EMBRY-RIDDLE
Aeronautical University™
SCHOLARLY COMMONS

Dissertations and Theses

Fall 2011

Integration of Unmanned Aerial Systems in Class E Airspace: The Effect on Air Traffic Controller Workload

Jeeja S. Vengal
Embry-Riddle Aeronautical University - Daytona Beach

Follow this and additional works at: https://commons.erau.edu/edt

🔾 Part of the Aviation Safety and Security Commons, and the Multi-Vehicle Systems and Air Traffic Control Commons

Integration of Unmanned Aerial Systems in Class E Airspace:
The Effect on Air Traffic Controller Workload

by

JEEJA S. VENGAL
B.S., Purdue University, 2004

A Thesis Submitted to the
Department of Human Factors & Systems
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Human Factors & Systems

Embry-Riddle Aeronautical University
Daytona Beach, Florida
Fall 2011

Integration of Unmanned Aerial Systems in the
National Air Space:
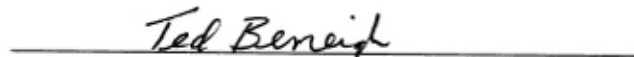The Effect on Air Traffic Controller Workload

by

Jeeja S. Vengal

This thesis was prepared under the direction of the candidate's thesis committee chair, Shawn Doherty, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

THESIS COMMITTEE

_____
Shawn Doherty, Ph.D., Chair

_____
Dahai Liu, Ph.D., Member

_____
Ted Beneigh, Ph.D., Member

_____
MS HFS Program Coordinator

_____
Department Chair, Department of Human Factors & Systems

_____ 12/12/11
Associate Vice President for Academics

ii

ABSTRACT

As technology rapidly advances and our imagination is no longer fantasy but instead reality, the aviation community needs to concentrate on the harsh truth of airspace safety. In the situation of integrating unmanned aerial systems (UASs) into the National airspace, UASs outside of terminal areas would generally be permitted to fly their preferred routes, and self-separate, with minimal intervention from air traffic control. From an air traffic control perspective, the integration could raise a number of human performance problems including workload extremes and passive-monitoring demands. One fundamental requirement for operation in the National Air Space is to preserve the safety of the general public. This paper describes an experimental evaluation of the effect different levels of UAS intent information has on air traffic controller workload. The simulation specifically manipulates intent sharing, that is, whether unmanned aerial vehicles provided advance notice of their intended maneuvers. The Effects on air traffic controller workload when control capability is altered were also explored.

Table of Contents

List of Figures

List of Acronyms

ADS-B: Automatic Dependent Surveillance- Broadcast

ARTCC: Air Route Traffic Control Center

ATC: Air Traffic Control

ATCo: Air Traffic Controller

CFIT: Controlled Flight into Terrain

ERAU-ATM: Embry Riddle Aeronautical University – Air Traffic Management

FAA: Federal Aviation Administration

IAF: Instrument Approach Fix

ISA: Instantaneous Self Assessment -- Instantaneous self-assessment

NARI: National Aviation Research Institute.

NAS: National Air Space

NASA: National Aeronautics and Space Administration

NASA TLX: NASA Task Load Index

NOAA: National Oceanic and Atmospheric Administration

SWAT: Subjective Workload Assessment Technique

TRACON: Terminal Radar Approach Control

UAS: Unmanned Aerial System

Introduction

   As technology rapidly advances and our imagination grazes closer and closer to reality, the aviation community needs to concentrate on the truth of airspace safety. The history of unmanned aircraft started soon after the first manned flight. Efforts to merge the novel technologies of aerodynamics, light-weight engines, and radios resulted in live experiments of unmanned aircraft on both the European and North American continents (Kumar, 1997). During the early days of aviation, the numbers of aircraft populating the skies rapidly increased, leading to a need for ground-based control of aircraft. In 1926, the United States developed its own set of air traffic rules after the passage of the Air Commerce Act (Komons, 1978). This legislation authorized the Department of Commerce to establish a set of common sense air traffic rules and provided for the registration, certification, and inspection of aircraft and the licensing of pilots and aviation mechanics (Komons, 1978). These regulations laid down rules for the navigation, protection, and identification of aircraft, including rules as to safe altitudes of flight and rules for the prevention of collisions between aircraft. The Air Commerce Act of 1926 introduced the basis of what is known today as Air Traffic Control (ATC). As traffic increased, revisions were made so that general rules were more stringent to prevent the increasing numbers of collisions. To date, the safety of our airspace relies on our air traffic controllers (ATCos), their mission being to maintain safe separation of all aircraft. For several years, Unmanned Aircraft Systems (UASs) involving flying vehicles without pilots present have been in our skies but have not proven to be a huge concern. As time passes, the curiosity and infatuation of UASs will grow due to their recent military

deployment successes and will raise awareness of UASs and verify their operational potential.

Currently, there are an ever-increasing number of UASs present in controlled airspace. Although unmanned aircraft systems have proven beneficial for the United States military, circumstances have arisen in which unmanned aircraft systems have come into conflict with air traffic (Newcome, 2004). This draws huge concern in terms of ATCo workload and overall safety and efficiency of the air traffic system. With UASs in the sky, traffic density increases and the aircraft flight characteristics become even more diverse. The overall dynamics of the airspace makes it difficult for the controller to maneuver other aircraft due to changes in traffic flow and airspace complexity. It has been predicted that increases in traffic complexity will increase the controller's workload (Wickens, Mavor, McGee & Parasuraman, 1997, 1998). Technologies and procedures must be created to harmonize the operation of UASs with the operation of civilian aircraft (Blazakis, 2004). One fundamental requirement for operation in the National Air Space (NAS) is to preserve the safety of the general public, since, it is the responsibility of ATCos to maintain safe separation of aircraft, they cannot be bombarded by additional tasks which could adversely affect the NAS. To ensure this safety, specifically, the impact of the integration of UAS in the NAS on air traffic controller workload needs to be thoroughly investigated.

Pressures from military operations and the UAS industry have increased to incorporate unmanned aircraft systems into controlled airspace (Newcome, 2004). However, it is important to transport these systems through the national airspace system safely and efficiently. To guarantee safety of the general public, it is essential to

recognize the influence alterations in system procedures can have on the operators of that specific system. This proactive approach leads to the development of procedures, which maximize system benefits (in terms of safety and cost), yet sustain minimal physical and mental responsibility for the controller (Pawlak, Brinton, Crouch & Lancaster, 1996). Additionally, it is imperative to provide the ATCos with more reliable and powerful equipment than ever before to ensure successful air space control and flow. In particular, to maintain current air traffic management standards the aviation industry needs to determine how to keep air traffic controller workload to a minimum and make sure the addition of UASs does not considerably affect their level of workload. The overall design of the new control system for the human operator should take into consideration human strengths and vulnerabilities. The identification of these strengths and weaknesses will indicate the appropriate equipment necessary to facilitate safe and efficient integration of UASs into the NAS.

Therefore, the implications of UAS intent information on ATC workload should be examined based upon the requirement to operate at an equivalent level of safety, as defined by the Federal Aviation Administration (FAA). The availability of intent information is when the ATCo is informed of the proposed direction of the aircraft. The purpose of this paper is to identify the effects of the integration of UASs on ATC when manipulating UAS intent information and ATC control capabilities.

Unmanned aerial systems

"The NAS is expected to change significantly over the next 16 years with the introductions of new technologies and procedures. Many of these changes will be motivated by increasing demand in the number and diversity of systems users, including

the addition of unmanned aerial vehicles" (DeGarmo, Nelson, 2004). The aviation community must be prepared for these changes. UASs (a term created by the US Military) are the latest generation of pilotless aircraft employing the most sophisticated remote control technology on the planet. 'Pilotless' can imply a remotely located pilot or no pilot at all, as the system is entirely self-autonomous (United States Department of Defense, 2001). Taken literally, UAS could describe nearly anything from kites, radio-controlled aircraft, to cruise missiles, so it's imperative to note the distinction between unmanned aircraft systems (UASs) and unmanned aerial vehicles (UAVs). In relation to the military, the term UAS is confined to reusable 'heavier-than-air' machines. The term unmanned aircraft system includes the entire weapon system that the Department of Defense has historically referred to as UAVs. In general, the terms UAS and UAV can be used synonomously, however the term UAS is more common than UAV (Weatherington, 2005). Unmanned aircraft systems are, in essence, remote-controlled aircraft, but are different and more sophisticated (United States Department of Defense, 2001). Interest in such machines has grown within the higher priorities of the US military, as they offer the possibility of cheaper weapons with great strike potential that can be used without risk to aircrews. Although these vehicles are unmanned, there is still an operator responsible for the flight of these systems. The operator's responsibility is to define destination points in the sky, while the system autonomously decides how to change and dynamically adjust its flight profile in-flight to get to those points.

While the predominance of UASs have been confined to military use in recent years, UASs also fill a vital and emergent role in the civilian aviation industry. Many jobs being performed by manned aircraft are dangerous, tedious, physically demanding or

incredibly expensive. "It has been estimated that over the past five years, on average, eight deaths have occurred annually in the geophysical survey industry, where pilots fly their instrumented aircraft over long routes, close to the ground, and over severe terrain" (Bargainer, Knuppel & Ogden, 2000). In many of these low altitude scenarios, the outcome is ultimately crashing into the low terrain. This type of accident is termed Controlled Flight Into Terrain (CFIT), thus in the majority of cases no mechanical failures cause the crash. These jobs, which entail such strenuous and complicated maneuvers, which lead to CFIT accidents, can be replaced with UASs as opposed to piloted aircraft. UASs eliminate the threat of death and/or harm to any pilot, as none are physically required to be present. UASs give researchers the ability to obtain information in dangerous regions or go places that man is physically incapable of going. For example, an UAS was an invaluable asset during Hurricane Ophelia, a storm that formed off the East Coast of the United States for several weeks in 2005. The National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and Aerosonde North America collaborated and ventured on an unprecedented mission in hurricane surveillance history. On September 16 an unmanned aircraft flew into winds over 80 mph. "The aircraft, known as an Aerosonde, provided the first ever detailed observations of the near-surface, high wind hurricane environment, and an area often too dangerous for manned aircraft to observe directly" (Koehler, 2005). The observations taken by UASs made unknown information about hurricanes accessible to researchers and may lead to due diligence for future natural disasters. In addition, the development and use of UASs will enhance current methods of reconnaissance for the United States government in several departments, such as The Department of Homeland

Security (DHS) and The Department of Transportation (DoT). The UASs are capable of such roles as border security, coast guard and maritime missions, transportation security and protection of critical infrastructure (Weatherington, 2005). Therefore, the use of UASs is beneficial and a solution which can reduce the number of accidents and negative incidents within the aviation industry.

However, the benefits of UAS use draw a subsidiary concern. The wide range of military UASs in controlled airspace threaten safety worldwide, as Air Traffic Control has magnified the issue of UASs in controlled airspace. This concern was first raised when UASs caused severe air traffic control problems in Bosnia and Kosovo due to that country's primitive altitude sensing system. The mishap occurred because the UASs that were flying in European airspace did not supply air traffic controllers with sufficient positioning information. This information is becoming particularly important in Europe as larger UASs are introduced to the military, multiplying air traffic, and in turn crowding available air space. Furthermore, the limitations on other equipment designed within the UAS have made it difficult to work safely within civilian airspace (Butterworth-Hayes, 2001). More specifically, the Globalhawk (a type of UAS) requires a variety of levels of airspace to perform its duties. The dynamic in airspace, when a UAS is present, makes it difficult for air traffic controllers to safely organize the airspace. A typical UAS climbs at an extremely slow rate in comparison to civilian aircraft, and a slow moving UAS across the sky is an obstacle that ATC has to direct traffic around (McCarley & Wickens, 2005). In view of that fact, a focus on the UAS ascent and descent will identify ATC human factors related aspects. The incursions in civilian controlled airspace due to uninhabited vehicles in Europe have shown that more awareness of how to incorporate

UASs in the NAS safely is essential in this sector of aviation. There is a justified need for UASs; however, there is an even greater need to incorporate this futuristic technology safely. Specifically, the aviation industry needs to look at UAS equipment and the authority of air traffic control, which will have an effect on overall cohesiveness in civilian airspace. UAS equipment can vary depending on the type of UAS in question. Each UAS has distinctive specifications and abilities, and it is vital to decipher these differences among the myriad types of UASs to choose the specific vehicles for this study.

