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WHAT TASKS TO AUTOMATE? AN INVESTIGATION OF WHAT TASKS MAKE SENSE TO AUTOMATE FOR FUTURE AVIATION PLATFORMS

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SYSTEMS ENGINEERING CAPSTONE REPORT

WHAT TASKS TO AUTOMATE?
AN INVESTIGATION OF WHAT TASKS MAKE SENSE TO AUTOMATE FOR FUTURE AVIATION PLATFORMS

by

Matthew W. Carter, Gregory S. Griffith, Peter V. Hamill Jr., and Jacen P. Lanclos

December 2021

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13. ABSTRACT (maximum 200 words)

The Army is developing a new generation of aircraft called Future Vertical Lift (FVL). These aircraft will integrate new technologies that change Army Aviation’s machinery, methods, and aircrew domains. Key to this effort is the development of automation to reduce pilot cognitive workload and prevent cognitive overload.

The purpose of this research was to develop an understanding of the factors that influence pilot cognitive workload and to provide insight into what tasks make sense to automate for FVL. Researchers used a mixed methods approach, relying on scholarly literature and semi-structured interviews to elicit cognitive workload data from Army rotary-wing pilots. Researchers used the data from a simple and a complex MEDEVAC flight scenario to develop an influence diagram that models pilot cognitive workload based on influencing factors and subfactors.

At a high level, the data indicate that pilot task demand and environmental factors have the most influence on cognitive workload during complex missions in challenging conditions. At a low level, the data indicate that light factors, intra-flight coordination, and task complexity are most influential on cognitive workload. The results suggest that tasks impacting these factors should be considered for automation to prevent pilot cognitive overload in FVL.

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The Army is developing a new generation of aircraft called Future Vertical Lift (FVL). These aircraft will integrate new technologies that change Army Aviation's machinery, methods, and aircrew domains. Key to this effort is the development of automation to reduce pilot cognitive workload and prevent cognitive overload.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHB	Assault Helicopter Battalion
AROC	Army Requirements Oversight Council
ARSOA	Army Special Operations Aviation
AvMC	Aviation and Missile Center
CCDC	Combat Capabilities Development Command
DA	Department of the Army
FAA	Federal Aviation Administration
FARA	Future Attack Reconnaissance Aircraft
FLRAA	Future Long-Range Assault Aircraft
FTUAS	Future Tactical Unmanned Aerial System
FVL	Future Vertical Lift
GSAB	General Support Aviation Battalion
HFES	Human Factors and Ergonomics
HSA-DM	Holistic Situational Awareness-Decision Making
ID	influence diagram
IMPRINT	Improved Performance Research Integration Tool
IRB	Institutional Review Board
MEDEVAC	medical evacuation
NASA	National Aeronautics and Space Administration
NG	National Guard
OPTEMPO	operational tempo
PEO-AVN	Program Executive Office-Aviation
TDD	Technology Development Directorate
TMRR	technology maturation and risk reduction
VFR	visual flight rules
VTC	video tele-conference

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EXECUTIVE SUMMARY

A. PROJECT SUMMARY

This purpose of this project was to provide insight into the factors that influence pilot cognitive workload to help inform Future Vertical Lift (FVL) task automation requirements. Researchers used scholarly literature to develop an understanding of what factors influence pilot cognitive workload. Next, researchers conducted semi-structured interviews with Army rotary-wing aircraft pilots to elicit cognitive workload data. After that, researchers conducted quantitative and qualitative analyses of the elicited data to develop an influence diagram that models pilot cognitive workload and its influencing factors. Finally, researchers used the model and pilot data to develop recommendations for FVL task automation requirements and future research needs.

B. BACKGROUND

The Army is developing a new generation of aircraft as part of the FVL initiative. The Army's intent is to make a generational leap forward in aviation technology and capability by developing the new platforms and operational concepts necessary to succeed in an increasingly contested and challenging battlespace. Core to the FVL initiative is integrating revolutionary and disruptive new technologies to drive changes in Army Aviation's machinery, methods, and aircrew domains. Without the addition of automation, there is an increased potential for pilots to reach cognitive overload due to the infusion of new technologies, data streams, and situational awareness tools on FVL platforms (M. Shivers, email to capstone advisor, May 27, 2021). As such, the FVL program is re-assessing what tasks should be automated to avoid pilot cognitive overload.

C. FINDINGS AND CONCLUSIONS

This project showed that influence diagrams are an effective tool to model the factors and factor relationships that influence pilot cognitive workload. Researchers expect the influence diagram and data from this project to inform future research on pilot cognitive workload and FVL task automation needs.

The most significant outcome of this project is the significant difference in cognitive workload values between a simple and complex MEDEVAC mission scenario, shown in Table ES-1. The data indicate that pilot workload varies significantly based on the operational conditions of the mission and that pilots experience exceptionally high cognitive workload during complex missions. This makes clear the need for automation to assist pilots in complex situations.

Table ES-1. Median participant cognitive workload values for simple and complex MEDEVAC scenarios.

	Simple Scenario	Complex Scenario	Delta
Cognitive Workload	9.14	76.22	67.08
Range of Individual Responses	1.00–39.98	42.94–94.16	

A high-level analysis of the primary factor influences, shown in Table ES-2, indicates that as task demand increases and the scenario becomes more complex, task demand becomes the most influential factor in cognitive workload. Additionally, the environmental factor accounts for the biggest increase in cognitive workload when transitioning from a scenario where cognitive overload is unlikely (i.e., a simple scenario) to a scenario where cognitive overload is likely (i.e., a complex scenario). Therefore, automation should be developed to reduce the effect of task demands and environmental conditions on cognitive workload.

Table ES-2. Median primary factor weights for simple and complex MEDEVAC scenarios.

Factor	Weighted Workload Scores		
	Simple Scenario	Complex Scenario	Delta
Environment	0.13	0.20	0.07
Task Demand	0.20	0.25	0.05
Operational Competency	0.20	0.20	0.00
Mission	0.23	0.20	-0.03
Fatigue	0.15	0.10	-0.05
Total Weight	0.91	0.95	0.04

In contrast to the primary factor analysis, the rank ordered list of influencing subfactors shown in Table ES-3 provides more focused insight into tasks that make sense to automate. To help avoid cognitive overload, pilots need automation the most in the complex scenario because that is where their cognitive workload is the highest. Setting aside subfactors that don't lend themselves to automation at present (e.g., pilot experience and currency), the data indicates that tasks impacted by light factors, intra-flight coordination requirements, and task complexity should be automated. This would result in the greatest potential cognitive workload reduction during peak demand situations.

Table ES-3. Top 8 most influential subfactors on cognitive workload in complex MEDEVAC scenario.

Subfactor	**Cognitive Workload Influence**
Experience	0.120
Light Factors	0.090
Currency	0.080
Intra-Flight Coordination	0.060
Primary Task Complexity	0.056
Concurrent Task Complexity	0.053
Airspace Coordination	0.045
Flight Profile	0.045

Finally, participants indicated during follow-up interviews that they expected automation would reduce their cognitive workload. While the anticipated magnitude of reduction varied, participants universally agreed that automation would be useful in reducing pilot cognitive workload in complex situations when cognitive overload is most likely.

In general, the data from this study revealed that no one subfactor is so dominant and influential that its automation alone could significantly reduce pilot cognitive workload. Instead, researchers assess that automation is likely to be needed in many subfactor areas to meaningfully reduce pilot cognitive workload.

D. RECOMMENDATIONS FOR FUTURE RESEARCH

Though the qualitative outputs of this method provide useful insights, the major takeaway is the identification of areas future research should explore in greater depth to inform finite task automation requirements. Based on the information elicited through interviews and data analysis, the research team has three recommendations for future research.

First, researchers recommend a task analysis be completed to determine what finite tasks impact the influencing factors and subfactors identified in this study. Those results could be used to evaluate the potential impact of task automation on pilot cognitive workload using a discrete-event modelling and simulation tool such as Improved Performance Research Integration Tool (IMPRINT).

Second, researchers recommend that the empirical threshold for pilot cognitive overload be measured and used to complement the pilot cognitive workload self-assessments identified in this project. This would allow the development of more accurate cognitive workload models and would provide more insight into the magnitude of cognitive workload reduction resulting from task automation.

Finally, researchers recommend that the cognitive workload capabilities of low-ability pilots (i.e., pilots with minimal flight experience) be assessed. This knowledge would help inform what tasks should be automated to avoid pilot cognitive overload in the user group most likely to experience it.

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We would like to express our sincere gratitude to Dr. Lawrence Shattuck and Dr. Robert Semmens for their invaluable advice, vision, guidance, patience, and encouragement throughout our capstone project. Their immense knowledge, research experience, and wisdom in both the human and technical domains of our subject area were essential in guiding us through the research process. Their mentorship and dedication to our academic development were vital in helping us overcome the challenges our research imposed.

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I. INTRODUCTION

A. BACKGROUND

The Army is developing a new generation of aerial platforms and technologies as a part of the Future Vertical Lift (FVL) modernization initiative (Department of the Army [DA] 2019a). According to the 2019 *Army Modernization Strategy*, the aim is to increase the "maneuverability, endurance, lethality, and survivability of Army aircraft" by making a generational leap forward in aviation technology and capability (DA 2019a). Developing new platforms and operational concepts will ensure the Army has the capability to succeed in an increasingly contested and challenging battlespace.

Core to the FVL initiative is integrating revolutionary and disruptive new technologies to drive changes in Army Aviation's machinery, methods, and aircrew domains. FVL platforms will change Army Aviation's performance capabilities in terms of range, speed, and payload (DA n.d.). Just as essential, the fundamental differences between legacy aircraft and FVL platforms provide an opportunity to change the human-machine workload balance as well as the manner and means in which humans and machines partner to accomplish a mission. The impending change in human-machine interaction requires a ground-up re-examination of what tasks can and should be automated (i.e., handled by technology). This re-examination, coupled with new automation and technological capabilities, will drive the creation of new human-machine teaming methods, ensuring aircrew can leverage their cognitive power and attention on tasks that require unique knowledge, expertise, and judgment.

The historical means of function allocation in legacy Army Aviation platforms has been static allocation (Fitts 1951). This means that pilots perform a certain set of functions while machines perform a different set of functions. While this function allocation and task automation strategy has been in use for decades, its main limiting factor is that it does not account for, or adjust to, the varying cognitive workloads required of pilots during different phases of flight or mission execution environments. Consequently, there is a potential for pilots to reach cognitive overload during particularly demanding mission profiles or conditions. Without function allocation or decision aid changes, pilot cognitive workload is expected to substantially increase with the inclusion of new technologies, data streams, and situational awareness tools on FVL platforms (M. Shivers, email to capstone advisor, May 27, 2021). Excessive cognitive workload can be detrimental to the aircraft's safe, efficient, and effective employment. As such, the FVL program is seeking to change existing human-machine function allocations by re-assessing what tasks should be automated to avoid pilot cognitive overload.

B. PROBLEM STATEMENT

The development of new platforms and technologies offers the Future Vertical Lift development team an opportunity to fundamentally re-imagine the function that aircrew serve, the methods of mission execution, and the core role automation plays in aviation. Key to this effort is gaining an understanding of pilot cognitive workload and its sources. Given constrained resources, this knowledge will help the FVL development team make informed decisions on where to invest their limited resources (e.g., time and money) to have the biggest impact on reducing pilot cognitive workload.

C. RESEARCH QUESTIONS

The primary research question of this project is: what tasks make sense to automate for Future Vertical Lift? (Note: the term "tasks" in this research question does not refer to any specific, pre-determined set of army aviation tasks with defined sub-tasks, conditions, and standards. Instead, it is used in the cognitive sense as a broad reference to anything that requires a pilot to use their cognitive power to access, retrieve, process, or otherwise use information.)

To address this high-level research question effectively, three sub-questions emerge:

- How should cognitive workload be assessed in FVL platforms?
- In an aircraft, how do attentional resources influence cognitive workload?
- Can influence diagrams model cognitive workload effectively?

D. STAKEHOLDERS

The primary stakeholders for this project are the Holistic Situational Awareness-Decision Making (HSA-DM) project team and Future Vertical Lift pilots, as shown in Table 1. The HSA-DM project team is a part of the U.S. Army Combat Capabilities Development Command Aviation and Missile Center (CCDC AvMC) Technology Development Directorate (TDD). This team will determine the task automation requirements for Future Vertical Lift. More specifically, they are responsible for identifying the main cognitive workload drivers, developing, and implementing cognitive workload management capabilities, and conducting the foundational work (e.g., architecture refinement, operational context decomposition, etc.) that will enable FVL development (email message to capstone advisor, 21 May 2021). Accordingly, the HSA-DM project team needs a cognitive workload prediction model to inform and validate FVL task automation requirements. Providing this model is the primary purpose of this project.

FVL pilots are also stakeholders for this project because they will be responsible for the safe operational employment of FVL platforms. In the context of this project, our goal is to avoid cognitive overload for these stakeholders. FVL developers can reach this goal by improving the cognitive workload management of FVL pilots through automation, allowing them to focus their limited cognitive capacity to those tasks that require their unique knowledge, expertise, and judgment.

Table 1. Stakeholder analysis

Stakeholder	Need	Goal
HSA-DM Project Team (CCDC AvMC)	Cognitive workload prediction model	Determine FVL task automation requirements
FVL Pilot	Improved cognitive workload management	Avoid cognitive overload

E. SCOPE

The scope of this project is limited to model development and verification with one mission scenario. The intent is to develop a model that can forecast cognitive workload, which will drive stakeholder understanding of major cognitive workload sources. This will enable informed decision making on task automation requirements development. All elements outside the boundary of the model (e.g., the methods used to gather context-specific cognitive workload data during FVL operation) are out of scope for this research project. Additionally, despite the primary stakeholder identifying seven operational context vignettes for their project team to consider, this research project will only use a MEDEVAC vignette for data collection and model verification.

F. PROJECT OVERVIEW

This purpose of this project is to provide useful information, models, and an understanding of pilot cognitive workload to assist FVL developers in determining task automation requirements. Accordingly, the four objectives of the project are:

- Elicit cognitive workload data from Army rotary-wing aviation pilots.
- Perform a quantitative and qualitative analysis of the elicited data.
- Produce an influence diagram (ID) model to convey the factors and subfactors that affect pilot cognitive workload
- Provide recommendations for automation requirements to reduce pilot cognitive workload.

This project uses a mixed methods approach, relying on scholarly literature and semi-structured interviews with army rotary-wing aircraft pilots to develop an influence diagram (Embrey et al. 2006). The team started by developing a seed model based on the literature (Embrey et al. 2006). Next, the team used an operational vignette to elicit data from army rotary-wing aircraft pilots to inform the weights and scores for each influencing factor and subfactor. This enabled the research team to analyze the cognitive workload data to determine the most significant factors that contribute to pilot cognitive workload.

Finally, the team re-engaged select pilots to verify the model and elicit insights on the potential impact task automation could have on pilot cognitive workload. The findings were used to make recommendations on how to reduce FVL pilot cognitive workload.

This report is arranged in six chapters. The literature review (Chapter II) examines previous research relevant to this project and provides a summary of the relevant literature for the reader. Next, the methods (Chapter III) explain the research and data collection design. Following that, the researcher team presents the results and key findings associated with the research (Chapter IV). Researchers then discuss and provide an interpretation of the key results and their implications (Chapter V). Finally, the research team offers conclusions, recommendations, and identifies opportunities for future research (Chapter VI).

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II. LITERATURE REVIEW

A. INTRODUCTION

The literature review provided the capstone team the knowledge needed to understand the problem and develop a suitable research approach. During this effort, the capstone team identified previous research relevant to this project. This chapter summarizes the relevant literature for the reader.

B. FUTURE VERTICAL LIFT

In accordance with the 2019 Army Modernization Strategy, the Army is developing a new family of military aircraft – Future Vertical Lift (DA 2019a). These aircraft are expected to incorporate a generational leap forward in technology that will keep Army Aviation capable of supporting evolving operational employment concepts for decades to come (DA n.d.). The FVL family of systems will include manned and unmanned platforms that can accomplish a wide array of Army mission sets including reconnaissance, attack, air assault, and air movement (DA 2020a). Long term, the Army intends to replace many of its current and recently retired aircraft (e.g., OH-58, UH-60, RQ-7) with the Future Vertical Lift family of aircraft. Two manned aircraft variants, the Future Attack Reconnaissance Aircraft (FARA) and Future Long-Range Assault Aircraft (FLRAA), are currently in the technology maturation and risk reduction (TMRR) phase of procurement and are being led by the Army Program Executive Office-Aviation (PEO-AVN) (DA 2020b; DA 2021a). Additionally, the Army Requirements Oversight Council (AROC) recently approved the requirements for an unmanned FVL aircraft variant (the Future Tactical Unmanned Aerial System [FTUAS]), putting it on the path toward formal initiation as a program of record (DA 2021b).

Driving the need for FVL development is an aging fleet of legacy aircraft that have been employed heavily during recent wars and a need to maintain a competitive advantage while performing multi-domain operations on future, contested battlefields (Drwiega 2013). Maintaining a competitive advantage against near-peer adversaries necessitates having vertical lift aircraft that can fly farther, faster, and with more payload than legacy aircraft (DA 2019a). It also necessitates supporting pilots with the data and information they need to enable the effective and efficient employment of the aircraft. Improving aircraft performance capabilities is a challenging aerospace engineering problem that requires substantial improvements in aviation technologies when compared to legacy Army aircraft. Perhaps more challenging though, is finding a way to provide more information to pilots in a way that helps them maintain situational awareness in complex, highly contested, and dynamically changing environments without reaching cognitive overload (M. Shivers, email to capstone advisor, May 27, 2021). The Army CCDC created the Holistic Situational Awareness-Decision Making (HSA-DM) office to help address this problem area.

The Army acknowledges that legacy rotary wing pilots are already operating in a cognitive overload state at times due to the expanding requirements of pilots and co-pilots to fly the aircraft and manage complex mission sets (M. Shivers, email to capstone advisor, May 27, 2021). The HSA-DM office notes that legacy aircraft employ "multiple, disparate, redundant data thread sources [that] demand operator attention, leaving little time for higher level mission management" (M. Shivers, email to capstone advisor, May 27, 2021). This inhibits the effective processing of information and contributes to the high cognitive workload demanded of pilots. Adding to high pilot cognitive workload are dynamic mission sets that do not allow detailed pre-mission planning (e.g., medical evacuation missions) and the need to maintain situational awareness of multiple concerns (e.g., obstacle avoidance, threat, route, targeting, etc.) throughout the course of a mission. Without changes to function allocation and information management, new technology may significantly increase both the task load and cognitive workload of FVL pilots. Thus, the Army believes that managing pilot cognitive workload to avoid an overloaded condition is essential to the safe, effective employment of next generation aircraft (M. Shivers, email to capstone advisor, May 27, 2021).

C. COGNITIVE WORKLOAD

1. Overview

Chen et al. (2016) defined cognitive workload as the "load experienced by working memory when humans engage in a variety of cognitively intensive tasks" (34). Accordingly, they propose that cognitive workload is a construct of human working memory in which there is a limited capacity to process information. In a slightly different interpretation, Hart and Staveland (1988) defined cognitive workload as "a hypothetical construct that represents the cost incurred by a human operator to achieve a particular level of performance… [therefore] workload is human-centered rather than task-centered" (140). They suggest that workload is not an inherent property of a task and instead results from the interaction of task requirements, the environment in which they are performed, and the operator's perceptions, behaviors, and skills. Both definitions provided researchers with a working understanding of the factors (e.g., working memory, environment, operator's skills, etc.) that can influence cognitive workload. Given the desired outcome of this project (i.e., recommendations for automation requirements to reduce pilot cognitive workload) researchers assessed that cognitive workload refers to the cognitive resources required to perform a task or set of tasks in a specific environment (Embrey et. al 2006). This broad definition allowed researchers to explain cognitive workload to Army pilots and elicit their subjective assessments of cognitive workload without requiring the collection or interpretation of complex, empirical cognitive workload measurements.

Experiencing cognitive workload is not inherently bad. For example, Fitts (1951) noted that humans become inattentive while performing tasks that require little activity. Fitts surmised that loss of attention, specifically resulting from inactivity or boredom, causes human operators to perform poorly when they need to act, such as in an emergency or when equipment fails. As a result, Fitts asserted that human tasks need to involve activity to maintain an appropriate level of operator attention (i.e., avoid cognitive underload). More recently, Young and Stanton (2002) found that attentional resources diminish when there is a lower demand for attention and expands when there is a higher demand for attention. This reinforces Fitts' concept that a human operator should strive to have continuous cognitive workload demand to ensure that they maintain the attentional resources and mental alertness to quickly respond when needed (e.g., emergency procedures, mission changes, etc.).

In contrast to a cognitive underload state, cognitive overload occurs when the mental demands placed on a person exceed their capacity to satisfy those demands (Embrey et. al 2006). In cognitive overload, a person is more likely to make errors and fail to complete a task with an acceptable level of performance (NASA 2020). Other researchers have come to a similar conclusion about the risk of high cognitive workload, finding that as task and cognitive workload demands increase human operators make more errors (i.e., perform worse) (de Waard 1996; Teigen 1994). Most recently, Galant, Zawada, and Maciejewska (2020) explored the relationship between cognitive workload and performance in aircraft pilots, finding that a pilot's ability to effectively perform a set of tasks decreased as their cognitive workload increased. Their findings indicate that both the number of tasks and the intensity or complexity of a task can affect the cognitive workload associated with performing the task. They inferred that cognitive overload has a significant effect on the quantity of mistakes a pilot makes and their ability to satisfactorily perform critical flight tasks. These findings are in line with previous research on the impact of high cognitive workload on performance, generally shown by the Yerkes-Dodson curve depicted in Figure 1 (Yerkes and Dodson 1908).

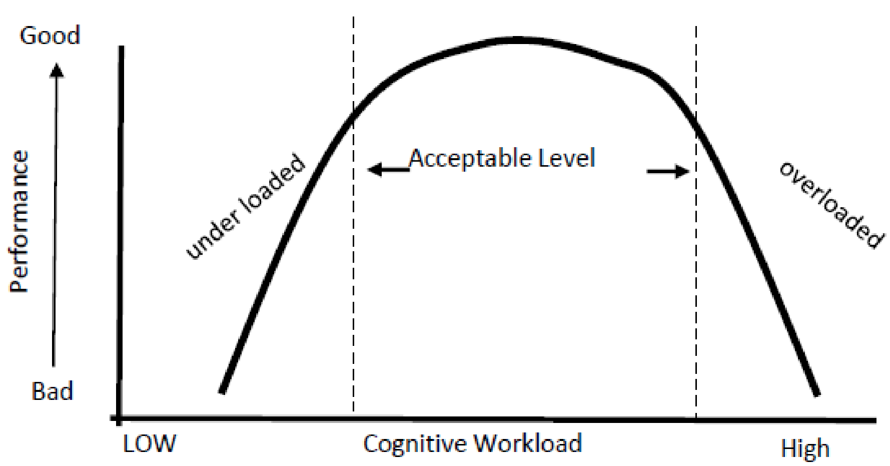

Figure 1. Yerkes-Dodson curve depicting the relationship between cognitive workload and performance. Source: NASA (2020).

2. Cognitive Workload in Future Vertical Lift

In relation to FVL, the literature suggests that if more tasks are required of pilots, or if the complexity of existing tasks increases due to the introduction of new technologies and capabilities, then the performance of pilots will likely decrease (Embrey et. al 2006; de Waard 1996; Teigen 1994; Galant, Zawada, and Maciejewska 2020). Similarly, the literature suggests that if the cognitive workload required of FVL pilots is exceptionally low, then they are likely to have a vigilance decrement and lack the attentional resources needed to be able to quickly respond to aircraft or mission contingencies (Fitts 1951; Young and Stanton 2002). In either case, investigators have determined that poor human performance (i.e., human error) has historically been the leading cause of aircraft accidents (Helmreich and Foushee 2010). Thus FVL designers should design the system so that pilots avoid both cognitive overload and underload conditions, helping ensure pilots can perform tasks at an acceptable level during FVL operation.

Without changes to function allocation between human and machine, the infusion of new technologies and capabilities in FVL platforms is expected to increase the workload of pilots through the addition of new and complex tasks (M. Shivers, email to capstone advisor, May 27, 2021). Accordingly, FVL designers will need to develop and implement a workload management strategy to prevent pilot cognitive overload. Two common methods of reducing pilot workload are adding manpower and adding automation. Additional manpower lowers the overall workload requirements of each individual by spreading the workload (i.e., tasks) between more people. In contrast, adding automation allows designers to allocate more functions and tasks to machines, thereby reducing the amount of work human pilots perform. Because additional manpower is expensive and would reduce the available aircraft payload, FVL designers are pursuing the development of automation and decision aids to reduce pilot cognitive workload (M. Shivers, email to capstone advisor, May 27, 2021).

3. Measurements

Understanding where automation should be infused to reduce pilot cognitive workload requires a contextual understanding of what variables (e.g., tasks, human factors, environmental factors, etc.) affect workload and human performance. The literature suggests both subjective (e.g., self-report rating scales) and objective (e.g., physiological or performance measurements) methods are viable options for assessing cognitive workload (Hart and Staveland 1988; Chen et al. 2016). The benefit of objective measures is that they provide empirical data researchers can quantitatively analyze. However, objectively measured empirical data cannot convey the source and context of the cognitive workload. In contrast, the strength of subjective cognitive analysis frameworks is that they consider outside factors, helping shed light on otherwise unnoticed conflicts such as unit standard operating procedures, fatigue, and level of task proficiency (Hart, Staveland 1988; Burns 2019). The focus of this project is to develop an understanding of the factors that influence pilot cognitive workload; therefore, researchers need qualitative information on the context of pilot workload. As such, a subjective method will best assist the research team in understanding the impact individual, situational, and aviation-specific workload factors have on pilot cognitive workload.

D. INFLUENCE DIAGRAM

An influence diagram is a "graphical representation and process for modelling complex relationships between variables that influence the probability of [event] outcomes." (Embrey et. al 2006, 102) Though initially developed to evaluate complex decision-making problem sets and used most often in connection with Bayesian networks, influence diagrams have recently been adapted to model the factors that influence the outcome of a certain situation (Bielza et al. 2011; Embrey et. al 2006). For example, Barsnick (2002) used an influence diagram to model the factors that impact combat outcomes, exploring the impact that humans and other influences have on combat decision-making. Similarly, Embrey et. al (2006) used an influence diagram to explore the factors that influence ship bridge operator cognitive workload and Luoma et. al

(2021) used an influence diagram to explore the relationship different aspects (e.g., social, ecological, and technical) have on biofouling management in shipping operations. These uses of influence diagrams to capture the relationships and influences that an array of factors have on the outcome of a situation show the unique insight that an influence diagram models can provide to complex problem sets. Based on these examples, researchers assessed that the use of an influence diagram was the best of the methods considered for modeling the factors that influence pilot cognitive workload.

E. AVIATION PROBLEM SET CONTEXT

Before developing an influence diagram model, it is important to understand the context of the problem set. In terms of aviation, the fundamental basics of pilotage task management is captured in the adage "aviate, navigate, communicate." (Federal Aviation Administration (FAA) 2018) This simple motto reminds pilots to focus their attention and cognitive ability on flight related tasks (i.e., controlling the aircraft) before attending to tasks that are less essential (e.g., making radio transmissions). Though basic, when pilots reach the point of task saturation or cognitive overload, this approach helps them prioritize the performance of flight critical tasks while delaying the performance of other tasks. In relation to this project, the adage provides a construct to analyze the type of influences that affect pilot cognitive workload. For example, a factor that might influence the "aviate" (i.e., control the aircraft's attitude, airspeed, and altitude) workload of a pilot might include the aircraft flight profile (i.e., height above terrain, airspeed, etc.). Similarly, factors that might influence the "navigate" (i.e., understand where you are and where you are going) workload of a pilot might include environmental factors like visibility and wind. Finally, factors that might influence the "communicate" (i.e., transmit information to others) workload of a pilot might include the density of air traffic, class of airspace, or number of aircraft participating in a military mission.

While "aviate, navigate, communicate" can help understand some aspects of pilot workload and task prioritization, military flight missions can have unique factors that would be unlikely to present themselves in general aviation pilot workload studies. For this reason, using a vignette to explore pilot workload in an operational context is useful for illuminating influencing factors. Of the seven potential operational context vignettes identified for exploration by the HSA-DM project office, the research team elected to use a medical evacuation (MEDEVAC) vignette for this project (M. Shivers, email to capstone advisor, May 27, 2021). A MEDEVAC mission can be one of the most challenging mission sets for a military pilot to perform. Not only are there a plethora of unique factors that influence cognitive workload (e.g., the need to maintain a stable aircraft to enable patient medical care in flight) but the mission includes almost all the traditional workload factors (e.g., controlling and navigating the aircraft) as well. The difference from a traditional flight mission is that MEDEVAC pilots do not have the benefit of being able to perform detailed pre-mission planning, they just get in the aircraft and go. This means that MEDEVAC pilots must contend with all manners of challenges that range from unfamiliar terrain, unfamiliar threat location and disposition, and unique mission equipment needs (e.g., hoist, litter, jungle penetrator, etc.) to aircrew fatigue, compressed mission execution timelines, and general terminal area chaos (e.g., unfamiliar landing zone, dynamic landing plans, degraded visual environment, vulnerability to engagement, etc.). These influencing factors can make every aspect of fundamental pilot tasks (i.e., aviate, navigate, communicate) exceptionally challenging, resulting in a high pilot cognitive workload. Thus, using a MEDEVAC scenario is helpful for identifying influencing factors and understanding how they can impact pilot cognitive workload.

