

5-2021

## Air Traffic Controllers' Occupational Stress and Performance in the Future Air Traffic Management

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**Air Traffic Controllers' Occupational Stress and Performance in the Future Air  
Traffic Management**

Hui Wang

Thesis Submitted to the College of Aviation in Partial Fulfillment of the Requirements  
for the Degree of Master of Science in Aeronautics

Embry-Riddle Aeronautical University

Daytona Beach, Florida

May 2021

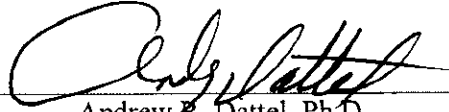
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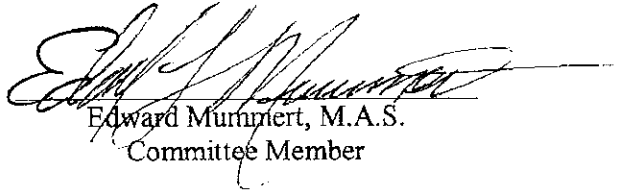
Hui Wang

This thesis was prepared under the direction of the candidate's Thesis Committee Chair,  
Dr. Andrew R. Dattel, and has been approved by the members of the thesis committee.

It was submitted to the College of Aviation and was accepted in partial  
fulfillment of the requirements for the Degree of  
Master of Science in Aeronautics.



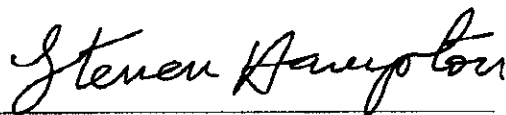
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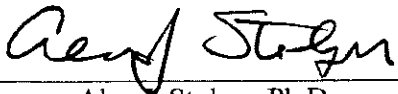
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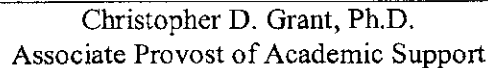
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## Abstract

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Title: Air Traffic Controllers' Occupational Stress and Performance in the  
Future Air Traffic Management

Institution: Embry-Riddle Aeronautical University

Degree: Master of Science in Aeronautics

Year: 2021

As demand for unmanned aerial vehicle (UAV) operations increases, it is vital to understand its effects on air traffic controllers and the safety of the national airspace system. This study's primary purpose is to determine how UAVs that operate in controlled airspace would influence air traffic controllers' occupational stress and performance. In a within-subject experimental research design, 24 participants sampled from a university's undergraduate Air Traffic Management (ATM) program completed three different air traffic control (ATC) scenarios on an en route ATC simulation system. The degree of UAV automation and control were varied in each scenario. The participants' stress levels, performance, and workload were measured with both objective and subjective measurements. Within-subjects ANOVA tests showed significant effects on the participants' stress level, performance, and workload when automated UAVs were present in the scenario. Participants experienced increased workload, the highest level of stress, and carried out the worst performance when with controllable UAVs in the airspace. These findings can inform UAV integration into controlled airspace and future research into UAV automation and control and ATC management.

## **Acknowledgments**

The completion of this thesis could not have been possible without the contribution and assistance of many people. First, I want to express my deep appreciation and indebtedness to my committee chair, Dr. Andrew Dattel, for his guidance and support in developing this project from a simple proposal. Next, I would like to thank my committee member, Professor Edward Mummert, for providing valuable advice and the tremendous amount of effort he put into helping me conduct the experiment.

I also would like to express sincere gratitude to the Philanthropy Council, Office of Undergraduate Research, and Dr. Alan Stolzer, particularly for funding the project, which enabled me to complete this research.

Special thanks to Syaza Haris, Patricia Buchanan, and Aaron Collard for contributing to this thesis with their specialties. Thanks to all friends, classmates, professors, and others who shared their support and motivation along the way.

Finally, I am extremely grateful to my parents for their love, caring, understanding, and encouragement. Heartfelt thanks to my family for providing me the necessity for my education and life.

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## **Chapter I: Introduction**

Manned aircraft have always been dominant in the National Aviation System (NAS); however, unmanned aircraft are gaining ground. The rapid development of unmanned aerial vehicles (UAVs) has broadened their utilization within the NAS due to their lower operation cost, shorter flight times, and more flexible launching locations (Lee, 2016). The growing demands of UAV operations have expanded to numerous applications in both military and civilian sectors because of UAVs' economic and operational benefits (Lee, 2016; Newcome, 2004). However, the continuous advancement in UAV technology and increased practical capacities present challenges to the current airspace system. Potential safety issues arise with the proliferation of UAVs in the NAS (Newcome, 2004). In fact, numerous aviation accidents are caused by UAVs that collide with other aircraft, and many near-miss incidents have occurred in different countries (British Broadcasting Corporation [BBC], 2020; Canadian Broadcasting Corporation. [CBC], 2017; Goglia, 2017).

As one of the essential components to ensure aviation safety, Air Traffic Control (ATC) has been required to reconsider the airspace structure to make UAVs manageable with current traffic. Due to ATC job requirement changes, stress level and performance of ATC personnel may be affected (Djokic et al., 2010; Hopkin, 1991). Numerous studies have shown that the additional functions added to the existing job procedures would have a detrimental impact on a controller's stress level and work performance (Hancock, 1989; Hockey, 1997; Matthews & Wells, 1996).

Moreover, as the level of UAV automation increases, the control that human UAS operators and air traffic controllers have over the air traffic scenarios decreases. Consequently, controllers could experience even greater stress at work (Billing, 1997; Karasek & Theorell, 1990). Given the need to ensure airspace safety, this study investigates whether the stress level and skill performance of air traffic controllers are affected by implementing UAVs into controlled airspace and by their lack of control (i.e., navigation directions) over UAVs.

### **Statement of the Problem**

Currently, UAVs have been mostly restricted to operate below 400 ft in uncontrolled airspace (Federal Aviation Administration [FAA], 2020). However, in the foreseeable future, the FAA plans to consign these unmanned aircraft to controlled airspace currently only allowed for manned aircraft operations. As a relatively new element to ATC operations, UAVs oversight will impose additional duty to the controllers' primary responsibilities. Implementation of these automated unmanned aircraft in the controlled airspace is desirable to some extent, but potential adverse effects can occur. Studies have shown that utilizing automation could aggravate the operational workload, and additional workload may increase the stress level, diminishing the controller's performance (Metzger & Parasuraman, 2005; Mouloua et al., 2001). Because overloaded stress and poor performance present a potential threat to aviation safety, it is

essential to assess how UAVs affect the air traffic controllers' stress level and how that stress impacts job performance.

### **Purpose Statement**

There is a lack of studies conducted on how air traffic controllers are affected by UAV operations in the NAS. The purpose of this study is to fill this gap in the literature by examining the results of the integration of UAVs in controlled airspace on air traffic controllers' stress levels. The results of the study should provide a better understanding of the impact of UAVs from the ATC perspective in maintaining safe and efficient airspace operations.

### **Significance of the Study**

This study investigates if controllers experience more stress in specific ATC scenarios when there are more unmanned aircraft presented and they have less control over those aircraft. Learning how less control affects controllers might lead to ways to mitigate safety issues (e.g., excessive stress and impaired performance).

### **Hypotheses**

#### ***H<sub>01</sub>***

There is no significant effect on an air traffic controller's stress levels under different degrees of control of an air traffic scenario.

#### ***H<sub>A1</sub>***

There is a significant effect on air traffic controller's stress levels under different degrees of control of an air traffic scenario.

***H<sub>02</sub>***

There is no significant effect on air traffic controller's working performance under different degrees of control of air traffic scenarios.

***H<sub>A2</sub>***

There is a significant effect on air traffic controller's working performance under different degrees of control of air traffic scenarios.

***H<sub>03</sub>***

There is no significant effect on air traffic controller's workload under different degrees of control of air traffic scenarios.

***H<sub>A3</sub>***

There is a significant effect on air traffic controller's workload under different degrees of control of air traffic scenarios.

**Delimitations**

The purpose of the current study is to evaluate the effect of the integration of UAVs in the NAS on ATC stress levels. The selection of participants for this experimental study was delimited to Embry-Riddle Aeronautical University (ERAU) students who were currently enrolled in the undergraduate Air Traffic Management (ATM) program or had graduated from the program, and with a major or minor studies program in ATM and having completed the ATC 405 En Route Radar Operations course.

**Limitations and Assumptions**

The number of participants that can be selected from the ATM students was limited, because there were few students who can meet the requirements to be qualified



to participate in this experiment. Therefore, the small sample size could affect the final results. It was initially assumed that the skill level of ATM students would be equivalent technically; therefore, the participants' ability to manage air traffic in the scenarios would be similar. However, their level of ATC ability was not similar, so this limitation led to disparate performance of student controllers, ultimately affecting the stress perceived. The experiment was also limited because the scenarios with the presence of UAVs could only be simulated, which would affect the generalizability to the NAS and ATC population. It was assumed that all participants have a sufficient level of English to understand the purposes and procedures of this experiment.

### **Summary**

Understanding the impact of UAV integration into the NAS is essential for future air traffic controllers and ATM because the demand for UAV operations is growing rapidly. The purpose of this research is to examine whether implementing UAVs in the airspace would interfere with air traffic controllers' stress and work performance, especially for UAVs that are fully automated and where the controller is unable to change trajectories for these unmanned aircraft. Knowing if UAVs in the controlled airspace increase controllers' stress and impair their performance is the first step in mitigating safety risks to the NAS. Moreover, safety mitigations would benefit the well-being of controllers, thereby helping to protect airspace safety.

The literature review in Chapter 2 describes the theoretical framework and relevant research outcomes for understanding the broader importance of this study to aviation. Hypotheses were tested by following through the procedures in the

methodology presented in Chapter 3. The results and conclusions of this study are provided in Chapters 4 and 5, respectively.

### **Definitions of Terms**

Unmanned Aerial Vehicle	An aircraft without a human operator on board.
Unmanned Aircraft System	An unmanned aircraft and all the equipment used to operate it remotely.

### **List of Acronyms**

ARTCC	Air Route Traffic Control Centers
ATC	Air Traffic Control
ATM	Air Traffic Management
BPM	Beats per Minute
CPDLC	Controller-Pilot Data Link Communication
DSR	Display System Replacement
ERAM	En Route Automation Modernization
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
GSR	Galvanic Skin Response
HRV	Heart Rate Variability
IRB	Institutional Review Board
JDC	Job Demand-Control
MSA	Master Science of Aeronautics

NAS	National Airspace System
NASA	National Aeronautics and Space Administration
P-E Fit	Person-Environment Fit
SA	Situation Awareness
SME	Subject-Matter Expert
SPSS	Statistical Package for the Social Science
TRACON	Terminal Radar Approach Control
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle

## **Chapter II: Review of the Relevant Literature**

Air Traffic Control is generally considered one of the most complex occupations (Costa, 1995). The job requires controllers to have high levels of knowledge and cognitive skills to accomplish various tasks that result in safe and efficient air traffic management. Potential stress factors in controllers' work environments may influence their performance and well-being (Hancock, 1989; Shahsavarani et al., 2015). Many studies have shown that automation is a stress factor although it has become more common in aviation (Hopkin, 1991; Lee, 2016; Newcome, 2004). Depending on the level of automation, an operator's control of the system may be minimized or even eliminated because the system performs tasks automatically. Similarly, UAVs usually utilize a higher degree of automation, resulting in less control for the controllers (Endsley & Kiris, 1995; Newcome, 2004). Studies have determined that controllers' stress levels and performances are more likely to be affected by higher degrees of UAV automation and lower levels of control by the air traffic controller (Endsley & Kiris, 1995; Leka & Houdmont, 2010). Moreover, adding UAVs to the existing airspace may increase the air traffic complexity as well as controllers' workload by having to manage more aircraft.

This chapter begins with an overview of ATC occupations, and is followed by an analysis of the literature on ATC work stress, and a review of the prominent theories of stress, automation, and their relationships to performance workload. The literature review also assesses the effects of implementing automation and UAVs into the existing airspace and balancing human control and machine automation. In general, this chapter presents

the importance of the current research study and the relevant research studies about stress, automation, and ATC.

### **Gaps in the Literature**

Establishing a set of standard air traffic regulations to promote safety has existed since the early days of aviation. The concept of ATC was first introduced in the Air Commerce Act of 1926 (FAA, 2017) to prevent aircraft collisions. Air traffic controllers manage airspace traffic by directing traffic flow and preventing aircraft collisions. Their job functions include many tasks and require specific skills to coordinate and solve problems. Controllers are required to continually process flight information by looking at radar displays and communicating with pilots (Costa, 1995).

The definition of UAV is an “aircraft which is intended to operate with no pilot on board” (International Civil Aviation Organization [ICAO], 2011, p. x). They are a component of the unmanned aircraft system (UAS) that consists of UAVs and all equipment associated with them (e.g., ground operation). The National Aeronautics and Space Administration (NASA) projects UAS to become significantly important for national defense and security, sciences, emergencies, and commercial usage (Gipson, 2016). Progress has been made with UAV integration although it is challenging. Gipson (2016) reports NASA is committing efforts to develop unmanned vehicle technologies to control and regulate UAVs to ensure airspace safety. The proliferation of UAVs in controlled airspace has required the modification of the NAS to reduce the potential conflicts with current air traffic. The ATM system has been evolving to accommodate these unmanned aircraft. In order to gain economic and public benefits of UAV missions,

NASA aims to inspect infrastructure at altitudes above 10,000 feet for UAVs in its 2020 UAS integration project (Conner, 2020). Therefore, the high-altitude operation of UAVs will inevitably occur in the near future. The concern of how UAVs will affect the ATM system is important to consider. Because UAVs have increased the complexity of airspace traffic, it can be difficult for controllers to manage both manned and unmanned aircraft. The present study is only concerned with how actual unmanned aircraft would interfere with a controller's occupational stress and performance.

By implementing UAVs to the airspace, controllers' workload may be increased when additional procedures and potential changes in decision-making are presented. It is evident that the increased traffic will affect controllers' workload that can further add to their mental stress (Costa, 1995; Finkelman & Kirschner, 1980). Hogan (2013) differentiates between acute stress and chronic stress. While acute stress only happens momentarily, chronic stress tends to occur on a regular basis. If chronic stress is untreated for a period of time, it can be incredibly harmful both physically and mentally. By examining controllers' stress levels, mental stress<sup>1</sup> will be inspected to discover the effects of UAV integration in the NAS. Moreover, performance is usually affected under such stressful conditions, and it can be a hidden danger to the overall safety of the airspace.