Types of unmanned aerial systems. It is important to distinguish that the label "Unmanned aircraft systems" can be applied to an expansive range of vehicle types, configurations and sizes. The slow pace and long haul characteristics of UASs are the features that trigger the Federal Aviation Administration's curiosity of their effects on systematically coordinating the controlled airspace. This wide spectrum of vehicles is illustrated in Appendix A, where several current UASs are pictured, along with their locations on a logarithmic mass scale (Weibel & Hansman, 2004).

The Predator and Global Hawk are examples of unmanned aircraft systems that are most regularly used within the NAS. The most commonly used UAS in the United States military is the Predator because of its small size. The Predator weighs about as much as a small private airplane, such as a Cessna 172 (Sweetman, 1997-2005). The Predator is a medium-altitude UAS that has long endurance and broad coverage area. It has been used operationally since 1994 and has been deployed continuously providing assistance during the ordeals in Kosovo. It cruises at speeds of 100 to 200 knots, at an altitude up to 26,000 feet and can go on missions as long as 24 hours (DoD Press Brief,

2001). Furthermore, the Predator can take off and land by the hardware and software built within. The largest UAS in use today is the Global Hawk. Similar to the Predator, the Global Hawk is a high-altitude system and is preprogrammed for destinations. With one command the UAS can take off, perform its mission and return and land accurately without further human intervention. The main concern lies in accountability of the remote pilot in receiving and returning messages from ATC (Newcome, 2004). It cruises at speeds of 340 knots at altitudes up to 65,000 feet and can go on missions as long as 40 hours (DoD Press Brief, 2001). The specifications of the Predator and Global hawk drastically differ to civilian aircraft. A commercial aircraft can cruise at speeds of up to 460 knots. The choice of UAS to be used in this study is based on altitude, weight and speed. They vary in weight and reach high altitudes, which adequately interfere with normal air traffic similar to that of a real situation.

In general, the command and control of both the Predator and Global Hawk is completed by systems developed by their manufacturer, General Atomics Aeronautical Systems and Northrop Grumman, respectively. The United States Air Force has committed to elevated assembly rates of the Predator and Global Hawk because of its promising operational needs. In turn, the Predator and Global Hawk compared with other UASs will be prominent and have an increased chance of implementation in the NAS, which may affect air traffic control. The heightened demand for these craft has increased interest of the impact they will have in the NAS. There is a growing interest to find ways of allowing UASs and civilian air traffic to peacefully co-exist. However, prior to the intervention of UASs air traffic controllers mastered the method of keeping the NAS safe.

Therefore, it is important to explore the ATC arrangement and the changes that occur on air traffic controllers when UASs enter the equation.

Air Traffic Control

The role of an air traffic controller is extensive, stressful and strategic. The country's air traffic control system is accountable for managing a complete blend of air traffic from commercial, general, corporate, and military aviation. The principal task is to maintain separation between aircraft. Air traffic controllers accomplish this task by using aircraft and airspace information, and other available resources to successfully control and calculate prospective conflicts, which jeopardize this separation. It is the responsibility of the air traffic controllers to keep the airspace safe and efficient. The aviation community still has many obstacles to overcome to assure the growing demand of UASs is met. The existing stress and strain of air traffic controllers needs to be assessed. This investigation will lead to the discovery of regulations and qualifications of unmanned aircraft systems so that a safe and integrated sky can exist. The goal is to bring insight of what is necessary so that air traffic controller workload is minimized.

Intent Information.

For the purpose of this study, intent information can be more specifically defined as automatic dependent surveillance–broadcast (ADS-B+) information provided to the controller. As defined by the Federal Aviation Administration, ADS-B+ is when aircraft (or other vehicles or obstacles) broadcast a message on a regular basis, which includes their position (such as latitude, longitude and altitude), velocity, and possibly other information. This broadcasted information is then relayed to ATCo so that they know precise locations and future intents of aircraft within their airspace. Other aircraft or

systems can also receive this information for use in a wide variety of applications. This study attempts to examine some of the human performance parameters (workload) that may be associated with or without representation of ADS-B+ information. Under the conditions in which there is an absence of ADS-B+ the controller will no longer know the exact route that an UAS is expected to follow. Adding any variable to the ATC environment could have an effect on overall observable and perceived workload (Wilson & Flemming, 2002). However, adding unmanned aircraft systems; that can make unanticipated maneuvers, create a variable the air traffic controller may not have any control over and therefore could significantly affect each of the mental processes of workload. The absence of intent information establishes uncertainty for the ATCo. Therefore the ATCo will need to interrogate the UAS controller to obtain sufficient information to manage the controlled airspace safely. Furthermore, if the ATCo wants to mitigate this physical workload of interrogation by taking control of the UAS, supplementary physical tasks would develop. The supplementary tasks include physical manipulations to trajectory change points or flight levels. The amount of intent information can either help or hinder ATC workload. If there is more sharing of UAS intent information the better the trajectory model of the aircraft is for the ATCo. Thus, there will be less communication and data entry tasks (physical) for the controller when rearranging the airspace. On the contrary, reliance on intent information can also lead to false conflict anticipations, mainly if trying to anticipate conflicts more than a few minutes into the future (Yang & Kuchar, 1997).

In addition, the level of difficulty to control traffic, which includes UASs with no ADS-B+, will most likely increase because the ATCo cannot predict UAS maneuvers.

An investigation of ADS-B+ will lead to the understanding of the effects on ATCo workload; however, this study will also investigate the affect on ATCo workload when there are manipulations to action implementation. Basically, the effect when ATCo only has the ability to control civilian aircraft and there are uncontrolled aircraft in the NAS.

Action implementation.

Action implementation can appropriately be defined as the physical action of "control" in terms of the ATCo. The implementation of action denotes the ATCo has the ability to take control of the UAS. The opposite holds true as well, when there is an absence of the ability to implement action the ATCo cannot take control of the UAS. When the air traffic controller has the ability to overtake the UAS they will and that is due to the fact that they will have the ability to maneuver aircraft around the system without hesitation. This is reaffirmed by the notion that when aircraft appear to be in conflict it is much simpler for the ATCo to take control of the UAS and rearrange the airspace rather than have extensive communication with the UAS controller to inquire on their flight path and objective. This issue can only be examined meticulously with proper test measures. The variables; change in intent information and change in control capability need to be measured accurately. Furthermore, since the overall task of the controller is dynamic the individual is undergoing several mental processes continuously because they have to be vigilant to numerous aircraft. The continuous vigilance leads to the phenomenon that occurs when the ATCo is processing multiple tasks. The processing of multiple tasks can be better understood by defining dual task performance and single resource theory. Therefore, it is important to analyze the current mental and physical processes ATCos experience.

Single Resource Theory

Humans are thought to process information via a single mode (Craik, 1947), a theory that specifies that each person has a narrow processing capacity, with the mechanisms required to perform tasks and mental activities in one band of resources (Moray, 1967). This capacity could be dispersed in considerable amounts to various activities depending on their difficulty or demand for resources. This concept emphasizes the flexible characteristic of attention or processing resources, as all tasks and mental activities share the same resources. Task demands increase either by making the elements of the task more difficult or by imposing additional responsibilities (DiDomenico, 2003). Thus, as task demands increase, the available resources may be insufficient in balancing the additional resource demands. Consequently, limited resources coincide with decreased task performance or increase in workload. The most favorable situation is during single-task performance when all resources are devoted to one task. Performing simultaneous tasks redirects resources from the original task to another task and possibly degrades task performance. The variation in performance or workload is determined by both the characteristics of the original task and any additional task (DiDomenico, 2003). A task is data-limited if performance is maximized by the quality of the data, not by the resources used (DiDomenico, 2003). On the other hand, if performance is distorted with added or depleted resources, the task is resource-limited (DiDomenico, 2003). This and similar theories assume that individuals have the ability to adapt during multiple task situations and allocate resources between tasks. Investigations of situations requiring the completion of parallel tasks have acknowledged limitations to single-resource theory. The resources required to perform a task are

partially determined by the difficulty of the task. Additional resources are required for tasks of greater difficulty performed at the same level of efficiency. However, interference between tasks is not merely determined by the difficulty of the tasks, but by their composition (Wickens, 1984a).

Individuals have the ability to share their resources on multiple tasks. However, in regards to air traffic control, the tasks of controlling the airspace all use the same resources (Wickens, 1984). In regards to the study, there is no distinction of resources when directing a UAS or civil aircraft. However, as explained previously the performance of the workload will be affected if task demands are more difficult. The following study varies the task demands by the changes the availability of UAS intent information and ability to control the aircraft. The change in variables may require additional resources or an increase in workload as suggested by the single resource theory. This leads to the hypothesis that workload will increase when there is an absence of intent information. This is due to the limited knowledge of the flight paths of UASs which demand an increase in ATCo resources in order to maintain separation. The understanding of the theories behind an individual's ability to process tasks leads to the discussion of workload management.

Dual Task Performance

Situations involving multi-tasking are to be expected in air traffic control, making the issue of human performance being affected by multiple tasks simultaneously incredibly relevant (Wicken & Gosney, 2003). Dual task performance is defined as occurring when no physical limitations prevent two tasks from concurrent performance yet limitations in cognitive processing still occur. Dual task performance can create a

slowing in reaction times to stimuli in one task when another task is performed simultaneously.

Dual task theory plays a significant role in relation to air traffic control. "Several dual-task and multitask studies have shown that removing a task from the operators control can benefit performance and workload if these requirements are met" (Wickens, Mavor & McGee, 1997). This statement relates to the dual task of ATC overtaking UASs when managing airspace. One aspect of this study concentrates on the effect the ability to take control of UASs has on an ATCo. If the ATCo does not implement action then workload and performance will benefit. This slight decrease in workload and increase in performance is created because all of the ATCo's attention is given to the initial task. Furthermore, additional physical tasks would be eliminated because the controller would not have to decipher and coordinate the UASs flight path. This information cultivates the prediction that workload will decrease when the ATCo does not have the ability to take control of the UAS. Similar to dual task theory, single resource theory can provide an explanation for the mental and physical processes that an ATCo experiences.

Workload

For at least 30 years, researchers have investigated the myriad facets surrounding the relationship between humans and automation. Automation is becoming ubiquitous, appearing in work environments as diverse as medical care, motor vehicle operation and aviation. In essence, it is "technology that actively selects data, transforms information, makes decisions, or controls processes" (Lee & See, 2004). UASs possess these qualities, which introduce human factors concern for ATC trying to maintain separation.

Therefore, a key concern that is often ignored is the human component involved in the system. In aviation, a safety-critical domain, the interaction between humans and automation needs to encompass several qualities to be optimal. By investigating and accommodating the human mental and physical aspects involved within the interaction of automation in UASs and ATC, propositions can be made which will lead the aviation society to a better and more successful system. Currently, the human bears the burden of excessive change, such as increases in ATCo workload.