F. PILOT WORKLOAD SOURCES

With an understanding of the problem context, researchers performed a review of scholarly literature and Army experiential knowledge publications (e.g., field manuals, training circulars, instruction materials, etc.) to identify the factors and subfactors that influence pilot workload. These factors were used to develop an influence diagram and establish a hierarchy that depicts their relationship to pilot cognitive workload. The influencing factors were categorized into five broad primary factor categories: task demand, fatigue, environment, operational competency, and mission factors. During the literature review, 19 subfactors influencing cognitive workload were identified, shown in Table 2. The literature supporting each of the factors and subfactors, as well as their influence on pilot workload is described in the following sections.

Table 2. Summary of factors and subfactors influencing pilot workload

Factors	Subfactors
Task Demand	Task Type
	Memory and Information Processing Requirements
	Complexity
Fatigue	Crew Rest
	Time of Mission
	Operational Tempo
	Duration of Mission
Environment	Altitude
	Light Factors
	Temperature
	Visibility
	Wind
Mission	Airspace Coordination
	Intra-flight Coordination
	Risk
	Flight Profile
Operational Competency	Currency
	Experience

Of note, the research team used the ship bridge operator's cognitive workload influence diagram developed by Embrey et. al (2006) to assist in identifying what factors and subfactors might influence pilot cognitive workload. Researchers assessed that many of the influencing factors the authors identified as affecting the cognitive workload of ship bridge operators (e.g., fatigue, primary and concurrent task demands, task complexity, environmental conditions, etc.) also influence pilot cognitive workload and are likely common to many job domains.

1. Task Demand

The research team focused on attentional resource theory to identify the task demand factors that contribute to cognitive workload. Attentional resource theory suggests that performance gets worse as attentional resource demands of a task exceed the resources available (Young and Stanton 2002). Literature also suggests that operators can experience vigilance decrement, which occurs when an operator's performance decreases over time while executing a task, regardless of the attentional resources available (Davies and Parasuraman 1982; Caggiano and Parasuraman 2004; Wiggins 2011). Different factors such as attentional resource pool allocation, task type, memory requirements, stimulus processing rates, stimulus resolution, and time of execution all affect attentional resources and vigilance decrement in different ways (Parasuraman 1979; Nuechterlein, Parasuraman, and Jiang 1983; Wiggins 2011; Arrighi, Lunardi, and Burr 2011; Wahn and König 2015). Due to the relationship between attentional resources and vigilance decrement, the research team assessed that a similar relationship likely exists between attentional resource factors and cognitive workload whereby increases in attentional resource demands increase the cognitive workload requirements of an operator.

a. Task Demand Subfactor: Task Type

Multi-tasking is an inherent part of operating an aircraft and the various combinations of task types and the senses used to complete those tasks affects attentional resources differently. Arrighi, Lunardi, and Burr's (2011) quantitative study supports the idea that when humans use their visual senses for one task and simultaneously use their auditory senses for another task, they are using different attentional resources. This suggests that a human can perform two tasks (one spatial, one discriminatory) requiring sustained attention at once with no degradation if they use different senses (Arrighi, Lunardi, and Burr 2011; Wahn and König 2015). In another quantitative study, Wahn and König (2015) concluded that visual and auditory senses share attentional resources when two spatial tasks are performed. Therefore, the results of Arrighi, Lunardi, and Burr should be considered in the context of a paired spatial and discriminatory task but may not be applicable when considering two tasks of the same type. Based on both these studies, if one pilot task is spatial, requiring one sense (i.e., auditory), and a concurrent task is discriminatory, requiring another sense (i.e., visual), the concurrent task may not increase pilot cognitive workload. Conversely, if an operator is expected to simultaneously perform multiple spatial tasks, the attentional resources required will come from the same resource pool, regardless of whether different senses are used (Wahn and König 2015). Due to these findings, the task type of both primary and concurrent tasks likely impacts pilot cognitive workload.

b. Task Demand Subfactor: Memory and Information Processing Requirements

Memory requirements and information processing rates also influence attentional resources (Parasuraman 1979; Wiggins 2011). Tasks requiring memory and higher rates of information processing use more attentional resources and cause a larger vigilance decrement when compared to tasks with lower demands on memory or information processing (Parasuraman 1979; Wiggins 2011). Parasuraman (1979) conducted a study where participants performed simultaneous discrimination task requiring no memory, and a successive discrimination task requiring memory at both low and high rates of execution. He found that performance decrements occurred in tasks that required more memory and were performed at higher rates, suggesting that the combination of memory requirements and high rates of information processing cause performance decrements. Furthering support for memory’s effect on performance decrement, Wiggins (2011) conducted a study where pilots performed a flight simulation in which they performed tasks requiring different levels of memory retrieval. He found that there was a vigilance decrement in tasks requiring memory retrieval over time in comparison to tasks that did not require memory retrieval. The results of these studies suggest that memory and information processing rates are factors that likely influence cognitive workload.

c. Task Demand Subfactor: Complexity

The literature also suggests that task complexity can influence cognitive workload. Studies have shown that the more tasks a person simultaneously performs, the higher that person’s cognitive workload (Hoang et. al 2020). While there is some disagreement in the literature regarding whether humans truly perform tasks simultaneously or whether they are performed sequentially, there is no doubt that pilots are expected to simultaneously address multiple lines of effort that include controlling the aircraft, navigating the aircraft, and communicating (Welford 1967; Wickens 2002). Cognitive workload studies also suggest that people require more time to perform complex tasks (i.e., tasks that require multiple actions or focused effort to perform at an acceptable level) in comparison to simple tasks (Huang and Zhou 2016). Huang and Zhou also found that individuals completing complex tasks experienced a higher cognitive workload. This study suggests that the cognitive workload required to perform complex flight tasks will be greater than what is required to perform simple tasks. Therefore, the sheer quantity of tasks requiring pilot attention and action, as well as the relative complexity of those tasks, can impact pilot cognitive workload.

2. Fatigue

In addition to task demands, the literature identifies fatigue as a contributing factor to cognitive workload. The fatigue subfactors identified in the literature as influencing cognitive capabilities and workload include time of mission execution, the duration of a mission, crew rest, sleep, and operational tempo.

a. Fatigue Subfactor: Crew Rest

Pilot crew rest cycles encompass both downtime (i.e., time for off-duty activities of the pilot's choice) and sleep, which influence pilot cognitive performance (DA 2018, Nieuwenhuys et. al 2021). A lack of downtime and periods of low cognitive workload can contribute to pilot fatigue and exhaustion (DA 2018). Additionally, the amount and quality of sleep affects cognitive performance (Nieuwenhuys et. al 2021). Nieuwenhuys et. al conducted a mixed methods study to assess how sleep duration impacted cognitive performance on submariners during a 67-day mission. They found that the average amount of sleep and reaction time on the vigilance task declined for the participants over the 67-day period, indicating that sleep impacts cognitive performance. Although the researchers acknowledge other factors such as shifts, confined spaces, and lighting could have contributed to the impact on cognitive performance, the study suggests that the effects of sleep and fatigue on pilot cognitive workload should be explored to better understand their impact and determine if automation can mitigate the effects.

b. Fatigue Subfactor: Time of Mission

The time of day a mission occurs relative to a pilot's circadian rhythm can have an impact on pilot performance and cognitive function. Garbarino et. al (2001) conducted a qualitative study that compared the percentage of sleep-related vehicle accidents to non-sleep related vehicle accidents, and the times of the day in which sleep-related accidents occurred using Italy's highway vehicle accident data. They found that sleep-related accidents accounted for 3.2% of all accidents and that the time of day greatly influenced the amount of sleep-related accidents. The sleep related accidents were in line with circadian rhythm as there were low rates of sleep-related accidents between 9–11 AM and 6–9 PM, and higher rates of sleep-related accidents in the early morning and early afternoon (Garbarino et. al 2001). This suggests that the time of day pilots perform missions relative to their circadian rhythm may affect sleepiness and subsequently influence their ability to effectively perform a task.

c. Fatigue Subfactor: Duration of Mission

The duration of a mission impacts fatigue, which influences a pilot's cognitive workload (Rosa et. al 2020). Rosa et. al conducted a quantitative study to assess fatigue's effects on cognitive performance in pilots over a long duration flight and assess when the effects of fatigue occurred. They measured the performance of cognitive tasks, subjective fatigue ratings, and metacognitive ratings while participants operated a fighter aircraft flight simulator over an 11-hour flight. They found that fatigue affected cognitive performance in terms of reaction time using a psychomotor vigilance task after seven hours of operation but found no changes in cognitive performance in any of the other cognitive functions. Although, this study did not identify many cognitive functions that degraded over a long mission, it does suggest that arousal and sustained attention (measured by reaction time) does decrease as fatigue increases (Rosa et. al 2020). Therefore, fatigue caused by a long flight or mission duration may cause a reduction in pilot cognitive capacity.

d. Fatigue Subfactor: Operational Tempo

Like the duration of a mission, operational tempo (OPTEMPO) contributes to fatigue, which can increase cognitive workload. Miller, Shattuck, and Matsangas (2011) conducted a qualitative study to assess the sleep patterns of Army Officers and their units during combat deployments as well as the mitigation techniques used to prevent fatigue during deployments. In their study, they asked Army Officers multiple sleep related questions that included categorizing their deployment as high, moderate, or low OPTEMPO, daily sleep and nap habits, and symptoms of sleep deprivation. The results indicated that officers in higher OPTEMPO environments received less sleep, fewer naps, exhibited greater sleep deprivation symptoms, and experienced higher levels of perceived stress (Miller, Shattuck, and Matsangas 2011). Based on their results and the previously discussed findings from Nieuwenhuys et al. (2021) regarding the impact of sleep on cognitive performance, researchers expect that OPTEMPO affects fatigue, which subsequently impacts pilot cognitive capacity and workload.

3. Environment

In addition to fatigue, the literature suggests that environmental conditions influence pilot workload. Environmental conditions include altitude and light factors as well as atmospheric conditions like wind, visibility, and temperature. Of note, most of the literature for environmental factors was found in Department of the Army publications, which references pilot workload rather than cognitive workload. The research team inferred that pilot workload is equivalent to cognitive workload.

a. Environment Subfactor: Altitude

Aircraft altitude affects pilot workload by impacting the physiological performance of the pilot as well as altering the performance characteristics of the aircraft (DA 2016, 2018). Flight relies on the interaction of control surfaces with the air to maintain positive control of the aircraft (DA 2016). In general, the higher the altitude, the less dense the air and the more challenging it is to control the aircraft (DA 2016). At higher altitudes, rotary-wing aircraft flight control inputs take longer to produce the desired control effect, making control of the aircraft more challenging and increasing pilot workload (DA 2016). At the same time, the lower oxygen density in a non-pressurized aircraft results in poorer pilot performance and physiological function, exacerbating the higher workload caused by aircraft performance (DA 2018). Simply put, as altitude increases, pilot workload increases and pilot performance worsens.

b. Environment Subfactor: Light Factors

The availability of light and its relative position impacts the workload of a pilot. As the availability of light decreases, pilot workload when flying under Visual Flight Rules (VFR) tends to increase due to the added challenges of perceiving aircraft position relative to terrain, other aircraft, and obstacles (DA 2018). Additionally, the position of light sources (e.g., sun, moon, cultural lighting, etc.) relative to the aircraft influences pilots' ability to decipher their position (DA 2018). Saleem and Kleiner (2005) reinforced the relationship between light factors and workload during a study of the effects of visual conditions on pilot performance, finding that VFR pilots perceived a greater workload during nighttime flight operations and during degraded visual flight conditions caused by light factors.

c. Environment Subfactor: Temperature

Temperature impacts pilot workload by affecting the performance of the aircraft and the cognitive and physiological capabilities of the pilot (DA 2016, 2018). The warmer the temperature, the higher the density altitude and the worse an aircraft performs with respect to lift capability and controllability (DA 2016). Like altitude, this can increase the workload of pilots while simultaneously decreasing their physiological capability (DA 2018). Extreme temperatures (high or low) also impact pilots' metabolic rates and oxygen requirements, decreasing their tolerance of hypoxia and impacting their ability to perform a task (DA 2018). Finally, extreme temperatures can be distracting and affect a pilot's ability to focus and physically perform the required tasks (DA 2018).

d. Environment Subfactor: Visibility

Visibility restrictions (e.g., dust, rain, fog, snow, etc.) reduce ambient light and decrease the visual acuity of pilots (DA 2016). The reduction in visual acuity increases the workload of pilots by making it more challenging to process aircraft position relative to potential threats (e.g., aircraft, obstacles, terrain, etc.) (Saleem and Kleiner 2005). Similarly, Gao and Wang (2020) found that poor weather (including conditions with restricted visibility) increased a pilot's perceived cognitive workload and the risk associated with flight operations.

e. Environment Subfactor: Wind

Strong wind conditions can create unsafe operating conditions for aircraft by increasing the need for pilot flight control inputs to counteract the wind effects and maintain control of the aircraft (DA 2016). The variable nature of wind (e.g., turbulence, thermals, gusting, etc.) can also increase the challenge of controlling the aircraft, thus increasing pilot workload (DA 2016). As with visibility and light factors, general aviation research has shown that piloting aircraft in adverse weather increases the cognitive workload of pilots (Gao and Wang 2020).

4. Mission

In addition to environmental factors, the literature suggests that mission-related factors influence cognitive workload. Specifically, airspace and intra-flight coordination requirements, risk (i.e., threat and patient criticality), and flight profile influence pilot cognitive workload. Like environmental factors, most mission-related subfactors were identified in Department of the Army publications.

a. Mission Subfactor: Airspace Coordination

The density of air traffic can greatly impact the workload of pilots based on the amount of deconfliction necessary to coordinate flight in a particular area (DA 2016). Additionally, in military environments, aircraft must deconflict and share airspace with other users such as other aircraft (manned and unmanned) and fires (e.g., artillery, air-to-ground, etc.) (DA 2020a). Regardless of nature of airspace co-users, airspace coordination and deconfliction is an essential component of a pilot's responsibility. Therefore, as airspace usage density increases, so does the need to maintain situational awareness and coordinate with other entities to deconflict flight routing, altitude, and timing, increasing pilot cognitive workload.

b. Mission Subfactor: Intra-flight Coordination

Like airspace coordination, the more intra-flight coordination (i.e., coordination within the pilot's aircraft or within a group of aircraft flying together) required, the higher the pilot workload (DA 2016). This is a result of the increased need to communicate time sensitive information (e.g., obstacles, threats, routing, airspace deconfliction, etc.) critical to the safe performance of flight operations. Additionally, the more crewmembers in an aircraft or the more aircraft operating in a flight, the greater the intra-flight coordination necessary to ensure synchronized and deconflicted efforts, which influences pilot cognitive workload.

c. Mission Subfactor: Risk (Threat / Patient Criticality)

The combination of military threat (i.e., "any combination of any combination of actors, entities, or forces that have the capability and intent to [cause] harm") and other mission variables creates a complex and challenging operational environment (DA 2019b, 1–3). The more complex an operational environment, the greater the mitigation measures (e.g., route, flight profile, external asset mitigation, etc.) a pilot must take to reduce the risk to flight operations (DA 2016). Mitigation measures generally increase the complexity of flight operations, thereby increasing pilot workload. Threat also induces stress, which Lieberman et. al (2005) showed to reduce cognitive performance in military personnel. Thus, the greater the risk and stress of a particular mission, the higher the expected pilot cognitive workload and the worse the expected cognitive performance. In the context of a MEDEVAC mission, the criticality of the patient (i.e., how quickly the patient needs to receive higher level medical care) can induce pilot stress. Therefore, patient criticality was included as a subfactor of risk.

d. Mission Subfactor: Flight Profile

Aircraft flight profile (i.e., height above terrain and formation) influences pilot workload. The closer an aircraft is to terrain, other aircraft, and obstacle, the higher the physical and cognitive demands on the pilot (DA 2016). This can be exacerbated by a limited field of view, reduced visual acuity and depth perception, and more complex aircrew coordination requirements, all commonly associated with flight near terrain (DA 2016). While thorough flight planning, pre-flight coordination, and increased proficiency can mitigate cognitive workload requirements, the added workload brought on by a challenging flight profile cannot be wholly mitigated or eliminated (DA 2016).

5. Operational Competency

In addition to mission factors, the literature suggests that operational competency influences cognitive workload. Specifically, flight currency and aviation experience (both general and task specific) influence operational competency and pilot cognitive workload. Like mission factors, operational competency subfactors were identified in part by Department of the Army publications.

a. Operational Competency Subfactor: Currency

Task currency, which is the recency with which a pilot has performed a specific task, impacts a pilot's proficiency in performing the task (DA 2016). Having a lower task proficiency can increase the workload associated with performing a task (Bosse et. al 2015). Therefore, pilot task proficiency is expected to influence the cognitive workload associated with task performance.

b. Operational Competency Subfactor: Experience

The experience of pilots, both overall experience and in a specific mission profile, directly impacts their ability to perform flight tasks efficiently and effectively (DA 2016). Flight experience also impacts a pilot's flight proficiency and their ability to mitigate the effects of particularly demanding flight environments (e.g., terrain flight), allowing them to safely perform complex tasks and missions (DA 2016). Causse, Chua, and Remy (2019) also found that pilots with more flight experience showed a better preserved spatial working memory performance, suggesting that more experience can reduce the cognitive workload associated with piloting an aircraft. Therefore, the more experience a pilot has, the lower the cognitive workload is expected to be for the performance of a flight task.

G. SUMMARY

Unmitigated, the inclusion of new technologies and capabilities in FVL aircraft is expected to increase the task burden and pilot cognitive workload associated with operating the aircraft during complex, dynamic missions. Understanding the factors that influence pilot cognitive workload will allow system designers to develop automation and mission aids to help manage cognitive workload to avoid pilot cognitive overload. Based on the aim of this research and the aviation problem area, researchers chose to use an influence diagram to model the relationship between pilot cognitive workload and the factors and subfactors that influence it. Based on the literature review, researchers identified five broad, primary factors and 19 subfactors that influence pilot cognitive workload. This knowledge will be used in the development of the influence diagram model, described in further detail in Chapter III.

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III. METHODS

A. OVERVIEW

The primary aim of this research project is to produce an influence diagram (ID) model that combines and assesses multiple influencing factors to determine what factors contribute to pilot cognitive workload and to what degree. This ID will facilitate answering the question of what tasks to automate in FVL. The research team used an approach similar to Embrey et al. (2006) to develop and test an influence diagram. Our method consisted of three distinct phases: Phase 1 – ID Development (Seed Model), Phase 2 – Interviews and ID Modification, and Phase 3 – Follow-on Interviews.

B. PHASE 1: ID DEVELOPMENT (SEED MODEL)

Phase 1 entailed the development of the initial ID (seed model) based on existing literature, U.S. Army aviation doctrine and training publications, and subject matter expert experience internal to the research team, which included three U.S. army aviators with diverse airframe and organizational experience (Embrey et al. 2006). The seed model is the rough draft of the ID and assisted in the identification and organization of the factors that contribute to cognitive workload (Embrey et al. 2006). It also enabled the research team to verify that the model can produce different cognitive workload scores for operational scenarios of varying difficulties (Embrey et al. 2006). Finally, the seed model structure served as an ID template for use during data collection, enabling researchers to elicit data from participants on influencing factors and associated weights during Phase 2 interviews (Embrey et al. 2006).

1. Design

The ID model consists of a top-level outcome, cognitive workload, and the factors and subfactors that collectively contribute to cognitive workload. The top-level outcome reflects the cognitive workload of a pilot by calculating the cumulative cognitive workload score of all influencing factors. The second level of the model is composed of the primary influencing factors, each with an associated weighted score that reflects its contribution to the overall cognitive workload score. The third level is composed of the influencing subfactors with an associated weighted score that reflects its contribution to the second level primary factor's cognitive workload score. Finally, the fourth and fifth levels are composed of the influencing subfactors and associated weighted scores that influence the next higher level. The ID is composed of the following components, which will be described in detail in subsequent sections (Embrey et al. 2006):

- Cognitive Workload Score – a calculated numeric value between 1 and 100 that indicates a level of pilot cognitive workload. There is no specific score that represents the threshold for cognitive overload, thus it is only meant to be used to compare the relative difference in the cognitive workload scores of different operational context scenarios.
- Factors/Subfactors – shown as boxes within the ID hierarchy, depicting the sources that influence cognitive workload.
- Factor/Subfactor Weight – a numeric value between 0 and 1 assigned to indicate the factor or subfactor's contribution to cognitive workload relative to other factors or subfactors within a hierarchical grouping.
- Subfactor Raw Score – a numeric value between 1 and 100 assigned to indicate the relative difficulty of the situation specific operational conditions affecting the subfactor (1 indicates a relatively benign condition and 100 represents an exceptionally challenging condition).
- Factor/Subfactor Weighted Score – a calculated numeric value between 0 and 100 computed by multiplying a factor or subfactor's weight by its raw score.
- Arrows – depict the hierarchical connections used to indicate influence between subfactors, factors, and cognitive workload.

During the literature review researchers identified 19 subfactors of cognitive workload, categorizing them into five broad primary factor categories. Researchers further decomposed the 19 subfactors into 31 subfactors that influence cognitive workload. This decomposition created division between the task demands of primary tasks (i.e., a pilot's main task such as executing flight control inputs) from concurrent tasks (e.g., other task demands a pilot might concurrently attend to such as making a radio call). The decomposition also added clarity and specificity by differentiating unique aspects of a general subfactor (e.g., separating sleep and downtime within the crew rest subfactor). Subfactors were decomposed only when needed to capture more contextual data during collection.

Researchers next created the seed model shown in Figure 2, depicting the expected relationships between the factors and subfactors. The top level shows the cognitive workload score. The second level depicts the primary factors influencing a pilot's cognitive workload: Environment, Fatigue, Mission, Task Demand, and Operational Competency. The third level depicts the subfactors that influence the second level factors. For example, the second level primary factor Environment has three subfactors that influence it, shown on the third level: Altitude, Atmospherics, and Light Factors. Similarly, the fourth level shows the subfactors for the influencing factors on the third level. For example, the third level subfactor Atmospherics has three subfactors that influence it on the fourth level: Wind, Visibility, and Temperature. Lastly, the fifth level shows the subfactors for the subfactors on the fourth level. A blank seed model can be found in Appendix A and the ID factor and subfactor definitions are listed in Appendix B.

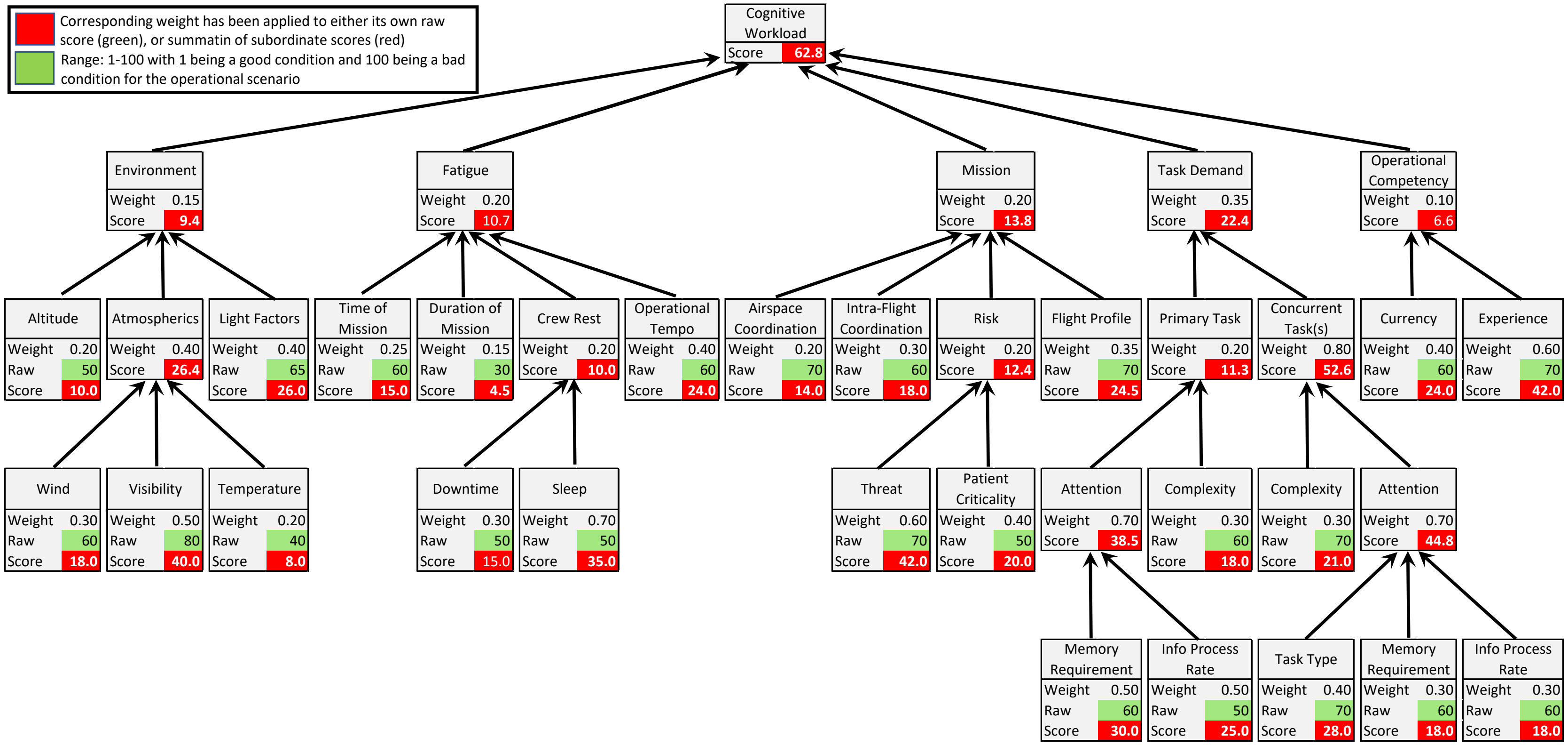

Figure 2. Cognitive workload seed model depicting values expected during a complex MEDEVAC flight scenario

a. Factor Weight

The weights of each primary influencing factor reflect that factor's proportional influence on the overall pilot cognitive workload. Similarly, the weights of each subfactor reflect that factor's proportional cognitive workload influence on the factor or subfactor that it influences. The weights are shown as a percentage; all the factor or subfactor weights for each hierarchical group add up to 100 percent (Embrey et al. 2006). This indicates that the collective cognitive workload influence for each decomposed factor or subfactor is fully considered. These weight percentages are subjectively assigned.

A factor with a greater influence on cognitive workload is assigned a higher value than a factor with a lower influence. For example, in the seed model shown in Figure 2, the Environment factor was assigned a weight of 0.15, Mission a weight of 0.20, Fatigue a weight of 0.20, Task Demand a weight of 0.35, and Operational Competency a weight of 0.10. These are all the factors that directly influence cognitive workload and they collectively account for 100% (i.e., 1.00) of the influence on cognitive workload. While the use of percentages for weights is not customary within the human factors area of research, it is most suitable for this project because it forces relative comparisons within factor groupings.

An example of factor weight assignment and verification of influence accountability using the Fatigue influencing factor is presented in Figure 3 and Table 3. Fatigue is a primary influencing factor to cognitive workload with a weight of 0.20. Time of Mission, Duration of Mission, Crew Rest, and Operational Tempo are subfactors of Fatigue and are assigned weights associated with their influence on Fatigue. As shown in Table 3, their weights add up to 1.00, indicating that all the influences on fatigue are accounted for.

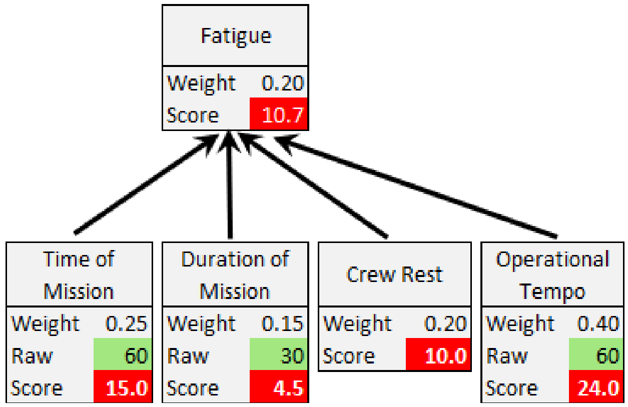

Figure 3. Seed model excerpt indicating subfactor weight assignments for weight accountability demonstration

Table 3. Weight accountability demonstration showing that subfactor weights account for 100% of influence on primary factor

Subfactor	Weight
Time of Mission	0.25
Duration of Mission	0.15
Crew Rest	0.20
Operational Tempo	0.40
Total	**1.00**

b. Factor Raw Score

Raw scores capture the operational conditions of a designated scenario situation and are shown in the green portion of the subfactors blocks on the seed model. The model uses the subfactor raw score and the weight to calculate the weighted score. Thus, the raw score determines the impact that situation specific conditions have on cognitive workload by impacting the weighted scores used to determine overall cognitive workload (Embrey et al. 2006). The model only uses raw scores for the subfactors at the lowest level of decomposition. This means that if a factor or subfactor is decomposed to a lower level then it does not have a raw score. Instead, raw scores from the lowest level subfactors are combined with the subfactor weight to determine a weighted score. The weighted scores of higher-level factors or subfactors are determined using the weighted scores of subordinate factors, thus there is no need for a raw score on the higher level of factors and subfactors.