Often, the operation of UAVs relies on automation (Newcome, 2004). Therefore, the existence of UAVs not only increases the complexity of traffic but also the use of automation. Although regulations may be changing as a result of additional UAVs in the

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<sup>1</sup> Stress mentioned in this paper is referred to as mental stress.

NAS, air traffic controllers will need to adapt to managing and communicating with UAVs. Implementation of automation can change how people perceive and respond to particular situations, especially when some of these changes were not intended by the system designer. Studies discovered that changes in the normal routine due to automation can sometimes affect the operators' cognitive process when they face a difficult time to adjust to the change (Billings, 1997; Costa, 1995; Parasuraman & Riley, 1997). Costa (1995) pointed out that although automation aims to reduce human workload and error to improve safety and efficiency, the extra cognitive process and operative procedures may be problematic because automation can increase job demands and creates job complexity. Costa (1995) believes that while there are benefits to automation, unfortunately, it can cause additional stress for the operators.

Although research studies have been assessing the effects of automation and UAVs and associated with stress and performance, the literature has not addressed how the existence of UAVs in the current airspace could affect controllers' stress level and performance.

## **Theoretical Framework**

### ***Overview of ATC Occupations and Job Functions***

It takes much more behind-the-scenes effort for airplanes to become airborne than some people may imagine. One of the most indispensable functions to safely operating any aircraft is the ground-based ATC services provided by the air traffic controllers who coordinate the aircraft from taking off to landing. The notion of air traffic control was initially introduced at London Croydon Airport in 1920 with a wooden hut control tower

that provided basic advisory information (over a 2-way radio) to the pilots about weather, traffic, and location (BBC, 2020). As commercial flights rapidly grew and the number of deadly aircraft collisions also increased, national governments realized that the skies must be managed to ensure proper separation between aircraft and smooth air traffic movement. Since then, ATC has become essential to keep aircraft operations safe and boost the efficiency of airspace usage. The controllers' primary job functions include directing the air traffic flow by preventing aircraft collisions in the airspace and accelerating the flow of traffic by providing advising information and other support for aircraft (FAA, 2010).

In the modern ATC systems, there are three primary facilities of ATC: airport traffic control tower, terminal control, and en route control. Airport control towers are used primarily to control aircraft in the airport environment. Tower controllers visibly coordinate the aircraft on airport surfaces and aircraft in the air near the airport (U.S. Department of Labor Statistics, 2020). Tower controllers are also responsible for the departure and landing of aircraft. Terminal control facilities, also known as Terminal Radar Approach Control (TRACON) in the U.S., are associated with many airports. Terminal controllers provide ATC advisory services to airborne aircraft that are close to the airport (U.S. Department of Labor Statistics, 2020). When flights depart terminal control airspace, they are handed off to en route control. En route controllers usually work in air traffic control centers, frequently referred to as Air Route Traffic Control Centers (ARTCCs) in the U.S. They use radar systems to issue clearances and instructions for airborne aircraft at cruising altitude within the region (U.S. Department of



Labor Statistics, 2020). It is mandatory for flights to comply with every controller's instructions; for example, in maintaining appropriate separation, climb, and descent to an assigned altitude (FAA, 2010). As flights reach the boundary of an ARTCC's airspace, they are handed off to the next control center on a different radio frequency.

The duties that controllers are expected to perform on the job make ATC occupations complex. Studies that investigated the job functions of ATC personnel have concluded that ATC jobs generally require multitasking skills to ensure the safe and efficient operation of air traffic (Older & Cameron, 1972; Sells, Dailey & Pickrel, 1984). Older and Cameron (1972) analyzed the activities and tasks performed by air traffic controllers and listed the required skills as input skills (monitoring), processing skills (information processing), and output skills (controlling). Sells et al. (1984) studied a series of reports and further verified this list by stating controllers have abilities to constantly transfer quantitative inputs about aircraft required to process the information; and then form a mental picture to be used as the basis for planning and controlling courses of action for the aircraft. In order to efficiently direct and coordinate the air traffic, it would be expected that controllers master a massive load of information (e.g., detailed knowledge of manuals, maps, regulations), and maintain communications with aircraft pilots. The constant mental demands of the ATC job are far beyond the capability of an average person, which makes the job more complex than many other occupations (Sells et al., 1984). Factors such as advancements in technology and increased traffic complexity have made the controllers' jobs more complicated as additional information and procedural processing are required in the modern ATC environment. In order to

handle the growing traffic load, controllers' coordinating skills must be adequate to sustain the same level of safety and operational efficiency. Hence, it is critical to find out how to assist them in controlling traffic effectively and reducing the complexity of their occupational demands.

### ***Occupational Stress***

Stress exists in the daily life of humans. Psychological stress refers to the sense of mental pressure and tension that can be caused by either the external environment or internal perceptions of the person (Shahsavarani et al., 2015). The optimal level of stress, also called *eustress*, is desired and essential for people to adapt to their environment and improve their performance through positive motivation. Nevertheless, high levels of stress can adversely affect humans, resulting in biological, psychological, and other harmful problems (Shahsavarani et al., 2015). There have been numerous theories that explained different conceptualizations of stress over the years. In recent decades, stress and its influences have been studied to a greater extent because of the increased amount of stress in workplaces. Instead of informing the definition of occupational stress, researchers have perceived stress as the interaction between persons and their situational environment (Hassard & Cox, 2015; Lazarus & Folkman, 1984; Leka & Houdmont, 2010; Werner, 1993). In the case of air traffic control, assessment of controllers' stress level is essential to discover where stress is from and how it can be coped with for the dual purposes of maintaining aviation safety and controllers' health. Theories of stress have been developed over the years to clarify the causes of and mechanisms associated with work-related stress.

**Theories of Stress.** There are two major categories of prominent theories established to explain stress, including transactional theories and interactional theories. Lazarus and Folkman (1984) focused on studying an individual's perceived stress, coping techniques, and cognitive appraisals. As a result, they detected a relationship between the person and the situation, and defined a process of situational demands that trigger stress, also known as the transactional model. This model describes stress as a product of a relationship (e.g., transaction) between individuals and their environment. Therefore, stress is viewed as an intermediary factor which can affect both individuals and the environment. Researchers have adopted the concept of stress as a transaction. For example, Werner (1993) traced the development paths of children who had been exposed to stress caused by family environmental issues, and discovered that the type, degree, and effect of stress depend on personal, social, and environmental situations. More recently, by interpreting the nature and management of occupational stress through transactional theory, Hassard and Cox (2015) discovered that stress could occur when a person's appraisal of demands and capabilities are impacted by their work environment, especially when the perceived demands outweigh their perceived capability.

In addition to transactional theories, interactional theories focus on emphasizing an individual's responses to environmental stimuli as a reflection of stress experience (Hassard & Cox, 2015; Leka & Houdmont, 2010). Person-environment fit (P-E fit) theory has been defined by Leka and Houdmont (2010) to introduce occupational health psychology through the definition of the subject matter. This theory addresses the importance of environmental stimulus in shaping a person's response as well as

highlighting the importance of the person's perceptions of the environment, themselves, and their interactions. The word "fit" suggests the balance of environmental demands and individual needs; in other words, the individual's ability to match what the environment provides. It also argues that stress occurs when there is a lack of fit between a person's ability and available resources (demands of the work environment). Edwards, Caplan, and van Harrison (1998) provided a conceptual overview of the P-E fit theory and explained that the lack of fit occurs when the demands of the work environment overstretch an employee's ability or when the employee's needs fail to be met by the work environment.

The job demand-control (JDC) theory further explains work-related stress by suggesting that job strain results from the interaction between psychological job demands and job control (Leka & Houdmont, 2010). The JCD theory is expressed through the matrix of this interaction, where Leka and Houdmont (2010) argue that high demands with low-control jobs are exposed to the most risk of experiencing psychological strain and work-related stress. This job condition can also result in physical and mental health issues like musculoskeletal disorders and cardiovascular disease (Leka & Houdmont, 2010). Beehr et al. (2001) collected data from questionnaires passed to manufacturing company employees. They found that although control did not show much effect on psychological strain, excessive demands are associated with workload, such as cognitive and emotional demands, decision authority, and skill discretion, which lead to work strain and occupational stress.

In addition to subjectively measuring stress using a questionnaire, stress can also be objectively determined by measuring heart rate and galvanic skin response (GSR), the latter being measured by skin conductance. Published research has demonstrated that autonomic nervous system reactions such as heart rate and muscle activity can be evoked intensively by stress (O'Keane et al., 2005), and stress can also increase the skin conductance signal (Lin et al., 2011). These signals reflect the changes in sweat gland activity that indicates the intensity of the human emotional state, also known as emotional arousal. The emotionally-relevant environment (e.g., stress) can result in an increase in arousal, and such experiences also increases sweat gland activity (Salimpoor et al., 2009); resulting in higher signals being captured by the GSR electrodes.

By explaining the relationship between people and their work environment, these prominent theories have provided the fundamental interpretation of the causes of stress and the feasibility to assess occupational stress in a specific situation. By understanding stress, it is predictable that air traffic controllers are more likely to experience stress because of their work demands and personal capabilities to deal with these demands. Further, different measurements can be used to validate the predication of stress.

**Effects on Workload and Performance.** Stress, workload, and performance are sometimes analyzed collectively by researchers because of the interrelationship among them. Stress and workload affect an individual's performance, and additional workload increases the stress levels of the individual (Beehr et al., 2000; Hancock, 1989; Hockey, 1997; Yerkes & Dodson, 1908).

The study of stress as a factor of performance can be traced back to when Yerkes and Dodson (1908) discovered that rats were motivated to complete a maze when they experienced mild electrical shocks. By discovering the rats would run around in random directions when the shocks became strong, the researchers proposed the inverted U-shaped relationship between performance and arousal, or stress, where good performance can be motivated by optimal arousal (mild electrical shocks), and performance begins to deteriorate when the arousal gets excessive (strong shocks that result in a stressful situation). Studies further suggested that although the optimal level of stress (eustress) placed on humans can potentially improve performance, performance can be adversely affected by overload stress (Hockey, 1997; Yerkes & Dodson, 1908). Furthermore, this inverted U concept is used to explain why excessive occupational stress should be avoided to ensure quality performance.

In addition to stress, studies have shown that performance can be negatively influenced by workload. Controllers are expected to maintain high-quality performance to complete an extensive number of tasks on the job, which results in high demanding workload. Djokic et al. (2010) analyzed the data collected from en route ATC simulation that used Controller-Pilot Data Link Communication (CPDLC) technology and found that ATC complexity and communication load can contribute to controllers' workload. Costa (1995) pointed out that increased workload, such as more traffic load and new operating procedures, can significantly impact performance efficiency.

Workload has not only been shown to affect performance, but it also affects situation awareness (SA). Endsley and Kiris (1995) define SA as defined as the cognitive

process about what is going on in the surroundings when accomplishing a task. In many complex fields such as the aviation industry, SA is recognized as a crucial concept when people apply their knowledge in a task-related situation to achieve a correct action. After examining en route controllers' SA and workload when there were operational errors presented in the air traffic situation, Endsley (1997) found that higher workload was reported when operational errors existed, which further resulted in reduced attention and decreased SA to the overall situation. Mogford (1997) asked ATC trainees to recall a set of basic aircraft data during a simulation and found that trainees with good SA achieved higher scores in the ATC simulator assessment exam. Although the reduction in SA would not always be associated with poor performance, such studies indicated that lack of SA increases the risk of reduction in performance; having good SA contributes to the chances of good performance (Tenney et al., 1992). In order to measure workload during the completion of tasks to help determine whether performance is impaired, studies often measure heart rate variability (HRV). Research has shown that low HRV is related to greater anxiety or depression and can increase the risk of cardiovascular disease and death (Lin et al., 2011). Delliaux et al. (2019) define HRV as the measure of the variation in time between each heartbeat, which has been shown to indicate an operator's mental workload and effort. This variation depends on behavioral change and reflects how the human nervous system reacts to physical and psychological activities. For example, when a person is in an active state (e.g., completing a written exam) the variation between subsequent heartbeats is low; conversely, the variation between beats is high when the human body is relaxed.

The interrelationship among these three factors has been explained by many researchers. Hancock (1989) analyzed literature to achieve a comprehensive approach to stress and performance. By explaining the relationship model of stress and sustained attention, he concluded that sustained attention, as a source of stress, was profoundly affected by the reflection of increased mental workload. Hockey (1997) later provided the framework to assess the effects of stress and workload on performance in his research, where he stated the disruption of performance would occur with an increased number of tasks and subsidiary activities, and it could eventually result in producing stress. These conclusions laid the foundation for later research to present how stress would affect workload and performance. Beehr et al. (2000) examined job stressors to performance and mental strains by conducting a self-report survey and collecting performance data from company records. Beehr et al. found the measure of job-specific stressors (e.g., workload) was the strongest predictor of poor performance. The overall findings indicate stress should be kept at an optimal level and excessive workload should be avoided to sustain efficient performance.

**ATC Occupational Stress.** Numerous researchers have found that the complexity of ATC jobs is a contributing factor to controllers' stressfulness (Djokic et al., 2010; Older & Cameron, 1972; Sells, Dailey & Pickrel, 1984). Controllers perform their daily duties of controlling air traffic and applying and demonstrating knowledge of ATC regulations and techniques. Thus, typical controllers need to continually process and transfer the input skills to output performance, especially in a busy and dynamic traffic scenario (Older & Cameron, 1972). However, large-scale mental demands and job



complexity can contribute to higher chances of committing safety-related errors. Potential risk factors include “volume of traffic, frequency congestion, quality of radar, controller workload, higher priority duties, and the pure physical inability to scan and detect [problems]” (FAA, 2010, § 2-1-1). Considering controllers perform an extensive number of job functions, several researchers investigated the factors of occupational stress that impact controllers’ daily performance and well-being (Costa, 1995; Finkelman & Kirschner, 1980; Hopkin, 1988; Huey & Wickens, 1993). Costa (1995) discovered that increased workload, such as more traffic load and new operating procedures, can cause stress which impacts performance efficiency. As the workload increases, more processing information may be required. By analyzing research literature that presented evidence of stress in ATC and discussing the effect of stress on ATC performance, Finkelman and Kirschner (1980) concluded that work stress came from high information-processing demands, and resulted in longer performance time for controllers under such stress.

Huey and Wickens (1993) further reviewed the qualitative effects of work stress and have listed the potential outcomes, including working memory loss, broken-down communications, disrupted long-term memory, and bad decision-making. These research studies illustrate excessive stress has always been a problematic condition for air traffic controllers, which can impair their working performance and eventually became a potential threat to aviation safety.