Workload has been a topic of interest for researchers and psychologist worldwide. Workload is one of the most noteworthy characteristics of the air traffic controller's task (Wickens, Mavor & McGee, 1997). While many factors augment the complexity of an air traffic control situation, the impact of complexity on the controller can be dissected under the requisites of both physical and mental workload. The changes that occur in the airspace due to the addition of UASs can impact the ATCo physically and mentally. A comprehensive analysis of air traffic control workload can only be accomplished if both physical (objective) and mental (subjective) characteristics of demand on a controller are noted (Cardosi & Murphy, 1995). The physical aspect includes elements in the ATC environment which are visible or require physical manipulations that the controller has to perform. On the other hand, mental workload is each controller's individual experience or subjective perception of the demands imposed by the ATC environment. A controller's mental processes are also heavily impacted by increased complexity, therefore the argument is supported that measures of physical processes are not enough in order to fully understand the complexity of ATC (Pawlak, Brinton, Crouch & Lancaster, 1996). Alternatively, mental workload can be defined as the amount of cognitive activity

spent performing such tasks as the evaluating, planning, and monitoring of air traffic control. Mental workload is not directly observable or measurable but must be inferred, based on measures and observations of other elements. Both of these aspects of workload can better be defined by sectioning workload as a whole into its individual processes.

Currently, the air traffic controller's job involves four main processes: planning, implementation, monitoring, and evaluation (Pawlak, Brinton, Crouch, & Lancaster, 1996). It is important to investigate the individual processes to determine the level of mental or physical workload each step entails. Throughout the 'planning' stage, the controller's ideal purpose is to determine the best course of action needed to resolve each traffic conflict. In addition, the controller must also evaluate the impact of that decision on the rest of the system. This stage is a mentally and physically challenging stage. The ATCo is systematically organizing the airspace in manner that is logical for expeditious and safe flow of traffic in the airspace. The ATCo physically inputs changes to aircraft flight parameters (flight level, speed, heading, etc.). The 'implementation' stage, the subsequent stage, is predominately physical although it does require some mental processing. Once the controller has defined the appropriate actions, the plan established in the first stage is implemented through a range of communication and data entry tasks (physical). In addition, prior to physically typing, the controller is thinking about the best manner in which to alter each aircraft (mental). After implementation, the controller must proceed to the third stage of 'monitoring' the scenario to ensure it is in accordance with the plan. The monitoring stage is considered to be predominantly mentally challenging, as it requires the controller to mentally assess whether the pilot has followed

earlier commands. Finally, the air traffic controller enters the last step of workload

processing, the 'evaluation' stage. The ATCo evaluates the effectiveness in resolving the

original conflict. This last step heavily relies on mental workload ability of the

controller. The diagram in Figure 1 is a visual representation of the ongoing mental

processes of an air traffic controller.
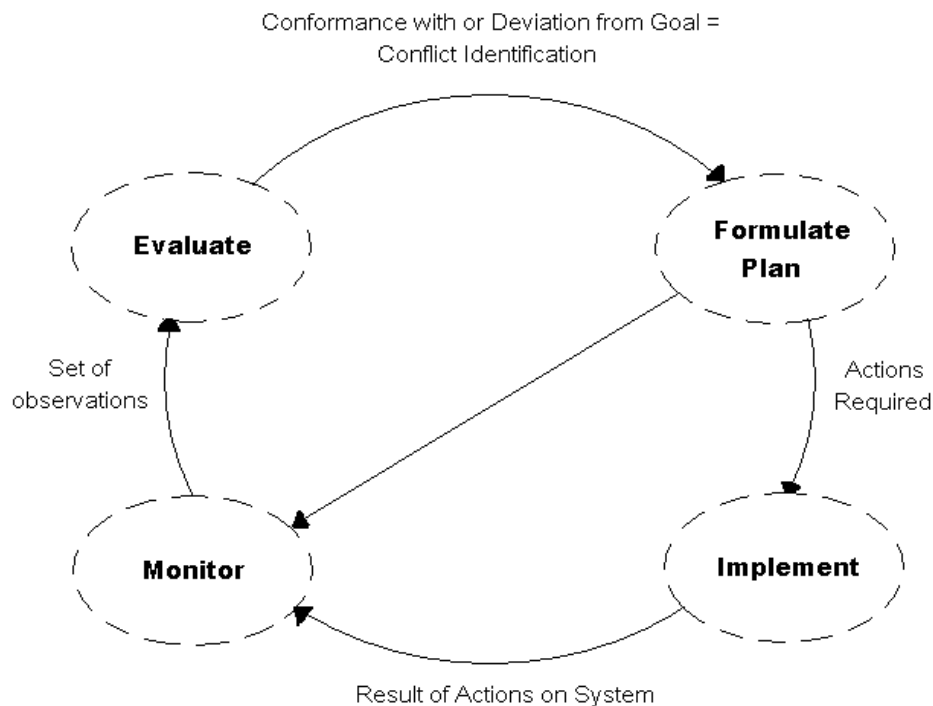
Figure 1. A Model of Air Traffic Control Activity (Pawlak, Brinton, Crouch &

Lancaster, 1996).

Many studies have been conducted to analyze the effect on air traffic control

workload when aircraft outside of terminal areas are free to fly user-preferred routes, and

modify their trajectories enroute, with minimal intervention by air traffic control

(Hilburn, Bakker, Pekela, & Parasuraman, 1997). Similar to the proposed study

researchers evaluated the effect on ATC when aircraft shared their intentions before

maneuvering and scenarios without notification of intent (Hilburn, Bakker, Pekela, & Parasuraman, 1997). The results deemed that under high traffic, controllers felt significantly more workload when they controlled aircraft than they did when they didn't have control and were also uninformed of aircraft intent (Hilburn, Bakker, Pekela, & Parasuraman, 1997). Furthermore, the controllers felt strongly that aircraft intentions should always be available to the controller. The ADS-B+ allows controllers to make better decisions because they have a better understanding of aircraft intentions and where the airspace is free or congested. The ADS-B+ feature in the current study will assist the air traffic controller in predicting confliction points before they occur. Visualization, the process of using a visual mental model, is perhaps the most important cognitive function the controller performs. Visual mental models are what we usually think of when we speak of mental models- we "see" them in our "mind's eye' (Wickens, Mavor, Parasuraman & McGee, 1998). Accordingly, it can be predicted that workload will increase when the ADS-B+ is not made available to ATCo. Furthermore, it can be predicted the controller workload will decrease when the level of UAS intent information is at its highest meaning the ADS-B+ function in present. The lack of knowledge of aircraft intent compels the controller to become more reactive to unnotified changes causing them to overtake the uncontrolled aircraft (Wilson & Flemming, 2002). This leads to the prediction that workload will increase when ATC has the ability to implement action or take control of the UAS. Overall, studies indicate workload reductions are greater for an ATCo when they cannot control the aircraft yet have access to intent information rather than without intent information; that is, shared intent information reduced controllers' indicated workload (Hilburn, Bakker, Pekela, &

Parasuraman, 1997). However, when the controller does have the ability to take control of the aircraft and no intent information, workload will increase. The accurate testing measures provide the proper evidence to verify or invalidate the hypotheses. This leads to the discussion of workload measures.

Workload measures. Seeing as the definition of mental workload is multifaceted, no distinct measurement technique can be expected to account for all the essential features of human mental workload. A variety of methods are available to measure workload based on the distinct approach and practical need in a particular scenario (Tattersall & Foord, 1996). The three board categories of techniques are subjective ratings, performance measures and physiological measures (Damos, 1991). As opposed to physiological and performance measures, subjective measures offer a more simple and succinct method of assessing workload. Well known subjective ratings scales include the subjective workload assessment technique (SWAT), the NASA TLX, and the Modified Cooper-Harper scale, which measure perceived workload after the task is completed (Tattersall & Foord, 1996). Post-event subjective ratings tend to be skewed due to the lapse in time between task completion and reporting task workload. The reduction in stress due to task completion or lapse in time between task completion and workload report may lead to a weaker participant rating of workload, as opposed to workload reported during the simulation.

The following experiment measured workload with the use of an instantaneous self-assessment to measure mental workload. Instantaneous self-assessment (ISA) is a scheme that has been created as a measure of workload to provide immediate subjective ratings of work demands during the performance of primary work tasks. According to

researchers, ISA is found to be consistent with other workload measures. Subjective ratings of the ISA were compared to mean heart rate, heart rate variability, and error in the primary task of tracking in previous studies. Results showed that the ISA was sensitive to the variations in task difficulty, as compared with levels indicated by the physiological measures (Tattersall & Foord, 1996). The fundamental difference of the ISA compared to other methods of workload measures is that it is possible to collect time-based subjective ratings that are more clearly related to changing task demands. Changes in task demand are a key aspect for air traffic controllers throughout the air traffic control process. Thus, the ISA pinpoints high or low workload to its associated task during the simulation (Tattersall & Foord, 1996).

Controller workload in the current study was assessed subjectively by requiring inputs to an Instantaneous Subjective Assessment panel. The subjective information was collected concurrently with an air traffic control task and although this may affect the primary task, it was a better assessment of workload because of its ability to pinpoint workload ratings during an ongoing task, rather than post task subjective ratings (Tattersall & Foord, 1996). The mental workload was quantified subjectively from the ISA. Accordingly, 5 minutes into the exercise and every 5 minutes after that, the controller was prompted to indicate a "workload factor" rating from the ISA on the pop-up on-screen display. Furthermore, it is expected that the ISA did not cause interference. It would only make a significant impact on ATCo performance or workload if the same physical and mental processes required to controlling traffic were the same as those required to answer the ISA. In the scheme of things, the ISA requires minimal effort. The mental effort to answer the question on the panel is insignificant compared to the

mental effort necessary for air traffic separation (Wickens, 1984).   In addition, the ISA is only displayed every 300 seconds, so it is not a constant obstruction.

In combination with the ISA, physical records of the ATCo were recorded with the National Aviation Research Institute (NARI) simulator.   The NARI simulation collected objective data such as the number aircraft in the sector, the response time of controllers to the ISA, the communication time between controllers and pilots, the number of aircraft awaiting handoff, the time each controller took to accept handoffs and the number of separation conflictions. Further information such as trajectory data, losses of separation and observation were also collected. Trajectory data, which is the achieved trajectory of each flight in the simulation, was recorded. This can be used to provide information on the number of interventions and the efficiency of the achieved trajectories. The system recorded exceptions where there were losses of separation providing information on closest aircraft involved in the incident. These, in conjunction with observation, may give some indication of the safety level of that simulation. Controllers were monitored and transmissions were recorded to capture unusual events that my not be seen in the other data. These data can provide an index into air traffic controller physical workload.

By investigating and accommodating to the mental and physical aspects involved within the interaction we can make developments which will lead the aviation society to a better and more successful system. Workload is one of the most noteworthy characteristics of the air traffic controller's task and should be investigated to assess UAS impact on air traffic controller workload.

Statement of Hypotheses

In this report two scales will be utilized: one representing levels of automation that can be applied to the dimension of UAS intent information and the other which is related to the dimension of action implementation. The level of UAS intent information is determined by the presence or absence of automatic dependent surveillance broadcast (ADS-B+) information. The feature displays current path and the trajectory change points of the UAS. The dimension of action implementation is simply if the controller has the ability to take control of UASs in their sector of airspace. In regards to the following study, a complete understanding of the effects of altering UAS intent information and action implementation supplies insight to the make the following hypotheses in relation to the overall affect on ATCo workload:

Hypothesis 1: ATCo workload will increase as the ability to influence UAS control increases. This hypothesis is supported by the fact that a mental process occurs that forces one task to wait for another. In addition, the same resources are needed for the original mental process to control the UAS (single resource theory). Thus, the controller needs to compensate for the relapse via extra mental or physical actions. In addition, this hypothesis is reaffirmed by the notion that when aircraft appears to be in conflict it is much simpler for the ATCo to take control of the UAS and rearrange the airspace rather than have extensive communication with the UAS controller to inquire on their flight path and objective.