A raw score is subjectively assigned a value on a scale of 1–100 (1 implies an optimal condition and 100 implies the worst possible condition) based on the situation specific conditions of the scenario (Embrey at al. 2006). For example, a pilot assessing a mission that lasts 12 hours (Duration of the Mission subfactor) might subjectively determine the condition to be challenging and assign it a relatively high score (i.e., close to 100). Conversely, when assessing a one-hour mission, the operator may subjectively determine that as easy and assign it a relatively low score (i.e., close to 1). Although Embrey 2006 used positive and negative scoring, the research team elected to do a positive scale from 1–100 with no negative scaling. The primary reason for this decision was because all factors and subfactors identified during the literature review were determined to contribute to cognitive workload, not take away from it. While changes to some factors or subfactors could help reduce cognitive workload, for simplicity during data collection the research team elected to frame the influencing factors and subfactors as contributors to cognitive workload. In this case, the weighted score captures whether the factor or subfactor's contribution to overall cognitive workload was small or large.

c. Factor Weighed Score Calculation

The weighted score is shown in the red portion of the factor and subfactor blocks on the ID. To calculate the weighted score of a factor with no subfactors, the raw score of the factor is multiplied by its corresponding weight (Embrey et al. 2006). To calculate the weighted score of a factor that has been decomposed, the weighted scores of each subordinate subfactor are added together and multiplied by the weight of the parent factor (Embrey et al. 2006). An example of the weighted score calculation using the Fatigue influencing factor (decomposition hierarchy shown in Figure 4) is presented in Figure 5.

Figure 4. Seed model excerpt indicating subfactor weights, raw scores, and weighted scores for use in weighted score calculation demonstration

Subfactor	Weight		Raw Score		Weighted Score
Downtime	0.3	x	50	=	15
				+	
Sleep	0.7	x	50	=	35
					50

Factor	Weight		Sum of Subfactor Weighted Scores		Weighted Score
Crew Rest	0.2	x	50	=	10

Subfactor	Weight		Raw Score		Weighted Score
Crew Rest					10
				+	
Operational Tempo	0.4	x	60	=	24
				+	
Duration of Mission	0.15	x	30	=	4.5
				+	
Time of Mission	0.25	x	60	=	15
					53.5

Factor	Weight		Sum of Subfactor Weighted Scores		Weighted Score
Fatigue	0.2	x	53.5	=	10.7

Figure 5. Example weighted score calculations to demonstrate calculation methodology

2. Development

The seed model weights were based on a generalized assessment of the factor and subfactor influences on pilot cognitive workload, not a specific operational scenario. Researchers relied on personal experience to subjectively assign weights to each primary factor based on its perceived influence on overall cognitive workload in a generic flight environment. Researchers assigned subfactor weights based on their perceived influence on the parent factor.

Once the weights were assigned, researchers ran through a simple and complex MEDEVAC scenario, assigning raw scores to verify the ID could calculate different cognitive workload scores for different operational conditions. The simple MEDEVAC scenario (described in Appendix C) included benign flight conditions and a straightforward mission scenario. Conversely, the complex scenario (described in Appendix D) included challenging flight conditions and a complex mission scenario. Researchers used their previous flight experience to reflect on how each of these conditions would impact the mission and assigned raw scores. Next, researchers calculated the cognitive workload score for each scenario to verify the seed model's ability to differentiate cognitive workload in two dissimilar operational contexts.

C. PHASE 2: INTERVIEWS AND ID MODIFICATION

Phase 2 entailed conducting interviews with Army rotary-wing aircraft pilots to validate the factors and subfactors identified from the literature review and to identify any influencing factors not accounted for in the model. These interviews were approved by the NPS Institutional Review Board (IRB). This phase also entailed validating the relationship hierarchy of the factors and subfactors. Lastly, researchers asked participants to provide weights and raw scores (where applicable) for each factor and subfactor in a simple scenario and a complex scenario. Although the research team used just one set of weights to internally verify the ID during Phase 1 (i.e., used the same weights for the simple and complex scenarios), researchers asked participants for factor weights for both the simple and complex scenarios. Researchers did this to help determine whether there are differences between factor weights during different scenarios. This knowledge allowed researchers to assess how cognitive workload influences change during different missions and it provided scoring anchors (i.e., the lowest and highest expected values for cognitive workload during a MEDEVAC scenario) that enabled the identification of the subfactors with the highest influence on pilot cognitive workload.

1. Participants

Researchers collected data from 20 U.S. Army rotary-wing aircraft pilots stationed at Joint Base Lewis-McChord and assigned to either an Assault Helicopter Battalion (AHB), an Army Special Operations Aviation (ARSOA) Battalion, or a National Guard (NG) General Support Aviation Battalion (GSAB). Each participant was a current and qualified aviator and serving in a flight position as their primary duty. Collectively, the participants had flown over 15 different aircraft (e.g., MH-60M, HH-60M, MH-47G, AH-64E, etc.), indicating a diverse set of operational backgrounds and aviation experience. Participants were also diverse in both their years of flight experience (summarized in Table 4) and their quantity of flight hours (summarized in Table 5).

Table 4. Research participant flight experience (years)

Years of Flight Experience	Quantity of Participants
1-5	7
6-10	6
11+	7

Table 5. Research participant flight experience (flight hours)

Flight Hours	Quantity of Participants
0-499	5
500-999	4
1000-1999	5
2000+	6

2. Procedure

Following IRB and local command approval, researchers recruited participants via bulk email (Appendix E). Researchers conducted in-person interviews with participants using a semi-structured format and an interview script (Appendix F). A pair of researchers (one to read the script and ask questions and the other to take notes) conducted interviews with one participant at a time. With the consent of participants, researchers also audio recorded the interviews to enable data transcription.

Researchers started each interview by asking participants to complete a demographics questionnaire (Appendix G) to capture their experience and qualifications. Next, researchers presented an ID (shown in Figure 6 and found in Appendix H) and explained the general structure of the model, the relationships depicted between factors and subfactors, and how the model uses weights and raw scores to determine pilot cognitive workload. The ID consisted of the influencing factors and subfactors from the seed model with no weights or raw scores. Each subfactor with no subordinate subfactors consisted of two sets of blank weight and raw scoring spaces, one for the simple scenario (teal and yellow boxes on top portion of each subfactor box), and one for the complex scenario (pink and tan boxes on the bottom portion of each subfactor box). Each influencing factor or subfactor with subordinate factors (i.e., no raw score data needed) consisted of two blank weight score spaces, one for the simple scenario (teal) and one for the complex scenario (pink). Finally, researchers provided each participant with a copy of the model definitions and examples for each factor and subfactor (Appendix B) as well as a copy of the scenario descriptions for a simple and a complex MEDEVAC mission (Appendices C and D).

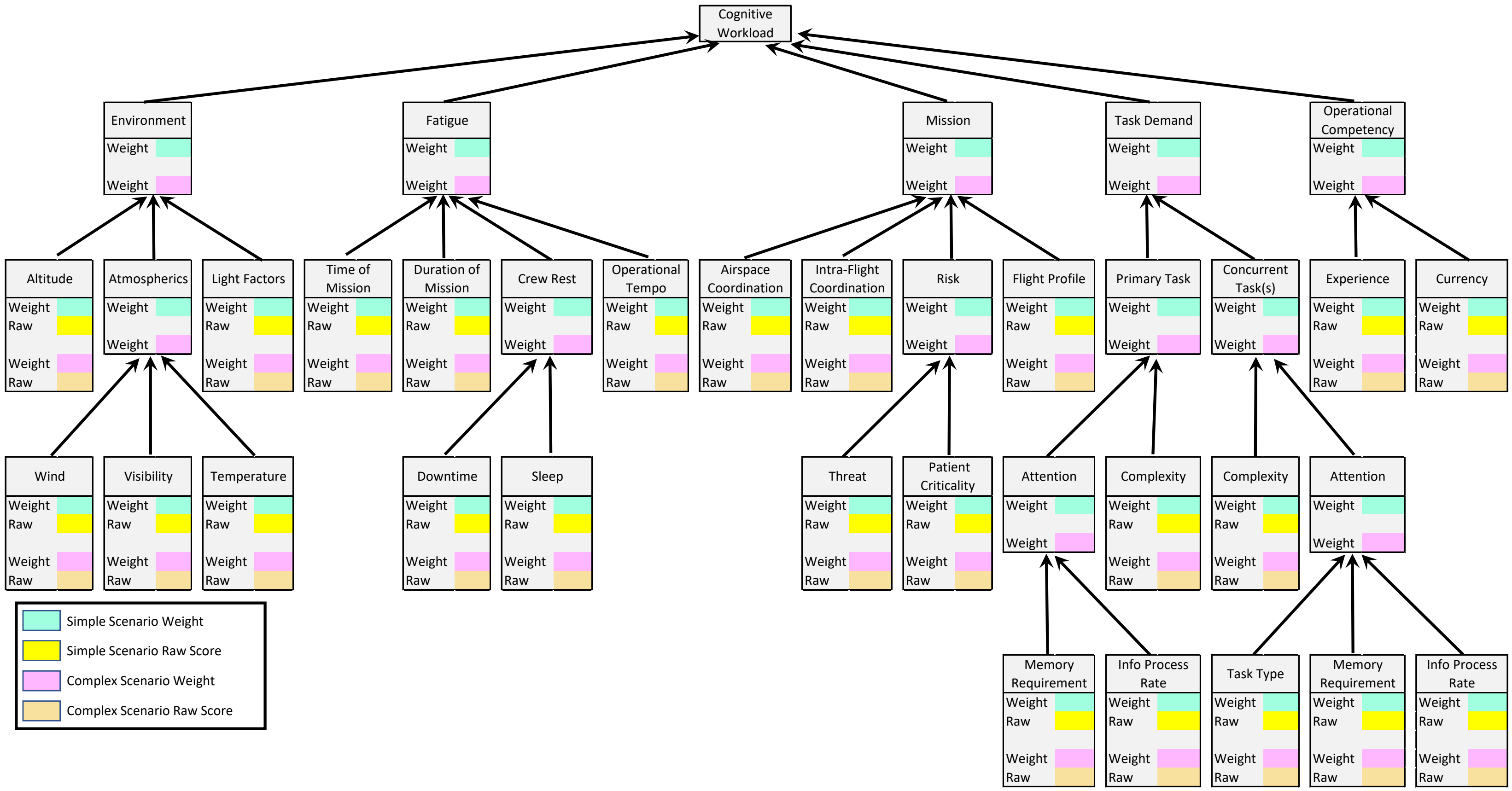

Figure 6. Sterile influence diagram used to collect participant data during interview

After explaining the model and answering questions, researchers presented the simple MEDEVAC scenario. After ensuring comprehension of the scenario, researchers asked participants to provide a raw score for each subfactor specific to the simple scenario conditions. After collecting raw score data, researchers asked the participants to assign a weight to each factor and subfactor relative to the others within its hierarchical grouping. Participants handwrote the raw scores and weights on the ID model in the respective block.

After participants provided data on the simple scenario researchers presented the complex MEDEVAC scenario. Like the simple scenario, researchers asked participants to provide raw scores and weights for the complex scenario. After collecting the raw scores and weights for both scenarios, researchers asked each participant what ID structural changes they recommend. Examples of structural changes include adding or removing factors or changing the hierarchy and relationships between factors and subfactors. Participant raw data can be found in Appendix I.

D. PHASE 3: FOLLOW-ON INTERVIEWS

The final phase of the research project entailed conducting follow-on interviews with a few previously interviewed participants. The goal of these interviews was to 1) verify the updated model (adjusted using data collected during initial interviews), 2) solicit ideas on how to automate the subfactors with the most influence on cognitive workload, and 3) verify that, if implemented, well-placed automation could reduce a pilot's cognitive workload.

1. Participants

Researchers recruited participants for the follow-on interviews from the pool of initial participants. In total, four pilots (two pilots with less than 500 flight hours and two pilots with more than 2000 flight hours) participated in the follow-on interview.

2. Procedure

Researchers directly emailed phase two interview participants to recruit follow-on interview participants (recruitment script shown in Appendix J). Researchers conducted follow-on interviews via Video Tele-Conference (VTC), using a semi-structured format and an interview script (Appendix K). A pair of researchers (one to read the script and ask questions while the other takes notes) conducted interviews with one participant at a time. With the consent of participants, researchers also audio recorded the interviews to enable data transcription.

Researchers initiated the follow-on interviews by re-orienting the participants to the influence diagram and how it functions. Next, researchers presented an updated ID model (Appendix L) for the complex scenario that included values for the raw scores, weights, and weighted scores based on the mean of the initial interview data. Researchers then presented a table showing the top 10 subfactors contributing to pilot cognitive workload based on the complex scenario initial interview data. Researchers specifically highlighted the top three contributors to cognitive workload for use during future interview questions.

Next, researchers asked participants to what extent automation or mission aids could mitigate the cognitive workload associated with the three most influential subfactors. Researchers captured participant responses using a five-response Likert scale. The researchers then asked the participants how they would like to see automation or mission aids used to address the three most influential sources of cognitive workload. After that, researchers described the complex MEDEVAC mission scenario (Appendix D) and asked the participants to provide updated raw scores for the three most influential subfactors previously discussed as if their automation and mission aid recommendations had been implemented. Researchers also asked the participant to estimate how much their cognitive workload for the three most influential subfactors would decrease if their automation and mission aid recommendations had been implemented. Researchers transcribed all participant responses on a data collection form (Appendix M).

IV. RESULTS

A. OVERVIEW

Using the method described in Chapter III, researchers developed an influence diagram seed model and interviewed Army rotary wing pilots to elicit cognitive workload data. Accordingly, the aim of this chapter is to present the results and key findings associated with the research. This chapter will focus on conveying the key data points that are important for answering the primary research question while leaving data interpretation for discussion in Chapter V.

B. PHASE 1: ID DEVELOPMENT (SEED MODEL)

As described in the Methods section, researchers identified five primary influencing factors and 31 subfactors that influence pilot cognitive workload during MEDEVAC missions. The seed model is shown in Chapter III Figure 2 and found in Appendix A.

C. PHASE 2: INTERVIEWS AND ID MODIFICATION

1. Overview

Researchers interviewed 20 Army rotary-wing pilots with varying operational backgrounds and levels of experience. The interviews verified the hierarchy of the ID seed model, provided cognitive workload data for simple and complex MEDEVAC mission scenarios, and provided qualitative data regarding the factors that influence pilot cognitive workload. Researchers used the data to determine the subfactors that have the greatest influence on pilot cognitive workload. This provides designers an idea of where to invest their limited resources (i.e., time, money, and manpower) to develop automation that will have the greatest impact on reducing pilot cognitive workload. This aids in answering the primary research question of what tasks make sense to automation in FVL. Overall, the results of this research are:

- ID Hierarchy – 18 of 20 participants agreed with seed model hierarchy and influencing factors

- Cognitive Workload – the expected cognitive workload for the complex scenario was significantly higher than that of the simple scenario
- Primary Factor Influences – the mission factor was the most influential on pilot cognitive workload during the simple scenario while the task demand factor was the most influential during the complex scenario
- Primary Factor Weights – there was a statistically significant difference between the primary factor weights between the simple and complex scenario for the Environmental factor but not for any other primary factors
- Subfactor Influences – the top three subfactors influencing pilot cognitive workload for the complex scenario were determined to be pilot experience, pilot currency, and light factors

The data supporting these findings are presented later in this chapter.

2. ID Hierarchy

The pilots interviewed generally agreed with the seed model hierarchy and influencing factors, with only 2 of the 20 participants recommending hierarchical relationship changes. The recommended relationship changes were to combine the temperature and altitude environmental subfactors and to create an influence relationship between crew rest and the information processing rates required for primary and concurrent tasks. Additionally, 6 of the 20 participants recommended creating a “personal life” subfactor within the fatigue category. The participants relayed that personal life circumstances such as finances, relationships, family dynamics, and other life stressors were distractions that added to their fatigue.

3. Cognitive Workload

The data collected showed different cognitive workload scores for the simple and complex scenarios for each participant in each scenario. This verified that the ID can effectively convey the cognitive workload differences of varying operational conditions. The participant cognitive workload values did not follow a normal distribution for either the simple or complex scenario. Accordingly, researchers used the median of the participant workload values to capture the midpoint of the distribution. A summary of the median cognitive workload values for both scenarios is shown in Table 6.

Table 6. Median participant cognitive workload values for simple and complex MEDEVAC scenarios.

	Simple Scenario	Complex Scenario	Delta
Cognitive Workload	9.14	76.22	67.08
Range of Individual Responses	1.00–39.98	42.94–94.16	22.46–82.76

4. Simple MEDEVAC Scenario

Participant raw scores and weights are not normally distributed. In response, researchers used the median value of each raw score and influencing factor weight to create an influence diagram for the simple scenario, shown in Figure 7 and Appendix N. The use of median values breaks the influence diagram constraint that the weights of each factor or subfactor grouping must add up to one. Thus, the maximum possible cognitive workload value achievable using the simple scenario influence diagram with the median factor weight values is 86.6. This maximum value is lower than that of the seed model due to the use of median values to represent weight values provided by the participants.

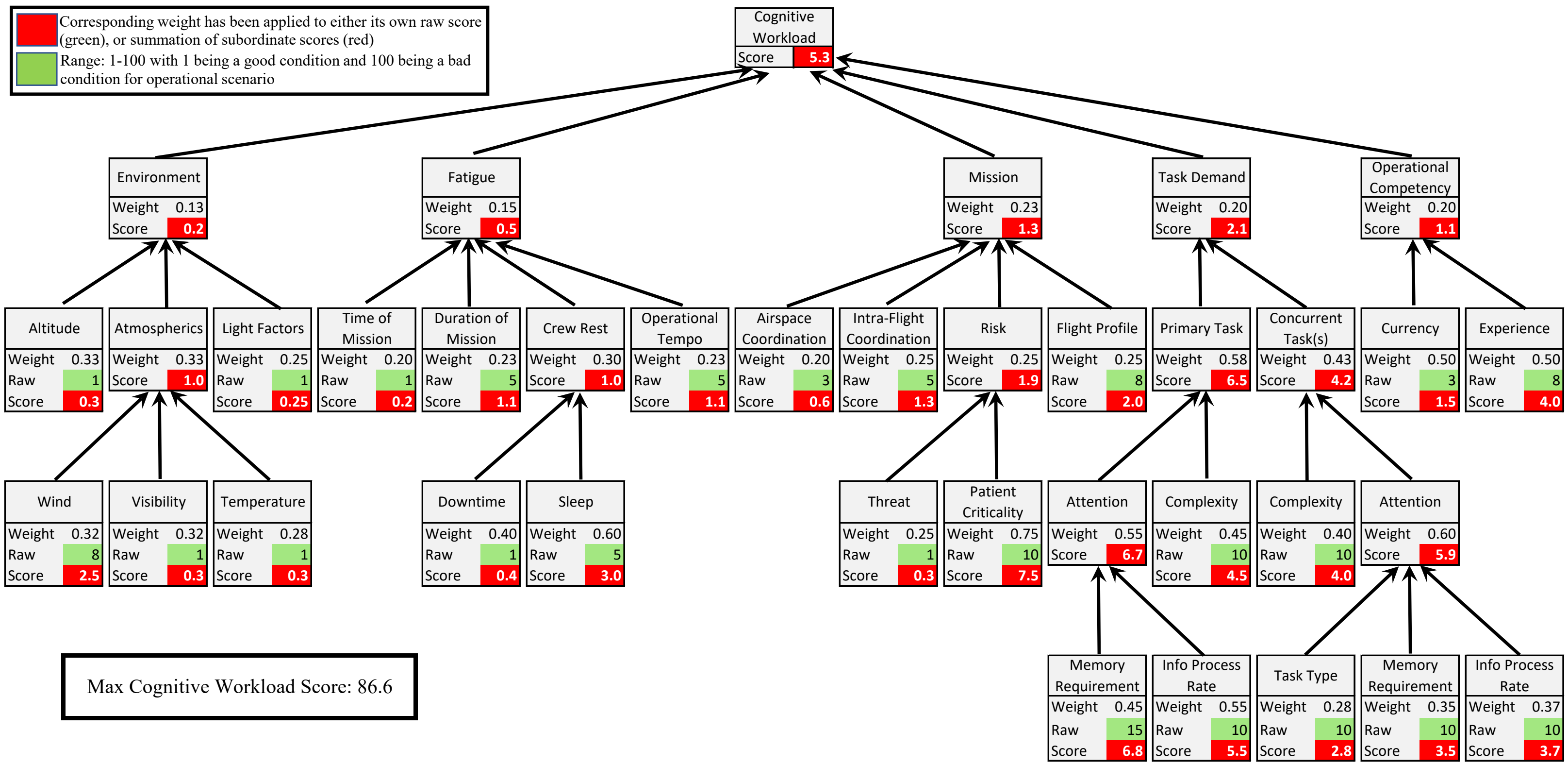

Figure 7. Simple scenario influence diagram showing the median values of all participants' raw scores and factor weights

The median weights of the primary factors from the simple MEDEVAC scenario are summarized in Table 7. This indicates that participants assessed mission subfactors to have the greatest impact on their cognitive workload while environment subfactors had the least impact on their cognitive workload. These values are useful for indicating the relationship between factor influences (i.e., which factors have more influence and which have less) but they do not necessarily capture the empirical relationship between factors.

Table 7. Median primary factor influence weights of simple MEDEVAC scenario.

Factor	Median Influence Weight
Mission	0.23
Task Demand	0.20
Operational Competency	0.20
Fatigue	0.15
Environment	0.13
Total Weight	0.91

5. Complex MEDEVAC Scenario

Like the simple MEDEVAC scenario, the complex scenario participant data are not normally distributed. As such, researchers used the median value of each raw score and influencing factor weight to create an influence diagram for the complex scenario, shown in Figure 8 and Appendix O. The use of median values breaks the influence diagram constraint that the weights of each factor or subfactor grouping must add up to one. Thus the maximum possible cognitive workload value achievable using the complex scenario influence diagram with the median factor weight values is 93.2. This maximum value is higher than the simple scenario model but lower than that of the seed model due to the use of median values to represent weight values provided by the participants.

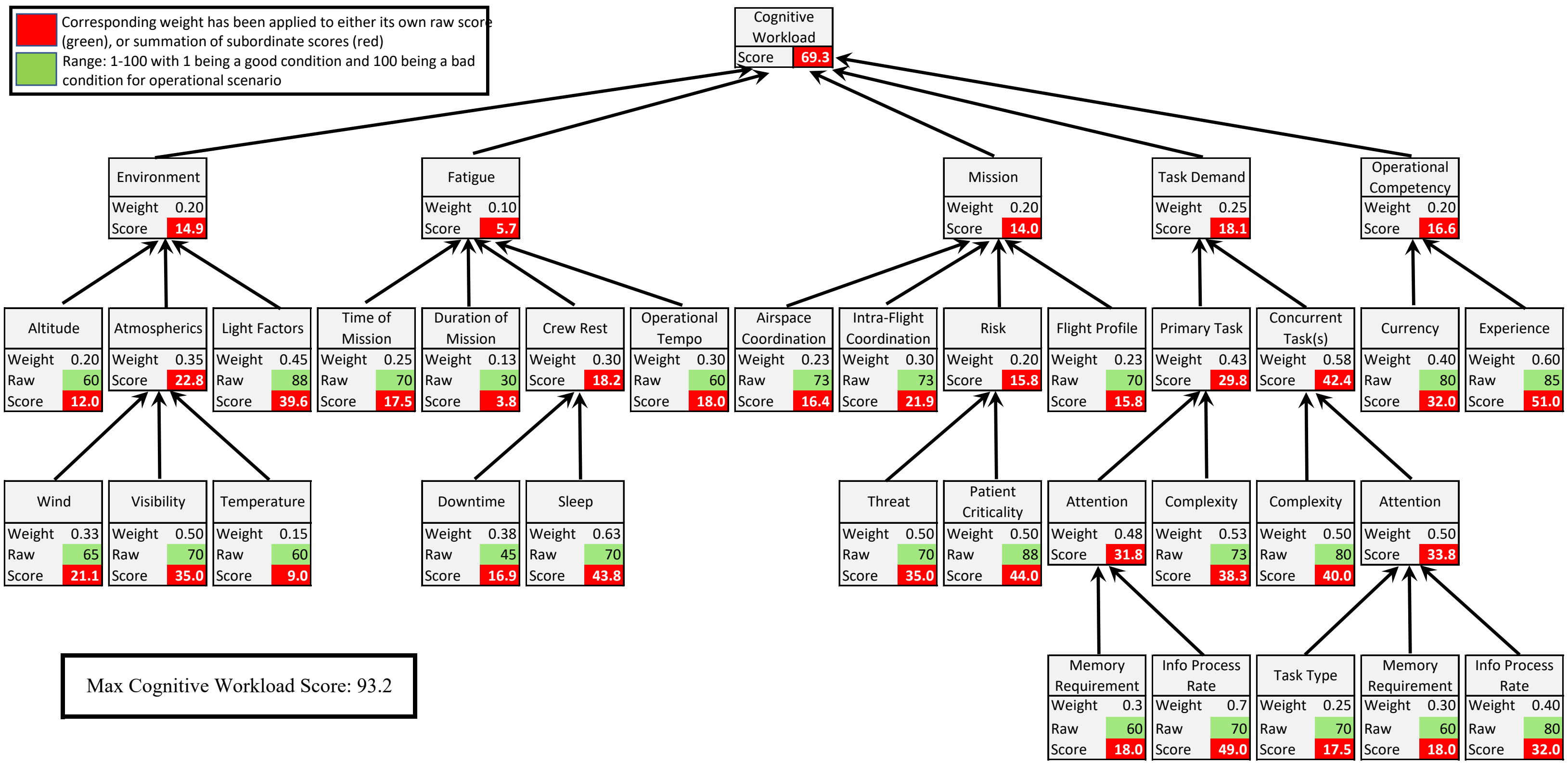

Figure 8. Complex scenario influence diagram showing the median values of all participants' raw scores and factor weights

The median weights of the primary factors from the complex MEDEVAC scenario are summarized in Table 8. This indicates that participants assessed task demand subfactors to have the greatest impact on their cognitive workload while fatigue subfactors had the least impact on their cognitive workload. These values are useful for indicating the relationship between factor influences (i.e., which factors have more influence and which have less) but they are do not necessarily capture the empirical relationship between factors.

Table 8. Median primary factor influence weights of complex MEDEVAC scenario.

Factor	Median Influence Weight
Task Demand	0.25
Environment	0.20
Mission	0.20
Operational Competency	0.20
Fatigue	0.10
Total Weight	0.95

6. Inter-Scenario Primary Factor Comparisons

a. Weighted Scores

The median weighted scores varied substantially between the simple and complex scenarios. The differences in weighted scores for the five primary factors are shown in Table 9 and differences of all the subfactor weighted scores can be found in Appendix P. These values show participants expected a substantially higher cognitive workload in the complex MEDEVAC scenario than the simple MEDEVAC scenario. These data show the expected pilot cognitive workload increases as the operational conditions worsen.

Table 9. Median primary factor weighted workload scores for simple and complex MEDEVAC scenarios.

Factor	Weighted Workload Scores		
	Simple Scenario	Complex Scenario	Delta
Task Demand	2.81	18.13	15.32
Operational Competency	1.07	16.19	15.12
Environment	0.59	14.04	13.45
Mission	1.56	14.33	12.77
Fatigue	0.72	6.49	5.77

b. Weights

The median factor weights also varied between the simple and complex scenario. The differences in weights for the five primary factors are shown in Table 10 and differences in subfactor weights can be found in Appendix Q. These values show that participants expected the relative influence of some factors to increase as operational conditions worsen (e.g., environment and task demand) while the relative influence of other factors decreases as operational conditions worsen across the spectrum of factor influences (e.g., fatigue and mission). The data also show participants expected the relative influence of pilot operational competency on cognitive workload to remain constant between operational scenarios.

Table 10. Median primary factor weights for simple and complex MEDEVAC scenarios.

Factor	Weighted Workload Scores		
	Simple Scenario	Complex Scenario	Delta
Environment	0.13	0.20	0.07
Task Demand	0.20	0.25	0.05
Operational Competency	0.20	0.20	0.00
Mission	0.23	0.20	-0.03
Fatigue	0.15	0.10	-0.05
Total Weight	0.91	0.95	0.04

c. Significance Test

The factor weights of the simple and complex scenarios are not normally distributed. As such, researchers used a nonparametric statistical test, the two-sided Wilcoxon signed-rank test, to determine the significance of differences of the matched samples for each participant. A summary of the results is shown in Table 11 and the full results can be found in Appendix R. This test showed a significant difference (i.e., p-value was less than 0.05) between the environment factor weights of the simple and complex MEDEVAC scenario. This means that the change in environmental factor weights between scenarios are likely the result of the scenario differences and not chance. The test showed no significant difference (i.e., p-value greater than 0.05) for any of the other primary factors.

Table 11. Wilcoxon signed rank test results comparing simple and complex MEDEVAC scenario primary influencing factors weights.

Factor	p-value	Assessment
Environment	0.0188	Significant difference
Fatigue	0.1648	No significant difference
Task Demand	0.2969	No significant difference
Mission	0.3185	No significant difference
Operational Competency	0.9407	No significant difference

7. Subfactor Influence Analysis

The influence of each lowest level subfactor (i.e., subfactors that are not decomposed and have raw scores associated with them) on cognitive workload was determined by multiplying the subfactor median weight by the median weights of each higher-level factor within its hierarchy. This allowed the direct comparison of subfactors within the same scenario to identify which subfactors have the greatest influence on pilot cognitive workload. A summary of the top eight most influential subfactors in the simple MEDEVAC scenario is shown in Table 12 and a summary of the top eight most influential subfactors in the complex MEDEVAC scenario is shown in Table 13. The full list of subfactor influences can be found in Appendix S.

