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HEY LARRY! INVESTIGATING INTERRUPTIONS IN FUTURE VERTICAL LIFT PLATFORMS

by

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**HEY LARRY! INVESTIGATING INTERRUPTIONS IN FUTURE VERTICAL
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ABSTRACT

Using technology to improve human performance is critical to maximizing the benefits of future combat systems. This study explores the effects of interruptions during high and low cognitive load states when completing dynamic tasks. Furthermore, it provides insight into how to integrate artificial intelligence and virtual assistants into future aircraft effectively. This research and the following analysis provided the Holistic Situation Awareness and Decision Making (HSA-DM) program office with meaningful data and recommendations that will enable them to reduce the impact of interruptions while improving the performance of future pilots.

Specifically, this study collected and examined heart rate variability, subjective cognitive load, flight metrics, interruption lag, and task resumption lag while participants piloted an aircraft and performed dynamic tasks in a flight simulator. There were three different modalities used to assist participants with completing interrupted tasks while performing their primary task. The research team determined that the tactile activated artificial intelligence was the most effective at reducing total interruption time while having the smallest effects on flight performance and cognitive load.

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LIST OF ACRONYMS AND ABBREVIATIONS

AH	attack helicopter
AI	artificial intelligence
ANOVA	analysis of variation
CH	cargo helicopter
DA	Department of the Army
DOD	Department of Defense
FARA	future attack and reconnaissance aircraft
FLRAA	future long-range assault aircraft
FVL	future vertical lift
HR	heart rate
HRV	heart rate variability
HSA-DM	Holistic Situation Awareness and Decision Making
HSD	honestly significant difference
HSI	human systems integration
IBI	interbeat interval
ICS	intercommunications system
KIAS	knots-indicated air speed
MSL	mean sea level
NASA	National Aeronautics and Space Administration
NCMAS	National Commission on Military Aviation Safety
OH	observation helicopter
PEO	Program Executive Office
PNS-I	parasympathetic nervous system index
SA	situation awareness
SD	standard deviation
SP	special performance
C-SWAG	continuous subjective workload assessment graph
TLX	task load index
UH	utility helicopter
US	United States

USACRC
VA

United States Army Combat Readiness Center
virtual assistant

EXECUTIVE SUMMARY

The U.S. Army introduced the idea of Future Vertical Lift (FVL) in 2009 and approved the initial strategic plan in 2011. FVL is an Army led program but is planned to bring capabilities to each service within the Department of Defense (DOD). The overall goal of the program is to develop technology that will increase the range, payload, speed, maneuverability, reliability and reduce the logistic footprint when contrasted with current vertical lift platforms. The research conducted in this study is intended to help combat the effects of interruption lag, secondary task duration, and resumption lag for helicopter pilots in a dynamic environment.

To answer the research question, we collected various data streams while putting participants through an experiment, organized and validated the data then analyzed the data to compare it against a hypothesis and provide a way forward for Future Vertical Lift. A total of 26 participants, 21 non-pilots from varying backgrounds and 5 pilots, conducted this experiment in a sterile lab setting. X-Plane 11 was the flight simulation platform used for the study along with several data collection methods using Polar HR11 for raw heart rate, Kubios 3.5.0 for heart rate variability, NASA TLX surveys, continuous subjective assessment of workload assessment, and stopwatches for interruption timing collection periods throughout the simulation. The software programs R, Kubios, and Microsoft Excel were used to analyze the data.

The result of our research and analysis of three modalities; no artificial intelligence, voice-activated artificial intelligence, and tactile activated artificial intelligence, indicates that introducing an artificial intelligence activated by a tactile modality will reduce the total interruption time. The total interruption time will also be impacted by the cognitive load as suggested by our analysis with the shortest interruptions occurring in low cognitive load states, the tactile artificial intelligence displayed the lowest subjective cognitive load of the three modalities and the highest subjective workload was demonstrated by the voice-activated artificial intelligence. Artificial intelligence can reduce the impact of interruptions when implemented in a way that accommodates the users limitations and the systems strengths.

While the primary and secondary questions were answered by the research team, more specific and detailed experimentation can be conducted in relation to this project. Due to the limited availability of pilots, the team was limited to a stable aviation platform. The team was also unable to conduct the test with a pilot-only population that would have enabled conducting the experiment in more realistic environmental conditions and permitted the utilization of a simulated rotary wing aircraft.

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I. INTRODUCTION

Department of Defense (DOD) combat helicopter platforms (CH-47 Chinook, AH-64 Apache, UH-60 Black Hawk, and OH-58 Kiowa Warrior) are all centered on designs from the 1960s and 1970s. Several of these platforms are still in production and actively used in global contingency operations. The U.S. Army is currently the lead in DOD's attempt to adopt the next generation of helicopter technology. The Future Vertical Lift (FVL) program, a subsidiary of PEO aviation, is a DOD research and development endeavor devoted to discovering, examining, and enhancing the technologies to equip the DOD with the next generation of vertical lift aircraft. The program's objective is to create technologies that enhance maneuverability, range, speed, payload, survivability, reliability and reduce the system logistical footprint compared with the current helicopter platforms.

The U.S. Army lists the FVL program as one of its top modernization priorities. Although the FVL project expects to aid all U.S. armed services, and aspects of the program's development are joint, the Army is currently heading up the project and supplying most of the funding for FVL via the Army's research and development budget. The FVL program is still in the initial stages of development, and the various aircraft that will stem from this programs' effort is not anticipated to be in operation until the early 2030s.

Future Vertical Lift is presently investigating five capability sets of helicopters with various sizes, ranges, and lift capacities. Still, the primary focus area is an intermediate transport variant that will serve as the successor to the current U.S. Army UH-60 Black Hawk and U.S. Marine H-1 Huey helicopters—the Future Long-Range Assault Aircraft (FLRAA). The secondary focus area is the future attack/reconnaissance variant that will replace the current AH-64 Apache, currently deemed the Future Attack and Reconnaissance Aircraft (FARA).

In conjunction with the development of future mechanical platforms, the FVL program is investigating integrating artificial intelligence (AI) technology that will augment pilot and crew during the flight. The HSI interruption capstone team seeks to

provide value to the program office by exploring an AI solution capable of assisting pilots and crew members to recover from interruptions more efficiently. Our capstone project aims to produce an actionable solution that will allow FVL to successfully implement AI technology into all FVL variants, subsequently enhancing the safety and effectiveness of the FVL platform.

A. PROBLEM STATEMENT

In military flight operations, interruptions of activities can have dire consequences if the aircrew cannot quickly and seamlessly resume the disrupted activity. Aircrew interruption, like task interruption, is a fact of life; they are unavoidable for pilots and their crew. Given the potentially high cost of inefficient task resumption for an aircrew, it is critical to identify the causes of inefficient task resumption to develop effective tools for mitigation.

B. RESEARCH QUESTIONS

The HSI Interruption capstone aims to answer one primary research question: what is the impact of introducing an artificial intelligence aid on interruption lag, secondary task duration, and resumption lag for helicopter pilots in a dynamic environment?

Two sub-research questions provide further fidelity and support answering the primary research question:

- How do an individual's resumption time and accuracy level vary relative to high and low-load cognitive states?
- To what extent does the introduction of an artificial intelligence aid impact flight characteristics during an interruption?

C. STAKEHOLDERS

Illustrated in Table 1, the HSI Interruption capstone project team considered requirements derived from three stakeholders: Program Manager, Project Engineer, Rated Air Crew Members.

Table 1. Project Stakeholders

Stakeholder	Category	Need	Goal
Program Manager	Beneficial Stakeholder	Interruption and resumption lag feedback	Improve current development of the FVL program
Project Engineer	Beneficial Stakeholder	Improved interruption understanding	Improve development of interruption recovery systems
Rated Air Crew	Beneficial Stakeholder	Improved interruption recovery	Improved performance during aircraft procedures

The program manager is the primary stakeholder of this program and is a beneficial stakeholder. The program manager provides overall guidance towards research and design to stay within the requirements while also meeting cost, schedule, and performance goals. The benefits the program receives from this study will improve the development of FVL.

The project engineer is a beneficial stakeholder in this program. The engineer provides direction for research while also collecting data and analysis to produce innovative designs that meet the system requirements towards interruption recovery within FVL. The aircraft is still in development, and systems are still being designed with the input and data collection provided through this study.

The FVL rated aircrew are beneficial stakeholders due to the vital feedback they will provide towards the program with the hands-on knowledge they have with current and past airframes in use by the military. The future of this program, once fielding begins, is projected to supply twelve Combat Aviation Brigades across the Army and different variants across the special operations forces and sister services.

D. PROJECT OVERVIEW

This study examines how task interruption affects task resumption during complex tasks and discusses the relevance and application of cognitive load theory and situational awareness to task resumption lag. The objectives of this research are:

- Gather objective (HRV and IBI) and subjective (NASA TLX and Subjective Workload Assessment Graph) measures of cognitive workload.
- Conduct analysis of qualitative data measuring task interruption lag, secondary task duration, and resumption lag.
- Provide recommendations for training solutions or design parameters for an artificial intelligence system to assist human operators combat the deleterious effects of interruptions.

The scope of this capstone project is to investigate human cognitive load as it relates to task resumption. It will evaluate individuals' cognitive load in a laboratory setting while conducting a dynamic task. Individuals will be exposed to interruptions while performing this task, and we will gather data on task resumption time. This experiment aims to capture data that measures cognitive load for research subjects in an experimental lab environment. Our experiment will collect objective and subjective data. The investigation will also capture qualitative data to measure secondary task interruption lag, the duration of the secondary task, and the primary task resumption lag. After analysis, this information will allow the capstone research team to recommend a viable solution to reduce the effects of interruptions on cognitive load concerning primary task resumption. Resolution of this issue will result in increased safety for FVL pilots, crew, and supported units.

The research team has completed a comprehensive literature review of the scientific literature on the factors contributing to task resumption lag, cognitive load theory, situational awareness, and potential human system integration solutions which will be explained in Chapter II. After understanding the nature of interruptions and their effects on cognitive ability, it appears that the root cause of interruptions is cognitive overload. Several studies explain that interruptions prime mistakes because interruptions put more strain on a person's mental processes and decrease attention allocation on the current activity (Monk et al. 2004; Salthouse et al. 1998; and Altmann and Trafton 2007). The research highlighted the inherent risk of interruptions and the mistakes caused by them, especially in complex situations like what future vertical lift platforms will experience. Therefore, the research team sought ways to measure cognitive load to redirect tasks from

overloaded pilots to prevent unnecessary interruptions. We learned that there is an unintrusive way to measure a pilot's cognitive load using heart rate variability because the findings of Solhjoo et al. (2009) seem to suggest that a subjective rise in a subject's mental strain appears to manifest as an increase in both parasympathetic and sympathetic parts of the nervous system. While the literature reviewed showed a correlation with high cognitive load and adverse effects on task performance, those studies have been conducted in a static environment. We assume that these findings still apply in a dynamic environment while performing a complex task. Our study will contribute to the scientific body of knowledge by showing the relationship between cognitive load and task performance.

There were several theories and models that attempt to explain an interruption. Trafton and Monk (2007) clearly defined the anatomy of an interruption. Our capstone group proposes a study of how a person's mental state throughout the sequence of events shown in this model, particularly their cognitive load, affects the timing and accuracy of interruption recovery. Chapter III explains the methodology of the study. The proposed study involves an analysis of physiological measures such as heart rate variability and subjective measures such as the NASA Task Load Index (NASA TLX) that correlate to changes in cognitive load throughout a primary task. Once our group's baseline analysis is complete, we intend to study how interruptions exacerbate these changes and how variations in cognitive load contribute to recovery times and accuracy. Chapter IV explains the collected data results, and Chapter V summarizes the recommendations and findings of the experimental study.

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II. LITERATURE REVIEW

The purpose of the literature review is to gain awareness of current information regarding interruption lag, secondary task performance, and task resumption lag. The literature review examines the nature of interruptions and their imposed cost as understood in a static task environment. The effect of dynamic environments on humans. The role of cognitive workload regarding interruptions as well as methods for measuring it. The current state of human machine teaming and its implications regarding reduction of interruption and resumption lag and reducing secondary task duration. There are numerous tasks that a virtual assistant (VA) could assist pilots within dynamic, complex environments. This study will explore the effects of cognitive load on task performance and examine whether a VA can assist with mundane tasks and reduce workload.

A. INTERRUPTIONS

Upon being interrupted, aircrews often exhibit varying degrees of lag when attempting to resume aviation tasks. Since the founding of the United States Army Air Corps in 1926, preventable aviation mishaps have presented an enormous challenge for members of the profession. In general, these mishaps are attributed to material failure/malfunction, environment, human error, or a combination of the three (United States Army Combat Readiness Center [USACRC] 2021). According to the National Commission on Military Aviation Safety's December 1, 2020, report, historical records indicate that approximately 80 percent of aviation mishaps are attributed to human factors among aircrews and maintainers. (National Commission on Military Aviation Safety [NCMAS] 2020) Though task resumption lag may not always be a contributing factor in those mishaps attributed to human error, every second matters when responding to changes in flight profile, environmental conditions, and emergencies. Given the extraordinary costs and survivability concerns associated with aviation mishaps, it is important to investigate the causes and magnitude of this phenomenon and, ultimately implement potentially lifesaving solutions.

B. ANATOMY OF AN INTERRUPTION

In Figure 1, Trafton and Monk (2007) illustrate the anatomy of an interruption by depicting the sequence of events from beginning the primary task to eventually resuming that task following the interruption of a separate secondary task. In the context of this capstone project, a pilot begins to execute a primary task (i.e., bringing the aircraft to a hover). During the performance of that task, there is a sudden interruption (i.e., radio transmission from higher headquarters) that causes the pilot to abandon that primary task and either perform or acknowledge and delay a secondary task. The time between the interruption alert and execution of the secondary task is referred to as interruption lag which will be discussed in greater detail in subsequent sections. Similarly, resumption lag can be defined as the time it takes to resume the primary task following the completion of the secondary task.

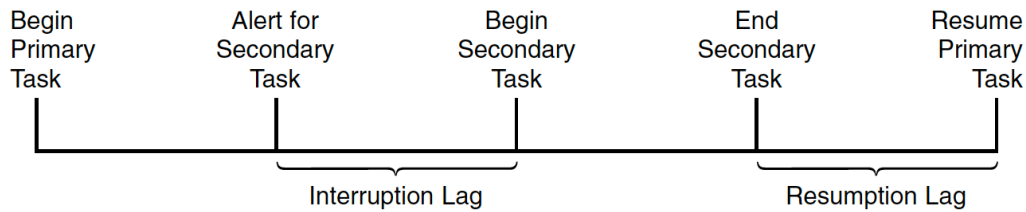


Figure 1. Anatomy of an Interruption. Source: Trafton and Monk (2007, 114).

C. EFFECTS OF INTERRUPTIONS IN DYNAMIC ENVIRONMENTS

Not all interruptions are equal. Several factors influence how a task may impact an individual and that also depends on an individual's cognitive state. Depending on the nature of the interruption, it can increase or decrease the primary task's performance after the interruption is resolved. When switching to a new task rather than a task repetition, performance is slower, so the similarity of tasks improves performance (Waszak, Hommel, and Allport 2003, 406). Furthermore, decision time increases, and decision accuracy decreases when the frequency of interruptions is high (Speier, Valacich, and Vessey 2003, 350) and mid-task interruptions have the biggest impact on resumption lag (Monk, Boehm-

Davis, and Trafton 2004, 650). Most significant to our study is the finding that when dealing with complex tasks, interruptions are more detrimental to performance, whereas, in simple tasks, performance can improve with interruptions (Spier, Vessey, and Valacich 2003, 771).