Hypothesis 2: ATCo workload will decrease as UAS intent information increases. This hypothesis is supported because the ADS-B+ information allows controllers to make more accurate decisions because they have a better understanding of aircraft intentions

and where the airspace is free or congested. Therefore unnecessary physical manipulation or communication will diminish, in turn, reducing workload.

Hypothesis 3: ATCo workload will be highest when the ATCo has the ability to control the UAS and cannot obtain UAS intent information compared to when the ATCo has the ability to control the UAS and can acquire intent information. This hypothesis is supported for the same reasons as in hypothesis 1. The ATCo will still have to inquire on UAS intent information.

Hypothesis 4: ATCo workload will be lowest when the ATCo does not have the ability to control the UASs and can acquire UAS intent information compared to when the ATCo does not have the ability to control UASs and cannot obtain UAS intent information. This hypothesis is supported because the ATCo will not be tempted to take control of the UASs because they are incapable of doing so. Additionally, the ATCo knows the intentions of the UAS, so they can direct the controlled aircraft appropriately and efficiently as to avoid the UASs.

<div align="center">Method</div>

Participants

The participants used were 10 Embry Riddle Aeronautical University's (ERAU) current air traffic control students. Each of the ATCos were randomly selected from those enrolled in AT300, AT315 or AT400. These three courses were only offered to students once they completed the prerequisites or were in their final year of the ERAU air traffic control program. This assured they had a sufficient knowledge of air traffic control rules and regulations. Using students in their final year eliminated the influence of inexperience on actual ATCo workload. In addition, it was ideal the ATCo

participants had previous experience with the NARI simulation which reduced confusion and the need for training. However, it was necessary to have all participants with the same experience. Therefore, all of the participants must have had NARI experience. This was so that their familiarity with the equipment wasn't considered a confounding variable.

Five male students and six female students volunteered from the ERAU air traffic control courses. Participants had a mean age of 22.54 years, with a range of 19-26 of years. All participants were informed about the experimental procedures and provided written informed consent prior to participation. Several demographic and experience level question were asked. The participants' mean (SD) values for ATC lab time, number of aircraft perceived to equal light workload, and number of air traffic courses taken were 121.36 hours, 17.45 aircraft, and 6 classes out of 8, respectively.

This study also required the use of pseudo pilots to control the aircraft. They are coined 'pseudo' pilots because they followed a script to respond when set conflicts and separation issues occur and therefore do not necessarily have official control of their aircraft. The same pseudo pilots were used for each scenario. The pseudo pilots used were experienced ERAU flight instructors. Using flight instructors was necessary because they were familiar with the airspaces and normal operating procedures and eliminated the need for training. Each pseudo pilot was responsible in this exercise for communicating with the controller and taking instructions from the controller to fly the aircraft. The UASs was controlled by a pseudo pilot to ensure the UASs were not manipulated by the ATCo to do maneuvers the machine was incapable of performing. The trajectory points are previously programmed in. However, the ATCo had the ability

to contact the UAS controller (pseudo-pilot) and change its path. The ATCo would change the path of the UAS by manipulating flight parameters (e.g.trajectory change points, climb descent rate) to reduce the amount of airspace it would have originally consumed. The UAS continued to its intended destination by means of its new flight parameters. This was completed via the parameters of the simulator.

Both the ATC participants and pseudo pilots assisted the study on a voluntary basis. The ATC student participants and ERAU instructor pilots all spoke English. This was asked in order to deter discrepancies due to miscommunication. The ATCo student participants all had passed the core ERAU ATC classes. The ERAU instructor pilots had their FAA certified pilot license and were current with the medical and 24 month flight review.

Apparatus

The NARI simulator created by ERAU- Air Traffic Management (ATM) laboratories, the National Aviation Research Institute (NARI) and National Aeronautics and Space Administration (NASA) was used. The system was designed to allow for rapid prototyping of current and future Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC) operations. This same system is used to simulate the integration of unmanned aerial vehicles in the national air space by researchers at the ERAU- ATM laboratory (Wilson & Flemming, 2002). The experiment consisted of four different scenarios with alteration in the independent variables. During this exercise the controllers controlled traffic in the Ocala sector, as seen in Appendix B. The NARI simulator was designed using the Ocala sector because was the closest sector to ERAU with a busy traffic pattern. Participant familiarity with the Ocala sector did not

adversely affect the following experiment because all ATCos were aware of the locations of the aircraft destination fixes. Destination fixes inform the controller of the aircraft's ultimate destination. Therefore, this knowledge informs the controller of what airspace the craft needs to cross to get to the fix. This increases ATCo prediction accuracy of where aircraft will be located. Traffic arrived and departed different routes from their departure airfields to the arrival fixes and from the Orlando complex airfields to their destinations. Each scenario was 30 minutes long and began with the first 10 minutes as a low traffic sample, increased to high traffic level and then decreased back to low traffic for the last 10 minutes. A low traffic sample consisted of 0-10 aircraft of which 1-3 were UASs and a high traffic sample consisted of 10-20 aircraft of which 4-6 were UASs. Approximately fifteen minutes into the simulation the participants encountered the highest density level of traffic. The traffic then reduced in the last 10 minutes at a comparable rate as it increased in the first 10 minutes. The scenario increased in number of aircraft at a steady metered pace. Figure 2 shows a visual representation of the variations in traffic over time.
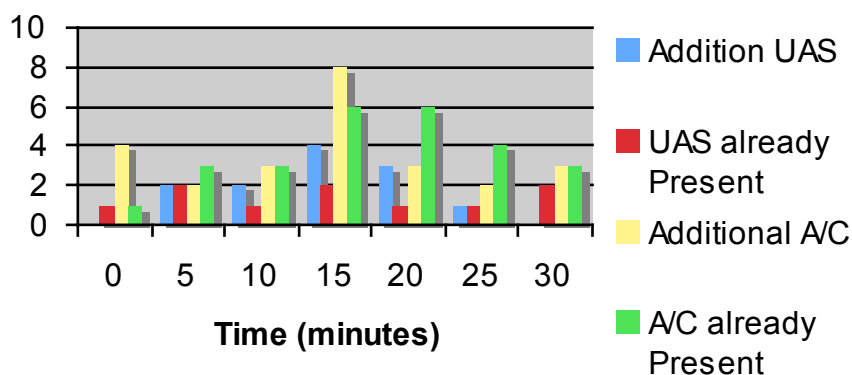
Traffic Flow over Time

Figure 2. Traffic load over time

The density of the scenarios was based off of real traffic samples in Ocala with the only new difference of the introduction of UASs. The mix of traffic consisted of a combination of both civil aircraft and an equal number of the Predator UAS and the GlobalHawks UAS. While, the scenarios were designed to be sufficiently different to mitigate a "learning effect', they were still similar enough such that the main difference between scenarios was the presence of the intent display or ability of control for each individual scenario. In order to accomplish this, the call signs were changed between scenarios and the geometrical relationship between aircraft that were involved in conflicts was altered. The change in call signs has shown to be enough of a modification to eradicate the learning effect (Fleming, Lane & Corker, 2000).   In each of the scenarios the conflicts occurred in different locations of the sector. The unmanned aerial vehicles used in the scenario (Predator and Global Hawk) flew at standard specified UAS speeds (200-400kts) (DoD Press Brief, 2001). The controlled aircraft descended to the Instrument Approach Fixes (IAFs) at their 'preferred' rate. Departing aircraft climbed unrestricted on their preferred routes. The controller had complete regular communication and control of the aircraft accordingly for safe separation. The mix of traffic was thought to be representative of a normal scenario and also provided a particularly challenging traffic mix for controllers (Hopkin, 1995).

Each scenario was equipped with an ISA response box. The purpose of this response box was to establish a workload assessment as seen in Appendix C. It was important for the participants to enter an accurate indicator of their subjective workload, since it was the whole reason for carrying out these tests. Accordingly, 5 minutes into the

exercise and every 5 minutes after, the ISA prompted the ATCo to indicate a "busy-factor" on prepared performance. The ISA was an on-radar-screen Likert Scale which required the subject controller to enter a value ranging from 1 meaning: idle, 2 meaning: low level work, 3 meaning: moderate work level (associated with normal operations), 4 meaning: constantly busy and 5 meaning totally occupied (no more tasks possible). Supplementary workload data was gathered by measuring the length of time taken to enter the workload response. This study collected physical data by an analysis tool, contained in the NARI simulation, which measured sector complexity and the ability of controllers to handle newly designed airspace through controller input and work station analysis. At the end of the exercise the participant filled out a questionnaire about the exercise. The questionnaire acquired post-experiment subjective data. This subjective data included open-ended questions concerning traffic scenarios, conflicts, environment and the experimental scenarios and then followed up with a likert scale question sheet on workload contribution. In addition to the subjective questionnaire a demographic questionnaire collecting information concerning the participants was used.

Design

This experiment was a 2 X 2 within subject, fully factorial design. All the participants were briefed of their responsibilities before the start of the experiment. The independent variables in this study were UAS intent information and UAS action implementation. The first independent variable was the level of UAS intent information or the amount of information provided in the display about the projected path of the UAVs in the air space being controlled, as seen Appendix D. The second independent variable in the study was the level of action implementation or the amount of control the

air traffic controller had over the UAVs in the scenario. Action implementation was

varied at two levels of no control of UAS and control of UAS. Figure 3 is a block

diagram displaying the different levels of the independent variables.

		Intent Information	
		Absence	*Presence*
Action Implementation **(Control)**	*Absence*	Scenario 1	Scenario 2
	Presence	Scenario 3	Scenario 4

Figure 3. Diagram of Independent Variables

UAS intent information had two levels that included the absence of intent

information and the presence of intent information.   This study acquired two dependent

measures, mental and physical workload. Mental workload was assessed via ISA and

physical workload was assessed via the analysis tool contained in the NARI simulator

that included individual components of number of keystrokes, number of controller voice

communication, the number of handoffs, and the length of time for the controller to

respond to the ISA. All of the participants had the same experimental conditions for each

scenario. Therefore each participant was exposed to the same conditions**.**

Procedure

Once the subjects arrived to the lab the purpose of the study was explained to them. The participants were confined to the lab experimental area and were kept unaware of the pseudo pilots as to preserve the notion of the "unmanned pilot' in the case of UASs. Both the participants and pseudo-pilots were provided with a set of instructions, as seen in Appendix E and F. Both the participants and pseudo-pilots were asked to sign a voluntary subject consent form, as seen in Appendix G and H. The participants were asked to answer a demographic questionnaire just to collect background information, as seen in Appendix I. Separately, the participants were briefed on their obligations and all of their questions and concerns were addressed. Albeit, the pseudo pilots served as assistants to the study they were also briefed and given a script to familiarize themselves, to keep singularity for all the participants. The same pseudo pilots were used for all of the scenarios. The ATCo participants were shown the ISA prompt so that they were familiar with the subjective rating scale. Prior to actually beginning the experiment, the participants sat through a scenario, which consisted of the air traffic control sector with no changes to the independent variables. During the experiment each of the participants saw all four scenarios. However, the order in which they were delivered was randomized as to increase the internal validity of the experiment. Each participant ran the ATC scenarios at one time, to eliminate surrounding distraction. Soon after each scenario was completed, the ATCo participant filled out an additional subjective questionnaire, as seen in Appendix J. This was a post experiment subjective analysis, which was used in the case of misunderstandings that result from the actual simulator. The ATCo were asked not to discuss the experiment with other participants

until the testing was done. Contact information regarding the study was also distributed in case the participants were curious of the results.