Table 12. Top 8 most influential subfactors on cognitive workload in simple MEDEVAC scenario.

Subfactor	Cognitive Workload Influence
Experience	0.100
Currency	0.100
Intra-Flight Coordination	0.056
Flight Profile	0.056
Primary Task Complexity	0.052
Concurrent Task Complexity	0.046
Airspace Coordination	0.045
Patient Criticality	0.042

Table 13. Top 8 most influential subfactors on cognitive workload in complex MEDEVAC scenario.

Subfactor	Cognitive Workload Influence
Experience	0.120
Light Factors	0.090
Currency	0.080
Intra-Flight Coordination	0.060
Primary Task Complexity	0.056
Concurrent Task Complexity	0.053
Airspace Coordination	0.045
Flight Profile	0.045

D. PHASE 3: FOLLOW-ON INTERVIEWS

1. Overview

Researchers conducted follow-on interviews with 4 of the original 20 participants to explore the potential impact of automation. The major results are:

- Participants agree that cognitive workload can be reduced by adding automation or mission aids
- Participants have varying concepts of how automation could be applied to reduce the workload of different subfactor

- Participants vary in their estimate of how much cognitive workload can be reduced by task automation

The highlights of these results are presented in the following sections. The data and notes from each interview are shown in Appendix T.

2. Workload Mitigation Using Automation

Researchers asked participants to what extent they agree whether cognitive workload from the light factors, primary task complexity, and flight profile subfactors could be mitigated (i.e., reduce) by task automation. Participants responded using a 5-point Likert scale. A summary of participant responses is shown in Figure 9. Note, researchers chose the subfactors to explore based on the rankings of their influence in the complex scenario and an assessment of whether they were likely to be mitigated with automation based on participants' understanding of automation capabilities.

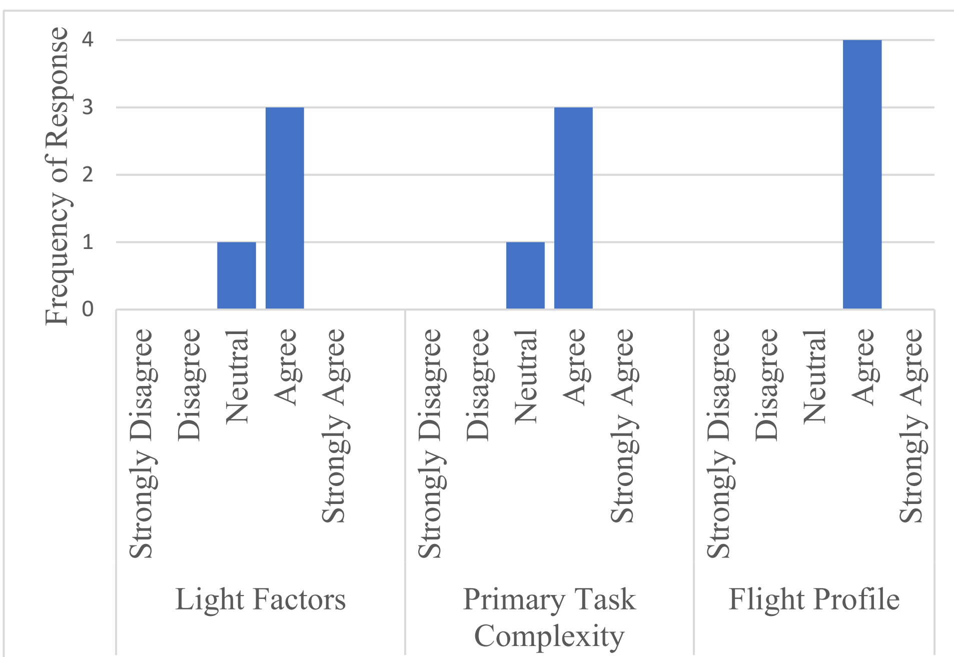

Figure 9. Bar chart showing agreement that automation can mitigate subfactor cognitive workload requirements

3. Automation Concepts

Researchers asked participants to convey how they would like to see automation used to mitigate the cognitive workload associated with the light factors, primary task complexity, and flight profile subfactors. The following subsections summarize participant recommendations for each subfactor.

a. Flight Profile

- Add or improve the aircraft flight director (used to display the required aircraft pitch and bank angles required to follow a designed flight path)
- Add tactile feedback mechanism (e.g., vibrating seat or vest) to communicate aircraft position information (e.g., buzz when below desired height above terrain)
- Add or improve heads up display to reduce the need to look at flight instruments in the aircraft
- Add or improve ability to display threats (e.g., terrain, other aircraft, etc.) as overlay on aircraft moving map display

b. Primary Task Complexity

- Enhance usability by simplifying system interfaces and allowing customization to suit user preferences
- Improve reliability and availability of existing automation to build user trust
- Add or enhance ability to couple the aircraft to the flight director (akin to autopilot where the aircraft makes flight control inputs to keep the aircraft on a designed flight path)

c. Light Factors

- Add or improve sensors for low illumination environments (e.g., forward looking infrared radar (FLIR), light detection and ranging (lidar), etc.)
- Add or improve ability to overlay and fuse data from multiple sensors on aircraft multifunctional display
- Add or improve night vision goggle capabilities

4. Automation Impact on Cognitive Workload

Researchers asked participants to assess the expected reduction in subfactor raw scores if developers implemented their individual task automation ideas. All participants expected cognitive workload to decrease with the implementation of automation. A summary of the subfactor weighted score changes and reduction in overall cognitive workload is shown in Table 14.

The influence diagram researchers used to collect these data displayed the mean values of all participants' raw scores and factor weights. Researchers made the decision to use mean values for the follow-up interview influence diagram prior to determining the data was not normally distributed. Researchers acknowledge that the actual cognitive workload decreases may differ given a different set of subfactor starting values (i.e., using medians instead of means as the before automation value). However, all participants indicated that they expected overall cognitive workload to decrease due to automation implementation. Therefore, researchers assess that participants are confident that task automation can reduce pilot cognitive workload, especially if used to address highly influential subfactors.

Table 14. Summary of the expected impact task automation would have on reducing cognitive workload

Subfactor	Time of Assessment	Subfactor Raw Score			
		Participant			
		14	17	18	20
Flight Profile	Before Automation	68.0			
	After Automation	63.0	56.0	50.0	61.0
Primary Task Complexity	Before Automation	66.8			
	After Automation	62.0	54.0	60.0	55.0
Light Factors	Before Automation	83.8			
	After Automation	78.0	50.0	40.0	80.0
Overall Cognitive Workload	Before Automation	69.3			
	After Automation	68.3	65.6	65.0	67.8
	Delta	**-1.0**	**-3.7**	**-4.3**	**-1.5**

V. DISCUSSION

A. OVERVIEW

We used the results presented in Chapter IV to answer the primary and sub-research questions. Our primary research question was what tasks make the most sense to automate? Understanding which factors influence cognitive workload during peak demand situations (i.e., a complex mission scenario) provided insight into what tasks should be automated to avoid pilot cognitive overload. While there were a few unexpected observations, we believe that the method we used and the results it produced largely answer our research question and sub-questions. This chapter will focus on discussing the key results and our interpretation of their implications.

B. PRIMARY RESEARCH QUESTION—WHAT TASKS MAKE SENSE TO AUTOMATE FOR FUTURE VERTICAL LIFT?

The most significant outcome of our research is the difference in cognitive workload values between a simple and complex MEDEVAC mission scenario. The large difference between cognitive workload scores (simple scenario: 9.14, complex scenario: 76.22) indicates that pilot workload varies significantly based on the operational conditions of the mission. Additionally, the workload values indicate that pilots experience exceptionally high cognitive workload during complex missions. We believe this makes clear the need for automation to assist pilots during FVL operations in complex situations.

Our results also indicate that there are a plethora of factors and subfactors that influence pilot cognitive workload. However, no one factor or subfactor is so influential or dominating that its automation could significantly reduce pilot cognitive workload. Instead, our results suggest that many subfactors have a noticeable influence on cognitive workload. As such, we believe that automation is likely needed in multiple subfactor areas to produce a meaningful reduction in overall workload. Therefore, we believe it is useful to explore the primary research question from both a high primary factor level and a more narrowly focused subfactor level.

1. Primary Factor Influence on Automation Requirements

A high-level analysis of primary factor influences, and the results of the Wilcoxon signed-rank test allowed us to better understand what broad task areas make sense to automate. The significant difference of the environment factor's influence between the simple and complex scenario suggests that as environmental conditions worsen, and the scenario becomes more complex, environmental conditions have a greater impact on cognitive workload. We think this means that environmental factors account for the biggest increase in cognitive workload when transitioning from a scenario where cognitive overload is unlikely (i.e., a simple scenario) to a scenario where cognitive overload is likely (i.e., a complex scenario). Therefore, tasks that are affected by the environment, such as light factors, make sense to automate because the environment's contribution to cognitive workload is significantly greater in situations where cognitive overload is likely. Thus, we think that automation should be developed to reduce the effect of environmental conditions on cognitive workload.

Although there was no significant difference between the other four primary factors in the simple and complex scenarios, we believe that the results still provide useful insight. In particular, pilots thought that task demand was the most influential factor in the complex scenario. They also assessed that the influence of task demand was higher in the complex scenario while the influence of the other three primary factors (fatigue, mission, and operational competency) stayed the same or slightly decreased. This suggests that as task demand conditions get worse and the scenario becomes more complex, task demand influences cognitive workload more. Therefore, we expect that automating tasks that impact the task demand factor and its subfactors would have a substantial effect on reducing cognitive workload in complex situations where cognitive overload is likely.

2. Subfactor Influence on Automation Requirements

In contrast to the high-level primary factor analysis, we believe that the rank ordered list of influencing subfactors (shown in Chapter IV, Table 13) provides more focused insight into tasks that make sense to automate. Although we analyzed both the simple and complex scenario, based on the cognitive workloads expected in each scenario we believe that FVL designers should use the complex scenario subfactor influences to inform automation decisions. We assess that cognitive overload is most likely in the complex scenario, thus that is when pilots need automation the most. Setting aside subfactors that do not lend themselves to automation right now (e.g., pilot experience and currency), our results indicate the subfactors influencing cognitive workload the most are light factors, intra-flight coordination, primary task complexity, concurrent task complexity, airspace coordination, and flight profile. We believe that tasks influencing these subfactors should be automated because it would result in the greatest potential cognitive workload reduction.

One aspect of subfactor influence we found interesting was that pilot experience and currency ranked in the top three most influential subfactors for both the simple and complex scenarios. Although using automation to address these factors would likely reduce cognitive workload the most, we expect that the automation needed to address these factors is likely not within the scope of HSA-DM's current work. However, we believe that additional research should explore whether automation affecting pilot operational competency is feasible within FVL's resource constraints (i.e., schedule and budget) because it could significantly reduce pilot cognitive workload.

Another interesting aspect is that light factors was the second most influential subfactor in the complex scenario but was not in the top ten factors for the simple scenario. This leads us to the same conclusion as the environment factor findings previously discussed. Namely, like its parent factor environment, pilots expect that as light factor conditions worsen, and the scenario becomes more complex, light factors have greater influence on cognitive workload. We think this means that FVL designers should consider automating tasks that are impacted by light factors because doing so would provide the greatest potential for cognitive workload reduction in peak demand situations.

C. RESEARCH SUB-QUESTION—HOW SHOULD COGNITIVE WORKLOAD BE ASSESSED IN FVL PLATFORMS?

Our literature review and interview results suggest that cognitive workload should be assessed using both qualitative and quantitative analysis. We believe that an empirically accurate quantitative cognitive workload value would be useful in objectively measuring pilot workload. We also think it would be useful in helping determine the threshold for cognitive overload. However, purely quantitative methods do not always provide the same level of insight as more qualitative techniques.

We developed an influence diagram seed model based on our literature review. Of the 20 pilots interviewed, 18 agreed with the cognitive workload factors identified and their hierarchy. This suggests that the qualitative approach provided value in confirming the influencing factors and their hierarchy with respect to pilot cognitive workload. Furthermore, the influence diagram enabled the capture of pilots' subjective cognitive workload assessments in simple and complex scenarios. This provided insight into how subfactor cognitive workload influences change based on the conditions and complexity of different missions. Given the importance of our qualitative data to our research question, and the value that quantitative measurements could provide, we believe that both types of data are essential to understanding pilot cognitive workload.

D. RESEARCH SUB-QUESTION—IN AN AIRCRAFT, HOW DO ATTENTIONAL RESOURCES INFLUENCE COGNITIVE WORKLOAD?

As expected, we believe our results indicate that as attentional resource demand increases, pilot cognitive workload increases. As discussed in Chapter II, the attentional resource subfactors identified for primary and concurrent tasks were memory requirements, information processing requirements, and task type (only applicable to concurrent tasks). Although none of these individual subfactors made it into the top eight most influential subfactors, they greatly influence their parent factor, task demand. As previously discussed, task demand was the most influential primary factor in the complex scenario. Therefore, we surmise that pilot attentional resource availability and the demands placed on them have the potential to significantly affect pilot cognitive workload.

E. RESEARCH SUB-QUESTION—CAN INFLUENCE DIAGRAMS MODEL COGNITIVE WORKLOAD EFFECTIVELY?

We believe that the vastly different cognitive workload scores between simple and complex scenarios shows that influence diagrams can effectively model and assess cognitive workload for different operational situations. We believe that the low cognitive workload value of the simple scenario (9.14) is reasonable based on the simplicity of the scenario. Additionally, we believe that the high cognitive workload value of the complex scenario (76.22) and its significant difference from the simple scenario is reasonable given the scenario's challenging conditions and high complexity.

1. Influence Diagram Scaling

We deliberately chose to model one of the simplest MEDEVAC scenarios that we believe would be a realistic mission. We also deliberately chose to model one of the most complex and challenging MEDEVAC scenarios that realistically would be performed. As such, we believe that the two scenarios analyzed likely represent anchor points for the best- and worst-case cognitive workloads pilots can expect during a MEDEVAC mission.

The influence diagram scaling that our results produced is slightly different than we expected. We expected the cognitive workload scale to remain 1–100 and the weights of factor groupings to add up to one. This expectation was based on our assumption that the weight data collected would be normally distributed. This would have allowed us to use the mean of our participant data to represent the central tendency in our influence diagram factor weights. However, our participant data was not normally distributed, so we used the median value to represent the central tendency of our participant data. The impact of using medians is that it breaks the constraint that the factor weights must add up to one for each hierarchical factor grouping. The removal of this constraint effectively changes the cognitive workload scale for each scenario (e.g., the complex scenario cognitive workload scale is 1–93.2). It also means that comparing cognitive workload values between scenarios that use different weights (such as the simple and complex scenarios) is not straight forward. Thus, it may not be empirically accurate to directly compare the cognitive workload values between different scenarios due to slightly different scaling. However, we still believe it is valid to compare workload values between scenarios to infer the general direction and magnitude of cognitive workload change. It just is not as straight forward as we had expected based on the results of previous research that used influence diagram models.

2. Cognitive Overload

Based on our results and the qualitative feedback from the pilots interviewed, we expect that the conditions in the complex scenario would likely result in pilot cognitive overload. However, based on the method used and our results, we cannot determine the point at which pilot cognitive overload occurs (i.e., we cannot determine a definitive cognitive workload value that equates to overload). Additionally, based on qualitative feedback during our interviews, we assess that the point of cognitive overload is likely different for each person. We think it would be useful to be able to definitively pinpoint when cognitive overload occurs so that we could predict its onset and use automation to avoid an overload state. However, we do not believe this is feasible in the near-term, given the dynamic nature and cognitive differences between pilots. Therefore, we recommend that FVL designers should automate tasks based on the low end of their target user population's cognitive capabilities. We believe that designing FVL to prevent cognitive overload within this low ability user group would be the best way to prevent cognitive overload within the greater population of FVL pilots.

F. ADDITIONAL OBSERVATIONS

1. Personal Factors

Although 18 out of 20 participants agreed with the influence diagram factors and hierarchy, 6 of the 20 participants recommended creating a "personal life" subfactor within the fatigue category. They relayed that personal life circumstances such as finances, relationships, family dynamics, and other life stressors were a distraction that added to their collective fatigue. Due to the consistency of feedback by multiple participants, we recommend this factor for inclusion in future pilot cognitive workload influence diagrams. However, it is unlikely that the impact of personal life stressors could be directly mitigated using automation.

2. Sample Size and Characteristics

This research project relied on a relatively small sample size in comparison to the population of Army rotary-wing aviators. We tried to recruit a diverse set of participants based on unit, aircraft qualifications, mission set specialty, flight experience, and gender. However, we acknowledge that our sample likely does not accurately represent the population. Additionally, we did not perform any inferential statistics to determine whether we can use the results from this sample to make predictions about the population. As such, we believe that the best use of our results is to inform future research activities and as a proof of concept for the use of influence diagrams to inform automation requirements.

G. PARTICIPANT TRENDS

1. Dunning-Kruger Effect

One of the most interesting observations from our interviews was the difference in opinion between junior and senior pilots about the scenario complexity and conditions. We found that junior pilots with minimal flight experience (e.g., pilots that recently graduated from flight school) assessed the complex scenario conditions as being more benign than more experienced pilots. For example, one of the junior pilots assigned lower raw scores (which capture the difficulty of the conditions) than the senior pilot in his battalion in 19 of the 24 subfactors, often by a large margin. We expected that experienced pilots would assign lower scores than junior pilots because they would likely have greater operating proficiency in those conditions, and they might have developed mitigation strategies to help cope with the workload. However, our results generally showed the opposite. We believe that our results might indicate the presence of the Dunning-Kruger effect (i.e., the cognitive bias of people with low ability to overestimate their ability, and of people with high ability to underestimate their ability) (Kruger and Dunning 1999). An alternative hypothesis is that junior pilots might not be able to appreciate the difficulty of piloting an aircraft in extremely challenging and complex conditions in the same way that experienced pilots likely can. Regardless of the cause, we still believe that the data from junior pilots is important to informing automation requirements because systems must be designed to equally support pilots with low and high ability.

2. Factor Weighting

In addition to the Dunning-Kruger effect, the way in which pilots thought about assigning factor weights was interesting. Pilots had to subjectively assign weights to influencing factors within the constraint that the weights in each hierarchical grouping must sum to one. Based on how pilots verbalized their decision logic, we observed that many pilots would quickly identify the one or two factors that had the most influence on their cognitive workload and assign relatively high weights. The pilots would then determine how much weight they had left to assign and spread that relatively evenly between the remaining factors. This indicates that the pilots were not thinking of weights as empirical values, but rather in an ordinal manner. This supports our assessment noted earlier that the influence diagram weights, and cognitive workload values should not be treated as empirically accurate or compared in an empirical sense. Instead, we think insights should be gleaned based on the ordinal changes between compared values. This also supports our assessment that additional quantitative research is needed to make an empirically accurate assessment of cognitive workload and of individual subfactor influence.

Another aspect of factor weighting that we found interesting was the fact that our Wilcoxon analysis only identified the environment factor as statistically significant between the simple and the complex scenarios. Using our method, for one factor influence weight to increase another must decrease. Based on this constraint we expected that if the participants universally agreed that one factor's weight increased, then they might also universally agree that another factor's weight decreased. This would have yielded at least two factors with significant differences between the scenarios, which was not the case. This means that participants agreed that the environment's influence on cognitive workload increased. However, they disagreed which factor decreased in influence to support the increase in environment influence. Most participants identified fatigue or mission as the factor that decreased in influence, though neither factor had a statistically significant difference from the simple scenario.

Finally, we noticed that there was a mismatch between our results and the robust literature examining the impact of fatigue on operator performance. Our results indicate that fatigue becomes less of a factor for pilots in complex scenarios. However, the literature suggests that fatigue has a large impact on operator performance and their ability to manage workload (Nieuwenhuys et. al 2021; Rosa et. al 2020). We suspect that pilots' perception of fatigue in our research was dominated by the scenario difficulty in the other primary factor domains (e.g., task demand, environment, etc.). We also suspect that this was exacerbated by the relatively short duration of the MEDEVAC mission (~2 hours) when compared to the long assault and air mobility missions that many of the interviewed pilots normally fly in combat (~6 hours). Therefore, due to the constrained weight distribution and mission duration, pilots may have under-rated the impact of fatigue. We wonder if our results would be the same if the factor weights within each hierarchical grouping did not have to add up to one. If the factor weights were not constrained then pilots may have weighted factors differently, resulting in a different distribution of factor influence on cognitive workload.

3. Pilot Thoughts on Automation

During the follow-on interviews, we asked pilots about their thoughts and feedback on what tasks could or should be automated, and what the implications of automation would be on their cognitive workload. In general, the responses provided seemed to be constrained to what pilots believe is possible now. The pilots interviewed, especially the more experienced aviators, seemed to limit their frame of reference to what they thought was feasible today and not what could be feasible in the future. Even though they all thought that cognitive workload would decrease with the addition of automation, their constrained ideas on what should be automated gave the impression that automation could only decrease pilot cognitive workload by a relatively small amount. Based on the many areas in which automation could conceivably be used, we believe that automation could collectively reduce pilot cognitive workload by a larger margin than the participants expect.

Another recurring theme during the follow-on interviews was that pilots were cautiously optimistic, at best, about the potential of automation. Many of the pilots interviewed expressed that they would be reluctant to trust automation due to their belief that it would be unreliable or not available when they needed it the most. They also expressed that the automation of certain tasks could actually increase their cognitive workload by forcing them to process what is happening while also monitoring the system's performance of the automated task. The pilots pointed out that they would need to understand how and why the automation was making decisions so that they could compare the system response to what their own response would be, effectively doubling their workload. Based on the pilots' sentiment, we believe that the FVL design team will need to find a way to build pilot trust in the system before automation can truly reduce pilot cognitive workload.

H. SUMMARY

Based on the results presented in Chapter IV and the analysis in this chapter, we believe that our research has been successful in answering our primary question and at least partially successful in addressing our sub-questions. Specifically, we believe that our results identified what tasks make sense to automate from both a high level (i.e., primary factor level) and a more narrowly focus level (i.e., subfactor level). The combined insight of those two perspectives identified multiple influencing areas which should be researched further to better understand how to use automation to reduce pilot cognitive workload. We also believe that our research showed influence diagrams are effective in modeling cognitive workload for varying conditions and operational scenarios. Though our influence diagram is not empirical and is best used in an ordinal manner, it does provide useful qualitative insights into the complex interactions between the factors and subfactors that influence pilot cognitive workload. Finally, we believe that our general observations (i.e., those not directly tied to the research questions) provide context that could be useful to the FVL design team when determining future research and task automation requirements.

VI. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY

This purpose of this project was to investigate pilot cognitive workload to assist FVL developers in determining task automation requirements. Specifically the four objectives of the project were to:

- Elicit cognitive workload data from Army rotary-wing aviation pilots.
- Perform a quantitative and qualitative analysis of the data.
- Produce an influence diagram model to convey the factors and subfactors that affect pilot cognitive workload.
- Provide recommendations for automation requirements to reduce pilot cognitive workload.

To achieve these objectives the research team reviewed scholarly literature to develop an understanding of what factors influence pilot cognitive workload. Next, researchers conducted semi-structured interviews with Army rotary-wing aircraft pilots to elicit cognitive workload data. After that, researchers performed quantitative and qualitative analyses of the elicited data to develop an influence diagram that models pilot cognitive workload and its influencing factors. Finally, researchers used the model and pilot data to develop recommendations for FVL task automation requirements and future research needs.

B. CONCLUSIONS

This research project showed that influence diagrams are an effective tool to model pilot cognitive workload. Researchers expect this knowledge and this project's influence diagram framework to provide useful insight into the factors that influence pilot cognitive workload. Researchers also expect this knowledge to help inform future cognitive workload and automation requirements research.

Analysis of interview results revealed a substantial difference between the expected pilot cognitive workload requirements of simple and complex MEDEVAC scenarios. A high-level analysis of the data revealed that task demand is the most influential primary factor during complex situations when cognitive overload is most likely. The data also revealed that the influence of environmental conditions on cognitive workload was significantly higher during the complex scenario. This indicates that as environmental conditions worsen, and a mission becomes more complex, environmental conditions influence pilot cognitive workload more.

A low-level analysis of the data revealed that no one subfactor was so dominant and influential that its automation could significantly reduce pilot cognitive workload. Instead, the data indicate that automation will likely need to be developed for many subfactors to have the effect of meaningfully reducing pilot cognitive workload. In particular, data analysis showed that light factors, intra-flight coordination, and task complexity (primary and concurrent tasks) are the subfactors that have the largest influence on pilot cognitive workload in complex situations. Thus, the development of automation to reduce those factors' influence has the greatest potential to decrease pilot cognitive workload.

Finally, analysis of the interview data indicated that the pilots universally agreed that automation could reduce their cognitive workload requirements during complex situations. However, the magnitude of cognitive workload reduction pilots expected varied based on the tasks being automated and how the automation was incorporated. Based on qualitative and quantitative interview observations, researchers recommend that the needs of low ability users should drive FVL task automation requirements. This will help ensure that FVL developers design systems to prevent cognitive overload in the user population most likely to experience it.

C. RECOMMENDATIONS FOR HSA-DM

Recommendations for task automation requirements and considerations that may impact automation development are:

- Determine task automation requirements by evaluating pilot cognitive workload during peak-demand situations (i.e., a complex mission with challenging conditions).

- Determine task automation requirements by evaluating the cognitive workload of the low ability target user group.

- Consider developing automation that will reduce pilot task demand (e.g., decrease task complexity or reduce task attentional resources demands).

- Consider developing automation to reduce the influence of poor environmental conditions on pilot workload (e.g., reduce the workload associated with flying in challenging environmental conditions).

- Consider developing automation to reduce the influence of light factors, intra-flight coordination, and task complexity on pilot cognitive workload.

- Evaluate the potential of automation to reduce the influence of pilot experience and currency on cognitive workload.

- Evaluate the effect of personal factors (e.g., life stressors) on fatigue and cognitive workload.

- Develop a strategy to build pilot trust in automation and ensure that automation has a high availability and reliability prior to fielding.

D. RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this project indicate that influence diagrams can be a useful tool in modeling the relationships and factors that influence cognitive workload. The qualitative outputs of this research also provide useful insight into pilot task automation requirements. However, the major project take-away is the identification of areas that future research should explore in greater depth to inform finite task automation requirements. Based on the information elicited through interviews and data analysis, the research team has three recommendations for future research.

The first recommendation is to conduct a study that explores in greater depth the factors and subfactors that are most influential on pilot cognitive workload during complex missions. The objective of this research would be to perform a task analysis to determine what finite tasks impact the influencing factors and subfactors identified in this study. Next, a discrete-event modelling and simulation tool like Improved Performance Research Integration Tool (IMPRINT) could be used to evaluate the potential impact of task automation on pilot cognitive workload. Understanding the impact of automation on cognitive workload would allow FVL designers to ensure that task automation achieves the desired effect of reducing pilot cognitive workload.

The second recommendation is to conduct a study that empirically determines cognitive workload. The objectives of this research would be to determine the empirical threshold for pilot cognitive overload and to use empirical data to validate the pilot cognitive workload self-assessments identified in this project. These data would lead to the development of more accurate tools to model and simulate pilot cognitive workload. It would also provide more insight into pilot automation needs by providing a better understanding of the magnitude of impact that automation can have in reducing pilot cognitive workload.

The final recommendation is to conduct a study on the cognitive workload of low-ability pilots. The objective would be to develop a better understanding of how cognitive workload requirements and influences impact low-ability pilots. These data would enable FVL designers to determine automation requirements such that low ability users avoid cognitive overload. In theory, this would ensure that that the preponderance of low and high ability pilots avoid cognitive overload while operating FVL aircraft.