D. SPATIAL DISORIENTATION

Physiological responses to the aviation environment as they pertain to task resumption, present an interesting challenge, as many of the contributing factors are difficult to identify and remedy. According to the National Commission on Military Aviation Safety's (NCMAS 2020) report, historical records indicate that approximately 80 percent of aviation mishaps are attributed to human factors among aircrews and maintainers. Furthermore, mishap reports from 2013 through 2018 indicate that 38 percent of class A mishaps can be attributed to "preconditions," which include factors such as physical problems, state of mind, sensory misperception, mental awareness, and physical/technical environment (NCMAS 2020). Factors such as these, particularly sensory misperception, can ultimately lead to spatial disorientation which "remains a contributing factor in more aircraft accidents than any other physiological factor in flight" (Department of the Army [DA] 2018, 127).

In aviation, the term spatial disorientation can be used to describe conditions in which an aviator improperly perceives their position, attitude, or motion relative to the surface of the earth (Gradwell and Rainford 2006). Since the first instrument-only flight in 1929, the attitude indicator has been recognized as one of the few means of preventing spatial disorientation in flight (Wickens et al. 2007). Consequently, few changes have been made to the original design of the Sperry Artificial Horizon since its adoption by the military in the early 1930s. In 2007, a team of Air Force Academy students examined how variables in flight displays, particularly attitude indicators, contributed to speed of recovery when exposed to a series of unusual attitudes in a low fidelity flight simulator (Wickens et al. 2007). Participants for Wickens et al.'s (2007) study included novices and experienced aviators, each exposed to two different displays. Three variables were measured during each trial: (1) time until initial stick input, (2) number of roll reversal errors, and (3) total

time to recovery (Wickens et al. 2007). Though the results of the study were intended to reveal how changes to the presentation of pitch and roll data impacted these variables, the more concerning finding, as it pertains to task resumption, is how high the mean values of all three measures were, regardless of the display.

Following 24 trials with each display, Wickens et al. (2007) found that the mean time before the initial stick input from each participant was 1.1618 seconds after being exposed to an unusual attitude, with an average of 1.25 roll reversal errors per trial. The most concerning statistic, however, is the mean recovery time of 11.8066 seconds from each unusual attitude (Wickens et al. 2007). Given that many rotary-wing aviation missions are conducted in a terrain flight profile (≤ 200 feet above ground level), recovery times afforded to aviators are dramatically reduced. A recovery time of 11.8066 seconds in a standard, 500-foot per-minute landing profile would result in a 98-foot descent. A more severely disoriented aviator would likely experience more dramatic changes to altitude and airspeed that could yield catastrophic results left uncorrected for over 11 seconds.

E. SYSTEM RELATED FACTORS

Radios in an aircraft are crucial pieces of equipment that allow pilots to communicate internally and externally. However, they can also induce audible distractions for pilots and aircrews. Dismukes et. al. (1998) determined that going through a checklist while having radio calls come in to discuss traffic alerts reduced the likelihood that pilots remember which step they were on. Vertical lift platforms will have multiple radios, including an Intercommunications System (ICS). This system interrupts each pilot and crew member indiscriminately with every radio transmission. Additionally, pilots receive tasks while flying, requiring them to adjust the mission plan, thus taking mental processing power away from their current task (Edgington 1976). Additionally, communication chatter and constant auditory distractions such as the noise produced by rotor blades, are known to exacerbate the effects that interruptions have in dynamic situations (Hodgetts, Vachon, and Tremblay 2013, 17).

F. COGNITIVE WORKLOAD

There are numerous factors that contribute to interruptions experienced by pilots and aircrew, making it crucial to understand the effects of interruptions on working memory and task completion ability. Because the interruptions are delivered by various modalities, cognitive load theory provides insight into what is taking place in the individual's mind pre, intra, and post interruption. Cognitive load theory is a derivative of the architecture of human cognition, which is made up of three processing elements and one memory element (Nielsen and Molich 1990). The processing elements are perceptive, cognitive, and senso-motoric (Paas, Renki, and Sweller 2003). They operate alongside long-term and working (short-term) memory as required by human information processing (Paas, Renki, and Sweller 2003). The name cognitive load is given to the mind's cognition resources generated by task demand (Chalmers 2003). In the literature, the definition of cognitive load is further distilled into three types: inherent, superfluous, and appropriate.

- **Inherent cognitive load:** Working memory strain caused by the inherent intricacy of the information that is examined. Every task has a degree of difficulty that is intrinsic to it (Chalmers 2003). The intrinsic cognitive load results from the inherent sophistication of the activity, as evidenced by the fact that mathematic addition creates a smaller inherent load on a person's mental processes when compared to solving a differential equation.
- **Superfluous cognitive load:** Superfluous cognitive load comes from how information is presented. Superfluous cognitive load is a measurement of the strain on cognition caused by a task's design. How information is presented can serve as a control measure for a cognitive load of this type (Chalmers 2003). Higher volume and more complex data require more working memory. For example, numbers presented as roman numerals (XXIII) rather than Arabic numerals (23) will increase the extraneous cognitive load.

- Appropriate cognitive load: Appropriate cognitive load is committed to the managing, building, and mind's automating of representations (Chalmers 2003). Representations are the models encoded by previous learning outcomes on the brain's neural network. Attempting to complete a task in a novel way increases the appropriate cognitive load.

G. WORKLOAD AND INTERRUPTIONS

More than one source of information vying for attention in a moment will increase the inherent and extraneous cognitive load experienced by that person. Therefore, it is not surprising that Monk and colleagues (2004); Salthouse and colleagues (1998); and Altmann and colleagues (2007) all found that interruptions have a detrimental effect on the performance of primary tasks. These findings indicate that there is a positive relationship regarding mental load and task resumption lag. Monk and colleagues (2004); Salthouse and colleagues (1998); and Altmann and colleagues (2007) also found that interruptions prime mistakes because interruptions put more strain on a person's mental processes and decrease their focus allocation on the current activity. The increased cognitive demand results in increased difficulty resuming the primary task post interruption. Following an interruption, individuals must mentally reconstruct the primary task, remember where they left off, recall the next step in the process, and then resume the primary task to complete the task successfully (Monk et al. 2004). Task resumption post interruption is not easy because most tasks do not provide cues (i.e., placing a finger where you left off in a book) to aid a person in successfully resuming the primary activity. A larger cognitive cost is inflicted by an interrupting task which limits a person's ability to practice active goal rehearsal during the interruption period and decreases the possibility of successful task resumption (Cades et al. 2007).

H. PSYCHOPHYSIOLOGICAL MEASUREMENTS OF COGNITIVE WORKLOAD

The Department of Defense (DOD) has been investigating the use of psychophysiological measures as an approach for assessing human performance in operational contexts since 1994 (Caldwell 1994). According to the Advisory Group for

Aerospace Research and Development report on psychophysiological measures (1994) the DOD tested eight psychophysiological measures and their relation to various aspects of human performance. DOD concluded that six of the eight measures were suitable measures in relation to mental workload: electroencephalography, electro-oculography, bodily fluids, electrocardiogram, respiration rate, and body temperature (Caldwell 1994). The heart rate is the most frequently used psychophysiological measure for flight and flight related tasks. Two general findings emerged from the studies (1) heart rate, heart rate variability, and inter-beat interval provide a reliable measure of workload and (2) the pilot is in control of a two-pilot aircraft will experience the higher heart rate, lower heart rate variability, and decreased inter-beat interval (Caldwell 1994).

I. HEART RATE VARIABILITY AND INTER-BEAT INTERVAL

Wilson (1993) conducted an experiment in which he attempted to use physiological measures as a non-intrusive way to measure fighter pilot workload. After each trial, the pilots completed a subjective workload scale corresponding to each segment of flight to validate the physiological measurements that were collected (Wilson 1993). Wilson (1993) found that heart rate variability and inter-beat interval had the greatest degree of correlation when compared to the pilot's subjective assessments. Heart rate variability has gained prominence recently as a measure of the human body's recovery level related to optimal physical performance. Using the idea of heart rate variability as a proxy for performance, Solhjoo et al. in 2019 attempted to correlate heart rate and subjective cognitive load in surgeons. The researchers discovered consistent correlations between heart rate variability and subjective measurements of mental workload during daily rotations (Solhjoo et al. 2019). Because the correlations they observed were not present in the measurements, they took in the preceding 24 hours, when each subject was off duty. Also, because the correlations were most pronounced during emergency events (a cancer patient in extreme duress and a pulmonary embolism), the researchers concluded that there is reason to believe that heart rate variability can be used to measure cognitive load (Solhjoo et al. 2019). Building on the work of Wilson (1993) and Solhjoo et al. (2019) our team plans to utilize two subjective workload measures (NASA TLX and Continuous Subjective Workload Assessment Graph) to validate our physiological findings.

J. SUBJECTIVE MEASURES

When cognitive load theory began in the early 1980s, there was no direct measure for cognitive load (Sweller, Ayres, and Slava 2011). The mental workload measurement emerged from experiments investigating the relationship between critical thinking and education. As cognitive load theory progressed, the need arose for a way to gauge cognitive load directly. In 1992 Paas created the first subjective measure of cognitive strain utilizing a Likert scale comprised of nine points that range from very, very low mental effort (1) to very, very high mental effort (9) (Sweller, Ayres, and Slava 2011). Since their development in 1992, subjective measures of cognitive load consistently match performance information with surprising accuracy (Sweller, Ayres, and Slava 2011). NASA TLX affords a precise gauge of total workload as it differentiates amongst tasks of different mental and physical demands (Gawron 2019). NASA TLX is also validated in flight situations and is used by NASA, the U.S. Air Force, U.S. Navy, U.S. Army, U.S. Coast Guard, and several NATO allies (Gawron 2019). Continuous subjective assessment of workload has been validated with subjects being able to provide accurate ratings as often as every three seconds (Gawron 2019). It is more sensitive to in-trial workload changes when compared to a subjective measure that is collected post experiment as the subject is providing immediate feedback (Gawron 2019).

K. SITUATION AWARENESS

As we consider the effects of interruptions on task resumption lag with respect to future vertical lift platforms, a solid understanding of situation awareness and its relationship to cognitive load theory is critical. Trafton and Monk's anatomy of an interruption (Figure 1) fails to distinguish between static and dynamic tasks. Maintaining situation awareness adds an additional layer of complexity to understanding task resumption lag that must be understood to truly make advances in the aviation community. Endsley (1995, 65), one of the most prominent researchers in the field, defines situational awareness as the "understanding of the state of the environment (including relevant parameters of the system) which provides the primary basis of subsequent decision making and performance in the operation of complex, dynamic systems." Wickens (2002, 129)

researched situation awareness through an aviation lens. He asserted that the “the three aspects of situation awareness that most relevant for aviation are three-dimensional spatial awareness, system awareness, and task awareness.” For spatial awareness, a pilot must monitor six variables consisting of pitch, roll, yaw (heading), altitude, lateral deviation from a flight path, and position along a flight path (Wickens 2002, 129). With respect to system awareness, modern aircraft have an assortment of high-tech, complex, and dynamic flight control systems that must be monitored (Wickens 2002). In terms of task awareness, Wickens (2002) states that pilots perform four generic classes of tasks: aviation, navigation, communication, and systems management.

According to St. John and Smallman,

Dynamic operational tasks, such as airspace monitoring and civil emergency operations, require maintaining awareness of changing situations, in part by detecting and interpreting significant changes. Poor change detection ability makes this maintenance difficult enough while monitoring a situation display uninterrupted but multitasking and interruptions increase the difficulty because the situation can change during the interruptions. (2008, 118)

St. John and Smallman make a clear distinction between static tasks and dynamic tasks, such as a pilot monitoring airspace. When executing a “static task, such as programming a videocassette recorder, the task does not change during the interruption. In these cases, recovering from interruptions and resuming performance of the task requires retrieving task states and goals from memory or recovering them afresh from the task display” (St. John and Smallman 2008, 118). However, “dynamic tasks require maintaining awareness of situations that are constantly changing” (St. John and Smallman 2008, 119). For example, a helicopter pilot executing a banking maneuver must maintain situation awareness of his/her surroundings throughout the interruption to ensure the safety of the aircraft and aircrew. A couple years after Endsley’s 1995 publication, researcher Debra Jones (1997) came to similar conclusions that situation awareness, especially when performing dynamic tasks, is vital to the decision-making process.

L. REDUCING COGNITIVE LOAD AND INCREASING TASK ACCURACY WITH VIRTUAL ASSISTANTS

Surprisingly, the aviation profession has several head-down tasks that divert a pilot's attention away from piloting aircraft. In view of this, it is no surprise that in a review of National Transportation Safety Board data over a 12-year period, Dismukes and Young (1999) found that one-fifth of the accidents during flight or taxiing involved the pilot being involved in head-down work. The findings from Dismukes and Young (1999) are not surprising because humans are better able to detect and react to warnings or indicators when they are in the peripheral of their primary visual focus (Posner, Snyder, and Davidson 1980). Having indicators or information within our periphery also reduces time for resumption of a primary task when interrupted (Ratwani, Andres, and McCurry 2007). This research clearly points to opportunities to improve pilot performance using interfaces that keep pertinent information visually accessible. Additionally, this highlights the value of integrating a VA that can complete mundane tasks that shift a pilot's focus from their flight related tasks and their flight instruments. Degani and Wiener (1990) posit that checklist failures often occur when interruptions cause lapses in working memory. They describe the difficulties of indexing a "pointer" in working memory since it can be "easily displaced by any other form of activity during this sequence" (Degani and Wiener 1990, 35). A human-machine team-based solution for this problem is incorporating a VA that guides a pilot through the checklist and provides a digital "pointer" to keep track of the process. This enables a pilot to resume the checklist after being distracted and provides audio or even visual cues that show the pilot where they left off before being interrupted.

Use of VAs to assist employees with work related tasks is gaining traction in the public sector because of their ability to enhance performance by reducing cognitive workload. Initially, studies suggested that providing problem-solving guidance from another form or entity increased cognitive workload and hampered performance (Tarmizi and Sweller 1988). However, more recent studies using VAs have demonstrated the opposite. Brachten et al. (2020) demonstrated that the use of an intuitive, easy-to-use VA decreases real and perceived cognitive load and increases task performance. Similarly, De Melo et al. (2020) determined that VAs improve human task performance while allowing humans to control their cognitive load. Additionally, they found that "information

communicated verbally had the most relevance for task performance” (De Melo et al. 2020, 8). These studies show that in the last 30 years, AI technology has vastly improved and may be mature enough to enhance human performance.

M. SUMMARY

This chapter establishes foundational knowledge to develop a structured methodology. The investigation of interruptions, flight specific environmental factors, cognitive workload, situational awareness, and artificial intelligence aids provided insight into the problem and solution space. The analysis of current research and publications discovered commonality to avert redundancy while concurrently discovering gaps in evidence necessary for this capstone.

Furthermore, this chapter examined the anatomy of an interruption, environmental stressors common to aviation, and cognitive load theory which combined formed the basis for the secondary task used throughout our experiment. Based on the literature review, heart rate variability, NASA TLX, and C-SWAG will elicit the data required to analyze the effect of cognitive workload across all variables. Our analysis of situational awareness and artificial intelligence aids informed the various VAs provided to each participant. The evidence compiled and evaluated during this literature review aided in the advancement of the methodology. The methodology defined in Chapter III accomplishes the required tasks to ascertain the distinctions that exist between total interruption time, interruption lag, secondary task duration, and resumption lag regarding various flight parameters, cognitive workload states, and levels of artificial intelligence aid.