### ***Automation***

Human errors contribute to a large percentage of aviation system accidents. Implementation of automation has always been an approach to reduce the chances of

committing human errors (Endsley & Kiris, 1995). Applications of automation have been used in various areas to reduce operational costs, diminish the operator's workload, decrease performance errors, and ensure safety, especially in highly complex fields. For instance, automation has been increasingly utilized in the aviation industry to support many functions to complete tasks that aim to lessen direct human intervention to a system and increase the efficiency in operations (Hopkin, 1991; Woods, 1996).

Automation can reduce human workload and improve performance by lowering operators' cognitive workload. By decomposing the work tasks in ATC, Hopkin (1991) agreed that automation was necessary for ATC to assist human cognitive functions and promote strategic control. Automation would require less involvement of direct human control to the system for performing certain tasks for example, by updating reliable data accurately and planning traffic flow as the result of reducing the need for simple tactical instructions (Hopkin, 1991). However, automation is sometimes believed to negatively influence controllers as it would change the cognitive process, creating delays in traffic conflict detection and performance (Endsley & Kiris, 1995). The failure of fixing the problem can further generate mental stress for controllers, which impacts the job safety and their well-being (Costa, 1995).

**Unmanned Aerial Vehicle.** As mentioned, UAV advancements and development has been prolific in recent years. The increasing number of operating UAVs has been beneficial in various aspects (Cambone et al., 2005; Lee, 2016; Newcome, 2004). These unmanned aircraft were first heavily used in the military to complete "dull, dirty, or dangerous" (Cambone et al., 2005, p. 1) missions that could not be effectively performed

by manned aircraft. For example, UAVs were used by the U.S. Air Force and Navy to collect radioactive samples through nuclear clouds in the late 1940s, which would otherwise have caused the deaths of pilots from being trapped after crashing by the heavy lead suits they had to wear or from long-term radiation and fallout effects (Cambone et al., 2005). In a sense, the use of unmanned aircraft is preferred to manned aircraft not only because of their continuous working efficiency, but also because of the lower risk and higher probability of mission accomplishment. Such beneficial attributes of UAVs became potent motivators for the development of unmanned aircraft. Commercial applications of UAVs have become more valuable in recent years. Lee (2016) analyzed the benefits of commercial UAVs in a study of UAV integration. By adopting automatic aircraft technologies, the areas of agriculture, meteorological sensing, and videography heavily depend on UAVs to complete the tasks that could be challenging for humans. Although unmanned aircraft would not entirely replace manned aircraft, Newcome (2004) predicted that unmanned flight would significantly complement the incapability's of manned flight as automation technologies are being continuously enhanced, as exemplified by remotely-piloted planes to fully automatic aircraft. However, if the trend goes as projected, the growth of UAVs is more likely to interfere with other manned aircraft and possibly become a potential threat to current air traffic operations. Because of the enhancement in technology and the broadened capabilities of unmanned aircraft, the proliferation of UAVs will inevitably result in UAVs integration into controlled airspace. As it is now, controllers must coordinate the air traffic with the presence of both manned

and unmanned aircraft in the airspace (Cambone et al., 2005; Lee, 2016; Newcome, 2004).

Presently, UAVs usually rely on automation for operation (Newcome, 2004). Therefore, it is essential to understand the effects of automation to ensure successful implementation of UAVs. In order to maintain the efficient and safe flow of airplane traffic while handling the UAV traffic, controllers must process additional information and do so in less time to direct each aircraft (Hopkin, 1991). Information overload can contribute to controllers' stress and diminish their performance. Diminished performance is when capacity of processing information reaches an upper-limit and controller performance is negatively impacted by stress (Costa, 1995; Finkelman & Kirschner, 1980). Multiple studies have determined the effects of automation in the aviation industry (Bowers et al., 1996; Fern, Rorie, & Shively, 2014). For example, Bowers et al. (1996) specifically concentrated on the team performance of pilots with the use of automation. Pilots spent more time monitoring and managing the dynamic environment and their task load increased when communication, coordination, and decision-making capabilities were unintentionally interfered with because of automation. The researchers indicated operators reported a greater workload while automation was utilized in team performance. Moreover, Djokic et al. (2010) found removing the pilot from the cockpit may decrease the communication exchanged between the controllers and pilots. In fact, there might be a communication delay between the UAV remote operator because there is no immediate communication established (Newcome, 2004). If future UAVs operate with full automation, communication between controllers and operators might not be

necessary. Therefore, it is probable that controllers' stress level might be immediately negatively impacted when they lose their ability to communicate with unmanned aircraft.

**Control.** In the workplace, certain levels of control could help moderate the effects of overload demands (Karasek & Theorell, 1990; Leka & Houdmont, 2010). Job control is defined in the JDC model, where Karasek and Theorell (1990) assessed how physical and psychological demands (e.g., work demands, decision making, and social support) determine the stress employees suffer. Moreover, they suggested the interaction between job demand and job control predicts psychological strain; meaning, higher degree of control can diminish stress caused by work demands. According to this model, low control along with high job demands and low social support are job characteristics associated with a higher level of stress and a higher risk of psychological problems (Karasek & Theorell, 1990). Accordingly, they determined the two factors that predict work control are skill utilization and the power to make a work-related decisions. In the process of implementing automated systems, the role of human operators has drastically changed from performing the task to supervising and monitoring the system that completes the tasks automatically. Therefore, the degree of control that a human operator has on the system decreases as the level of automation increases. This is why it has become essential to evaluate optimal level of automation and adequate degree of operator control to help diminish the effects of stress.

Although automation has shown capability in promoting performance efficiency and reducing human mental workload, the distribution of functions to automation and humans has to be thoroughly understood to minimize adverse effects. Studies have

addressed various models to determine the levels of automation, which indicates the flexibility of involvement of human control and (automated) machine control in task performance (Endsley & Kiris, 1995; Sheridan & Verplank, 1978). For example, Sheridan and Verplank (1978) categorized automation into 10 levels from full human control (human operator completes the task without support from automation) through partial automation (human operator can veto the initial decision by the machine) to full automation control (machine completes the task autonomously without human involvement). The model developed by Endsley and Kiris (1995) defines five levels of automation that consist of no automation, decision support automation, consensual automation, monitored automation, and full automation. They indicated that there would be less human intervention required to operate a system when the automation level utilized in that system gets higher. The concept of defining the levels of automation aims to examine the different types of automation and human combinations to determine whether a more controlled system could be more beneficial to overall system effectiveness. No evidence shows which level of automation can be the most advantageous to implement in all systems; however, Endsley and Kiris (1995) reported human operators take less time to detect and solve a problem caused by a malfunction of the machine under intermediate levels of automation (with partial human control). Lower level automation usually requires more involvement of human operators in the sense that they need to consistently oversee the automated systems when manual control is needed (Endsley & Kiris, 1995). Human operators are expected to complete the task when unanticipated circumstances or automation failures arise. Therefore, compared to having

full operational control of the system, a combination of human control and machine automation is more likely to cause a stressful situation for the operators when automation increases the complexity of accomplishing the tasks (Costa, 1995; Djokic et al., 2010).

In the case of ATC, automation has helped controllers balance workload and improve the efficiency of ATC operations. Nevertheless, it is arguable whether ATC automation should be designed to assist controllers or to replace them (Newcome, 2004). When there is mixed traffic with both manned and unmanned aircraft, controllers not only need to memorize and apply the ATC procedures for both types of aircraft, it is likely they would also face additional mental workload to recognize what degree of control they have over the particular traffic scenario (Sheridan & Verplank, 1978). Furthermore, Endsley and Kiris (1995) discovered that performance can be impaired when control is taken away from the controllers to coordinate traffic. With UAVs that fly on predefined routes, controllers would have less or no capabilities to give commands or alter their flight trajectories depending on the level of automation the UAVs utilize. This lack of ability to control UAVs via ATC system automation is more likely to create stress (Endsley & Kiris, 1995). Plus, managing the combination of both types of aircraft (manned and unmanned) requires different degrees of control by the controllers. The question remains whether it is acceptable to implement full automation to the system. Billings (1997) investigated the role of automation in the ATC environment to understand the effects of high-level technologies on human operators/controllers in the aviation system. By evaluating the human-machine relationship, Billings (1997) stated a fully automatic ATC system would have economic benefits because of fewer labor costs.

However, he indicated that the unexpected contingencies would always require human intervention. Thus, a cooperative human-machine system has potential to enhance ATC performance even though the foreseeable development in ATC technology will automatically handle air traffic conflicts. It is possible to conclude that it is not always stress-free when human control is eliminated from the operation process because of automation. Accordingly, the degree of shared task responsibilities between humans and machines should be assessed to understand which level of control should be applied in ATC scenarios for automation to promote controller performance and reduce stress.

### ***Research Model***

The current research study employed a within-subjects experimental research design with three conditions conducted in a laboratory. These conditions differed by the number of unmanned aircraft in the airspace and the level of control over the aircraft that the participants need to manage. Specifically, the high-fidelity en route air traffic simulation system, I-SIM, was utilized to simulate the ATC scenarios for the experiment. This simulation system can be used for various purposes, such as ATC training, air space design/analysis, advanced computer-human interface development, and UAV integration to the airspace is also supported (Circelli, 2017). Devices were used to measure stress and performance. Heart rate monitor and GSR sensors objectively measured stress (Lin et al., 2011; O'Keane et al., 2005) while I-SIM recordings objectively measured participant performance. NASA-TLX assessed participants' perceived workload during the experiment. Participant performance was also subjectively measured with the Certified ATC Specialist Subjective Rating Form, which provides a practical and comprehensive



evaluation for each participant's performance and situation awareness (Sollenberger, Stein, and Gromelski, 1997).

### ***Hypotheses and Support***

The purpose of this study is to determine whether the integration of UAVs in air traffic scenarios affects an air traffic controller's stress level, work performance, and workload. Studies have shown that stress and performance are influenced by workload and job complexity (Costa, 1995; Djokic et al., 2010). The implementation of automation increases the complexity of airspace traffic, as well as workload, which ultimately impacts stress and ATC performance (Beehr et al., 2000; Hancock, 1989; Hockey, 1997; Yerkes & Dodson, 1908). Furthermore, the less degree of control that a controller can exercise, the more likely it is that UAVs in the airspace will adversely affect the controller's stress level and task performance (Endsley & Kiris, 1995; Sheridan & Verplank, 1978). Based on the literature review, it was hypothesized that a low degree of ATC control over the UAVs would negatively affect controller stress and task performance.

### **Summary**

The literature review shows the occupational stress of air traffic controllers comes from ATC job complexity and highly demanding tasks, which influence their performance. Although automation can help decrease human cognitive workload to some extent, UAV implementation can affect a controller's performance by adding additional FAA procedures and ATC decision-making demands. However, little research remains to

connect the presence of UAV operations and their effects on stress levels and performance of air traffic controllers.

The fundamental knowledge and evidence presented provide the foundation for the hypotheses of the current study. By determining the objective and subjective measures of stress and performance in different air traffic scenarios involving UAVs, the effects of having a higher level of automation and a lower level of control can be ascertained to quantify the effects on air traffic controllers.

In conclusion, the effects of adding UAVs to the existing system must be understood to maintain airspace safety and protect the well-being of the ATC workforce. This understanding can help determine the optimal level of automation over UAVs in the ATC environment that is necessary to complete tasks automatically and efficiently and reduce human errors. This study bridges the gap in literature by presenting the results of a within-subjects experimental research design investigating stress and performance effects on air traffic controllers associated with the integration of UAVs in three different air traffic scenarios.

### **Chapter III: Methodology**

This study examined how the integration of UAVs in the existing airspace affects air traffic controllers' stress levels, performance, and workload. This chapter introduces the participants, apparatus, research design, and procedures. In order to measure the participants' stress levels and performance during the traffic scenarios, an experiment was conducted using the I-SIM simulation systems to mimic ATC situation and record task performance. Within-subject ANOVA tests were conducted to determine whether the hypotheses were rejected (statistically significant).

#### **Research Method Selection**

An experimental research design was chosen because it is frequently used to identify potential causes for the occurrence of specific behaviors (Privitera, 2020). An experimental research design allows for manipulation of independent variables, to measure their effects on dependent variables, showing a cause-effect relationship, rather than just a relationship between variables. Therefore, it was suitable to study the effects of UAVs in different conditions (scenarios) on controller stress and performance in a simulated ATC environment.

#### **Population/Sample**

This study aims to investigate the association of the presence of UAVs in controlled airspace on air traffic controller stress and task performance. Although this study is relevant to the population of air traffic controllers, the targeted subpopulation is students enrolled in the ATM program at Embry-Riddle Aeronautical University (ERAU), and the samples were drawn from this group. This present research can be

extended in future studies by sampling from the ATC population to be able to generalize the findings to actual air traffic controllers.

### ***Population and Sampling Frame***

Participants were selected from the students who are currently enrolled or had enrolled in the ATM program to perform as en route radar controllers. Participants were required to have sufficient knowledge of en route ATC procedures and be able to operate the I-SIM simulator. Therefore, the sample was limited to students who had taken all core ATM classes, and have taken or were currently enrolled in AT 405 (En Route Radar Operations).

### ***Sample Size***

Twenty-four participants were recruited for this research. A power analysis was conducted using G\*Power, a well-developed tool to run sample size calculations for different statistical tests (Faul et al., 2007). The sample size needed to be a number that is divisible by three because of counterbalancing purposes for the within-subject design. Therefore, the sample size was 24 based on three groups (within-subjects) with an alpha of .05 and moderate effect size (Cohen's  $d = .50$ ) to have adequate power for the results.

### ***Sampling Strategy***

Using non-probability sampling, participants were recruited from the accessible population via email from the Master Science of Aeronautics (MSA) program and advertising flyers posted around the ERAU campus. Specifically, convenience sampling (one type of non-probability sampling) was chosen for sample selection because of the small number of qualified students in the targeted population.

## **Data Collection Process**

All 24 participants completed all three simulated scenarios on I-SIM one at a time. The researcher, the SME, and the student assistant were in the same laboratory (i.e., en route simulation classroom) to record the experiment data. Both objective and subjective measurements were utilized during the experiment to measure stress levels and performance.