APPENDIX A. COGNITIVE WORKLOAD SEED MODEL

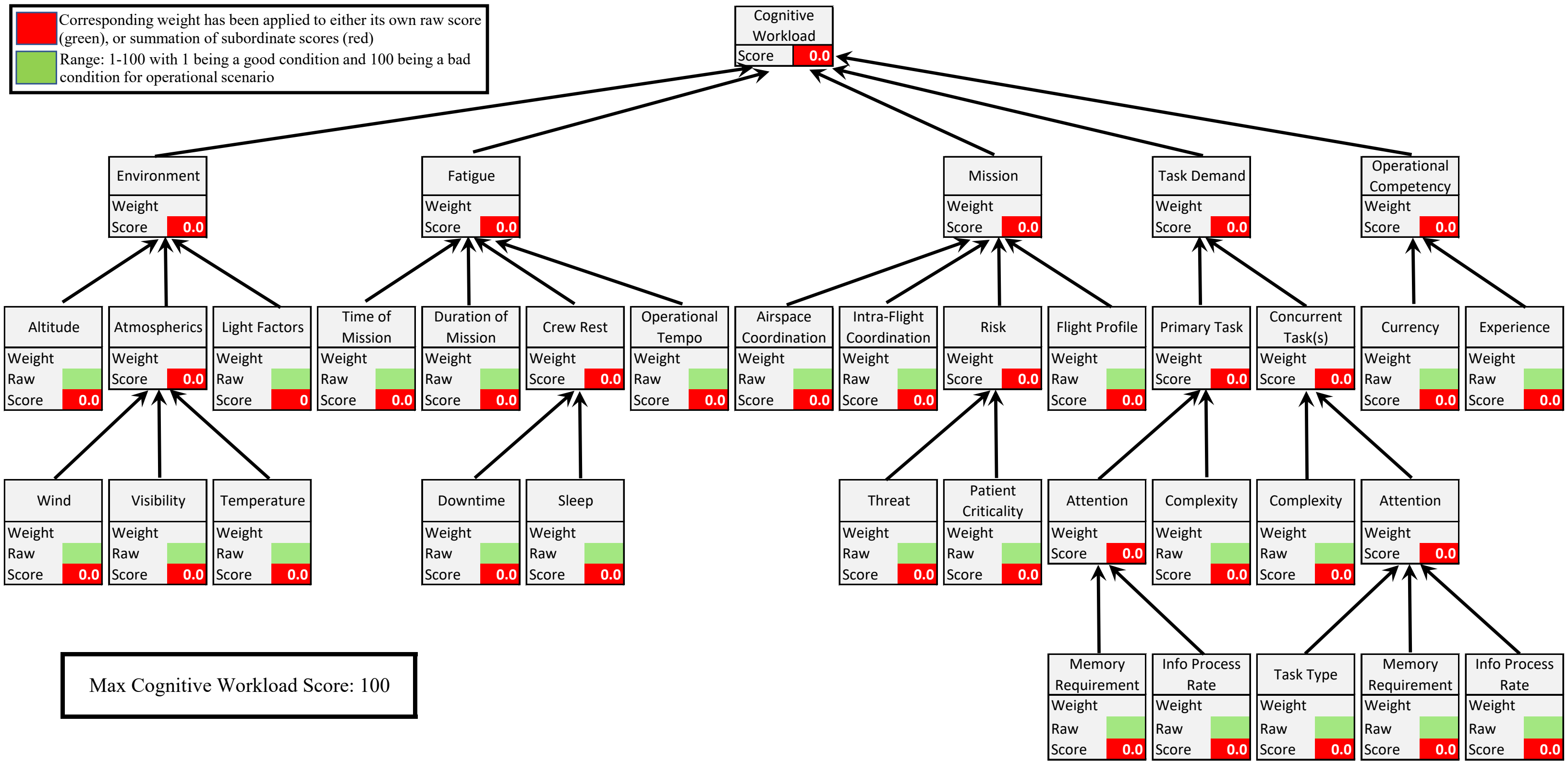

Figure 10. Cognitive workload seed model depicting the expected influencing factor and subfactor hierarchical relationships

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APPENDIX B. FACTOR AND SUBFACTOR DEFINITIONS

1. Environment

1.1. Altitude – a measure of the height above mean sea level during flight operations (on the ground and in the air during the mission) (includes physiological effects of altitude as well as projected challenges to aircraft performance and controllability).

- Easy – sea level
- Challenging – 14,000 MSL

1.2. Atmospherics

1.2.1. Wind – a measure of the atmospheric wind conditions (e.g., wind speed, gust spread, chop/turbulence, wind shear, etc.) (can include both on the ground and inflight winds).

- Easy – No wind
- Challenging – Winds at threshold for loss of aircraft control

1.2.2. Visibility – a measure of the distance at which an object or light can be clearly discerned (includes presence of visual obscurants and precipitation).

- Easy – Unrestricted, no impediments to vision
- Challenging – visibility at threshold for IFR conditions or loss of visual contact with terrain

1.2.3. Temperature – a measure of the degree or intensity of heat pilot expects to encounter during flight operations (on the ground and in the air) (include physiological response to temperature as well as projected challenges to aircraft performance).

- Easy – mild to moderate temperature
- Challenging – extremely hot or extremely cold

1.3. Light Factors – a measure of illumination or visible light available during flight operations (includes sun, moon, celestial, and artificial illumination) as well as the relative position of the light source (e.g., flying into sun or moon) and the challenges imposed by transition periods (e.g., sunset, EENT, BMNT, sunrise, etc.).

- Easy – sun directly overhead
- Challenging – no illumination or flying directly into the sun or moon

2. Fatigue

2.1. Time of Mission – the relative time during a pilot's duty day (work cycle) when the flight operations will take place (e.g., at the beginning of the duty day, near the end of the duty day, or during designated downtime or rest cycle).

- Easy – flight near the beginning of the duty day (first third)
- Challenging – flight near the end of the duty day (last third) or during extensions

2.2. Duration of Mission – the relative length of a flight mission in relation to pilot duty day and regulatory or policy driven flight hour limitations (e.g., how long will a pilot be out conducting flight operations).

- Easy – short flight, less than a tank of gas
- Challenging – extended flight requiring operations near flight hours limits, or duty day limits

2.3. Crew Rest

2.3.1 Downtime – the relative quantity and activity conducted during designated downtime where a pilot is not working and considered to be on their crew rest cycle (e.g., how much time does a pilot have to do what they want that is not work related, how much effort or work [mental, physical, or otherwise] does a pilot expend while on their crew rest cycle [e.g., personal affairs, strenuous activities that tax their mind or body like working out, etc.]).

- Easy – 14 hours between duty days with no strenuous activity

- Challenging – short duration between duty days with an intense workout that pushes you to the limit (outside of normal scope).

2.3.2 Sleep – the quantity of time a crew member rests during their crew rest cycle (e.g., how much sleep and what is the quality of sleep a pilot gets during their rest cycle).

- Easy – optimal sleep for your personal needs

- Challenging – minimal sleep or sleep with multiple interruptions

2.4. Operational Tempo – a relative measurement of the speed and intensity of the pilots' actions relative to the events unfolding within the operational environment (e.g., have pilots been flying a lot of missions recently? How taxing have the days and missions leading up to the mission in question been?).

- Easy – a few short flights per week (enough to stay engaged and proficient without being overly taxing)

- Challenging – multiple challenging flights or planning iterations that are physically or mentally taxing, multiple days in a row

3. Mission

3.1. Airspace coordination – a relative measurement of how much and how challenging airspace coordination is during flight operations (e.g., air traffic control, common traffic advisory frequency, inter-flight coordination, restricted operations zone coordination, time/altitude/location coordination and deconfliction between other airborne entities, familiarity with airspace, etc.).

- Easy – uncontrolled airspace with no other aircraft operating nearby

- Challenging – operations in an area of dense air traffic, coordinating entry and flight in a ROZ with a JTAC and working to deconflict fires with flight route.

3.2. Intra-Flight Coordination – a relative measurement of how much and how challenging intra-flight coordination is during flight operations (e.g., intra-aircraft communications [ICS], intra-flight aircraft communications/coordination [between sister-ships], etc.).

- Easy – single ship operations
- Challenging – multi-ship flight with multiple people talking on the aircraft ICS (crew chief, medic, ground force, pilots, etc.) and the need to talk between aircraft (for flight plan changes, obstacle avoidance, landing plan briefs, etc.).

3.3. Risks

3.3.1. Threat – a relative measure of the risk to mission and risk to force stemming from the mission characteristics or from direct threats (e.g., enemy direct fire engagements).

- Easy – No enemy threat, stateside mission
- Challenging – effective enemy fire is imminent

3.3.2. Patient Criticality – a relative measure of the need to get a patient to a higher level of care (includes considerations such as the severity of injury and distance to the higher care facility).

- Easy – routine patient, short distance
- Challenging – multiple PAX, urgent surgical, far distance

3.4. Flight Profile – a relative measurement of how challenging the particular flight profile requirements are (e.g., how close to the ground does a pilot need to fly, where in time/space does a pilot need to fly in relation to other aircraft (formation flight), familiarity with terrain, etc.).

- Easy – Single ship at a cruise altitude in familiar terrain
- Challenging – multi-ship formation flight maneuvering tactically in unfamiliar terrain in a nap of the earth profile.

4. Task Demand

4.1. Primary Task

4.1.1 Attention

4.1.1.1 Memory Requirement – a relative measurement based on the amount of memory that is required to execute the task (e.g., memory of the order that flight procedures are executed, memory of call signs, memory of phase lines, etc.) (Parasuraman 1979, Wiggins 2011). Memory requirements may be reduced due to automation or other systems (e.g., Navigation systems reduce navigation memory requirements).

- Easy – The task does not require any memory to execute (maintaining pitch or balance)
- Challenging – A lot of memory required to execute the task (requiring memory of phase lines, ROZs, ROEs, procedures, etc.).

4.1.1.2 Info Processing Rate – a relative measurement based on the amount of information that is processed during the execution of a task and how quickly that information needs to be processed (Parasuraman 1979).

- Easy – the OE is unchanging along flight path
- Challenging – rapidly changing OE being monitored or flown in where the amount of information being processed could lead to

performance decrements (e.g., rapid, constant, and frequent obstacles/threats presenting themselves)

4.1.2 Complexity – a relative measure of based on the number of actions required to control flight and the difficulty/complexity of those actions.

- Easy – Minimal actions required to control flight
- Challenging – Many actions required to control flight

4.2. Secondary Task(s)

4.2.1 Attention

4.2.1.1 Memory Requirement – a relative measurement based on the amount of memory that is required to execute the task (e.g., memory of the order that flight procedures are executed, memory of call signs, memory of phase lines, etc.) (Parasuraman 1979, Wiggins 2011). Memory requirements may be reduced due to automation or other systems (e.g., Navigation systems reduce navigation memory requirements).

- Easy – No memory needed for the execution of a task such as (e.g., if secondary task is monitoring radio, there are no call signs on the radio or minimal reporting requirements).
- Challenging – A lot of memory required to execute one or multiple secondary tasks (e.g., if secondary task is monitoring the radio, there are a challenging amount of call signs to remember, a challenging amount of reporting requirements to remember; if a secondary task is airspace coordination it could be remembering multiple phase lines, ROZs, etc.).

4.2.1.2 Info Processing Rate – a relative measurement based on the amount of information that is processed during the execution of a task and how quickly that information needs to be processed (Parasuraman 1979).

- Easy – a little information is needed to be processed (e.g., in-frequent radio calls)
- Challenging – a lot of information is processed (e.g., rapid, and constant radio calls over multiple radio channels)

4.2.1.3 Task Type – a relative measurement based on the type of secondary task or tasks in comparison to the primary tasks. This can be based on the type of task and/or the sense used to execute the task, such as executing two separate tasks while using the same sense (e.g., executing a spatial and a discriminatory task, or executing two spatial tasks, or whether one is using the same sense or different senses for multiple tasks). *Literature shows us that the execution of two spatial tasks causes a performance decrement regardless of if different senses are used (Wahn and Konig 2015). However, it shows that if different senses are used for a discrimination task and a spatial task, there is no performance decrement (Arrighi, Lunardi, and Burr 2011).*

- Easy – different sense used for a different type of task (e.g., using vision for flying and hearing for monitoring a radio)
- Challenging – same sense is used as the primary task and multiple other secondary tasks and it is a similar type of task (e.g., all tasks require vision to facilitate controlling flight, avoiding obstacles, visually looking for suitable landing, looking at a

moving map or GRG, identifying friendly from enemy)

4.2.2 Complexity – (different than primary task complexity) a relative measure of based on the number of SECONDARY TASKS required, number of actions required for each secondary task, and the difficulty/complexity of those actions.

- Easy – Minimal easy actions required to execute 1 secondary task
- Challenging – multiple secondary tasks, all requiring many difficult actions, in addition to the primary task

5. Operational Competency

5.1. Experience – a relative measurement of how much flight and operational experience a pilot and crew have, both in general and regarding the specific mission requirements and conditions (e.g., how much flight experience do the pilot and crew have? How much experience do they have in the mission set and conditions they are encountering?)

- Easy – crew with a lot of flight hours in the mission tasks required and conditions being experienced that are familiar with each other and function well as a team
- Challenging – crew with limited experience (low flight hours) and minimal operational experience conducting the tasks required in the conditions experienced that have not flown together

5.2. Currency – a measurement of the recency and degree to which a pilot/crew has met policy and regulatory requirements for conducting (in either a training or actual mission environment) the tasks required during the mission (e.g., has the pilot/crew met regulatory requirements for flight or task currency? Has the pilot/crew recently conducted the flight tasks required for the upcoming mission?)

- Easy – crew conducted multiple iterations of the mission tasks required in the days leading up to the flight
- Challenging – the crew has not conducted the mission tasks for a long time and is near the limit for task or aircraft currency

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APPENDIX C. SIMPLE MEDEVAC FLIGHT SCENARIO DESCRIPTION

OPERATIONAL CONTEXT:

Background Assumptions:

- Crew is battle rostered and have been flying training missions together for 2 weeks
- Crew is very familiar with the area of operation
- Crew is current in all modes of flight and has conducted numerous training flights requiring similar flight tasks and procedures as a MEDEVAC mission within the last 2 weeks

Scenario Initiation:

- A 9-Line MEDEVAC request is received - 1x walking wounded, priority. The pickup location is a 25-minute flight from your airfield and a 25-minute flight from the care center you will fly the patient to. The crew is familiar with the flight procedures at all locations (i.e., approach/landing procedures, airspace, communications, etc.)

GENERAL SCENARIO CONDITIONS:

- MEDEVAC request is stateside in response to a simple training accident
- No hostile threat
- Mission launch will occur in the first four hours of the crew's mission window and take place during daylight hours
- Pilots and crew have had greater than 12 hours of crew rest. No strenuous physical activity took place during the rest period. Each pilot and crew member slept seven hours and woke up 3 hours before the show time/crew brief

- Flight will occur in non-mountainous terrain at or below 3000’ MSL. There are no flight hazards (e.g., no wires, no structures higher than 20’, etc.)
- Single-ship mission in an area of low air traffic density and no communication requirements (class G airspace)
- Both pilots are PCs with greater than 1000 hours. In the past week the same crew have flown 3x simple training missions lasting ~2 hours each

POINT-IN TIME - SPECIFIC SCENARIO CONDITIONS:

Actions on the Objective – RP Inbound

- Improved landing site with little threat of dust or brownout conditions
- Atmospheric Conditions:
    - Daytime – sun overhead, not impeding your ability to see
    - Visual Flight Rules (VFR)
    - Ceiling – None
    - Visibility – Unrestricted
    - Winds – None
    - Precipitation – None
    - Temperature – 68ºF/20°C
    - No threat of adverse Weather
- The HLZ is at 500’ MSL
- You are at 200’ AGL, aligned on the final approach path with the landing area in sight

- You have no concerns with aircraft power or performance limitations that would impede your ability to safely land the aircraft
- No ongoing radio calls
- You are the pilot on the controls and your primary task is to control the aircraft. Your secondary tasks include any task required during this phase of the operation such as communicating over the ICS or radio, monitoring instruments, or looking for the LZ

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APPENDIX D. COMPLEX MEDEVAC FLIGHT SCENARIO DESCRIPTION

OPERATIONAL CONTEXT:

Background Assumptions:

- Crew is newly battle rostered and have not yet flown together
- Crew has been in the area of operations for ~2 weeks and is still learning the area
- Crew is current in all modes of flight and required tasks (to include dust landings), but none of the crew members have completed a training flight requiring MEDEVAC mission tasks in over 45 days

Scenario Initiation:

- A 9-Line MEDEVAC request is received – 2x Urgent Surgical patients. The pickup location is 35-minute flight from the aircraft location and a 35-minute flight from the care center

GENERAL SCENARIO CONDITIONS:

- MEDEVAC request is in a combat theater in response to wounds inflicted via enemy contact
- Hostile threat is possible (Small arms, heavy weapons, and RPGs known to be in vicinity of evacuation site; engagements with enemy continue sporadically)
- Mission will occur at night (under NVGs) and launch in the last third of the crew's mission window.
- Pilots and crew members have had 10 hours of crew rest. Pilots and crew have flown 4 times (~6 hours each) in the past 5 days supporting local area orientations and training flights, but have not flown together. During your

crew rest period, you and the crew members performed a strenuous, 30min, workout at the gym. You and the crew slept five hours during the crew rest period and woke up 2 hours before your crew brief/show time

- The flight will occur in mountainous terrain and will require crossing multiple ridgelines up to 9,500' MSL. There are numerous flight hazards (e.g., power lines, towers, etc.) throughout the AO.
- The mission will be a 4-ship mission (2x MEDEVAC ACFT, 2x AH-64s). You are in the lead aircraft and the objective area is in an area of high air traffic density. Airspace deconfliction will be necessary throughout the flight.
- You are the PC and have 500 hours. Your co-pilot is a PI and has 200 hours.

POINT-IN TIME - SPECIFIC SCENARIO CONDITIONS:

Actions on the Objective – RP Inbound

- Atmospheric Conditions:
    - Visual Flight Rules (VFR)
    - Ceiling – AGL equivalent of 10,000' MSL
    - Visibility – 3 SM with haze
    - Winds – 20G30 kts
    - Precipitation – None
    - Temperature – 90ºF/32°C
    - Threat of thunderstorms, though it has not yet materialized
    - Illumination – 0%

- You just passed the release point and are now heading inbound to pick up 2x Urgent Surgical Patients.
- No landing area is available – the patients will require extraction via 30' hoist with brownout expected
- Pre-landing checks and crew briefing for hoist operations are complete
- The HLZ is at 5500' MSL
- You are flying into a valley at 200' AGL and have limited go-around options, flying into the wind.
- You have OGE + 15% power margin with no expected performance limitations that would impede your ability to safely hover the aircraft
- You are the pilot on the controls and your primary task is to control the aircraft. Your secondary tasks include any task required during this phase of the operation such as communicating over the ICS or radio, monitoring instruments, understanding where other aircraft are in time and space, or looking for the LZ
- Your copilot is coordinating with the JTAC on the ground to deconflict your approach path and routing with on-going air to ground fires
- Your copilot is also coordinating a hold point and rejoin plan for your chase aircraft
- The JOC is radioing and asking for an update on your ETA
- The flight medic is asking for a MIST update to ensure they are prepared to receive the patient
- You are monitoring your HSD and looking outside, trying to correlate your location, avoid obstacles, and identify the hoist area, but you are having trouble due to the terrain, marginal visibility, and illumination

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APPENDIX E. INITIAL INTERVIEW RECRUITMENT SCRIPT

Recruitment script disseminated to unit pilots via bulk e-mail.

XXX Pilots,

My name is Greg Griffith and I am a graduate student in the Systems Engineering department at the Naval Postgraduate School. I am a part of a team conducting a research study examining the cognitive workload of pilots and you are invited to participate in the study. This study will influence the development of task automation and mission aids for the Future Vertical Lift program. If you agree to participate you will be asked to participate in an individual interview lasting approximately 45 minutes during which you will be asked to provide input on the extent to which various factors influence pilot cognitive workload.

Participation in this study is voluntary. Your identity as a participant will remain confidential during and after the study. The data collected will be associated with a subject number and will not be directly associated with your name or other personally identifiable information.

If you have questions or would like to participate, please contact me at XXX@nps.edu, XXX@mail.mil, or XXX-XXX-XXXX. The principal investigator for this study is Dr. Lawrence Shattuck, XXX@nps.edu, XXX-XXX-XXXX. The institutional review board chair is Mr. Bryan Hudgens, XXX@nps.edu, XXX-XXX-XXXX.

Thank you in advance for your time and consideration.

Respectfully,

MAJ Gregory S. Griffith
Graduate Student, Naval Postgraduate School
Email: XXX@nps.edu
Cell: (XXX) XXX-XXXX

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APPENDIX F. INITIAL INTERVIEW SCRIPT

Expected Interview Length: 45–60 Minutes

Interview Format: Semi-structured

Interview Location(s): all interviews will occur at JBLM, WA

*Text in italics is intended to represent the things an interviewer might say or the way they might ask a question. Actual wording and phraseology may differ.

With subjects recruited and interviews scheduled, the following procedures will be followed:

**Hand out flight experience demographics questionnaire and consent form early and have interviewees complete prior to interview if able

- **Welcome/Orientation** (Interviewee will arrive at the interview location and be provided a brief orientation to the interview location)
    - Typical welcome (e.g., hello, how are you, etc.)
    - Site orientation (orientation dependent on actual site location… include things like diagram, note-taking material (if they want), audio recording device, computer for interviewer to type in notes, etc.)
- **Consent Form** (Explain form and have interviewee sign it)
    - *Before we start the formal portion of the interview, I would like you to take a few minutes and read through the consent form if you have not already and then sign if you give your consent to participate in the research. Just to highlight a few things: participation is voluntary and there will not be any compensation or incentives for your participation other than helping inform future system design. Likewise, there will be no penalty if you refuse to participate - you are free to leave at any time. The interview will involve a description of two MEDEVAC scenarios*

and questions regarding your assessment of the conditions and projected cognitive workload requirements during those scenarios.

- *The information collected during the study will be kept confidential to the full extent permitted by law. The data collected from you will be separated from your personally identifiable information and only the research team will have access to your PII. Once the data analysis and study are complete, your PII will be deleted.*
- *If you are comfortable with participating in an interview, please indicate that on the form and sign and date it.*

- **Start Audio Recording** (Interviewer will initiate audio recording for interview)
  - *As noted on the consent form, I will be recording the audio of the interview to use as a reference during data analysis if needed. An example of use might be if one of the data points you provide seems to be an outlier, then I might listen to the audio recording to make sure the information was transcribed correctly, and no mistakes were made on data entry. Nobody outside of the research team will have access to the audio recording.* (Example – nobody at the unit will have access, to include the command team) ***Do you mind if we continue to record this?***
- **Project Explanation** (Interviewer will provide a brief background of the research project, objectives, and expected outcomes and impacts)
  - **Background:** *A little bit of background about the project: the Army is developing a new generation of aerial platforms as part of the Future Vertical Lift (FVL) initiative. The Army's intent is to make a generational leap forward in aviation technology and capability, developing the new platforms and operational concepts necessary to succeed in an increasingly contested and challenging battlespace. Key to this effort is gaining an understanding of pilot cognitive workload and the factors and subfactors that contribute*

to it. With this understanding the Army can conduct a ground up re-examination of what tasks can and should be automated to avoid pilot cognitive overload during FVL operation. In simple terms – we want to figure out what should be automated to avoid task saturation and cognitive overload in FVL.

- **Objective:** *The objective of the research project is to develop a model that can forecast the cognitive workload of an aviator based on situation specific factors and subfactors. The research team will facilitate meeting the objective by accomplishing the following goals:*

    1. Identify the cognitive workload factors of rotorcraft aviators
    2. Develop a model that depicts the relationship between cognitive workload and its factors/subfactors
    3. Verify the model using a MEDEVAC scenario test

- **Expected Outcomes/Impacts:** *This study is expected to influence the development of task automation and mission aids for the Future Vertical Lift program.*

- **<u>Questions</u>** (Interviewer will offer to answer any questions the interviewee has at any time)
    - *Before we get started - do you have any questions I can answer about the research or what you can expect during this interview?*
- **<u>Pilot Experience and Qualifications</u>** (Interviewee will be asked to complete the flight experience demographics questionnaire if they have not already done so. The targeted flight experience demographic data questions will be used as necessary to extract information)
    - **Questionnaire Not Complete:** *Please take a moment to fill out the flight experience demographics questionnaire. Flight hour estimates are fine if you do not know your exact hour numbers.*
    /----------Pause to allow time to complete questionnaire----------/

Is there anything related to your flight experience or background that was not captured by the questionnaire that you would like to share?

- **Questionnaire Complete:** *Thank you for completing the flight experience questionnaire before the interview. Is there anything related to your flight experience or background that was not captured by questionnaire that you would like to share?*

- **<u>Model Explanation</u>** (Interviewer will present the seed model influence diagram to the interviewee (paper copy) and explain how it is structured, how it works, and the rating scales and weighting factors used)
  - *I am handing you an Influence Diagram intended to represent the factors and subfactors that influence a pilot's cognitive workload, and the relationship between those factors and subfactors. Think of it as a hierarchy where data from the boxes at the bottom feeds into and is aggregated at higher and higher levels that eventually produce a value that indicates a level of cognitive workload.*
  - *The diagram works by having a user estimate a raw value, indicated by the yellow boxes, for each of the subfactors based on the situation conditions. The range of each raw score is 1 to 100 with 1 being a good condition and 100 being a terrible condition.*
  - *Let's look at the environmental group as an example* **(Point to model)**. *Wind, visibility, and temperature are the subfactors that make up atmospherics within the environment factor grouping. For wind, a no wind condition is usually considered pretty good so you might give it a relatively low score. However, if the winds on the ground were 20 knots sustained, gusting to 35, and there was low level wind shear at your intended flight altitude, you might give that a score close to the top end of the range, meaning the flight conditions are pretty challenging. You will get to make those assessments for each of the subfactors.*

- *The raw score you provide for each subfactor is multiplied by the weight of the subfactor to determine a weighted score. Then the weighted subfactor scores within that grouping are added together and multiplied by the higher level factor weight to determine the weighted score for the higher-level factor. Thinking again of the atmospherics subfactor, the score is determined by adding together the weighed scores of wind, visibility and temperature and multiplying that value by the weight of atmospherics. This is done for all of the factors and subfactors until a cognitive workload value is determined.*
- *The subfactor weights, indicated by the teal boxes, are determined separately from the raw score based on their proportion of contribution to cognitive workload relative to each other. For each factor and subfactor, the weights of the influences feeding into it must add up to 100%. As an example, the atmospherics subfactor is composed of wind, visibility, and temperature. Relative to each other, you might decide that visibility contributes 50%, wind contributes 30%, and temperature contributes 20% to your cognitive workload. These are the all of the subfactors that make up atmospherics and their weights add up to 100% so we are good to go. Similarly, the environment factor is composed of altitude, atmospherics, and light factors. Those 3 elements must be compared to each other to determine what their proportional contribution is to the environmental induced cognitive workload. Remember, the weights must add up to 100%.*
- *Stated simply, the raw scores are determined based on situation specific conditions and judged on a scale of 1 to 100 with 1 being a great condition and 100 being a terrible condition. Conversely, the weights are determined based on your evaluation of how much*

each element contributes to cognitive workload relative to the other elements in its group.

- *Does this model make sense, and do you understand the hierarchy and relationships depicted by the lines and arrows?*
- *Do you understand the difference between weights and raw scores as well as how those values are used to determine higher level scores as you work from the bottom to the top of the diagram?*

- **<u>MEDEVAC Scenario Description (Simple)</u>** (Interviewer will read the simple MEDEVAC scenario description and answer any question the interviewee has)
  - *Okay – let's get started with the first MEDEVAC scenario. I am handing you a print out of the specified conditions for the scenario so you can follow along as I read through it. In a few minutes, you will use these conditions and your flight experience to determine the raw scores and weights for all of the subfactors on the diagram. Remember – you can stop me and ask questions at any time.*
  - ***Background Assumptions:***
    - *Crew is battle rostered and have been flying training missions together for 2 weeks*
    - *Crew is very familiar with the area of operation*
    - *Crew is current in all modes of flight and has conducted numerous training flights requiring similar flight tasks and procedures as a MEDEVAC mission within the last 2 weeks*
  - ***Scenario Initiation:***
    - *A 9-Line MEDEVAC request is received - 1x walking wounded, priority. The pickup location is a 25-minute flight from your airfield and a 25-minute flight from the care center you will fly the patient to. The crew is familiar with the flight procedures at all locations (i.e.,*

approach/landing procedures, airspace, communications, etc.).

- ***General Scenario Conditions:***
    - *MEDEVAC request is stateside in response to a simple training accident*
    - *No hostile threat*
    - *Mission launch will occur in the first four hours of the crew's mission window and take place during daylight hours*
    - *Pilots and crew have had greater than 12 hours of crew rest. No strenuous physical activity took place during the rest period. Each pilot and crew member slept seven hours and woke up 3 hours before the show time/crew brief.*
    - *Flight will occur in non-mountainous terrain at or below 3000' MSL. There are no flight hazards (e.g., no wires, no structures higher than 20', etc.)*
    - *Single-ship mission in an area of low air traffic density and no communication requirements (class G airspace)*
    - *Both pilots are PCs with greater than 1000 hours. In the past week the same crew have flown 3x simple training missions lasting ~2 hours each*
- ***Point-in Time - Specific Scenario Conditions:***
    - *Let's fast forward to actions on the objective. I would like you to think about yourself at a specific moment of time during operations in the terminal area – you just passed the release point and are proceeding inbound to pick up the wounded person.*
    - *Improved landing site with little threat of dust or brownout conditions*
    - *Atmospheric Conditions:*

- *Daytime – sun overhead, not impeding your ability to see*
- *Visual Flight Rules (VFR)*
- *Ceiling – None*
- *Visibility – Unrestricted*
- *Winds – None*
- *Precipitation – None*
- *Temperature – 68ºF/20°C*
- *No threat of adverse Weather*

- *The HLZ is at 500' MSL*
- *You are at 200' AGL, aligned on the final approach path with the landing area in sight*
- *You have no concerns with aircraft power or performance limitations that would impede your ability to safely land the aircraft*
- *No ongoing radio calls*
- *You are the pilot on the controls and your primary task is to control the aircraft. Your secondary tasks include any task required during this phase of the operation such as communicating over the ICS or radio, monitoring instruments, or looking for the LZ*
- *Do you have any questions before we move on to filling in the influence diagram?*

- **Raw Score Data Collection (Simple MEDEVAC)** (Interviewer will ask the interviewee to quantify (raw score on a scale of 1 to 100 with 1 being the best possible condition and 100 being the worst possible condition) the relative conditions of each subfactor under the scenario described conditions)
  - *Now it is time to determine the raw scores of each subfactor based on the first scenario. Let's work our way from bottom to top and*

left to right all the way through the model. I will name a subfactor and then you write down and tell me what you think the raw score should be based on the scenario conditions with 1 being great conditions and 100 being terrible conditions. Please stop me at any time and let me know if you have any questions about what any of the factors or subfactors mean. To alleviate any confusion, raw scoring does not need to equal 100 when added together, that is only for the weighting.

