of indicator scores leads to an overall score for the interface, as show in Table 2.4. At this point in the tool development, guidelines that are N/A do not negatively impact the score for an interface and all indicators are equally weighted; however, the tool has the flexibility to be modified with criteria weighting factors based on expert evaluator perceptions of the importance of particular indicators and sub-indicators.

Table 2.4: Global M-GEDIS-UAV Score

Indicators	Score
Display Layout (DL)	78%
Information Presentation (IP)	83%
Color (C)	64%
Text (T)	95%
Map and Navigation (MN)	91%
Status and Devices (SD)	70%
Data Entry Commond (DEC)	67%
Alarm (A)	84%
Physical Control (PC)	90%
Global Evaluation Score	80%

Application of the M-GEDIS-UAV involves an analyst independently evaluating an interface, based on the features and functions presented. Video recordings of users can also be used as a basis for analysis of identified interface functions. Preliminary testing of the tool on several prototype UAV interfaces revealed application times of 2.5 hours for expert

analyst use. This same testing involved multiple expert analysts and interface evaluation results were used as a basis for assessing inter-rater reliability. An intra-class correlation coefficient (ICC) was calculated based on the M-GEDIS-UAV indicator scores for three analysts. The ICC had a “moderate” value of 0.429 with human factors experts and “low” value (0.204) for novice analysts. Bliese (1998) considered ICC ≥ 0.7 to be acceptable for clinical studies. The relatively low ICC was mostly attributable to disagreement among analysts in identifying whether guidelines were applicable or not. That is, while one analyst assigned a score for some criteria (“Y” or “N”), another analyst might have considered the same design criteria to be not applicable to the system interface. In a follow-on assessment of application of the new tool, an additional group of evaluators was required to have a meeting and establish agreement on which evaluation criteria (sub-indicators) are applicable or not applicable to UAV interface design. When this updated procedure was followed, results of the additional human factors expert evaluations of interface yielded a “high” ICC of 0.83.

The primary limitation of the M-GEDIS-UAV is the use of the “N/A” grade for sub-indicators and specific design criteria. The tool is presently designed to evaluate aspects of an interface that are available but not penalize an interface for the absence of components. For example, an evaluator would not grade the “Auditory Signal” sub-indicator as part of the “Alarms” indicator as a “0” if an interface does not have an audio component; rather, the evaluator assigns “N/A” because the component is not present and therefore cannot be evaluated. Additionally, with over 300 individual criteria, it takes about 3 hours for an expert to apply the tool to a new interface.

2.5 Selection of Workload Measurements and Interface Evaluation Tool

Given its comprehensive framework and strong basis in the literature, the present study utilized the M-GEDIS-UAV as a platform to objectively evaluate UAV interfaces. The M-GEDIS-UAV was used to objectively grade components of prototype interfaces in a systematic manner with a very high level of detail.

As a means by which to assess cognitive workload imposed by UAV interface designs, the present study also applied the NASA-TLX. The NASA-TLX was chosen as it is a multi-dimensional tool addressing mental demand, physical demand, temporal demand, performance, effort, and frustration. The NASA-TLX has been found to be time-consuming but accurate and it provides strong diagnosticity, making it the preferred choice for many researchers (Miller, 2001). Moreover, the NASA-TLX has been used in the UAV domain and has been found to be sensitive to different levels of task workload.

Beyond these tools and measures, in order to assess operator performance in UAV control tasks, as mediated by various interface design variations, a battery of primary task performance measures were identified, including accuracy and sub-task completion time. These measures can provide indicators of the frequency of errors in each task as well as operator efficiency during UAV missions. The responses can also be linked to operator use of specific interface features for task performance. The NASA-TLX and these primary task performance measures were used to characterize the impact of supervisory control interface designs on operator performance and as basis for assessing the utility of the M-GEDIS-UAV for effective interface evaluation.

3. Problem Statement

3.1 Research Motivation

With the increase in available UAV technology for civilian and military applications, the present work sought to assess the validity of an objective methodology for UAV interface design evaluation. A pilot's ability to navigate, monitor vehicle status, and manipulate flight parameters is essential for successfully accomplishing UAV missions – no matter what the objective may be. Taking off, navigating a given flight path, and dealing with emergencies are all actions UAV pilots are expected to be able to perform, and are especially important as any error can have serious financial or even life-threatening consequences. The design of UAV supervisory control interfaces mediates pilot capability to effectively complete such tasks. Beyond this, pilot experience, or lack thereof, can also be a critical factor. The FAA, under Part 107, licenses a 16 years old, who passes an aeronautical test, to fly a 55 pound UAV up to 100 miles per hour (FAA, 2016) – with no live demonstration of competence; basically, anyone can become an UAV pilot and occupy air space. This situation further emphasizes the importance of development of system interfaces that make necessary functions and features accessible and easy to use for operators; thereby minimizing cognitive load and supporting performance.

According to the Air Line Pilots Association (2007), UAS vehicles and controls are often fielded without a comprehensive assessment and mitigation of any human factors issues; any number of simple issues could lead to mission failure, damaged equipment, or even injury. Human Factors and Ergonomics standards need to be created and engineers need to apply these standards to make designs more operator friendly and tolerant of human

limitations (Waraich et al., 2013). At present there are no comprehensive human factors guidelines for the design of UAV interfaces for civilian unmanned aircraft (Hobbs & Lyall, 2016). A guideline based interface evaluation tool could serve several functions: (a) assist system developers to identify potential design problems, (b) objectively evaluate existing systems, (c) promote interface design standardization, reducing the likelihood of design-induced errors, and (d) supporting regulatory agencies in identifying guidelines when developing regulations or advisory material (Hobbs & Lyall, 2016).

Researchers and designers need to create, compare, and re-design control interfaces to minimize operator workload and improve performance. Designers need an empirically-based tool to establish design pedigrees for interfaces, pinpoint targets for design improvements, and provide the most effective user interface for an UAV pilot.

3.2 Objectives

The overarching objective of this research was to assess the validity of the M-GEDIS-UAV interface evaluation tool for sensitivity and reliability in analysis of UAV interfaces and for prediction of workload and performance outcomes of interface use. An experiment was conducted to test the sensitivity of the tool to changes in UAV interface features and the capability of the tool for identifying or selecting an interface that reduces cognitive demand. Additionally, an objective was to identify the workload and performance response differences among interface designs and to associate these differences with differences in M-GEDIS-UAV scores. Lastly, the research sought to examine how different interface designs may be more or less robust for supporting operators in dealing with different levels of cognitive workload, specifically UAV control speeds.

4. Method

An experiment was designed to assess the sensitivity of the M-GEDIS-UAV tool to different UAV control interface design configurations and to determine the implications of those same designs on user workload and performance responses. The experiment analyses were also intended to determine whether the M-GEDIS-UAV results could be used as a basis for selecting among interfaces in terms of attempting to reduce operator workload and supporting performance.

4.1 Participants

Twenty-four participants, 13 male and 11 female, were recruited for the study through posted flyers distributed around North Carolina State University campus. The inclusion criteria for the experiment were as follows: no previous UAV flight or simulation experience, 20/20 corrected vision, full color vision, and between the ages of 18 and 40 years.

Participants were excluded if they had contact lenses, were over 40 years of age, had UAV flight experience or UAV simulation experience. The age restriction was due the fact that the lens of the eye thickens after 40 years of age and significantly affects the pace of shape changes for focus in shifting visual attention (Bruce, Atchison, & Bhoola, 1995). The 24 participants had an average age of 24.91 years (range: 20 - 31, standard deviation: 3.38). There were no participants with manned flight experience and only 2 with a moderate amount of flight simulator experience. It was expected that flight simulator experience might be a covariate with observations on workload in interface use. Each participant was compensated at a rate of \$15.00 per hour and the experiment lasted approximately 2 hours for each participant.

4.2 Independent Variables

This study manipulated two independent variables (IVs), including the UAV control interface variation (V) and the simulated vehicle ground speed (S). The interface variation (V) had two levels, including a baseline interface that was representative of a commercially available design as well as an enhanced usability interface condition. In addition, there were two levels of vehicle ground speed (S), slow and fast, applied in presenting test scenarios. The vehicle speeds were held constant throughout trials and translated to two levels of task event rate. To minimize a learning or carryover effect among test trials, two scenarios were used as replications where the only difference was the location of waypoints (WPs), targets, and areas of interest (AOIs).

4.2.1 Scenarios

Two experimental scenarios were created to facilitate replications in assessing the impact of the IV manipulations on the on the various response measures; the scenarios were not identified as controlled manipulations. Scenario 1 and Scenario 2 were identical in format, number of targets presented, number of NAIs, number of WPs used, number and type of tasks required, and number of instructions given to participants. The scenarios only differed in terms of the geographic area of targets, NAIs, and WPs. All of this information, with the exception of the targets, was provided to participants in a two-page Mission and Map brief specific to the scenario and interface variation. The document provided the user with: (a) scale map or pictorial representation of the operating environment also shown on the UAV control interface, (b) a “scheme of maneuver” instructing the participant which tasks to execute and in which order, (c) the mission scenario, (d) an acronym list, (e) system

status parameters with units and normal ranges, (f) how to resolve system alarms, and (g) alarm prioritization categories. The schemes of maneuver, general content, and associated tasks were aligned with typical military UAV reconnaissance tasks seen in operation orders. Figures 4.1 and 4.2 present examples of the Mission and Maps documents for Scenario 1 using the Baseline Interface. Mission and Maps documents for all interface and scenario combinations can be found in Appendices A, B and C.

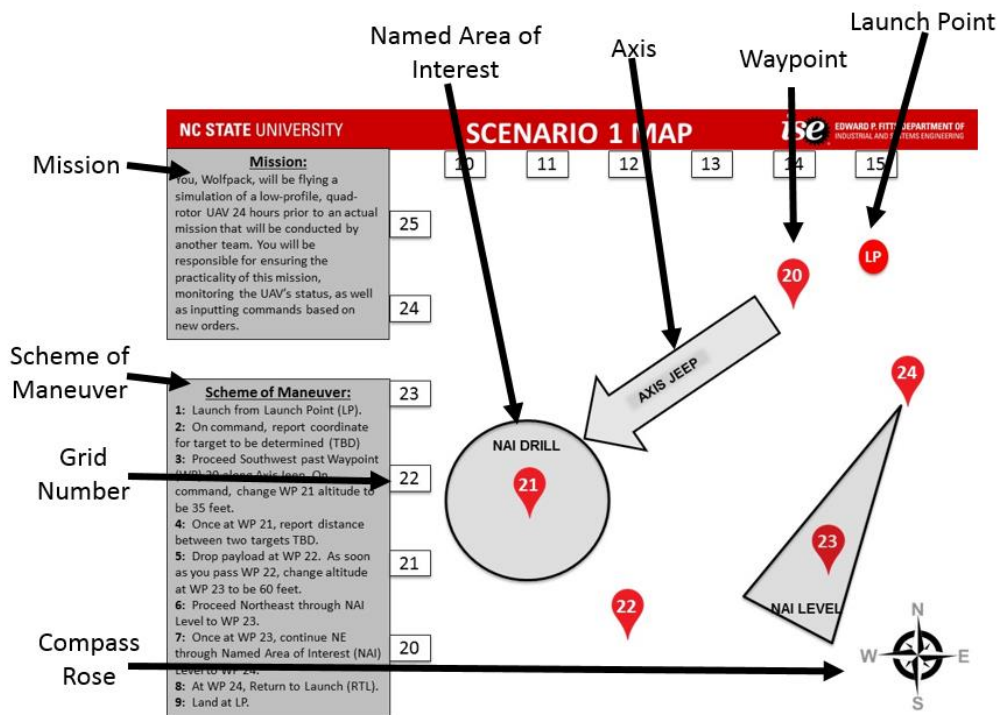


Figure 4.1: Scenario 1 Map for Baseline Interface

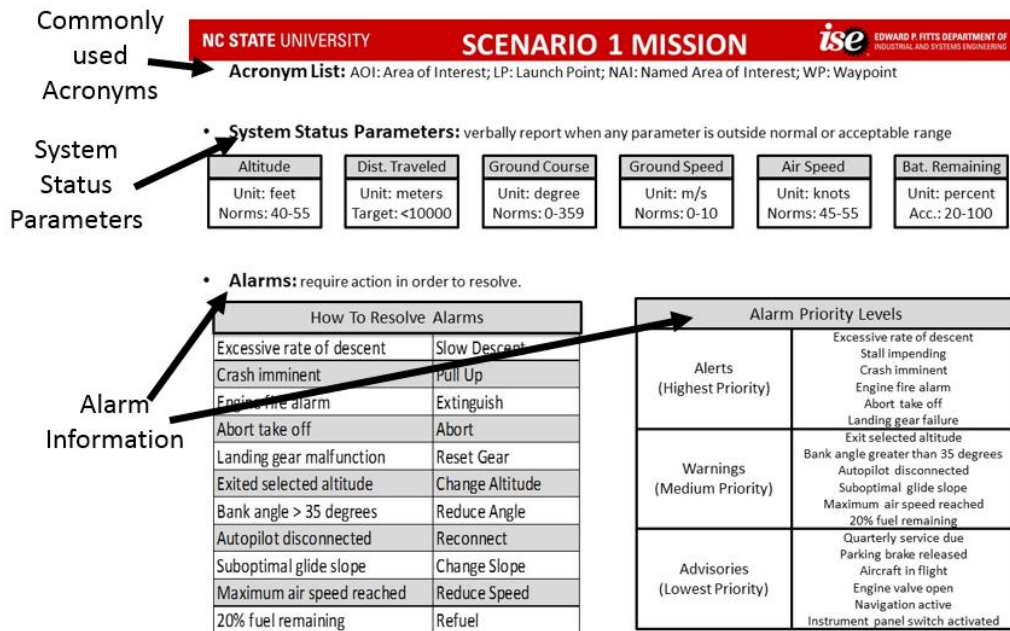


Figure 4.2: Scenario 1 Mission Detail for Baseline Interface

4.2.2 Task Pacing

One of the controlled manipulations in the experiment was task temporal demand. In Hart and Staveland’s (1988) workload framework, task pace is considered to be a predictor of overall workload with increased operational tempo leading to increases in participant workload during a trial. Liu, Peterson, Vincenzi and Doherty (2013) validated this relationship in the context of UAV operation, showing that time pressure, created by a high operational tempo, generally increased operator workload and degraded performance. Considering this research, the two UAV speeds (Fast and Slow) investigated in this study included the Slow speed taking 65 % longer than the Fast speed for trial completion. The task pacing settings were validated through pilot testing and subjective workload assessments

regarding the pace of demands and queries from an experimenter during task completion. The Fast speed was considered to represent high workload setting and the Slow speed was considered as the low workload condition.

4.2.3 *Interface Variations*

For this experiment, an adaptation of the ARDU Pilot Mission Planner interface was used to create the prototype UAV supervisory control interfaces for testing. The JustInMind Prototyping Tool was used for all interface development. The research team developed two different interactive interfaces for testing. Both interfaces included functions representative of those current commercially available interfaces in terms of information presentation and functionality. Each interface had the same functionality for executing UAV control tasks; the difference between the interfaces was in how information was presented to users (more details are provided below). These differences were then verified using a heuristic evaluation as well as the M-GEDIS UAV evaluation tool. Within each interface prototype, not every button or option was active, but every task was achievable with the active controls.

The JustInMind Prototyping Tool allowed for changes in interface features to occur at discrete intervals while maintaining a level of interactivity for the user. In general, the interfaces allowed users to launch a simulated UAV, change flight parameters, navigate menu options, monitor changing system status, and monitor a UAV icon as it continuously moved past WPs along a flight path. All vehicle behavior animations and interface feature changes were programmed in JustInMind. Figure 4.3 presents an image of the basic components of each interface, including a Navigation Display, Primary Flight Display (PFD), and Multi-Control Display Unit (MCDU). Participant interaction with the interface occurs

through these components and their respective sub-components. Follow-on sections address each interface variation and all functional components in detail.

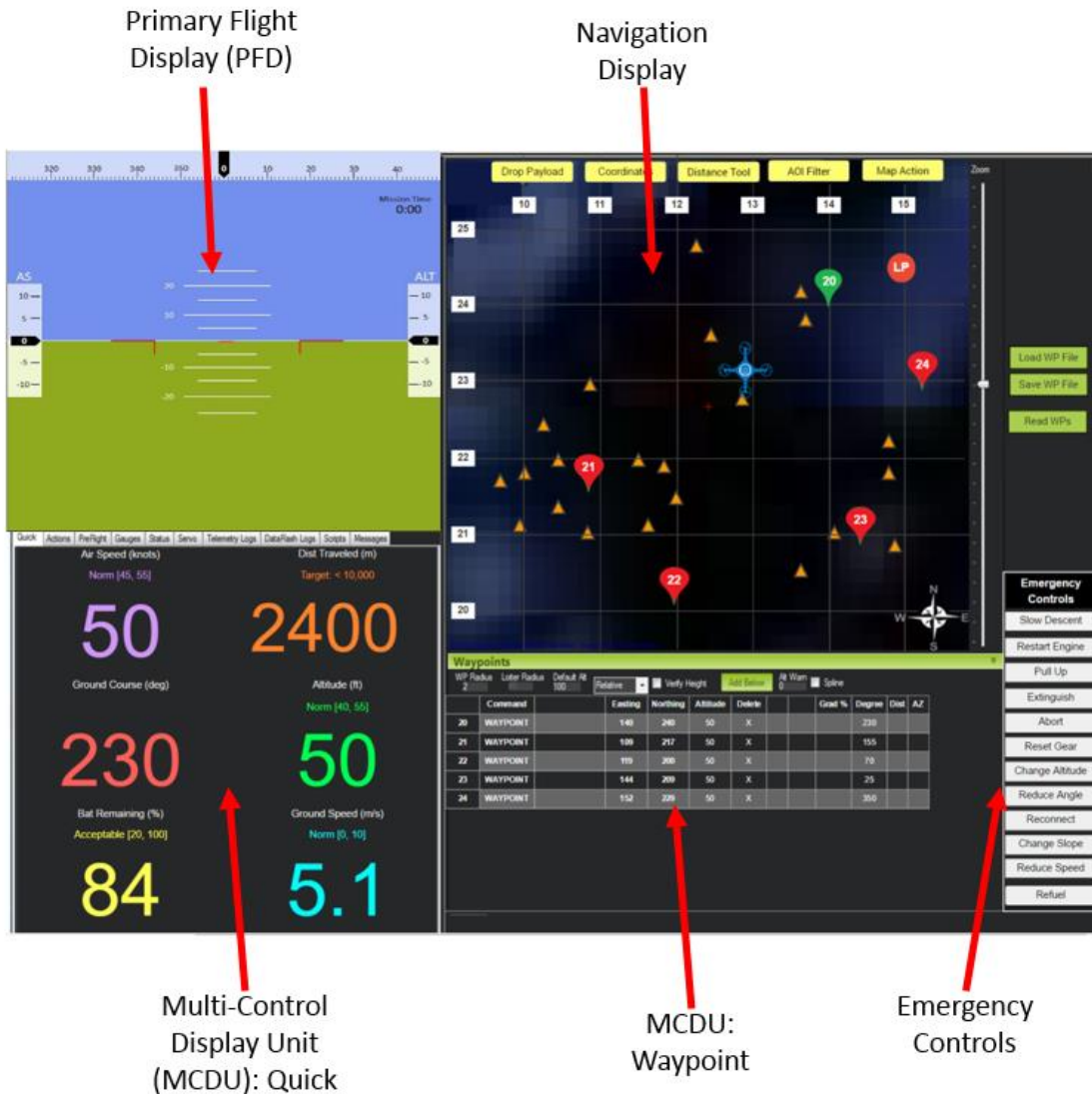


Figure 4.3: Common Interface Components

When creating the Baseline Interface, every step was taken to maintain the information presentation of current commercially available UAV interfaces. While there were some limitations of the JustInMind tool, such as not being able to simulate continuous

updates of the Primary Flight Display, the overall functionality and presentation remained representative of the original ARDU Pilot interface design. Before creating the Enhanced Interface, the research team conducted a heuristic analysis and applied the M-GEDIS-UAV tool to the ARDU Pilot Mission Planner. Enhancements to the ARDU Pilot interface were identified based on design issues and deviations from guidelines identified through the evaluations. The changes that were made for the Enhanced Interface design generally included improved functionality, greater usability, and greater adherence to human factors standards, as typically found in more mature UAV interfaces. Table 4.1 presents a list of the variable features among the Baseline and Enhanced interfaces and how each feature was displayed as part of each interface. The table is divided into major interface interactions with the Navigation Display, Multi-Control Display Unit (MCDU), and system Alarms. The following section details the different interface features of the Enhanced and Baseline Interfaces, providing an accounting of what participants saw during the experiment.

Table 4.1: Modifications for Enhanced and Baseline Interface Variations

	Interface Component	Enhanced Interface	Baseline Interface
Navigation Display	Map Actions Menu	Menu items presented in 8 function groups, where most time critical items are placed at the top of the menu.	Menu items are grouped by logic function, but time critical functions are not at the top. All 23 options are shown to the user at once.
	Shortcuts	Gives user a 1-click shortcut to drop a payload - a time critical task. Also, gives user ability to determine coordinates and distance between objects.	No shortcuts available.
	Waypoints	Traditional waypoint icons are used and numbered according to the flight plan. Waypoints also change color once the UAV has passed beyond the waypoint.	Traditional waypoint icons are used and numbered according to the flight plan.
	Coordinates	Auxiliary grid lines are provided with coordinates. Coordinates and Distance Tools are available for the user.	Auxiliary grid lines are provided with coordinates.
	Area of Interest (AOI)	A filter provides shade coding for AOIs and is accessible from a shortcut button.	A filter provides line coding for AOIs and is accessible from a shortcut button.
Multi-Control Display Unit (MCDU)	MCDU: Quick	Acceptable range of system status values provided for each parameter. System gives a small warning icon for any deviation.	Acceptable range of system status values provided for each parameter.
	MCDU: Waypoints	When changing a flight parameter (i.e. altitude), user can click enter to confirm the change. Confirmation window does not cover any important information and goes away automatically.	When changing flight parameter, the user must use mouse to click 'Write WPs' button. Confirmation window covers the Navigation Display for several seconds before disappearing automatically.
Alarms	Fix	Alarm message indicates the cause, priority, and how to fix the alarm. A help function is available, if needed. Alarm uses consistent color and symbol coding across the interface. The way to fix the alarm is relocated to be right by the alarm notification for ease of the user.	Alarm message indicates the cause and priority of alarm. Help function is available, if needed. Alarm does not tell user how to fix the issue, nor does it use color and symbol coding. The way to fix the alarm is somewhat difficult to find.
	Prioritize	To indicate the priority of alarm, the interface uses consistent color and symbol coding.	With a lack of color and symbol coding, user must recall information on alarm priority from training.

4.2.3.1 Enhanced Interface

The Enhanced Interface was designed for high conformance with the human factors and UAV domain-specific design standards captured in the M-GEDIS-UAV tool. Figure 4.4 identifies many of the specific features of the major components of the control interface. The Navigation Display consists of a map, targets, map icons, grid lines and identifiers, a Map

Action menu, and shortcut buttons. A close-up of the Map Action menu is presented in Figure 4.5. The menu is a standardized hierarchical menu with options appearing under the following items: Drop Payload, WP, Loiter, Jump To, Overlays, Draw, Commands, and Clear Mission. This structured approach to menu presentation was intended to minimize search time, reduce working memory demands, and reduce the extent of obstruction of the Navigation Display when in use.

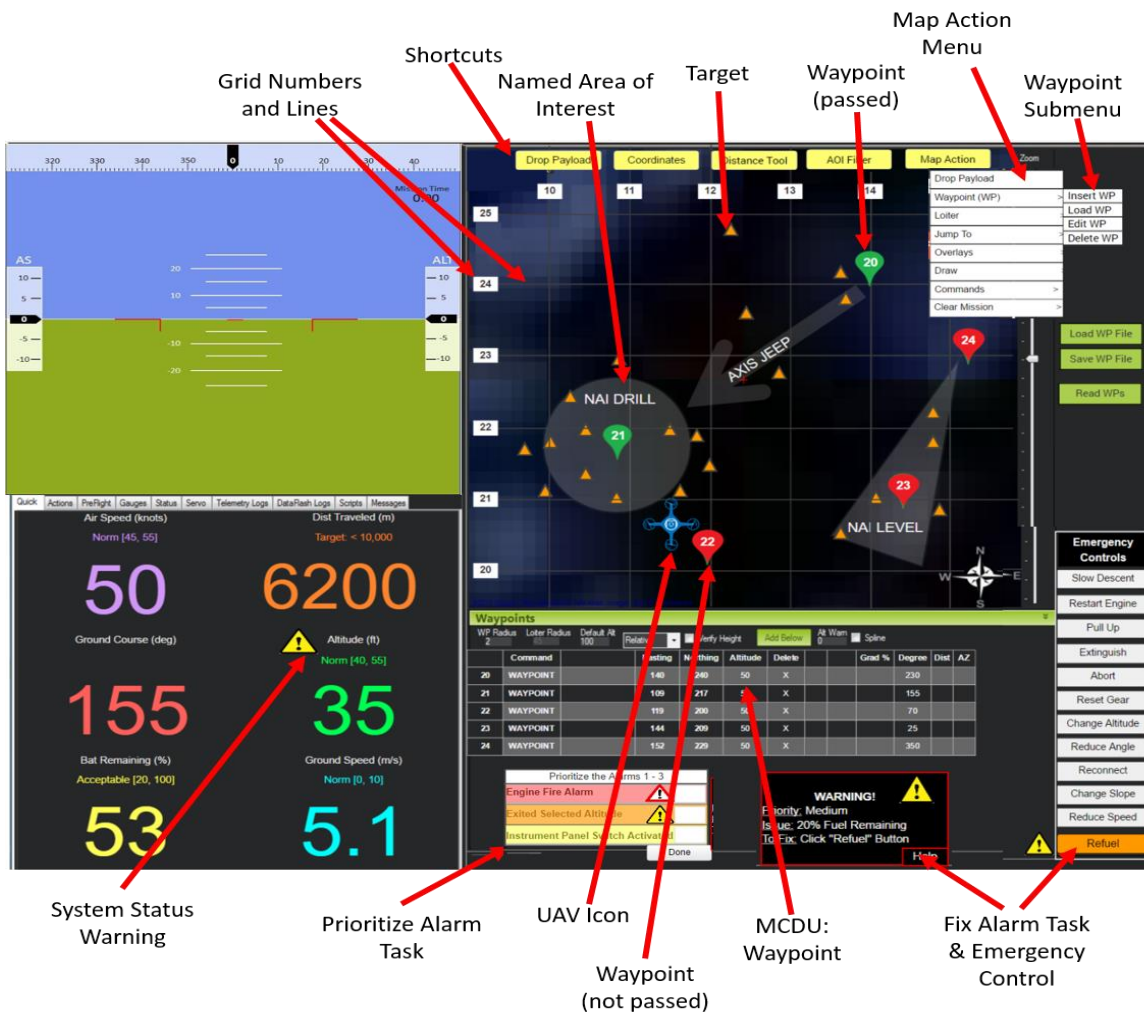


Figure 4.4: Enhanced Interface Features

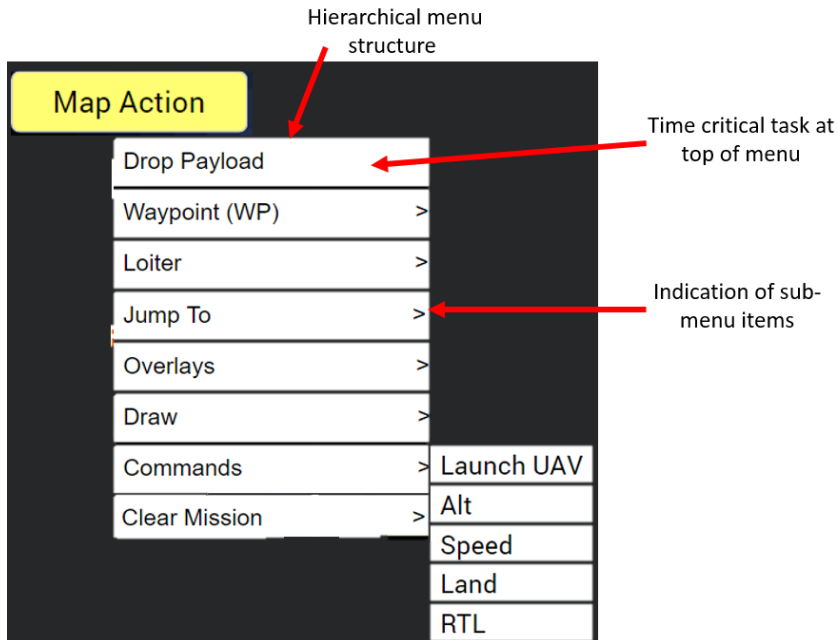


Figure 4.5: Enhanced Interface Map Action Menu

The Enhanced interface design also provided shortcuts for users to facilitate time critical tasks or access to commonly used tools (see Figure 4.6). Available shortcuts included large buttons for: Drop Payload, (object) Coordinates, (inter-object) Distance Tool, and AOI Filter. The ‘Drop Payload’ shortcut reduced the amount of time and visual attention needed to execute a time critical task. The Coordinates tool provided exact Military Grid Reference System (MGRS) coordinates for a specified object on the map, reducing user long-term memory load and potential inaccuracies in object position identification by providing precise coordinates. For example, in Figure 4.6, the western-most target outside of NAI Drill had coordinates of 097 217. The Distance Tool provided the exact distance between two specified objects on the map, reducing demand on the user to estimate distances using grid lines and potential inaccuracies in estimation by providing exact distances. When the tool is used,

target objects are temporarily highlighted and a yellow dialogue box appears with the exact distance between the two objects. For example, in Figure 4.6, the Launch Point (LP) and WP 24 are highlighted in red and the distance of 1,600 meters is shown. The AOI Filter highlighted identified areas on the map, overlaying exact physical dimensions of the areas. This feature enabled more accurate location of targets in reference to AOIs by not requiring mental translation of the picture from the Scenario Map onto the Navigation Display.