## ***Design and Procedures***

A within-subjects experimental design was conducted to determine how UAVs affect controllers' stress levels and performance in the en route ATC scenarios. There were two dependent variables: controller stress levels and performance. The independent variable was the different types of traffic scenarios that incorporated different numbers of manned aircraft and unmanned aircraft and the manipulation involved changing the numbers of UAVs presented and whether the participant (controller) had control over them in a scenario. As shown in Table 1, the Manned scenario was fully controlled by the participant and there were 12 manned aircraft and zero unmanned aircraft. The Mixed scenario was also fully controlled by the participants and there were six manned aircraft and six unmanned aircraft. The UC scenario was partially controlled by participants to the extent of controlling only six manned aircraft, and the other six uncontrollable aircraft were unmanned aircraft with pre-defined flight plans that could not be changed by the participants.

**Table 1***Manned and Unmanned Aircraft Scenarios*

Numbers	Full Control		Partial Control
	Manned Scenario	Mixed Scenario	UC Scenario
<b>Manned Aircraft</b>	12	6	6
<b>UAVs</b>	0	6	6

*Note.* UAV = unmanned aerial vehicle. Full control included control of both manned and unmanned aircraft. Partial control included control over only manned aircraft. UC = uncontrolled.

In order to operate the en route air traffic simulation, two positions were required to perform the complete traffic scenarios: a radar controller and a pseudo pilot. The participants performed as radar controllers while a co-researcher played the role of a pseudo pilot/remote pilot. The pseudo pilots were recruited from the ATC lab assistants who have experiences and knowledge working with the I-SIM simulation system. The pseudo pilot kept communicating with the controllers and converting their instructions into actual commands on the simulator to maneuver the aircraft in the scenarios. As radar controllers, participants had the primary responsibilities to coordinate the movement of aircraft to ensure a smooth flow of traffic and maintain efficient communication with pseudo pilots. Before the experiment began, each participant was briefed about the purpose and procedures of the study and presented a hardcopy consent form (see Appendix B5). The number of aircraft and the level of control over the aircraft in each scenario were explained to the participants upfront. In addition, they were informed about the 10-second delay every time the participant-controller establishes communication with

the UAV remote pilot in the Mixed scenario. Then, each participant was assigned with a random participant number for confidentiality purposes. Each participant completed a demographic form (see Appendix B3) to collect information about their age and gender. After signing the consent form and filling out demographic form, participants were given 5 minutes to practice a moderate air traffic scenario to refresh their knowledge of procedures and re-familiarize themselves with the simulator.

When the practice scenario was complete, the participants were asked to coordinate the air traffic in three different scenarios. At the same time, they were asked to wear a fingertip heart rate monitor on a middle finger, as well as two GSR sensor strips on the index and ring fingers on their left hands because their right hands were used to control the track ball that was fixed on their right side. All three ATC scenarios used the map of Sector 66, and they were set to be moderate-busy air traffic. Each scenario lasted 15 minutes with the same traffic load of 12 aircraft. In order to mitigate the carryover effect that could alter the participant's performance by learning from the previous scenario(s), the positions of the aircraft in three scenarios were placed in different areas in the sector: The aircraft in different scenarios had different flight trajectories.

The three scenarios differed by the degree of control that a participant had over the traffic scenarios, but the difficulty of each scenario remained the same. Flight plans and routes of all aircraft (both manned and unmanned) were displayed on the radar display in the same way as a regular practice class. Additionally, intent information of unmanned aircraft was indicated on the screen by a call sign that started with UAV; thus,

participants would know which aircraft were operated by remote operators or flew as pre-defined.

**Full Control Scenarios.** The participants had full control over all aircraft (both manned and unmanned) in the Manned and the Mixed scenarios. In the Manned scenario, participants were required to establish immediate communication with the pseudo pilot to coordinate all 12 manned aircraft. In the Mixed scenario, participants were required to establish communication with the pseudo pilots for both manned and unmanned aircraft to coordinate the overall traffic. However, the Mixed scenario differed from having immediate communication with the six manned aircraft in that there was a 10-second communication delay to communicate with the six unmanned aircraft to simulate the communication connection time between remote operators of UAVs and air traffic controllers.

**Partial Control Scenario.** The participants had partial control of aircraft to the extent that they only had control over manned aircraft in the UC scenario. In this scenario, participants were only required to communicate with the pseudo pilot for six manned aircraft while taking handoffs to the unmanned aircraft and making point-outs of their traffic to the manned aircraft to prevent conflicts and maintain separation between aircraft.

The different levels of control in different scenarios provided a way to examine the effect of implementing automation in the ATC system. In this study, low level of control represented high level of automation and was indicated by the UAVs in the air traffic scenarios. It was expected that participants would display the greatest amount of



stress in the UC scenario because they would have the least amount of control when there was the highest level of automation presented in the scenario (UAVs flying as pre-defined); thus control was manipulated in these different scenarios. Stress and performance were measured objectively and subjectively.

In all three scenarios, standard ATC procedures and commands had to be applied for separation. In the Manned scenario and 2, the pseudo pilot/remote pilot carried out the participant-controller's air traffic instructions and requests to maneuver manned and unmanned aircraft. In the UC scenario, the unmanned aircraft automatically followed the trajectory programmed into the simulator.

The same level of trajectory points, traffic conflicts, and scenario play speed were pre-programmed in all scenarios. Data tags of aircraft that showed their altitude, speed, exits, and airports were displayed on the screen. During the scenarios, the SME—ATM Professor Edward L. Mummert—conducted an observational evaluation for every participant using his knowledge and expertise in air traffic control. He monitored the behaviors and actions of each participants and evaluated their performance by filling out the Certified ATC Specialist Subjective Rating Form (see Appendix B4). After each scenario, every participant was asked to take 5 minutes to complete a hardcopy of the NASA-TLX questionnaire on the perceived workload during the scenario (see Appendix B2).

### *Apparatus and Materials*

**I-SIM®.** The ATC modeling and simulation system in the En Route laboratory at ERAU Daytona Beach campus (see Figure C1) delivers high-fidelity en route air traffic

and airspace training scenarios. It also supports UAV integration into the airspace. The system emulates the en route sector used in FAA Academy training in both En Route Automation Modernization (ERAM) and Display System Replacement (DSR) environments. Map display of Sector 66 (Jackson Low) was used for this experiment because this map is used to train ATM students for en route operations at ERAU. The study participants were required to use their knowledge of phraseology and coordination procedures to maintain vertical, lateral, and longitudinal separation of aircraft in the preconfigured scenarios. Simultaneously, the participants needed to utilize compatible keyboard commands and maintain proper communications with the pseudo pilots through a headset. The I-SIM system also provides an objective measure of performance in the number of missed handoffs. Poor participant performance was indicated by a greater number of missed handoffs.

**NeXus-10 MKII.** This device is a collective and adjustable system developed by Mind Media Company (Mind Media) and is used to measure psychophysiological responses in research. It can measure different physiological signals such as electroencephalogram (EEG), electromyography (EMG), electrocardiogram (ECG), and electrooculography (EOG), as well as peripheral signals like skin conductance, heart rate, and body temperature. For this study, the device provided objective measures of galvanic skin response (GSR), heart rate, and heart rate variability (HRV) to determine the participants' stress levels and mental workload during each scenario.

The participants wore a heart rate fingertip monitor (see Appendix B1) on their middle finger of their left hand. It measured their heart rate in beats per minute (BPM)

and heart rate variability in millisecond [ms] as the difference between the high and low BPM. Their galvanic skin response (skin conductance) was measured as electrical signals detected via the skin in units of microSiemens [ $\mu\text{S}$ ] (see Appendix B). Because the hands have the highest number of sweat glands, the NeXus-10 MKII strips with Ag/AgCl silver-chloride contact points were wrapped around participants' index and ring fingers of their left hands to collect the GSR signals.

The fingertip monitor and skin conductance sensor were plugged into the NeXus-10 MKII equipment during the experiments to collect data, and these data were uploaded into a computer system and displayed using BioTrace+ software that accompanies the NeXus system. It displays the data as visualized feedback while computing and analyzing statistics and exports the results for reporting purposes.

**Demographic Form.** A self-report form developed for this study was used to collect age and gender data from the participants. Demographic data provide the general characteristics of the sample.

**NASA Task Load Index (NASA-TLX).** This multidimensional rating-scale questionnaire was developed by the National Aeronautics and Space Administration (NASA) to subjectively-assess perceived mental workload while performing a task. The NASA-TLX is divided into the following six subjective subscales:

- mental demand
- physical demand
- temporal demand
- performance

- effort
- frustration.

Descriptions of subscales were provided to the participants so they would understand the purpose of the questionnaire and be able to answer the questions accurately.

**Certified ATC Specialist Subjective Rating Form.** Developed by Sollenberger, Stein, and Gromelski (1997), this ATC evaluation form is used by certified ATC specialists to evaluate the performance of air traffic controllers. Generally, these specialists are experienced controllers proficient in operational ATC procedures and preset ATC scenarios used on the I-SIM. The rating form consists of questions that reflect a subjective measure of the overall performance of participants, questions but also cover other factors associated with ATC, such as situation awareness. The SME for this research served as the ATC specialist and used the rating form to evaluate the task effectiveness of the participants completing the ATC scenarios in the simulation environment.

### ***Sources of the Data***

There were three primary data sources utilized in the study. First, the NASA-TLX questionnaire was handed to each participant to assess perceived mental workload when performing the ATC tasks. Second, the SME filled out the Certified ATC Specialist Subjective Rating Form to evaluate the participants' performance and situation awareness during the scenarios. The third was the objective performance data obtained from the I-SIM that measured the number of handoffs missed in each scenario.

### ***Measurement Instruments***

The standardized measurement instruments used in this study were the Certified ATC Specialist Subjective Rating Form, the NASA-TLX, and the performance measures from the I-SIM. The rating form provided SME measurements of the participants' performance and situation awareness. Performance was also measured by the I-SIM. The NASA-TLX measured the participants' perceived workload.

### **Ethical Consideration**

The risks of participating in this study were minimal, and the benefits of outweighed the risks. Moreover, the informed consent form ensured the willingness and voluntariness of the participants. Each participant was assigned a random participant number to ensure the confidentiality of records. Any responses and collected data are protected and stored in a secured place. All procedures of the experiment followed the Institutional Review Board (IRB) requirements. The IRB approval letter is included in Appendix A.

### **Data Analysis Approach**

The researcher entered the data scores and into the IBM® SPSS software and ran within-subject ANOVA tests. All experiment procedures were strictly followed to prevent issues for data recording (e.g., lost data) and minimize experimenter bias. By administering the NASA-TLX in-person survey, the participants' response rates were maintained at 100% to eliminate the response bias. To ensure the participants would not be offended, appropriate and unbiased language was used during the experiments, both verbally and written (Privitera, 2020).

### ***Reliability and Validity Assessment Method***

The NASA-TLX rating form has been used for workload assessment in many fields (Hart, 2006) to investigate a variety of performance factors such as stress (Reilley et al., 2002) and situation awareness (Endsley & Rodgers, 1997). This subjective measurement technique is favored by researchers because of its assessed reliability and validity (Battiste and Bortolussi, 1988; SESAR Joint Undertaking, 2012). According to Battiste and Bortolussi (1988), the reliability of NASA-TLX for repeated measures has shown correlations of .077. Moreover, the split-half reliability and Cronbach's alpha coefficient is reported to be more than .80, indicating good consistency (SESAR Joint Undertaking, 2012). Research studies have presented the validity of the Certified ATC Specialist Subjective Rating Form to subjectively measure the performance and situation awareness of aviation personnel (Endsley et al., 1997; Endsley et al., 2000; Sollenberger, Stein, and Gromelski, 1997). Both NASA-TLX and the ATC Specialist Subjective Rating Form have good structure validity obtained through a structure validity factor analysis (Endsley et al., 1997; Endsley et al., 2000; SESAR Joint Undertaking, 2012).

### **Summary**

This chapter explained the methodology section of the study. Twenty-four participants completed all three pre-programmed ATC scenarios on the I-SIM system. These three scenarios differed by the number of UAVs in the airspace and the control level over the aircraft that the participants needed to manage. There were a total of 12 aircraft in each scenario. However, the Manned scenario had 12 manned and no (zero) unmanned aircraft, while the Mixed scenario had six manned and six unmanned aircraft.

Participants had full control in the Manned scenario and the Mixed scenario for both types of aircraft. In the UC scenario, there were six manned and six unmanned aircraft, but participant-controllers only had control over the six manned aircraft while the six unmanned aircraft flew as pre-defined; they were not allowed to change those UAVs' behaviors. Thus, there was no communication exchanged between the participant-controller and the six unmanned aircraft. Stress, performance, and workload were measured using the GSR, heart rate monitor, Certified ATC Specialist Subjective Rating Form, NASA-TLX questionnaire, and the I-SIM recordings as described in this chapter. The data collected were analyzed, and the results are presented in Chapter 4, and their interpretation is presented in the discussion and conclusions in Chapter 5.

## Chapter IV: Results

This chapter describes the statistical findings based on the methodology, consisting of demographics, descriptive statistics, quantitative data analysis results. The results showed that stress and performance were significantly different in three ATC scenarios that required different degrees of control and had different quantities of UAVs.

### Demographics Results

A total of 24 participants, 20 males and four females, were randomly selected from the students who currently majoring or minoring or had the ATM program at ERAU. The mean age of participants was 21.88 ( $SD = 2.13$ ).

### Descriptive Statistics

Both objective and subjective measures of stress and performance were collected. Measurement of stress included GSR data and heart rate data. Measurement of performance included ATC Specialist Evaluation scores and I-SIM recording of missed handoffs. Measurement of workload included HRV data and NASA-TLX scores.

### Quantitative Data Analysis Results

Three hypotheses were tested in this research study. Within-subjects ANOVAs were conducted to determine whether there were any statistically significant differences in air traffic controllers' stress levels, working performance, and workload in different air traffic scenarios that require different degrees of control.