Data Analysis

Results

This experiment was a 2 X 2 within subject, fully factorial design. The independent variables in this study were UAS intent information and UAS action implementation. Three dependent variables were measured in this study; the instantaneous self-assessment value, the reaction time necessary to respond to the ISA and the number of physical inputs. The workload measures were collected in six different rounds throughout each scenario. The data used in the analysis was taken from the middle of each scenario. Specifically, the measures collected during the third round, which was taken approximately 15 minutes into the simulation where the participants encountered the highest density of level of traffic. The middle portion was selected because if there were to be a difference in performance in the dependent measures it would be most evident at this level of the simulation with high workload activity.

In addition, outliers can occur by chance in any distribution, but they are often indicative of measurement error. The options are to discard them or use statistics that are robust to outliers (Thorne & Giesen, 2003). In this case the removal of anomalous observations from data through outlier detection would be best. The outliers were removed because they were not found to be indicative of normal behavior and thus would have disproportionate influence on the study. Outliers can have negative effects on statistical analyses. First, they commonly contribute to increase error variance and

31

reduce the power of statistical tests. Second, if deliberately distributed they can decrease

normality, altering the odds of making both Type I and Type II errors. Third, they can

bias or influence estimates that may be of practical interest. The presence of outliers can

lead to inflated error rates and substantial distortions of parameter and statistic estimates

when using either parametric or nonparametric tests (Zimmerman, 1994). The outliers

were extracted from the data, which was determined by converting raw data to z-scores,

which transformed the data into distance from the group mean in standard deviation

terms. Any data with a value that exceeded 3 or more standard deviations from the mean

was eliminated and in this study only one outlier was evident in the data. Distinctively,

time to respond to ISA category for one participant was discarded. The remaining means

and Standard Deviations for workload data are depicted in Figure 4.

	D-Variable	Mean	Std. Deviation
Absence of Action and Intent	ISA Value	2.91	.70
	TRISA	3.80	1.99
	Phys	36.91	23.53
Presence of action & Absence of Intent	ISA Value	3.09	1.04
	TRISA	3.55	1.81
	Phys	30.27	20.28
Absence of Action & Presence of Intent	ISA Value	3.09	.83
	TRISA	4.64	2.38
	Phys	28.18	12.24
Presence of Action and Intent	ISA Value	3.09	.83
	TRISA	19.36	26.84
	Phys	41.36	40.38

Figure 4. Descriptive Statistics for Workload Data

The data were analyzed using a two-way repeated measures analysis of variance

(ANOVA) to calculate the effects of intent information and action implementation on Air

traffic controller workload. Effects reported as significant in this experiment met a

criterion of $\alpha \leq .05$.

There was a marginally significant main effect of intent information on reaction time to ISA, $F = 4.87$, $dF = 1$, $p = .055$. An eta^2 of .351 indicated that 35% of variability in reaction time to ISA was caused by the absence or presence of intent information. Observed power was .504. This study found that absence of intent information reduced the time to react to ISA compared to when intent information was present.

There was a non-significant effect of action implementation on reaction time to ISA, $F = 3.56$, $dF = 1$, $p = .092$. An eta^2 of .284 indicated 28% of variability in reaction time to ISA was caused by the ability to implement or not implement action. Observed power was .393. This study found no effects of action implementation on time to react to ISA.

This study found no effects of both intent information and action implementation on time to react to ISA. There was a non- significant effect of the interaction of both intent information and action implementation on reaction time to ISA, $F = 3.207$, $dF = 1$, $p = .107$. An eta^2 of .263 indicated 26% of variability in the reaction time to ISA was caused by the interaction effect. Observed power was .360.

The following graph (figure 5) shows intent vs. action implantation for reaction time to ISA.
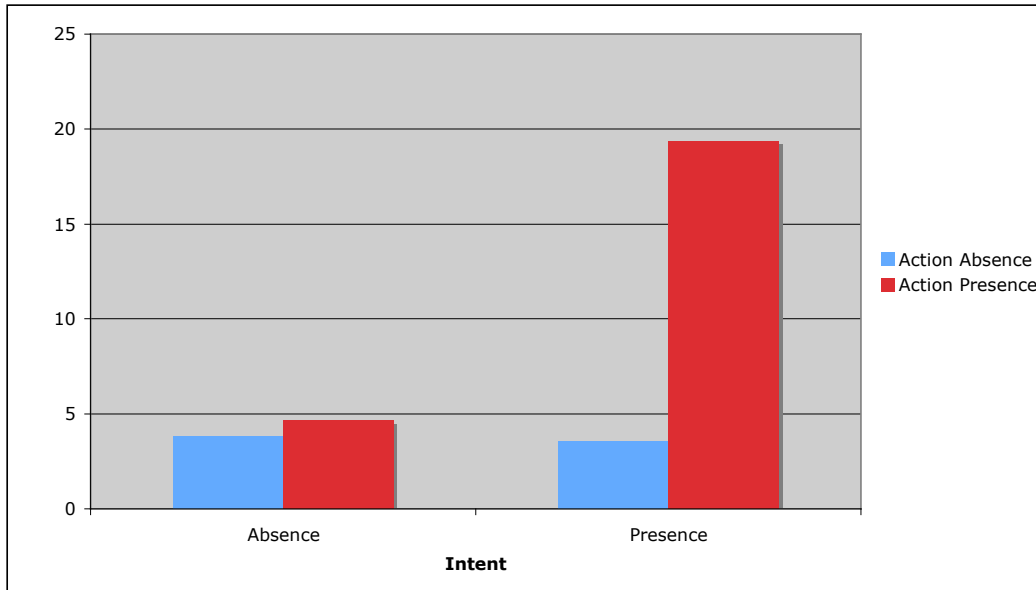
Figure 5. UAS Intent and Control vs. based on Time to react to ISA

There was a non-significant main effect of intent information on ISA value, $F =$ .185, dF = 1, p = .676. An eta^2 of .018 indicated 1.8% of variability in the ISA value was caused by intent information. Observed power was .068. The study found no effects of intent information on ISA value.

This study found no effects of action implementation on ISA value. There was a non-significant effect of action implementation on ISA value, $F = .092$, dF = 1, p = .768. An eta^2 of .009 indicated .9% of variability in the ISA value was caused by action implementation. Observed power was .059.

There was a non-significant effect of the interaction of both intent information and action implementation on ISA value, $F = .102$, dF =1, p = .107. An eta^2 of .010 indicated 1% of variability in the ISA value was caused by the interaction effect. Observed power was .360. This study found no effects of both intent information and action implementation on ISA value.

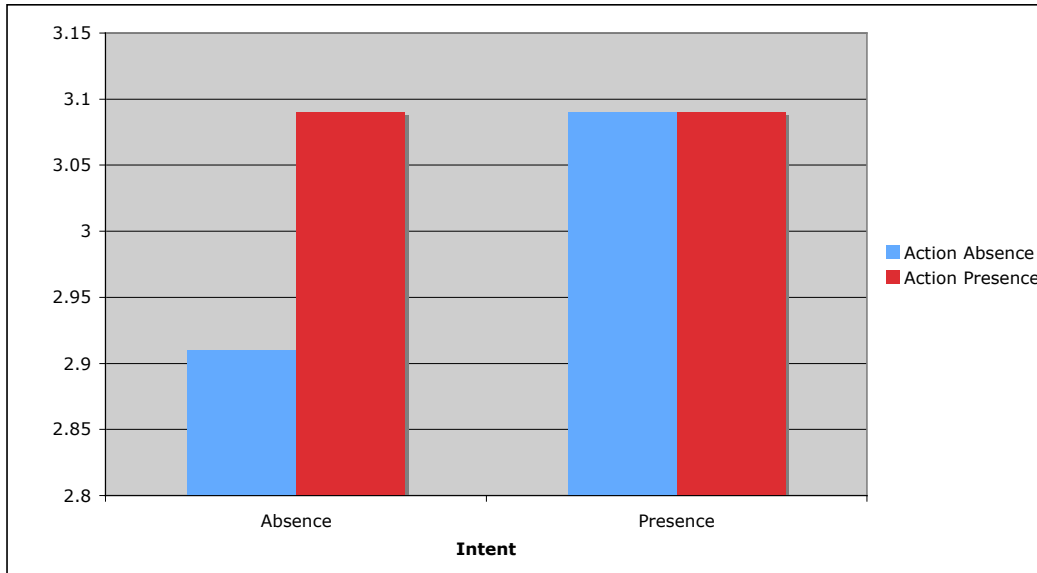Figure 6 shows intent and action implementation for ISA value.

Figure 6. UAS Intent and Control based on ISA Value

This study found no effects of intent information on the number of physical inputs. There

was a non-significant effect of intent information on the number of physical inputs, F =

.032, dF = 1, p = .861. An eta^2 of .003 indicated .3% of variability in the number of

physical inputs was caused by intent information.   Observed power was .053.

There was a non-significant effect of action implementation on the number of

physical inputs, F = .551, dF = 1, p = .475. An eta^2 of .052 indicated 5.2% of variability

in the number of physical inputs was caused by action implementation. Observed power

was .103. This study found no effects of action implementation the number of physical

inputs.

This study found no effects of both intent information and action implementation

on number of physical inputs. There was a non-significant effect of the interaction of

both intent information and action implementation on ISA value, F = 1.29, dF =1, p =

.107. An eta^2 of .114 indicated 1.4% of variability in the number of physical inputs was

caused by the interaction effect. Observed power was .360.

The following graph (Figure 7) shows UAS intent and action implementation based on the number of physical inputs.
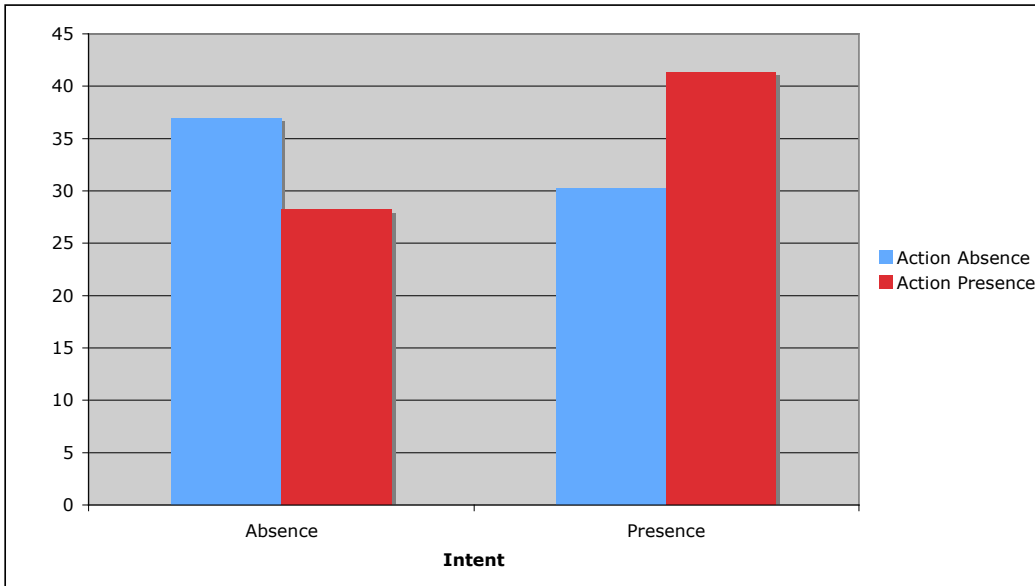

Figure 7. UAS Intent and Control based on the number of physical inputs

Discussion

This study set out to research the effect different levels of UAS intent information had on air traffic controller workload as well as the effect when UAS control capabilities (action implementation) were changed. Past research findings vary regarding the level of UAS intent information and the level of action implementation. The results deemed in most studies under high traffic, which involved both independent variables, was that controllers felt significantly more workload when they controlled aircraft than they did when they didn't have control and were also uninformed of aircraft intent (Hilburn, Bakker, Pekela, & Parasuraman, 1997).