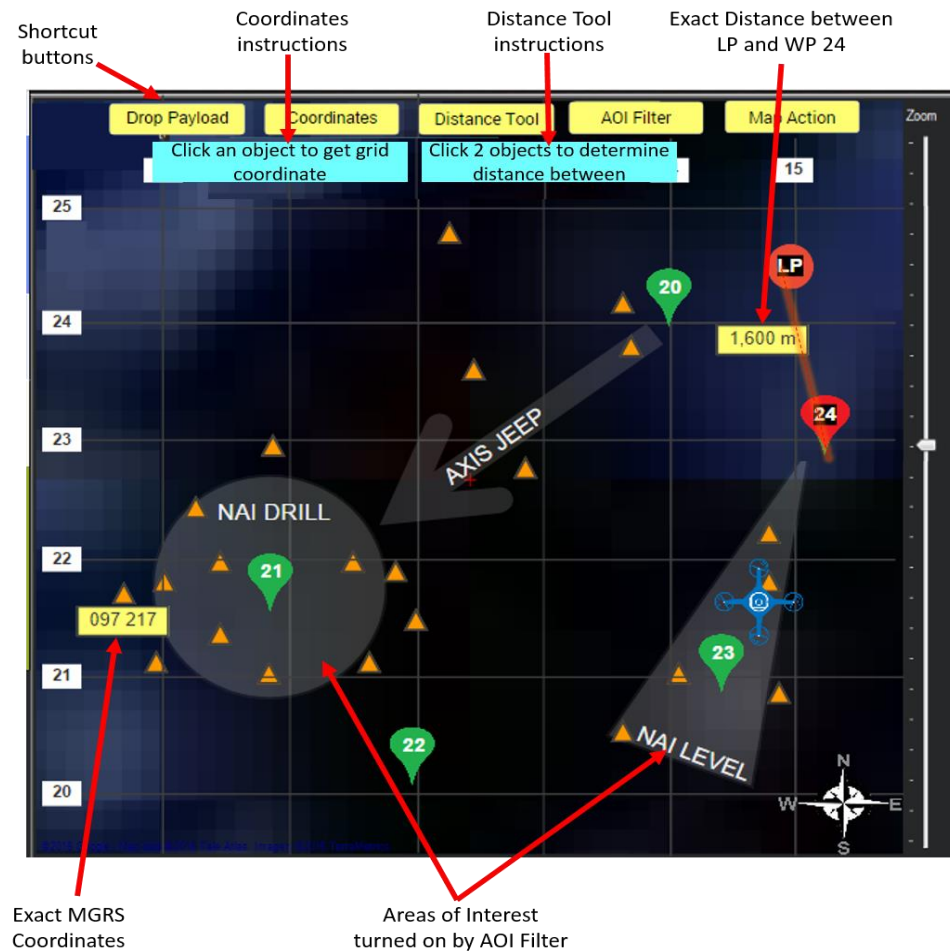


Figure 4.6: Enhanced Interface Navigation Display

The Primary Flight Display was discretely updated with vehicle Air Speed, Altitude, and Ground Course (see Figure 4.7). These values displayed the optimal flight conditions in conjunction with the MCDU: Quick Display values. The horizon remained horizontal during the entire flight due to the UAV's bank angle never changing.

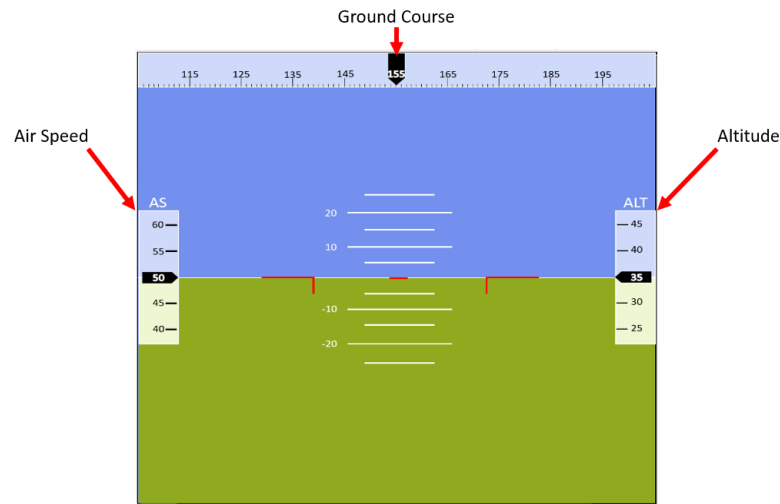


Figure 4.7: Primary Flight Display Components

The MCDU has three major components, including: a Quick Display, a WP list, and Actions tab. The Quick Display (see Figure 4.8) shows the UAV's system status, including: (a) Air Speed, (b) Distance Traveled, (c) Ground Course, (d) Altitude, (e) Battery Remaining, and (f) Ground Speed. The display presents values for these parameters as they progress through the flight, and provides a localized warning when a parameter deviates from norms. For example, Figure 4.8 shows the UAV's altitude was 35 feet and outside of the parameter norm of 45 to 55. A parameter warning icon also appears in the display to inform the user of the deviation.

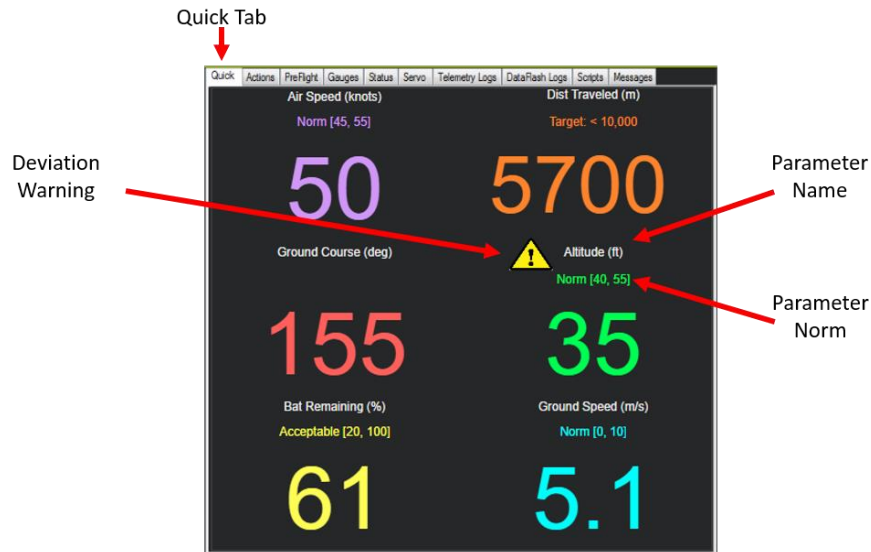


Figure 4.8: Enhanced Interface MCDU Quick Display

The MCDU Actions tab (see Figure 4.9) allows a user to take actions during nominal flight of the UAV. The launch sequence, consisting of pressing the buttons ‘Arm/Disarm’ and ‘Launch UAV’ in sequence, is accessible under this tab. Initially, the ‘Launch UAV’ button is greyed-out (following color coding conventions) to indicate the option is not available to launch the UAV. Moreover, if a user moves the mouse over the ‘Launch UAV’ button prematurely, a dialogue box appears with specific instructions of what action should be taken next (instead of selecting launch). These two formatting characteristics are intended to prevent user errors and provide guidance on what appropriate actions should be taken to launch the vehicle. The Return to Launch (RTL) action is also found under this tab. These are the only three active buttons on this menu.

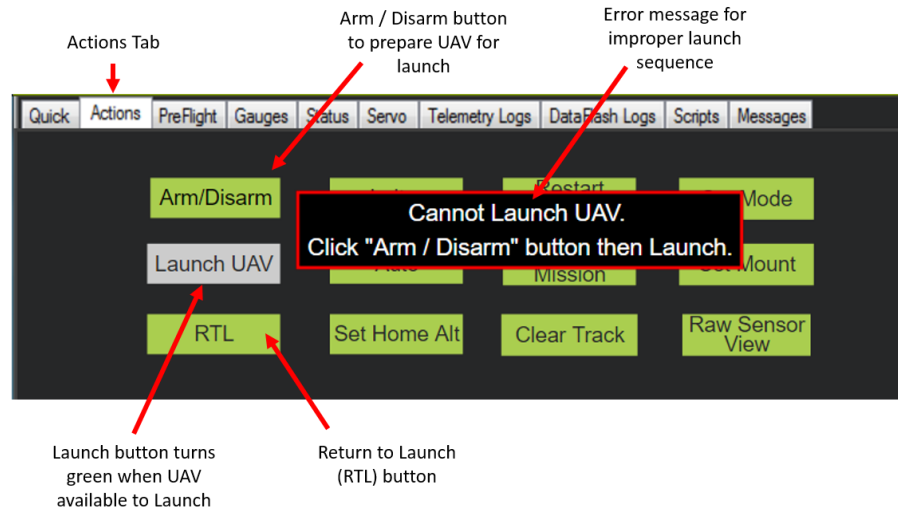


Figure 4.9: Enhanced Interface MCDU Actions Tab

The MCDU WPs table (see Figure 4.10) allows a user to change future flight parameters and anticipate future WP characteristics. For each WP, the Easting, Northing, altitude, and ground course degree can be found in the MCDU table. Specifically, a user has the capability to manipulate WP altitude during flight. When an altitude is changed, the user presses the ‘Enter’ key and a small confirmation box appears next to the changed value for 3 seconds before disappearing. As compared to the Baseline Interface, the WP confirmation box represents the same functionality with a reduction in features. The Baseline Interface’s confirmation box covers up pertinent map information and imposes a greater demand on the user’s working memory; whereas, the Enhanced Interface’s confirmation box is localized and does not block any information. The functionality of each interface is the same, but the Enhanced Interface offers a simplified operation.

			Easting, Northing, and Altitude Information for Waypoints				Ground Course Degree for Waypoints				
	Command		Easting	Northing	Altitude	Delete		Grad %	Degree	Dist	AZ
20	WAYPOINT		140	240	50	X			230		
21	WAYPOINT		109	217	75						
22	WAYPOINT		119	200	50	X			70		
23	WAYPOINT		144	209		X			25		
24	WAYPOINT		152	229	50	X			350		

Data Entry Box for Altitude
Confirmation for WP 21 Altitude Change

Figure 4.10: Enhanced Interface MCDU Waypoints

At various times during the UAV control scenarios, users were required to prioritize system alarms according to priority levels of Alert (highest priority), Warning (medium priority), and Advisory (lowest priority). The Scenario Mission document presented all possible system alarms as well as the alarm priority level. When system alarms occurred, conventional color coding and symbology were used to designate Alerts, Warnings, and Advisories. Consequently, with the Enhanced interface design users did not have to rely solely on their memory of priority levels or verify an alarm priority from the Scenario Mission document in order to successfully complete the task. In Figure 4.11, Plate 1, ‘Engine Fire Alarm’ is presented in red with a red alert icon to designate the highest priority level; whereas, ‘Instrument Panel Activated’ is displayed in yellow to designate the lowest priority alarm. This color coding and symbology was consistently applied across interface features for alerting of system alarms. When an alarm occurred that required an Emergency Control action, the problem, the priority level, and how to fix the alarm were presented; if needed, a help option was also available for more information on the alarm fix. Additionally, an icon

and highlighted Emergency Control indicated the correct action to be taken by the user. For example, Plates 2a and 2b in Figure 4.11 show a warning of 20 % Fuel Remaining and the list of Emergency Controls with highlighting of the Refuel action. The ‘Refuel’ button was highlighted in orange with a warning icon appearing to direct user visual attention to the appropriate control.

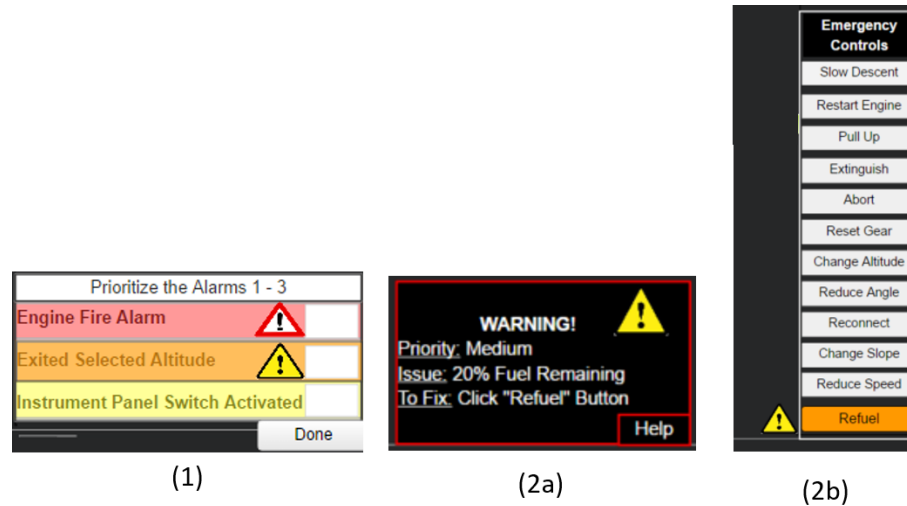


Figure 4.11: Enhanced Interface Alarms to which users responded: (1) Alarms to prioritize from 1 to 3, (2a) Dialog box for new alarms to fix using Emergency Controls, and (2b) Corresponding Emergency Controls with highlighted option.

4.2.3.2 Baseline Interface

The Baseline Interface was prototyped to model the ARDU Pilot’s current level of conformance to human factors and UAV domain-specific standards. The Baseline Interface has the same primary components as the Enhanced Interface, and the same functionalities, but there were differences in terms of presentation of features that make this interface sub-optimal. Only the PFD remained unchanged from the Enhanced Interface.

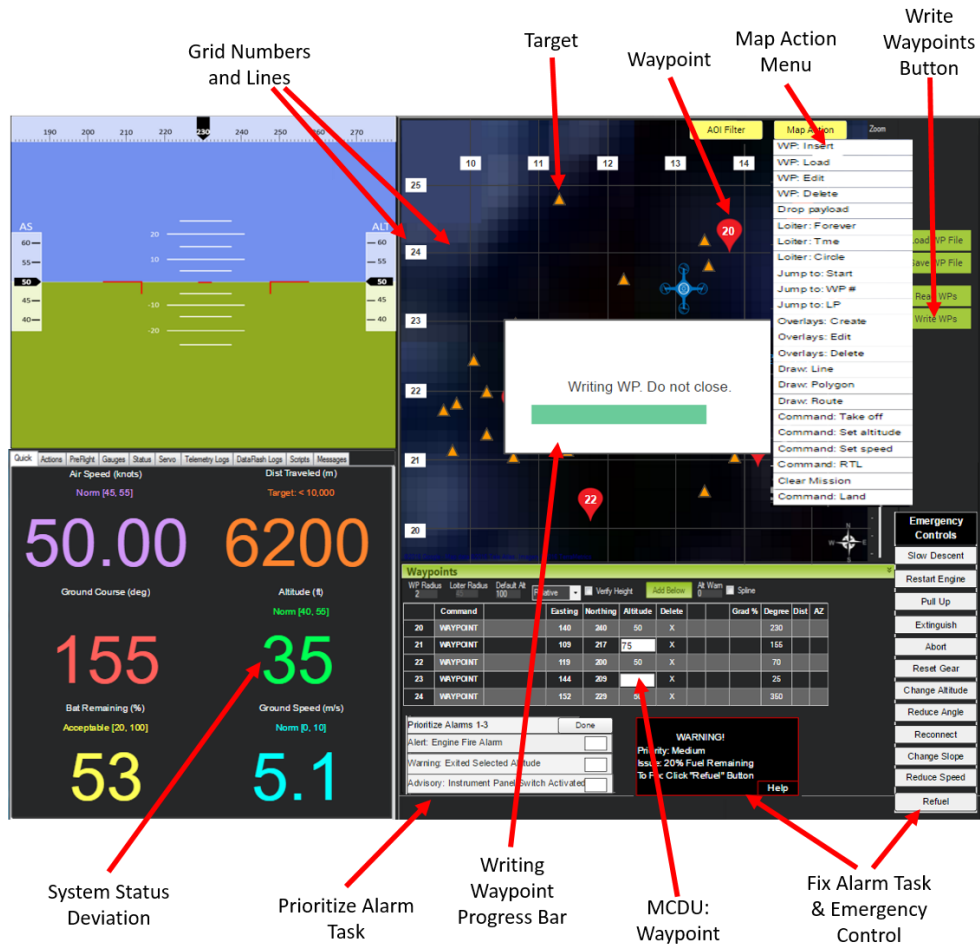


Figure 4.12: Baseline Interface Features

The Navigation Display consisted of the map, targets, WPs, AOI filter, and the Map Action menu. The Map Action menu (see Figure 4.13) was displayed in a single vertical column, with all menu item options grouped together. Although the options were typically organized, the structure was expected to overload user working memory and force them to search through more options to find a desired action. Additionally, time-critical or common tasks were not organized in a manner to facilitate usage. For example, the ‘Drop Payload’ button was the fifth option in menu, which was not conducive to quickly executing the task.

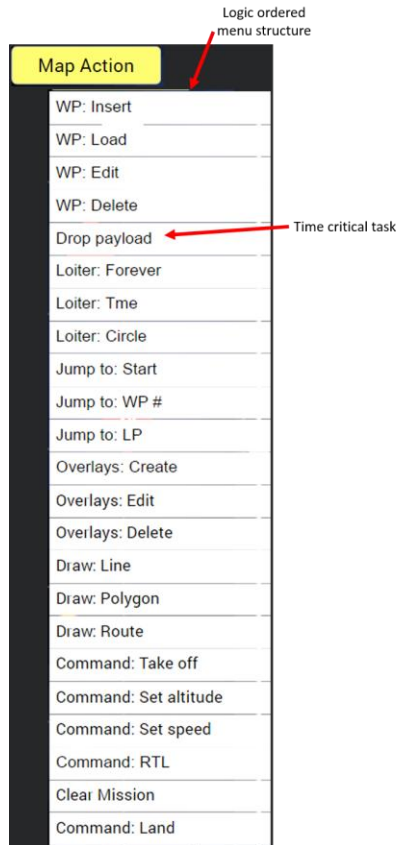


Figure 4.13: Baseline Interface Map Action Menu

The Baseline Navigation Display (see Figure 4.14) was similar to the Enhanced Interface in that it featured the AOI Filter, providing the capability to overlay mission specific graphics onto the map. However, there were no shortcuts or additional tools available as part of the Baseline Interface. This design forced users to take extra cognitive and motor steps to execute the time-critical task of Drop Payload through the Map Action Menu. In addition, missing from the Navigation Display were the Coordinates and Distance Tools. This lack of features forced users to rely on their long-term memory to recall how to read MGRS coordinates and estimate distances between objects. The absence of these features also introduced potential errors in task performance. With respect to the display

icons, the Baseline Interface WPs remained red during the entire flight and did not provide an indication of whether they had been passed by the UAV or not. Although a “Write Waypoint” feature was not included in the Navigation Display, the confirmation box for any change to a WP flight parameter obscured the map display for a period of 5 seconds after a user made changes to the UAV flight path. This overlap of features resulted in a situation where users could not track the UAV position or quickly answer an experimenter question about information on the Navigation Display during task performance.



Figure 4.14: Baseline Interface Navigation Display

The Baseline Interface’s MCDU Quick Display (see Figure 4.15) was similar to the Enhanced Interface. All six system parameters, along with their normal or acceptable ranges and units of measurement, were presented, which was identical to Enhanced Interface. However, no additional indicators were provided when a parameter deviated outside of acceptable system norms. This lack of feedback caused users to more actively monitor the MCDU Quick Display and either continually read parameter norms or encode the information in memory.

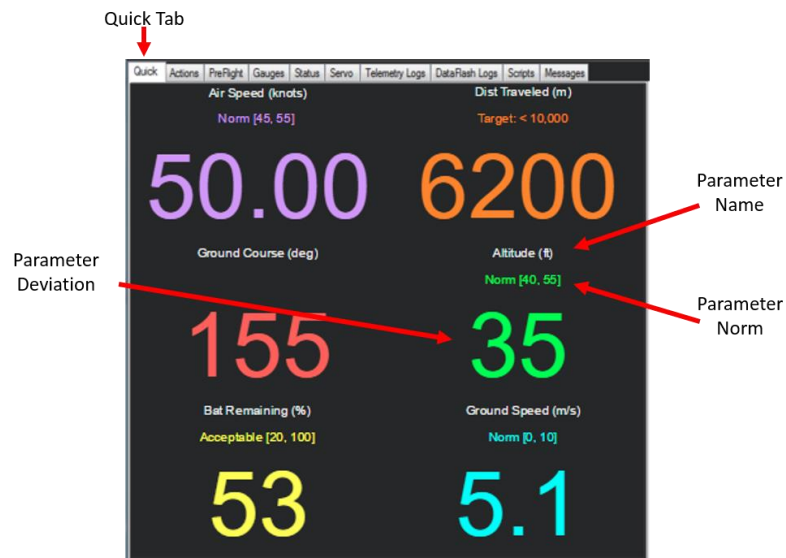


Figure 4.15: Baseline Interface MCDU Quick Display

The Baseline Interface’s MCDU Actions Tab (see Figure 4.16) had the same options as the Enhanced Interface. The difference was the error prevention methods utilized by the Enhanced Interface were not provided to users of the Baseline Interface. There was no color coding of the ‘Launch UAV’ button to indicate that the option was not acceptable at various

times in a scenario. Additionally, there were no error messages provided to instruct users on what actions to take next if an error was made. In the test scenarios, the launch sequence was only a two-step process so there was little need for more constructive error messages.

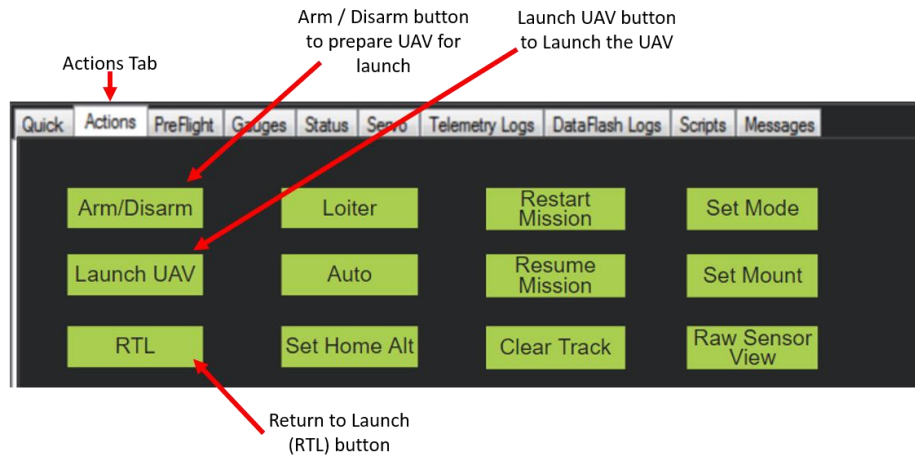


Figure 4.16: Baseline Interface MCDU Actions Tab

In the MCDU WPs display (see Figure 4.17), the same information is presented to the user for each WP parameter. When manipulating the altitude for a particular WP, the ‘Write WP’ button is presented outside of the MCDU WP dialog, which requires distribution of visual attention for the user. As previously mentioned, once a WP parameter was modified a confirmation box appeared and partially blocked the participant’s view of the Navigation Display for several seconds until it automatically disappeared. This confirmation box blocked nearly 20 % of the map and forced the participant to remember what information was beneath the window. The confirmation box was not co-located with the WP interface controls, forcing a user to shift their attentional focus to a different area of the interface.