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III. METHODOLOGY

A. OVERVIEW

The research team investigated human cognitive load as it relates to task resumption lag. We evaluated individuals' cognitive load in a laboratory setting while they conducted a dynamic task (simulated flight in X-Plane 11). Individuals were exposed to interruptions while they performed a dynamic task, and we gathered data specific to the interruption, such as interruption lag time and task resumption time. We also collected heart rate variability and perceived cognitive workloads to gain insight into participants' cognitive load. Lastly, we gathered flight parameters to determine the performance of the primary task of flying the aircraft.

As a part of this study, we tested a mitigation strategy (use of an AI assistant) that might reduce the effects of cognitive load and improve primary task resumption. This experiment was a within-subject design that consisted of one trial per test subject, totaling approximately one hour. Independent variables were cognitive load states and secondary task types. Participants were subject to performing a secondary task during high and low cognitive load states. The secondary task was changing a radio frequency without an AI assistant (via manual keyboard entry), with a voice-activated AI assistant, or a button-activated AI assistant. The dependent variables measured were interruption lag time, resumption lap time, and deviations from the designated flight parameters (airspeed, heading, and altitude) before, during, and after the interruption.

B. PARTICIPANTS

The population used to conduct this study was from the Naval Postgraduate School civilian and student body with a combination of aviators and non-aviators. The sample size for this experiment was 26. A breakdown of the participants is shown in Table 2. The participants did not need aviation experience to complete this study as it was conducted in a flight simulator, and their data would be compared against themselves and how they reacted.

Table 2. Breakdown of Experiment Participants

Category	Quantity
Rated-Aviators	5
Inexperienced Aviator	5
Non-Aviator	16

The research team applied to conduct human subjects research to the Naval Postgraduate School Institutional Review Board. The research was approved as a minimal risk study. Participation in this study was voluntary, and the capstone team used convenience sampling to achieve a viable sample size to conduct the study. The research team advertised the experiment to the Naval Postgraduate School population through flyers and electronic mail. The study involved participants from different programs, but most participants were from the Systems Engineering Department. The idea to use aviators and non-aviators in this study was to include data identical to soon-to-be pilots about to go through flight school so the team could provide data and findings to military training institutions.

The volunteer population consisted of five military rated-aviators, five inexperienced aviators, and 15 non-aviators. The military rated-aviators all had over 1000 flight hours. The inexperienced aviator category had less than 1000 flight hours. Thirteen of the participants have used flight simulators before, whereas the other 12 participants had not. Of the rated and inexperienced aviators, four were fixed-wing pilots, three were rotary-wing pilots, and two piloted both types of aircraft.

C. EQUIPMENT AND TOOLS

For this study, the research team used one flight simulator station comprised of the X-Plane 11.55 software and simulated helicopter controls manufactured by Pro Flight Trainer based in Canada. This control configuration included cyclic, collective, throttle, and foot pedals. The participants flew a Cessna 172-SP during the simulation. The video interface for the simulator was a vertical dual screen monitor with one monitor centered on the forward-facing cockpit window and another monitor displaying the panel flight instruments. The simulator also included audio output simulating typical plane engine

sounds. Figure 2 depicts the complete simulator setup. The participants were also outfitted with a heart rate monitor (Polar HR XI) via a chest strap to gather heart rate data every second. The heart rate data was transmitted and recorded in the HRV + application. These data were analyzed using Kubios software version 3.5.0 to achieve a heart rate variability (HRV) metric for each participant. The X-Plane 11.55 software captured flight data every second, including altitude, airspeed, attitude, and heading.



Figure 2. Task Interruption Lag Analysis Laboratory

D. PROCEDURES

Participants completed a pre-study questionnaire before the experiment began (see Appendix A). Then participants began an X-Plane 11 instruction and flight control familiarization. During this familiarization, participants practiced manipulating the controls and maneuvering the aircraft. After the familiarization, test subjects began a

simulated flight consisting of navigating the aircraft along an assigned route depicted in Figure 3 while maintaining a prescribed airspeed and altitude. The specified flight parameters were:

- Airspeed: 110 knots (KIAS)
- Altitude: 2,000 feet above mean sea level (MSL)

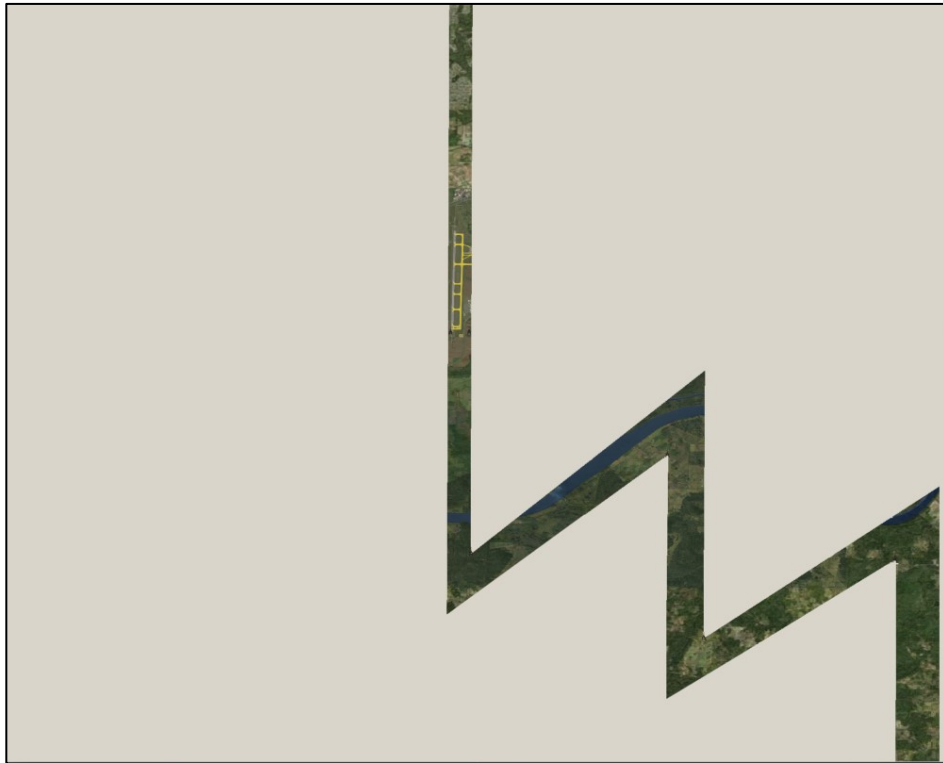


Figure 3. Map of the X-Plane 11 Simulation Flight Path

At the start of the simulation, participants had to fly to the start point approximately three nautical miles (nm) away. Participants then completed a straight and curve segment with no interruptions to capture baseline data. After that, participants piloted the aircraft through a series of three, 135 degree turns, totaling a span of approximately 18 nm. At the straight vectors and during each turn, participants were interrupted with a secondary task to change the six-digit frequency on a radio either through manual input, a voice-activated AI assistant, or a button-activated AI assistant. The interruptions at the approaches were

considered low cognitive load states, whereas the interruptions at the turns were deemed to be high cognitive load states. This meant that data was collected and measured in eight different segments:

- Segment 1: low cognitive load; no interruption.
- Segment 2: high cognitive load; no interruption.
- Segment 3: low cognitive load; no AI assistant
- Segment 4: high cognitive load; no AI assistant
- Segment 5: low cognitive load; voice-activated AI
- Segment 6: high cognitive load; voice-activated AI
- Segment 7: low cognitive load; button-activated AI assistant
- Segment 8: high cognitive load; button-activated AI assistant

The presentation order for each type of interruption was altered for each participant to normalize data and to reduce the effects of learning in the experiment. The research team used three cycles as described in Table 3.

Table 3. Interruption Cycle Descriptions

Cycle	Interruption 1	Interruption 2	Interruption 3
A	Keypad, No AI Assistant	Voice-Activated, AI Assistant	Tactile-Activated, AI Assistant
B	Tactile-Activated, AI Assistant	Keypad, No AI Assistant	Voice-Activated, AI Assistant
C	Voice-Activated, AI Assistant	Tactile-Activated, AI Assistant	Keypad, No AI Assistant

The research team collected the participants' cognitive load and heart rate data throughout the experiment. A baseline heart rate was established by having participants complete approaches and turns while only focusing on the primary task. This baseline heart rate data was used to compare subjects' data to the data collected while being interrupted in the six conditions. Additionally, researchers captured participant's continuous subjective workload (C-SWAG) every 30 seconds. The researcher asked participants to rate their stress levels on a scale of 1 to 100. At the end of the study, each participant filled out a post-experiment questionnaire and a NASA TLX post-activity workload assessment for each modality: no AI assistant (manual input), a voice-activated AI assistant, and tactile AI assistant (button-activated).

In summary, there were several dependent variables measured during this study. Objective data collected was heart rate variability to assess the cognitive load, flight parameters (altitude and speed), task interruption lag (sec), and resumption lag (sec). Subjective data collected was the NASA TLX post-activity workload assessment (see Appendix C) and subject workload graphs (see Appendix B) to assess cognitive workload.

E. DATA ANALYSIS

Data analysis of the total interruption time, interruption lag, secondary task duration, and resumption lag we will conduct multiple one-way ANOVAs in RStudio. The first one-way ANOVA will compare total interruption time across all three modalities presented in the experiment for combating interruptions. If a statistically significant difference is discovered by the one-way ANOVA, we will then perform Tukey's Honestly Significant Difference (HSD) test in RStudio to discern if the statistical significance persists when directly comparing the modalities. We will use the same data analysis techniques regarding interruption lag, secondary task duration, and resumption lag.

For the cognitive workload data, the analysis will be broken down by heart rate variability, NASA TLX, and C-SWAG. Regarding heart rate data, we are first going to enter the raw data into the Kubios 3.5.0 software and then take 30 second epochs from our baseline data and the eight segments of flight for each participant corresponding to their parasympathetic nervous system index (PNS-I). After data collection is complete, we will

average the PNS-I for the baseline and each flight segment and report the mean values plus and minus one standard deviation in a line graph for ease of interpretation. Concerning NASA TLX data, once all data has been collected, our first step will be graphing a histogram for each parameter and each interruption assistance modality to determine the measure of central tendency that best represents our data. After determining the best measure of central tendency, we will create a bar graph of the central tendency and standard deviation for each parameter of the NASA TLX corresponding to the three modalities. We will then create a box and whisker plot to display the variation between the total NASA TLX scores for the modalities. For the C-SWAG data we will collect subjective workload measurements from each participant every thirty seconds during the experiment. Once all data is collected; we will average the C-SWAG for each flight segment and report the mean values plus and minus one standard deviation in a line graph for ease of interpretation.

Our research team intends on evaluating flight performance by comparing altitude and airspeed deviation values from each participant's baseline flight segments to their altitude and airspeed values from all subsequent segments. First, we intend to convert all participant flight data from raw altitude and airspeed values to deviation values by subtracting the prescribed flight parameters of 2,000 feet MSL and 110 KIAS respectively. Next, we will divide the deviation values into the same eight flight segments used during the C-SWAG data analysis and calculate the mean deviation for each using the absolute value of the deviation values. Once complete, each participant will have a total of eight mean altitude deviation and eight airspeed deviation values, corresponding to each flight segment. We will then average the values for each segment across all 20 participants and determine the standard deviation prior to graphing and comparing the results.

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IV. RESULTS

Using the methodology described in Chapter III, the experiment and surveys elicited data from 26 participants. All participants completed the experiment and corresponding surveys resulting in 21 non-pilot data sets and five pilot data sets. However, one of the non-pilots was not included in the analysis due to a system malfunction resulting in data loss. Although there were no issues with pilot data collection, they were excluded from detailed analysis because during the initial analysis one participant's data presented as more than three standard deviations from the mean. After the exclusion of that participant only four data sets remained, making any conclusions drawn from the data ungeneralizable. Thus, data from 20 participants were examined. First, chapter four acknowledges the project's small sample and succinctly illustrates the data analysis method. Then, the results of the two sub-research inquiries are given, which will assist answering the main research question: What is the impact of introducing an artificial intelligence aid on interruption lag, secondary task duration, and resumption lag for helicopter pilots in a dynamic environment?

The small project sample size of 20 participants is a cause to two major influences. First, COVID-19 guidelines impeded access to campus and the Systems Engineering lab. Secondly, due to telecommuting and community distancing constraints throughout the study's timeline, entry for participants to the experiment was limited. The results offered now may not have gathered complete demographics essential to the system. These findings must be taken as an indication, not comprehensive, or all-inclusive. However, the experiment and assessments could be useful for upcoming research.

The data elicited from participants during the experiment and surveys were categorized and coded. The categories corresponded to the flight experience of the participants and the codes were developed to group the qualitative data into the eight segments identified in Table 4. The code and categorization structure were built prior to the experiment commencing and administration of the surveys to alleviate bias. Utilizing the established code configuration, two capstone team representatives analyzed the surveys and, experiment data and the findings were verified by a third capstone project member.

There were no modifications or amendments to the code or categorization structure following the beginning of the analysis. The coding and categorization structure was identical for both the experiment data and surveys. A description of the code and categorization structure and the results of the data analysis and surveys are annotated in Appendices E, F, G, H, I and J.

Table 4. Legend for Reading Line Graphs in Chapter Four

Legend	
0	Baseline
1	No Interruption Straightaway
2	No Interruption Curve
3	No Virtual Assistant (Keypad) Straightaway
4	No Virtual Assistant (Keypad) Curve
5	Voice Activated Virtual Assistant Straightaway
6	Voice Activated Virtual Assistant Curve
7	Tactile Activated Virtual Assistant Straightaway
8	Tactile Activated Virtual Assistant Curve

A. FINDINGS OF THE PRIMARY RESEARCH QUESTION

What is the impact of introducing an artificial intelligence aid on interruption lag, secondary task duration, and resumption lag for helicopter pilots in a dynamic environment?

We examined the impact of keypad entry, voice-activated artificial intelligence, and tactile activated artificial intelligence on total interruption time, interruption lag, secondary task duration, and resumption lag. We performed a one-way ANOVA to compare the effect

of the three conditions on total interruption time. The one-way ANOVA revealed that there was a statistically significant difference in mean total interruption time between at least two conditions ($F(2, 57) = [4.241]$, $p = 0.0189$). Tukey's HSD test for multiple comparisons found that the mean value of total interruption was not significantly different between the keypad and voice conditions ($p=0.875$) or between the keypad and the tactile conditions ($p=0.073$). However, there was a significant difference between the voice and tactile conditions ($p = 0.022$, 95% C.I. = $[-13.59, -0.87]$). We performed additional one-way ANOVAs to compare the effect of the conditions on interruption lag, secondary task duration, and resumption lag, respectively. The one-way ANOVA performed to compare the effect of the conditions on interruption lag revealed that there was no statistically significant difference between groups ($F(2, 57) = [0.706]$, $p = 0.497$). The one-way ANOVA performed to compare the effect of the conditions on secondary task duration revealed that there was no statistically significant difference between groups ($F(2, 57) = [0.936]$, $p = 0.397$). The one-way ANOVA performed to compare the conditions on resumption lag revealed that there was no statistically significant difference between groups ($F(2, 57) = [0.857]$, $p = 0.448$).

In addition to our examination of the impact of the various modalities on total interruption time and the components of an interruption we administered a post experiment questionnaire to all participants. The questionnaire located in Appendix D asked the participants to rank the modalities from most to least preferred using one, two, or three with one being most preferred and three being least preferred. Our initial analysis of these findings located in Appendix J revealed that 70% of participants preferred the tactile activated artificial intelligence assistant while just 20% and 10% preferred the voice-activated and keypad modalities, respectively. We then performed a chi-square test and found that the proportion of participants who preferred the tactile activated modality over the other modalities was significant, $X^2(2, N = 20) 7.07$, $p = .0043$.