- *Environment:*
  - *Wind, Visibility, Temperature, Altitude, Light Factors*
- *Fatigue:*
  - *Time of mission (with respect to point in duty day of mission), Duration of Mission, Downtime, Sleep, Operational Tempo*
- *Mission:*
  - *Airspace coordination, Intra-flight Coordination, Threat, Patient Criticality, Flight Profile*
- *Task Demand:*
  - *Primary Task: Memory Requirement, Information Processing Rate, Complexity*
  - *Concurrent Tasks: Task Type, Memory Requirement, Information Processing Rate, Complexity*
- *Operational Competency:*
  - *Experience, Currency*

- **Weight Data Collection (Simple MEDEVAC)** (Interviewer will ask the interviewee to quantify the proportional influence each subfactor has on the parent factor/subfactor in the hierarchy [all weights must add to 1.0 for each parent factor/subfactor])
  - *Now it is time to determine the weights of each subfactor in the MEDEVAC scenario. Let's work our way from bottom to top and*

left to right all the way through the model just the same as before. I will list the subfactors and then you tell me what you think the relative weight of each in terms of how much you estimate it contributes to your cognitive workload. Remember, all groupings have to add up to 100%.

- *Environment:*
    - *Wind vs. Visibility vs. Temperature*
    - *Altitude vs. Atmospherics vs. Light Factors*
- *Fatigue:*
    - *Downtime vs. Sleep*
    - *Time of Mission vs. Duration of Mission vs. Crew Rest vs. Operational Tempo*
- *Mission:*
    - *Threat vs. Patient Criticality*
    - *Airspace Coordination vs. Intra-flight Coordination vs. Risk vs. Flight Profile*
- *Task Demand:*
    - *Primary Task:*
        - *Memory Requirement vs. Info Processing Rate*
        - *Attention vs. Complexity*
    - *Concurrent Task(s):*
    - *Task Type vs. Memory Requirement vs. Info Processing Rate*
    - *Complexity vs. Attention*
    - *Primary Task vs. Concurrent Task(s)*
- *Operational Competency:*
    - *Experience vs. Currency*
- *Top Level:*
    - *Environment vs. Fatigue vs. Mission vs. Task Demand vs. Operational Competency*

- **<u>Question(s)</u>** (Interviewer will ask the interviewee if he/she has any questions or any changes based on an evolving comfort or understanding of how the model works)
    - *With your improved understanding of how it works, do you have any changes you want to make before we move on to our complex scenario?*
- **<u>MEDEVAC Scenario Description (Complex)</u>** (Interviewer will read the Complex MEDEVAC scenario description and answer any question the interviewee has)
    - *Okay – lets go through a second MEDEVAC scenario now. I am handing you a print-out of the specified conditions for the scenario so you can follow along as I read through it. Remember – you can stop me and ask questions at any time. You will use these conditions and your flight experience to determine raw scores for all of the subfactors in the influence diagram in a few minutes.*
    - ***Background Assumptions:***
        - *Crew is newly battle rostered and have not yet flown together*
        - *Crew has been in the area of operations for ~2 weeks and is still learning the area*
        - *Crew is current in all modes of flight and required tasks (to include dust landings), but none of the crew members have completed a training flight requiring MEDEVAC mission tasks in over 45 days*
    - ***Scenario Initiation:***
        - *A 9-Line MEDEVAC request is received – 2x Urgent Surgical patients. The pickup location is 35-minute flight from the aircraft location and a 35-minute flight from the care center.*
    - ***General Scenario Conditions:***

- *MEDEVAC request is in a combat theater in response to wounds inflicted via enemy contact*
- *Hostile threat is possible (Small arms, heavy weapons, and RPGs known to be in vicinity of evacuation site; engagements with enemy continue sporadically)*
- *Mission will occur at night (under NVGs) and launch in the last third of the crew's mission window*
- *Pilots and crew members have had 10 hours of crew rest. Pilots and crew have flown 4 times (~6 hours each) in the past 5 days supporting local area orientations and training flights, but have not flown together. During your crew rest period, you and the crew members performed a strenuous, 30min, workout at the gym. You and the crew slept five hours during the crew rest period and woke up 2 hours before your crew brief/show time*
- *The flight will occur in mountainous terrain and will require crossing multiple ridgelines up to 9,500' MSL. There are numerous flight hazards (e.g., power lines, towers, etc.) throughout the AO*
- *The mission will be a 4-ship mission (2x MEDEVAC ACFT, 2x AH-64s). You are in the lead aircraft and the objective area is in an area of high air traffic density. Airspace deconfliction will be necessary throughout the flight*
- *You are the PC and have 500 hours. Your co-pilot is a PI and has 200 hours*

- ***Point-in Time - Specific Scenario Conditions:***
    - *Let's fast forward to actions on the objective. I would like you to think about yourself in a specific moment of time during operations in the terminal area*
    - *Atmospheric Conditions:*

- *Visual Flight Rules (VFR)*
- *Ceiling – AGL equivalent of 10,000' MSL*
- *Visibility – 3 SM with haze*
- *Winds – 20G30 kts*
- *Precipitation – None*
- *Temperature – 90ºF/32°C*
- *Threat of thunderstorms, though it has not yet materialized*
- *Illumination – 0%*

- *You just passed the release point and are now heading inbound to pick up 2x Urgent Surgical Patients*
- *No landing area is available – the patients will require extraction via 30' hoist with brownout expected*
- *Pre-landing checks and crew briefing for hoist operations are complete*
- *The HLZ is at 5500' MSL*
- *You are flying into a valley at 200' AGL and have limited go-around options, flying into the wind*
- *You have OGE + 15% power margin with no expected performance limitations that would impede your ability to safely hover the aircraft*
- *You are the pilot on the controls and your primary task is to control the aircraft. Your secondary tasks include any task required during this phase of the operation such as communicating over the ICS or radio, monitoring instruments, understanding where other aircraft are in time and space, or looking for the LZ*
- *Your copilot is coordinating with the JTAC on the ground to deconflict your approach path and routing with on-going air to ground fires*

        - *Your copilot is also coordinating a hold point and rejoin plan for your chase aircraft*
        - *The JOC is radioing and asking for an update on your ETA*
        - *The flight medic is asking for a MIST update to ensure they are prepared to receive the patient*
        - *You are monitoring your HSD and looking outside, trying to correlate your location, avoid obstacles, and identify the hoist area, but you are having trouble due to the terrain, marginal visibility, and illumination*
    - *Do you have any questions before we move on to filling in the influence diagram?*
- **<u>Raw Score Data Collection (Complex MEDEVAC)</u>** Interviewer will ask the interviewee to quantify (raw score) the degree to which each subfactor in the scenario described conditions contributes to their cognitive workload:
    - *Now it is time to determine the raw scores of each subfactor based on the first scenario. Let's work our way from bottom to top and left to right all the way through the model. I will name a subfactor and then you write down and tell me what you think the raw score should be based on the scenario conditions with 1 being great conditions and 100 being terrible conditions. Please stop me at any time and let me know if you have any questions about what any of the factors or subfactors mean. To alleviate any confusion, raw scoring does not need to equal 100 when added together, that is only for the weighting.*
    - *Environment:*
        - *Wind, Visibility, Temperature, Altitude, Light Factors*
    - *Fatigue:*

        - *Time of mission (with respect to point in duty day of mission), Duration of Mission, Downtime, Sleep, Operational Tempo*
    - *Mission:*
        - *Airspace coordination, Intra-flight Coordination, Threat, Patient Criticality, Flight Profile*
    - *Task Demand:*
        - *Primary Task: Memory Requirement, Information Processing Rate, Complexity*
        - *Concurrent Tasks: Task Type, Memory Requirement, Information Processing Rate, Complexity*
    - *Operational Competency:*
        - *Experience, Currency*
- **<u>Weight Data Collection (Complex MEDEVAC)</u>** (Interviewer will ask the interviewee to quantify the proportional influence each subfactor has on the parent factor/subfactor in the hierarchy [all weights must add to 1.0 for each parent factor/subfactor])
    - *Now it is time to determine the weights of each subfactor in the MEDEVAC scenario. Let's work our way from bottom to top and left to right all the way through the model just the same as before. I will list the subfactors and then you tell me what you think the relative weight of each in terms of how much you estimate it contributes to your cognitive workload. Remember, all groupings have to add up to 100%.*
    - *Environment:*
        - *Wind vs. Visibility vs. Temperature*
        - *Altitude vs. Atmospherics vs. Light Factors*
    - *Fatigue:*
        - *Downtime vs. Sleep*

        - *Time of Mission vs. Duration of Mission vs. Crew Rest vs. Operational Tempo*
    - *Mission:*
        - *Threat vs. Patient Criticality*
        - *Airspace Coordination vs. Intra-flight Coordination vs. Risk vs. Flight Profile*
    - *Task Demand:*
        - *Primary Task:*
            - *Memory Requirement vs. Info Processing Rate*
            - *Attention vs. Complexity*
        - *Concurrent Task(s):*
        - *Task Type vs. Memory Requirement vs. Info Processing Rate*
        - *Complexity vs. Attention*
        - *Primary Task vs. Concurrent Task(s)*
    - *Operational Competency:*
        - *Experience vs. Currency*
    - *Top Level:*
        - *Environment vs. Fatigue vs. Mission vs. Task Demand vs. Operational Competency*
- **Questions** (Interviewer will ask the interviewee if they have any questions or any changes based on an evolving comfort or understanding of how the model works)
    - *Do you have any questions about what we just did or any changes you want to make before we move on? Do not worry – we are almost done.*
- **What is Missing?** (Interviewer will ask the interviewee if there is anything that he/she believes contributes to cognitive workload that is not included in the model)

- *Now that we have been through the influence diagram a few times and talked through it, are there any things you believe contribute to your cognitive workload that are not accounted for in the model?*
- *Are there any subfactors or factors that you think are in the wrong place or connected to the wrong elements in the diagram hierarchy? For instance, are there any things you want to move around or any arrows you want to change to make a different connection?*

- **Interview Closeout** (Interviewer will thank the interviewee for his/her time and provide contact information in the event the interviewee has questions or needs to reach out for any reason)
    - *That completes the interview. Thank you for making the time to talk with me today and help shape our research. If you have any questions at any time you can contact me or any of the points of contact listed at the bottom of the consent form. Thanks again and have a great day!*
- **Stop Audio Recording** (Interviewer will cease audio recording of the interview)

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APPENDIX G. INITIAL INTERVIEW DEMOGRAPHICS QUESTIONNAIRE

Flight Experience Demographics Questionnaire
FVL Task Automation: Pilot Cognitive Workload Capstone

***Estimates of flight hours are perfectly fine if you do not know the actual numbers*

Participant Number *(filled in by interviewer)*:___________________________________

Gender:____

Readiness Level:____

Aircraft Qualifications *(e.g., UH-60M)*:____

Years of Flight Experience:____

Total Flight Hours:____

Combat Flight Hours:____

NVG Flight Hours:____

Instrument Flight Hours *(include Hood/Weather)*:_______________________________

Number of Deployments:____

Deployment Location(s) *(country)*:____

Duty Position:____

Aviation Track(s) (if applicable):____
(e.g., IP, MTP, AMSO, Safety Officer)

Number of MEDEVAC/CASEVACs Flown:___________________________________

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APPENDIX H. INITIAL INTERVIEW DATA COLLECTION INFLUENCE DIAGRAM

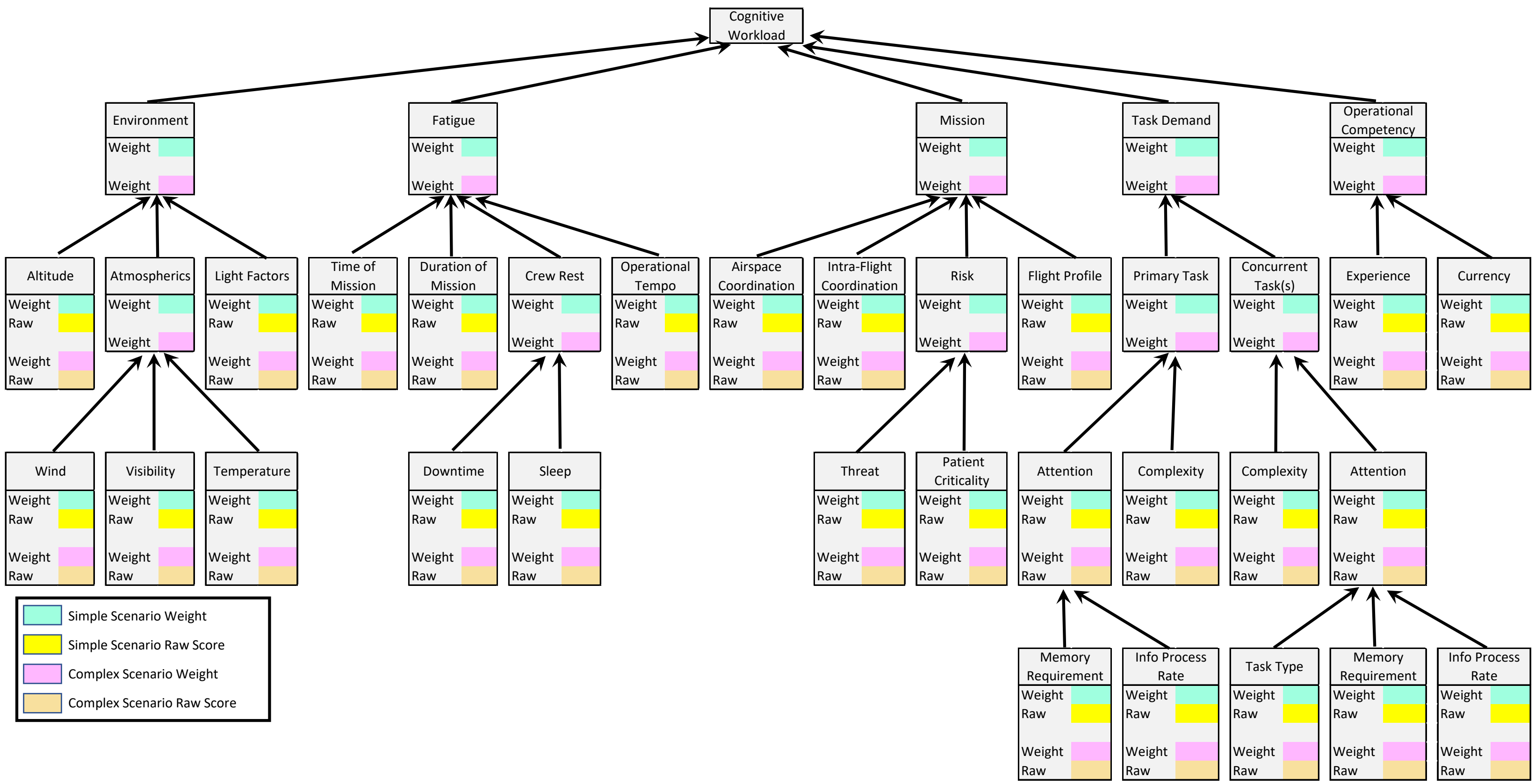

Figure 11. Sterile influence diagram used to collect participant data during the initial interview

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APPENDIX I. INITIAL INTERVIEW RAW DATA

Table 15. Participant provided subfactor raw scores for the simple MEDEVAC scenario

Participant #	Wind	Visibility	Temperature	Altitude	Light Factors	Downtime	Sleep	Time of Mission	Duration of Mission	Operational Tempo	Airspace Coordination	Intra-Flight Coordination	Threat	Patient Criticality	Flight Profile	Primary Task Memory Requirements	Primary Task Information Process Rate Requirements	Primary Task Complexity	Concurrent Task Type	Concurrent Task Memory Requirements	Concurrent Task Information Process Rate Requirements	Concurrent Task Complexity	Experience	Currency
1	5	5	15	20	5	20	20	15	15	10	15	15	15	10	10	20	10	10	10	10	10	15	15	15
2	10	1	10	1	1	5	5	10	10	5	10	5	1	10	5	5	5	5	5	5	5	5	10	10
3	1	1	10	5	1	1	5	1	5	5	1	1	1	25	10	20	20	10	10	20	10	10	10	5
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	10	1	1	1	1	1	1	1	1	1	1	15	1	10	1	5	5	1	1	5	1	1	1	1
6	5	5	5	5	5	5	5	10	5	5	5	1	1	5	5	15	10	10	10	10	15	10	15	5
7	1	1	1	1	1	1	1	5	1	20	10	10	1	30	1	20	15	10	10	20	15	10	10	10
8	20	1	1	1	1	1	20	1	1	1	30	1	1	20	1	60	10	10	10	50	20	10	5	1
9	10	1	1	1	1	1	10	1	1	1	1	1	10	30	10	10	20	20	30	30	30	30	1	1
10	10	1	10	1	1	5	1	10	10	50	1	10	1	20	10	20	10	10	10	10	10	20	10	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	10	10	10	30	1	10	10	20	20	20	30	20	1	50	70	40	50	30	60	40	50	50	20	20
13	1	1	1	5	1	1	15	1	10	20	1	1	1	30	1	30	10	10	30	10	10	20	20	1
14	1	1	1	20	10	1	1	1	5	1	10	1	1	5	25	15	10	5	10	5	10	5	5	1
15	1	1	5	20	1	1	15	10	5	10	10	15	10	10	30	5	20	10	15	30	20	15	5	5
16	10	5	10	5	1	10	5	1	5	10	1	5	10	20	20	1	5	5	10	10	5	5	1	1
17	15	1	1	1	1	1	1	1	1	1	1	10	15	20	10	20	20	20	20	20	20	20	15	10
18	20	1	1	1	10	1	20	1	5	1	20	10	1	5	1	5	5	5	10	5	5	5	10	5
19	1	1	1	1	1	1	1	1	1	10	1	1	1	1	1	1	1	1	1	1	10	1	1	1
20	15	1	15	20	5	5	5	10	10	10	5	5	1	3	10	20	10	20	20	15	20	15	5	10

Table 16. Participant provided factor and subfactor weights for the simple MEDEVAC scenario

Participant #	Wind	Visibility	Temperature	Altitude	Atmospherics	Light Factors	Downtime	Sleep	Time of Mission	Duration of Mission	Crew Rest	Operational Tempo	Threat	Patient Criticality	Airspace Coordination	Intra-Flight Coordination	Risk	Flight Profile	Primary Task Memory Requirements	Primary Task Information Process Rate Requirements	Primary Task Attention	Primary Task Complexity	Concurrent Task Type	Concurrent Task Memory Requirements	Concurrent Task Information Process Rate Requirements	Concurrent Task Attention	Concurrent Task Complexity	Primary Task	Concurrent Task	Experience	Currency	Environment	Fatigue	Mission	Task Demand	Operational Competency
1	0.20	0.20	0.60	0.40	0.40	0.20	0.40	0.60	0.25	0.20	0.35	0.20	0.15	0.85	0.20	0.35	0.30	0.15	0.35	0.65	0.50	0.50	0.30	0.40	0.30	0.50	0.50	0.60	0.40	0.35	0.65	0.10	0.20	0.25	0.15	0.30
2	0.10	0.60	0.30	0.50	0.40	0.10	0.20	0.80	0.10	0.30	0.50	0.10	0.80	0.20	0.15	0.15	0.50	0.20	0.40	0.60	0.40	0.60	0.60	0.10	0.30	0.40	0.60	0.90	0.10	0.40	0.60	0.15	0.10	0.15	0.30	0.30
3	0.20	0.50	0.30	0.30	0.30	0.40	0.50	0.50	0.20	0.20	0.30	0.30	0.50	0.50	0.15	0.40	0.15	0.30	0.40	0.60	0.50	0.50	0.20	0.30	0.50	0.50	0.50	0.50	0.50	0.30	0.70	0.25	0.10	0.15	0.25	0.25
4	0.30	0.40	0.30	0.33	0.33	0.33	0.40	0.60	0.10	0.10	0.40	0.40	0.40	0.60	0.25	0.25	0.25	0.25	0.50	0.50	0.50	0.50	0.40	0.30	0.30	0.50	0.50	0.50	0.50	0.50	0.50	0.25	0.20	0.15	0.15	0.25
5	0.30	0.50	0.20	0.10	0.50	0.40	0.50	0.50	0.30	0.20	0.30	0.20	0.00	1.00	0.05	0.35	0.10	0.50	0.50	0.50	0.50	0.50	0.30	0.40	0.30	0.80	0.20	0.50	0.50	0.70	0.30	0.10	0.10	0.25	0.15	0.40
6	0.25	0.25	0.50	0.25	0.50	0.25	0.25	0.75	0.30	0.30	0.30	0.10	0.00	1.00	0.00	0.25	0.50	0.25	0.75	0.25	0.50	0.50	0.20	0.60	0.20	0.75	0.25	0.75	0.25	0.80	0.20	0.10	0.10	0.20	0.30	0.30
7	0.30	0.50	0.20	0.40	0.30	0.30	0.40	0.60	0.10	0.30	0.20	0.40	0.00	1.00	0.25	0.25	0.25	0.25	0.40	0.60	0.50	0.50	0.10	0.35	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.10	0.10	0.30	0.20	0.30
8	0.50	0.25	0.25	0.50	0.30	0.20	0.20	0.80	0.10	0.10	0.30	0.50	0.20	0.80	0.30	0.10	0.10	0.50	0.50	0.50	0.80	0.20	0.30	0.40	0.30	0.50	0.50	0.70	0.30	0.70	0.30	0.20	0.30	0.10	0.10	0.30
9	0.50	0.25	0.25	0.33	0.33	0.33	0.40	0.60	0.15	0.25	0.30	0.30	0.30	0.70	0.20	0.20	0.30	0.30	0.40	0.60	0.60	0.40	0.20	0.30	0.50	0.80	0.20	0.70	0.30	0.40	0.60	0.20	0.10	0.25	0.25	0.20
10	0.40	0.10	0.50	0.20	0.70	0.10	0.70	0.30	0.20	0.10	0.60	0.10	0.10	0.90	0.10	0.00	0.70	0.20	0.60	0.40	0.90	0.10	0.10	0.20	0.70	0.70	0.30	0.70	0.30	0.20	0.80	0.10	0.30	0.30	0.20	0.10
11	0.25	0.50	0.25	0.80	0.10	0.10	0.50	0.50	0.25	0.25	0.25	0.25	0.00	1.00	0.10	0.10	0.10	0.70	0.50	0.50	0.70	0.30	0.10	0.40	0.50	0.70	0.30	0.80	0.20	0.50	0.50	0.10	0.10	0.60	0.10	0.10
12	0.70	0.30	0.00	0.70	0.30	0.00	0.20	0.80	0.25	0.25	0.25	0.25	0.10	0.90	0.10	0.00	0.60	0.30	0.40	0.60	0.50	0.50	0.10	0.45	0.45	0.70	0.30	0.40	0.60	0.70	0.30	0.05	0.20	0.50	0.20	0.05
13	0.00	0.80	0.20	0.20	0.20	0.60	0.10	0.90	0.30	0.20	0.30	0.20	0.65	0.35	0.25	0.25	0.25	0.25	0.60	0.40	0.70	0.30	0.20	0.40	0.40	0.80	0.20	0.75	0.25	0.75	0.25	0.25	0.25	0.15	0.25	0.10
14	0.33	0.33	0.33	0.50	0.25	0.25	0.45	0.55	0.10	0.40	0.25	0.25	0.20	0.80	0.30	0.20	0.20	0.30	0.40	0.60	0.60	0.40	0.25	0.35	0.40	0.60	0.40	0.30	0.70	0.60	0.40	0.15	0.05	0.20	0.40	0.20
15	0.40	0.30	0.30	0.30	0.40	0.30	0.40	0.60	0.20	0.20	0.40	0.20	0.70	0.30	0.10	0.30	0.10	0.50	0.40	0.60	0.80	0.20	0.25	0.50	0.25	0.80	0.20	0.40	0.60	0.50	0.50	0.10	0.15	0.35	0.30	0.10
16	0.50	0.20	0.30	0.25	0.50	0.25	0.50	0.50	0.25	0.25	0.30	0.20	0.20	0.80	0.20	0.40	0.10	0.30	0.30	0.70	0.90	0.10	0.40	0.30	0.30	0.90	0.10	0.70	0.30	0.30	0.70	0.10	0.10	0.30	0.40	0.10
17	0.50	0.25	0.25	0.30	0.40	0.30	0.50	0.50	0.25	0.25	0.25	0.25	0.40	0.60	0.10	0.25	0.40	0.25	0.50	0.50	0.60	0.40	0.33	0.34	0.33	0.60	0.40	0.60	0.40	0.55	0.45	0.15	0.15	0.40	0.15	0.15
18	0.80	0.10	0.10	0.10	0.70	0.20	0.10	0.90	0.10	0.20	0.60	0.10	0.40	0.60	0.30	0.20	0.40	0.10	0.50	0.50	0.50	0.50	0.40	0.30	0.30	0.50	0.50	0.50	0.50	0.60	0.40	0.25	0.25	0.15	0.15	0.20
19	0.33	0.33	0.33	0.33	0.33	0.33	0.50	0.50	0.25	0.20	0.25	0.30	0.40	0.60	0.25	0.25	0.25	0.25	0.50	0.50	0.50	0.50	0.30	0.30	0.40	0.50	0.50	0.55	0.45	0.50	0.50	0.20	0.20	0.20	0.20	0.20
20	0.20	0.60	0.20	0.60	0.30	0.10	0.40	0.60	0.20	0.30	0.30	0.20	0.40	0.60	0.20	0.20	0.30	0.20	0.30	0.70	0.60	0.40	0.30	0.30	0.40	0.60	0.40	0.50	0.50	0.40	0.60	0.10	0.20	0.20	0.30	0.20

Table 17. Participant provided subfactor raw scores for the complex MEDEVAC scenario

Participant #	Wind	Visibility	Temperature	Altitude	Light Factors	Downtime	Sleep	Time of Mission	Duration of Mission	Operational Tempo	Airspace Coordination	Intra-Flight Coordination	Threat	Patient Criticality	Flight Profile	Primary Task Memory Requirements	Primary Task Information Process Rate Requirements	Primary Task Complexity	Concurrent Task Type	Concurrent Task Memory Requirements	Concurrent Task Information Process Rate Requirements	Concurrent Task Complexity	Experience	Currency
1	60	70	25	65	75	25	70	70	45	50	50	65	85	95	65	55	70	65	75	75	80	75	95	80
2	90	70	70	70	80	80	90	70	60	60	80	80	90	90	80	60	80	80	70	60	80	80	90	90
3	75	75	90	80	90	50	50	70	15	80	75	75	90	95	25	30	80	80	60	50	99	90	90	90
4	70	90	10	70	90	60	80	50	50	60	70	70	60	90	90	40	75	80	80	40	80	80	80	90
5	70	50	70	60	100	60	70	70	30	90	100	100	100	100	100	60	80	40	40	90	80	50	100	100
6	30	70	60	70	60	40	65	70	30	70	85	85	50	60	40	75	60	85	70	60	75	60	85	85
7	40	45	20	40	50	5	35	65	20	40	60	40	60	90	70	60	60	75	50	50	70	60	85	45
8	70	50	70	10	80	40	50	70	10	20	100	70	50	90	100	70	90	40	40	50	80	100	80	100
9	70	80	60	60	85	40	60	60	1	70	85	65	60	75	80	50	80	70	90	80	80	90	80	80
10	90	80	60	60	100	90	80	80	80	100	100	100	90	100	90	100	100	90	90	90	100	90	100	80
11	60	70	70	85	85	15	15	25	20	75	90	85	80	95	80	80	70	90	85	85	85	90	95	90
12	40	30	40	40	70	80	80	60	40	60	50	50	30	80	90	60	60	30	50	60	80	70	70	70
13	40	75	60	50	95	60	85	80	30	65	75	85	80	85	50	60	60	70	85	90	90	85	65	65
14	40	20	10	20	60	20	20	80	10	30	25	40	80	80	60	25	60	30	40	35	30	40	70	60
15	60	80	60	50	90	70	70	80	40	30	50	80	80	60	40	20	65	30	85	95	90	90	70	50
16	95	50	75	40	95	50	80	80	60	85	95	100	90	75	65	40	80	90	80	90	100	95	90	80
17	90	100	75	65	100	40	50	65	20	80	50	90	30	90	100	90	100	100	95	95	95	100	85	80
18	80	60	50	60	100	50	70	70	80	50	70	40	30	80	70	20	70	100	70	50	50	50	90	90
19	40	30	25	50	90	20	80	30	10	20	60	60	35	50	25	50	70	50	70	30	70	70	70	25
20	25	40	30	20	80	10	20	30	20	30	50	30	40	60	40	60	50	40	50	40	60	60	70	90

Table 18. Participant provided factor and subfactor weights for the complex MEDEVAC scenario