		Easting, Northing, and Altitude Information for Waypoints					Ground Course Degree for Waypoints				
	Command		Easting	Northing	Altitude	Delete		Grad %	Degree	Dist	AZ
20	WAYPOINT		140	240	50	X			230		
21	WAYPOINT		109	217	35	X			155		
22	WAYPOINT		119	200	50	X			70		
23	WAYPOINT		144	209	75	X			25		
24	WAYPOINT		152	229	50	X			350		

Data Entry Box for Altitude while Progress Bar is going

Figure 4.17: Baseline Interface MCDU Waypoints

As with the Enhanced Interface, during each simulated UAV flight scenario, baseline interface users had to prioritize and resolve system alarms. Users were provided with a printed alarm prioritization table, which listed every possible alarm and their associated priority levels. When prompted to prioritize a set of three alarms during interface use, users were presented with the levels of alert as an aid to determine the prioritization, as shown in Figure 4.18, Plate 1. As an example, Engine Fire Alarm was an Alert, indicating the highest priority. Whereas, Instrument Panel Switch Activated was an advisory, indicating the lowest priority. In this way, the user could reference the levels of priority (Alert, Warning, Advisory) and did not have to memorize each alarm or look up each alarm on the priority table each time the classification task occurred. The user only needed to remember the prioritization levels of Alert, Warning, and Advisory from training instructions and respond accordingly to the alarms. There was no color-coding or other indicator to aid the user in this task.

When an alarm occurred that required a fix, as shown in Figure 4.18, Plate 2a, the user had to locate the correct emergency control (Plate 2b) to resolve the alarm. There was an available printed table that described each possible alarm along with the Emergency Control that would resolve the alarm. The alarm dialog box provided an indication of the alarm priority, the problem, and offered a help option if the user needed additional information that was not initially available. Most importantly, the alarm box provided information for the user on how to fix the alarm using the given set of control buttons. There were 12 Emergency Controls that had to be scanned to find the button to resolve the issue, and there were no other indicators to help the user navigate to the correct control.

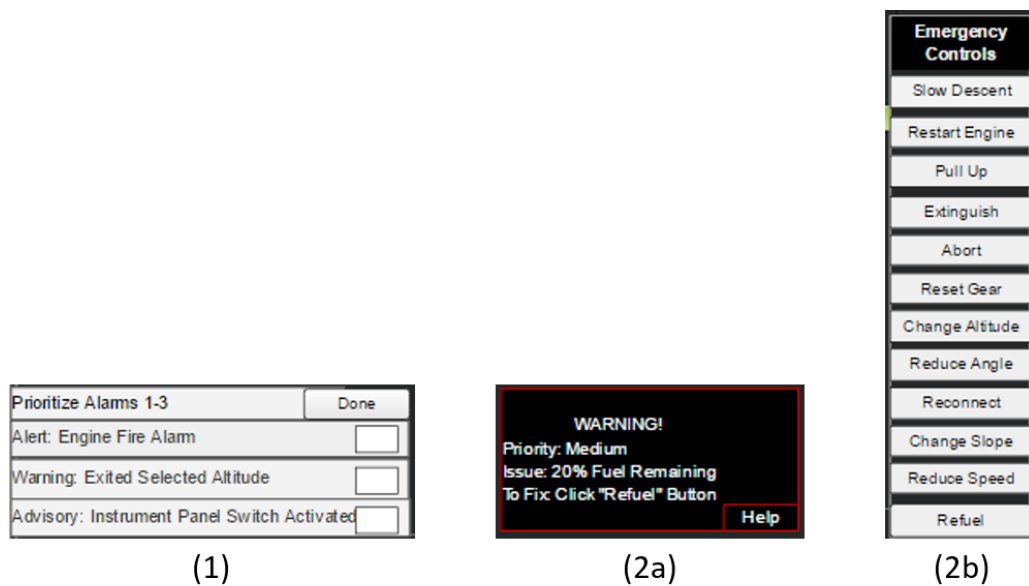


Figure 4.18: Baseline Interface Alarms to which a user responded: (1) Alarms to prioritize from 1 to 3, (2a) Dialog box for new alarms to fix using Emergency Controls, and (2b) Corresponding Emergency Controls.

4.2.4 *Interface Evaluations*

In order to evaluate the two control interfaces, two current methods of interface evaluation were used, as described in the Literature Review – a heuristic evaluation and the

M-GEDIS-UAV tool. For the heuristic evaluation, each interface was evaluated by individual human factors expert and a panel was then convened for a discussion of findings. Each of ten design heuristics were classified as being “satisfied”, “partially satisfied”, or “not-satisfied” based on expert ratings. Explanations of each heuristic were provided to the experts in advance of the evaluation (Appendix D). The results of the evaluation are presented in Figure 4.19, with the colors of green, amber, and red used to identify heuristics that were satisfied, partially satisfied, and not-satisfied, accordingly. The heuristic evaluation and integration of expert opinions revealed that the two interfaces were substantially different from each other. Generally, the Enhanced Interface was considered to be more usable than the Baseline Interface, and it is expected that tasks performed using the Enhanced Interface would be executed faster and more accurately.

The Enhanced Interface scored better than the Baseline Interface in terms of minimizing a user’s memory load. The Enhanced Interface provided more information to users for specific tasks, rather than forcing them to remember facts about a mission scenario or system constraints. The interface also facilitated common tasks by highlighting specific pieces of information alleviating the need for users to recall what features to use and potential memory overload.

The Enhanced Interface scored better than the Baseline Interface in terms of error messages and error prevention heuristics. For example, in an alarm fix, the Enhanced Interface provided color coding of the Emergency Controls to reduce a user’s search time.

The Enhanced Interface scored better than the Baseline Interface in terms of providing action shortcuts for users. The additional tools to find an object’s coordinates and

distance between two objects gave the Enhanced Interface a significant advantage over the Baseline Interface.

Heuristic	Enhanced Interface	Baseline Interface
Simple and Natural Dialogue	Green	Green
Speak the User's Language	Green	Green
Minimize the User's Memory Load	Green	Yellow
Be Consistent	Green	Yellow
Provide Feedback	Green	Green
Provide Clearly Marked Exits	Green	Green
Provide Shortcuts	Green	Red
Provide Good Error Messages	Green	Yellow
Error Prevention	Green	Yellow

Figure 4.19: Heuristic Evaluation Results

For the M-GEDIS-UAV evaluation, the methodology originally described by Zhang et al. (2016), and previously outlined in the Literature Review, was applied. The scores for each interface were sub-divided by indicator, as seen shown below in Table 4.2. While the two interfaces scored similarly for several of the indicators (desired design features), based on evaluations by multiple analysts, there were specific indicators for which the Enhanced Interface was found to be superior to the Baseline Interface in terms of conformance with guidelines and design standards. These indicators, included Map & Navigation and Alarms.

These results suggested that for tasks involving the Navigation Display or alarms, the Enhanced Interface might have an advantage for increased task accuracy and decreased sub-task completion times. This expectation is also in-line with the results of the heuristic evaluation. Additionally, based on the increased conformance of the Enhanced interface with human factors standards, it was expected that the interface would have a greater potential for moderating user workload, as captured with the NASA-TLX, under the high UAV control speed setting, as compared with the Baseline Interface.

Table 4.2: M-GEDIS-UAV Evaluation Results

	Enhanced Interface	Control Interface
Display Layout	93	85
Information Presentation	87	83
Color	86	86
Text	100	100
Map & Navigation	95	74
Status & Devices	83	83
Data Entry Command	88	86
Alarm	96	35
Physical Control	80	80
Global Evaluation Score	90	79

4.3 Tasks

The experiment tasks were formulated based on Hobbs and Lyall's (2016) model of the responsibilities of a UAS pilot, as shown in Figure 4.20. The responsibilities tested during the experiment are circled in the Figure and were captured by common tasks that a pilot would execute during a mission. With respect to the responsibility of 'Manage:

Recognize and respond to non-normal conditions’, participants responding to UAV system alarms. With respect to the responsibility of ‘Navigate: Control and monitor location and flight path of aircraft’, participants were required to determine the coordinates of an object, distance between objects, and change the altitude of the UAV at a WP in a flight plan.

Images of the specific interface menu items used for addressing each of these tasks with both interfaces are presented and described below. Additionally, participants answered verbal queries regarding performance of various sub-responsibilities, including ‘monitor aircraft systems’ and ‘communicate with ground support.’ Mission relevant queries were developed with the intent of requiring participants to search different areas of the interface in order to identify task-relevant information (see Appendix E for a list of the queries).

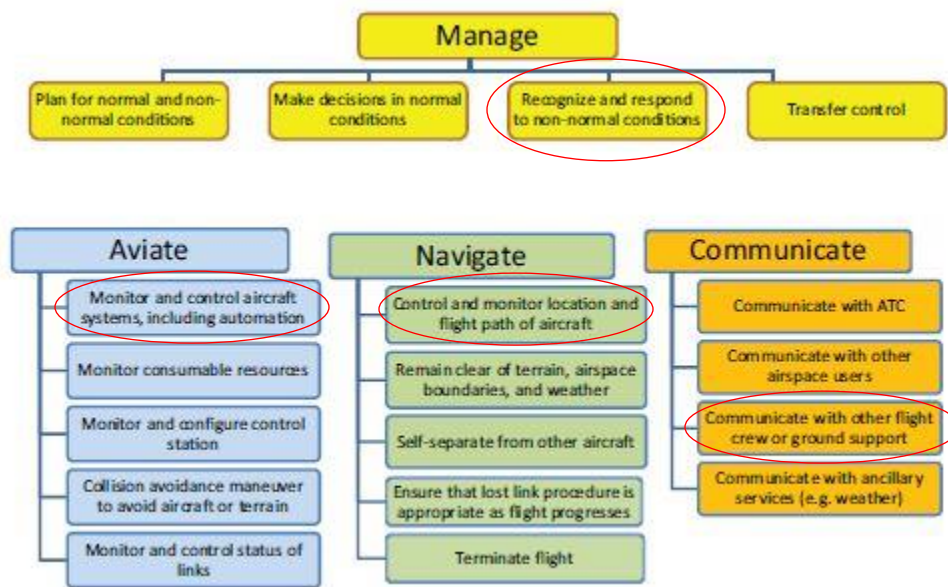


Figure 4.20: A Model of the Responsibilities of a UAS Pilot

In regard to the task of identifying object coordinates, the experimenter gave a participant a verbal cue of “Report the coordinate of the Western most target outside of NAI Drill.” The Enhanced Interface provided the most efficient means by which to acquire the coordinates. Referring to Figure 4.21, the user clicked the Coordinates shortcut located at the top of the Navigation Display and then clicked the identified target; task instructions were provided for the user’s convenience, if needed. The precise coordinates were shown next to the target and the participant verbally reported the displayed information. In this case, “097 217” was reported. For the Baseline Interface, the user needed to accurately recall the following information from the interface training: (a) how to determine an Easting, (b) how to determine a Northing, and (c) the order in which to report digits – Eastings then Northings. After recalling this task procedure, the user had to estimate the 3rd digit of each Easting and Northing using the grid lines on the interface, which introduced a potential for error. Once both digits had been estimated, the user reported the coordinate. In this case, the grid lines had to be used to estimate the Easting as 097 and the Northing as 217. Lastly, the coordinate of 097 217 was verbally reported to complete the task. In addition to the potential for error in coordinate identification, the extra cognitive steps taken by the user caused slower response times, as compared to use of the Enhanced Interface.

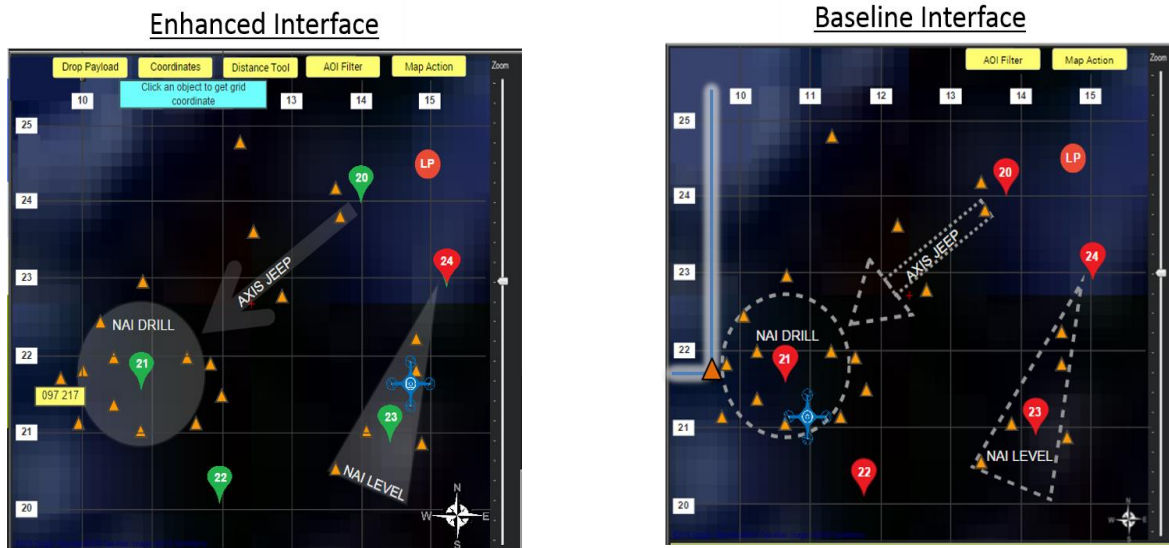


Figure 4.21: Coordinate (estimation) Task Performance with Enhanced and Baseline Interfaces

In regard to the Distance (estimation) Task, the experimenter gave participants a verbal cue of “Report the distance between the LP and WP 24.” The Enhanced Interface provided the most accurate method by which to determine the distance between two objects via the Distance Tool shortcut at the top of the Navigation Display. As shown in Figure 4.22, a user clicked the Distance Tool shortcut and instructions appeared, if the user needed them. Next, the user clicked on the assigned objects, including the LP and WP 24. As feedback on these actions, the interface changed the background color of each target to black with a red surround. After clicking both objects, a yellow window appeared informing the user of the distance between the points (1,600 meters). The user then reported this distance verbally. With the Baseline Interface, the user had to recall information from the interface training, including: (a) the unit for reporting distance, (b) the distance between grid lines, (c) how to estimate distances that are at an angle to each other, and (d) the need to measure from the

center of the LP icon and bottom tip of the WP icon. The user then estimated the distance between the two objects using the grid lines as an aid. In the example case, the user saw that there was one full grid box between the objects, the LP was in the middle of the next grid box, and WP24 was slightly below the 23 Northing. This information had to be integrated to make the distance estimate of 1,600 meters. Once reported verbally, the task was considered complete. The Enhanced Interface did require some additional motor behaviors of users for task performance but it reduced the number of cognitive steps and provided precise distance information.

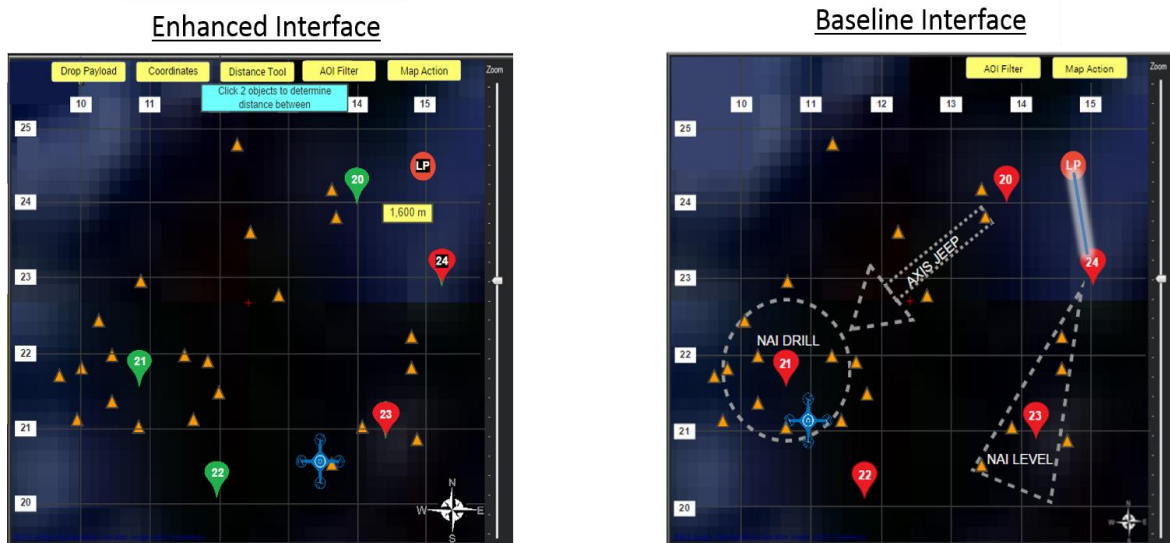


Figure 4.22: Distance (estimation) Task Performance with Enhanced and Baseline Interfaces

For the Fix Alarm Task, a user had to “fix” an alarm that appeared on the interface screen below the MCDU WP dialog. The user was also provided a verbal cue of “Fix the Alarm shown.” With the Enhanced Interface (see Figure 4.23, left side), the user recognized the alert symbol and was instructed as to which button to click to fix the alarm. Additionally,

the Emergency Control button for fixing the alarm was highlighted to decrease the user search time in locating the correct button; in this case, the highlighted button ‘Refuel’. For the Baseline Interface (see Figure 4.23, right side), the user had to read how to fix the alarm and then read through all the Emergency Controls to locate the ‘Refuel’ button. Once ‘Refuel’ was clicked, the task was complete.

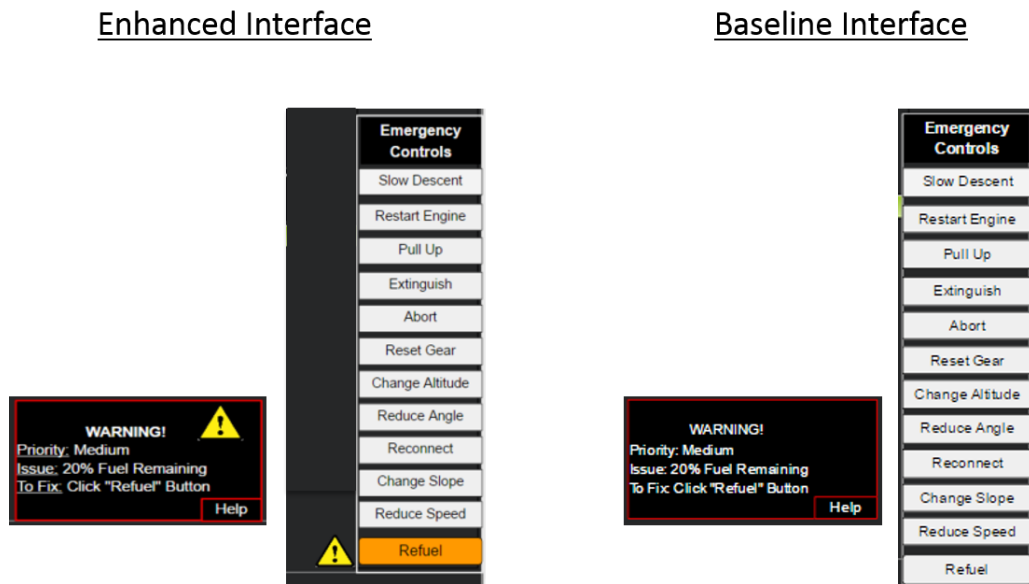


Figure 4.23: Fix Alarm Task with Enhanced and Baseline Interfaces

For the Prioritize Alarm Task, a user had to prioritize a list of alarms that appeared on the interface display below the MCDU WP box. For every prioritization task, there was one alarm at each prioritization level presented to the user. At the time of the alarm, the experimenter provided a verbal cue of “Prioritize the alarms per your training.” For the Enhanced Interface (see Figure 4.24, left side), the user had to recall from their interface training either the color or symbol associated with each alarm priority and then order the

alarms in priority from 1-3. The interface provided memory aids and used conventional warning colors to facilitate alarm prioritization. For the Baseline Interface (see Figure 4.24, right side), the user had to read the alarms, recall the priority level of the alarm categories, and then order the alarms in priority from 1-3. The names of the alarm categories were provided but the interface did not provide any other aid to the user. When the ‘Done’ button was clicked, the task was considered complete.

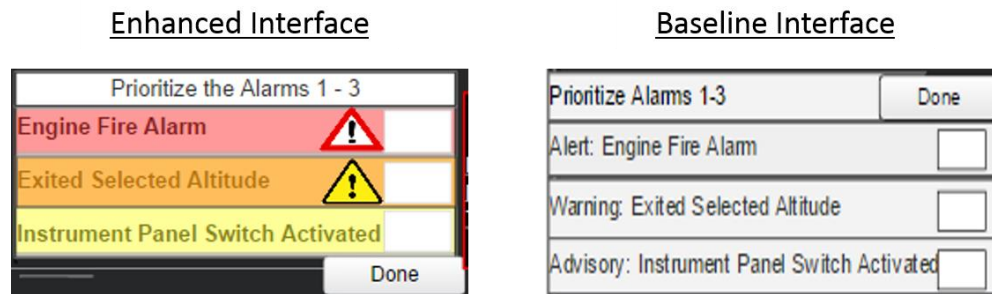


Figure 4.24: Prioritize Alarm Task Comparison

Before each test trial, participants were reminded to monitor the Quick Display for system status parameters. Each interface presented the norms for each parameter but the Enhanced Interface included a warning icon that appeared whenever a parameter deviated, as shown below in Figure 4.25. The user only had to recognize that there was a new icon on the MCDU Quick Display rather than reading vehicle status values and recalling the norms for each parameter. The Baseline Interface forced users to scan all system parameters and recall, or read, norms before reporting that there was a deviation and saying, for example, “Warning: Altitude.”

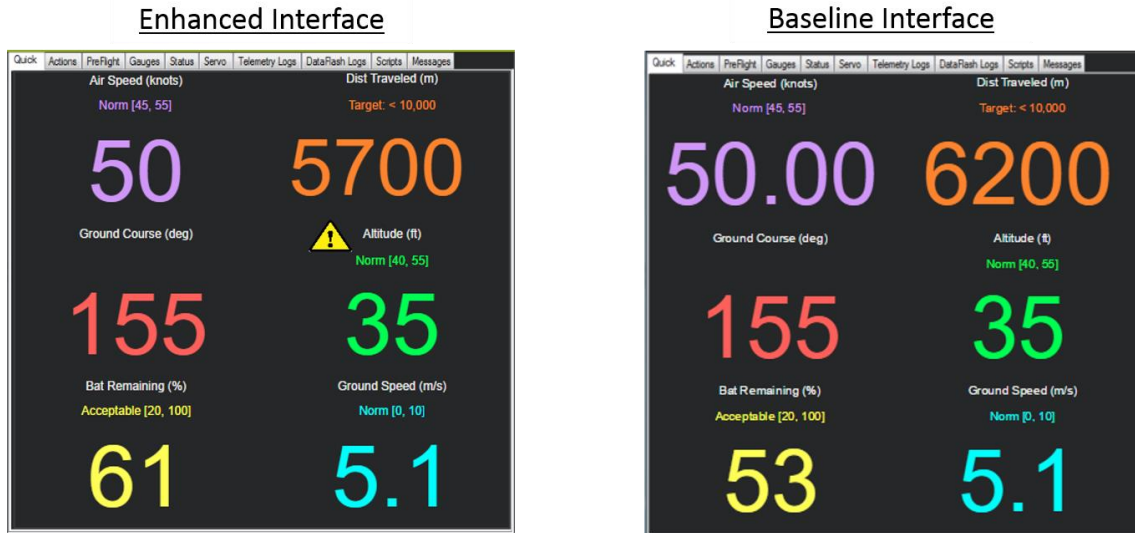


Figure 4.25: System Parameter Deviation Monitoring with Enhanced and Baseline Interfaces

4.4 Set-Up and Apparatus

The experiment set up included a desktop computer for presenting the interface simulations, as shown below in Figure 4.26. A QWERTY keyboard and standard mouse were provided for participant to interact with and enter commands into the UAV control interface. Printed copies of the scenario map and mission description were located on an adjustable platform directly to the left of the monitor. Participants sat in front of the computer monitor during all trials, and were allowed to adjust the monitor angle and viewing distance for comfortable use. Camtasia (Version 9.0) was used to record video and audio of each participants' performance at the control interface. The recordings were used to verify the time and accuracy of all sub-task performance. (Task time was recorded to the hundredth of a second). Audio recordings were used to present all orders to participants to ensure consistency in order speech, tone, and pace across participants.



Figure 4.26: Experiment Setup

4.5 Design of Experiment

The experiment followed a mixed factor design. The interface manipulation served as a between-subject factor. The vehicle speed (workload manipulation) served as a within-subject factor. The mixed-factor design was selected over other designs (e.g., completely within-subjects), as pilot testing revealed that presenting multiple interfaces to one participant introduced confusion among interface features and learning effects across trials.

Each participant was randomly assigned to an interface variation and completed two mission scenarios under the two vehicle speed/event rate settings. Therefore, a Split Plot Design (SPD) was chosen as a basis for data analysis, in which the whole plot followed a Completely Randomized Design (CRD) and the split plot followed a Randomized Complete Block Design (RCBD). In this design, the interface variation was considered as the whole-plot factor and was applied to each participant. The vehicle speed was considered as the split-plot factor and was applied to each trial. The mission scenario was used as a replication. Geographical features presented in the mission map (or navigation display) were varied between the two scenarios in order to prevent potential participant learning effects. However, the vehicle control tasks were the

same among the scenarios. Table 4.3 shows the schedule of trials for each experiment participant, including the crossings of vehicle speed and mission scenarios within the assigned interface condition.

Table 4.3: Treatments for Participants

Participant	Interface	Trial 1	Trial 2	Trial 3	Trial 4
1	Enhanced	1	4	3	2
2	Baseline	5	8	6	7
3	Baseline	5	6	7	8
4	Enhanced	3	1	2	4
5	Enhanced	3	1	2	4
6	Baseline	8	6	5	7
7	Enhanced	1	3	4	2
8	Baseline	5	6	8	7
9	Enhanced	4	2	3	1
10	Baseline	7	8	5	6
11	Baseline	6	8	5	7
12	Enhanced	2	1	4	3
13	Enhanced	4	3	2	1
14	Baseline	5	7	6	8
15	Baseline	7	6	5	8
16	Enhanced	1	2	4	3
17	Enhanced	1	4	2	3
18	Baseline	5	8	6	7
19	Baseline	6	5	8	7
20	Enhanced	3	2	4	1
21	Baseline	8	5	7	6
22	Enhanced	4	1	2	3
23	Enhanced	1	3	4	2
24	Baseline	5	8	7	6

Note. Prototype 1 and 5 were Scenario 1 and Fast speeds. Prototype 2 and 6 were Scenario 2 and Slow speeds. Prototype 3 and 7 were Scenario 2 and Fast speeds. Prototype 4 and 8 were Scenario 1 and Slow speeds.

4.6 Dependent Variables

4.6.1 Sub-Tasks Time and Accuracy / Error

Dependent variables were classified as either task process or product measures. Process measures included sub-task completion times leading to total mission time. Product measures included task accuracy levels, or the total number of errors record for a complete task. Both types of measures were analyzed for each common task for a better understanding of participant behavior as mediated by the control interface design variation and event pacing. To ensure precision, all response times were painstakingly verified using the screen capture video and audio recordings.