Our findings suggest that integrating an artificial intelligence aid activated via a tactile modality will reduce the total interruption time (keypad $m(18.955)$, $SD(9.35)$; voice-activated $m(19.203)$, $SD(8.58)$; tactile activated $m(14.315)$, $SD(7.37)$) during a flight. As supported by sub-research question one and two, respectively a reduction in total

interruption time corresponds with reduced cognitive workload, and improved flight parameters during the interruption.

B. FINDINGS OF RESEARCH SUB-QUESTION 1

How does an individual's total interruption time vary relative to high and low-load cognitive states?

Our initial hypothesis postulated that having the pilots fly a varied course that included both straightaways and curves would induce states of lower and higher cognitive load that would affect total interruption time. We performed a one-way ANOVA to compare the effect of different flight conditions on total interruption time. The one-way ANOVA revealed that there was no statistically significant difference between conditions ($F(2, 57) = [1.302], p = 0.28$).

We collected three additional measurements that we used to correlate participants cognitive workload to the eight segments of flight. First, heart rate data was collected for each participant enabling our analysis of heart rate variability. Second, we collected continuous subjective workload measurements for each participant via a continuous subjective workload graph. Finally, post hoc we collected NASA TLX data for each participant with respect to the three interruption modalities that were presented in the experiment.

Heart Rate Variability represented in our study by PNS-I served as our objective measure of cognitive workload. A PNS-I of zero represents that a participant's parasympathetic nervous system activity is equivalent to the normal population mean. Similarly, a positive PNS-I is representative of how many standard deviations above the normal population mean the participant's values are, and a negative value represents how many standard deviations below the normal population mean the participant's values are. A negative PNS-I value is associated with increased mental and physical stress. Figure 4 illustrates that on average participants experienced a marked increase in cognitive load when comparing baseline measurement to any segment of flight, which is to be expected considering the lack of flight experience in our participant pool. The figure also illustrates that the objective measure of workload does not contradict our subjective workload

measurement and as further explained by the primary research question and sub-research question two these states of higher cognitive workload also correlate with increased total interruption time and decreased flight performance.

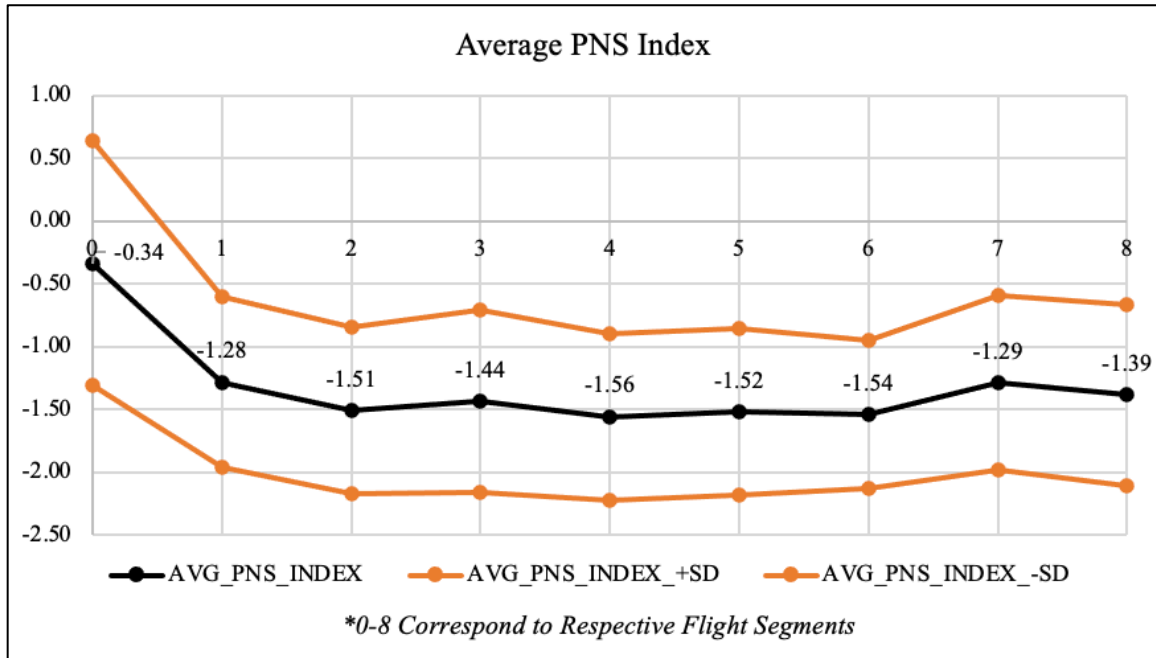


Figure 4. PNS-I Data Comparison Across Flight Segments

We collected C-SWAG measurements from each participant through each individual trial. Participants assessed their subjective workloads at 30 second epochs. The subjective workload data in Figure 5 was captured at each segment for each participant and subsequently aligned to the segments described in methodology. The data collected at each segment was compared across all participants to determine the mean for the study sample. The C-SWAG data suggests that the tactile AI assistant was the most effective at reducing participant workload when compared to the other modalities regarding both straight and curve flight parameters. Using a voice-activated AI reduced cognitive workload on curved segments when compared to no AI assistant but did not have the same results on straight segments.

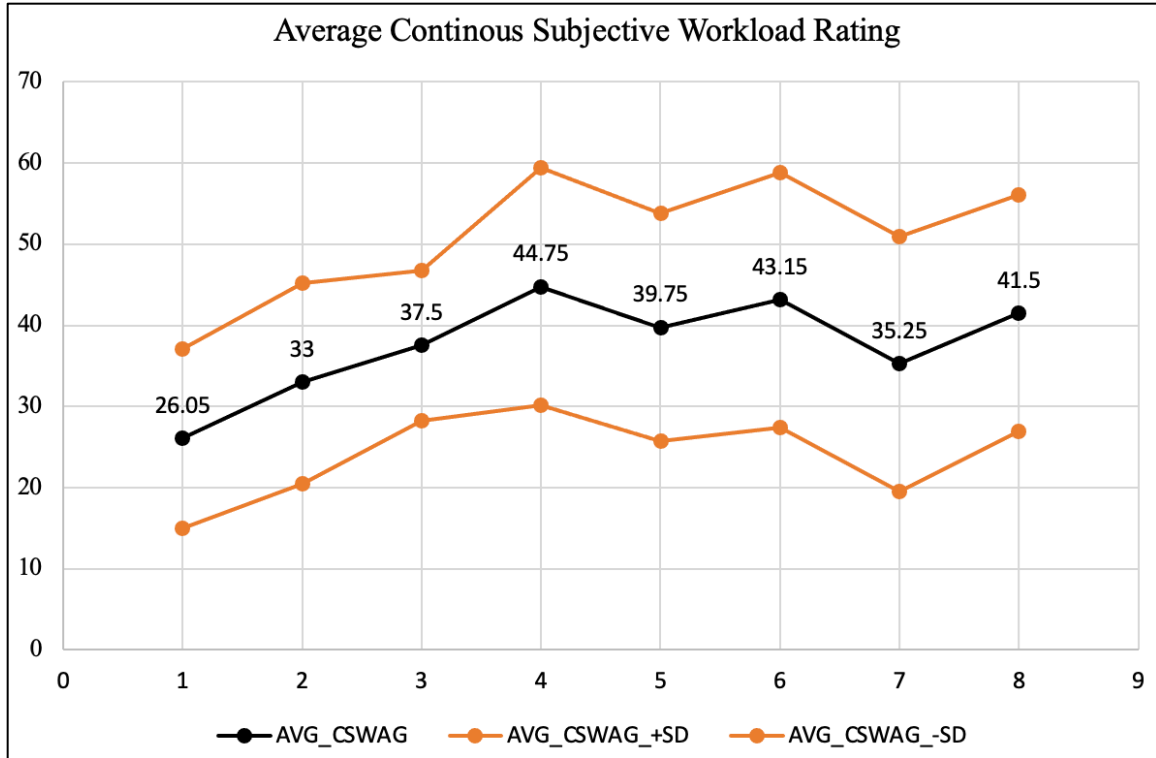


Figure 5. C-SWAG Data Comparison Across Segments of Flight

We collected participant post hoc perceived workload via NASA TLX for the primary and secondary task regarding each modality. The six categories of the NASA TLX are mental demand, physical demand, temporal demand, performance, effort, and frustration. Each category was assessed with 1 being the minimum value and 21 being the maximum value. We calculated the median and standard deviation for participants regarding each category. Figure 6 is a graphical representation of the collected data.

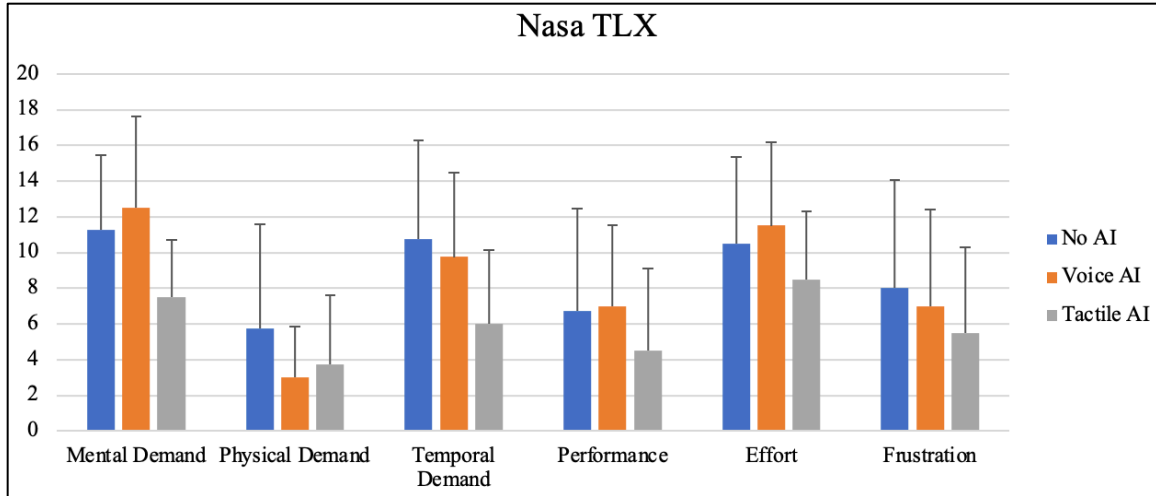


Figure 6. Nasa TLX Median and Standard Deviation (All Participants)

Tactile AI assistance proved to have the least physical and temporal demand while causing the least amount of effort and frustration. Additionally, participants perceived that their performance was the best using the tactile AI assistant (regarding NASA TLX, a performance score of one means perfect while a score of 21 means failure). Surprisingly, using a voice-activated AI assistant was more mentally demanding and involved more effort than all other modalities. Figure 7 displays the summary statistics when all six categories were combined. The minimum value was 6 and the maximum value was 120. The median overall workload score for no AI was the highest (57.975), followed by the voice AI (44), while the tactile AI had the lowest overall workload (37.5) among all participants ($n=20$). After our initial analysis revealed that the tactile AI modality corresponded to the lowest workload, we then performed a Kruskal-Wallis test and found that the median difference in NASA TLX scores for the various modalities was significant, $H(2) = 6.50$, $p = .039$.

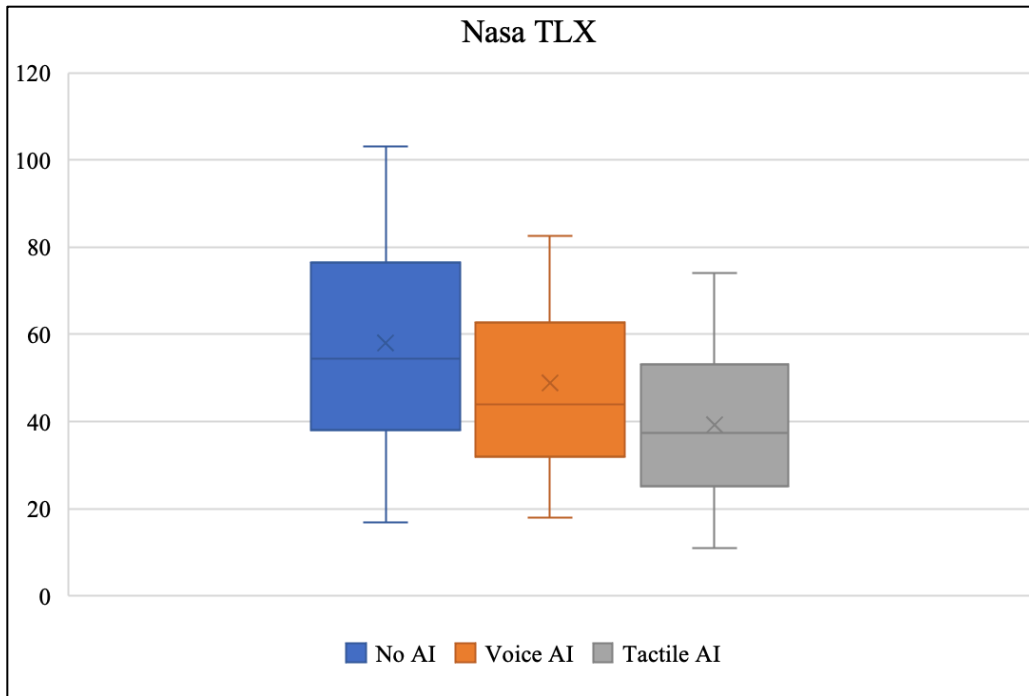


Figure 7. NASA TLX Summary Statistics per Modality

C. FINDINGS OF RESEARCH SUB-QUESTION 2

To what extent does the introduction of an artificial intelligence aid impact flight characteristics during an interruption?

The Army aviation community evaluates flight proficiency using a prescribed set of standards based on ideal conditions, often referred to as “common standards.” For in-flight maneuvers, evaluators assess heading, altitude, airspeed, and trim to determine an aviator’s individual degree of proficiency. Though our research team collected data for each of these flight parameters, our results specifically focus on deviations from the objective altitude and airspeed values assigned at the beginning of the experiment. We excluded heading data due to the nonlinear flight route assigned to the participants and trim due to marginal changes resulting from no-wind flight conditions. Based on the results of 20 participants, the mean altitude and airspeed deviation values suggest that participants performed better during interruptions with the tactile activated AI assistant than any other interrupted mode of flight. Airspeed data also suggests that participants performed worse when responding to interruptions with the voice-activated AI assistant than with the keypad

or tactile activated assistant; however, altitude data is divided between the voice-activated AI assistant and keypad modalities.

1. Altitude

Figure 8 illustrates the mean altitude deviation for 20 participants during each flight segment and the corresponding standard deviation. The approximate mean altitude deviation values during the baseline flight segments were 280 feet with a standard deviation 305 feet and 214 feet with a standard deviation of 213 feet for the straightaway and turn respectively.