Participant #	Wind	Visibility	Temperature	Altitude	Atmospherics	Light Factors	Downtime	Sleep	Time of Mission	Duration of Mission	Crew Rest	Operational Tempo	Threat	Patient Criticality	Airspace Coordination	Intra-Flight Coordination	Risk	Flight Profile	Primary Task Memory Requirements	Primary Task Information Process Rate Requirements	Primary Task Attention	Primary Task Complexity	Concurrent Task Type	Concurrent Task Memory Requirements	Concurrent Task Information Process Rate Requirements	Concurrent Task Attention	Concurrent Task Complexity	Primary Task	Concurrent Task	Experience	Currency	Environment	Fatigue	Mission	Task Demand	Operational Competency
1	0.35	0.50	0.15	0.40	0.35	0.25	0.20	0.80	0.20	0.15	0.45	0.20	0.60	0.40	0.25	0.40	0.20	0.15	0.35	0.65	0.55	0.45	0.25	0.35	0.40	0.50	0.50	0.45	0.55	0.75	0.25	0.15	0.05	0.30	0.25	0.25
2	0.20	0.50	0.30	0.50	0.40	0.10	0.20	0.80	0.10	0.30	0.50	0.10	0.80	0.20	0.15	0.15	0.50	0.20	0.30	0.70	0.40	0.60	0.50	0.10	0.40	0.40	0.60	0.90	0.10	0.50	0.50	0.15	0.10	0.15	0.30	0.30
3	0.20	0.50	0.30	0.30	0.30	0.40	0.70	0.30	0.30	0.10	0.30	0.30	0.50	0.50	0.15	0.40	0.30	0.15	0.40	0.60	0.50	0.50	0.20	0.30	0.50	0.50	0.50	0.40	0.60	0.30	0.70	0.25	0.10	0.20	0.25	0.20
4	0.20	0.70	0.10	0.20	0.20	0.60	0.30	0.70	0.10	0.20	0.40	0.30	0.40	0.60	0.15	0.15	0.30	0.40	0.30	0.70	0.45	0.55	0.40	0.20	0.40	0.55	0.45	0.60	0.40	0.50	0.50	0.20	0.10	0.10	0.40	0.20
5	0.40	0.50	0.10	0.10	0.40	0.50	0.60	0.40	0.20	0.20	0.30	0.30	0.60	0.40	0.30	0.30	0.10	0.30	0.50	0.50	0.30	0.70	0.10	0.60	0.30	0.20	0.80	0.60	0.40	0.90	0.10	0.20	0.10	0.25	0.25	0.20
6	0.30	0.40	0.30	0.20	0.40	0.40	0.30	0.70	0.30	0.10	0.30	0.30	0.25	0.75	0.20	0.40	0.20	0.20	0.70	0.30	0.40	0.60	0.40	0.30	0.30	0.60	0.40	0.75	0.25	0.80	0.20	0.10	0.15	0.20	0.15	0.40
7	0.40	0.50	0.10	0.15	0.45	0.40	0.30	0.70	0.20	0.10	0.30	0.40	0.40	0.60	0.30	0.10	0.30	0.30	0.30	0.70	0.50	0.50	0.20	0.10	0.70	0.50	0.50	0.40	0.60	0.90	0.10	0.10	0.10	0.30	0.20	0.30
8	0.40	0.50	0.10	0.10	0.45	0.45	0.50	0.50	0.30	0.10	0.40	0.20	0.50	0.50	0.20	0.50	0.10	0.20	0.10	0.90	0.10	0.90	0.33	0.33	0.33	0.10	0.90	0.10	0.90	0.50	0.50	0.20	0.10	0.10	0.50	0.10
9	0.35	0.45	0.20	0.20	0.40	0.40	0.30	0.70	0.25	0.10	0.25	0.40	0.60	0.40	0.20	0.20	0.30	0.30	0.30	0.70	0.40	0.60	0.20	0.35	0.45	0.50	0.50	0.60	0.40	0.50	0.50	0.25	0.15	0.20	0.20	0.20
10	0.60	0.30	0.10	0.10	0.40	0.50	0.60	0.40	0.20	0.20	0.40	0.20	0.40	0.60	0.40	0.30	0.20	0.10	0.20	0.80	0.60	0.40	0.20	0.30	0.50	0.60	0.40	0.40	0.60	0.90	0.10	0.10	0.20	0.40	0.20	0.10
11	0.20	0.50	0.30	0.20	0.20	0.60	0.50	0.50	0.20	0.15	0.15	0.50	0.30	0.70	0.20	0.20	0.40	0.20	0.50	0.50	0.40	0.60	0.25	0.25	0.50	0.50	0.50	0.20	0.80	0.80	0.20	0.20	0.20	0.20	0.20	0.20
12	0.30	0.30	0.40	0.30	0.30	0.40	0.50	0.50	0.30	0.10	0.30	0.30	0.20	0.80	0.25	0.25	0.25	0.25	0.25	0.75	0.70	0.30	0.20	0.40	0.40	0.80	0.20	0.30	0.70	0.50	0.50	0.20	0.20	0.20	0.20	0.20
13	0.25	0.60	0.15	0.10	0.15	0.75	0.20	0.80	0.30	0.10	0.30	0.30	0.80	0.20	0.25	0.25	0.35	0.15	0.50	0.50	0.70	0.30	0.20	0.30	0.50	0.65	0.35	0.55	0.45	0.65	0.35	0.15	0.20	0.25	0.25	0.15
14	0.60	0.30	0.10	0.20	0.60	0.20	0.60	0.40	0.30	0.10	0.30	0.30	0.50	0.50	0.30	0.30	0.20	0.20	0.30	0.70	0.40	0.60	0.60	0.20	0.20	0.50	0.50	0.20	0.80	0.80	0.20	0.10	0.10	0.20	0.50	0.10
15	0.20	0.65	0.15	0.20	0.35	0.45	0.35	0.65	0.40	0.15	0.30	0.15	0.80	0.20	0.10	0.40	0.20	0.30	0.40	0.60	0.60	0.40	0.20	0.50	0.30	0.50	0.50	0.30	0.70	0.60	0.40	0.20	0.10	0.25	0.35	0.10
16	0.60	0.30	0.10	0.10	0.20	0.70	0.35	0.65	0.25	0.10	0.30	0.35	0.70	0.30	0.10	0.30	0.20	0.40	0.25	0.75	0.50	0.50	0.20	0.40	0.40	0.60	0.40	0.40	0.60	0.60	0.40	0.30	0.10	0.15	0.30	0.15
17	0.30	0.50	0.20	0.20	0.30	0.50	0.40	0.60	0.20	0.20	0.30	0.30	0.40	0.60	0.15	0.30	0.15	0.40	0.40	0.60	0.50	0.50	0.33	0.34	0.33	0.50	0.50	0.85	0.15	0.60	0.40	0.30	0.10	0.30	0.15	0.15
18	0.50	0.30	0.20	0.10	0.30	0.60	0.40	0.60	0.25	0.20	0.40	0.15	0.20	0.80	0.25	0.10	0.40	0.25	0.30	0.70	0.10	0.90	0.40	0.30	0.30	0.50	0.50	0.75	0.25	0.50	0.50	0.25	0.20	0.20	0.25	0.10
19	0.45	0.40	0.15	0.05	0.40	0.55	0.30	0.70	0.30	0.15	0.35	0.20	0.70	0.30	0.30	0.36	0.14	0.20	0.30	0.70	0.50	0.50	0.25	0.25	0.50	0.50	0.50	0.40	0.60	0.90	0.10	0.25	0.15	0.18	0.17	0.25
20	0.30	0.40	0.30	0.30	0.30	0.40	0.40	0.60	0.40	0.10	0.20	0.30	0.50	0.50	0.30	0.20	0.20	0.30	0.50	0.50	0.40	0.60	0.30	0.30	0.40	0.60	0.40	0.60	0.40	0.30	0.70	0.25	0.10	0.25	0.15	0.25

APPENDIX J. FOLLOW-ON INTERVIEW RECRUITMENT SCRIPT

Recruitment script emailed directly to initial interview participants by the research team.

XXX,

My name is Greg Griffith and I am a graduate student in the Systems Engineering department at the Naval Postgraduate School. You previously participated in a study examining the cognitive workload of pilots. As a part of that study I would like invite you to participate in a brief follow-up interview lasting ~15 minutes, administered over Microsoft Teams. This interview will examine the potential impact of automation on pilot cognitive workload and will influence the development of task automation and mission aids for the Future Vertical Lift program.

Participation in this follow-up interview is voluntary. Your identity as a participant will remain confidential and the data collected will not be directly associated with your name or other personally identifiable information.

If you have questions or would like to participate, please contact me at XXX@nps.edu, XXX@mail.mil, or XXX-XXX-XXXX. The principal investigator for this study is Dr. Lawrence Shattuck, XXX@nps.edu, XXX-XXX-XXXX. The institutional review board chair is Mr. Bryan Hudgens, XXX@nps.edu, XXX-XXX-XXXX.

Thank you in advance for your time and consideration.

Respectfully,

MAJ Gregory S. Griffith
Graduate Student, Naval Postgraduate School
Email: XXX@nps.edu
Cell: (XXX) XXX-XXXX

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APPENDIX K. FOLLOW-ON INTERVIEW SCRIPT

Expected Interview Length: 15 Minutes

Interview Format: Semi-structured

Interview Location(s): all interviews will be conducted via Microsoft Teams. The interviewer will be physically located in Monterey, CA and the interviewee will be physically located at JBLM, WA.

*Text in italics is intended to represent the things an interviewer might say or the way they might ask a question. Actual wording and phraseology may differ.

With subjects recruited and interviews scheduled, the following procedures will be followed:

- ***<u>Welcome</u>*** *Typical welcome (e.g., hello, how are you, etc.)*
- ***<u>Consent Form</u>*** *(explains that the initial consent is still applicable and verify that the interviewee would like to participate in the follow-up interview)*
    - Before we start the formal portion of the interview, I would like to remind you that the initial consent form you completed in August is still valid and covers this interview. As a reminder:
        - *Participation is voluntary and there will not be any compensation or incentives for your participation.*
        - *There will be no penalty if you refuse to participate.*
        - *The information collected during the study will be kept confidential to the full extent permitted by law and the data collected will be separated from your personally identifiable information. Once the data analysis and study are complete, your PII will be deleted.*
- **<u>Start Audio Recording</u>** (Interviewer will initiate audio recording for interview)

- *Similar to our interview in August, I will be recording the audio of the interview to use as a reference if needed. Nobody outside of the research team will have access to the audio recording. Do you mind if we continue to record this?*

- **Project Explanation** (Interviewer will provide an updated overview of the research project and its current status)

  - **Overview:** *The aim of this project remains the same – developing an influence diagram to depict pilot cognitive workload and the factors and subfactors that contribute to it. This understanding will be used to help determine what tasks should be automated to avoid task saturation and cognitive overload in FVL.*

  - **Current Status:** *Influence diagram interviews and data collection are complete, and the data is currently being analyzed. As a part of that analysis, this interview will provide context and ideas to the FVL development team on potential areas for automation from the perspective of a pilot as well as the expected impact that automation would have on cognitive workload*.

- **Influence Diagram Presentation (Complex Scenario)** (Interviewer will provide the final influence diagram with raw scores derived from the aggregated complex scenario interview data and the averaged weights of the simple and complex scenario aggregated interview data. The interviewee will be given time to review the influence diagram and ask questions.)

  - *I am now screen-sharing the influence diagram we used during our interviews in August. The only difference is that the weights and raw scores have been filled into the diagram. The weights and raw scores shown were determined by averaging all of the data points we collected during our interviews in August.*

- *Please take a moment to re-familiarize yourself with the influence diagram and the relationships of the factors and subfactors to pilot cognitive workload*

- *If you have any questions about what the factors or subfactors refer to please ask at any time.*

- **Cognitive Workload Driver Results Presentation (Rank Ordered)** (Interviewer will show the interviewee a rank ordered list of the top 10 subfactors contributing to pilot cognitive workload and will highlight the top 3 subfactors.)

  - *I am now screen-sharing a list of the top 10 drivers of cognitive workload for pilots during the complex MEDEVAC scenario. These data were derived from an analysis of the data collected during our interviews in August. Of note, the top 3 drivers of cognitive workload were: **Flight Profile**, **Primary Task Complexity**, and **Light Factors**.*

- **Questions** (interviewer will ask the interviewee open-ended questions about their interpretation of the results, their ideas for how to use automation to reduce the source of the cognitive workload, and how much their ideas would reduce their workload)

  **Use the interview template to collect and annotate data

  - *To what extent do you agree or disagree that each of the top 3 sources of cognitive workload can be mitigated using automation or mission aids? Please indicate whether you strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree for each of the following factors.*

    - *Flight Profile*

- *Primary Task Complexity*
- *Light Factors*

**Use 5-response Likert scale as shown on interview template

- *How, or in what way would you like to see automation or mission aids used to address these sources of cognitive workload?* (Interviewer will take notes and intentionally leave the question open-ended to encourage maximum use of creativity and personal opinion)
    - *Flight Profile*
    - *Primary Task Complexity*
    - *Light Factors*
- *I am now screen-sharing the complex MEDEVAC mission scenario. Please take a moment to refresh your memory of the scenario.* (Pause briefly)
- *I am now screen-sharing the complex scenario influence diagram.*
- *If implemented as described, what would be the new raw score (with 1 being a good condition and 100 being a terrible condition) of each top-3 subfactor given the complex scenario? How much do you estimate your cognitive workload related to that subfactor would decrease?*
    - *Flight Profile*
    - *Primary Task Complexity*
    - *Light Factors*

- **<u>Questions</u>** (Interviewer will ask the interviewee if they have any questions, would like to make any changes to their answers, and if they have any open-ended comments or automation ideas they would like to provide.)
- Do you have any questions about what we just did or any changes you want to make before we move on?
- Do you have any thoughts or comments that you would like to share regarding ideas for where the design team should focus their efforts in developing automation and mission aids to help reduce pilot cognitive workload?
- **<u>Interview Closeout</u>** (Interviewer will thank the interviewee for his/her time and provide contact information in the event the interviewee has questions or needs to reach out for any reason)
    - *That completes the follow-up interview. Thank you for making the time to talk with me today and help shape our research. If you have any questions at any time, you can contact me or the principal investigator at any time. Thanks again and have a great day!*
- **<u>Stop Audio Recording</u>** (Interviewer will cease audio recording of the interview)

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APPENDIX L. FOLLOW-ON INTERVIEW INFLUENCE DIAGRAM

The influence diagram shown in Figure 12 shows the mean weights and raw scores from the initial interview complex MEDEVAC scenario. The influence diagram was provided for participants to reference during follow-on interviews. Researchers assumed the interview data would be parametric and, as such, developed the influence diagram for the follow-on interview using means to represent the central tendency of the data. After completing the follow-on interviews researchers determining the initial interview response data was nonparametric, thus median is most appropriate to represent the central tendency of the data. This diagram is shown for transparency on what participants referenced during the follow-on interviews. It should not be used for any purpose other than reference to follow-on interview responses.

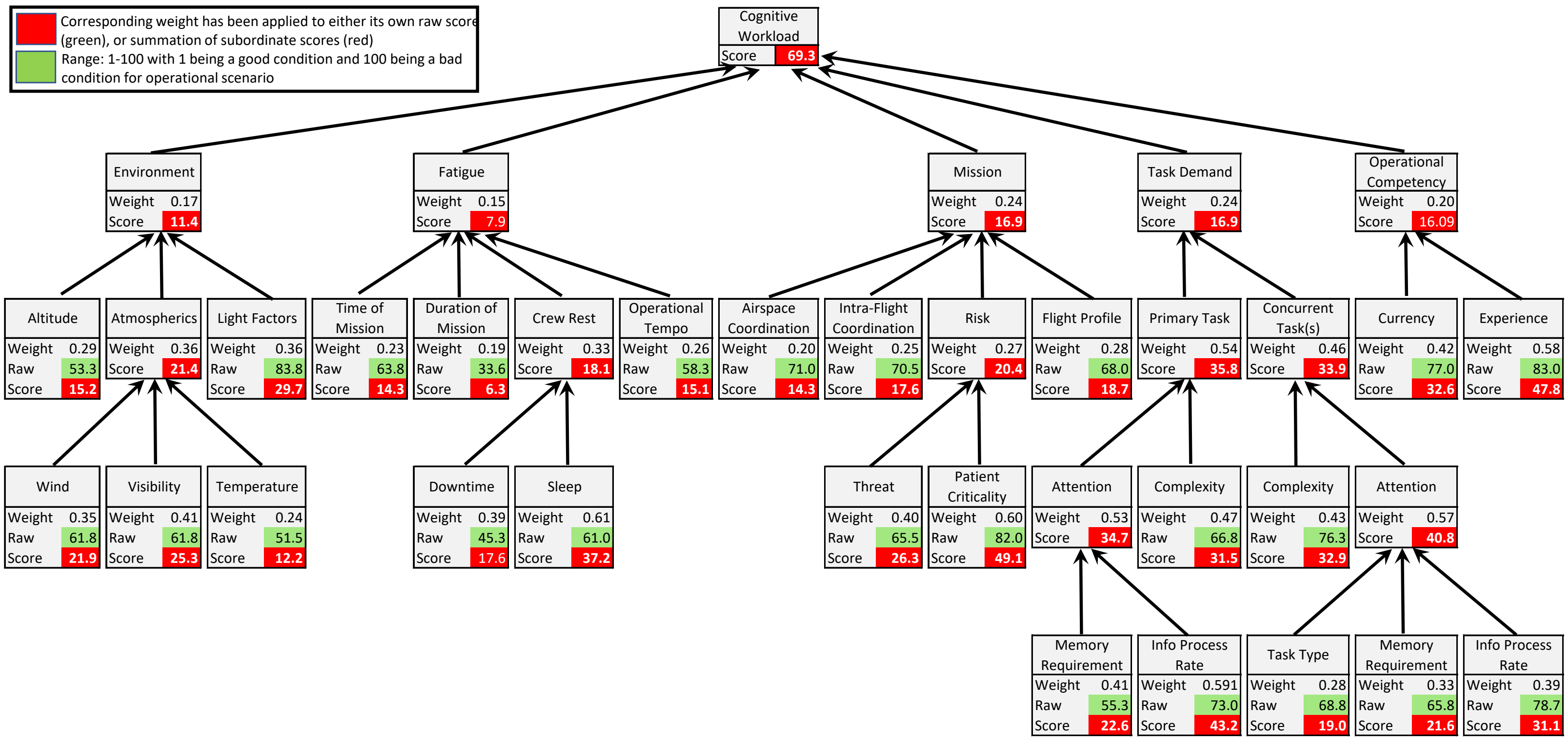

Figure 12. Cognitive workload influence diagram depicting the initial interview mean participant responses to the complex MEDEVAC flight scenario

APPENDIX M. FOLLOW-ON INTERVIEW DATA COLLECTION TEMPLATE

Follow-Up Interview Data Collection
FVL Task Automation: Pilot Cognitive Workload Capstone

Participant Number:

1.) To what extent do you agree or disagree that each of these sources of cognitive workload can be mitigated using automation or mission aids?

Subfactor	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Flight Profile					
Primary Task Complexity					
Light Factors					

*Mark the box that best reflects interviewee response

2.) How, or in what way would you like to see automation or mission aids used to address these sources of cognitive workload?

Flight Profile:

Primary Task Complexity:

Light Factors:

3.) If implemented as described, what would be the reduction in your cognitive load in the complex scenario? (Interviewee provides new complex scenario raw score after automation)

Subfactor	Updated Raw Score	Cognitive Workload Reduction
Flight Profile		
Primary Task Complexity		
Light Factors		

Misc. Notes:____

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APPENDIX N. SIMPLE MEDEVAC SCENARIO INFLUENCE DIAGRAM

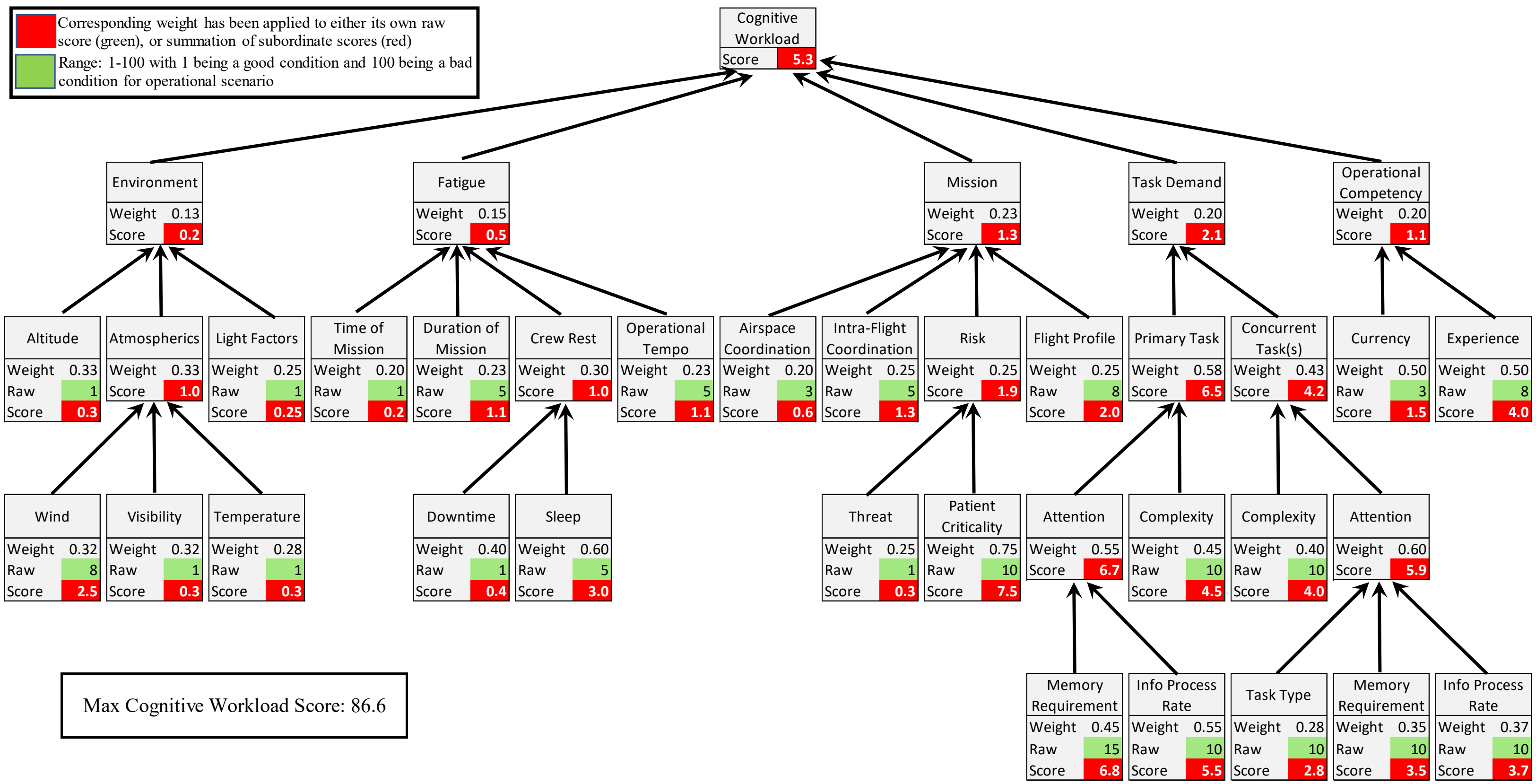

Figure 13. Simple MEDEVAC scenario influence diagram showing the median values of all participants' raw scores and factor weights during the initial interview

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APPENDIX O. COMPLEX MEDEVAC SCENARIO INFLUENCE DIAGRAM

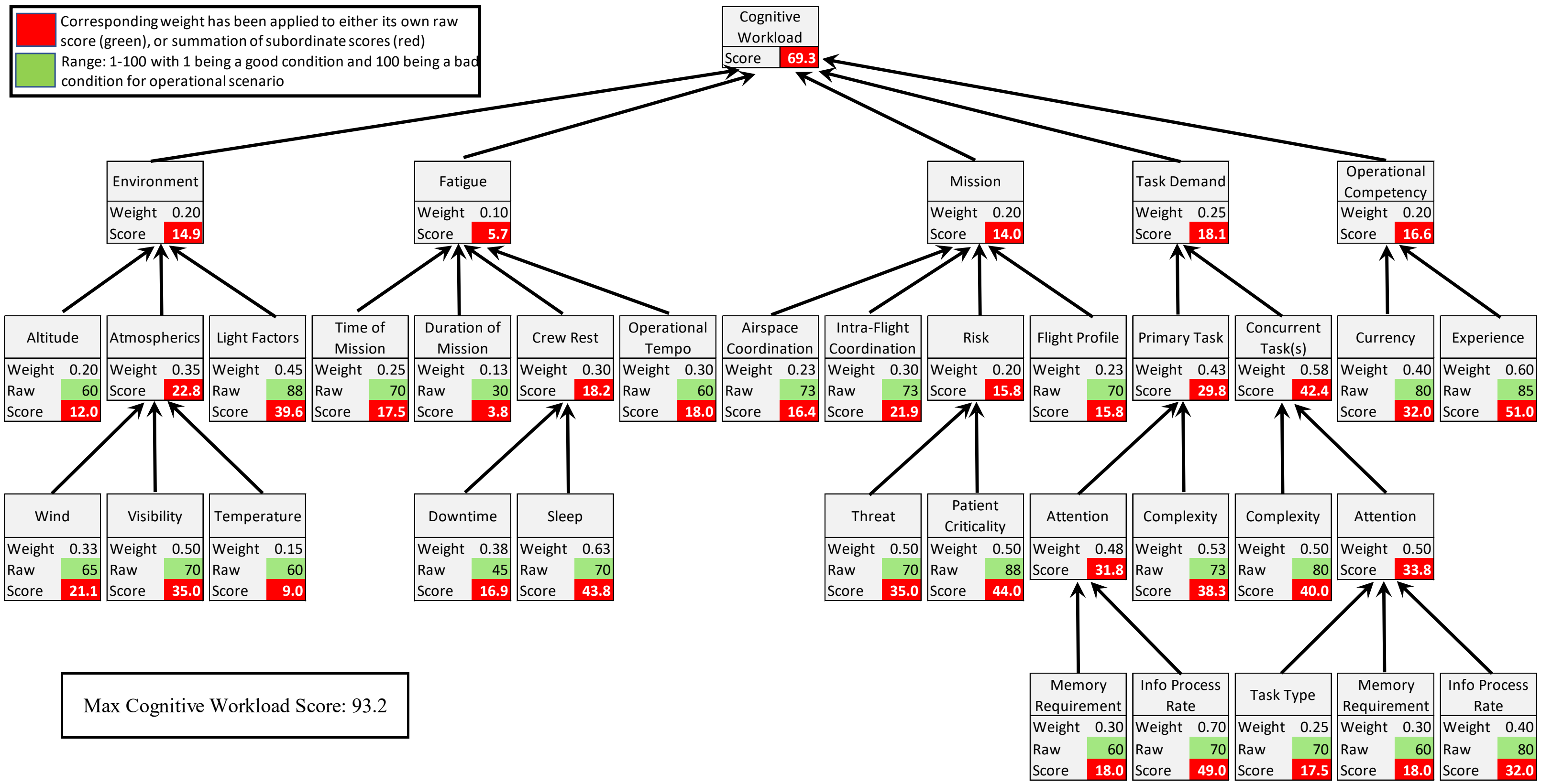

Figure 14. Complex MEDEVAC scenario influence diagram showing the median values of all participants' raw scores and factor weights during the initial interview

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APPENDIX P. FACTOR AND SUBFACTOR WEIGHTED SCORES

Table 19 depicts the factor weighted scores for the simple and complex scenarios. Table 20 depicts the subfactor weighted scores for the simple and complex scenarios. Researchers calculated the weighted scores using the initial interview median weight and raw score for each factor and subfactor. These tables reflect values from the influence diagrams shown in Appendix N and O.

Table 19. Median primary factor weighted workload scores for simple and complex MEDEVAC scenarios

Factor	**Weighted Workload Scores**		
	Simple Scenario	**Complex Scenario**	**Delta**
Task Demand	2.81	18.13	15.32
Operational Competency	1.07	16.19	15.12
Environment	0.59	14.04	13.45
Mission	1.56	14.33	12.77
Fatigue	0.72	6.49	5.77

Table 20. Median subfactor weighted workload scores for simple and complex MEDEVAC scenarios

Subfactor	Weighted Scores Using Median Weights and Median Raw Scores		
	Simple Scenario	Complex Scenario	Delta
Experience	4.0	51.0	47.0
Primary Task Information Processing Rate Requirements	5.5	49.0	43.5
Sleep	3.0	43.8	40.8
Light Factors	0.3	39.6	39.4
Concurrent Task	4.2	42.4	38.2
Patient Criticality	7.5	44.0	36.5
Concurrent Task Complexity	4.0	40.0	36.0
Threat	0.3	35.0	34.8
Visibility	0.3	35.0	34.7
Primary Task Complexity	4.5	38.3	33.8
Currency	1.5	32.0	30.5
Concurrent Task Information Processing Rate Requirements	3.7	32.0	28.4
Concurrent Task Attention	5.9	33.8	27.8
Primary Task Attention	6.7	31.8	25.1
Primary Task	6.5	29.8	23.4
Atmospherics	1.0	22.8	21.8
Intra-Flight Coordination	1.3	21.9	20.7
Wind	2.5	21.1	18.6
Time of Mission	0.2	17.5	17.3
Crew Rest	1.0	18.2	17.2
Operational Tempo	1.1	18.0	16.9
Downtime	0.4	16.9	16.5
Airspace Coordination	0.6	16.4	15.8
Concurrent Task Type	2.8	17.5	14.8
Concurrent Task Memory Requirements	3.5	18.0	14.6
Risk	1.9	15.8	13.9
Flight Profile	2.0	15.8	13.8
Altitude	0.3	12.0	11.7
Primary Memory	6.8	18.0	11.3
Temperature	0.3	9.0	8.7
Duration of Mission	1.1	3.8	2.6

APPENDIX Q. FACTOR AND SUBFACTOR WEIGHT COMPARISONS

Table 21 depicts the initial interview median factor weights for the simple and complex MEDEVAC scenarios. Table 22 depicts the initial interview subfactor weights for the simple and complex MEDEVAC scenarios. These tables reflect values from the influence diagrams shown in Appendix N and O.