4.6.1.1 Coordinate Task

The Coordinate Task time and errors were recorded for each participant in each test trial. The task time started with presentation of the audio recording, “Report the coordinate of...” and ended when a participant reported all 6 coordinate digits. Responses were measured in terms of absolute deviation from the exact grid using the Pythagorean Theorem, as depicted below in Figure 4.27. If no response was given, a miss/error was recorded.

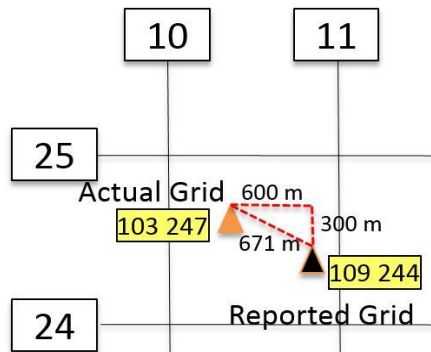


Figure 4.27: Coordinate Task Error

4.6.1.2 Distance Task

The Distance Task time and errors were recorded for each participant in each test trial. The task time started with presentation of the audio recording, “Report the distance between...” and ended when a participant reported a number. Error in this task was measured as the absolute deviation from the exact distance between objects, and presented as a deviation percentage (i.e., if the actual distance was 1600 meters and the reported distance was 1200 meters, then the deviation was calculated as 25 %). If no response was given for the task, it was assessed as a miss for that task.

4.6.1.3 Fix Alarm Task

The Fix Alarm Task time and accuracy were recorded for each participant in each test trial. The task time started when an alarm appeared below the MCDU WP box. (Although there was also a verbal cue of “Fix the alarm shown”, the task time began upon appearance of the alarm.) The task time ended when a participant clicked the interface button that fixed the alarm.

4.6.1.4 Prioritize Alarm Task

The Prioritize Alarm Task time and accuracy were recorded for each participant in each test trial. The task time started when an alarm appeared below the MCDU WP box. (Although there was a verbal cue of “Prioritize the alarms per your training”, the task time began upon the appearance of the alarm.) The task time ended when a participant clicked the ‘Done’ button after prioritizing the alarms from 1-3. An accuracy percentage (33 %, 66 %, or 100 %) was measured based on the number of correctly prioritized alarms.

4.6.1.5 System Parameter Warnings

The System Parameter Warnings Task time and accuracy were recorded for each participant in each test trial. The task time started when a parameter value occurred outside the identified normal or acceptable ranges. The task time ended when a participant verbally reported the warning. If no response was provided for a specific deviation, a miss/error was recorded for the specific warning.

4.6.2 Subjective Ratings (NASA-TLX)

The NASA-TLX was used as the dependent measure of participant cognitive workload. Hart and Staveland's (1988) standard NASA-TLX forms and definitions (see Appendix F) were used in the experiment. Participants completed the 15 pair-wise comparisons of demands after the mission familiarization and training were completed. Each demand component was then rated subsequent to performance of each test trial. Ratings were made on 5-inch bi-polar visual analog scales with anchors of "low" and "high"; ratings were measured from the low anchor with a resolution of $\frac{1}{16}$ " and transformed to a 100-point scale. Rankings and ratings were combined to compute an overall workload score for each test trial. The overall TLX score accounted for the ratings of each demand, including physical, mental, effort, performance, frustration, and temporal.

4.7 Procedure

4.7.1 Demographic Questionnaire

Prior to the experiment, potential participants were screened according to the inclusion criteria. Only eligible participants were scheduled to visit the NC State Ergonomics Lab for experiment testing. Upon their arrival at the lab, participants were given a brief

introduction to the study and presented with a consent form (Appendix G). Once they agreed to participate, a brief demographic questionnaire was administered (Appendix H).

Participants were asked to provide their age, gender, visual acuity, general computer usage level, gaming experience, and their level of expertise in manned flight or flight simulator experience.

4.7.2 *Training*

Each participant received a thorough block of instruction specific to the interface they were to use (see Appendices I and J), which took approximately 30-40 minutes. A participant was trained on one interface and then completed four trials with that same interface. During training, participants were introduced to the specific interface features and functionalities. This familiarization session ensured that participants understood the capability of the interface prototypes and critical interactions/commands to complete the control tasks in a mission scenario.

Following the completed blocks of instruction, a participant went through a full training mission scenario, executing tasks and answering queries, to introduce some temporal demands while still using the same map and mission information. All training objectives were considered to be met when a participant correctly answered every query, correctly executed every task, and announced every system parameter warning during the training mission. If questions were not answered correctly, the experimenter explained the correct answer to each question by referring to the interface content and the participant completed the training mission again. Every participant correctly answered every question and executed

every task before moving onto the experimental trials. Once complete with the training, participants were required to complete the NASA-TLX demand component ranking form.

4.7.3 *Experiment*

Once participants passed the training session and felt comfortable with the UAV control interface, the experimental trials were conducted. Per the provided scheme of maneuver, participants received all verbal cues from an audio recording and reported all tasks verbally to the experimenter. Timelines for all trials are presented in Appendix K. During test trials, participants flew a planned route with defined flight parameters and executed the same vehicle control tasks as instructed in the training scenario. The only difference between the training and test trials was the geographic area over which the UAV was flown.

Table 4.4 presents a summary of a participant's experiment procedure. After familiarization was completed, the participant performed a training trial and was required to correctly execute all tasks before proceeding with the experimental test trials. Once the training exercise was complete, the participant completed four test trials with either the Enhanced or Baseline interface. The NASA-TLX demand component ratings were completed at the close of each trial followed by a 2-minute rest. Lastly, the participants filled-out a usability questionnaire (see Appendix L) and were asked to provide comments on the general usability of the test interface. The participants were then thanked for their participation, paid, and dismissed from the study.

Table 4.4: Example Experiment Procedure

Experiment Procedure		
Pre-Experiment Screening		
Informed Consent Form		
Orientation		
Familiarization and Training		
NASA-TLX Demand Component Ranking		
Trial 1: Scenario 1 - Slow	NASA-TLX Rating	Rest
Trial 2: Scenario 1 - Fast	NASA-TLX Rating	Rest
Trial 3: Scenario 2 - Slow	NASA-TLX Rating	Rest
Trial 4: Scenario 2 - Fast	NASA-TLX Rating	Rest
Usability Questionnaire		
Debriefing and Payment		

4.8 Hypotheses

Based on the human-computer interaction literature review, it was expected that the Baseline Interfaces, lacking conformance with existing human factors guidelines, would impose a greater cognitive workload on users. Alternatively, the Enhanced Interface was expected to generate the lowest cognitive workload response for both vehicle speeds. These general research hypotheses are translated here in terms of specific DVs and IVs recorded and manipulated during the experiment:

- Hypothesis 1: M-GEDIS-UAV scores were expected to be higher for the Enhanced UAV interface design than the baseline interface.
- Hypothesis 2: Sub-task completion times were expected to be lower for the Enhanced Interface.
- Hypothesis 3: Sub-task accuracy was expected to be higher for the Enhanced Interface.
- Hypothesis 4: The mean perceived workload was expected to be lower for the Enhanced Interface than the Baseline Interface.

- Hypothesis 5: Perceived workload with the Enhanced Interface was expected to remain constant across UAV control task event rates; whereas, perceived workload with the Baseline Interface was expected to have a positive correlation with task event rate.
- Hypothesis 6: M-GEDIS-UAV scores were expected to be predictive of interface workload and performance outcomes.

4.9 Data Analysis

Analyses of Variance (ANOVA) was applied to all response measures collected during the experiment. Prior to application of the parametric procedure, diagnostics on response measure data were conducted in order to determine if the assumptions of the parametric procedure were met, including constant variance of responses among settings of the IVs and normality of response residuals across all experimental conditions. Barlett's test (Snedecor & Cochran, 1989) and Shapiro-Wilk's test (Shapiro & Wilk, 1965) were used to assess data conformance with the homoscedasticity and normality assumptions, respectively. If the equal variance and residual normality assumptions were violated, transformations were applied to response measures (e.g., log or square root transformations). If transformations were ineffective in ensuring that parametric assumptions were upheld, a nonparametric procedure was applied to the measures or ranked observations were submitted to the parametric test procedure (ANOVA).

In order to assess the workload and performance effects of the UAV control interface variations (V_i) and vehicle speeds (S_k) (scenario event rates) as well as their interaction

(VS_{ik}), a statistical model was formulated. As shown in Equation 1, y_{ijklm} represents the dependent variable for analysis. Participant nested within the interface condition was used as the whole plot error in order to test the significance of the interface variation. Mission scenario (M_l) and trial number (T_m) were also included in the statistical model. The split-plot error, specifically the interaction of the vehicle speed setting with the participant nested in the interface condition was lumped into the omnibus error term as part of the model.

$$y_{ijklm} = \mu + V_i + P(V)_{j(i)} + S_k + VS_{ik} + M_l + T_m + \epsilon_{ijklm} \text{ (Equation 1)}$$

This model was applied to each dependent variable in order to identify any significant main effects and whether the interaction was influential in responses. A significance level of $\alpha=0.05$ was used to limit the false rejection rate.

With respect to the number of observations on each response measure, 12 participants were assigned to each interface variation (i.e., 24 participants in total). Each participant was required to complete 4 trials (2 vehicle speeds * 2 mission scenarios). Each workload response measure was aggregated for each trial. On this basis, the total number of observations for each response was 94. Based on this approach, the degrees of freedom (DOF) for the ANOVA model were calculated and are presented in Table 4.5.

Table 4.5: DOF Breakdown for ANOVA Model

Variable	DOF
Interface Variation	2
Participant (Interface Variation)	22
Vehicle Speed	1
Interface Variation * Vehicle Speed	2
Error	67
Total	94

5. Results

In the instructions to the experiment, participants were told to execute every task and answer every question as quickly and accurately as possible. Consequently, the results on each task are discussed in a couplet of time and accuracy. Tables 5.1 and 5.2 present the descriptive statistics for each DV for each speed setting within each interface condition as well as for each interface across speeding settings (overall).

Table 5.1: Descriptive Statistics for Dependent Variables by Interface and Speed

		Coordinate Task Time (sec)	Coordinate Task Error (meters)	Distance Task Time (sec)	Distance Task Error (%)	Fix Alarm Time (sec)	Fix Alarm Accuracy (%)
Baseline Interface	Fast Speed	12.88 (SD: 2.80)	69.71 (SD: 79.76)	11.00 (SD: 4.10)	10.38 (SD: 12.74)	5.65 (SD: 2.21)	100 (SD: 0)
	Slow Speed	12.99 (SD: 4.18)	81.00 (SD: 63.78)	12.73 (SD: 4.83)	13.46 (SD: 15.08)	6.37 (SD: 2.59)	100 (SD: 0)
	Overall	12.94 (SD: 3.55)	75.49 (SD: 71.38)	11.87 (SD: 4.52)	11.92 (SD: 13.90)	6.01 (SD: 2.41)	100 (SD: 0)
Enhanced Interface	Fast Speed	10.16 (SD: 1.71)	0 (SD: 0)	9.53 (SD: 3.07)	.27 (SD: .01)	3.70 (SD: 1.88)	100 (SD: 0)
	Slow Speed	10.14 (SD: 2.49)	0 (SD: 0)	9.28 (SD: 3.55)	1.76 (SD: .09)	4.03 (SD: 4.08)	100 (SD: 0)
	Overall	10.15 (SD: 2.14)	0 (SD: 0)	9.41 (SD: 3.29)	1.03 (SD: .06)	3.87 (SD: 3.14)	100 (SD: 0)

Table 5.2: Descriptive Statistics for Dependent Variables by Interface and Speed

		Prioritize Alarm Time (sec)	Prioritize Alarm Accuracy (%)	Parameter Warning Time (sec)	Parameter Warning Accuracy (%)	NASA-TLX
Baseline Interface	Fast Speed	12.19 (SD: 8.72)	92 (SD: 23)	9.35 (SD: 7.05)	91 (SD: 15)	57.37 (SD: 15.59)
	Slow Speed	10.11 (SD: 3.63)	94 (SD: 19)	10.33 (SD: 7.23)	95 (SD: 12)	53.52 (SD: 14.14)
	Overall	11.15 (SD: 6.69)	93 (SD: 21)	9.84 (7.08)	93 (SD: 14)	55.44 (SD: 14.86)
Enhanced Interface	Fast Speed	8.13 (SD: 3.23)	92 (SD: 23)	4.16 (SD: 3.56)	94 (SD: 12)	50.57 (SD: 13.03)
	Slow Speed	7.75 (SD: 2.52)	92 (SD: 23)	4.02 (SD: 2.77)	97 (SD: 10)	47.97 (SD: 11.40)
	Overall	7.94 (SD: 2.87)	92 (SD: 22)	4.09 (SD: 3.16)	96 (SD: 11)	49.27 (SD: 12.18)

Table 5.3 presents a summary of all statistically significant effects for each DV, which are discussed individually in the following sections.

Table 5.3: Summary of Statistically Significant Effects

Dependent Variable	Transformation	Statistical Test	Significant Effects	F Value	P Value
Coordinate Task Time	Log	ANOVA	Interface	$F(1,22) = 45.11$	0.004
			Trial Number	$F(1,62) = 5.32$	0.025
Coordinate Task Error	Ranks	ANOVA	Interface	$F(1,22) = 55.52$	<.0001
Distance Task Time	Ranks	ANOVA	Interface	$F(1,22) = 23.13$	0.016
			Scenario	$F(1,66) = 8.66$	0.005
Distance Task Error	Ranks	ANOVA	Interface	$F(1,22) = 154.92$	<.0001
Fix Alarm Task Time	Log	ANOVA	Interface	$F(1,22) = 55.85$	<.001
			Trial Number	$F(1,67) = 13.18$	0.0005
Fix Alarm Task Accuracy	None	ANOVA	None		
Prioritize Alarm Task Time	Normal	ANOVA	Interface	$F(1,22) = 26.37$	0.033
Prioritize Alarm Task Accuracy	Ranks	ANOVA	Trial Number	$F(1,67) = 7.24$	0.009
System Parameter Warning Time	Log	ANOVA	Interface	$F(1,22) = 43.59$	<.0001
System Parameter Warning Accuracy	Ranks	ANOVA	Trial Number	$F(1,67) = 7.86$	0.007
NASA-TLX	Log	ANOVA	Trial Number	$F(1,68) = 14.40$	0.0003
			Scenario	$F(1,68) = 5.01$	0.028

5.1 Coordinate Task Time and Error

Due to normality assumption violations, a logarithm transformation was used on the data for statistical analysis of the Coordinate Task times. An ANOVA performed on the transformed response times revealed significant effects of interface ($F(1,22) = 45.11$, $p = .004$) and trial number ($F(1,62) = 5.32$, $p = .025$); there was no significant effect of speed ($F(1,62) = .5643$, $p = .455$), and the interaction of speed and interface was not present ($F(1,62) = .175$, $p = .677$). Figure 5.1 shows that participant using the Enhanced Interface were, on average, 2.81 seconds faster than participants using the Baseline Interface.

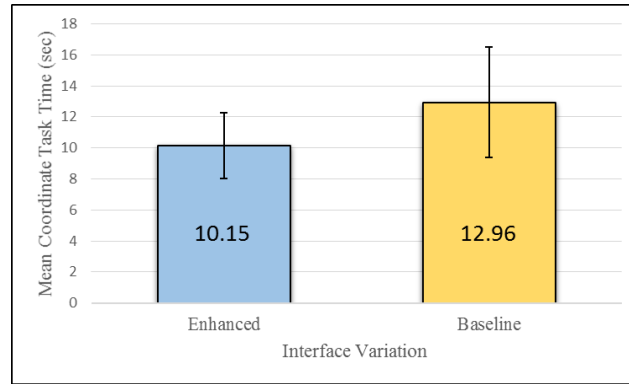


Figure 5.1: Mean Coordinate Task Time by Interface

For Coordinate Task error, the absolute deviation of participant responses from the coordinates was determined using Euclidean distance. All participants using the Enhanced Interface provided the exact object coordinates, and therefore had no deviations. Participants using the Baseline Interface had a mean deviation of 75.49 meters (SD: 71.38) across all four trials. Based on the 6 digit MGRS coordinate, all responses had one of the following deviations: 0, 100, 141, 200, or 282 meters. Figure 5.2 presents a bullseye charts with rings associated with each level deviation in coordinate estimation for the Baseline Interface and Enhanced Interface participants separated by trial.

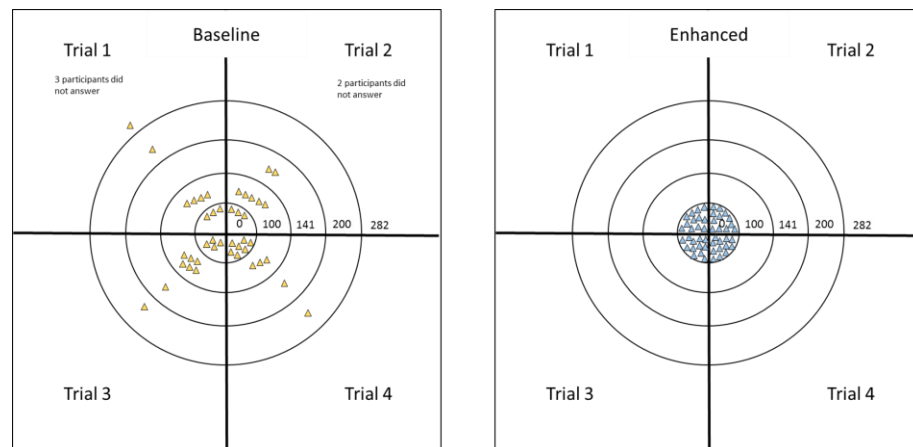


Figure 5.2: Baseline and Enhanced Interface Coordinate Task Deviation by Trial

5.2 Distance Task Time and Error

Due to normality assumption violations, transformations were attempted on the Distance Task times. Logarithm, inverse, and square root transformations were attempted but failed to uphold the parametric assumptions of normality and equal variance. Consequently, a ranks transformation of the Distance Task times was submitted to the ANOVA procedure. The ANOVA revealed a significant effect of the interface ($F(1,22) = 23.13, p = .016$), and scenario ($F(1,66) = 8.66, p = .005$); trial number was also found to be marginally significant ($F(1,66) = 3.67, p = .059$). No significant effects were found for speed ($F(1,66) = .91, p = .344$) or the interaction of speed and interface ($F(1,66) = 2.45, p = .122$). Figure 5.3 presents the mean Distance Task times for each interface condition. The plot reveals that participants using the Baseline Interface took, on average, 2.46 seconds longer to complete the task than participants using the Enhanced Interface.

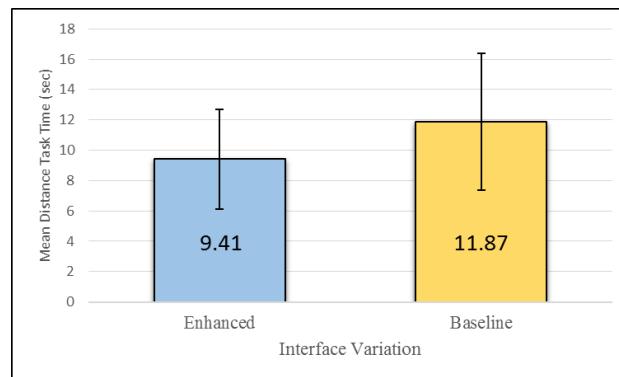


Figure 5.3: Mean Distance Task Time by Interface

Distance Task error was gauged in terms of the absolute percent deviation of participant estimates relative to the correct distances. Due to normality assumption

violations, transformations were attempted on the Distance Task error. Logarithm, inverse, and square root transformations were attempted but failed to uphold the parametric assumptions of normality and equal variance. Consequently, a ranks transformation was applied to the response, which was then submitted to the ANOVA procedure. The ANOVA revealed a significant effect for the interface ($F(1,22) = 154.92, p < .0001$); however, trial number ($F(1,67) = 1.79, p = .186$), scenario ($F(1,67) = .011, p = .916$) and the interaction of interface and speed ($F(1,67) = 2.53, p = .117$) were not found to be significant. Figure 5.4 shows the mean Distance Task error percentage for each interface. On average, participants using the Baseline Interface were off by 11.92 % in their estimates, as compared to 1.03 % for participants using the Enhanced Interface.

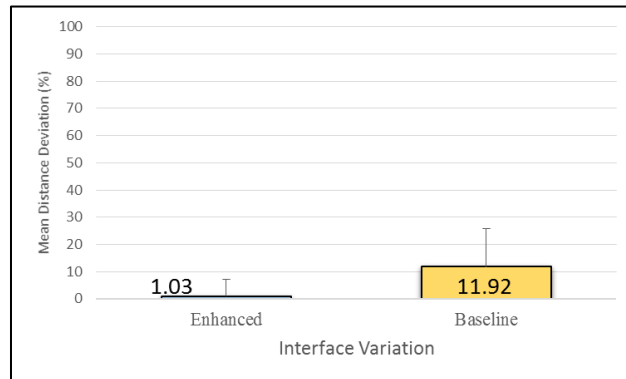


Figure 5.4: Mean Distance Deviation % by Interface

5.3 Fix Alarm Task Time and Accuracy

Due to normality assumption violations, a logarithm transformation was applied to the Fix Alarm Task time data for statistical analysis. An ANOVA on the task times revealed significant effects of interface ($F(1,22) = 55.85, p < .001$) and trial number ($F(1,67) =$

13.18, $p = .0005$); however, speed ($F(1,67) = .85$, $p = .361$), scenario ($F(1,67) = .52$, $p = .474$) and the interaction of speed and interface condition ($F(1,67) = .67$, $p = .417$) were all found to be insignificant. Figure 5.5 shows that participants using the Enhanced Interface were, on average, 2.14 seconds faster in fixing a given alarm as compared to participants using the Baseline Interface. For Fix Alarm Accuracy, every participant in every trial correctly accomplished the task.

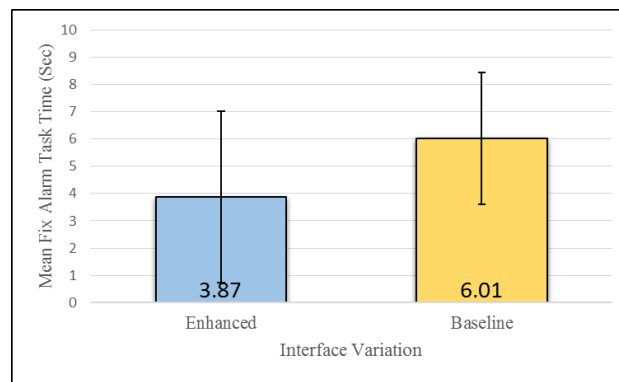


Figure 5.5: Mean Fix Alarm Time by Interface

5.4 Prioritize Alarm Task Time and Accuracy

Prioritize Alarm Task time met the ANOVA assumptions of homoscedasticity and normality. The interface manipulation ($F(1,22) = 26.37$, $p = .033$) was found to be significant; however, speed ($F(1,67) = 1.39$, $p = .242$), scenario ($F(1,67) = .01$, $p = .943$), trial number ($F(1,67) = 2.73$, $p = .103$), as well as the interaction between speed and interface ($F(1,67) = .49$, $p = .487$), were all found to be insignificant. Figure 5.6 shows that participants using the Enhanced Interface were, on average, 3.21 seconds faster in Prioritizing Alarms.

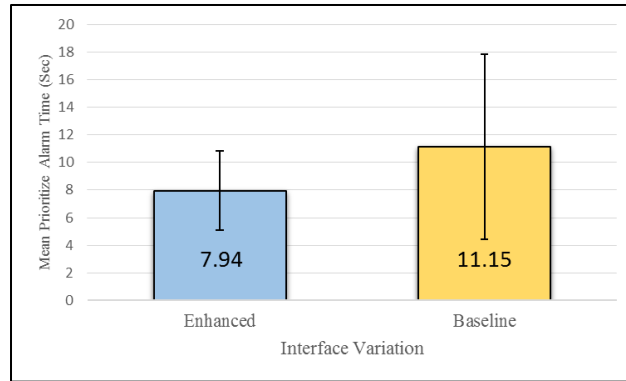


Figure 5.6: Mean Prioritize Alarm Time by Interface

For the Prioritize Alarm task accuracy, only trial number was shown to be significant ($F(1,67) = 7.24, p = .009$). For both interfaces and speeds, the mean accuracy of the Prioritize Alarm Task was 93 %.

5.5 System Parameter Warning Time and Accuracy

Due to normality assumption violations, a logarithm transformation was applied to the System Parameter Warning task time data for statistical analysis. An ANOVA on the task times revealed a significant effect of the interface condition ($F(1,22) = 43.59, p = <.0001$); however, speed setting ($F(1,67) = .24, p = .623$), scenario ($F(1,67) = .18, p = .674$), trial number ($F(1,67) = 2.75, p = .102$), and the interaction of speed and interface ($F(1,67) = .01, p = .920$) were all found to be insignificant. As shown in Figure 5.7, participants using the Enhanced Interface were, on average, 5.75 seconds faster than participants using the Baseline Interface.

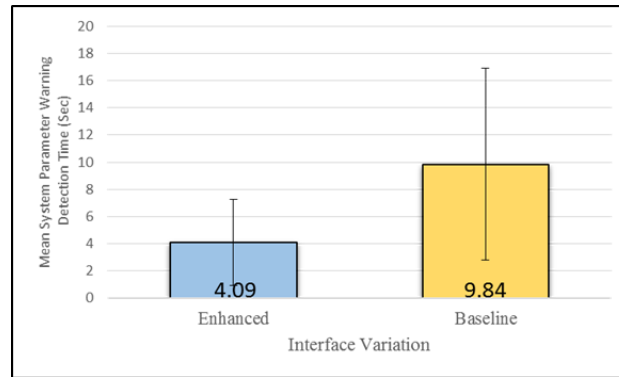


Figure 5.7: Mean Parameter Warning Detection Time by Interface

Due to normality assumption violations, transformations were attempted on the System Parameter Warning task accuracy. Logarithm, inverse, and square root transformations were attempted but failed to uphold the ANOVA assumptions of normality and constant variance. Consequently, a rank transformation was applied to the response and this data was submitted to the ANOVA procedure. For the System Parameter Warning accuracy, only trial number was found to be significant ($F(1,67) = 7.86, p = .007$). For both the Baseline and Enhanced interfaces, the mean accuracies in warning identification were 93 % and 96 %, respectively.

5.6 NASA-TLX

Due to normality assumption violations, a logarithm transformation was applied to the NASA-TLX response data for statistical analysis. An ANOVA on the overall TLX score revealed significant effects of the trial number ($F(1,68) = 14.40, p = .0003$) and scenario ($F(1,68) = 5.01, p = .028$); however, the interface condition ($F(1,22) = 1.47, p = .239$), speed setting ($F(1,22) = 1.95, p = .168$), and the interaction of interface and speed ($F(1,68) = .26, p = .609$) were not significant. The mean workload rating for the Enhanced Interface was

49.27 versus 55.44 for the Baseline Interface, but this difference was not statistically significant due to variability in ratings across participants. Figure 5.8 shows that the workload rating for Scenario 1 to be 4.92 points higher than the workload rating for Scenario 2 on the 100-point score scale.