When this study was initiated, the hypothesis was based on the accentuated findings of the literature review. It was hypothesized ATCo workload would increase as the ability to influence UAS control increased and the ATCo does not have intent

information. However, in this study, results did not prove that to be evident. There was no significant difference in workload with the presence of UAS control and the lack of intent information.

Subsequently, it was hypothesized ATCo workload would decrease as the ability to influence UAS control decreased and the intent information increased. However, in this study, results did not prove that to be evident. There was no significant difference in workload with the absence of UAS control and the availability of intent information. None of the dependent measures showed value of significance when altering the independent measures. The lack of significance leads one to ask what the difference was between this study and the aforementioned studies that suggested the line of thought for the first two hypotheses. The most significant difference would be the participants. The skill level of a veteran ATCo versus student controllers presents a varying ability to control aircraft at different workload levels. Thus, the skills or experience level could have caused a difference in the effect of the independent variables on workload. Previous experience would provide the controller hindsight in times of turmoil. Therefore, the controller may perceive a reduced intensity of workload. Vice versus, an amateur controller may show signs of exaggerated perception of workload due to inexperience. Additionally, although the scenario was comprised of aircraft, which constituted moderate to high workload, the number of aircraft may have been underestimated to decipher the slight variation in the independent variables. The final hypothesis, ATCo workload would be lowest when the ATCo would not have the ability to control the UASs but there was a presence of UAS intent information compared to when the ATCo would not have the ability to control UASs but UAS intent information was absent, can

also be argued by the our findings. The results revealed the contrary. The absence of intent information creates less workload based on the time to respond to ISA. The question then arises; how were the participants compensating for the lack of intent information if they were not working harder to decipher intent? This hypothesis can both be disproved by our results, which were found to have a significant effect. There was a significant effect found on time to respond to ISA when there was an absence of intent information and an absence of the ability to control UAS. Workload decreased when there was a presence of both intent information and control. Although our significance didn't satisfy our significance criterion of $\alpha = .05$. It can be supported by our observed power, which proves to be of moderate value. Given that the observed power was only moderate it means that the effect could have been strengthened most likely through increasing the sample size and if that effect were strengthened then the difference would most likely be found.

Perhaps some of the results of this study would have shown differently had we adjusted for some limitations that were not anticipated. Primarily, there was low feedback for workload in all four scenarios. Low feedback constitutes that the majority of workload feedback levels selected by the participants were either average or below average, more specifically a value of 1 (idle), 2 (low) or 3 (moderate). The data collected showed that 33 out of 55 of the ISA responses were idle, low or moderate. One reason behind this could have been exposed had there been a secondary task. The score or involvement of this secondary task would have led to more insight. The participant could have been inundated with mental processes that could not have been determined by the three dependent measures; or on the contrary the participant could have successfully

completed a secondary task. With this in mind, "secondary task methodology should be the most intrusive of the major categories of techniques, since the capacity associated with its uses should be substantial and would overlap temporarily with the demands of the primary task. In fact, secondary task methodology has the potential to suffer not only from such capacity interference, but also from so called peripheral interference, which stems from physical input or output constraints" (Wickens, 1984). Hence, a secondary task could have the ability to target or embellish the perceived levels of workload creating a more accurate depiction of perceived worked due to the influence of the independent variables.

Furthermore, the range of workload response was limited to a 5-point, Likert scale. "Likert scale is also argued to contravene one of the important principles of formulating an instrument: clarity and conciseness. That each Likert scale items measures more than one dimension at a time is considered increasing cognitive complexity, thus elevating measurement error (Hodge & Gillespie, 2003). With this is mind; a 5-point scale may have made it difficult for the participant to pinpoint the exact workload level. Especially, the third point, which participants may be confused for a neutral position and was not a categorical value of workload (ie. high or low). This neutral value may have skewed the data and consequently the results were inconclusive. "Neither agree nor disagree" is confused with "don't know" or "not available" (Raaijmakers et. al., 2000).

Finally, effect of sample size on the power of the study could lead to skewed results. Specifically, the larger the sample sizes the greater the power of the test will be. The reason for this involves one of the properties of the sampling distributions of means:

the larger and larger the sample size the sampling distribution becomes more and more compact (Thorne & Giesen, 2003). Power in all of the results is considered to be of a low value. The sample size was kept to ten participants due to the difficulty in finding fourth year ATC students. Increasing our sample size could have had an effect on the results.

Future research could be quite helpful in findings ways to increase safety and reduce air traffic controller workload. Before we can completely eliminate levels of high workload we must define and establish the factors that increase workload and the perception of workload. For example, there are various applications to measure workload that could be presumably superior methods, but practical considerations limited pursuit of those alternate methods. In addition, as stated earlier, a study incorporating a secondary task may show significance. It compares to reality, in that, air traffic controllers constantly complete secondary duties in addition to their chief responsibilities.

Conclusion

In conclusion, although the results of this study were not as hypothesized, they were quite revealing of not only the mental process that occurs, but also the ability of a human to adapt to change. The introduction of new technologies such as UASs into the NAS may have an unanticipated but fundamental impact on controllers' working methods, strategies, and workload. Since a controller's mental and physical processes are heavily impacted by increased complexity, there is a need to investigate and determine the origin and introduce methods to alleviate increased complexity. Studies such as this one help us to understand more about the impact of UASs on the ATCo workload and will show benefit to future inventions. It is vitally important to take note the effect of the change in airspace dynamics has on ATCo workload to ensure expeditious handling of

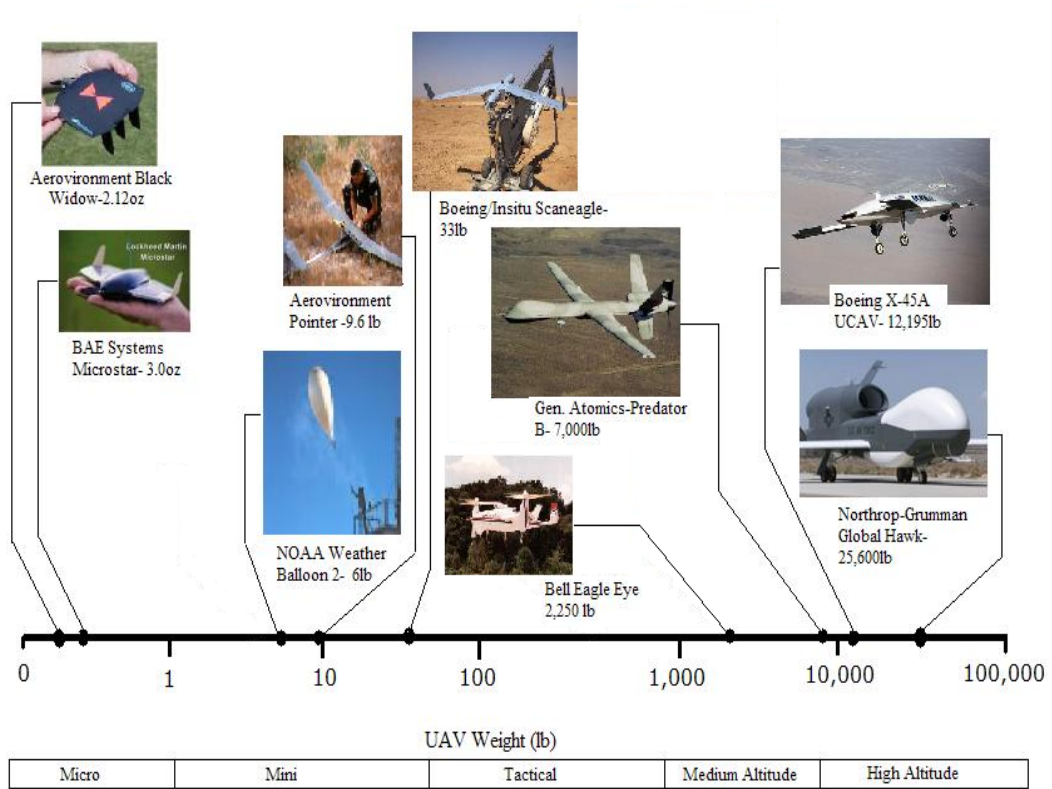aircraft and that safety is never compromised.

References

Bargainer, C.A., Knuppel, R.D., & Ogden, D.A. (2000, Spring). Computers in the sky. *Technology Today*. Retrieved November 8, 2005, from http://www.swri.org/ 3pubs/ttoday/spring00/uav.htm

Blazakis, Jason. (2004). Border security and unmanned aerial vehicles. *Congressional Research Service: The Library of Congress*. CRS Report RS2169

Butterworth-Hayes, P. (2001). Flying Robots causing concern for air traffic controllers, new European project to attempt solutions. *Jane's Airport Review*. Retrieved September 22, 2005, from http://www.janes.com/press/pc010601.shtml.

Cardosi, K.M. & Murphy, E. D. (1995). *Human Factors in the Design and Evaluation of Air Traffic Control Systems.* Springfield, Virginia. Federal Aviation Administration.

Craik, K. W. J. (1947). Theory of the human operator in control systems I: The operator as an engineering system. *British Journal of Psychology*, 38, 56-61.

Damos, D.L. (1991, ed). *Multiple Task Performance*. London, England: Taylor & Francis.

DeGarmo, M., & Nelson, G.M. (2004). Prospective unmanned aerial vehicle operations in the future national airspace system. *American Institute of Aeronautics and Astronautics*, 6243.

DiDomenico, A.T. (2003). *An investigation on subjective assessments of workload and postural stability under conditions of joint mental and physical demands*. Unpublished doctoral dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Fleming, K., Lane, J., & Corker, K. (2003). Measuring controller reactions to free flight in a complex transition sector. Human Automation Integration Laboratory.

Hilburn, B. G., Bakker, M. W. P., Pekela, W. D., & Parasuraman, R. (1997). The effect of free flight on air traffic controller mental workload: Monitoring and system performance. *Proceedings of the 10th International CEAS Conference on Free Flight,* Amsterdam, 14, 1-12.

Hodge, D. R. and Gillespie, D. (2003). 'Phrase Completions: An Alternative to Likert Scales' Social Work Research, 27, 45-55.

Hopkin, V.D. (1995). *Human factors in air traffic control.* Bristol, PA: Taylor & Francis Inc.

Koehler, K. (2005). NASA, NOAA and Aerosonde team up on hurricane observation milestone.   National Aeronautics and Space Administration, Goddard Space Flight Center. Retrieved November 8, 2005, from http://www.nasa.gov/vision/earth/lookingatearth/aerosonde.html

Komons, N, A. (1978). Bonfires *to beacons: Federal Civil Aviation policy under the Air Commerce Act, 1926-1938.* Washington, DC: U.S Department of Transportation & Federal Aviation Administration.

Kumar, R., (1997). Tactical reconnaissance: UAVs versus manned aircraft. Unpublished thesis, the research department Air command and Staff College.

Lee, J.D., & See, K.A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors. 46*, 50-80.

McCarley, J. S., & Wickens, C. D. (2005). Human factors implications of UAVs in the National Airspace. FAA Technical Report AHFD-05-05/FAA-05-01. Savoy, IL.