Table 21. Median primary factor weights for simple and complex MEDEVAC scenarios

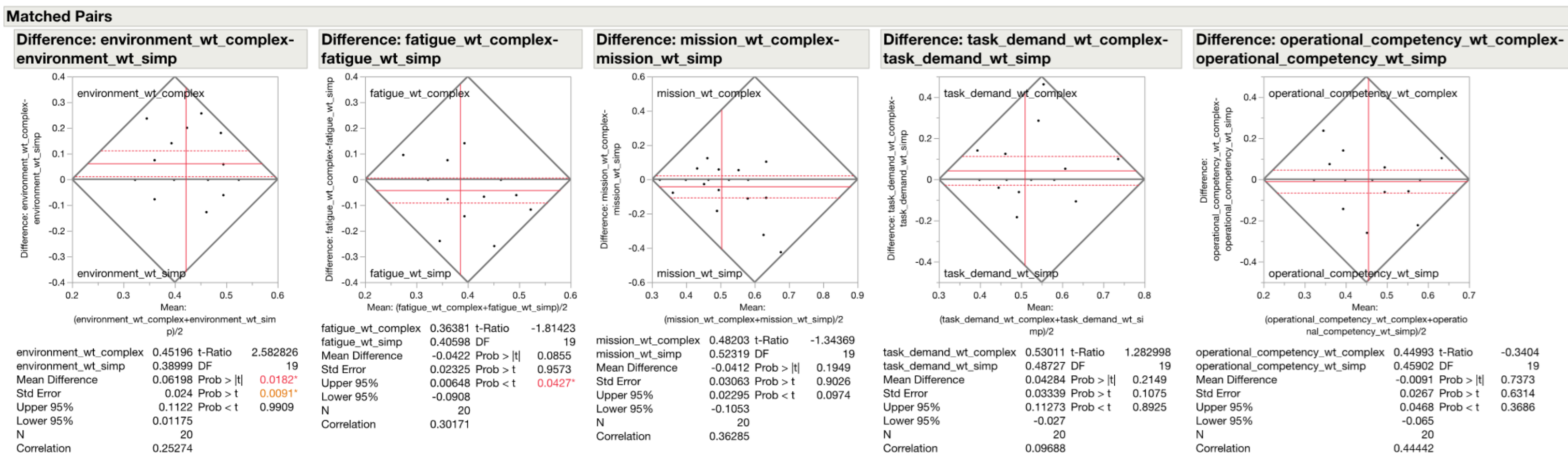
Factor	**Median Weights**		
	Simple Scenario	**Complex Scenario**	**Delta**
Environment	0.13	0.20	0.07
Task Demand	0.20	0.25	0.05
Operational Competency	0.20	0.20	0.00
Mission	0.23	0.20	-0.03
Fatigue	0.15	0.10	-0.05

Table 22. Median subfactor weights for simple and complex MEDEVAC scenarios

Subfactor	Median Weights		
	Simple Scenario	Complex Scenario	Delta
Threat	0.25	0.50	0.25
Light Factors	0.25	0.45	0.20
Visibility	0.32	0.50	0.18
Concurrent Task	0.43	0.58	0.16
Primary Task Information Processing Rate Requirements	0.55	0.70	0.15
Concurrent Task Complexity	0.40	0.50	0.10
Experience	0.50	0.60	0.10
Primary Task Complexity	0.45	0.53	0.08
Operational Tempo	0.23	0.30	0.08
Time of Mission	0.20	0.25	0.05
Intra-Flight Coordination	0.25	0.30	0.05
Concurrent Task Information Processing Rate Requirements	0.37	0.40	0.04
Sleep	0.60	0.63	0.03
Airspace Coordination	0.20	0.23	0.03
Atmospherics	0.33	0.35	0.02
Wind	0.32	0.33	0.01
Crew Rest	0.30	0.30	0.00
Flight Profile	0.25	0.23	-0.03
Downtime	0.40	0.38	-0.03
Concurrent Task Type	0.28	0.25	-0.03
Concurrent Task Memory Requirements	0.35	0.30	-0.05
Risk	0.25	0.20	-0.05
Primary Task Attention	0.55	0.48	-0.07
Concurrent Task Attention	0.60	0.50	-0.10
Currency	0.50	0.40	-0.10
Duration of Mission	0.23	0.13	-0.10
Temperature	0.28	0.15	-0.13
Altitude	0.33	0.20	-0.13
Primary Task	0.58	0.43	-0.15
Primary Task Memory Requirements	0.45	0.30	-0.15
Patient Criticality	0.75	0.50	-0.25

APPENDIX R. INTER-SCENARIO STATISTICAL ANALYSIS OF FACTOR WEIGHT DATA

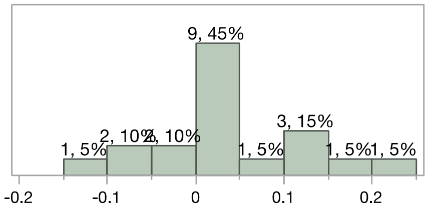
Researchers conducted a statistical analysis of the inter-scenario factor weight data using JMP. The Wilcoxon significance test results is shown in Figure 15. Additionally, bar charts depicting the distribution of response data are shown in Figures 16–25 These charts depict the magnitude and direction of change for the primary factors between the simple and complex scenarios.



	environment_wt_complex-environment_wt_simp	fatigue_wt_complex-fatigue_wt_simp	mission_wt_complex-mission_wt_simp	task_demand_wt_complex-task_demand_wt_simp	operational_competency_wt_complex-operational_competency_wt_simp
Test Statistic S	57.500	-40.500	-22.500	26.000	-1.500
Prob>|S|	0.0188*	0.1648	0.3185	0.2969	0.9407
Prob>S	0.0094*	0.9176	0.8408	0.1484	0.5297
Prob<S	0.9906	0.0824	0.1592	0.8516	0.4703

Figure 15. Results of the Wilcoxon signed rank test exploring the difference of factor weights between simple and complex scenario participant responses

Environment D



Quantiles

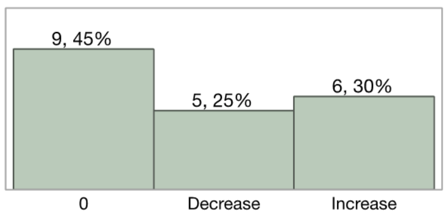
100.0%	maximum	0.2
99.5%		0.2
97.5%		0.2
90.0%		0.145
75.0%	quartile	0.0875
50.0%	median	0
25.0%	quartile	-0.0375
10.0%		-0.1
2.5%		-0.15
0.5%		-0.15
0.0%	minimum	-0.15

Summary Statistics

Mean	0.0125
Std Dev	0.0856477
Std Err Mean	0.0191514
Upper 95% Mean	0.0525844
Lower 95% Mean	-0.027584
N	20
Interquartile Range	0.125
Median Absolute Deviation	0.05

Figure 16. Magnitude of inter-scenario factor weight change for Environment

Environment D 2



Frequencies

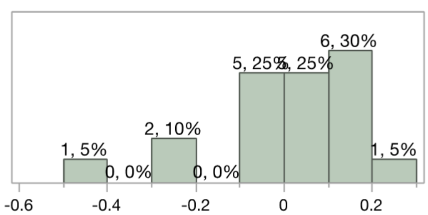
Level	Count	Prob
0	9	0.45000
Decrease	5	0.25000
Increase	6	0.30000
Total	20	1.00000

N Missing 0

3 Levels

Figure 17. Direction of inter-scenario factor weight change for Environment

fatigue D



Quantiles

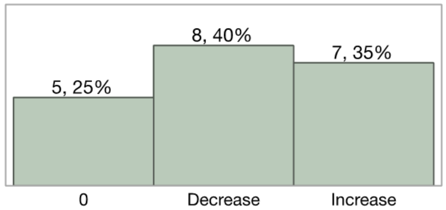
100.0%	maximum	0.2
99.5%		0.2
97.5%		0.2
90.0%		0.145
75.0%	quartile	0.1
50.0%	median	0
25.0%	quartile	-0.1
10.0%		-0.295
2.5%		-0.5
0.5%		-0.5
0.0%	minimum	-0.5

Summary Statistics

Mean	-0.0325
Std Dev	0.1680186
Std Err Mean	0.0375701
Upper 95% Mean	0.0461351
Lower 95% Mean	-0.111135
N	20
Interquartile Range	0.2
Median Absolute Deviation	0.1

Figure 18. Magnitude of inter-scenario factor weight change for Fatigue

fatigue D 2



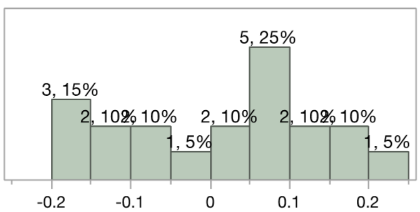
Frequencies

Level	Count	Prob
0	5	0.25000
Decrease	8	0.40000
Increase	7	0.35000
Total	20	1.00000

N Missing 0
3 Levels

Figure 19. Direction of inter-scenario factor weight change for Fatigue

Mission D



Quantiles

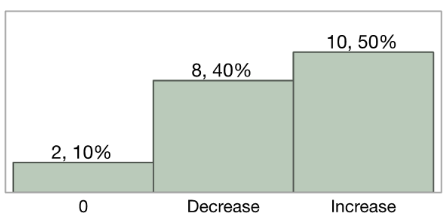
100.0%	maximum	0.2
99.5%		0.2
97.5%		0.2
90.0%		0.15
75.0%	quartile	0.0875
50.0%	median	0.025
25.0%	quartile	-0.1375
10.0%		-0.2
2.5%		-0.2
0.5%		-0.2
0.0%	minimum	-0.2

Summary Statistics

Mean	-0.01
Std Dev	0.1262829
Std Err Mean	0.0282377
Upper 95% Mean	0.0491022
Lower 95% Mean	-0.069102
N	20
Interquartile Range	0.225
Median Absolute Deviation	0.1

Figure 20. Magnitude of inter-scenario factor weight change for Mission

Mission D 2



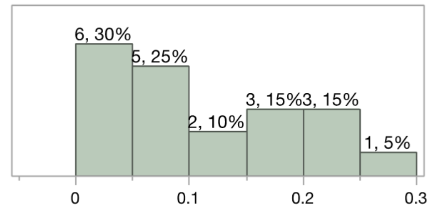
Frequencies

Level	Count	Prob
0	2	0.10000
Decrease	8	0.40000
Increase	10	0.50000
Total	20	1.00000

N Missing 0
3 Levels

Figure 21. Direction of inter-scenario factor weight change for Mission

Task demand D



Quantiles

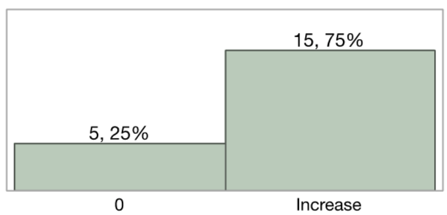
100.0%	maximum	0.25
99.5%		0.25
97.5%		0.25
90.0%		0.2
75.0%	quartile	0.15
50.0%	median	0.05
25.0%	quartile	0.0075
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.089
Std Dev	0.0811042
Std Err Mean	0.0181355
Upper 95% Mean	0.1269579
Lower 95% Mean	0.0510421
N	20
Interquartile Range	0.1425
Median Absolute Deviation	0.05

Figure 22. Magnitude of inter-scenario factor weight change for Task Demand

Task demand D 2



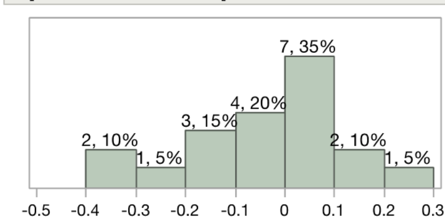
Frequencies

Level	Count	Prob
0	5	0.25000
Increase	15	0.75000
Total	20	1.00000

N Missing 0
2 Levels

Figure 23. Direction of inter-scenario factor weight change for Task Demand

Operational competence D



Quantiles

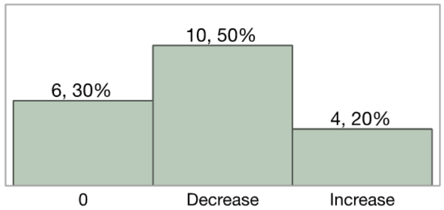
100.0%	maximum	0.25
99.5%		0.25
97.5%		0.25
90.0%		0.1
75.0%	quartile	0
50.0%	median	-0.025
25.0%	quartile	-0.15
10.0%		-0.385
2.5%		-0.4
0.5%		-0.4
0.0%	minimum	-0.4

Summary Statistics

Mean	-0.066
Std Dev	0.1612908
Std Err Mean	0.0360657
Upper 95% Mean	0.0094864
Lower 95% Mean	-0.141486
N	20
Interquartile Range	0.15
Median Absolute Deviation	0.09

Figure 24. Magnitude of inter-scenario factor weight change for Operational Competence

Operational competence D 2



Frequencies

Level	Count	Prob
0	6	0.30000
Decrease	10	0.50000
Increase	4	0.20000
Total	20	1.00000

N Missing 0
3 Levels

Figure 25. Direction of inter-scenario factor weight change for Operational Competence

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APPENDIX S. SUBFACTOR INFLUENCE

Table 23. Subfactor influence on cognitive workload for the simple MEDEVAC scenario

Subfactor	Weight (Median)				Cognitive Workload Influence
	Subfactor	4th Level Parent	3rd Level Parent	2nd Level Parent	
Experience	0.500	N/A	N/A	0.200	0.100
Currency	0.500	N/A	N/A	0.200	0.100
Intra-Flight Coord	0.250	N/A	N/A	0.225	0.056
Flight Profile	0.250	N/A	N/A	0.225	0.056
Primary Task Complexity	0.450	N/A	0.575	0.200	0.052
Concurrent Task Complexity	0.400	N/A	0.575	0.200	0.046
Airspace Coordination	0.200	N/A	N/A	0.225	0.045
Patient Criticality	0.750	N/A	0.250	0.225	0.042
Altitude	0.333	N/A	N/A	0.125	0.042
Primary Task Information Processing Rate Requirements	0.550	0.550	0.575	0.200	0.035
Duration of Mission	0.225	N/A	N/A	0.150	0.034
Operational Tempo	0.225	N/A	N/A	0.150	0.034
Light Factors	0.250	N/A	N/A	0.125	0.031
Time of Mission	0.200	N/A	N/A	0.150	0.030
Primary Task Memory Requirements	0.450	0.550	0.575	0.200	0.029
Sleep	0.600	N/A	0.300	0.150	0.027
Concurrent Task Information Processing Rate Requirements	0.365	0.600	0.575	0.200	0.025
Concurrent Task Memory Requirements	0.345	0.600	0.575	0.200	0.024
Concurrent Task Type	0.275	0.600	0.575	0.200	0.019
Downtime	0.400	N/A	0.300	0.150	0.018
Threat	0.250	N/A	0.250	0.225	0.014
Wind	0.317	N/A	0.333	0.125	0.013
Visibility	0.317	N/A	0.333	0.125	0.013
Temperature	0.275	N/A	0.333	0.125	0.016

Table 24. Subfactor influence on cognitive workload for the complex MEDEVAC scenario

Subfactor	Weight (Median)				Cognitive Workload Influence
	Subfactor	4th Level Parent	3rd Level Parent	2nd Level Parent	
Experience	0.600	N/A	N/A	0.200	0.120
Light Factors	0.450	N/A	N/A	0.200	0.090
Currency	0.400	N/A	N/A	0.200	0.080
Intra-Flight Coord	0.300	N/A	N/A	0.200	0.060
Primary Task Complexity	0.525	N/A	0.425	0.250	0.056
Concurrent Task Complexity	0.500	N/A	0.425	0.250	0.053
Airspace Coordination	0.225	N/A	N/A	0.200	0.045
Flight Profile	0.225	N/A	N/A	0.200	0.045
Altitude	0.200	N/A	N/A	0.200	0.040
Primary Task Information Processing Rate Requirements	0.700	0.475	0.425	0.250	0.035
Visibility	0.500	N/A	0.350	0.200	0.035
Operational Tempo	0.300	N/A	N/A	0.100	0.030
Time of Mission	0.250	N/A	N/A	0.100	0.025
Wind	0.325	N/A	0.350	0.200	0.023
Concurrent Task Information Processing Rate Requirements	0.400	0.500	0.425	0.250	0.021
Threat	0.500	N/A	0.200	0.200	0.020
Patient Criticality	0.500	N/A	0.200	0.200	0.020
Sleep	0.625	N/A	0.300	0.100	0.019
Concurrent Task Memory Requirements	0.300	0.500	0.425	0.250	0.016
Primary Task Memory Requirements	0.300	0.475	0.425	0.250	0.015
Concurrent Task Type	0.250	0.500	0.425	0.250	0.013
Duration of Mission	0.125	N/A	N/A	0.100	0.013
Downtime	0.375	N/A	0.300	0.100	0.011
Temperature	0.150	N/A	0.350	0.200	0.011

Table 25. Comparison of subfactor influence on cognitive workload for the simple and complex MEDEVAC scenarios

Subfactor	**Weight**		**Delta**
	Simple Scenario	**Complex Scenario**	
Light Factors	0.031	0.090	0.059
Visibility	0.013	0.035	0.022
Experience	0.100	0.120	0.020
Wind	0.013	0.023	0.010
Concurrent Task Complexity	0.046	0.053	0.007
Threat	0.014	0.020	0.006
Primary Task Complexity	0.052	0.056	0.004
Intra-Flight Coord	0.056	0.060	0.004
Primary Task Information Processing Rate Requirements	0.035	0.035	0.001
Airspace Coordination	0.045	0.045	0.000
Temperature	0.012	0.011	-0.001
Altitude	0.042	0.040	-0.002
Operational Tempo	0.034	0.030	-0.004
Concurrent Task Information Processing Rate Requirements	0.025	0.021	-0.004
Time of Mission	0.030	0.025	-0.005
Concurrent Task Type	0.019	0.013	-0.006
Downtime	0.018	0.011	-0.007
Concurrent Task Memory Requirements	0.024	0.016	-0.008
Sleep	0.027	0.019	-0.008
Flight Profile	0.056	0.045	-0.011
Primary Task Memory Requirements	0.029	0.015	-0.013
Currency	0.100	0.080	-0.020
Duration of Mission	0.034	0.013	-0.021
Patient Criticality	0.042	0.020	-0.022

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APPENDIX T. FOLLOW-ON INTERVIEW RAW DATA

Follow-Up Interview Data Collection
FVL Task Automation: Pilot Cognitive Workload Capstone

Participant Number: 14

1.) To what extent do you agree or disagree that each of these sources of cognitive workload can be mitigated using automation or mission aids?

Subfactor	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Flight Profile				*X*	
Primary Task Complexity				*X*	
Light Factors			*X*		

*Mark the box that best reflects interviewee response

2.) How, or in what way would you like to see automation or mission aids used to address these sources of cognitive workload??

Flight Profile: *Participant 14 expressed that the UH-60s current heads-up display (HUD) is helpful, but that it could be enhanced. Participant 14 could not elaborate on what the enhancements should be. Participant 14 also recommended improving situational awareness by being able to or pull HUD display into their primary flight display as well as more customization of the HUD.*

Primary Task Complexity: *Participant 14 mentioned that a coupled flight directed is helpful for primary task complexity, but cited lack of experience for a lack of recommendations or ideas for automation and/or mission aids.*

Light Factors: *Participant 14 noted that exterior aircraft lighting causes often creates blind spots for pilots, and recommended NVGs that could drown out exterior aircraft lighting. Participant also suggested that modifying the lighting on the aircraft itself could resolve this issue (blinders or guards over the lights). Participant 14 also recommended a tented or transition windscreen to reduce the effects of light factors on pilots. Finally, Participant 14 recommended making the aircraft search light cover a larger area, rather than the spotlight they currently have.*

3.) If implemented as described, what would be the reduction in your cognitive load in the complex scenario? (Interviewee provides new complex scenario raw score after automation)

Subfactor	Updated Raw Score	Cognitive Workload Reduction
Flight Profile	*63*	*HUD improvements would free up pilot to focus on increasing secondary tasks and better crew coordination.*
Primary Task Complexity	*62*	*Participant noted that they did not lower the raw score much because the scenario is still very complex mission. "Even if you had autopilot, primary task complexity would be difficult due to environmental factors. Workload would still be high." External stressors will always be present.*
Light Factors	*78*	*Participant noted that changes to the system would allow you to have more trust in your equipment, which would help with the relatively inexperienced crew.*

Misc. Notes: *The following Note were captured while Participant 14 was answering question 1.*
Flight Profile – Participant agreed that automation could help with flight profile but only to a point. Participant noted that too much automation "might draw pilot inside the cockpit more."

Follow-Up Interview Data Collection
FVL Task Automation: Pilot Cognitive Workload Capstone

Participant Number: 17

1.) To what extent do you agree or disagree that each of these sources of cognitive workload can be mitigated using automation or mission aids?

Subfactor	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Flight Profile				*X*	
Primary Task Complexity				*X*	
Light Factors				*X*	

*Mark the box that best reflects interviewee response

2.) How, or in what way would you like to see automation or mission aids used to address these sources of cognitive workload?

Flight Profile: *Participant 17 stated that once a pilot is established in their flight profile, automation would free up pilot to do subordinate tasks. They also expressed that automation is best when a pilot is weak or inexperienced. Participant 17 recommended improving upon the current Blackhawk flight director system. Another recommendation was having a vest that ties into aircraft that could provide feedback to the pilot (buzzes the pilot). Further, Participant one recommends an improved hover page, similar to the system installed in the UH-60V ("people were excited"). Additional recommendations where improved heads up display (HUD), and daylight capable HUD. Finally, Participant 1 stated that interfaces should operate more like Apple devices ("like and iPad"), should have Foreflight (foreflight) linked into their multi-function displays (MFD), and the capability to update flight plans on the go (a device that could be operated by the back seater) would shed workload from the pilots.*

Primary Task Complexity: *"primary task changes with every mission" – Participant 17. Participant 17 again expressed that systems interfaces need to be simplified, he once again referenced Apple products as the ideal interface, "I'm an apple guy because it works, things need to be simple and work." It was recommended that automation that could reduce the pilot having to look down at lower consoles to perform task would help, "things that take me to the lower console are distractors." Finally, Participant 17 recommended customizable systems that are adjustable to the user, like the way a pilot can adjust their HUD to their preferences, or "like a car sport mode vs. normal mode."*

Light Factors: *Participant 17 stated that the biggest issue right now is operation of the aircraft requires a lot of illumination in the cockpit. Participant 17 compared the different Blackhawk models stating in the UH-60A/L the pilot could dial illumination and lighting down, but the M model is too bright. Participant 17 recommended making things tactile so that the pilot would not have to rely on cockpit lights. Finally, Participant 17 spoke on the* *new white phosphorus goggles expressing that they are really bright, making low illumination conditions worse, and that they do not adjust well when transitioning between inside and outside of the aircraft.*

3.) If implemented as described, what would be the reduction in your cognitive load in the complex scenario? (Interviewee provides new complex scenario raw score after automation)

Subfactor	Updated Raw Score	Cognitive Workload Reduction
Flight Profile	*56*	*So long as systems are working as designed you could have a 15–20% improvement. Fees pilot up to do other things. Makes me (participant) more comfortable near the ground and provides predictability in flight.*
Primary Task Complexity	*54*	*Would reduce workload in certain profiles but not in others. Close to the ground it would be less beneficial.*
Light Factors	*50*	*Significantly.*

Misc. Notes: *Participant expressed that gains from automation would be dependent on flight profile. During straight and level flight a pilot would get more gains than when flying near the ground. Our (Participant) mission or profile changes regularly depending on mission so it may be beneficial in some modes but less in other (Pinnacle landing vs wide open field, etc.)*

Light factors – "anything is beneficial in zero illumination."

Participant one added that not only would automation help inside a singular cockpit, but aircraft to aircraft capabilities should be explored, offering – "chalk 1 always busy, chalk 2 less of a workload. Figure out how to automate ship-to-ship to prevent midair (coordinate with ASE systems)."

Follow-Up Interview Data Collection
FVL Task Automation: Pilot Cognitive Workload Capstone

Participant Number: 18

1.) To what extent do you agree or disagree that each of these sources of cognitive workload can be mitigated using automation or mission aids?

Subfactor	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Flight Profile				*X*	
Primary Task Complexity			*X*		
Light Factors				*X*	

*Mark the box that best reflects interviewee response

2.) How, or in what way would you like to see automation or mission aids used to address these sources of cognitive workload?

Flight Profile: *Participant 18 recommended improving the moving maps currently in the UH-60 to include 3D maps that can display terrain. Participant referenced Foreflight 3D flight environment as an example, "something similar [to Foreflight] overlaid in aircraft maps." Participant 18 also recommended imposing other aircraft on these maps for traffic avoidance, much like other aircraft with ADS-B. Finally, Participant recommended the use touch screen interfaces and making things more user friendly.*

Primary Task Complexity: *Participant stated that current systems in the UH-60 would reduce cognitive workload if they worked as intended, or the pilot could trust the systems to work as intended. Participant used the UH-60 hover-hold as an example, "it's great in theory, but fails so often it's not super usable and you don't trust it." Participant shared that automation will not help if the pilot cannot trust that the automation will perform the tasks it is asked to do. Finally, Participant 18 recommended fielding a "better" GPS that is more user friendly, "like Garmin."*

Light Factors: *Participant 18 stated that the UH-60 needed more sensors for low illumination environments, specifically a forward looking infrared (FLIR) system that can be used for flight. Further, Participant 18 recommended the capability for a sensor that can be overlaid on the aircraft MFD and used for flight.*

3.) If implemented as described, what would be the reduction in your cognitive load in the complex scenario? (Interviewee provides new complex scenario raw score after automation)

Subfactor	Updated Raw Score	Cognitive Workload Reduction
Flight Profile	*50*	*Improve cognitive workload, you can take your mind off terrain, obstacle avoidance, etc., and focus on more important tasks.*
Primary Task Complexity	*60*	*Would reduce workload because you are not second guessing and double checking (doubling workload) to ensure the system is responding as intended. Significant reduction of cognitive workload with trust.*
Light Factors	*40*	*Would reduce significantly in terms of stress. When you ca not see, it is very stressful and that takes away from everything else.*

Misc. Notes: *User friendly flight director (FD) and flight management systems (FMS) would help reduce pilot cognitive workload. Participant stated that the current systems will hold airspeed (AS), altitude (ALT), and (HDG); but will fail if the pilot does not press the buttons in the right sequence. Additionally, Participant 18 stated that pilots do not use many of the FMS capabilities because they are too cumbersome.*

Notes taken while Participant was answering Question 1:

FP- *"we have BFT, we can generally see where other AC are, but they are not super friendly, they lag behind."*

PTC – *"not super trustworthy, can fail. For super complex primary task you have to revert back to experience. Would be beneficial if it were dependable. We do not trust the mitigation."*

LF – *"limitation of night vision devices. Light is what it is. Nothing outside of better NVG that could make LFs better. Maybe FLIR could."*

Follow-Up Interview Data Collection
FVL Task Automation: Pilot Cognitive Workload Capstone

Participant Number: 20

1.) To what extent do you agree or disagree that each of these sources of cognitive workload can be mitigated using automation or mission aids?

Subfactor	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Flight Profile				*X*	
Primary Task Complexity				*X*	
Light Factors				*X*	

*Mark the box that best reflects interviewee response

2.) How, or in what way would you like to see automation or mission aids used to address these sources of cognitive workload??

Flight Profile: *Participant 20 stated that when a pilot is developing their scanning technique (scanning of cockpit instrumentation), one can often be overwhelmed by the clutter of current interfaces (Participant specifically mentioned clutter in the heads up display). Participant stressed that interfaces should be limited to basic needs of pilot information and listed airspeed, altitude, attitude, and heading. Further, Participant stated that feedback in for of color, flashing, audio, and visual aids are beneficial so long as they are not overbearing. Finally, Participant 4 mentioned the hover hold system in the UH-60 stating that it was "helpful but outdated," and that an updated system is needed.*

Primary Task Complexity: *Participant 20 mentioned the new Flight Reference Card (FRC) checklist, which simplifies emergency procedures, and has limited complexity for pilots in emergency situations, stating that, "you're able to focus on flying rather than trying to recall steps from a checklist." The Participant stated that it would be an improvement if FVL could automate the FRC in some way. Participant listed images, warning advisories, visual representations, color representations, and underlines immediate actions as ways to integrate the FRC into the aircrafts multi-function displays. Finally, Participant 20 recommended that the MFDs should have more pictorial representation on what the pilot is experiencing in flight.*

Light Factors: *Participant 20 noted that the new white phosphorus NVG are an improvement in low illumination conditions but can be too bright in high illumination conditions. Participant 4 further expressed that experiencing low illumination conditions more often would be of benefit and recommended incorporating a system for pilots to wear that would condition their eyes for night flight.*

3.) If implemented as described, what would be the reduction in your cognitive load in the complex scenario? (Interviewee provides new complex scenario raw score after automation)

Subfactor	Updated Raw Score	Cognitive Workload Reduction
Flight Profile	*61*	*Participant stated that these changes would make it easier to maneuver and control the aircraft. Participant also mentioned some stressor would be reduced.*
Primary Task Complexity	*55*	*Participant stressed that when implementing automation, the pilot gains more assistance with primary tasks, reducing overthinking, and head movements (not having to "look around") as much.*
Light Factors	*80*	*Participant shared that automation would allow the pilot to feel more comfortable in environments with low illumination.*

Misc. Notes: None.

SUPPLEMENTAL

Influence Diagrams and Cognitive Workload Data

This file contains the influence diagrams and cognitive workload raw data used in the completion of this project. It contains the information found in Appendices A, I, N, and O. The influence diagrams can be used to determine a cognitive workload score based on user provided raw scores and weights for each factor and subfactor. Additionally, the cognitive workload raw scores and weights elicited from participants during the initial interviews are available for review and analysis.

Those interested in obtaining the supplemental data file can contact the Naval Postgraduate School's Dudley Knox Library.

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