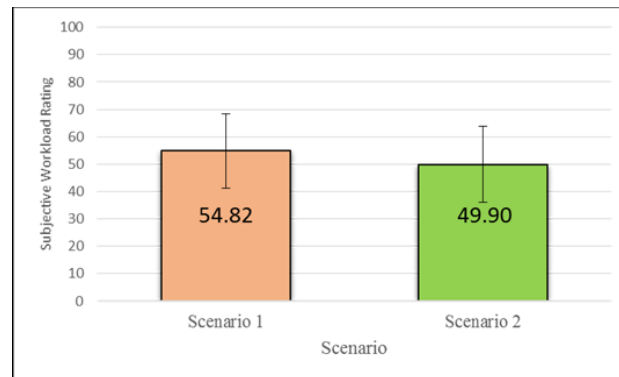


Figure 5.8: Mean NASA-TLX Workload Rating by Scenario

5.7 Predictive M-GEDIS-UAV Scores

An ANOVA with the M-GEDIS-UAV scores for the Enhanced and Baseline Interfaces as predictors of participant performance and workload responses was used to further assess the capability of the tool for characterizing the impact of interface design features on UAV operator behavior. Results revealed the M-GEDIS-UAV scores to be predictive of some user performance measures. As seen in Tables 5.4 and 5.5, the M-GEDIS-UAV scores were significant in relation to the Coordinate Task time, Coordinate Task error, Distance Task time, Distance Task error, Fix Alarm time, and Parameter Warning response time. The analysis also revealed a marginal relation of the interface scores with Prioritize Alarm accuracy, and Parameter Warning accuracy, as well as the subjective

workload response measured with the NASA-TLX. Fix Alarm accuracy was not included in this analysis as there was no variability in the response among the environmental conditions.

Table 5.4: Predictability of M-GEDIS-UAV Score on Dependent Variables

	Coordinate Task Time	Coordinate Task Error	Distance Task Time	Distance Task Error	Fix Alarm Time
F-Value	F(1,22) = 45.07	F(1,22) = 70.63	F(1,22) = 23.13	F(1,22) = 154.92	F(1,22) = 56.59
P-Value	0.004	<.0001	0.016	<.0001	0.0006
Significance	Yes	Yes	Yes	Yes	Yes

Table 5.5: Predictability of M-GEDIS-UAV Score on Dependent Variables

	Prioritize Alarm Time	Prioritize Alarm Accuracy	Parameter Warning Time	Parameter Warning Accuracy	NASA-TLX
F-Value	F(1,22) = 18.81	F(1,22) = .186	F(1,22) = 44.24	F(1,22) = 1.23	F(1,22) = 1.47
P-Value	0.068	0.839	<.0001	0.324	0.239
Significance	Marginal	No	Yes	No	No

6. Discussion

6.1 M-GEDIS-UAV Pedigree

Hypothesis 1 stated that the M-GEDIS-UAV scores would be greater for the Enhanced UAV interface. As summarized in Table 4.1, there were substantial functionality and usability changes made from the Baseline to the Enhanced Interface. These differences led to overall scores of 90 and 79 for the Enhanced and Baseline Interface, respectively. Specifically, within those scores, the Enhanced Interface had a 21-point advantage over the Baseline Interface in terms of the Maps and Navigation indicators (features) and a very large 61-point advantage in terms of the Alarms feature. There were tangible UAV interface changes made that resulted in substantially different scores through the M-GEDIS-UAV evaluation. These observations supported the expectation of M-GEDIS-UAV sensitivity to interface manipulations.

Related to these findings, it is important to note that the human factors experts applying the tool in this study took approximately 1.5 hours to come to an agreement on the applicable set of design criteria for the UAV interface evaluations. Related to this, the tool is very specific in terms of which human factors and UAV-domain design standards are useful for evaluating interface designs. Each analyst also took another 2.5 hours to evaluate each interface. Although the tool appears to be very effective at differentiating between interfaces, based on the degree of design feature conformance with guidelines, it is labor-intensive in application. In addition to application as an existing design evaluation tool, the M-GEDIS-UAV provides designers with a comprehensive list of guidelines that can be used in the

systems development process. The specific criteria, along with their references, provide objective bases for “optimizing” interface design.

6.2 Sub-Task Completion Times

Hypothesis 2 stated that the Enhanced Interface would facilitate faster sub-task completion times for the process DVs. The interface manipulation was significant for all the sub-task time measures. Furthermore, Figure 6.1 below shows that for all the process DVs the Enhanced Interface facilitated a faster response. The faster sub-task completion times were in support of Hypothesis 2.

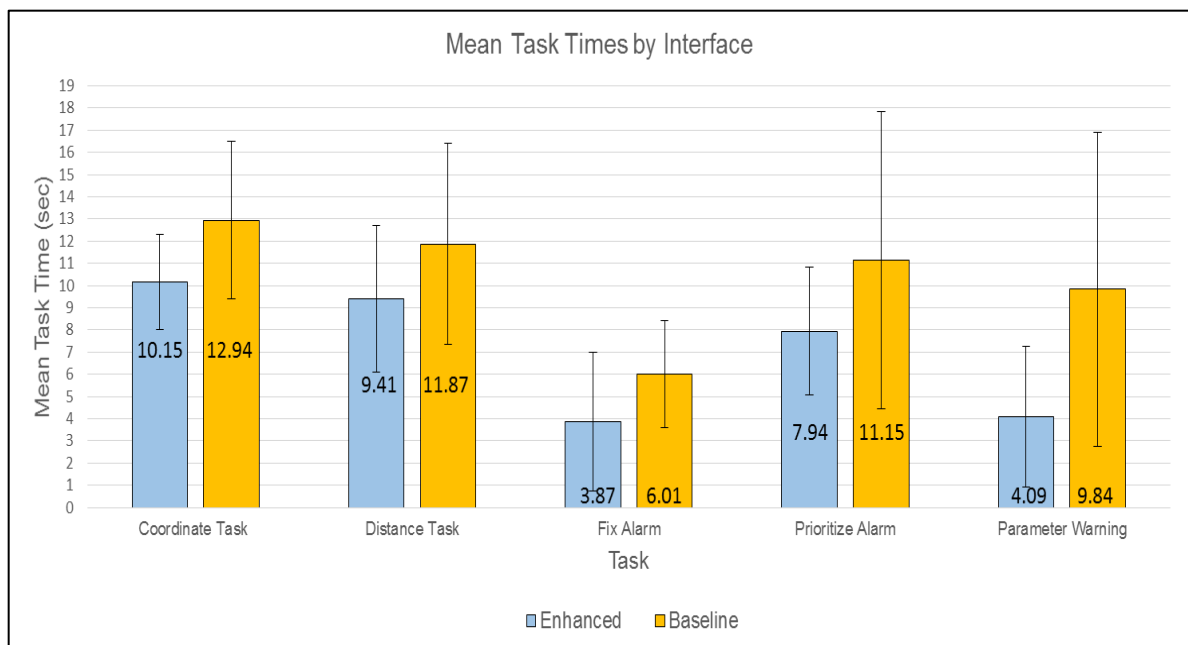


Figure 6.1: Mean Task Times by Interface

These results may, in part, be attributable to the Enhanced Interface providing some automation of tasks that was not available for the Baseline Interface users. It is also important

to note that this automation was “perfect”; that is, there were no reliability issues in the function of the automated tools of the Enhanced Interface.

In terms of further explanation of the task time results, the various automated tools can be conveniently classified according to automated functions identified by Parasuraman, Sheridan and Wickens (2000), including information acquisition, information analysis, decision making and action implementation. For example, the Coordinate and Distance Tasks tools both represented information analysis automation for the cognitive processes of object coordinate location and inter-object distance estimation, respectively. Whereas, the Fix Alarm Task aids represented information acquisition and information analysis automation; in terms of information analysis, an algorithm determined what emergency control button was needed to resolve an alarm. The information acquisition automation highlighted the correct button to facilitate user perception. The Prioritize Alarm Task aids represented information acquisition automation by providing semantically consistent color and symbol coding of alarms to help participants in prioritization. The System Parameter Warnings task was also aided by information acquisition automation under the Enhanced Interface condition with warning icons being presented next to deviant system parameters. These cues supported human sensory processes. In each case of an alarm, the automation provided a suggestion, or an indication, to facilitate a faster decision and response selection by users.

When automation is applied judiciously and relative to system user cognitive and physical demands, research has demonstrated substantial performance and workload benefits (Parasuraman et al., 2000; Kaber & Wright, 2003; Kaber & Endsley, 2004; Kaber, Wright, Prinzel, & Clamann, 2005). The various forms of information automation as part of the

Enhanced Interface design were targeted at only the most demanding user tasks; therefore, the decreased sub-task completion times were expected and supported Hypothesis 2.

6.3 Sub-Task Accuracy

Hypothesis 3 stated that the Enhanced Interface would facilitate more accurate responses across product-type DVs. The interface manipulation was significant for performance in both the Distance Task and Coordinate Task, but was not significant for any other DVs. Table 6.1 shows the mean deviations (errors) for the Coordinate and Distance Tasks and the accuracies for rest of the product DVs.

Table 6.1: Summary of Mean Accuracies for Product Dependent Variables

Task	Baseline Interface Deviation	Enhanced Interface Deviation	Deviation Difference
Coordinate Task	75.49 meters	0 meters	75.49 meters
Distance Task	11.92%	1.03%	10.89%
	Baseline Interface Accuracy (%)	Enhanced Interface Accuracy (%)	Accuracy Difference (%)
Fix Alarm Task	100	100	0
Prioritize Alarm Task	93	92	1
System Parameter Warning	93	96	3

The more accurate responses for the Coordinate and Distance Tasks for participants using the Enhanced Interface support Hypothesis 3. The Distance and Coordinate Tasks, as noted in the Usability Questionnaire, were anecdotally the most difficult tasks for the Baseline Interface participants while the Enhanced Interface’s automation assisted those participants with the cognitive process of determining the distance or exact coordinates. These are results are in line with previous literature that automation can improve

performance and decrease workload (Parasuraman et al., 2000; Kaber & Wright, 2003; Kaber & Endsley, 2004; Kaber et al., 2005).

Conversely, for accuracies involving warnings or alarms, there was a negligible difference between the two interfaces. Despite the advantages that Enhanced Interface users had, the response accuracies were indistinguishable and were all at or near 100 % accurate. The instructions were that the participant executed each task as quickly and accurately as possible; however, given the results, it is apparent that the participants placed more importance on task accuracy rather than on the completion time for these tasks.

6.4 Perceived Workload

Hypothesis 4 stated that the Enhanced Interface would produce lower perceived workload across both vehicle speed settings. While the mean NASA-TLX rating was lower for the Enhanced Interface (Enhanced = 49.27 vs. Baseline = 55.44), this difference was not significant. Neither the interface or speed conditions were significant in terms of the NASA-TLX composite scores. Consequently, the statistical results did not support the hypothesis. However, participant comments to the Usability Questionnaire indicated that the Baseline Interface was considered difficult to use; whereas the Enhanced Interface was considered easy for use in the range of required tasks. These comments were in-line with Hypothesis 4.

As previously mentioned, since the speed/event rate manipulation was not sufficient to impose a difference in perceived temporal demand, there was no opportunity to test the robustness of either interface for supporting operators in addressing “high” workload situations. Therefore, Hypothesis 5 was ultimately not tested by the present study.

6.5 Event Rate Manipulation

Across all dependent variables, the event rate manipulation of ‘Fast’ versus ‘Slow’ was not significant, which was counter to expectation. Liu et al. (2013) showed that the faster task pacing produced greater workload and could therefore reveal differences in the usability of interfaces during times of high temporal demand. Despite pilot testing of the vehicle speed settings in advance of the experiment, and differences in pilot subject subjective ratings of workload, the Fast and Slow settings were not perceived as different by the test participants. Related to this finding, the pilot testing utilized the same training procedure as applied in the experiment. It is possible that the event rate of the Fast trials was still too slow, especially once a user became comfortable with the UAV control and more of an expert user in use of the assigned interface in later trials.

Based on the Usability Questionnaire administered at the end of the study, participants who experienced the ‘Fast’ manipulation first felt that it was “very taxing and the pace of [activities] was almost overwhelming.” However, others who received the ‘Slow’ manipulation first observed that the pace was “easy to deal with” and that they “got used to it quickly.” The experiment design did not account for the possibility of participants becoming experts under the ‘Slow’ speed setting and then utilizing that expertise on the ‘Fast’ setting. There was also no expectation that participants would quickly become expert in interface use. Related to this, Sterling and Perala (2007) previously observed that operators with less experience in UAV control experienced high levels of workload.

The lack of a taxing temporal demand through the ‘Fast’ speed manipulation compromised the opportunity to assess whether either interface was more robust than the

other for assisting operators in managing workload. In order to prevent this type of issue in future studies, when conducting pilot tests to determine temporal demand settings for UAV control experiments, it may be advisable to use expert operators to identify taxing task pacing levels and to apply these levels in any follow-on interface tests with novice operators or experts.

6.6 M-GEDIS-UAV Selectivity

Hypothesis 6 stated that that the M-GEDIS-UAV would be useful for identifying interfaces with better performance outcomes and interfaces posing the lowest cognitive workload for users among a set of alternatives. Application of the tool to the Enhanced Interface revealed an overall higher score on the Global Evaluation Index than for the Baseline Interface. This higher score predicted that the Enhanced Interface would have better performance responses as well as lower perceived workload on the NASA-TLX than the Baseline Interface. The M-GEDIS-UAV tool appears to be selective among interfaces in terms of performance but the study did not afford sufficient sensitivity for assessing selectivity of the tool in terms of interface workload.

On average, the Enhanced Interface did produce a lower NASA-TLX mean score than the Baseline Interface; however, this result was not statistically reliable. The overall means for each interface were in-line with expectation but the statistical test results did not support Hypothesis 4. These findings are likely due to the failure of the vehicle speed/event rate manipulation and a lack of difference in terms of user perceived temporal demands among the two interfaces. Additionally, there was an interface learning effect that appeared to influence the workload ratings. The trial number was significant in the TLX results and

workload substantially decreased for participants across trials. As a result of these two experimental issues, the present study cannot say that Hypothesis 6 was supported and that the M-GEDIS-UAV tool has the potential for predicting differences in UAV interface user (perceived) workload responses.

6.7 Trial Number Effect

There was a relatively consistent trial effect across several performance measures. From the usability survey, some participants commented that by Trial 3, they “felt comfortable” with the interface, which indicated that they might have still been learning the use of certain features during the first two test trials. Despite the thorough training protocol and strict criteria-based assessment during the training mission, a more extensive training protocol may be needed to prevent any learning effects during experiment test trials. One way to accomplish a more comprehensive training regimen, while still incentivizing participants to perform at a high level, would be to conduct six test trials and only collect data from the last 4. During the first two “test” trials, participants may make the transformation from novice to expert users, and the third through sixth trials would not reflect transient performance behavior. Analyzing each participant’s first trial would have provided a method for quantifying any learning effects and accounting for such effects in analyses of later trial data. However, given the present study design, a larger sample size and additional power would have been required for statistically reliable analysis of the first trial data.

7. Conclusion

The objectives of this research were to assess the validity of the M-GEDIS-UAV interface evaluation tool for sensitivity to UAV control interface design manipulations and to determine if the tool might be useful for identifying or selecting interface alternatives that would impose lower levels of cognitive workload for users. A between-subjects experiment was conducted in which two distinctly different UAV interfaces (Enhanced and Baseline) were used by participants to address common UAV control tasks under two speeds of vehicle flight, or scenario event rates (Fast and Slow). Participant performance and workload were captured using a battery of DVs with repeated observations.

Results of the experiment suggested that additional forms of information automation as part of the Enhanced Interface significantly improved task performance in terms of execution time. There was also evidence that the interface automation aided users in executing difficult cognitive tasks and reducing errors. Furthermore there was anecdotal evidence that the Enhanced (usability) Interface imposed a lower workload for users than the Baseline (commercially representative) Interface condition. These results were generally in-line with findings of previous studies and were expected based on the higher M-GEDIS-UAV score for the Enhanced Interface design. The results of this study strongly support the sensitivity of the M-GEDIS-UAV evaluation tool to interface design variations and moderately support the tool for selection among interfaces to identify low workload options.

A more comprehensive evaluation of the M-GEDIS-UAV requires an interface with poor adherence to human factors and UAV domain-specific guidelines as well as more challenging UAV control task event rates imposing high temporal demands.

7.1 Applications

The findings of this research may be most useful for UAV designers or potentially military acquisitions personnel making long-term decisions with large financial implications. The M-GEDIS-UAV tool provides an objective basis for choosing an interface among comparable design variations while maintaining a fair amount of flexibility in terms of analyst identification of which indicators (design features) and sub-indicators (feature characteristics) are relevant and important for interface assessment/comparison.

The tool might also be effective in use by commercial UAV interface designers. Consumers expect usable equipment and the M-GEDIS-UAV tool outlines specific, proven criteria for advancing interface usability. Application of the M-GEDIS-UAV tool can provide designers with an understanding of why one interface design may be better than another in terms of both functionality and information presentation. Additionally, with safety considerations in mind, designers have an obligation to communities making use of UAVs to ensure that control interfaces are robust for supporting performance and safe flight operations. Usage of the M-GEDIS-UAV tool can ensure the necessary level of interface functionality to address common UAV control tasks.

7.2 Limitations

There are four major limitations of the research presented here. The most important limitation was the lack of significance of the vehicle speed manipulation, as mentioned previously in the discussion section. A higher workload, compared across functionally similar interfaces, is needed to further validate the capability of the M-GEDIS-UAV tool for selecting among interface designs in terms of cognitive workload.

The second limitation of this study was that not every control appearing in the prototype interfaces was active; for example, the coordinates and distance buttons only worked on specific objects appearing in the interface navigation display, which did not allow for full participant exploration of the interface. An interface exploration period, provided in conjunction with the structured training regimen, could increase a user's level of interface competence and decrease any learning effect in experiment test trials. Although the interfaces tested in this study had "high" face-validity, the functionality was superficial and limited to the exact tasks required by a specific scenario. The best way to mitigate learning effects and avoid prototype flaws would be to test expert UAV pilots on a specially formulated scenario using a fully functional UAV simulation system. Of course, such research is resource and time intensive, and has its own limitations, but such study would be a logical follow-on to the present work in order to address the aforementioned issues.

Another limitation of the present research was the use of performance measures (time and sub-task accuracy) as indicators for comparing and identifying superior interface design features. Although participant exposure to the test conditions was randomized, the inclusion criteria for the study was limited and individual differences and spare mental capacity might have played significant roles in the results. That is, two tasks may be performed equally, but one person's mental capacity may be pushed to the limit while another person's may not be pushed at all. Additionally, it is difficult to measure changes in performance unless task workload levels are very high (Miller, 2001). While the present research was planned with this constraint in mind, once again, a significant operational tempo manipulation would likely better demonstrate performance differences among interface design conditions.

The last limitation was use of the NASA-TLX as a sole measure of participant workload. This singular subjective measure of task demands relies heavily on consistency of participants in making ratings from one test trial to the next, as all subjective measures do. Unfortunately, changes in internal scaling of workload can occur with task experience and developing proficiency. In addition, participants filled-out the NASA-TLX rating form at the completion of each test trial and this approach of recall of workload experienced during a test is inherently biased by participant memory. Per Hart and Staveland's (1998) NASA-TLX procedure, the pairwise comparison was completed after the training and the individual demand ratings were completed after each trial. However, given the level of learning experienced by participants in the first two trials of this study, additional pairwise rankings of demands before each test trial might have served to increase the accuracy of the calculated NASA-TLX scores. Physiological measures should be used in future studies, in combination with subjective workload ratings using the NASA-TLX, in order to provide a more complete and potentially accurate picture of UAV operator cognitive demand responses.

7.3 Future Work

The literature review revealed a need for a means of objective evaluation of UAV control interface designs. The present research sought to assess the validity of the M-GEDIS-UAV tool; however, further work is needed in terms of interface designs for evaluation, interface testing conditions, and interface workload measurements for relation to M-GEDIS-UAV scores.

To continue assessment of the validity of the M-GEDIS-UAV, a third degraded interface condition should be compared against the Baseline and Enhanced interfaces to provide a more complete picture of how interface scores fluctuate based on design feature manipulations. With respect to interface test conditions, any control task event rates need to be verified with expert users to ensure that user workload levels are sufficiently high in order to reveal any differences in user performance that might result due to interface feature variations. Additionally, off-nominal conditions could be imposed to ramp-up workload. During nominal conditions, the Enhanced Interface performed better under low workload situations; therefore, it is expected that the Enhanced Interface would support even greater performance under extreme flight or environmental conditions. In regard to measurement methods, the use of subjective workload ratings should be complemented with other types of workload measures, such as physiological responses; e.g., pupillography, heart rate, or heart rate variability. These additional measures could make clearer the utility of the M-GEDIS-UAV tool for identifying interface designs imposing lower or higher workload levels for operators.

Given that the present study supported the sensitivity and selectivity of the M-GEDIS-UAV tool, future work should compare the results from the M-GEDIS-UAV against simpler and more established evaluation tools like the MCH-UVD. If future data supports greater utility of the M-GEDIS-UAV tool, then designers would have additional justification/motivation for usage and implementation of the tool.

Given the identification of benefits of using the M-GEDIS-UAV tool for analyzing simplistic UAV control interfaces, as studied here, additional research is needed with higher

fidelity interfaces. The present study used a prototyping tool to simulate relatively simplistic UAV interface functions. The interface prototypes had inherent limitations in terms of the breadth and depth of actual functionality. Future research should leverage current military UAV simulations, like Vigilant Spirit, as well as an expert user population using a similar experimental design in order to further evaluate the usefulness of M-GEDIS-UAV tool.

Additional work could also be done to improve the M-GEDIS-UAV tool. At this point there are no weighting factors for any specific design criteria, sub-indicators, or indicators. Within each indicator, certain mission critical criteria could be determined for which non-conformance would result in an automatic failure of the interface evaluation. Adherence to these critical criteria would ensure a minimum level of safety, performance, and usability of the interface. Additionally, each indicator or sub-indicator could be locally or globally weighted based on importance to UAV performance; however, the methodology by which to assign these weights has yet to be determined.

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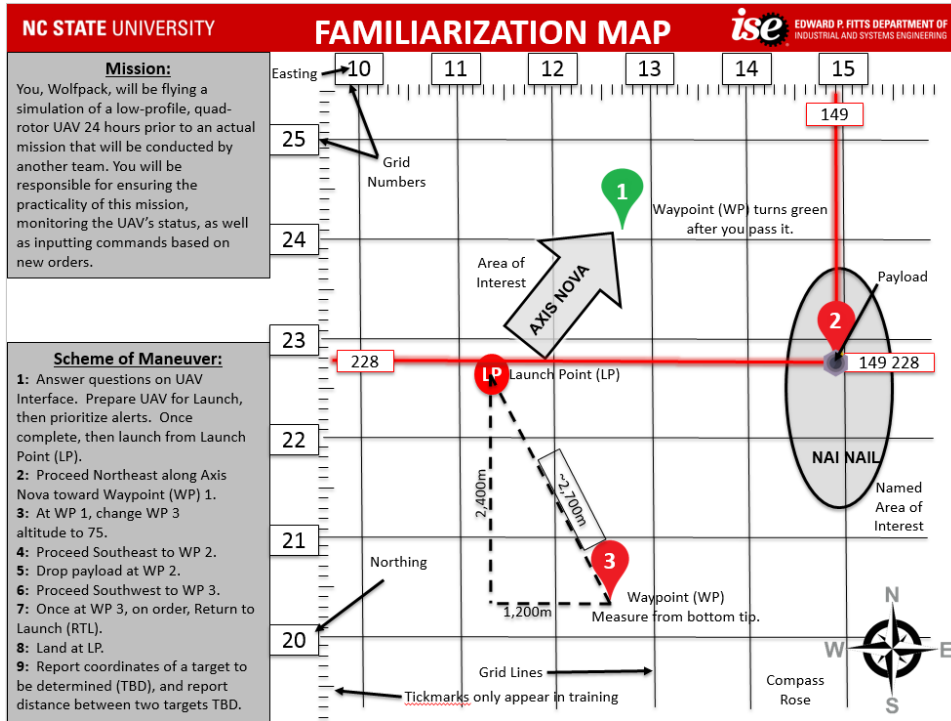
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9. Appendices

9.1 Appendix A: Enhanced Interface Mission and Map Sheets



NC STATE UNIVERSITY **FAMILIARIZATION MISSION** **ise** EDWARD P. FITTS DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

- Acronym List:** AOI: Area of Interest; LP: Launch Point; NAI: Named Area of Interest; WP: Waypoint
- System Status Parameters:** verbally report when any parameter is outside normal or acceptable range

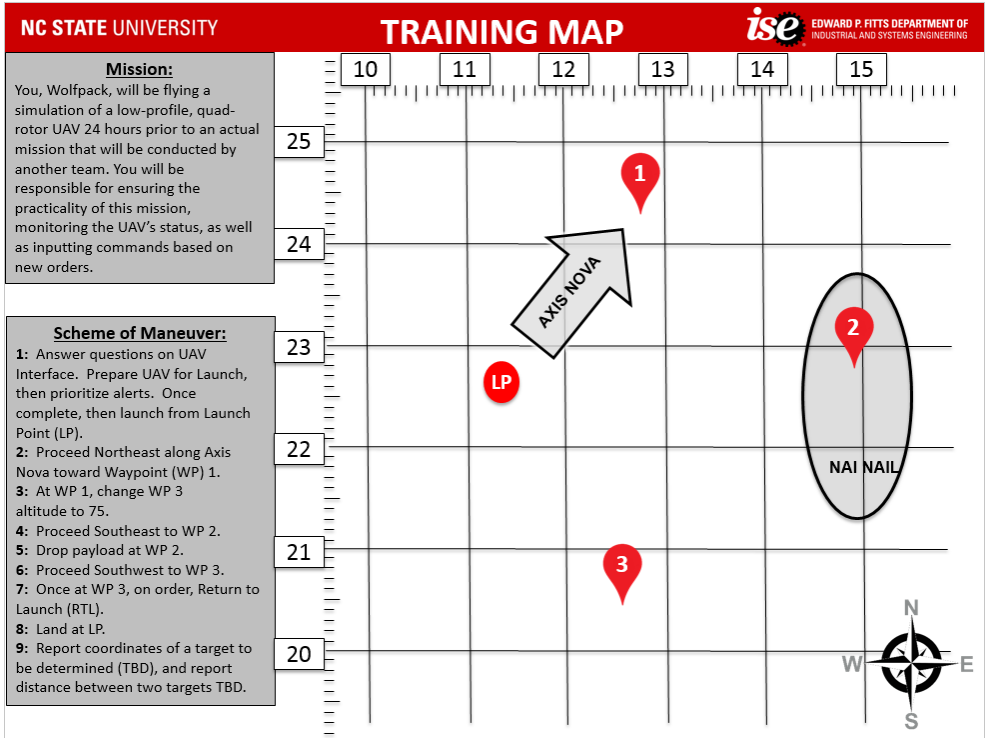
Altitude Unit: feet Norms: 40-55	Dist. Traveled Unit: meters Target: <10000	Ground Course Unit: degree Norms: 0-359	Ground Speed Unit: m/s Norms: 0-10	Air Speed Unit: knots Norms: 45-55	Bat. Remaining Unit: percent Acc.: 20-100
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Alarms found below Mission Planning Tool

- Alarms:** require action in order to resolve.