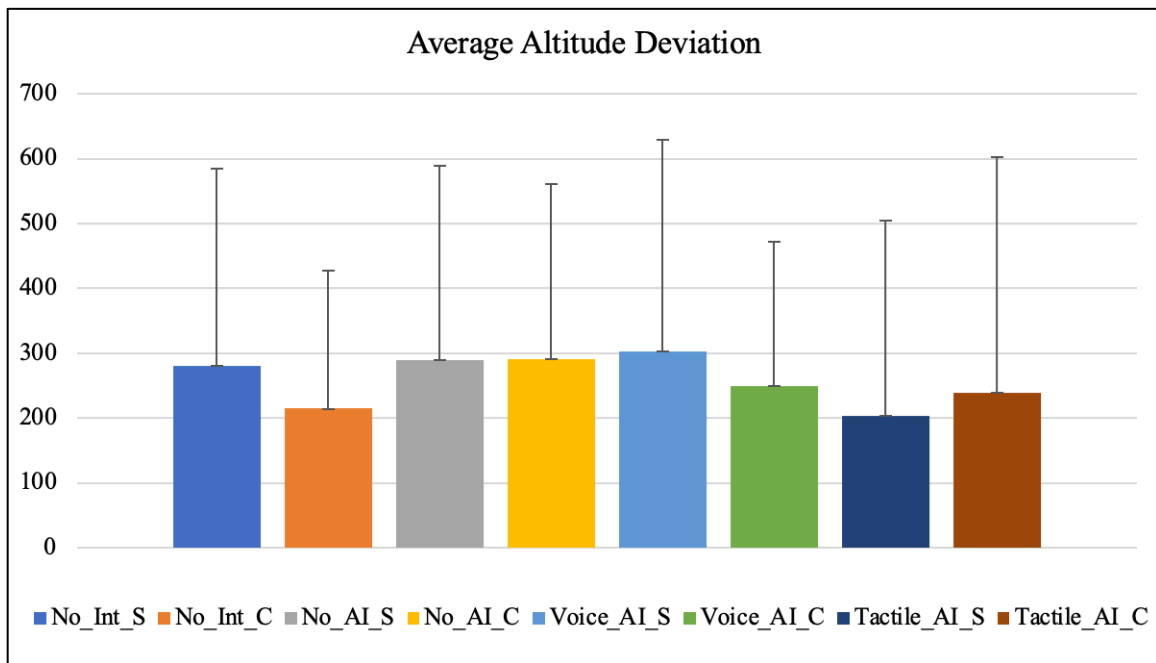


Figure 8. Average Altitude Deviation

Table 5 displays the difference between the mean altitude deviation of each flight segment and the baseline mean altitude deviation. In both straight and turning flight profiles with the tactile activated AI assistant, participants' mean altitude deviation was closest to, or in the case of the straightway, better than the baseline. Participants also exhibited lower altitude deviation during the straight segments while using the keypad as opposed to the voice-activated AI assistant; however, altitude deviation during turns illustrates an inverse relationship.

Table 5. Altitude Difference from Baseline

Altitude (feet) Difference from Baseline			
	Keypad (No AI)	Voice AI	Tactile AI
Straight	8.956922389	22.972239	-76.61425705
Turn	75.90225883	35.10330144	24.61727361

2. Airspeed

Figure 9 illustrates the mean airspeed deviation during each flight segment and the corresponding standard deviation. The approximate mean airspeed deviation values during the baseline flight segments were 8.2 KIAS with a standard deviation 6.6 KIAS and 8.4 KIAS with a standard deviation of 6.0 KIAS for the straightaway and turn respectively.

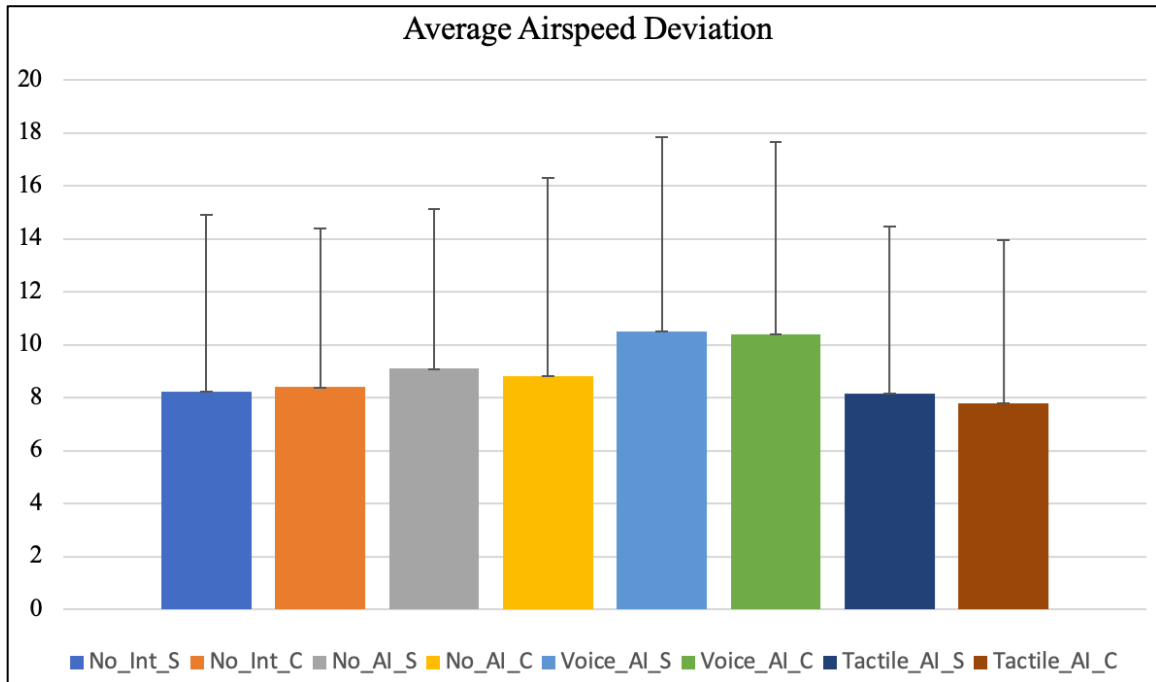


Figure 9. Average Airspeed Deviation

Table 6 displays the difference between the mean airspeed deviation of each flight segment and the baseline mean airspeed deviation. In both straight and turning flight profiles with the tactile activated AI assistant, participants' airspeed deviation was less than

all other modalities, including the baseline. Unlike the altitude data, participants' airspeed deviation was significantly lower while using the keypad as opposed to the voice-activated AI in both flight profiles.

Table 6. Airspeed Difference from Baseline

Airspeed (KIAS) Difference from Baseline			
	Keypad (No AI)	Voice AI	Tactile AI
Straight	0.856524895	2.281602731	-0.076396171
Turn	0.414190977	2.012914514	-0.606109771

The results indicate that participants' flight performance was better when using tactile activated digital assistant than any other mode of flight. In three out of four modalities, participants also outperformed their baseline; however, this can likely be attributed to the learning effect as the baseline always occurred prior to introducing AI. Participants also performed better in three out of four modalities when using the keypad as opposed to the voice-activated AI assistant.

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V. SUMMARY, CONCLUSION, AND FOCUS AREA FOR FURTHER RESEARCH

The FVL program is one of the Army's top modernization priorities. Therefore, the program office seeks to integrate next-generation capabilities into each platform to maximize vertical lift dominance. The purpose of this research was to illustrate the impact of integrating one such capability into FVL platforms, artificial intelligence. The research team designed the experiment around exploring how artificial intelligence impacts interruption times, cognitive workload, and aviator performance in a dynamic environment.

The team designed a flight scenario to simulate optimal flight conditions in a non-tactical flight profile. We tasked participants to fly four iterations of straightaways, intended to minimize cognitive workload and turns, meant to increase cognitive workload. The first iteration served as a baseline for all participants. At the beginning of all subsequent iterations, participants were oriented to a keypad or introduced to one of two AI assistants, voice-activated and tactile activated, to assist with their interruption response. Our research team recorded each participant's interruption response time, heart rate, altitude, airspeed, and subjective cognitive workload assessment throughout the experiment, among other data. Following 26 trials, the research team divided each participant's data into eight segments and analyzed interruption response performance, flight performance, and cognitive workload.

The results revealed that interruption response times were lowest when the tactile activated digital assistant aided participants. Interruption response times also suggest that the voice-activated AI hampered participants when responding to interruptions, indicating that not all implementations of AI improve performance. Flight data analysis revealed similar results, with lower deviations in altitude and airspeed during tactile AI segments and deviations peaking during the voice-activated AI segments. Finally, the analysis of subjective and physiological measures of cognitive workload suggests that participants experienced lower periods of workload when responding to interruptions with the tactile activated AI assistant and higher periods of workload during segments with the keypad.

Based on these results, the research team provided recommendations to the FVL program office to assist with integrating an AI solution to combat interruption response times and flight performance. Given the limitations of this study, the complexity of the aviation environment, and the rapid development of emerging AI technologies, the research team also suggests that additional studies be conducted to add levels of realism and AI integration to these findings. One of the significant limitations of this study was rotary-wing aviator availability, resulting in a larger sample of inexperienced participants. Furthermore, the COVID-19 environment limited our research team's access to additional resources and participants that may have benefited the study.

A. CONCLUSION

The experiment results appear to align with De Melo et al.'s (2020) determination that VAs improve human task performance while allowing humans to control their cognitive load. Our primary research question focused on the first portion of this determination by exploring the impact of keypad entry, voice-activated artificial intelligence, and tactile activated artificial intelligence on total interruption time, interruption lag, secondary task duration, and resumption lag. Based on the mean of the total interruption times for each modality, participants completed their secondary tasks approximately 25% faster when aided by the tactile activated AI instead of the keypad or voice-activated AI systems. Similarly, the results of our secondary research question on flight performance also show that the magnitude of airspeed and altitude deviations for participants aided by the tactile activated AI was less than that of any other modality and, in some cases, even their baseline performance.

Our third research question focused on investigating how interruption times vary relative to high and low-load cognitive states. The experiment incorporated two subjective workload measures, NASA TLX and C-SWAG, and a physiological measure, the PNS index. The results from all three measures appear to nest with the findings from the interruption and flight performance data. Participants reported lower cognitive workload when aided by the tactile activated AI than while using the keypad or voice activate AI. PNS index data does not contradict that participants' physiological response to

interruptions in the same modality correlates to their perceived cognitive workload. In addition to our findings of task performance and cognitive workload, it is also worth noting that the results of the post-experiment survey indicate that 70% of participants preferred the tactile activated AI over the other two modalities.

B. RECOMMENDATIONS FOR HOLISTIC SITUATION AWARENESS AND DECISION MAKING (HSA-DM) AND FUTURE VERTICAL LIFT (FVL)

The FVL program seeks to deliver the most capable and complex rotary-wing platform globally, which will undoubtedly require a population of highly proficient, focused aviators. To best serve these aviators, the research team makes the following recommendations for HSA-DM and FVL:

- Consider the use of AI, particularly tactile activated solutions, as a mechanism for minimizing the impact of interruptions on aviators. However, to avoid resistance from the userbase, incorporate it as an option rather than eliminating manual capabilities.
- Explore opportunities to simplify common tasks such as frequency changes, transponder code updates, and altimeter setting adjustments. In most cases, these tasks require aviators to divert their attention to the inside of the aircraft, generally resulting in longer resumption lag times. In our experiment, participants exhibited resumption times as low as .6 seconds when aided by the tactile activated AI, which allowed them to perform the secondary task without diverting their attention inside.
- Consider integrating the use of tactile AI into existing procedures to avoid extra steps. In general, aviators key the radio and repeat all frequencies, transponder codes, and altimeter settings to their controlling agency. Allowing the AI assistant to monitor outgoing radio traffic would eliminate the need for any additional steps.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

Though the results of this study suggest that participants responded positively to the integration of a tactile activated AI assistant, the experiment merely scratched the surface of exploring the complexities of interruptions in an aviation environment. As near-peer threats continue to adapt and evolve in response to our existing capabilities, warfighters are becoming increasingly reliant on emerging technologies to maintain a marked advantage on the battlefield. As such, our team makes the following recommendations for future research:

- The research team elected to conduct trials on 21 non-pilot participants due to time constraints and the limited availability of rotary-wing aviators. This constraint also resulted in the research team using a more stable, fixed-wing aircraft instead of a rotary-wing platform. Furthermore, all aviator data was excluded from detailed analysis because one participant's data presented as more than three standard deviations from the mean. Therefore, consider conducting a similar experiment using a larger sample of aviators in a rotary-wing aircraft to see how experience and platform impact the results.
- Consider adding layers of realism to the scenario, such as night operations, tactical mission tasks, or adverse weather conditions to assess the impact of the operational environment on response times, cognitive workload, and flight performance in each modality.
- Consider designing an AI system with the flexibility to monitor more than just an aviator's commands. Our research team suggested exploring a fourth modality with an AI assistant that monitor's transmissions for frequency change requests. Once complete, the AI presents them to the aviator in a queue for approval. An AI solution like that eliminates the need for the aviator to repeat the frequency and simplifies the process to a single button push, assuming the AI is correct.

- Consider replicating the experiment and introducing proven task resumption techniques for a subset of the sample population. Throughout our experiment, we observed a handful of participants utilizing various strategies to mitigate the impacts of an interruption on secondary task accuracy and duration. Some participants said the 6-digit radio frequency to themselves before engaging the tactile-activated AI assistant, while others paused and said the frequency to themselves before activating the voice-activated AI assistant. This supports Trafton and Monk's (2007, 117) discussion about the memory for goals theory and suggest that rehearsals, known as strengthening, and the use of environmental cues, commonly referred to as priming, are the two primary ways to reduce memory decay. Resumption lag training coupled with an AI assistant could further mitigate the impacts of an interruption in FVL platforms.

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APPENDIX A. PRE-EXPERIMENT DEMOGRAPHIC QUESTIONNAIRE

Participant Pre-Experiment Demographic Questionnaire

1. Do you have any experience flying a fixed wing or rotary wing aircraft?
 - a. Yes
 - b. No

2. If you answered yes to Question 1, quantify your experience in terms of airframe type(s) and total number of hours.
 - a. Fixed Wing
 - b. Rotary Wing
 - c. Both

_____ total hrs

3. Do you have any experience flying aircraft in a flight simulator?
 - a. Yes
 - b. No

4. Select your preferred handedness.
 - a. Right-Handed
 - b. Left-Handed
 - c. Ambidextrous

5. Do you have any known health conditions that could influence your heart rate? (i.e. – arrhythmia, anxiety, etc.)
 - a. Yes
 - b. No

6. Rate how sensitive you are to motion sickness on a scale from 1 to 7 (1 – Not at all; 7 – Very Sensitive)

7. Have you smoked or used any tobacco products within the last 8 hours?
 - a. Yes
 - b. No

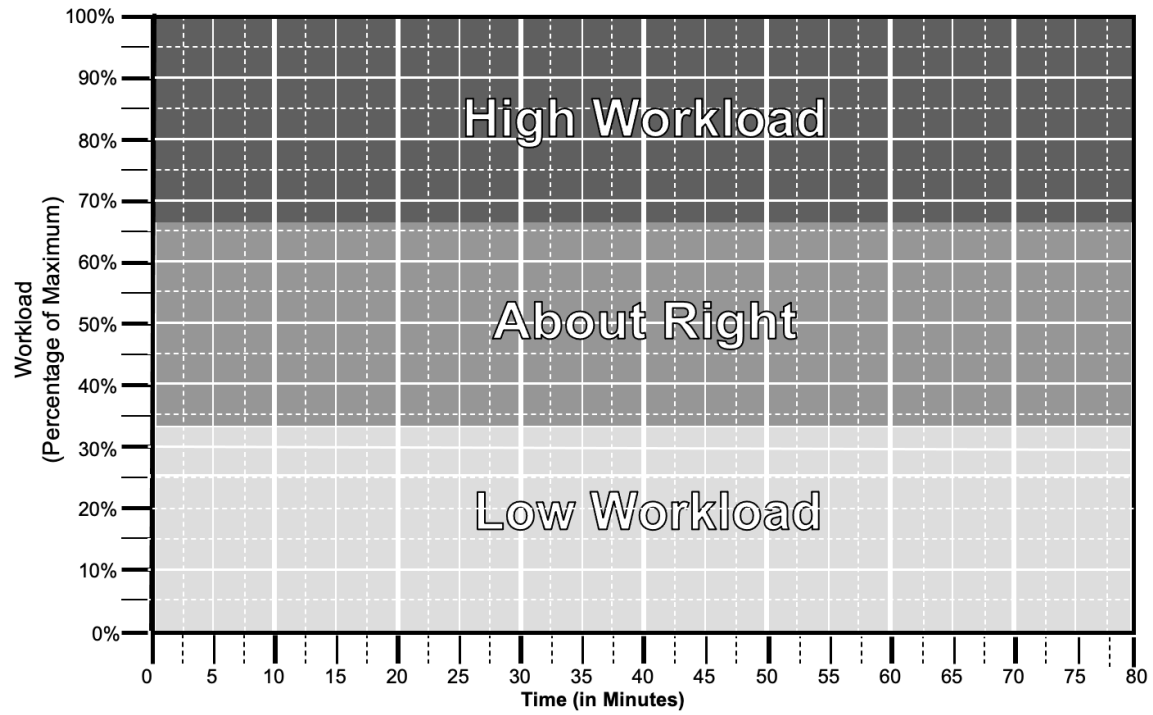
8. Do you play first-person video games?
 - a. Yes
 - b. No