Moray, N. (1967). Where is attention limited? A survey and a model. *Acta Psychologica*, 27, 84-92.

Newcome, Laurence R. (2004). *Unmanned Aviation: A Brief history of unmanned aerial vehicles.* Reston, Virginia: *American Institute of Aeronautics and Astronautics Inc.*

Pawlak, W.S., Brinton, C.R., Crouch, K., & Lancaster, K.M. (1996). A framework for the evaluation of air traffic control complexity.   *American Institute of Aeronautics and Astronautics*, 3856.

Raaijmakers, Q. A. W., Van Hoof, A., 'T Hart, H., Verbogt, T. F. M. A., and Vollebergh, W. A. M. (2000). Adolescents' Midpoint Reponses on Likert-Type Scale Items: Neutral or Missing Values? *International Journal of Public Opinion Research*, 12, 208-217.

Sweetman, Bill & Editors of Microsoft® Encarta® Online Encyclopedia. (1997-2005). Unmanned Aerial Vehicle. *Encarta Online Encyclopedia.*   Retrieved February 1, 2006 from Encarta Online Encyclopedia on the World Wide Web: http://encarta.msn.com/text_701610394__1/Unmanned_Aerial_Vehicle.html

Tattersall, A.J., Foord, P. S., (1996). An experimental evaluation of instantaneous self-assessment as a measure of workload. *Ergonomics*. 39, 5, 740-748.

Thorne, M.B., Giesen, M.J., (2002). *Statistics for Behavioral Science*. New York: McGraw-Hill.

Weatherington, Dyke. (2005, November). *Unmanned aircraft systems: Roadmap, 2005-2030.* Presented at the 4th Annual Conference on UCAVS & Armed UAVs: Needs Opportunities & Challenges. Washington, D.C.

Weibel, R.E. & Hansman, R.J. (2004). Safety Considerations for Operation of Different Classes of UAVs in the NAS. *American Institute of Aeronautics and Astronautics*, 6421.

Wickens, C. (1984a). *Engineering Psychology and Human Performance*. Columbus, OH: Merrill.

Wickens, C.D. (1984). Processing resources and attention, in R. Parasuraman and R. Davies (eds), Varieties of Attention (Academic Press, New York).

Wickens, C.D., & Gosney, J.L. (2003). Redundancy, modality, and priority in dual task interference. Submission to *Human Factors*.

Wickens, C.D., Mavor, A.S., & McGee, J.P. (1997). *Flight to the future: Human factors in air traffic control.* Washington, DC: National Academy Press.

Wickens, C.D., Mavor, A.S., Parasuraman, R., & Mcgee, J. (1998). The future of Air traffic control: Human operators and automation. Washington, DC: National Academy Press.

Wilson, I., & Flemming, K. (2002) Controller reactions to free flight in a complex transition sector re-visited using ADS-B+. ERAU.

Yang, L.C. & Kuchar, J. (1997). Prototype conflict alerting logic for free flight. *American Institute of Aeronautics and Astronautics*, 0220.

UAVs: DoD Press briefing October 31, 2001. Predator UAV (Air Force).

UAVs: DoD Press briefing October 31, 2001. Global Hawk (Air Force).

United States Department of Defense. (2001). Background Briefing on unmanned aerial vehicles. Washington, DC: The Pentagon. Retrieved September 22, 2005 from http://www.defenselink.mil/transcripts/2001/t11012001_t1031uav.html

United States Department of Defense. (2001). *Dictionary of military and associated terms*, Joint Publication. 1-02.

Zimmerman, D. W. (1994). A note on the influence of outliers on parametric and nonparametric tests. *Journal of General Psychology*, 121(4), 391-401.

APPENDIX A

Spectrum of Current Unmanned aircraft systems

Aerovironment Black Widow- 2.12oz

BAE Systems Microstar- 3.0oz

Aerovironment Pointer -9.6 lb

NOAA Weather Balloon 2- 6lb

Boeing/Insitu Scaneagle- 33lb

Gen. Atomics-Predator B- 7,000lb

Bell Eagle Eye 2,250 lb

Boeing X-45A UCAV- 12,195lb

Northrop-Grumman Global Hawk- 25,600lb

| 0 | 1 | 10 | 100 | 1,000 | 10,000 | 100,000 |

UAV Weight (lb)

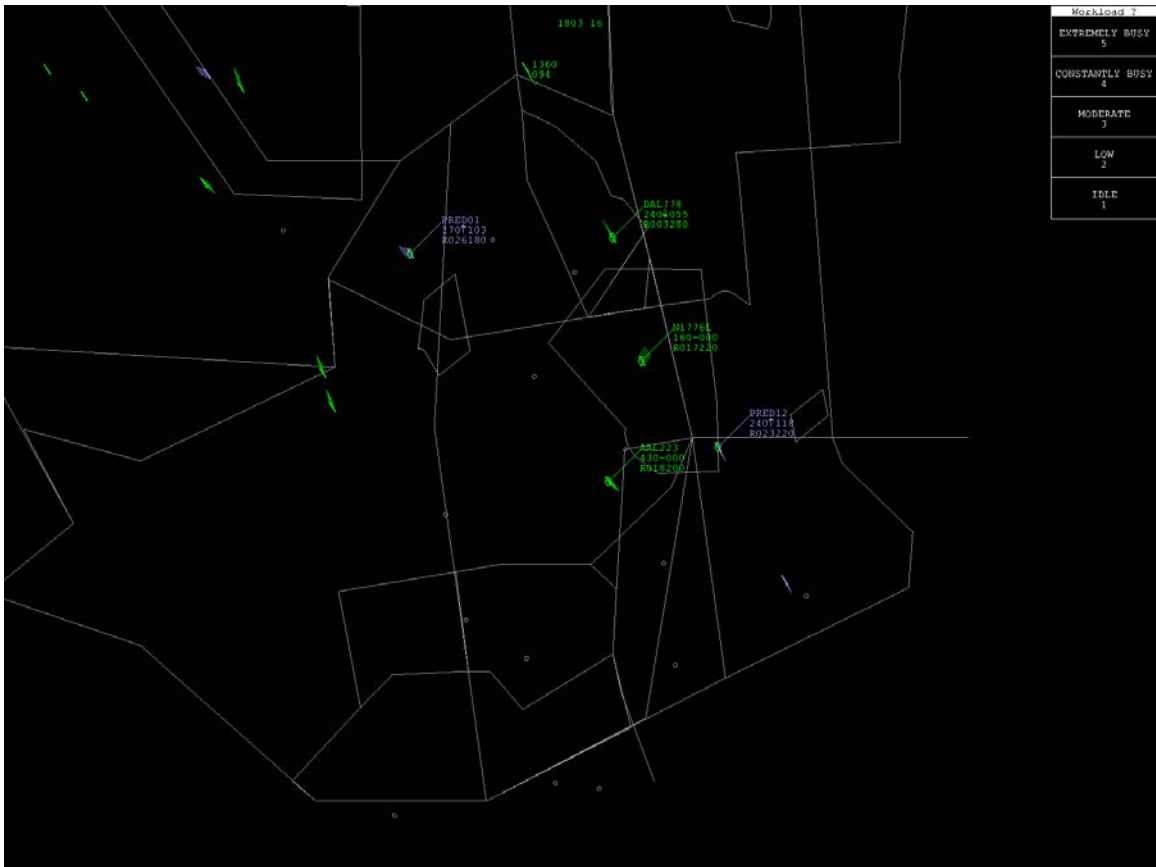| Micro | Mini | Tactical | Medium Altitude | High Altitude |

APPENDIX B

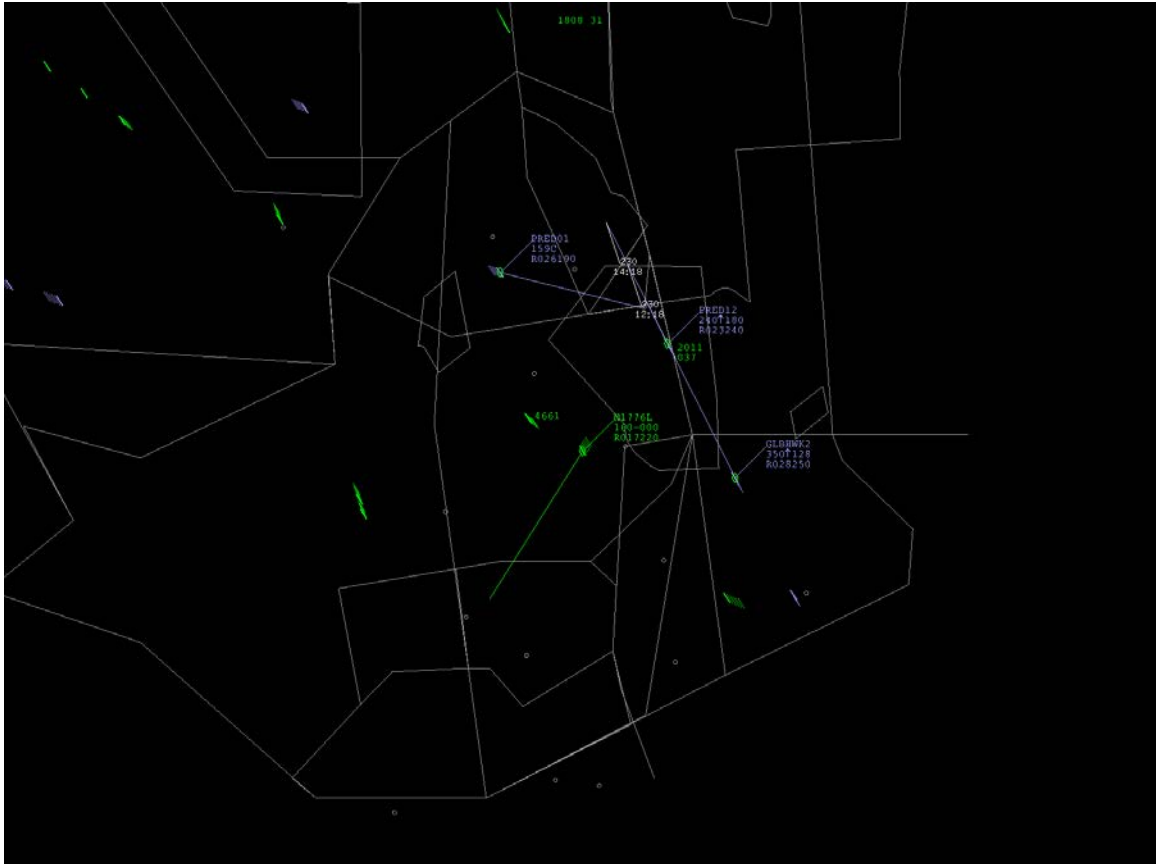Air traffic control screen of Ocala sector
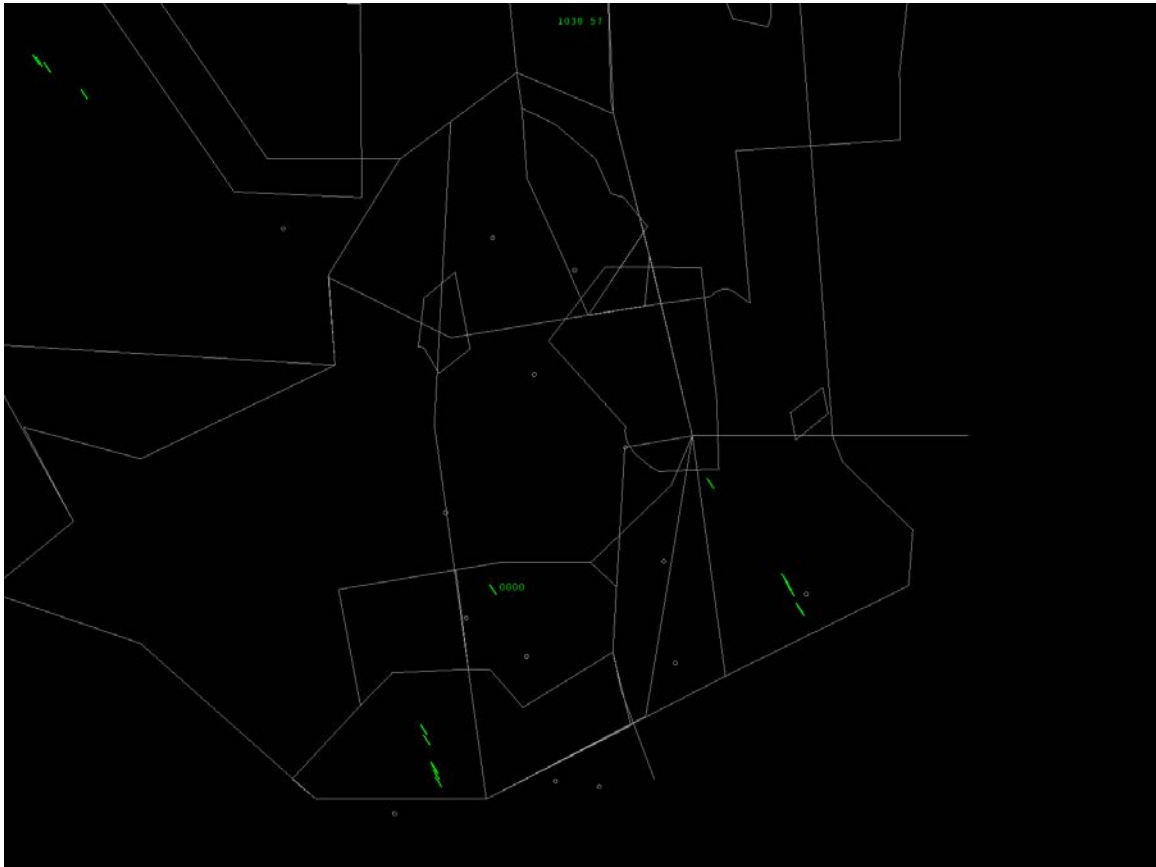
APPENDIX C