#### *GSR, Heart Rate, HRV*

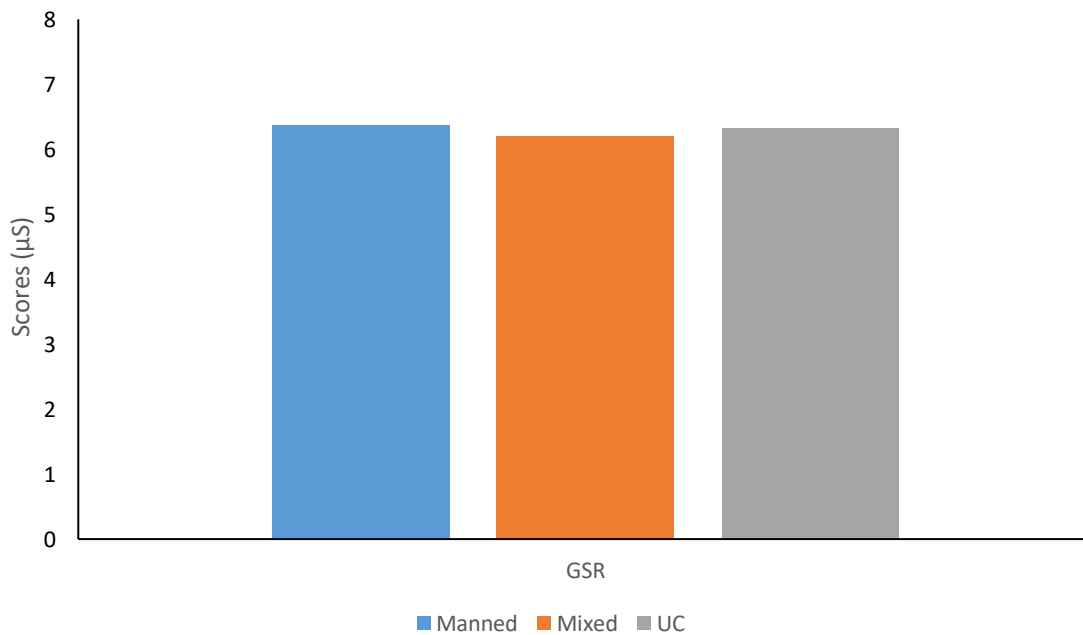
A one-way within-subjects ANOVA for GSR measures indicated the assumption of sphericity was met, as assessed by Mauchly's test of sphericity,  $\chi^2(2) = 1.1, p = .577$ .



As shown in Figure 1, different degrees of control did not show statistically significant changes in stress levels,  $F(2, 24) = .52, p = .598, \eta^2 = .022$ .

**Figure 1**

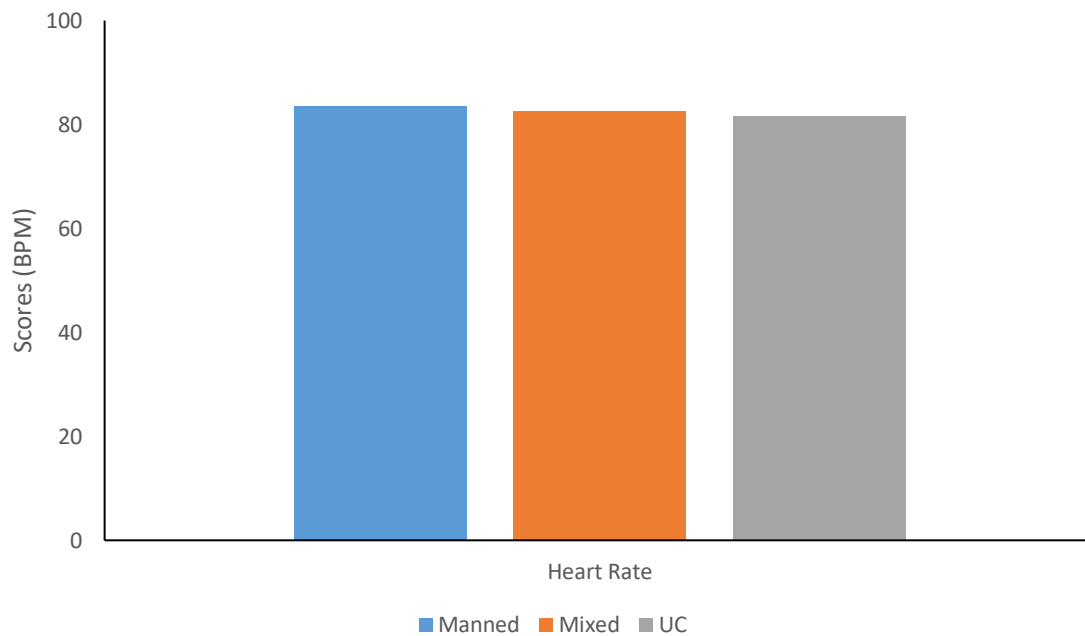
*Mean Difference of GSR Scores in Three Scenarios*



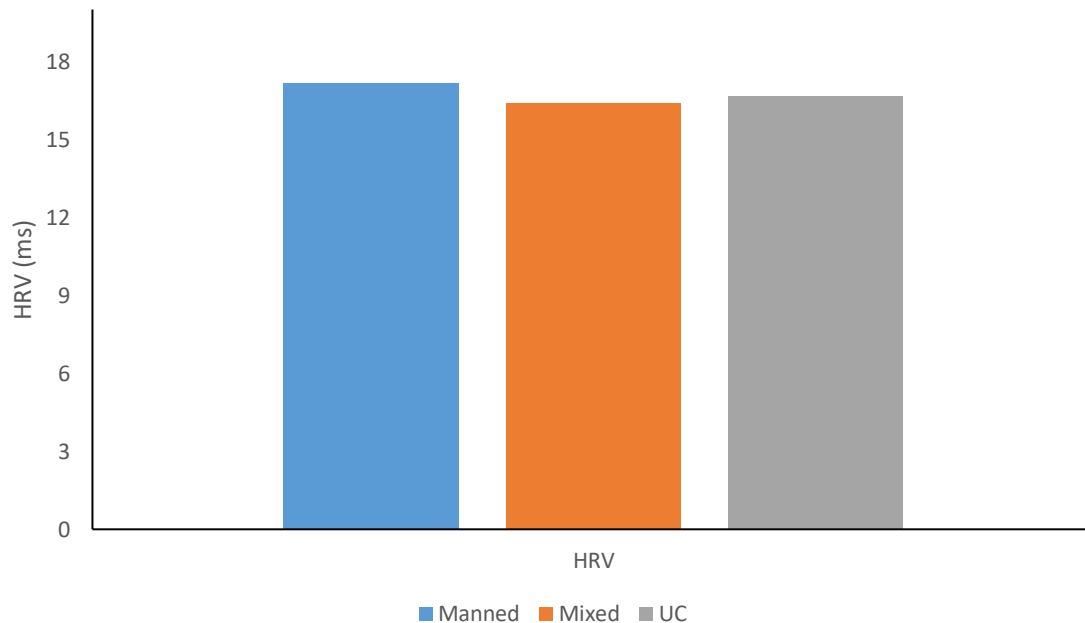
The one-way within-subjects ANOVA for heart rate measures indicated the assumption of sphericity was met, as assessed by Mauchly's test of sphericity,  $\chi^2(2) = 4.42, p = .110$ . There is no significant difference in participants' stress levels different types of ATC scenarios (Figure 2),  $F(2, 24) = 1.28, p = .289, \eta^2 = .053$ .

**Figure 2**

*Mean Difference of Heart Rate Scores in Three Scenarios*



The one-way within-subjects ANOVA for HRV measures indicated the assumption of sphericity was met, as assessed by Mauchly's test of sphericity,  $\chi^2(2) = .263, p = .877$ . Figure 3 shows the different degrees of controls in three scenarios did not lead to any statistically significant changes in mental workload,  $F(2, 24) = .906, p = .411, \eta^2 = .038$ .

**Figure 3***Mean Difference of HRV Scores in Three Scenarios****Missed Handoffs***

Using the recording feature on the I-SIM system, the number of missed handoffs was recorded to measure the participants' performance objectively. There was a total of 12 handoffs that participants were supposed to make during each scenario. Hence, a bigger number of missed handoffs indicates worse performance.

The Mauchly's test for sphericity was significant at  $\chi^2(2) = 14.14, p = .001$ , indicating that the assumption of sphericity was violated. The Greenhouse-Geisser correction was applied to the one-way repeated measures ANOVA, which showed that the number of missed handoffs was significantly different in the three scenarios (see Table 2),  $F(1.36, 24) = 19.79, p < .001, \eta^2 = .463$ . Hypothesis  $H_{02}$  is rejected. Figure 4

shows the mean difference of missed handoffs in three scenarios. LSD post hoc analysis showed that there were significantly more missed handoffs in the Mixed scenario than the UC scenario, and significantly more missed handoffs in the UC scenario than the Manned scenario.

**Table 2**

*One-Way Within-Subjects ANOVA for Missed Handoffs*

Variable	<i>M</i>	<i>SD</i>
Manned Scenario	0	0
Mixed Scenario	1.54	1.35
UC Scenario	.42	.72

*Note.* *M* = mean. *SD* = standard deviation.

### ***NASA-TLX***

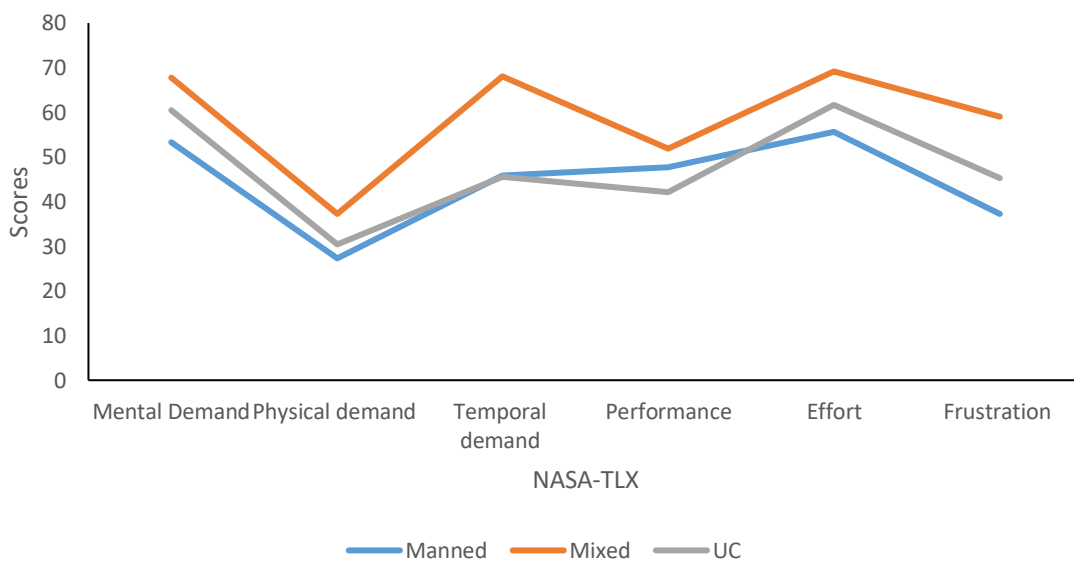
Every participant completed the NASA TLX for each scenario. The questionnaire measures participants' perceived workload based on six subjective subscales. By conducting 3 x 6 Factorial ANOVA tests, the results showed the assumption of sphericity was met for each subscale: mental demand, temporal demand, performance, effort, and frustration. These scores are based on a 21-mark scale, and each space between two marks represents 5 points. Therefore, the highest score that a participant could put is 100. Moreover, higher scores indicate a higher perceived workload.

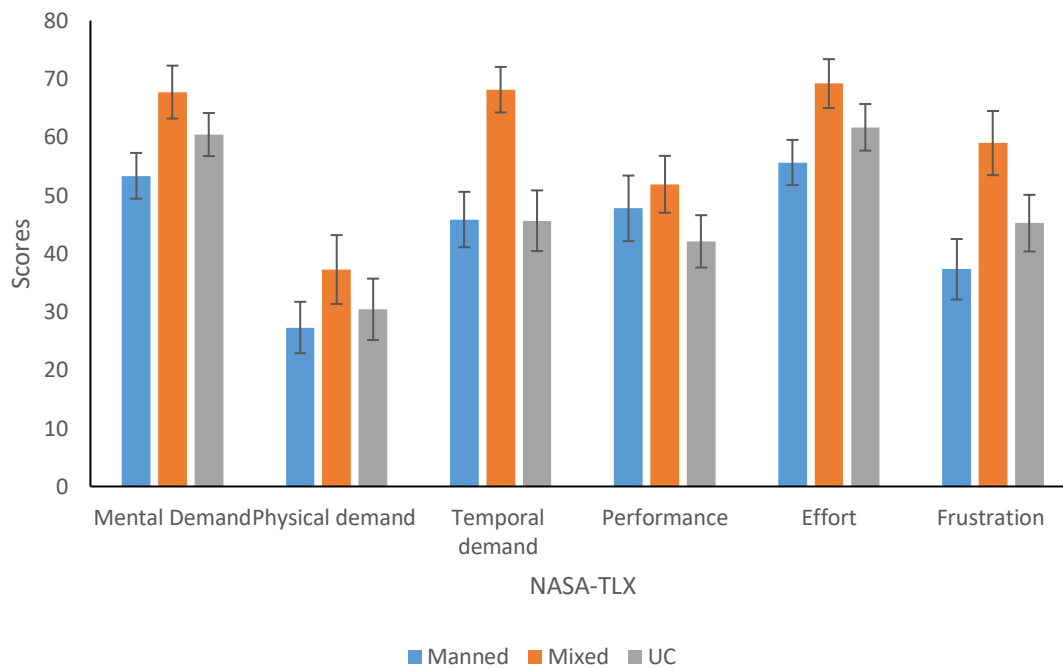
The Mauchly's test shows the sphericity was violated for the 3 x 6 repeated measures ANOVA,  $\chi^2(54) = 83.73, p = .008$ . Greenhouse-Geisser was applied for correction. The ANOVA showed an interaction between scenarios and the NASA-TLX

subscales,  $F(5.76, 24) = 2.66, p = .02, \eta^2 = .104$ . Figure 4 shows the interaction between three scenarios and NASA-TLX subscales. Simple main effect test of the interaction showed the significant differences of the score for each subscale across three scenarios (see Figure 5). Table 3 shows performance was not significantly different, but mental demand, physical demand, temporal demand, effort, and frustration were significantly different across scenarios. Greenhouse-Geisser was applied to correct the violation of the Mauchly's test for physical demand  $\chi^2(2) = 7.33, p = .026$ . Because the frustration rating was significantly higher,  $F(2, 24) = 11.06, p < .001, \eta^2 = .325$ . LSD post hoc analysis revealed that frustration was the highest in the Mixed scenario; therefore, hypothesis  $H_{01}$  is rejected.