9. If you answered yes to Question 8, approximately how many hours do you play each week?

_____ hrs

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APPENDIX B. CONTINUOUS SUBJECTIVE WORKLOAD ASSESSMENT GRAPH (C-SWAG)



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NASA Task Load Index

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APPENDIX D. POST-EXPERIMENT QUESTIONNAIRE

Participant Post-Experiment Questionnaire

1. Rank order each of the three radio frequency input methods listed below from easiest to hardest (1 – Easiest, 2 – Moderate, 3 – Hardest)

_____ Keypad (No AI)

_____ Voice-Activated, AI Assistant

_____ Tactile-Activated, AI Assistant

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APPENDIX E. PRE-EXPERIMENT DEMOGRAPHIC QUESTIONNAIRE DATA

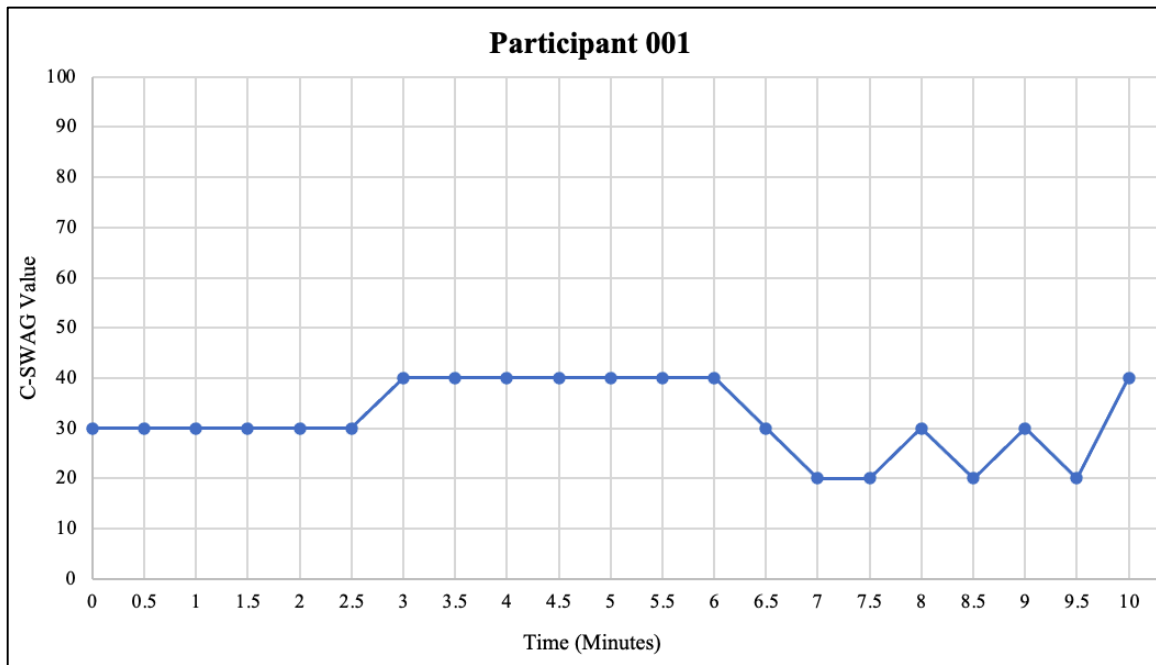
Pre-Experiment Participant Demographic Questionnaire Data										
Participant Number	Q1	Q2	Q2 Hours	Q3	Q4	Q5	Q6	Q7	Q8	Q9
001	No			Yes	Right	No	2	No	Yes	2
002 (Rated Pilot)	Yes	Both	2000	Yes	Right	No	2	No	No	0
003	No			No	Right	No	3	No	No	0
004 (Rated Pilot)	Yes	Both	1480	Yes	Left	No	5	Yes	No	0
005 (Rated Pilot)	Yes	Rotary	950	Yes	Left	No	3	No	Yes	0.25
006	No			No	Right	No	1	No	No	0
007	No			No	Right	No	1	Yes	Yes	2
008	No			No	Right	No	6	No	Yes	0
009 (Rated Pilot)	Yes	Rotary	380	Yes	Left	No	2	No	No	0
010	No			Yes	Left	No	1	No	No	0
011	Yes	Fixed	10	Yes	Right	No	1	No	Yes	1
012	No			No	Right	No	2	No	No	0
013	No			Yes	Left	No	1	No	Yes	1
014 (Rated Pilot)	Yes	Rotary	1000	Yes	Right	No	1	No	No	0
015	No			No	Right	No	1	No	Yes	1
016	No			Yes	Right	No	6	No	Yes	3
017	Yes	Fixed	60	Yes	Right	No	1	Yes	No	0
018	No			No	Right	No	4	No	Yes	0.5
019	No			No	Right	No	1	Yes	Yes	8
020	No			No	Left	No	2	No	Yes	4
021	No			No	Left	No	6	No	Yes	2
022	No			No	Right	Yes	3	No	Yes	2
023	Yes	Fixed	0.5	Yes	Right	No	1	No	Yes	2
024	No			No	Right	No	1	No	No	0
025	No			No	Right	No	1	No	No	0
026	No			Yes	Right	No	6	No	No	0

Questions:

1. Do you have any experience flying a fixed wing or rotary wing aircraft?
2. If you answered yes to Q1, annotate the airframe type(s) and total flight hours.
3. Do you have any experience flying aircraft in a flight simulator?
4. Designate your preferred handedness
5. Do you have any known health conditions that could influence your heart rate? (i.e. - arrhythmia, anxiety, etc.)
6. Rate how sensitive you are to motion sickness on a scale from 1 to 7 (1 - Not at all, 7 - Very Sensitive)
7. Have you smoked or used any tobacco products in the last 8 hours?
8. Do you play first-person video games?
9. If you answered yes to Question 8, approximately how many hours do you play each week?

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APPENDIX F. C-SWAG DATA



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APPENDIX G. NASA TLX DATA

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name 001	Task KEYPAD (NO AI)	Date 20 SEP 2021
-------------	---------------------------	---------------------

Mental Demand How mentally demanding was the task?

Very Low 7 Very High

Physical Demand How physically demanding was the task?

Very Low 3 Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low 5 Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect 8 Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low 2 Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low 0 Very High

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name 001	Task VOICE - ACTIVATED AI ASSISTANT	Date 20 SEP 2021
-------------	---	---------------------

Mental Demand How mentally demanding was the task?

5

Very Low Very High

Physical Demand How physically demanding was the task?

1

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

3

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

10

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

1

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

0

Very Low Very High

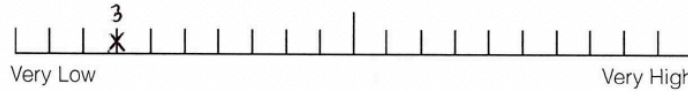
NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name 001	Task ~~TACTILE- ACTIVATED~~ AI ASSISTANT	Date 20 SEP 2021
-------------	--	---------------------

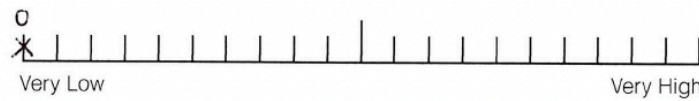
Mental Demand

How mentally demanding was the task?



Physical Demand

How physically demanding was the task?



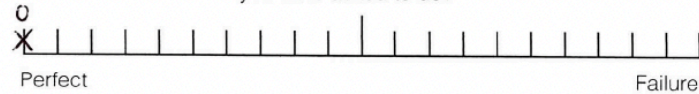
Temporal Demand

How hurried or rushed was the pace of the task?



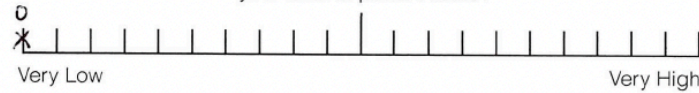
Performance

How successful were you in accomplishing what you were asked to do?



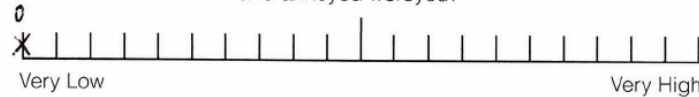
Effort

How hard did you have to work to accomplish your level of performance?



Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?



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APPENDIX H. HEART RATE DATA

Participant 001					
Interval #	RR Interval (s)	Interval #	RR Interval (s)	Interval #	RR Interval (s)
1	0.819	51	0.885	101	0.896
2	0.86	52	0.893	102	0.916
3	0.88	53	0.913	103	0.935
4	0.869	54	0.918	104	0.912
5	0.865	55	0.899	105	0.908
6	0.872	56	0.895	106	0.901
7	0.856	57	0.884	107	0.867
8	0.851	58	0.872	108	0.878
9	0.868	59	0.88	109	0.883
10	0.915	60	0.879	110	0.886
11	0.931	61	0.878	111	0.847
12	0.943	62	0.895	112	0.833
13	0.916	63	0.907	113	0.822
14	0.917	64	0.914	114	0.804
15	0.917	65	0.927	115	0.801
16	0.891	66	0.903	116	0.825
17	0.9	67	0.906	117	0.824
18	0.893	68	0.902	118	0.828
19	0.875	69	0.884	119	0.839
20	0.853	70	0.869	120	0.863
21	0.866	71	0.848	121	0.857
22	0.873	72	0.826	122	0.877
23	0.877	73	0.824	123	0.87
24	0.894	74	0.844	124	0.849
25	0.91	75	0.868	125	0.862
26	0.901	76	0.871	126	0.869
27	0.908	77	0.843	127	0.872
28	0.92	78	0.823	128	0.88
29	0.911	79	0.823	129	0.856
30	0.904	80	0.817	130	0.841
31	0.81	81	0.823	131	0.869
32	0.823	82	0.854	132	0.888
33	0.833	83	0.851	133	0.865
34	0.865	84	0.885	134	0.852
35	0.876	85	0.913	135	0.843
36	0.875	86	0.886	136	0.841
37	0.852	87	0.878	137	0.847
38	0.865	88	0.872	138	0.847
39	0.91	89	0.852	139	0.827
40	0.91	90	0.852	140	0.836
41	0.923	91	0.865	141	0.831
42	0.91	92	0.853	142	0.815
43	0.879	93	0.864	143	0.822
44	0.884	94	0.876	144	0.837
45	0.896	95	0.867	145	0.85
46	0.879	96	0.887	146	0.836
47	0.878	97	0.908	147	0.828
48	0.862	98	0.894	148	0.829
49	0.845	99	0.904	149	0.804
50	0.858	100	0.91	150	0.791

151	0.795	203	0.795	205	0.825
152	0.805	204	0.805	206	0.816
153	0.896	204	0.824	207	0.788
154	0.916	204	0.855	208	0.781
155	0.935	204	0.854	209	0.767
156	0.912	204	0.845	210	0.762
157	0.908	204	0.862	211	0.763
158	0.901	204	0.846	212	0.754
159	0.867	204	0.835	213	0.76
160	0.878	204	0.844	214	0.758
161	0.883	204	0.848	215	0.748
162	0.886	204	0.825	216	0.746
163	0.847	204	0.825	217	0.752
164	0.833	204	0.813	218	0.755
165	0.822	204	0.8	219	0.763
166	0.804	204	0.812	220	0.764
167	0.801	204	0.827	221	0.79
168	0.825	204	0.806	222	0.808
169	0.824	204	0.823	223	0.805
170	0.828	204	0.844	224	0.773
171	0.839	204	0.825	225	0.736
172	0.863	204	0.838	226	0.71
173	0.857	204	0.819	227	0.719
174	0.877	204	0.792	228	0.704
175	0.87	204	0.786	229	0.72
176	0.849	204	0.749	230	0.758
177	0.862	204	0.7	231	0.802
178	0.869	204	0.706	232	0.804
179	0.872	204	0.735	233	0.788
180	0.88	204	0.777	234	0.768
181	0.856	204	0.794	235	0.754
182	0.841	204	0.799	236	0.75
183	0.869	204	0.802	237	0.765
184	0.888	204	0.762	238	0.793
185	0.865	204	0.748	239	0.773
186	0.852	204	0.749	240	0.774
187	0.843	204	0.739	241	0.784
188	0.841	204	0.739	242	0.779
189	0.847	204	0.751	243	0.794
190	0.847	204	0.764	244	0.798
191	0.827	204	0.774	245	0.81
192	0.836	204	0.79	246	0.827
193	0.831	204	0.796	247	0.825
194	0.815	204	0.807	248	0.811
195	0.822	204	0.83	249	0.815
196	0.837	204	0.815	250	0.791
197	0.85	204	0.817	251	0.753
198	0.836	204	0.814	252	0.718
199	0.828	204	0.789	253	0.749
200	0.829	204	0.806	254	0.791
201	0.804	204	0.798	255	0.875
202	0.791	204	0.806	256	0.851

257	0.85	309	0.819	361	0.863
258	0.812	310	0.823	362	0.867
259	0.805	311	0.834	363	0.84
260	0.808	312	0.879	364	0.835
261	0.811	313	0.878	365	0.794
262	0.83	314	0.877	366	0.81
263	0.825	315	0.833	367	0.809
264	0.812	316	0.824	368	0.798
265	0.815	317	0.814	369	0.799
266	0.827	318	0.805	370	0.815
267	0.833	319	0.805	371	0.803
268	0.836	320	0.803	372	0.807
269	0.837	321	0.793	373	0.81
270	0.835	322	0.781	374	0.804
271	0.852	323	0.773	375	0.817
272	0.845	324	0.777	376	0.816
273	0.855	325	0.765	377	0.833
274	0.843	326	0.753	378	0.848
275	0.858	327	0.745	379	0.847
276	0.854	328	0.739	380	0.852
277	0.849	329	0.753	381	0.83
278	0.854	330	0.764	382	0.791
279	0.864	331	0.761	383	0.776
280	0.878	332	0.775	384	0.755
281	0.875	333	0.807	385	0.757
282	0.854	334	0.808	386	0.773
283	0.833	335	0.807	387	0.79
284	0.82	336	0.775	388	0.787
285	0.809	337	0.761	389	0.777
286	0.809	338	0.75	390	0.76
287	0.832	339	0.75	391	0.771
288	0.832	340	0.766	392	0.779
289	0.858	341	0.775	393	0.787
290	0.871	342	0.788	394	0.791
291	0.876	343	0.777	395	0.777
292	0.852	344	0.781	396	0.781
293	0.83	345	0.796	397	0.783
294	0.832	346	0.82	398	0.781
295	0.822	347	0.81	399	0.779
296	0.807	348	0.803	400	0.767
297	0.798	349	0.792	401	0.757
298	0.778	350	0.785	402	0.751
299	0.788	351	0.778	403	0.735
300	0.81	352	0.775	404	0.724
301	0.84	353	0.79	405	0.717
302	0.853	354	0.791	406	0.71
303	0.835	355	0.786	407	0.734
304	0.819	356	0.802	408	0.754
305	0.816	357	0.815	409	0.753
306	0.804	358	0.833	410	0.735
307	0.801	359	0.851	411	0.739
308	0.81	360	0.864	412	0.772