How To Resolve Alarms	
Excessive rate of descent	Slow Descent
Crash imminent	Pull Up
Engine fire alarm	Extinguish
Abort take off	Abort
Landing gear malfunction	Reset Gear
Exited selected altitude	Change Altitude
Bank angle > 35 degrees	Reduce Angle
Autopilot disconnected	Reconnect
Suboptimal glide slope	Change Slope
Maximum air speed reached	Reduce Speed
20% fuel remaining	Refuel

Alarm Priority Levels	
Alerts (Highest Priority) ⚠️	Excessive rate of descent Stall impending Crash imminent Engine fire alarm Abort take off Landing gear malfunction
Warnings (Medium Priority) ⚠️	Exit selected altitude Bank angle greater than 35 degrees Autopilot disconnected Suboptimal glide slope Maximum air speed reached 20% fuel remaining
Advisories (Lowest Priority)	Quarterly service due Parking brake released Aircraft in flight Engine valve open Navigation active Instrument panel switch activated



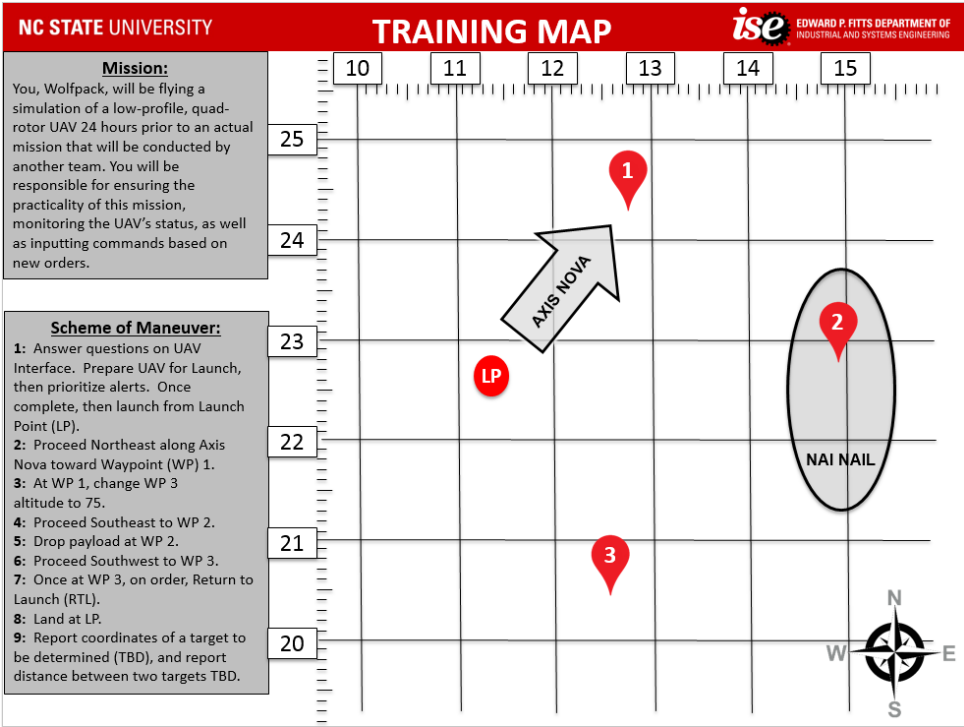
NC STATE UNIVERSITY **TRAINING MISSION** *ise* EDWARD P. FITTS DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

- Acronym List:** AOI: Area of Interest; LP: Launch Point; NAI: Named Area of Interest; WP: Waypoint
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NC STATE UNIVERSITY **TRAINING MISSION** *ise* EDWARD P. FITTS DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

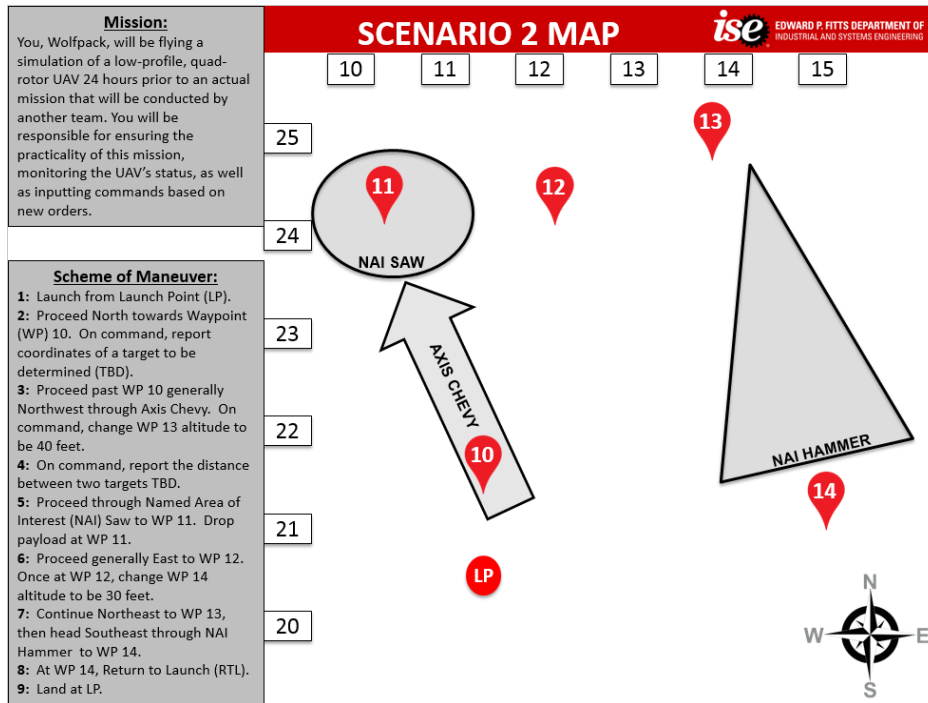
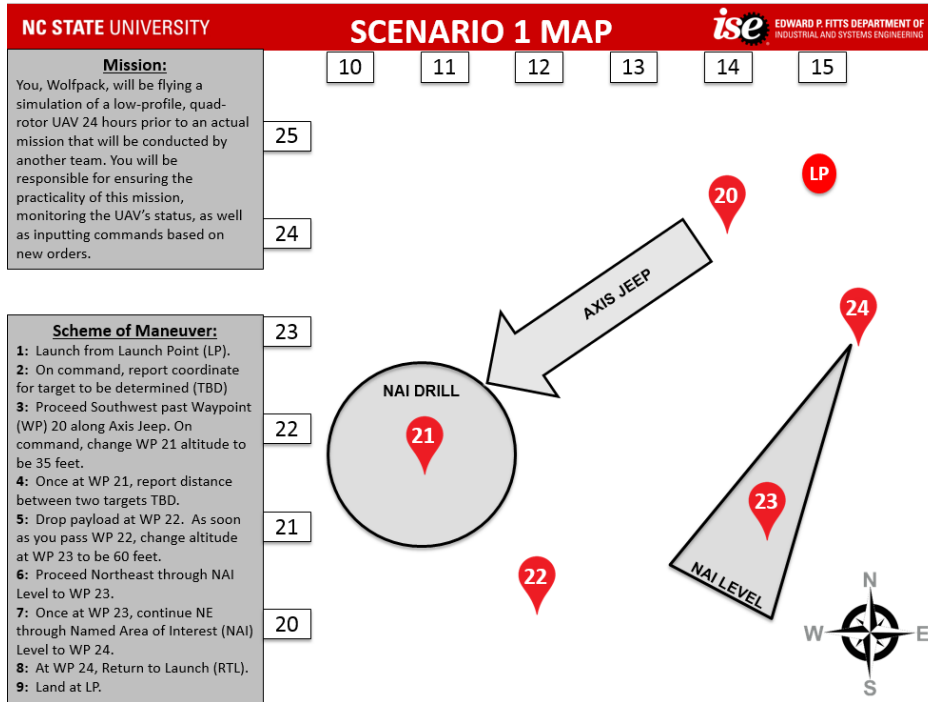
- Acronym List:** AOI: Area of Interest; LP: Launch Point; NAI: Named Area of Interest; WP: Waypoint
- System Status Parameters:** verbally report when any parameter is outside normal or acceptable range

Altitude Unit: feet Norms: 40-55	Dist. Traveled Unit: meters Target: <10000	Ground Course Unit: degree Norms: 0-359	Ground Speed Unit: m/s Norms: 0-10	Air Speed Unit: knots Norms: 45-55	Bat. Remaining Unit: percent Acc.: 20-100
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Suboptimal glide slope	Change Slope
Maximum air speed reached	Reduce Speed
20% fuel remaining	Refuel

Alarm Priority Levels	
Alerts (Highest Priority)	Excessive rate of descent Stall impending Crash imminent Engine fire alarm Abort take off Landing gear failure
Warnings (Medium Priority)	Exit selected altitude Bank angle greater than 35 degrees Autopilot disconnected Suboptimal glide slope Maximum air speed reached 20% fuel remaining
Advisories (Lowest Priority)	Quarterly service due Parking brake released Aircraft in flight Engine valve open Navigation active Instrument panel switch activated

9.3 Appendix C: Scenario 1 and Scenario 2 Maps for Enhanced and Baseline Interfaces



9.4 Appendix D: Heuristic Evaluation

Heuristic	Definition	Improved interface	Baseline Interface
Simple and Natural Dialogue	Dialogues should not contain irrelevant or rarely needed information. Every extraneous unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. All information should appear in a natural and logical order.	Satisfied. The Map Action menu logically organizes relevant information into sub-menus. The MCDU - Quick displays system statuses, normal parameters, and units of measurement. Alarms use normal language, not coding, and does not overload user with extraneous information.	Satisfied. The Map Action menu logically organizes relevant information by task. The MCDU - Quick displays system statuses, normal parameters, and units of measurement.
Speak the User's Language	The dialogue should be expressed clearly in words, phrases, and concepts familiar to the user rather than in system-oriented terms.	Satisfied. All commands in Alarms, Map Actions, and MCDU - Quick are expressed clearly to the user.	Satisfied. All commands in Alarms, Map Actions, and MCDU - Quick are expressed clearly to the user.
Minimize the User's Memory Load	The user's short-term memory is limited. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable when- ever appropriate. Complicated instructions should be simplified.	Satisfied - all information is presented to the user. On the PFD and MCDU - Actions there are indications of the system status. When preparing for launch, the user is instructed to Arm the UAV then launch before they have a chance to make an error. Also, instructions are available for how to use Coordinates and Distance tools.	Partially satisfied. In most cases, there is information on the interface to remind the user, for example, there are normal parameters for each UAV status. However, when the user has to prioritize alarms, they must remember their training on alarms. Furthermore, when fixing an alarm there is no further information available on how to fix the condition. The user must remember how to calculate a MGRS grid from their training.
Be Consistent	Users should not have to wonder whether different words, situations, or actions mean the same thing. A particular system action, when appropriate, should always be achievable by one particular user action. Consistency also means coordination between subsystems and between major independent systems with common user populations	Satisfied. Consistent wording from Map Actions to MCDU - Actions and across all alarms.	Partially satisfied. Mostly consistent wording across the interface, however inconsistent terminology for "Launch UAV" as "Take off" was used in the Map Action menu.

Heuristic	Definition	Improved interface	Baseline Interface
Provide Feedback	The system should always keep the user informed about what is going on by providing him or her with appropriate feedback within reasonable time.	Satisfied. Feedback is provided by grey-ing out inappropriate options when trying to launch the UAV as well as the "DISARMED" disappearing from the PFD when the UAV is launched.	Satisfied. Feedback is given, albeit slow, when writing waypoints to confirm altitude changes. When the UAV is Armed, the "DISARMED" disappears from the PFD.
Provide Clearly Marked Exits	A system should never capture users in situations that have no visible escape. Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue.	Satisfied. There is always a visible escape to any given function or menu item.	Satisfied. There is always a visible escape to any given function or menu item.
Provide Shortcuts	The features that make a system easy to learn-such as verbous dialogues and few entry fields on each display are often cumbersome to the experienced user. Clever shortcuts-unseen by the novice user-may often be included in a system such that the system caters to both inexperienced and experienced users.	Satisfied. There is a shortcut for dropping a payload to reduce time to execute a time-critical task. Also, for experienced users, they can use the Coordinates and Distance tool if more accurate information is needed on the targets in the scenario.	Not satisfied. All options are available, but the user has to navigate to all frequent and time critical tasks through the normal menu options.
Provide Good Error Messages	Good error messages are defensive, precise, and constructive. Defensive error messages blame the problem on system deficiencies and never criticize the user. Precise error messages provide the user with exact information about the cause of the problem. Constructive error messages provide meaningful suggestions to the user about what to do next.	Satisfied. Errors give the priority level, the issue, and tell the user how to fix the problem. Moreover, if the user needed additional information or help, there is a Help function available.	Partially satisfied. Error messages are precise and defensive. However, the error messages are not constructive because they don't provide suggestions on what to do next.
Error Prevention	Even better than good error messages is a careful design that prevents a problem from occurring in the first place.	Satisfied. The Launch UAV button is grey-ed out before proper procedures are done, indicating that the function is unavailable. Also, system status parameter information is presented on the MCDU - Quick to prevent monitoring errors.	Partially satisfied. Vehicle parameter normal ranges are present to prevent monitoring errors. But the interface doesn't present the error of launching UAV before arming it.

9.5 Appendix E: Mission Query Bank and Justifications

Identifier	Scenario	Speed	Element	Question	Justification
Map1	1	Slow	Map	How many targets are in NAI Drill?	Event requires knowledge of environment state.
Map2	1	Fast	Map	How many targets are in NAI Level?	Event requires knowledge of environment state.
Map3	1	Fast	Map	What Northing is Waypoint 20 closest to?	Event requires knowledge of environment state.
Map4	1	Slow	Map	What Easting is Waypoint 22 closest to?	Event requires knowledge of environment state.
Map5	1	Slow	Map	What is your current completion percentage for this mission?	Event requires knowledge of mission status.
Map6	1	Fast	Map	What is the name of the Axis?	Event requires knowledge of environment state.
Map7	1	Fast	Map	What is your current completion percentage for this mission?	Event requires knowledge of mission status.
Map8	2	Slow	Map	What are the names of the Axis?	Event requires knowledge of environment state.
Map9	2	Fast	Map	How many targets are in NAI Hammer?	Event requires knowledge of environment state.
Map10	2	Fast	Map	What are the names of the NAIs in the	Event requires knowledge of environment state.
Map11	2	Slow	Map	How many targets are in NAI Saw?	Event requires knowledge of environment state.
Map16	2	Slow	Map	What Easting is Waypoint 14 closest to?	Event requires of projection of vehicle status.
Map17	2	Fast	Map	What Northing is Waypoint 12 closest to?	Event requires of projection of vehicle status.
Actions_1	2	Fast	Map Actions	In map actions, how many Loiter options are available?	Event requires knowledge of command options.
Actions_2	2	Slow	Map Actions	In map actions, what are 2 of the 3 Overlay actions available?	Event requires knowledge of command options.
Actions_3	2	Slow	Map Actions	In map actions, where can you Jump to?	Event requires knowledge of command options.
Actions_4	2	Fast	Map Actions	In map actions, how many Waypoint options are available?	Event requires knowledge of command options.
Actions_5	2	Fast	Map Actions	What map action is Speed found under?	Event requires knowledge of command options.
Actions_6		Slow	Map Actions	In Map action, how many "Delete" options are available?	Event requires knowledge of mission status.
Actions_7	1	Slow	Map Actions	In map action, what can you Draw on the map?	Event requires knowledge of environment state.
Actions_8	1	Fast	Map Actions	For what map action command is "Land" an option?	Event requires knowledge of command options.
Actions_9	2	Slow	Map Actions	For what map action command is "Circle" an option?	Event requires knowledge of command options.
Actions_10	2	Fast	Map Actions	In map action, how many Overlay options are available?	Event requires knowledge of command options.
Quick_1	2	Fast	Quick	What is your current Battery Remaining?	Event requires knowledge of vehicle status.
Quick_2	2	Fast	Quick	What is your total distance traveled for this mission so far?	Event requires knowledge of vehicle status.
Quick_3	2	Slow	Quick	In meters / second, what is your current	Event requires knowledge of vehicle status.
Quick_4	2	Slow	Quick	In knots, what is your current speed?	Event requires knowledge of vehicle status.
Quick_4	2	Slow	Quick	In knots, what is your current speed?	Event requires knowledge of vehicle status.
Quick_5	2	Slow	Quick	What is your current ground course?	Event requires knowledge of vehicle status.
Quick_6	2	Fast	Quick	What is your current altitude?	Event requires knowledge of vehicle status.
Quick_6	1	Fast	Quick	What is your current altitude?	Event requires knowledge of vehicle status.
Quick_7	2	Fast	Quick	What is your current ground course?	Event requires knowledge of vehicle status.
Quick_8	1	Slow	Quick	What is your current Battery Remaining?	Event requires knowledge of vehicle status.
Quick_9	1	Fast	Quick	What is your current distance traveled?	Event requires knowledge of vehicle status.
Quick_10	1	Fast	Quick	What is your current ground speed?	Event requires knowledge of vehicle status.
Norm_1	1	Fast	Quick Norms	What is the normal range for UAV altitude?	Event requires knowledge of vehicle status.
Norm_2	1	Slow	Quick Norms	What is the target distance for the UAV?	Event requires knowledge of vehicle status.
Norm_3	1	Slow	Quick Norms	What is the minimum acceptable value for Battery Remaining?	Event requires knowledge of vehicle status.
Norm_4	1	Slow	Quick Norms	What is normal range for ground speed?	Event requires knowledge of vehicle status.
Norm_5	2	Slow	Quick Norms	What is the normal range for UAV altitude?	Event requires knowledge of vehicle status.
Norm_6	2	Slow	Quick Norms	What is the target distance for the UAV?	Event requires knowledge of vehicle status.
Norm_7	2	Fast	Quick Norms	What is the acceptable range for Battery Remaining?	Event requires knowledge of vehicle status.

9.6 Appendix F: NASA-TLX

Definitions of Task Demand Factors

Mental Demand

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals of the task set forth by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration Level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

NASA-TLX Questionnaire (Part I)

Participant Number: _____

For each of the pairs listed below, circle the scale title that represents the more important contributor to workload when you are performing tasks on the UAV interface.

- | | | |
|-----------------|----|-----------------|
| Mental Demand | or | Physical Demand |
| Mental Demand | or | Temporal Demand |
| Mental Demand | or | Performance |
| Mental Demand | or | Effort |
| Mental Demand | or | Frustration |
| Physical Demand | or | Temporal Demand |
| Physical Demand | or | Performance |
| Physical Demand | or | Effort |
| Physical Demand | or | Frustration |
| Temporal Demand | or | Performance |
| Temporal Demand | or | Frustration |
| Temporal Demand | or | Effort |
| Performance | or | Frustration |
| Performance | or | Effort |
| Frustration | or | Effort |

9.7 Appendix G: Informed Consent

North Carolina State University INFORMED CONSENT FORM for RESEARCH

Title of Study: Investigation of the effect of UAV interface on operator cognitive workload

Principal Investigator: Wenjuan Zhang, David Feltner

Faculty Sponsor: Dr. David Kaber

What are some general things you should know about research studies?

You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of this research is to gain a better understanding of how unmanned aerial vehicle interface design impact user workload and performance. You are not guaranteed any personal benefits from being in this study. The study only poses minimal risks to those that participate. In this consent form you will find specific details about the research. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

What is the purpose of this study?

The purpose of this study is to investigate Unmanned Aerial Vehicle (UAV) supervisory control interface design.

What will happen if you take part in the study?

If you agree to participate in this study, you will be asked to:

1. Complete a demographic questionnaire requesting information about your age, gender, eye sight, computer usage, and any experience in UAV supervisory control.
2. Participate in a brief training session to familiarize you with the experiment procedure and tools.
3. Perform training and 4 test trials of simulated UAV operation.
4. You will be asked to complete a short survey and be provided time to rest after each trial.

These steps will take place in the Human Factors and Ergonomics Lab (Daniels Hall, Room 448). In total, the experiment is expected to take approximately 1.5 hours of your time.

Risks

You may experience eyestrain during the interaction with computer interfaces. However, you will be provided with rest after each trial. You may also experience slight discomfort with a chest strap as part of a heart rate monitoring system. However, the discomfort will be minimal. Overall, the risks in the experiment are minimal.

Benefits

The results of this research are expected to be beneficial for UAV interface design. There is no direct benefit to you as a result of participation in this experiment.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely on the hard drives of a laboratory computer or researcher computers. In addition, video recordings will be of your use of control interface in all trials along with computer screen captures. Neither your face nor any other distinguishing physical features will be captured in recordings. Videos will be destroyed at the conclusion of the study. No reference will be made in oral or written reports that could link you to the study. You will NOT be asked to write your name on any study materials so that no one can match your identity to the responses you provide.

Compensation

For participating in this study you will receive payment at the rate of \$15 per hour. If you withdraw from the study prior to its completion, you will be paid for the amount of time you spent the experiment.

What if you are a NCSU student?

Your performance in this study will not affect your class standing or grades at NC State.

What if you are a NCSU employee?

Participation in this study is not a requirement of your employment at NCSU and your participation, or lack thereof, will not affect your job.

What if you have questions about this study?

If you have questions at any time about the study or the procedures, you may contact the researcher, Wenjuan Zhang, at wzhang28@ncsu.edu.

What if you have questions about your rights as a research participant?

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

Prior Knowledge of the Study and its Goals

If you have prior knowledge of the experiment and any goals, expected results, or other information that may affect the integrity of the experiment (e.g., based on conversations with other participants or experimenters), please let the experimenter know before signing below.

Consent to Participate

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Subject's signature _____ **Date** _____

Investigator's signature _____ **Date** _____

9.8 Appendix H: Demographic Questionnaire

(1) Please circle your gender: Male Female Prefer not to answer

(2) What is your age:

(3) What is your current corrected vision:

(4) Do you have full color vision?

(5) To what extent do you use a computer in daily life?

Very Little Occasionally Frequently Extensively

(6) Rate your video gaming experience:

None Very Little Some Moderate Expert

(7) Rate your manned flight experience:

None Very Little Some Moderate Expert

Hours: _____

Type Rating: _____

(8) Rate your flight simulator experience:

None Very Little Some Moderate Expert

9.9 Appendix I: Enhanced Interface Instructions

(Note: [] indicate required actions by an experimenter.)

(Note: An experimenter needs to read to participants the text in *italics*, as presented below.)

1. Checklist of materials prior to experiment

Forms:

- Consent forms
- Payment forms (2 copies)
- Demographic survey
- TLX ranking form
- TLX rating forms (4 copies)
- Training materials
 - Familiarization mission, maneuver, status and alarm documents
 - Training mission, maneuver, status and alarm documents
 - Timeline
 - Gradesheet
- Testing materials
 - Scenario 1 and Scenario 2 mission, maneuver, status and alarm documents
 - Prototypes 5-8 timelines
 - Prototypes 5-8 Gradesheet

Equipment:

- Desktop computer with extra monitor
- Eye-tracking cameras
- Interface simulations open and minimized
- Hide desktop tool bar
- Screen capture software and microphone working and ready for use
- HR monitor is working and ready for use
- Paper sheet protector
- Stop watch
- Pens
- Door sign “Experiment in Progress – Do Not Disturb” is ready
- Audio Recordings (phone on airplane mode)

2. Orientation

a. Introduction

[Record the time at which the participant arrives]

Thank you for agreeing to participate in this experiment. The objective of this experiment is to assess how Unmanned Aerial Vehicles (UAV) control interface design features may impact operator performance and cognitive workload in fundamental control operations. You will complete a training session and 4 testing

trials in total. The study will last approximately 1.5 hours, for which you will be compensated at a rate of \$15 per hour. Your heart rate and eye movement will be recorded during the experiment. A screen capture software will record your performance in using a testing computer and your audio interaction with the experimenter, but every step will be taken to preserve your anonymity in the recordings. Once the study is complete, all video and audio recordings will be destroyed. At this time, I ask that you turn off your cell phone or any other electronic device that may be a distraction to you during the experiment.

b. Informed Consent form

[Sit participant. Present both copies of the informed consent form and a pen.]

This is an informed consent form. It summarizes everything you need to know about the experiment, including your compensation, any potential risks, and your rights as an experiment participant. Please take the time to read the form carefully. Please inform an experimenter of any questions you might have. If you consent to participate, please sign and date both copies of the form. One form will be for your records and one for our records.

[Allow the participant time to read and sign the form.]

c. Demographic Questionnaire (DQ)

Now we ask that you complete a questionnaire requesting general information about your background. Please answer all questions as accurately as possible. As stated in the informed consent form, all of your answers will be kept confidential and none of this information will be published in any form that might reveal your identity.

[Allow the participant time to complete the DQ.]

3. Eye-tracking calibration

Now we need you to assist in the eye-tracking equipment calibration. Please sit in front of the monitors. The location and position of the monitors are very important for our measurement. Please do not touch or adjust the monitors. However, feel free to adjust your chair position and make sure you are comfortable viewing the screens, and using the mouse and keyboard. I will mark the position of your chair once you have made adjustments. You will be required to maintain the same body position and posture during all experiment trials.

[Sit participant in front of simulation]

d. Open FaceLab from the computer desktop.

e. Click “Recalibrate” from the bottom-left window. Click through the wizard and follow the instructions.

- f. Click “New head model” → “Manual”. Click through the wizard and follow the instructions.
- g. Attach calibration sheets to the monitor on the left. Click on the left plane and then click “show SID”. Instruct the participant to look at the calibration dots in sequence.
- h. Repeat Step (d) for the monitor on the right.

4. Training

[Ensure that the sign on the door indicates experiment in progress.]

[Sit the participant in front of the simulation]

Now that the calibration is complete. We will proceed to the training session.

[Maximize training prototype simulation]

a. Interface Familiarization

The monitor in front of you presents the UAV control interface that you will use during this experiment. This interface has a few components. Now I will go through them one by one. Please follow my instructions to interact with the interface and do not click unnecessary buttons. However, please feel free to ask any questions.