**Figure 4**

*Interaction between Scenarios and NASA-TLX Subscales*



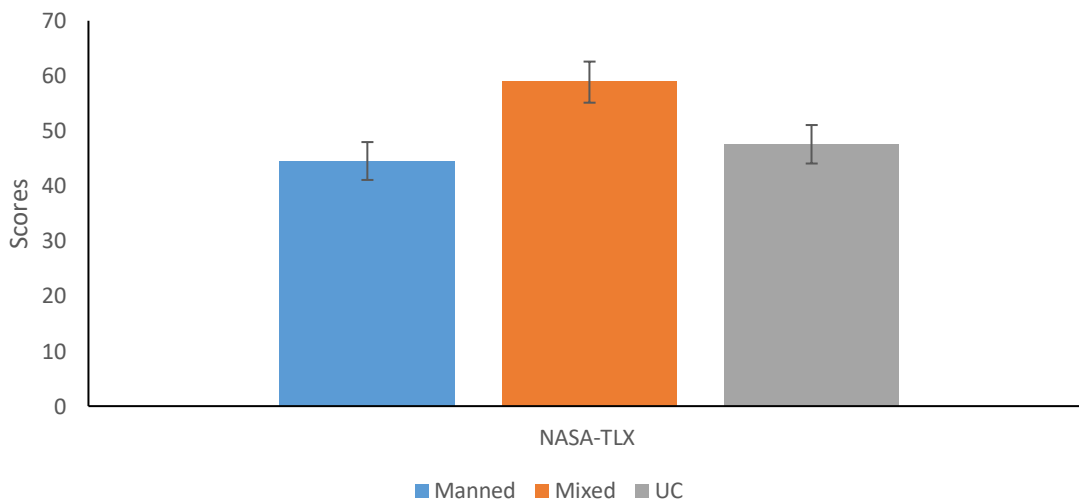
**Figure 5***Simple Main Effect of Interaction in 3 x 6 ANOVA***Table 3***Post Hoc Tests of NASA-TLX Subscales in Three Scenarios*

Variable	<i>F</i>	<i>df</i>	<i>p</i>
Mental Demand	5.19	2	.009
Physical Demand	3.86	1.56	.04
Temporal Demand	13.21	2	< .001
Performance	2.78	2	.073
Effort	5.09	2	.01
Frustration	11.06	2	< .001

The Mauchly's test shows the sphericity was assumed for the scenario main effect test of scenarios,  $\chi^2(2) = .98, p = .613$ . As shown in Figure 6, a statistically significant difference was shown for scenarios,  $F(2, 24) = 15, p < .001, \eta^2 = .395$ . The Mauchly's test shows the sphericity was violated for the NASA-TLX subscale main effect test,  $\chi^2(14) = 38.2, p = .001$ . Greenhouse-Geisser was applied for correction, a statistically significant difference was shown for NASA-TLX subscales,  $F(3.34, 24) = 17.8, p < .001, \eta^2 = .436$ . The 3 x 6 ANOVA showed that participants perceived the highest workload in the Mixed scenario; hence, hypothesis H<sub>03</sub> is rejected.

**Figure 6**

*Main Effect of Scenarios in 3 x 6 ANOVA*



### ***ATC Evaluation Form***

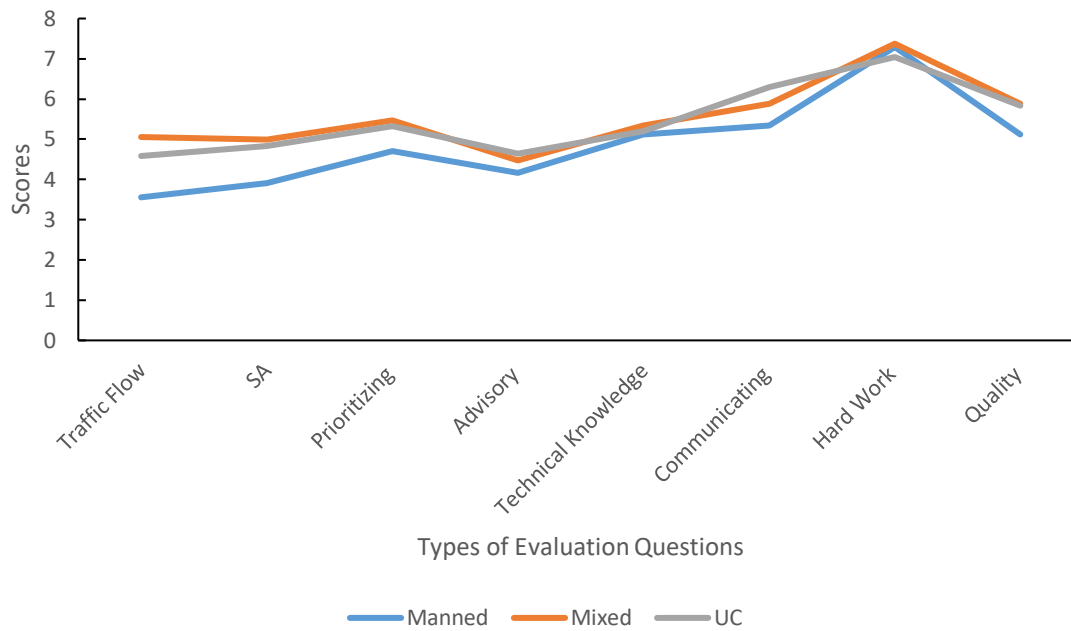
The SME subjectively evaluated each participant's performance for each scenario using the Certified ATC Specialist Subjective Rating Form. There were 29 questions related to ATC performance (e.g., situation awareness, use of phraseology, etc.) to assess participants' overall performance during the scenarios. The first 23 questions were categorized into eight groups based on their similarities in the topic. Because I-SIM system displays electronic strips instead of paper strips, Question number 10 for strip marking was taken out. The SME gave scores on an 8-point scale for each of these questions. Participants who were evaluated with higher scores performed better during the experiment.

A 3 x 8 factorial ANOVA was conducted to determine the effects of different controls in three scenarios on participants' ATC performance evaluation scores for different questions factors. The Mauchly's test shows the sphericity was violated for the interaction ANOVA,  $\chi^2(104) = 164.82, p < .001$ . Greenhouse-Geisser was applied for correction and a statistically significant interaction between scenarios and categorized evaluation scores was shown,  $F(7.33, 24) = 3.119, p < 0.001, \eta^2 = .119$  (see Figure 7). Simple main effect test of the interaction is illustrated in Figure 8. LSD post hoc analyses revealed that evaluation scores for traffic flow questions, situation awareness questions, prioritizing questions, and overall quality questions were significantly lower in the Mixed scenario than in the Manned scenario and the UC scenario (as shown in Table 4). Evaluation scores for advisory questions were only significantly higher in the Manned scenario.



**Figure 7**

*Interaction between Scenarios and ATC Evaluation Question Factors*

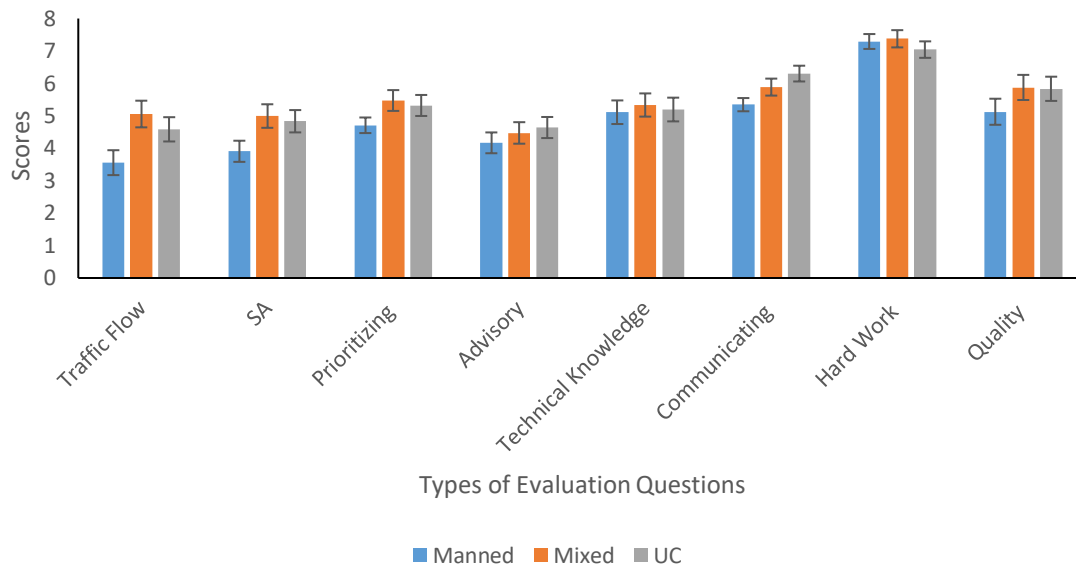
**Table 4**

*Post Hoc Tests of ATC Evaluation Question Factors in Three Scenarios*

Variable	<i>F</i>	<i>df</i>	<i>p</i>
Traffic Flow	9.94	2	.000
SA	5.95	2	.005
Prioritizing	6.36	2	.004
Advisory	2.5	2	.093
Technical Knowledge	.25	2	.779
Communicating	10.59	2	.000
Hard Work	.961	2	.39
Quality	4.81	2	.013

**Figure 8**

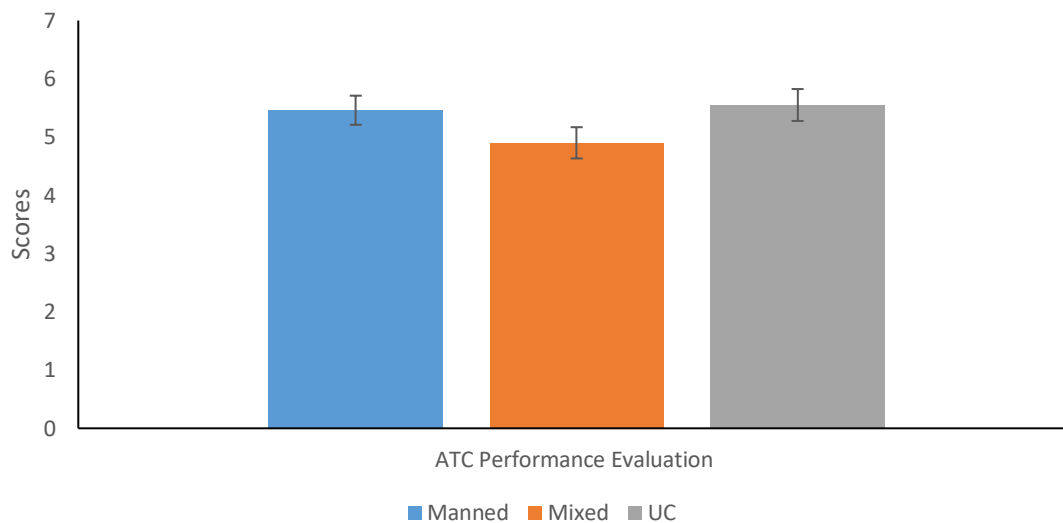
*Simple Main Effect of Interaction in 3 x 8 ANOVA*



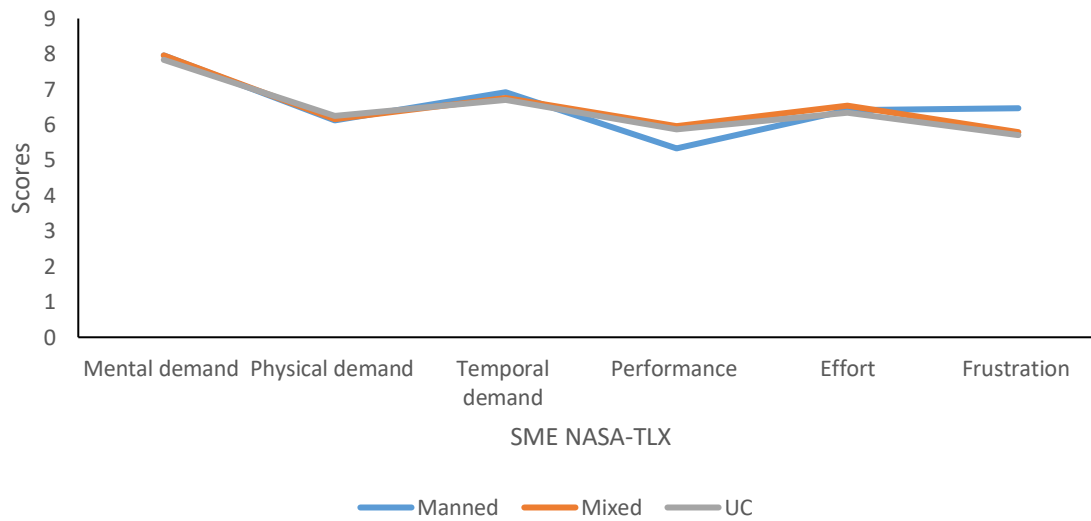
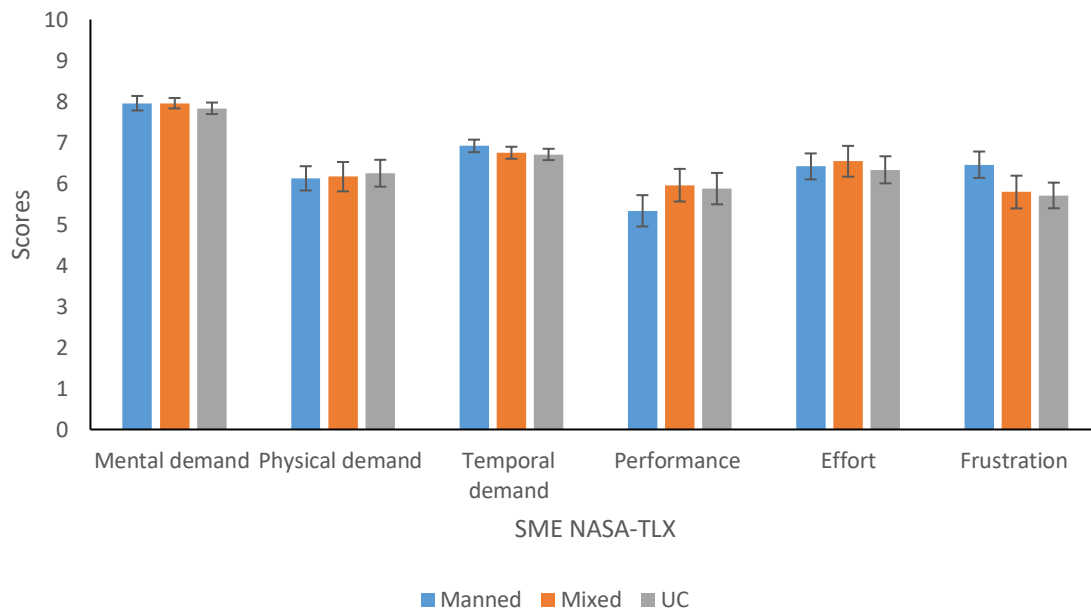
The Mauchly's test shows the sphericity was violated for the evaluation question factor main effect ANOVA test,  $\chi^2(27) = 85.78, p < .001$ . Greenhouse-Geisser was applied for correction, and a statistically significant difference was shown for ATC evaluation question factors,  $F(2.76, 24) = 34.55, p < .001, \eta^2 = .6$ . The Mauchly's test shows the sphericity was assumed for the scenario main effect test,  $\chi^2(2) = 5.8, p = .055$ . The overall evaluation score was significant different across three scenarios,  $F(2, 24) = 8.69, p = .001, \eta^2 = .274$  (see Figure 9). The 3 x 8 ANOVA showed that participants carried out the worst performance in the Mixed scenario; hence, hypothesis H<sub>02</sub> is rejected.