413	0.786	465	0.794	517	0.826
414	0.796	466	0.791	518	0.828
415	0.796	467	0.821	519	0.865
416	0.789	468	0.796	520	0.897
417	0.798	469	0.79	521	0.904
418	0.796	470	0.769	522	0.904
419	0.79	471	0.762	523	0.88
420	0.781	472	0.751	524	0.85
421	0.777	473	0.765	525	0.833
422	0.77	474	0.774	526	0.823
423	0.761	475	0.783	527	0.816
424	0.766	476	0.795	528	0.824
425	0.725	477	0.808	529	0.833
426	0.68	478	0.804	530	0.824
427	0.666	479	0.794	531	0.818
428	0.688	480	0.758	532	0.847
429	0.839	481	0.687	533	0.855
430	0.822	482	0.667	534	0.837
431	0.817	483	0.654	535	0.829
432	0.805	484	0.656	536	0.779
433	0.791	485	0.67	537	0.72
434	0.777	486	0.714	538	0.724
435	0.748	487	0.748	539	0.769
436	0.732	488	0.755	540	0.837
437	0.721	489	0.78	541	0.888
438	0.721	490	0.794	542	0.919
439	0.715	491	0.777	543	0.892
440	0.705	492	0.77	544	0.875
441	0.709	493	0.77	545	0.853
442	0.728	494	0.754	546	0.833
443	0.765	495	0.754	547	0.834
444	0.793	496	0.799	548	0.854
445	0.802	497	0.8	549	0.878
446	0.803	498	0.813	550	0.902
447	0.802	499	0.816	551	0.904
448	0.81	500	0.807	552	0.87
449	0.809	501	0.794	553	0.858
450	0.798	502	0.788	554	0.843
451	0.778	503	0.779	555	0.852
452	0.775	504	0.771	556	0.857
453	0.77	505	0.779	557	0.851
454	0.769	506	0.779	558	0.856
455	0.773	507	0.778	559	0.876
456	0.772	508	0.819	560	0.859
457	0.764	509	0.827	561	0.865
458	0.773	510	0.838	562	0.847
459	0.78	511	0.836	563	0.834
460	0.79	512	0.823	564	0.815
461	0.791	513	0.827	565	0.788
462	0.812	514	0.821	566	0.778
463	0.788	515	0.815	567	0.789
464	0.789	516	0.819	568	0.793

569	0.826	621	0.79	673	0.81
570	0.828	622	0.787	674	0.821
571	0.865	623	0.796	675	0.832
572	0.897	624	0.79	676	0.839
573	0.904	625	0.79	677	0.823
574	0.904	626	0.793	678	0.805
575	0.88	627	0.8	679	0.819
576	0.85	628	0.811	680	0.836
577	0.833	629	0.798	681	0.836
578	0.823	630	0.791	682	0.864
579	0.816	631	0.791	683	0.876
580	0.824	632	0.771	684	0.874
581	0.833	633	0.745	685	0.876
582	0.824	634	0.742	686	0.872
583	0.818	635	0.738	687	0.87
584	0.847	636	0.731	688	0.842
585	0.855	637	0.73	689	0.816
586	0.837	638	0.713	690	0.781
587	0.829	639	0.721	691	0.788
588	0.779	640	0.768	692	0.813
589	0.72	641	0.778	693	0.841
590	0.724	642	0.789	694	0.831
591	0.769	643	0.797	695	0.851
592	0.837	644	0.807	696	0.863
593	0.888	645	0.769	697	0.853
594	0.919	646	0.721	698	0.865
595	0.892	647	0.682	699	0.848
596	0.875	648	0.69	700	0.833
597	0.853	649	0.705	701	0.842
598	0.833	650	0.706	702	0.814
599	0.834	651	0.682	703	0.798
600	0.854	652	0.663	704	0.78
601	0.878	653	0.66	705	0.772
602	0.902	654	0.676	706	0.803
603	0.904	655	0.725	707	0.861
604	0.87	656	0.795	708	0.884
605	0.858	657	0.826	709	0.915
606	0.843	658	0.854	710	0.918
607	0.852	659	0.86	711	0.904
608	0.857	660	0.837	712	0.879
609	0.851	661	0.796	713	0.827
610	0.856	662	0.777	714	0.793
611	0.876	663	0.765	715	0.768
612	0.859	664	0.75	716	0.78
613	0.865	665	0.741	717	0.786
614	0.847	666	0.745	718	0.792
615	0.834	667	0.752	719	0.816
616	0.815	668	0.76	720	0.813
617	0.788	669	0.766	721	0.852
618	0.778	670	0.758	722	0.869
619	0.789	671	0.756	723	0.875
620	0.793	672	0.801	724	0.833

725	0.781	756	0.75	787	0.737
726	0.761	757	0.765	788	0.762
727	0.749	758	0.786	789	0.767
728	0.745	759	0.785	790	0.78
729	0.738	760	0.787	791	0.763
730	0.73	761	0.794	792	0.757
731	0.751	762	0.793	793	0.764
732	0.785	763	0.801	794	0.759
733	0.782	764	0.82	795	0.771
734	0.772	765	0.81	796	0.778
735	0.74	766	0.821	797	0.784
736	0.711	767	0.814	798	0.801
737	0.713	768	0.8	799	0.803
738	0.714	769	0.795	800	0.82
739	0.741	770	0.798	801	0.833
740	0.798	771	0.807	802	0.844
741	0.795	772	0.802	803	0.818
742	0.797	773	0.791	804	0.797
743	0.806	774	0.795	805	0.782
744	0.787	775	0.791	806	0.775
745	0.773	776	0.786	807	0.768
746	0.781	777	0.803	808	0.784
747	0.773	778	0.82	809	0.802
748	0.777	779	0.827	810	0.809
749	0.791	780	0.825	811	0.813
750	0.794	781	0.805	812	0.812
751	0.796	782	0.791	813	0.804
752	0.791	783	0.765	814	0.815
753	0.767	784	0.745	815	0.822
754	0.753	785	0.726	816	0.84
755	0.752	786	0.731		

APPENDIX I. FLIGHT DATA

Participant 001					
Timer Time	KIAS	Indicated ALT	Timer Time	KIAS	Indicated ALT
0.74437	110.69466	2135.53516	50.69806	111.84448	1852.48975
1.73801	110.54916	2130.11523	51.70617	112.07098	1844.02612
2.73851	110.29866	2125.85059	52.70865	112.21174	1836.23303
3.73212	109.97691	2122.54785	53.70908	112.26769	1829.15564
4.7291	109.63346	2119.68457	54.7019	112.24722	1822.87244
5.72206	109.36916	2116.323	55.70473	112.14222	1817.37708
6.72832	109.22042	2111.83154	56.70347	111.89972	1813.26233
7.73396	109.17977	2106.33081	57.70702	111.48982	1810.93298
8.73662	109.24333	2099.88354	58.71151	110.94025	1810.28589
9.73301	109.40244	2092.5127	59.71499	110.28915	1810.98792
10.72573	109.62809	2084.38306	60.72153	109.57127	1812.67859
11.71969	109.85391	2076.03931	61.72623	108.82171	1814.99414
12.71727	110.04263	2068.00537	62.71999	108.07072	1817.67432
13.71027	110.17197	2060.57275	63.72193	107.3392	1820.4209
14.71441	110.22165	2053.83911	64.7281	106.68324	1822.7113
15.71694	110.17805	2048.04712	65.73069	106.14857	1824.08545
16.71009	110.02523	2043.42004	66.7355	105.74291	1824.34473
17.71367	109.74885	2040.02771	67.73996	105.4576	1823.52856
18.71751	109.35473	2037.96899	68.74247	105.2546	1821.91626
19.71536	108.87528	2037.04492	69.74555	105.10897	1819.77869
20.72215	108.36713	2036.66992	70.74704	105.02408	1817.10925
21.71916	107.90302	2036.2373	71.74784	105.0273	1813.87195
22.72093	107.58112	2034.70667	72.74743	105.22293	1810.05981
23.71803	107.4496	2031.44556	73.74707	105.57574	1805.71509
24.7171	107.504	2026.32178	74.75131	106.01567	1800.95911
25.71559	107.68283	2019.7738	75.75284	106.47992	1796.22058
26.71262	107.92454	2012.44006	76.7582	106.77556	1792.9469
27.71051	108.15023	2005.01233	77.76459	106.81829	1792.45398
28.70772	108.34433	1997.99976	78.75929	106.59484	1795.04541
29.70909	108.50602	1991.3175	79.75462	106.07151	1800.83301
30.71255	108.60229	1985.19775	80.74833	105.37773	1808.7998
31.71228	108.59651	1980.04492	81.74967	104.63133	1817.67908
32.71082	108.48817	1975.93945	82.74561	103.9209	1826.55139
33.71102	108.30392	1972.70349	83.74561	103.31467	1834.73669
34.71188	108.08215	1969.98865	84.7523	102.84824	1841.80371
35.70839	107.89836	1967.15894	85.75676	102.54012	1847.49121
36.7062	107.79274	1963.63	86.75002	102.39813	1851.65625
37.70214	107.75313	1959.46533	87.75302	102.4212	1854.31042
38.69948	107.76615	1954.74268	88.75681	102.60732	1855.37708
39.69783	107.82007	1949.60583	89.75961	102.94263	1854.90332
40.70089	107.93715	1943.85449	90.76408	103.36954	1852.96973
41.70801	108.12416	1937.36951	91.76551	103.78411	1849.76233
42.70207	108.40878	1930.01672	92.76427	104.12115	1846.22534
43.70734	108.86129	1920.95544	93.76351	104.30489	1843.64734
44.70122	109.38453	1910.94153	94.76221	104.27382	1842.90979
45.69641	109.91131	1900.56506	95.75842	104.03452	1844.29236
46.69429	110.40346	1890.24622	96.76492	103.74999	1846.54871
47.68834	110.83358	1880.34204	97.76835	103.56158	1848.14209
48.68901	111.21521	1870.76672	98.76676	103.50771	1848.56897
49.69574	111.5567	1861.42078	99.76395	103.59547	1847.71399

100.76019	103.82957	1845.50952	152.89705	113.27805	1795.93835
101.75368	104.19916	1841.94165	153.88881	113.66434	1788.99878
102.7606	104.69033	1837.02014	154.8985	114.00365	1782.9353
103.76849	105.24045	1831.16882	155.89896	114.583	1775.26123
104.76266	105.6729	1825.89429	156.89516	115.17952	1766.89148
105.8003	105.81763	1822.86243	157.89117	115.39951	1759.59143
106.80275	105.5807	1823.51245	158.88683	115.17485	1754.4845
107.84017	104.97645	1827.87073	159.88803	114.90568	1749.99023
108.83734	104.11475	1835.04321	160.88948	114.97257	1742.5968
109.8323	103.07477	1844.34863	161.88855	115.28374	1732.42969
110.83054	102.12147	1853.71704	162.88597	115.60912	1721.44055
111.83163	101.44725	1861.00476	163.88953	115.8	1711.33167
112.8299	101.07748	1865.61218	164.89038	115.82676	1702.74829
113.83595	101.06136	1867.5415	165.89438	115.73823	1695.41333
114.83294	101.47452	1866.75916	166.90469	115.61964	1688.61108
115.82779	102.1789	1863.47119	167.90208	115.33923	1681.55383
116.82502	102.95703	1858.80688	168.87952	115.00827	1673.60022
117.82322	103.49708	1855.40552	169.97748	114.92523	1663.26331
118.82652	103.70483	1854.62415	170.9754	114.68798	1656.18079
119.82168	103.56233	1856.83167	171.99818	113.97421	1654.01917
120.85394	103.1415	1861.79065	173.02512	112.72903	1657.18494
121.85295	102.77522	1866.79028	174.02765	110.93147	1666.29541
122.84998	102.62661	1870.00891	175.0248	108.55791	1681.89099
123.84601	102.71638	1870.96558	176.01898	105.58315	1704.23096
124.85239	102.84883	1870.948	177.04953	101.99643	1733.07935
125.853	102.80181	1872.17908	178.05797	98.20908	1764.30286
126.85603	102.57244	1875.20251	179.04979	94.47751	1795.39502
127.85968	102.22928	1880.10022	180.06189	90.86676	1825.6261
128.86606	101.75728	1886.79871	181.06628	87.84846	1851.71741
129.85983	101.2402	1894.97754	182.07092	85.58986	1871.27161
130.86638	100.72575	1904.58423	183.07777	83.86484	1884.60193
131.86182	100.5215	1912.90735	184.07523	82.66662	1892.62366
132.85855	101.00756	1915.65356	185.06845	81.79591	1897.08997
133.85648	102.15382	1912.14917	186.07413	81.17564	1899.34607
134.85118	103.75743	1903.73669	187.07092	81.01618	1899.19104
135.84706	105.668	1891.59265	188.07672	81.29717	1895.58264
136.84953	107.60873	1877.28516	189.12454	82.9188	1887.12
137.85426	109.01013	1863.55188	190.13165	85.96051	1874.18677
138.85173	109.84105	1853.33398	191.13571	89.40479	1857.71362
139.88947	110.40669	1846.21997	192.13887	91.98119	1840.41064
140.88374	110.73373	1841.55481	193.14494	93.26572	1826.13281
141.87762	110.85828	1838.44043	194.14151	93.59189	1817.71667
142.87511	110.64558	1837.55798	195.13953	93.33195	1815.3042
143.88174	110.37784	1837.32263	196.13622	92.64838	1818.17053
144.87671	110.12439	1836.80444	197.14185	91.49824	1825.36536
145.88197	109.90463	1836.55518	198.14471	90.26663	1833.08594
146.87761	109.85149	1836.25317	199.15164	89.32179	1837.92261
147.88312	110.04929	1834.12695	200.1563	88.62961	1839.8988
148.88707	110.57901	1828.72729	201.15494	87.79441	1841.19446
149.88341	111.29484	1820.85535	202.14923	86.79108	1843.55774
150.8864	111.95262	1812.84033	203.4873	85.52349	1848.27979
151.89154	112.65436	1804.43579	204.49313	84.27045	1852.86841