(1) *UAV control buttons: Below the PFD are several UAV control buttons. Not every button is active, but all buttons that you need to use to accomplish tasks can be selected.*

- *“Arm/Disarm” button. This button allows you to arm or disarm the vehicle for flight. (The button does not refer to weapon system use.) It is necessary to arm the UAV before you launch it. Otherwise, the UAV will not launch. Now, please left click the Arm/Disarm button. **[Wait for participant to click Arm/Disarm button]** The UAV is now prepared to launch.*
- *“Launch UAV” button: Once you have successfully armed the UAV, please click “Launch UAV” and an UAV icon will appear on the Navigation Display at the launch point (LP) and start on its course.*
- *“RTL” Button: RTL stands for Return to Launch Point. This command takes the UAV back to the LP. You may need to do this at a designated time in the mission. An order to RTL will come from your headquarters; an audio message during a mission.*
[Instruct participant to click RTL one UAV reaches WP3]
- *Any questions on the UAV control buttons?*

(2) *Quick display: Click the Quick tab. During the mission, you need to monitor the status of vehicle air speed, distance traveled, ground course, altitude, battery remaining, and ground speed. All of these parameters are displayed*

under the quick tab, and they will change during the UAV's flight. Under some parameter headings, you may see a "Norm" or "Acceptable" range. These displays identify the normal or acceptable range of parameters. All ranges are summarized in this table. **[Point out Norms on paper]** I will also talk you through all the information presented under the Quick tab.

- *Air Speed: Now, please look at the top left number in purple; this is air speed indicator. Air Speed is how fast the UAV is flying through the air. It is measured in knots. Under the indicator, you can see "Norm [45,55]". This means that it is normal for this UAV to fly between 45 and 55 knots.*
- *Distance Traveled: Look at the top right number in orange; this is the distance in meters that the UAV has traveled during the mission. It does not accumulate from previous missions. Under this indicator, you can see "Target < 10,000". This means that your distance traveled should be less than 10,000 meters for a mission.*
- *Ground Course: Look at the middle number on the left side in red; this is the ground course, which is measured in degrees. Its value can range between 0 to 359 degrees. You do not need to worry about how this number is obtained. You only need to monitor the status during the flight.*
- *Altitude: Look at the middle number on the right-hand side; this is the UAV's altitude, which is measured in feet. The normal parameter range is from 40 to 55 feet, as shown below the altitude indicator.*
- *Battery Remaining: Look at the bottom left number in yellow; this is the UAV's battery life measured in percent remaining. The acceptable range for Battery Remaining is from 20 to 100 percent.*
- *Ground Speed: Look at the bottom right number in blue; this is the UAV's ground speed measured in meters per second. The normal parameter range is from 0 to 10.*
- *Parameter deviation: When any of the above parameters deviate outside the normal or acceptable range, a warning triangle will appear on the display adjacent to the parameter indicator **[point to warning sign]**; please immediately notify an experimenter by saying "Warning" then the parameter that is out of tolerance. For example, you may say "Warning: Altitude" or "Warning: Battery remaining". Now please identify all deviations from the current display. **[If any error, provide correct answer and explanation]***
- *Any questions on the quick display?*

(3) *PFD: On the top left of the screen, you see the PFD. It provides some vehicle status information, including ground course, air speed, and altitude. The display is not continuous and updates about every 10-15 seconds. The ground*

course is shown by the bar at the top, the black arrow will point to the current ground course which will match the quick display number. On the left side is a grey box labeled AS for Air Speed; the black arrow will point to the vehicle's current air speed, which will match the quick display number. On the right side is a grey box labeled ALT for Altitude; the black arrow will point to the vehicle's current altitude, which will match the quick display number.

- (4) *Mission Planning tool:* At the bottom right of the screen you will see a listing of flight waypoints (WPs) and some of their parameters. During the mission, you may be asked to make adjustments to the UAV's flight path. For example, you may need to change the altitude for WP3. To do this, simply find the Altitude column and the corresponding Waypoint row. Click once in the box for the input field to show up, and then click again to type in the new altitude. **[Wait for participant to click.]** Now you can type in the desired altitude in feet, for example, 99. After making this entry, you need to press the "Enter" button on the keyboard to confirm the change. **[Wait for participant to click.]** Once you click the button, a message window will show up to confirm your change. The window will disappear by itself. Now the updated altitude can be found in the table.
- (5) *Navigation display:* The top-right portion of the interface presents a navigation display.
- *Northing & Easting:* On the top and left sides of the map, you see a few boxes with numbers. They are called Eastings and Northings. You can use them to determine distances and locations on the map. I will explain how to read them in just a few minutes.
 - *Launch Point (LP):* The red circle is the home station for the UAV, and it is where you will launch from and land. You may be responsible for determining the vehicle coordinates, or distance between it and another object, at any time during a flight. The center point of the circle is where all measurements are taken from.
 - *Waypoints (WPs):* The red icons with a pointy tip are waypoints for this mission. The vehicle will fly through the waypoints in numerical order, and the waypoints will turn green once you have passed them. You may be responsible for determining WP coordinates, or the distance between two WPs. The bottom tip of a WP is where all measurements should be taken from. Waypoints also provide an indicator of the degree of mission completion. For example, you now see 3 waypoints on the screen now (the launch point does not count). If you are past WP1 but before WP2, then you are 33% complete with the mission.

- *Targets: The orange triangles represent targets on the map. You may be asked to count targets, obtain their coordinates or determine the distance between two targets. The center point is where all measurements are taken from.*
 - *Any questions on the navigation display?*
- (6) *Map action button: On the top right corner of the navigation display, you see a yellow button called “Map Actions”. Please click on the Map Action button. [Wait for participant to click] This menu provides you a way to interact with the UAV. Not every option in this menu is active, but all buttons that you need to use to accomplish tasks can be selected. I will highlight every option that is active. All others are inactive.*
- [Make sure the participant is able to locate the menu options. Demonstrate if necessary]**
- *Drop Payload: The “drop payload” button is active and allows you to drop your payload at a designated location. Payload is the cargo that the UAV is carrying that you must drop at a specific location. During a mission, your headquarters may require you to drop a payload at WP2. To do this, all you have to do is click the menu option, as soon as possible, when you receive the order. Now please click “Drop Payload”. Once you click the button, a payload icon will appear at WP2. The menu is currently blocking the dropping location. Please click the “Map Action” button to hide the menu. Now you can see the payload icon. The dropping location has been preprogrammed. Optimally, you should drop the payload within 3 seconds after receiving the order. Please click “Map Action” and show the menu again. We will continue with other menu options.*
 - *Waypoint (WP): “WP” is used as an acronym for waypoint. There are four options related to waypoints in the menu: Insert, Load, Edit, and Delete. These buttons are not active but you may be asked about them.*
 - *Loiter: There are three options for loiter: Forever, Time, and Circles. These buttons are not active but, once again, you may be asked about them.*
 - *Jump To: There are three options for “Jump To”: Start, WP #, and LP.*
 - *Overlays: There are three options for “Overlay”: Create, Edit, and Delete.*
 - *Draw: There are three options for “Draw”: Line, Polygon, and Route.*
 - *Commands: There are 5 options of “Commands” in the menu: Take off, Altitude, Speed, Land and RTL. Only RTL is an active option.*
 - *Clear Mission: There is only one option related to “Clear Mission”. You can find it at the bottom of the menu.*

- Any questions on the menu? If not, please click the Map Action button to close the menu. **[Wait for participant to close Map Action menu]**
- (7) *AOI filters: To the left of the Map Action button, there is a button named “AOI filters”. AOI stands for “area of interest”. This button helps you locate areas of interest on the map. Now please click the AOI filter button. **[Wait for participant to click AOI Filter button]**. The dotted outlines specify the AOIs for this mission. The name of AOIs will be shown in the shapes. Now please click the button again to hide the AOIs.*
- (8) *Distance Tool: To the left of the AOI Filters button is the Distance Tool. Click the Distance Tool button. **[Wait for participant to click Distance Tool button]** A blue dialogue box will appear instructing you to click objects, and then it will calculate the distance between the objects for you. Click the distance tool again. Now find and click the Eastern most and Southern most targets of interest. **[Wait for participant to click correct targets]** When you click the targets, they will turn green for 3 seconds and then return to their normal color in order to temporarily indicate which objects you selected. After you click two objects, a yellow dialogue box will appear with the exact distance between the two objects. This distance should be reported verbally in response to a query.*
- (9) *Coordinates: To the left of the Distance Tool is the Coordinates button. The coordinates button provides exact coordinates for a given object – whether it is a target or a waypoint. For example, if you wanted to determine the coordinates for WP1, then you would click the coordinates button and then WP1. Please do so now. **[Wait for participant to click coordinates button and waypoint 1]** Once you complete these actions, you will notice a yellow dialogue box with the object coordinates. These coordinates should be reported verbally in response to a query.*
- (10) *Drop Payload: Over on the far left side of the interface display, is the Drop Payload button. This button is a shortcut for same button that appears in the map actions menu. You can use this button or the one in the map actions menu.*
- (11) *Alarms: During the UAV mission, you may see alarms below the Waypoints table at different times. Please pay close attention to the following information because you will be responsible for handling these alarms. There are two types of alarms.*
- *The first type of alarm requires you to assign priority levels to alarm events. There are 3 levels of Alarms: Alerts, Warnings, and Advisories. **[Point out Alarm Priorities on paper]** Alerts are the highest priority and are depicted with the color red and a red warning icon. Warnings are*

medium priority and depicted with the color orange and a yellow warning icon. Advisories are the lowest priority and depicted with the color yellow. Please take a minute to read this. When this alarm box shows up, you will be required to prioritize the alarms from 1 to 3, with 1 representing highest priority. In this example, Stall impending is an alert as seen by using the alarm box, the color, and the red triangle icon, so you need to type “1” to the input box. **[Point the input box for participant]**.

“Navigation active” is advisory as seen by the alarm box and yellow color, so please type “3”. “Maximum air speed reached” is a warning as seen by using the alarm box, the color, and the yellow triangle icon, so please type “2”. Now that you finished assigning priority levels, please click the “Done” button. Then this alarm box will disappear. **[Wait for participant to click]**

- The second type of alarm requires you to select an action button to fix the issue. The solutions to all possible alarms are summarized in this table. **[Point out how to resolve alarms box]** In this example, the alarm says “Crash Imminent”. To fix this, you need to “pull up”. The button for this can be found on the right side of the interface under Emergency Controls. The correct button will be highlighted to help you find it in the Emergency Controls list. Please click it. Now that the issue is resolved, the alarm box will disappear and you will see a confirmation box saying the crash has been averted.
- Remember that these alarms require you to do something for them to be resolved. The buttons to resolve these alarms can be found under the “Emergency Control”. They are different from the immediate commands under the “Action” tab, which are only for normal vehicle operation. For the deviation of vehicle status parameters, as shown in the quick display, you only have to announce verbally. Any questions on the alarms?

(12) Any other questions on the interface?

b. Mission Familiarization

Now that you are familiar with the UAV control interface. Let’s move on to your mission.

[Point to Training Mission Familiarization sheet]

This paper summarizes important information on your mission.

This paper summarizes important information on your mission, including an acronym list, explaining commonly used acronyms. This is where you can find the norms for the system statuses we discussed earlier as well as the Alarm priorities and how to resolve alarms.

[Allow participant to read]

[If no questions, hand participant Familiarization sheet]

This paper presents you the mission map and steps to vehicle maneuver. The map is a to-scale representation of the area you will see presented on the interface.

- *The map presents a Military Grid Reference System (MGRS) to determine an object's location. All major horizontal and vertical grid lines are 1,000 meters apart, making each box a 1,000 m x 1,000 m square. The grid lines 10-15 are Eastings, which provide a designator as to how far East an object is. For example, the Easting WP2 is 149. To get 149, you read the 2 digit Easting that WP2 is past and estimate the third digit. Waypoint 2 is further East than 14 and is 90% of the way between 14 and 15, which gives you 149 **[Point to line on familiarization]**. The grid lines 20-25 are Northings, which provide a designator as to how far North an object is. The Northing of WP2 is 228. Similarly, to get 228, you read the 2 digit Northing that WP2 is past and estimate the third digit. Waypoint 2 is further North than 22 and is 80% of the way between 22 and 23, which gives you 228 **[Point to on familiarization]**. Taken together, these readings create a unique designation of 149,228 – the three digits of the Easting comes first then the three digits of the Northing. Now please report the coordinates for WP1. **[Correct answer: 127 243; If incorrect, provide explanation and ask for WP3 location; Correct WP3 location: 125 203]***
- *Every mission map and interface will present the numbered boxes, but the actual grid lines themselves may not be there, and the tick marks will not be there. The distance between objects can be estimated based on the grid lines or using the hypotenuse between the two objects. For example, the distance between WP3 and the LP is about 2.7 grids. Since each grid is 1000 meters, your estimation would be 2700 meters. Now please report the distance between WP2 and WP3 **[Correct answer: 3,400 meters; If incorrect, provide explanation and ask for distance between WP2 and LP; correct answer: 3,600 meters]***
- *At the bottom right of the map is a compass rose, which means that North is to the top, East is to the right, West is to the left, and South is towards the bottom.*
- *The LP is the red circle. **[Point out]** You will launch the UAV here and return to the LP at the end of the mission.*
- *To the Northeast of the LP, you see WP1. Similar to what you see on the interface, the Waypoints are numbered and the UAV will follow the WPs in numerical order.*
- *The next two grey shapes are AOIs. They represent a physical area of special interest to your mission. On the way to WP1, you will pass through a grey arrow named Axis Nova. On the Eastern side of the map, you see NAI nail. NAI stands for "Named Area of Interest".*
- *The areas of interest, the LP, the WPs, the compass, and the grid numbers will be on every mission map.*

- *On the left side of the sheet is a scheme of maneuver. This is a list of tasks you will be required to complete during the mission. It also indicates the order of your tasks. For example, in this mission, you will... [Read scheme of maneuver for participant] During the mission, headquarters will provide a verbal cue before a task must be executed. For example, ... [Play a single audio recording as example] Please wait for the verbal cue before you execute any tasks.*
- *Any questions on the mission map or tasks?*

c. Training scenario

[Re-simulate the training prototype]

Now that you are familiar with the interface and the mission, let's go through a mission scenario. This mission is also designed to help you learn the system.

Before we start, I'm going to ask you a few questions on what we covered during the familiarization session. If you don't know the answer to a question, feel free to let me know, and I will tell you the answer and provide an explanation in terms of the interface content or mission information.

[Ask familiarization queries – refer to Timeline at Time 0]

[Provide answers or point to related material/interface if necessary]

During the following training mission, you will be asked similar questions about the system, the task, and the environment. Do your best to answer these questions as quickly and accurately as possible; however it is ok to say that you do not know the answer to a question. All questions will be presented verbally and please respond with answers, verbally.

[After Time 0 questions]

The mission tasks are listed in the Scheme of Maneuver. Please read it carefully.

[Wait participant to read] *Again, please wait for verbal cues from your headquarters (an audio message) before executing any steps. As a reminder, you need to pay close attention to the UAV parameters under the quick display. The normal or acceptable ranges can be found on this document. [Point to paper] You need to verbally report any deviations but there is no action required.*

Finally, not all buttons within the interface are active, but all buttons that you need to use to accomplish tasks can be selected. Any questions?

Please launch when ready.

[Play audio recording to deliver scheme of maneuvers and ask SA questions]

Now you have completed the training mission. The experiment test missions will be similar to this mission. Do you feel comfortable with the mission procedure? If not, we can go through this mission again. [If needed, go through just the training scenario without the first 14 SA questions]

5. TLX Ranking

As I mentioned earlier, during this study we want to measure the degree of cognitive workload you perceive in using the UAV control interface for various mission trials. Related to this, we will ask you to complete workload surveys during the experiment. These surveys will require that you rate various task demands, including mental, temporal, effort, physical, frustration and performance. However, before you make ratings, we also want to ask you to rank these various demands in terms of importance to the UAV control task. Based on your training experience, we would now like to ask you to complete the first portion of the survey instrument. Please follow the instructions on the paper. Remember, to consider the mission you just completed as a basis for your answer.

[Hand participant TLX definitions and ranking sheet]

Let me know if you need any clarification on the demand definitions or what aspects of the task you should consider in making rankings. Please note that you will subsequently make ratings after each test trial.

6. HR monitor

Congratulations on completing the training. Now we ask that you don this heart rate (HR) monitor during the experiment. You can use the restroom to put it on. You need to moisten (but not soak) the sensor with water and secure the monitor around your chest very tightly. The sensor should be at the middle of the front of your chest and at the same height of your heart, just like in this picture. An experimenter can accompany you for donning the monitor.

[Show participant picture in watch manual, and escort him/her to the restroom.]

[When participant is back, test HR and RR interval signal.]

[To measure RR intervals:

- **The default display of Polar watch is a time display.**
- **Press “Up”/ “Down” button until you see “Tests”. Press the red button to select.**
- **Press “Up”/ “Down” button until you see “RR recording”. Press the red button to select.**
- **Select “Start recording” and press the red button. The watch will start searching for HR data from the sensor.]**
- **If the watch says “No HR found”, ask the participant to wet the sensor and adjust the strap again.**
- **To stop recording, hold the bottom left button for 3 seconds.]**

7. Experiment trials

a. Initial Test Trial

[Start screen capture software]

We will now begin the experimental testing. You will use the same UAV control interface. The mission will be similar to the training, but with different tasks.

[New trial starting point] *Please read through the scheme of maneuver before we begin. [Allow time to read] Any questions? Are you ready for this mission? Again, remember to verbally report parameter deviations. Please also try to maintain your posture during the mission and limit your head movement so the eye tracker can capture your gaze pattern.*

[Start Camtasia]

[Start RR recording]

[Start Eye-tracking]

Ok, the mission will begin. Launch when ready.

[Play audio recording once participant correctly Launches the UAV]

[Deliver SA queries according to Prototype Timeline; pay close attention]

[Second experimenter to record subtask performance and SA responses in gradesheet]

[Stop RR recording upon mission completion]

[Stop eye-tracking]

[Stop screen capturing upon mission completion]

b. Rest & TLX rating

[Save all files. Name properly, e.g., “P1_Trial1”]

You have completed this mission. Now we ask that you complete the second portion of the workload questionnaire, where you need to rate the workload demand components separately. Please follow the instructions on this paper.

[Hand participant TLX rating sheet] *Let me know if you need any clarifications on the definitions of the demand components or the aspects of the task that you should consider in your ratings.*

[If polar watch start to lose HR data, ask participant to wet the monitor again]

Thank you for completing the questionnaire. Now, please take a 2 min to rest break.

[Time 2 min]

Your resting period is now complete. We will now proceed to your next trial.

c. Repeat a-b 3 times. (4 trials in total for each participant).

8. Baseline measurement

Now you have completed all experiment trials. Before we close the experiment, we need to take some additional measurements with the eye-tracking system and the HR monitor. Please look anywhere on the UAV control screen. I need you to do this for 5 minutes. You do not need to perform any tasks but please do not direct your eyes away from the screen. Stay relaxed and just blink normally.

[Record eye-tracking, HR and RR-interval for 5 mins.]

9. Debrief

a. Complete Payment Form

[Hand payment form to participant.]

[Calculate the participant's compensation.]

Here is the form for your compensation for participation in the study. For your time today, you will receive \$____.

b. Departure and Thank You

[Give the participant a copy of his or her signed informed consent form as well as the original payment form.]

The experiment is now complete. The data we collected today will be used to investigate the effect of interface design on workload in UAV operations. You will not be personally identified in any of the data analyses or reports based on this study. If you are interested in future information about this experiment, you may contact Dr. David Kaber, whose contact information is included in the informed consent form.

10. Post-Experiment Procedure

- a. Organize all data sheets in participant folder
- b. Record subtask performance accuracy and times in spreadsheet; verify with videos if necessary
- c. Record TLX responses in spreadsheet
- d. Save video file with Participant #_Trial #
- e. Export HR data to txt files and name properly.
- f. Backup files
- g. Charge the Polar watch

9.10 Appendix J: Baseline Interface Instructions

(Note: [] indicate required actions by an experimenter.)

(Note: An experimenter needs to read to participants the text in *italics*, as presented below.)

2. Checklist of materials prior to experiment

Forms:

- Consent forms
- Payment forms (2 copies)
- Demographic survey
- TLX ranking form
- TLX rating forms (4 copies)
- Training materials
 - Familiarization mission, maneuver, status and alarm documents
 - Training mission, maneuver, status and alarm documents
 - Timeline
 - Gradesheet
- Testing materials
 - Scenario 1 and Scenario 2 mission, maneuver, status and alarm documents
 - Prototypes 5-8 timelines
 - Prototypes 5-8 Gradesheet

Equipment:

- Desktop computer with extra monitor
- Eye-tracking cameras
- Interface simulations open and minimized
- Hide desktop tool bar
- Screen capture software and microphone working and ready for use
- HR monitor is working and ready for use
- Paper sheet protector
- Stop watch
- Pens
- Door sign “Experiment in Progress – Do Not Disturb” is ready
- Audio Recordings (phone on airplane mode)

3. Orientation

a. Introduction

[Record the time at which the participant arrives]

Thank you for agreeing to participate in this experiment. The objective of this experiment is to assess how Unmanned Aerial Vehicles (UAV) control interface design features may impact operator performance and cognitive workload in fundamental control operations. You will complete a training session and 4 testing trials in total. The study will last approximately 1.5

hours, for which you will be compensated at a rate of \$15 per hour. Your heart rate and eye movement will be recorded during the experiment. A screen capture software will record your performance in using a testing computer and your audio interaction with the experimenter, but every step will be taken to preserve your anonymity in the recordings. Once the study is complete, all video and audio recordings will be destroyed. At this time, I ask that you turn off your cell phone or any other electronic device that may be a distraction to you during the experiment.

b. Informed Consent form

[Sit participant. Present both copies of the informed consent form and a pen.]

This is an informed consent form. It summarizes everything you need to know about the experiment, including your compensation, any potential risks, and your rights as an experiment participant. Please take the time to read the form carefully. Please inform an experimenter of any questions you might have. If you consent to participate, please sign and date both copies of the form. One form will be for your records and one for our records.

[Allow the participant time to read and sign the form.]

c. Demographic Questionnaire (DQ)

Now we ask that you complete a questionnaire requesting general information about your background. Please answer all questions as accurately as possible. As stated in the informed consent form, all of your answers will be kept confidential and none of this information will be published in any form that might reveal your identity.

[Allow the participant time to complete the DQ.]

4. Eye-tracking calibration

Now we need you to assist in the eye-tracking equipment calibration. Please sit in front of the monitors. The location and position of the monitors are very important for our measurement. Please do not touch or adjust the monitors. However, feel free to adjust your chair position and make sure you are comfortable viewing the screens, and using the mouse and keyboard. I will mark the position of your chair once you have made adjustments. You will be required to maintain the same body position and posture during all experiment trials.

[Sit participant in front of simulation]

- a. Open FaceLab from the computer desktop.**
- b. Click “Recalibrate” from the bottom-left window. Click through the wizard and follow the instructions.**

- c. Click “New head model” → “Manual”. Click through the wizard and follow the instructions.
- d. Attach calibration sheets to the monitor on the left. Click on the left plane and then click “show SID”. Instruct the participant to look at the calibration dots in sequence.
- e. Repeat Step (d) for the monitor on the right.

5. Training

[Ensure that the sign on the door indicates experiment in progress.]

[Sit the participant in front of the simulation]

Now that the calibration is complete. We will proceed to the training session.

[Maximize training prototype simulation]

a. Interface Familiarization

The monitor in front of you presents the UAV control interface that you will use during this experiment. This interface has a few components including a primary flight status display (PFD) in the upper left corner. I will now go through each component one by one and provide information for your use. Please follow my instructions to interact with the interface and do not click unnecessary buttons. However, please feel free to ask any questions.

- (1) *UAV control buttons: Below the PFD are several UAV control buttons. Not every button is active, but all buttons that you need to use to accomplish tasks can be selected.*
 - *“Arm/Disarm” button. This button allows you to arm or disarm the vehicle for flight. (The button does not refer to weapon system use.) It is necessary to arm the UAV before you launch it. Otherwise, the UAV will not launch. Now, please left click the Arm/Disarm button. **[Wait for participant to click Arm/Disarm button]** The UAV is now prepared to launch.*
 - *“Launch UAV” button: Once you have successfully armed the UAV, please click “Launch UAV” and an UAV icon will appear on the Navigation Display at the launch point (LP) and start on its course.*
 - *“RTL” Button: RTL stands for Return to Launch Point. This command takes the UAV back to the LP. You may need to do this at a designated time in the mission. An order to RTL will come from your headquarters; an audio message during a mission.*
[Instruct participant to click RTL one UAV reaches WP3]
 - *Any questions on the UAV control buttons?*
- (2) *Quick display: Click the Quick tab. During the mission, you need to monitor the status of vehicle air speed, distance traveled, ground course, altitude, battery*

remaining, and ground speed. All of these parameters are displayed under the quick tab, and they will change during the UAV's flight. Under some parameter headings, you may see a "Norm" or "Acceptable" range. These displays identify the normal or acceptable range of parameters. All ranges are summarized in this table. **[Point out Norms on paper]** I will also talk you through all the information presented under the Quick tab.

- *Air Speed: Now, please look at the top left number in purple; this is air speed indicator. Air Speed is how fast the UAV is flying through the air. It is measured in knots. Under the indicator, you can see "Norm [45,55]". This means that it is normal for this UAV to fly between 45 and 55 knots.*
- *Distance Traveled: Look at the top right number in orange; this is the distance in meters that the UAV has traveled during the mission. It does not accumulate from previous missions. Under this indicator, you can see "Target < 10,000". This means that your distance traveled should be less than 10,000 meters for a mission.*
- *Ground Course: Look at the middle number on the left side in red; this is the ground course, which is measured in degrees. Its value can range between 0 to 359 degrees. You do not need to worry about how this number is obtained. You only need to monitor the status during the flight.*
- *Altitude: Look at the middle number on the right-hand side; this is the UAV's altitude, which is measured in feet. The normal parameter range is from 40 to 55 feet, as shown below the altitude indicator.*
- *Battery Remaining: Look at the bottom left number in yellow; this is the UAV's battery life measured in percent remaining. The acceptable range for Battery Remaining is from 20 to 100 percent.*
- *Ground Speed: Look at the bottom right number in blue; this is the UAV's ground speed measured in meters per second. The normal parameter range is from 0 to 10.*
- *Parameter deviation: When any of the above parameters deviate outside the normal or acceptable range, please immediately notify an experimenter by saying "Warning" then the parameter that is out of tolerance. For example, you may say "Warning: Altitude" or "Warning: Battery remaining". Now please identify all deviations from the current display. **[If any error, provide correct answer and explanation]***
- *Any questions on the quick display?*

(3) *PFD: On the top left of the screen, you see the PFD. It provides some vehicle status information, including ground course, air speed, and altitude. The display is not continuous and updates about every 10-15 seconds. The ground course is shown by the bar at the top, the black arrow will point to the current ground course which will match the quick display number. On the left side is a grey box labeled AS for Air*

Speed; the black arrow will point to the vehicle's current air speed, which will match the quick display number. On the right side is a grey box labeled ALT for Altitude; the black arrow will point to the vehicle's current altitude, which will match the quick display number.