Air traffic control screen with instantaneous self assessment response box

APPENDIX D

Air traffic control screen with intent information

APPENDIX E

Air Traffic Controller Briefing and Instructions

Scenario

1. During this exercise you will be controlling traffic in the Ocala Sector. You should use the control techniques and standard operating procedures that you are already familiar with.

Traffic and routing

2. Traffic will arrive and follow current routing. Intensity will increase in three stages. Each stage will last for approx 20 minutes. At the beginning traffic will build quickly to approximate maximum of 6. After 20 minutes the rate will increase to 9 and for the last stage the traffic will build to 12. Note that the actual number may vary because of the way in which you control and sequence the aircraft. 3-5 unmanned aerial vehicles will be present throughout the scenario. Your ability to take control of the unmanned aerial vehicle and the amount of UAS intent information will differ depending on the scenario.

Control Techniques

You should use normal control techniques and separation for this exercise. That is a minimum of 5 nautical miles (nms) horizontal separation and 1000 ft vertical separation. Handoffs to TRACON should be at least 5 nms in trail.

Workload Assessment

3. The purpose of this exercise is to establish a baseline workload assessment. Accordingly, 5 minutes into the exercise and every 5 minutes after that you will be prompted to indicate a "busyness factor" on the pop-up on-screen display (Instantaneous Self Assessment). The factor ranges from 1 – 5 with 3 indicating a normal comfortable level. 1 would indicate "doing nothing – all the time in the world"; 5 would indicate "close to or actually at overload – I really have lost or am close to losing this situation."

4. Please be as accurate as you can in indicating your subjective workload experience.

5. At the end of each exercise you will be asked to fill out a questionnaire about the exercise. As with the workload assessment, this is vitally important and will as part of the human factors analysis.

ANY QUESTIONS?

APPENDIX F

Pseudo Pilot for Aircraft and Unmanned aircraft systems Briefing and Instructions

1. You are responsible in this exercise for communicating with the controller and taking instructions from the controller to "fly" the aircraft.

2. Your cue to make the initial call will be when you observe that the controller has accepted handoff on a potential aircraft. YOU SHOULD NOT MAKE CONTACT WITH THE CONTROLLER UNTIL HE/SHE HAS ACCEPTED THE HANDOFF

ANY QUESTIONS?

Controller Consent Form

Purpose: This analysis effort has been requested by Jeeja S. Vengal, a graduate student at Embry-Riddle Aeronautical University, to collect data for her thesis. The purpose of this study is to identify the effects of the integration of unmanned aircraft systems on air traffic controller performance.

Participant number: You will be randomly assigned a participant number. The number will be used in organizing the data. Please write down and remember this number, because it will be used again during the data collection activities.

Information Collected: The system will record performance information during the experiment. This information collected you will give me, along with the information I collect from other participants, will only be reported in the aggregate. There are no known risks in participating in this study.

Waiver: Your "on-line" work in the simulated Ocala sector will be video taped and audio-taped. By signing this from you give your consent to me to use your verbal statements, and your "on-line" work, but not your name, for evaluation and demonstration.

Confidentiality: Please understand that you participation in this study is strictly voluntary and may withdraw from this study at any time. Your privacy will be protected. Your participation in this study will be anonymous and will be held strictly confidential.

You may receive a copy of this consent form and/ or the final report on request. If there are any questions or comments the experimenter, Jeeja S. Vengal, or Shawn Doherty (Thesis committee Chair), can be contacted via email or phone.

Jeeja S. Vengal: jeeja26@hotmail.com or 216-225-6213.
Shawn Doherty: shawn.doherty@erau.edu or 386-226-6249

If you agree with these terms, please indicate your acceptance by signing below.

Signed_____ Date_____

Experimenter_____ Date_____

Pseudo Pilot Consent Form

Purpose: This analysis effort has been requested by Jeeja S. Vengal, a graduate student at Embry-Riddle Aeronautical University, to collect data for her thesis. The purpose of this study is to identify the effects of the integration of unmanned aircraft systems on air traffic controller workload when manipulating UAS intent information and ATC control capability.

Waiver: Your communication with air traffic control in the scenarios will be video taped and audio-taped. By signing this from you give your consent to me to use your verbal statements, and your "on-line" work, but not your name, for evaluation and demonstration.

Confidentiality: Please understand that you participation in this study is strictly voluntary and may withdraw from this study at any time. Your privacy will be protected. Your participation in this study will be anonymous and will be held strictly confidential.

You may receive a copy of this consent form and/ or the final report on request. If there are any questions or comments the experimenter, Jeeja S. Vengal, or Shawn Doherty (Thesis committee Chair), can be contacted via email or phone.

Jeeja S. Vengal: jeeja26@hotmail.com or 216-225-6213.
Shawn Doherty: shawn.doherty@erau.edu or 386-226-6249

If you agree with these terms, please indicate your acceptance by signing below.

Signed_____   Date_____

Experimenter_____   Date_____

Participant Demographic Questionnaire

Name: _____

Participant # _____

Sex: M   F

Age: _____

Course Work Completed
Please check if you have completed these courses

Course	Title	Credits	✔
AT 300	ATC in the National Airspace System	3	
AT 305	ATC Operations and Procedures	3	
AT 315	VFR Control Tower	3	
AT 401	Advanced Air traffic Control Operations	3	
AT 405	Air Traffic Management V	3	
WX 201	Meteorology I	3	
One of the following is required			
AS 120	Principles of Aeronautical Science	3	
AS 131	Commercial Flight Operations I	2	
	FAA Private Pilot Certificate	2	

Estimated time in aircraft as Pilot/ Copilot:
Simulated/Labs: _____hours
Real Time: _____hours

Estimated time in ATC lab: _____hours

During air traffic control Work,

1. What would you say is a general number of aircraft that would create a light workload in a 20 minute shift? _____

2. If you were on shift with your combined experiences as of today, would you view this number of aircraft as? _____

Light   Medium   Heavy   Extreme

APPENDIX J

Post Exercise Subjective Questionnaire

This questionnaire is in sections. It is recommended that you read quickly through the question in each section first, before you answer the question in it. Where options are given (e.g. Yes/No), please circle your answer and delete the alternatives that do not apply. It would be appreciated if you can take the time to add details about you answers and you reasons for them whenever you can.

Participant #_____

Traffic Samples

1. Did the presence of UAVs lead to any particular problems in handling the traffic in these samples?
   Yes/ No   If yes, please give details.

2. Was the amount of traffic in the traffic samples realistic compared to simulations conducted in ERAU courses?
   Yes/No   If no, please give details

3. Was the mix of types of traffic in the traffic sample realistic compared to simulations conducted in ERAU courses?
   Yes/No   If no, please give details

4. Were the four traffic samples approximately equal in terms of the ease or difficulty of controlling them as traffic?
   Yes/ No   If no please give details, as fully as you can, of how the four samples differed.

Conflicts

1. Were the conflicts between aircraft under normal control realistic?
   Yes/No   If No, in what ways were they unrealistic?

2. Did you find the behavior of the unmanned aerial aircraft predictable/ unpredictable? If unpredictable, in what ways were they unpredictable? Or if predictable, in what ways were they predictable?

Ergonomics of Simulation workspace

1. Were you ever distracted by the other person participating in the experiment at the same time as you?
       Yes/No   If yes, please give details of what distracted you.

2. Was all the information on the displays clearly visible?
       Yes/ No   If No, please give details

3.   Did you understand all the information on the displays?
       Yes/ No   If no, please give details of any information that you did not understand

4.   Was the information encoding used to designate a UAV acceptable to you?
       Yes/ No   If it was not, what coding to denote UAV would you prefer

5. Did the communication facilities(R/T, phone, etc.) function normally during this evaluation?
       Yes/ No   If they did not, what was abnormal about them?

6. Please give any further comments about the ergonomics of the workspace or comments about any other aspect of the human-machine interface in this experiment.

Workload Contribution was : (circle)										Workload Factors
Very Low						Very High				
1	2	3	4	5	6	7	8	9	10	# of Aircraft
1	2	3	4	5	6	7	8	9	10	# of Conflicts
1	2	3	4	5	6	7	8	9	10	# of route changes
1	2	3	4	5	6	7	8	9	10	# of altitude changes
1	2	3	4	5	6	7	8	9	10	# of airspeed changes
1	2	3	4	5	6	7	8	9	10	Pilot verbal response errors/delay
1	2	3	4	5	6	7	8	9	10	Pilot route/altitude deviations
1	2	3	4	5	6	7	8	9	10	Traffic Mix
1	2	3	4	5	6	7	8	9	10	Confidence in Unmanned aircraft systems
1	2	3	4	5	6	7	8	9	10	Housekeeping (moving data blocks, using the intentions info)
1	2	3	4	5	6	7	8	9	10	A/C flight characteristics (climb, descend, airspeed)

1	2	3	4	5	6	7	8	9	10	Monitoring and resolving conflicts
1	2	3	4	5	6	7	8	9	10	Interpreting the intentions information
1	2	3	4	5	6	7	8	9	10	Inputting Workload factor on ISA
1	2	3	4	5	6	7	8	9	10	Console Layout
1	2	3	4	5	6	7	8	9	10	Monitor size and position
1	2	3	4	5	6	7	8	9	10	Use pf PC keyboard
1	2	3	4	5	6	7	8	9	10	Unfamiliarity with procedures

Any Additional Comments