**Figure 9**

*Main Effect of Scenarios in 3 x 8 ANOVA*



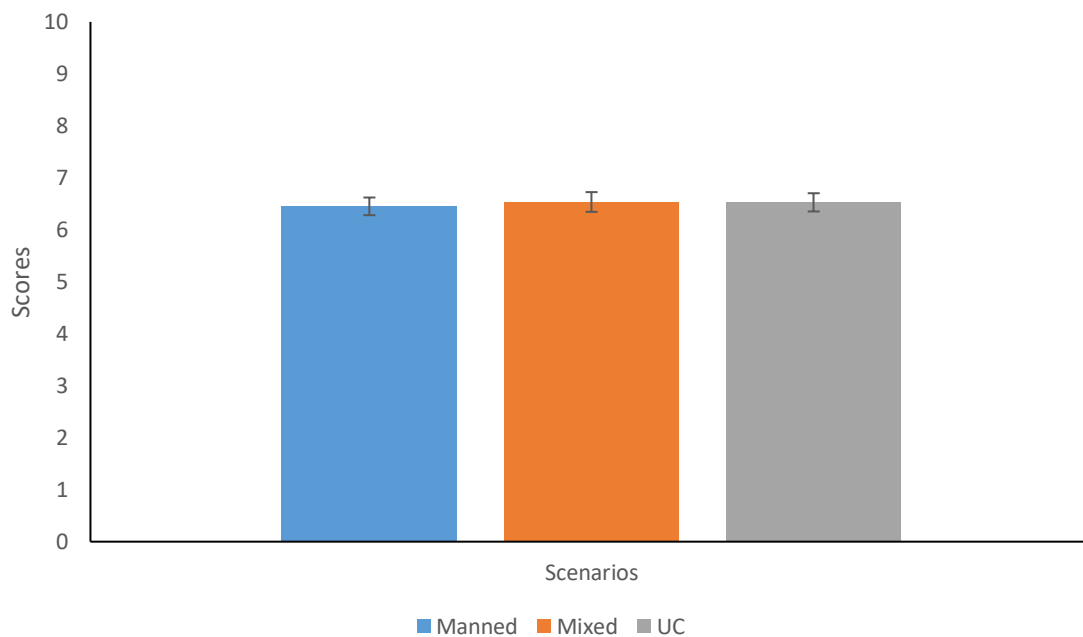
In addition to the 23 performance questions, the SME filled out the NASA-TLX questionnaire for question 24 to 29 on the evaluation form to assess participants' workload. SME NASA-TLX uses a 10-point scale for evaluation. A 3x6 repeated measures ANOVA was conducted to determine the effects of different controls in three scenarios on participants' ATC performance evaluation scores for NASA-TLX questions. The Mauchly's test shows the sphericity was violated for the interaction ANOVA,  $\chi^2(54) = 108.83, p < .001$ . Greenhouse-Geisser was applied for correction and a statistically significant interaction between scenarios and evaluation scores for SME NASA-TLX was shown in Figure 10,  $F(5.43, 24) = 3.936, p = .002, \eta^2 = .146$ . Figure 11 shows the simple main effect of the interaction.

**Figure 10***Interaction between Scenarios and SME NASA-TLX Factors***Figure 11***Simple Main Effect of Interaction in 3 x 6 ANOVA*

The Mauchly's test shows the sphericity was violated for SME NASA-TLX factor main effect test,  $\chi^2(14) = 95.8, p < .001$ . Greenhouse-Geisser was applied for correction, and a statistically significant difference was shown for SME NASA-TLX factor,  $F(2.59, 24) = 10.36, p < .001, \eta^2 = .311$ . Participants got higher scores in mental demand evaluation questions than the other five questions. As shown in Figure 12, main effect of scenarios was not significantly different,  $F(2, 24) = .29, p = .753, \eta^2 = .012$ . The 3 x 6 ANOVA showed that participants carried out the worst performance in the Mixed scenario; hence, hypothesis H<sub>02</sub> is rejected.

**Figure 12**

*Main Effect of Scenarios in 3 x 6 ANOVA*



## **Summary**

The statistical findings of this study have been in line with the hypotheses stated in the study and showed significant changes in air traffic controllers' stress levels and performance caused by UAVs. Although the psychological data didn't show any significant difference during the three different degrees of control, the participants' self-reports showed they had experienced more stress and carried out worse performance when there were both manned aircraft and UAVs in the aircraft that required coordination from the participants. The hypotheses were rejected when significant differences were found in the three ATC scenarios for missed handoffs, NASA-TLX scores, and ATC specialist evaluation scores. The statistical findings showed significantly that controllers' stress levels and performance were affected by the different degrees of control in the scenarios. The last chapter of this study will present an overall discussion of current findings and possible recommendations for future research.

## **Chapter V: Discussion, Conclusions, and Recommendations**

The purpose of this study was to examine the effects of UAV operation on air traffic controllers' stress and performance. This chapter presents a comprehensive discussion and conclusions substantiated by the findings of the current research, as well as recommendations for future studies.

### **Discussion**

The participants' stress, performance, and workload were significantly different in three en route ATC scenarios for all measures other than the psychological response measure. Greater stress and worse performance were found in the Mixed scenario where the participants had to control both manned aircraft and UAVs. Participants missed more handoffs in the UC scenario than the Manned scenario. The Mixed scenario had the greatest amount of workload. The effect sizes for these differences in the experiment validate medium to large observed effect in the population.

### ***Stress Measures***

The frustration subscale on the NASA-TLX form asked the participants to report their perceived stress during each scenario. More than half of the participants felt high frustration (score of 70 or above) in the Mixed scenario. The possible cause can be the 10-second communication connection delay designed in this scenario between the controller and the UAV remote operator. Traditionally, the communication between the pilot and the controller is instantaneous, which means the pilot confirms the controller's command with a readback as soon as they heard it through the radio. During the experiment, the researcher determined some participants were trying to confirm their

instructions with the pseudo pilot (UAV operator) when they did not hear an immediate readback from the pseudo pilot, even though the participants were initially made aware of the communication delay when taking handoffs to the UAVs. According to Billings (1997), changes in the normal routine can sometimes affect the operator's cognitive process when they face a hard time adjusting the change. After completing the experiment, several participants have expressed that the 10-second delay was a factor that interfered with their mental routine and created a more stressful condition to coordinate traffic.

High levels of automation can limit the operator's immediate control to manage a situation. It could be more likely to cause a stressful situation for the participants when there was less control of the UAVs, because they would lose the capabilities to give commands to the UAVs or change their trajectories to prevent conflicts (Endsley & Kiris, 1995). However, the results did not indicate that the participants were more stressed in the UC scenario compared to the Manned scenario. In this case, automation is less likely to be a stress factor.

In addition, the SME has rated the frustration level of participants on the NASA-TLX part of the ATC evaluation form. Although the evaluation was subjective, the significant difference for frustration scores showed the SME sensed that participants were frustrated the most when they coordinated traffic in the Mixed scenario. The results did not support the prediction about participants' stress levels being the highest when they have the lowest control of the scenario (UAVs fly pre-defined trajectories) (Leka & Houdmont, 2010). However, the 10-second communication delay posed additional



demand for the participants, and this rule was not included in their previous procedures. Therefore, the result supports Djokic et al., (2010)'s idea of job complexity as a contributing factor to controller's stress when a combination of human control and UAV automation is presented.

### ***Performance Measures***

The record of missed handoffs has shown that participants missed more handoffs in the Mixed scenario when controlling both types of aircraft, and more missed handoffs were presented in the UC scenario than in the Manned scenario. Interestingly, none of the participants missed any handoffs for the 12 manned aircraft in the scenario with only manned aircraft. The first 23 questions on the ATC evaluation form measured participants' working performance based on their primary job functions (Sollenberger et al., 1997). The significant interaction between scenarios and evaluation question factors showed that the participants demonstrated worse performance in the Mixed scenario. The main effect of evaluation question factors illustrate that participants received the lowest overall performance evaluation score in the Mixed scenario.

Because of the controllable UAVs and their corresponding rule (communication delay) in the Mixed scenario, the results showed that increased job complexity and information overload could impact controllers' performance (Costa, 1995). Also, because the participants experienced more stress in the Mixed scenario, the performance could be impaired by the overload stress they had to deal with (Hockey, 1997). The expectation of worse performance in the UC scenario was not met. The possible reason for the UC scenario not having the worst performance can be that enhanced technology of UAV

automation reduces the human workload by completing work tasks automatically with less or no human intervention (Hopkin, 1991). In the UC scenario, communication and control for the UAVs were completely removed from the controller's duty. Hence, the task of coordinating 12 aircraft was reduced to coordinating 6 manned aircraft while monitoring the other 6 UAVs. According to Metzger and Parasuraman (2005), as workload decreases, performance and efficiency of ATC operations are improved. However, because participants performed worse in the UC scenario than the manned scenario might be due to the automation interference with human control, which added to the job complexity of ATC (Endsley & Kiris, 1995).

### ***Workload Measures***

The NASA-TLX self-evaluation results have revealed that participants perceived higher mental demand, physical demand, temporal demand, and more frustration in the Mixed scenario than the Manned scenario. The interrelationship among stress, performance, and workload explains that these factors can influence each other. For example, Hockey (1997) demonstrated that excessive operational workload increases stress and diminishes performance. In the Mixed scenario, participants had to recognize the 10-second communication delay rule for the UAVs. This additional procedure led to increased demands and longer mental processes for the participants. Thus, controlling both types of aircraft would present a higher workload and further resulted in greater stress levels and impaired performance.

Workload also affected participants' SA. The scores of evaluation questions to determine participants' SA were significantly lower in the Mixed scenario, which showed

that a higher workload could have reduced the controllers' SA and further increasing performance errors (Endsley, 1997).

Although there were UAVs in the airspace in the UC scenario, the participants did not need to control them; instead, they were only asked to coordinate the traffic around the UAVs to solve any potential conflicts. The results showed that workload did not become a factor in the UC scenario. Therefore, stress and performance were less likely to be influenced by workload when uncontrollable UAVs were presented in the scenario.

Although the physiological measures have been valid to assess stress and workload in experimental settings, they did not show any effectiveness in detecting the differences in stress and workload in this study. Tran et al. (2007) discovered challenges when using physiological assessments, which might be possible factors that affected the results. First, the devices used for the current study may not be so accurate and precise in terms of measuring participants' physiological responses. Tran et al. (2007) also suggested that physiological sensors need to be worn for a longer time for reliable data collection and interpretation. In this study, participants were only wearing the sensors for 15 minutes for each scenario. Therefore, the quantity of data collected might not be very representative to analyze behavioral changes.

## **Conclusions**

This study determined that the implementation of UAVs in controlled airspace had increased the operational workload and negatively impacted the participants' stress and performance when they had to control both manned aircraft and UAVs in the airspace. The ability to have a higher degree of control over the UAVs did not diminish

stress caused by work demand. The participants' responses and self-evaluations should be valued because their perceptions of the scenarios were particularly intuitive.

Although automation is beneficial to the aviation industry as it can reduce human workload and improve work efficiency, the findings of the study suggest that air traffic controllers may have difficulties at the initial implementation phase of UAV operations in controlled airspace. The ATM system needs to work on protecting controllers' well-being while maintaining aviation safety as the time comes when both manned and unmanned aircraft would fly in the same airspace.

### ***Theoretical Contributions***

Previous studies have assessed the effects of automation and UAVs and how they are associated with stress and performance. The current study fills the gap to determine the UAV automation's impacts on air traffic controllers' occupational stress and performance. By investigating the effects of UAV automation on student controllers, the results of this study have significant implications for the understanding of how the stress and performance of air traffic controllers can be affected by the implementation of UAVs. It can be concluded that it is more likely that air traffic controllers would experience increased stress and conduct poor performance when they face mixed traffic with manned aircraft and UAVs.

### ***Practical Contributions***

Because it is foreseeable that UAV operations will be implemented in controlled airspace, it can create challenges for air traffic controllers. In order to protect controllers' well-being and ensure airspace safety, the insights gained from this study may be of

assistance to the ATM system in finding ways to mitigate these issues (e.g., excessive stress and impaired performance) when integrating UAVs into the NAS.

### ***Limitations of the Findings***

Two limitations were found that can impact the generalizability of the results. First, the experiment was limited because the presence of UAVs could only be simulated in the simulator. Second, because the sample was only selected from the student controllers at ERAU, the ultimate findings of this research may be less generalizable to actual air traffic controllers.

### **Recommendations**

While the findings of the study contributed to the assessment of UAVs' effects on air traffic controllers' occupational stress and performance, it enlightens practical implications and potential follow-up research. Also, it provides suggestions to improve future research methodology.

### ***Recommendations for the [Target Population]***

The findings of this study have a number of important implications for future practice. Due to the fact that UAVs would inevitably operate in the high-altitude controlled airspace (Conner, 2020), greater efforts are needed to ensure the safe integration of UAVs into the NAS. With the conclusions made in this current study, the ATM system should be developing techniques to reduce the excessive workload caused by UAVs, and the ways to help air traffic controllers improve performance and cope with stress, such as providing adequate training.

Furthermore, the study indicates that participants' performance was impaired when they were dealing with the uncontrolled UAVs in the UC scenario. It has brought to our consideration that whether utilizing full UAV automation would be beneficial for reducing ATC workload and personnel stress while enhancing the efficiency of ATC. More research needs to be conducted to examine such effects in implementing UAV automation to promote the most advantages of automation.

### ***Recommendations for Future Research***

Based on the finding of this study, considerably more research will need to be done to determine what techniques are effective to mitigate issues like excessive stress and impaired performance caused by UAVs. Further work should generalize these findings to actual air traffic controllers because this study was limited to student controllers at ERAU. Additionally, full UAV automation seems not to affect the controllers' stress and performance notably. Future research should also assess whether full UAV automation would be beneficial to ATC and ATM system.