205.49733	82.84633	1858.14954	257.50934	99.63216	1925.28638
206.49898	81.68375	1861.98547	258.50446	97.41001	1943.40186
207.50603	81.33661	1861.38757	259.50314	96.1516	1954.69836
208.50443	81.79999	1855.57336	260.49792	96.47132	1954.31409
209.50168	82.64981	1846.46191	261.50449	98.34122	1941.83679
210.50433	83.61453	1835.17188	262.50275	101.32532	1921.28467
211.49886	84.96969	1822.71948	263.51004	104.76408	1897.11243
212.49834	86.56419	1811.30151	264.51318	107.45617	1877.57397
213.49498	87.7737	1803.20081	265.50748	108.8643	1868.72205
214.49187	88.53072	1798.55469	266.51068	109.0741	1871.48718
215.49362	88.98326	1796.53345	267.51187	108.87949	1879.9364
216.49701	89.26663	1796.47693	268.51651	108.83867	1887.80896
217.49782	89.33633	1798.36353	269.5126	109.0944	1892.61768
218.49805	89.23033	1803.17004	270.5192	109.39458	1896.16541
219.49535	89.11172	1809.44067	271.5184	109.5524	1900.64392
220.49101	89.15249	1815.32129	272.51099	109.743	1905.23596
221.39731	89.48203	1819.18958	273.50458	110.00276	1909.26648
222.53123	90.43153	1821.23669	274.5094	110.32446	1912.90771
223.53749	91.63808	1820.58545	275.50714	110.70042	1916.21411
224.53172	92.94251	1818.31311	276.51541	111.25591	1918.21326
225.53313	94.19521	1815.63757	277.52048	112.07485	1917.42078
226.53958	95.24	1814.02795	278.51758	112.92923	1914.94836
227.5331	95.90491	1814.66577	279.52359	113.57079	1913.25867
228.52432	96.01024	1818.71313	280.52396	113.89667	1913.56543
229.52711	95.28306	1827.62598	281.52914	113.78407	1916.8479
230.53499	94.32307	1839.62878	282.53192	113.29217	1922.23352
231.53468	93.59784	1851.06934	283.52606	112.87193	1927.34705
232.53247	93.53135	1858.29736	284.53241	112.89293	1928.83936
233.5399	94.00757	1860.95349	285.53357	113.16485	1927.49768
234.53392	94.56793	1861.52429	286.53238	113.40511	1925.96997
235.52895	94.67852	1863.8761	287.52994	113.48083	1925.9043
236.53714	94.49684	1869.22742	288.51941	113.60362	1926.00134
237.54425	94.58546	1873.74988	289.51599	113.80927	1925.71606
238.5441	95.45303	1873.95642	290.50833	114.23703	1923.8606
239.53673	97.07554	1868.63354	291.50983	114.90123	1919.52954
240.53922	99.06195	1859.13696	292.51331	115.65402	1913.76807
241.54338	100.91108	1849.11035	293.52121	116.45227	1907.06628
242.54742	102.41984	1840.79382	294.51874	117.23788	1899.95642
243.54326	103.39022	1835.83459	295.51181	117.97521	1892.82422
244.54816	103.91055	1835.0083	296.50717	118.61355	1886.22351
245.54248	104.20609	1837.13379	297.50128	119.06106	1881.1908
246.53619	104.46101	1840.27722	298.50296	119.26909	1878.23804
247.5294	104.77914	1842.95544	299.5069	119.23154	1877.43225
248.52473	105.13589	1845.07666	300.51053	119.34808	1875.9115
249.51897	105.48897	1846.75342	301.50534	119.80642	1871.62122
250.51532	105.74179	1848.8158	302.50858	120.4884	1865.14709
251.5089	105.82118	1852.21729	303.51175	121.28378	1856.54004
252.50412	105.64003	1857.89294	304.50644	121.87296	1845.87134
253.50984	105.15915	1866.5188	305.50125	122.623	1832.44421
254.50543	104.44408	1877.60999	306.49704	123.71925	1815.2439
255.50882	103.54922	1890.56238	307.49255	124.99673	1795.41821
256.50458	101.97054	1906.15857	308.5119459	123.9871563	1866.964881

309.49045	127.40083	1754.25732	361.4903	93.40042	1781.43665
310.49728	128.22194	1736.92932	362.49701	92.24873	1790.71729
311.49622	128.60396	1724.05432	363.48911	92.04758	1793.83057
312.49768	128.01903	1714.9425	364.49716	92.82799	1790.64417
313.49075	126.74787	1708.28955	365.50092	94.44431	1781.35681
314.49579	125.27737	1702.36816	366.49902	96.15027	1770.05469
315.50278	123.8903	1695.84412	367.49496	97.51648	1760.26208
316.50513	122.60809	1688.45801	368.48743	98.30586	1753.89551
317.50159	121.28558	1682.50305	369.48618	98.42671	1752.59412
318.50735	119.90762	1679.5929	370.48978	98.02903	1756.02014
319.50687	118.26476	1680.86206	371.48669	97.33985	1762.25244
320.50574	116.32359	1686.32727	372.4873	96.70867	1770.11377
321.50989	114.20369	1694.59558	373.48462	96.32638	1778.34985
322.51761	112.05688	1704.02832	374.48816	96.19263	1785.78931
323.51126	110.04301	1712.88684	375.4895	96.28551	1792.41199
324.5192	108.2808	1719.50037	376.49615	96.5825	1798.94312
325.5163	107.46445	1720.07581	377.49722	96.89569	1805.82861
326.51221	107.82468	1712.95789	378.50217	97.1524	1813.01331
327.51794	108.71645	1700.39551	379.49561	97.43506	1819.59241
328.51736	109.55065	1686.55017	380.50177	97.76167	1825.54688
329.51639	110.60736	1671.44727	381.5069	98.06339	1831.12134
330.52063	111.96655	1654.96082	382.50003	98.23602	1837.1178
331.52783	113.08806	1640.75696	383.50491	98.29201	1844.10718
332.52051	113.72025	1630.73975	384.50058	98.24513	1851.73804
333.52646	113.80206	1625.35168	385.49487	98.14598	1859.8374
334.52783	113.54329	1623.66772	386.50018	98.23072	1866.80151
335.52945	113.07998	1624.4729	387.50247	98.4601	1872.33472
336.53281	112.4537	1627.28455	388.50629	98.71352	1877.38611
337.53116	111.70598	1631.70313	389.50046	98.92031	1882.7522
338.52774	110.81315	1637.77454	390.50455	99.12118	1888.71069
339.5293	109.64586	1646.73938	391.50089	99.30381	1894.98303
340.52689	108.21214	1658.83093	392.49698	99.40504	1901.80835
341.52573	106.94806	1670.92786	393.49579	99.38755	1909.56042
342.52588	105.92879	1681.28601	394.49323	99.32166	1918.14185
343.48367	104.71816	1692.19397	395.49045	99.30241	1926.76453
344.48444	102.93597	1705.29395	396.49625	99.45958	1934.08728
345.48087	101.57294	1715.86646	397.4982	99.81425	1939.4292
346.48236	100.99559	1720.40649	398.50021	100.27897	1943.31543
347.48529	101.25006	1718.21545	399.49863	100.76688	1946.61267
348.48962	102.36967	1708.56409	400.50357	101.32262	1949.07019
349.48276	103.59002	1696.97095	401.496	101.84582	1951.30505
350.47684	104.2498	1689.62183	402.50388	102.27692	1954.38806
351.47855	103.8009	1691.24292	403.49966	102.52248	1958.80554
352.48444	102.51643	1701.02954	404.49356	102.56763	1964.81091
353.4855	101.00341	1713.99719	405.49686	102.42554	1972.50696
354.48941	99.83218	1725.69006	406.49335	102.31692	1980.32129
355.48712	99.28396	1732.56653	407.49722	102.32936	1987.09985
356.4863	98.98909	1736.61963	408.49554	102.40104	1993.28979
357.47885	98.62028	1740.80005	409.49747	102.52142	1998.99316
358.48557	97.87024	1747.21301	410.50381	102.66579	2004.64954
359.4819	96.66883	1756.26917	411.50186	102.9334	2009.8938
360.48492	95.08337	1768.35901	412.50562	103.38446	2013.85388

413.50827	103.86646	2017.23364	465.50046	115.38192	1835.91772
414.50525	104.36248	2020.21326	466.50662	115.66512	1823.53357
415.4996	104.87127	2022.77856	467.50009	115.487	1814.54431
416.50589	105.42815	2024.70996	468.50064	115.12627	1806.83167
417.51263	105.91198	2026.78687	469.50742	115.07278	1797.00549
418.51971	106.30371	2029.45544	470.50293	115.65663	1782.38037
419.51938	106.64026	2032.47473	471.49756	116.38004	1764.76526
420.51459	106.95123	2035.77698	472.49814	116.51859	1749.74731
421.51587	107.23186	2039.35291	473.48929	116.16495	1740.56604
422.52377	107.45422	2043.35754	474.48639	115.3317	1737.35193
423.51776	107.56243	2048.20703	475.49426	114.05962	1739.4281
424.5145	107.60728	2053.76733	476.5018	112.80244	1743.59277
425.52161	107.84833	2058.00659	477.50125	111.59569	1748.23083
426.52377	108.46662	2058.50073	478.50134	110.4419	1752.67773
427.52554	109.20737	2056.90088	479.50323	109.11676	1758.29749
428.52429	109.89425	2055.2605	480.49738	107.6781	1765.33618
429.51837	110.49897	2054.06299	481.49438	106.34539	1772.20618
430.51358	111.04786	2053.20337	482.48746	105.14775	1778.55969
431.51218	111.52588	2052.66406	483.48346	104.04855	1785.58411
432.50723	111.83647	2053.2915	484.47797	102.96704	1793.46912
433.50259	112.01803	2055.07227	485.47092	101.9949	1801.98486
434.49976	112.425	2055.25464	486.47696	101.13683	1810.96643
435.4986	113.04557	2053.06885	487.47403	100.38943	1819.56458
436.50369	113.81246	2048.92456	488.47415	99.73846	1827.29236
437.49677	114.67265	2043.07825	489.47012	99.2291	1833.65552
438.50113	115.50027	2035.50366	490.46857	98.67486	1840.19897
439.50198	116.3038	2026.54712	491.47354	97.69979	1847.51123
440.50092	117.12546	2016.59033	492.47137	96.28398	1855.24475
441.49561	117.91867	2006.33313	493.47345	94.73373	1863.40308
442.49033	118.63922	1996.34326	494.47128	93.52871	1871.47815
443.49057	119.25536	1987.02649	495.46515	92.82844	1878.97107
444.48303	119.68545	1979.32495	495.61362	92.7578	1880.03162
445.48367	120.07184	1972.72998	496.61105	92.28396	1886.92749
446.48444	120.59412	1965.56091	497.60956	91.61285	1893.59937
447.48828	121.16969	1957.31848	498.60736	91.23015	1898.7002
448.49112	121.53286	1948.27271	499.60925	91.79759	1898.578
449.48581	121.62914	1938.74475	500.6376	93.21101	1892.44727
450.49216	121.46396	1928.70557	501.63358	94.87756	1883.20984
451.49393	121.1497	1918.54089	502.6315	96.41906	1873.9574
452.49713	120.69345	1908.78918	503.63348	97.75038	1866.01685
453.5007	120.03243	1900.83557	504.63129	99.03048	1858.6842
454.49619	119.15638	1895.52234	505.63174	100.32158	1850.94495
455.49844	117.97531	1893.58826	506.63425	101.40652	1844.60315
456.49231	116.21244	1897.19922	507.62738	102.19743	1840.63354
457.49487	114.14829	1904.62073	508.63229	102.66847	1839.44397
458.49747	112.65652	1909.74451	509.62985	102.84133	1841.11096
459.49362	111.93302	1910.06836	510.63541	102.80151	1844.92212
460.49448	111.92194	1904.70825	511.62933	102.76667	1849.38892
461.492	112.38206	1894.82996	512.62927	102.78809	1853.84119
462.49469	113.03468	1882.17236	513.62769	102.91615	1857.81995
463.49374	113.78654	1867.65552	514.63031	103.19549	1860.65332
464.49731	114.63757	1851.51404	515.62524	103.58285	1862.32007

516.61749	103.92701	1863.87036	568.70099	111.12878	1955.05554
517.61505	104.08987	1866.82825	569.7066	111.45766	1951.66809
518.62018	104.03813	1871.84338	570.71051	111.94379	1946.18262
519.62744	103.85439	1878.43823	571.70618	112.44188	1939.98462
520.6239	103.72919	1884.77087	572.69904	112.90656	1933.79309
521.6264	103.62283	1890.86072	573.69287	113.3213	1927.86743
522.62476	103.57656	1896.59326	574.69672	113.67829	1922.32007
523.62579	103.63062	1901.47485	575.70294	113.87746	1917.97705
524.62756	103.6937	1905.95325	576.70428	113.83997	1915.13196
525.62897	103.65747	1911.18054	577.70813	113.59001	1911.90576
526.62897	103.59016	1916.95996	578.7085	113.11803	1908.4364
527.62988	103.55515	1922.88074	579.71448	112.32072	1907.37927
528.63104	103.62531	1928.05066	580.73627	111.23504	1908.90649
529.62933	103.80701	1932.1366	581.74249	109.93259	1913.05078
530.6261	104.07355	1935.24731	582.73859	108.49991	1919.20544
531.62433	104.35714	1937.96204	583.73364	107.01797	1926.64111
532.62323	104.61983	1940.70459	584.73688	105.58839	1934.28662
533.61755	104.83068	1943.7085	585.73535	104.29167	1941.11377
534.61554	104.94905	1947.37292	586.73419	103.08659	1947.30371
535.61346	105.00748	1951.64587	587.73346	102.02192	1952.60999
536.6145	105.05662	1955.97644	588.7265	101.11299	1956.68372
537.61206	105.0572	1960.53992	589.72534	100.64461	1956.6145
538.61359	104.89775	1966.21448	590.72144	101.21399	1947.0647
539.61761	104.70493	1972.32178	591.7182	102.6034	1928.00928
540.60962	104.63597	1977.01794	592.72241	103.98614	1907.68835
541.60382	104.70073	1980.03711	593.72534	105.03773	1889.84778
542.60919	104.91543	1981.42908	594.73029	105.69288	1876.19543
543.61066	105.25353	1981.44263	595.73132	106.08521	1866.52295
544.61688	105.63818	1980.70154	596.72766	106.17397	1860.57605
545.60846	105.93058	1980.39563	597.73096	105.91222	1858.2605
546.61639	106.17268	1980.63818	598.72424	105.31118	1859.39465
547.61371	106.43243	1980.70203	599.72461	104.34475	1863.97974
548.60944	106.73295	1980.27502	600.72076	103.17913	1870.95825
549.61005	107.06119	1979.42834	601.72626	102.20456	1876.71802
550.60535	107.39341	1978.36816	602.7287	101.61786	1879.52979
551.6048	107.7204	1977.19861	603.7254	101.41301	1879.58948
552.6059	108.00614	1976.19556	604.72681	101.30431	1878.44751
553.61169	108.21565	1975.65039	605.72467	100.90632	1879.52576
554.61725	108.31883	1975.91821	606.72211	100.30797	1882.88586
555.61035	108.32458	1977.10681	607.72211	99.65059	1887.14233
556.61084	108.2647	1978.96497	608.72192	98.9894	1891.70679
557.61401	108.14926	1981.48682	609.71484	98.36397	1896.19263
558.61536	108.14893	1983.19702	610.71332	97.75551	1900.47913
559.6106	108.3335	1983.11267	611.71997	97.38684	1904.91211
560.60889	108.75561	1980.53003	612.72266	97.27958	1909.85815
561.60663	109.26311	1976.62622			
562.60583	109.78257	1972.13733			
563.59943	110.21776	1967.72815			
564.60193	110.56972	1963.66833			
565.698	110.86656	1959.89441			
566.69934	111.01721	1957.45496			
567.6958	111.04422	1956.30347			

APPENDIX J. POST-EXPERIMENT QUESTIONNAIRE DATA

Post-Experiment Questionnaire Data			
Participant Number	Keypad, No AI	Voice-Activated, AI Assistant	Tactile-Activated, AI Assistant
001	3	2	1
002 (Rated Pilot)	3	2	1
003	2	3	1
004 (Rated Pilot)	2	3	1
005 (Rated Pilot)	1	3	2
006	2	3	1
007	3	2	1
008	1	3	2
009 (Rated Pilot)	2	3	1
010	2	3	1
011	3	1	2
012	1	3	2
013	2	3	1
014 (Rated Pilot)	1	2	3
015	3	2	1
016	2	3	1
017	3	1	2
018	3	2	1
019	3	2	1
020	2	3	1
021	2	3	1
022	2	3	1
023	3	1	2
024	3	2	1
025	3	1	2
026	2	3	1
Question: Rank order each of the three radio frequency input methods listed below from easiest to hardest. Scale: 1 - Easiest 2 - Moderate 3 - Hardest			

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