- (4) *Mission Planning tool: At the bottom right of the screen you will see a listing of flight waypoints (WPs) and some of their parameters. During the mission, you may be asked to make adjustments to the UAV's flight path. For example, you may need to change the altitude for WP2. To do this, simply find the Altitude column and the corresponding Waypoint row. Click once in the box for the input field to show up, and then click again to type in the new altitude. **[Wait for participant to click.]** Now you can type in the desired altitude in feet, for example, 99. After that, you need to click the "Write WP" button on the right-hand side of the screen **[Point at the button]** to confirm the change. **[Wait for participant to click.]** Once you click the button, a message window will show up to confirm your change. The window will disappear by itself. Now the updated altitude can be seen in the table.*
- (5) *Navigation display: The top-right portion of the interface presents a navigation display.*
- *Northing & Easting: On the top and left sides of the map, you see a few boxes with numbers. They are called Eastings and Northings. You can use them to determine distances and locations on the map. I will explain how to read them in just a few minutes.*
 - *Launch Point (LP): The red circle is the home station for the UAV, and it is where you will launch from and land. You may be responsible for determining the vehicle coordinates, or distance between it and another object, at any time during a flight. The center point of the circle is where all measurements are taken from.*
 - *Waypoints (WPs): The red icons with a pointy tip are waypoints for this mission. The vehicle will fly through the waypoints in numerical order. You may be responsible for determining WP coordinates, or the distance between two WPs. The bottom tip of a WP is where all measurements should be taken from. Waypoints also provide an indicator of the degree of mission completion. For example, you now see 3 waypoints on the screen now (the launch point does not count). If you are past WP1 but before WP2, then you are 33% complete with the mission.*
 - *Targets: The orange triangles represent targets on the map. You may be asked to count targets, obtain their coordinates or determine the distance between two targets. The center point is where all measurements are taken from.*
 - *Any questions on the navigation display?*

(6) *Map action button: On the top right corner of the navigation display, you see a yellow button called “Map Actions”. Please click on the Map Action button. [Wait for participant to click] This menu provides you a way to interact with the UAV. Not every option in this menu is active, but all buttons that you need to use to accomplish tasks can be selected. I will highlight every option that is active. All others are inactive.*

[Make sure the participant is able to locate the menu options. Demonstrate if necessary]

- *Waypoint (WP): “WP” is used as an acronym for waypoint. There are four options related to waypoints in the menu: Insert, Load, Edit, and Delete. These buttons are not active but you may be asked about them.*
- *Drop Payload: The “drop payload” button is active and allows you to drop your payload at a designated location. Payload is the cargo that the UAV is carrying that you must drop at a specific location. During a mission, your headquarters may require you to drop a payload at WP2. To do this, all you have to do is click the menu option, as soon as possible, when you receive the order. Now please click “Drop Payload”. Once you click the button, a payload icon will appear at WP2. The menu is currently blocking the dropping location. Please click the “Map Action” button to hide the menu. Now you can see the payload icon. The dropping location has been preprogrammed. Optimally, you should drop the payload within 3 seconds after receiving the order. Please click “Map Action” and show the menu again. We will continue with other menu options.*
- *Loiter: There are three options for loiter: Forever, Time and Circles. These buttons are not active but you may be asked about them.*
- *Jump To: There are three options for “Jump To”: Start, WP #, and LP.*
- *Overlays: There are three options for “Overlay”: Create, Edit, and Delete.*
- *Draw: There are three options for “Draw”: Line, Polygon, and Route.*
- *Commands: There are 5 options of “Commands” in the menu: Take off, Altitude, Speed, Land and RTL. Only RTL is an active option.*
- *Clear Mission: There is only one option related to “Clear Mission”. You can find it at the bottom of the menu.*
- *Any questions on the menu? If not, please click the Map Action button to close the menu. [Wait for participant to close Map Action menu]*

(7) *AOI filters: To the left of the Map Action button, there is a button named “AOI filters”. AOI stands for “area of interest”. This button helps you locate areas of interest on the map. Now please click the AOI filter button. [Wait for participant to click AOI Filter button]. The dotted outlines specify the AOIs for this mission. The name of AOIs will be shown in the shapes. Now please click the button again to hide the AOIs.*

(8) *Alarms: During the UAV mission, you may see alarms below the Waypoints table at different times. Please pay close attention to the following information because you will be responsible for handling these alarms. There are two types of alarms.*

- *The first type of alarm requires you to assign priority levels to alarm events. **[Point out alarm on interface]** There are 3 levels of Alarms: Alerts, Warnings, and Advisories. **[Point out Alarm Priorities on paper]** Alerts are the highest priority, Warnings are medium, and advisories are lowest priority. Please take a minute to read this. When this alarm box shows up, you will be required to prioritize the alarms from 1 to 3, with 1 representing highest priority. In this example, Stall impending is an alert, so you need to type “1” in the input box. **[Point to the input box for the participant]**. “Navigation active” is an advisory so please type “3”. “Maximum air speed reached” is a warning so please type “2”. Now that you finished assigning priority levels, please click the “Done” button. Then this alarm box will disappear. **[Wait for participant to click]***
- *The second type of alarm requires you to select an action button to fix the issue. **[Point out alarm on interface]** The solutions to all possible alarms are summarized in this table. **[Point out how to resolve alarms table on paper]** In this example, the alarm says “Crash Imminent”. To fix this, you need to “pull up”. The button for this can be found on the right side of the interface under Emergency Controls. Please click it. Now that the issue is resolved, the alarm box will disappear and you will see a confirmation box saying the crash has been averted.*
- *Remember that these alarms require you to do something for them to be resolved. The buttons to resolve these alarms can be found under the “Emergency Control”. They are different from the immediate commands under the “Action” tab, which are only for normal vehicle operation. For the deviation of vehicle status parameters, as shown in the quick display, you only have to announce verbally. Any questions on the alarms?*

(9) *Any other questions on the interface?*

b. Mission Familiarization

Now that you are familiar with the UAV control interface. Let’s move on to your mission.

[Hand participant Training Mission Familiarization sheet]

This paper summarizes important information on your mission, including an acronym list, explaining commonly used acronyms. This is where you can find the norms for the system statuses we discussed earlier as well as the Alarm priorities and how to resolve alarms.

[Allow participant to read]

[If no questions, hand participant Familiarization sheet]

This paper presents you the mission map and steps to vehicle maneuver. The map is a to-scale representation of the area you will see presented on the interface.

- *The map presents a Military Grid Reference System (MGRS) to determine an object's location. All major horizontal and vertical grid lines are 1,000 meters apart, making each box a 1,000 m x 1,000 m square. The grid lines 10-15 are Eastings, which provide a designator as to how far East an object is. For example, the Easting WP2 is 149. To get 149, you read the 2 digit Easting that WP2 is past and estimate the third digit. Waypoint 2 is further East than 14 and is 90% of the way between 14 and 15, which gives you 149 **[Point to line on familiarization]**. The grid lines 20-25 are Northings, which provide a designator as to how far North an object is. The Northing of WP2 is 228. Similarly, to get 228, you read the 2 digit Northing that WP2 is past and estimate the third digit. Waypoint 2 is further North than 22 and is 80% of the way between 22 and 23, which gives you 228 **[Point to on familiarization]**. Taken together, these readings create a unique designation of 149,228 – the three digits of the Easting comes first then the three digits of the Northing. Now please report the coordinates for WP1. **[Correct answer: 127 243; If incorrect, provide explanation and ask for WP3 location; Correct WP3 location: 125 203]***
- *Every mission map and interface will present the numbered boxes, but the actual grid lines themselves may not be there, and the tick marks will not be there. The distance between objects can be estimated based on the grid lines or using the hypotenuse between the two objects. For example, the distance between WP3 and the LP is about 2.7 grids. Since each grid is 1000 meters, your estimation would be 2700 meters. Now please report the distance between WP2 and WP3 **[Correct answer: 3,400 meters; If incorrect, provide explanation and ask for distance between WP2 and LP; correct answer: 3,600 meters]***
- *At the bottom right of the map is a compass rose, which means that North is to the top, East is to the right, West is to the left, and South is towards the bottom.*
- *The LP is the red circle. **[Point out]** You will launch the UAV here and return to the LP at the end of the mission.*
- *To the Northeast of the LP, you see WP1. Similar to what you see on the interface, the Waypoints are numbered and the UAV will follow the WPs in numerical order.*
- *The next two grey shapes are AOIs. They represent a physical area of special interest to your mission. On the way to WP1, you will pass through a grey arrow named Axis Nova. On the Eastern side of the map, you see NAI nail. NAI stands for "Named Area of Interest".*
- *The areas of interest, the LP, the WPs, the compass, and the grid numbers will be on every mission map.*
- *On the left side of the sheet is a scheme of maneuver. This is a list of tasks you will be required to complete during the mission. It also indicates the order of your tasks. For example, in this mission, you will... **[Read scheme of maneuver for participant]** During the mission, headquarters will provide a verbal cue before a task must be executed. For*

example, ... [Play a single audio recording as example] Please wait for the verbal cue before you execute any tasks.

- *Any questions on the mission map or tasks?*

c. Training scenario

[Re-simulate the training prototype]

Now that you are familiar with the interface and the mission, let's go through a mission scenario. This mission is also designed to help you learn the system.

Before we start, I'm going to ask you a few questions on what we covered during the familiarization session. If you don't know the answer to a question, feel free to let me know, and I will tell you the answer and provide an explanation in terms of the interface content or mission information.

[Ask familiarization queries – refer to Timeline at Time 0]

[Provide answers or point to related material/interface if necessary]

During the following training mission, you will be asked similar questions about the system, the task, and the environment. Do your best to answer these questions as quickly and accurately as possible; however it is ok to say that you do not know the answer to a question. All questions will be presented verbally and please respond with answers, verbally.

[After Time 0 questions]

*The mission tasks are listed in the Scheme of Maneuver. Please read it carefully. **[Wait participant to read]** Again, please wait for verbal cues from your headquarters (an audio message) before executing any steps. As a reminder, you need to pay close attention to the UAV parameters under the quick display. The normal or acceptable ranges can be found on this document. **[Point to paper]** You need to verbally report any deviations but there is no action required. Finally, not all buttons within the interface are active, but all buttons that you need to use to accomplish tasks can be selected. Any questions?*

Please launch when ready.

[Play audio recording to deliver scheme of maneuvers and ask SA questions]

*Now you have completed the training mission. The experiment test missions will be similar to this mission. Do you feel comfortable with the mission procedure? If not, we can go through this mission again. **[If needed, go through just the training scenario without the first 14 SA questions]***

6. TLX Ranking

As I mentioned earlier, during this study we want to measure the degree of cognitive workload you perceive in using the UAV control interface for various mission trials. Related to this, we will ask you to complete workload surveys during the experiment. These surveys will require that you rate various task demands, including mental, temporal, effort, physical,

frustration and performance. However, before you make ratings, we also want to ask you to rank these various demands in terms of importance to the UAV control task. Based on your training experience, we would now like to ask you to complete the first portion of the survey instrument. Please follow the instructions on the paper. Remember, to consider the mission you just completed as a basis for your answer.

[Hand participant TLX definitions and ranking sheet]

Let me know if you need any clarification on the demand definitions or what aspects of the task you should consider in making rankings. Please note that you will subsequently make ratings after each test trial.

7. HR monitor

Congratulations on completing the training. Now we ask that you don this heart rate (HR) monitor during the experiment. You can use the restroom to put it on. You need to moisten (but not soak) the sensor with water and secure the monitor around your chest very tightly. The sensor should be at the middle of the front of your chest and at the same height of your heart, just like in this picture. An experimenter can accompany you for donning the monitor.

[Show participant picture in watch manual, and escort him/her to the restroom.]

[When participant is back, test HR and RR interval signal.]

[To measure RR intervals:

- **The default display of Polar watch is a time display.**
- **Press “Up”/ “Down” button until you see “Tests”. Press the red button to select.**
- **Press “Up”/ “Down” button until you see “RR recording”. Press the red button to select.**
- **Select “Start recording” and press the red button. The watch will start searching for HR data from the sensor.]**
- **If the watch says “No HR found”, ask the participant to wet the sensor and adjust the strap again.**
- **To stop recording, hold the bottom left button for 3 seconds.]**

8. Experiment trials

a. Initial Test Trial

[Start screen capture software]

We will now begin the experimental testing. You will use the same UAV control interface. The mission will be similar to the training, but with different tasks.

[New trial starting point] *Please read through the scheme of maneuver before we begin.*

[Allow time to read] *Any questions? Are you ready for this mission?*

Again, remember to verbally report parameter deviations. Please also try to maintain your posture during the mission and limit your head movement so the eye tracker can capture your gaze pattern.

[Start Camtasia]

[Start RR recording]

[Start Eye-tracking]

Ok, the mission will begin. Launch when ready.

[Play audio recording once participant correctly Launches the UAV]

[Deliver SA queries according to Prototype Timeline; pay close attention]

[Second experimenter to record subtask performance and SA responses in gradesheet]

[Stop RR recording upon mission completion]

[Stop eye-tracking]

[Stop screen capturing upon mission completion]

b. Rest & TLX rating

[Save all files. Name properly, e.g., "P1_Trial1"]

*You have completed this mission. Now we ask that you complete the second portion of the workload questionnaire, where you need to rate the workload demand components separately. Please follow the instructions on this paper. **[Hand participant TLX rating sheet]** Let me know if you need any clarifications on the definitions of the demand components or the aspects of the task that you should consider in your ratings.*

[If polar watch start to lose HR data, ask participant to wet the monitor again]

Thank you for completing the questionnaire. Now, please take a 2 min to rest break.

[Time 2 min]

Your resting period is now complete. We will now proceed to your next trial.

c. Repeat a-b 3 times. (4 trials in total for each participant).

9. Baseline measurement

Now you have completed all experiment trials. Before we close the experiment, we need to take some additional measurements with the eye-tracking system and the HR monitor.

Please look anywhere on the UAV control screen. I need you to do this for 5 minutes. You do not need to perform any tasks but please do not direct your eyes away from the screen. Stay relaxed and just blink normally.

[Record eye-tracking, HR and RR-interval for 5 mins.]

10. Debrief

a. Complete Payment Form

[Hand payment form to participant.]

[Calculate the participant's compensation.]

Here is the form for your compensation for participation in the study. For your time today, you will receive \$____.____.

b. Departure and Thank You

[Give the participant a copy of his or her signed informed consent form as well as the original payment form.]

The experiment is now complete. The data we collected today will be used to investigate the effect of interface design on workload in UAV operations. You will not be personally identified in any of the data analyses or reports based on this study. If you are interested in future information about this experiment, you may contact Dr. David Kaber, whose contact information is included in the informed consent form.

11. Post-Experiment Procedure

- a. Organize all data sheets in participant folder
- b. Record subtask performance accuracy and times in spreadsheet; verify with videos if necessary
- c. Record TLX responses in spreadsheet
- d. Save video file with Participant #_Trial #
- e. Export HR data to txt files and name properly.
- f. Backup files
- g. Charge the Polar watch

9.11 Appendix K: Scenario Timelines

Time	Air Speed	Distance	Degree	Altitude	Battery	Ground Speed	Location	Scheme of Maneuver	SA Questions	Alarm Prioritize	Alarm Fix	Verbal Cue	SA Answers
0:00	0	0	0	0	0	0	At LP	Launch after SA Questions and Alarms prioritized.	ST_TT_Scenario_Q1-Q14			Before we start, I'm going to ask you a few questions on what we covered during the session. If you don't know the answer, feel free to let me know, and I will help you.	
0:01	45	50	45	50	99	4.5				AL_P1_N2, AL_P3_N5, AL_P2_N5		Prioritize the alarms per your training.	1: Stall Impending 2: At Max Speed 3: Nav Active
0:17		750			95				ST_TT_Map_Q16; ST_TT_Map_Q17			What is the name of the NAI in the scenario?	NAI Nali;
0:33		1300			88							What is the name of the Axis in the scenario?	Axis Nova
0:50		1900	135		81		At WP 1	Change WP 2 a altitude to 75 feet				Change WP 2 a altitude to 75 feet.	75
1:06		3300			75				ST_TT_Map_Q15			How many targets are inside NAI Nali?	3
1:23		4700	220		66		At WP 2	Drop payload at WP 2.				Drop payload at Waypoint 2.	Dropped
1:39		6000			52				ST_TT_Map_Q21			What is your current completion percentage for this mission?	66 or 67
1:55		6700			47								
2:00		7500			44				ST_TT_Map_Q18			What Northing is the LP closest to?	23
2:12		8000			35				ST_TT_Map_Q20			What Easting is WP 3 closest to?	13
2:37		8800	305	75	29		At WP 3.	Return to Launch.			AL_P1_N3	Fix the alarm shown	Click Pull Up; Warning: Alt
2:45		9200			19							Return to Launch	Warning: Batt
2:50													Warning: Dist
2:55									ST_TT_Map_Q19			Report the coordinate of Waypoint 1.	128 240
3:07	0	10450	0	0	17	0	At LP		ST_TT_Map_Q19			Report the distance between the Eastern most and Southern most targets?	1.400 m; *Warning: Dist

Scenario Tasks (Prototypes: 1, 5, 3)												
Time	Air Speed	Distance	Degree	Altitude	Battery	Ground Speed	Location	Schedule of Launch from LP	Alarm Prioritize	Alarm Fix	Verbal Cue	SA Answers
0	0	0	0	0	0	0		Launch when ready.				
1	50	6	285	50	39	5.1						
13		850			96			Determine coordinate of a target TEO.			Report the coordinate of the Western most target outside of (NA) drill.	037, 217
20		1200	230		90		ALP20				What Morning is Waypoint 20 closest to?	240
26		1650			87			Change WP 21 altitude to be 35 feet.			Change WP 21 altitude to be 35 feet.	35
39		2400			84						What is your current Battery Remaining?	72%
52		3000			78						What is the name of the Axis?	Axis KEEP
1:05		3600			72						Report the distance from WP 24 to the Launch Point.	1,600 meters
1:18		4400			70			Determine distance of a target TEO.			For what Map Action command is "Land" an action?	"Warning, Alt Land"
1:31		4900			68						What map action's Speed found	Command
1:40		5200	155	35	65		ALP21				Drop payload	Dropped
1:57		5700			61						Change WP 23 altitude to be 60 feet	60
2:10		6200			53						In map actions how many (other actions are available?	3) Forever, Time Cycles)
2:23		6700			50						How many targets are in (NA) Level?	4
2:29		7100	70	50	48		ALP22	Drop payload at WP 22.				
2:31		7100			45			Change WP 23 altitude to be 60 feet				
2:36		7700			45							
2:49		8150			40							
3:02		8675			37							
3:07		9000			35							
3:15		9300			35							
3:28		9600	25	60	31		ALP23	Fix the alarm shown.	AL_P2_M6		Fix the alarm shown.	Rekuel
3:41		10000			29						What is the target distance to the "Warning, Lib"	< 10,000 meters
3:54		10400			26						What is your current altitude?	80 feet
4:07		10860			22							
4:20		11000			20							
4:27		11195			19			Prioritize alarms per your training.	AL_P1_M AL_P2_M1 AL_P3_M6		Prioritize alarms per your training.	1. Engine Fire 2. Evl Alt 3. Inst. Panel "Warning, Bar"
4:33		11380			17							
4:46		11775			13						What is the normal range for ground speed?	0-10 m/s
4:53		11900	350	50	5		ALP24				Return to launch.	
5:05		12740			1						What is the minimum acceptable value for Battery Remaining?	20%
5:12	0	13500			0	0	LP					

Scenario 1 Slow (Prototypes 4, 8, 12)

Time	Air Speed	Distance	Degree	Altitude	Battery	Ground Speed	Location	Scheme of Maneuver	Alarm Prioritize	Alarm Fix	Verbal Cue	SA Answers
0	0	0	0	0	0	0					Launch when ready.	
1	45	6	285	50	93	4.5						
21		850			96			Determine coordinate of a target (BD).			Report the coordinate of the Southernmost target in MAL level	136.205
31		1200	230		90		At WP 20					
41		1650			87						What Easting is Waypoint Z, closest to?	120
103		2400			84			Change WP 21 altitude to be 35 feet			Change WP 21 altitude to be 35 feet	35
123		3000			78						In knots, what is your current speed?	45
144		3600			72							
204		4400			70						Whats your current completion percentage for this mission?	20%
225		4900			68							
239		5200	85	35	65		At WP 21	Determine distance of a target (BD).			Report the distance from Waypoint Z2 to Waypoint Z3.	2,600 meters
306		5700			61						In Map Action, what are 2 of the 3 Overlay actions available?	*Warning, Alt Create, Edit, Delete
326		6200			53				AL_P1_N2, AL_P3_N2, AL_P2_N3		Prioritize the alarms per your training	1. Skill Impending 2. Altuplot 3. Parking brake
348		6700			50							
358		7000	70	50	48		At WP 22	Drop payload at WP 22.			Drop payload	Dropped
400								Change WP 23 altitude to be 60 feet			Change WP 23 altitude to be 60 feet	60
408		7700			45							
429		8150			40						What is the normal range for UAV altitude?	40-55 feet
449		8675			37						What is your total distance traveled for this mission so far?	8675 meters
510		9100			35				AL_P1_M4		Fix the alarm shown.	Extinguish
530		9600	25	60	31		At WP 23				In map actions, what are the waypoint options available?	*Warning, Alt Insert, Load, Edit, Delete
551		10000			23						In Map Action, where can you jump to?	*Warning, Dist Start, WP#, LP
611		10400			26							
633		10860			22						How many targets are inside MAL Diff?	6
653		11000			20							
703		11955			19						What is your current ground course?	*Warning, Bar 25 degrees
714		11800			17							
734		11715			13							
744		11900	350	50	5		At WP 24				Return to launch	
805		12740			1						In next second, what is your current speed?	4.5
815	0	13500		0		0	LP					

Scenario 2 Fast (Prototypes 3, 7, 11)												
Time	Air Speed	Distance	Degree	Altitude	Battery	Ground Speed	Location	Scheme or Maneuver	Alarm Prioritize	Alarm Fix	Verbal Cue	SA Answers
0	0	0	0	0	0	0					Launch when ready.	
1	50	50	355	50	99	5.1						
13		650			90			Determine coordinate of a target TEO.			What is the coordinate of the Northern most target in NA/Hammer? 141242	
26		1300	340		85		At MP10				For what map action command's "Land" action? Command	
39		1986			83			Change MP13 altitude to be 40 feet			Change MP13 altitude to be 40 feet	40
52		2682			80							
1:05		3300			77						What is your current distance traveled? 3,300m	
1:18		3855			74			Determine distance of a target TEO.			Report the distance from Waipoint 14 to Launch Point. 3,700m	
1:25		4233			72							
1:31		4879			68						What are the names of the MAs in the scenarios? SAW/HAMMER	
1:44		5700			64						What is your current altitude? 50 feet	
1:53		6450	70		60		At MP11	Drop payload at MP11			Drop payload Dropped	
2:13		6780			59						What is your current ground course? 70	
2:26		6600	78		56		At MP12	Change MP14 altitude to be 30 feet			Change MP14 altitude to be 30 feet 30	
2:36		7169			53							
2:49		7722			50						What Map Action command is circles under? Lower	
3:02		8254			48							
3:09		8740	182	40	44		At MP13				How many targets are inside NA/Saw? 4	
3:15		9600			41							
3:28		10763			38					AL_P1_M3	Fix the alarm shown. Crash/imminent *Warning List	
3:41		11428			29							
3:54		12000			25						What is your current completion percentage for this mission? 80%	
4:07		12600			20						In map actions what can you draw on the map? Line Polygon Route *Warning Bar	
4:20		12399			15							
4:33		13488			10				AL_P3_M5 AL_P2_M6 AL_P1_M5		Prioritize the alerts per your training. 1. Abort 2. Max Air Speed 3. Nav solve	
4:46		13890			7							
4:53		14000			4						What is the acceptable range for battery remaining? 20-100%	
5:06		14712			0						What is Working is Waipoint 12 object to? 240	
5:19		15100	255	30			At MP14				Return to launch	
5:32		17800		0			ALP					

Scenario 2 Slow (Prototypes: 2, 6, 10)

Time	Air Speed	Distance	Degree	Altitude	Battery	Ground Speed	Location	Scheme of Maneuver	Alarm Prioritize	Alarm Fix	Verbal Cue	SA Answers
0	0	0	0	0	0	0					Launch when ready.	
1	45	50	355	50	99	4.5						
22		650			90			Determine coordinate of a target TBD.			Report the coordinate of the Southern most target inside of NAI Saw	102 136
43		1300	340		85		At WP 10	Change WP 13 altitude to be 40 feet			Change WP 13 altitude to be 40 feet	40
53												
1:05		1986			83							
1:26		2682			80						What is your current battery remaining?	80%
1:38		3300			77						Report number of targets inside NAI Hammer.	6
2:09		3955			74							
2:19		4333			72			Determine distance of a target TBD.			Report the distance from Waypoint 10 to Waypoint 11.	3,100 m
2:31		4879			68							
2:52		5100			64						What is the name of the Axis?	CHEVY
3:07		5450	70		60		At WP 11	Drop payload at WP 11			Drop payload	
3:38		6160			58						In Map Action, how many "Delete" options are available?	2 (WP, overlay)
4:01		6600	78		56		At WP 12	Change WP 14 altitude to be 30 feet			Change WP 14 altitude to be 30 feet	30
4:17		7169			53							
4:40		7722			50						What is your current ground speed?	4.5 m/s
5:00		8054			48							
5:11		8740	182	40	44		At WP 13					
5:21		9600			41					AL_P2_M4	Fix the alarm shown.	Change slope
5:43		10763			38						For what map action command is "Circles" an option?	Loiter
												*Warning: Dist
6:05		11428			29				AL_P1_M1 AL_P3_M1 AL_P2_M2		Prioritize the alerts per your training.	1: Excessive descent 2: Autopilot 3: Service due
6:26		12000			25							
6:48		12600			20						What Easting is Waypoint 14 closest to?	15
7:09		12999			15						In map actions, what are the overlay options?	Create, Edit, Delete
												*Warning: Bat
7:31		13486			10						In knots, what is your current speed?	45
7:52		13890			7						What is the normal range for UAV	40-55 feet
8:02		14000			4							
8:24		14712			0						What is the target distance for the UAV?	<10,000 m
8:45		15100	255	30			At WP 14				Return to launch.	
8:56	0	17800		0		0	AT LP					

9.12 Appendix L: Usability Questionnaire

Usability Questionnaire

Participant #: _____

Please indicate if you agree or disagree with each of the following statement.

Strongly
disagree

Strongly
agree

	1	2	3	4	5
Overall, the UAV control interface was easy to use.					
It was easy to find information I needed.					
The interface was effective in helping me completing the tasks.					
The UAV control tasks were easy to accomplish.					

What comments/complaints do you have about the system interface?

What recommendations for improvement do you have for the interface?