Although the results showed that participants experienced more workload and stress and conducted worse performance in the Mixed scenario, it is unsure that if the communication delay caused this consequence or it was truly due to the coordination of the mixed traffic. Thus, more relevant research needs to be explored in the future.

Due to the gender distribution in the ATM program, there were only four female participants in this study. The question remains if gender would be a factor that affects the generalizability of the findings in this study. A further study could assess the effects

of gender difference in terms of UAV automation and ATC occupational stress and performance.

For future research or an imitated study, physiological measures should be utilized with concerns. According to Tran et al. (2007), two things should be looked out for in the future when using physiological measures. First, use more accurate and precise devices for measurements. It was hard for the controllers to keep their hands static during the operations. Therefore, researchers may need to use different devices attached to the body parts that will not be consistently moving. Second, in order to collect enough data for analysis, experiments should be designed for the participants to wear the sensors for an extended period of time.

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## Appendix A

### Permission to Conduct Research

#### Embry-Riddle Aeronautical University Application for IRB Approval EXEMPT Determination Form

**Principal Investigator:** Hui Wang

**Other Investigators:** Andy Dattel, Edward Mummert

**Role:** Student **Campus:** Daytona Beach **College:** Aviation/Aeronautics

**Project Title:** Assessment of Air Traffic Controllers' Occupational Stress and Performance in the Future Air Traffic Management

#### Review Board Use Only

**Initial Reviewer:** Teri Gabriel **Date:** 01/21/2021 **Approval #:** 21-066

**Determination:** Exempt

Dr. Beth Blickensderfer  
IRB Chair Signature: Elizabeth L. Blickensderfer, Ph.D.

Digitally signed by Elizabeth L. Blickensderfer, Ph.D.  
Date: 2021.01.26 16:08:11 -05'00'

#### Brief Description:

The purpose of this research is to investigate how the integration of unmanned aerial vehicles (UAVs) in airspace affects air traffic controllers' stress levels and performance. During this study, participants will be asked to coordinate air traffic in three ATC scenarios on a simulator while wearing external measurement devices on their fingers. They will also be asked to complete a questionnaire to assess their perceived workload after finishing each ATC scenario.

This research falls under the **EXEMPT** category as per 45 CFR 46.104:

(3)(i) Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses (including data entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection and at least one of the following criteria is met: (Applies to Subpart B [Pregnant Women, Human Fetuses and Neonates] and does not apply for Subpart C [Prisoners] except for research aimed at involving a broader subject population that only incidentally includes prisoners.) (Does not apply to Subpart D [Children])

- (A) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
- (B) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
- (C) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a **Limited IRB review** (use the Limited or Expedited Review form) to make the determination.

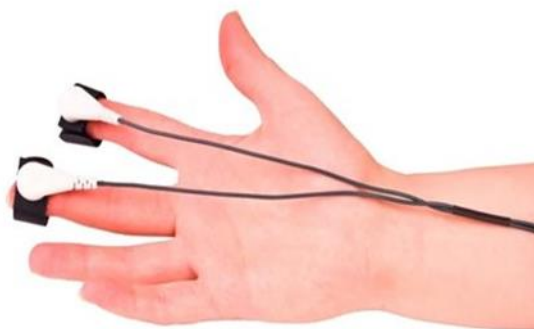
## **Appendix B**

### **Data Collection Device**

- B1 NeXus-10 System with GSR and Heart Rate Monitor
- B2 NASA-TLX
- B3 Demographic Form
- B4 Certified ATC Specialist Subjective Rating Form Air Traffic Control Evaluation
- B5 Consent Form

## Appendix B1

### *NeXus-10 System with GSR and Heart Rate Monitor*





**Appendix B3***Demographic Form*

<b>Demographic Form</b>
Participant Number:
Age:
Gender:



## Appendix B4

### *Certified ATC Specialist Subjective Rating Form*

#### Certified ATC Specialist Subjective Rating Form

##### Air Traffic Control Evaluation

#### Instructions for questions 1 – 21

This form was designed to be used by instructor certified air traffic control specialist to evaluate the effectiveness of controllers working in simulation environments. Observers will rate the effectiveness of controllers in several different performance areas using the scale show below. When making your ratings, please try to use the entire scale range as much as possible. You are encouraged to write down observations and you may make preliminary ratings during the course of the scenario. however, the researchers recommend that you wait until the scenario is finished before making your final ratings. Also, please write down any comments that may improve this evaluation form.

Rating	Label Description
1	Controller demonstrated extremely poor judgment in making intervention decisions and very frequently made errors
2	Controller demonstrated poor judgement in making some intervention decisions and occasionally made errors
3	Controller makes questionable decisions using poor intervention techniques which led to restricting the normal traffic flow
4	Controller demonstrated the ability to keep aircraft separated but used spacing and separation criteria which was excessive
5	Controller demonstrated adequate judgement in making intervention decisions
6	Controller demonstrated good judgement in making intervention decisions using efficient control techniques
7	Controller frequently demonstrated excellent judgement in making intervention decisions using extremely good control techniques
8	Controller always demonstrated excellent judgement in making even the most difficult intervention decisions while using outstanding control techniques

Maintaining Safe and Efficient Traffic Flow

1. Maintaining Separation and Resolving Potential Conflicts	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>• using control instructions that maintain safe aircraft separation</li> <li>• detecting and resolving impending conflicts early</li> </ul> <b>Comments:</b>								
2. Using Separation Interventions Effectively	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>• providing accurate navigational assistance to pilots</li> <li>• avoiding interventions that result in the need for additional instructions to handle aircraft completely</li> <li>• avoiding excessive vectoring or over-controlling</li> </ul> <b>Comments:</b>								
3. Overall Safe and Efficient Traffic Flow Scale Rating	1	2	3	4	5	6	7	8
<b>Comments:</b>								

Maintaining Attention and Situation Awareness

4. Maintaining Awareness of Aircraft Positions	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>• avoiding fixation on one area of the radar scope when other areas need attention</li> <li>• using scanning patterns that monitor all aircraft on the radar scope</li> </ul> <b>Comments:</b>								
5. Identifying Traffic Conflict Problems in a Timely Manner	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>• keeping up with traffic trajectories</li> <li>• protecting separation problems in a timely manner</li> <li>• avoiding excessive vectoring or over-controlling</li> </ul> <b>Comments:</b>								
6. Correcting Own Errors in a Timely Manner	1	2	3	4	5	6	7	8
<b>Comments:</b>								
7. Overall Attention and Situation Awareness Scale Rating	1	2	3	4	5	6	7	8
<b>Comments:</b>								

Prioritizing

8. Taking Actions in an Appropriate Order of Importance	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>resolving situations that need immediate attention before handling low priority tasks</li> <li>issuing control instructions in a prioritized, structured, and timely manner</li> </ul> <b>Comments:</b>								
9. Handling Tasks for Several Aircraft	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>shifting control tasks between aircraft when necessary</li> <li>avoiding delays in communications while thinking or planning actions</li> </ul> <b>Comments:</b>								
10. Marking Flight Strips while Performing Other Tasks	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>marking flight strips accurately while taking or performing other tasks</li> <li>keeping flight strips current</li> </ul> <b>Comments:</b>								
11. Overall Prioritizing Scale Rating	1	2	3	4	5	6	7	8
<b>Comments:</b>								

Providing Control Information

12. Providing Essential Air Traffic Control Information	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>providing mandatory services and advisories to pilots in a timely manner</li> <li>exchanging essential information</li> </ul> <b>Comments:</b>								
13. Providing Additional Air Traffic Control Information	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>providing additional services when workload is not a factor</li> <li>exchanging additional information</li> </ul> <b>Comments:</b>								
14. Overall Providing Control Information Scale Rating	1	2	3	4	5	6	7	8
<b>Comments:</b>								

Technical Knowledge

15. Showing Knowledge of LOAs and SOPs	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>controlling traffic as depicted in current LOAs and SOPs</li> <li>performing hand-off procedures correctly</li> </ul> <b>Comments:</b>								
16. Showing Knowledge of Aircraft Capabilities and Limitations	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>avoiding advisories that are beyond aircraft performance parameters</li> <li>recognizing the need for speed restrictions and wake turbulence separation</li> </ul> <b>Comments:</b>								
17. Overall Technical Knowledge Scale Rating	1	2	3	4	5	6	7	8
<b>Comments:</b>								

Communicating

18. Using Proper Phraseology	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>using words and phrases specified in JO 7110.65</li> <li>using phraseology that is appropriate for the situation</li> <li>avoiding the use of excessive verbiage</li> </ul> <b>Comments:</b>								
19. Communicating Clearly and Efficiently	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>speaking at the proper volume and rate for pilots to understand</li> <li>speaking fluently while scanning or performing other tasks</li> <li>communication delivery is complete, correct and timely</li> <li>providing complete information in each communication</li> </ul> <b>Comments:</b>								
20. Listening to Pilot Readbacks and Requests	1	2	3	4	5	6	7	8
<ul style="list-style-type: none"> <li>correcting pilot readback errors</li> <li>processing pilot requests correctly in a timely manner</li> </ul> <b>Comments:</b>								
21. Overall Communicating Scale Rating	1	2	3	4	5	6	7	8
<b>Comments:</b>								

## Instructions for questions 22 – 29

The following questions have a scale ranging from 1 to 10. Where 1 represents “extremely low”, “extremely infrequent”, “strong disagree”, etc. and 10 represents the other extreme of the spectrum.

These questions are the same as the researcher has asked the controller after the scenario. the researcher would like you to show your impression of how these questions will be rated by the controllers.

<p>22. Please circle the number below that best describes <b>how hard the controller was working</b> during this scenario.</p> <p style="text-align: center;">not hard 1 2 3 4 5 6 7 8 9 10 extremely hard</p> <p><b>Comments:</b></p>
--

<p>23. Please circle the number below that best describes <b>how well the controller managed traffic</b> during this scenario.</p> <p style="text-align: center;">extremely poor 1 2 3 4 5 6 7 8 9 10 extremely well</p> <p><b>Comments:</b></p>
--

## NASA-TLX

24. Please circle the number that describes the <b>mental demand</b> during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
25. Please circle the number that describes the <b>physical demand</b> during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
26. Please circle the number that describes The <b>temporal demand</b> during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
27. Please circle the number that describes overall <b>performance</b> during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
28. Please circle the number that describes the <b>effort</b> during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high
29. Please circle the number that describes the level of <b>frustration</b> during this scenario.	extremely low	1	2	3	4	5	6	7	8	9	10	extremely high



## Appendix B5

### *Consent Form*

#### INFORMED CONSENT FORM

##### *Assessment of Air Traffic Controllers' Occupational Stress and Performance in the Future Air Traffic Management*

**Purpose of this Research:** You are invited to participate in a research project for the purpose of examining air traffic controllers' stress and performance during daily work. During this study, you will be asked to coordinate air traffic in three ATC scenarios on a simulator. While you coordinate air traffic on the simulator, you will be asked to wear a fingertip heart rate monitor on the index finger of your left hand, as well as two sensor strips that measure galvanic skin response on your middle and ring fingers of your left hand. You will be asked to fill out a demographic questionnaire before you start the simulation. You will also be asked to complete a questionnaire to assess your perceived workload after finishing each ATC scenario. The duration of the experiment will be approximately 70 minutes.

**Eligibility:** To be in this study, you must be 1) at least 18 years old; 2) enrolled in the Air Traffic Management program or have a minor in ATM; 3) have taken or are currently enrolled in AT 405 (En Route Radar Operations).

**Risks or Discomforts:** The risks of participating in this study are minimal. Although the ATC simulator used will be the same as the one that you have been routinely using in your ATM class, there might be a slight possibility that you may experience headache, dizziness, or nausea due to consistently engaging with the radar screen while wearing a mask. If you feel any psychological or physical discomfort that is greater than what you can handle at any time during the experiment, you can request to discontinue or withdraw from the experiment with no penalty. You will be encouraged to contact the ERAU Health clinic at 386-226-7917 or via email [dbhealth@erau.edu](mailto:dbhealth@erau.edu), if necessary. Because of the current pandemic situation, there is a risk of contracting COVID-19. In addition to following the established ERAU university policies, the following cleaning procedures will be conducted prior to and during the research study to mitigate these risks:

- The researcher and participant will be required to wash their hands before each participant and touches nothing between the bathroom and research area.
- The researcher will use a disinfectant wipe to wipe all surfaces that are touched by the participant or researcher prior to and after the study.
- Participants and the researcher will remain socially distanced throughout the study.

**Benefits:** Although there will be no direct benefit to you, your assistance in this study will help us better understand the effects of automation on air traffic controllers' stress levels and performance for maintaining a safe and efficient airspace.

**Confidentiality of Records:** Your responses in all data resulting from this study will be confidential. In order to protect the confidentiality of your responses, each participant will be provided with a random ID for the study. No personal information will be collected other than basic demographic descriptors. Any data collected will be kept in a password-protected file on a password-protected computer or in a locked file cabinet. No one other than the researcher (myself) will have access to any of the responses. Identifiable private information collected as part of this research **will not be used or distributed** for future research studies.

**Compensation:** You will receive \$25 for your participation. If you withdraw from the study prior to completion, you will not be compensated.

**Contact:** If you have any questions or would like additional information about this study, please contact Hui Wang, [wangh3@my.erau.edu](mailto:wangh3@my.erau.edu), or the faculty member overseeing this project, Dr. Andy. Dattel, [andy.dattel@erau.edu](mailto:andy.dattel@erau.edu). For any concerns or questions as a participant in this research, contact the Institutional Review Board (IRB) at 386-226-7179 or via email [teri.gabriel@erau.edu](mailto:teri.gabriel@erau.edu).

**Voluntary Participation:** Your participation in this study is completely voluntary. You may discontinue or withdraw from the experiment at any time or refuse to answer any question that you may feel uncomfortable answering without any penalty. If you decide to discontinue your participation, any information or data collected will not be used for analysis and the data will be purged.

**CONSENT.** I have read and understand the above information, asked any questions I might have about this research study. By signing my name below, I consent to participate in the study.

A copy of this form can also be requested from Hui Wang, [wangh3@my.erau.edu](mailto:wangh3@my.erau.edu).

Signature of Participant: \_\_\_\_\_

Date: \_\_\_\_\_

Signature of Researcher: \_\_\_\_\_

Date: \_\_\_\_\_

## Appendix C

### Figures

C1 I-SIM Simulation System at ERAU



**Figure C1**

*I-SIM Simulation System*

