The Effects of System Reliability and Task Uncertainty on Unmanned Aerial Vehicle Operator Performance under High Time Pressure

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The Effects of System Reliability and Task Uncertainty on Unmanned Aerial Vehicle Operator Performance under High Time Pressure

By

Manuela Jaramillo

B.S., Embry-Riddle Aeronautical University 2007

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

Embry-Riddle Aeronautical University

Daytona Beach, FL

2011
The Effects of System Reliability and Task Uncertainty on Unmanned Aerial Systems
Operator Performance under High Time Pressure

By: Manuela Jaramillo

This thesis was prepared under the direction of the candidate’s thesis committee chair,
Dahai Liu, 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 and Systems.

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Associate Vice President of Academics
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For many years, the military has understood the value and versatility of Unmanned Aerial Systems (UAS). In the recent years, UASs have sparked the interest of other fields, and in the very near future, they will be introduced into the National Airspace System (NAS). With this inclusion come new concerns. Due to the future wide range applications for UASs, it is important to explore factors, which may affect operator performance. The UAS operator task differs from that of a manned aircraft pilot. An UAS operator does not get the same sensory cues as a pilot and their field of vision is significantly restricted among other limitations.

This study examined the effects of system reliability and task uncertainty on UAS operator performance, measuring image processing accuracy and image processing time through a primary task and three secondary tasks. The primary task was image processing that entailed differentiating between targets and distracters, making necessary changes to the identifications provided by the automation and processing images accurately within a five-second window. There were also three secondary tasks that are typical of UAS operations to which the participants had to respond as quickly as they could. Both system reliability and task uncertainty were found to be significant for primary task image processing time. In contrast, accuracy was not found to be significantly affected by either one of the independent variables. The results are examined, and recommendations for future research are discussed.
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Introduction

UAS Background

For many years, Unmanned Aerial Systems (UAS) have been widely used by the branches of the military in the United States. These systems have demonstrated time and time again how versatile, effective, and useful they can be. For these reasons, it was expected that by 2010, 1 out of every 3 military aircraft would be operated remotely (Pedersen, Cooke, Pringle, & Connor, 2006). For now, UASs fly in restricted zones just for them but this will soon change. UASs will be introduced to the National Airspace System (NAS) in the near future, which has sparked some concerns. The branches of the military have primarily used UASs for reconnaissance and attack missions. With the revamping of the NAS, the reality of more UASs being utilized for missions other than military applications is closer than ever. The expansion of UAS operations has the potential to change aviation forever. Moreover, with the increased potential uses of UASs, it is suggested that the use of UASs in an “urban close-air support” will be invaluable in the years to come, when undertakings like the war on terror creates missions that are more urban in nature (Hottman & Sortland, 2006).

The environment and intended mission scenarios in which UASs operate differ significantly. These technologies have advanced to the point where their applications can be useful for many practical purposes such as drug banning, border monitoring, law enforcement, agriculture, communication relays, aerial photography and mapping, emergency management, and scientific and environmental research. For some of these fields, UASs are already in use but not quite as extensive as it could be. To suffice for each intended domain of operation, user-interfaces would ultimately need to be designed.
in a fashion that allows for the most effective means of operation, thereby requiring different operating tasks on behalf of the UAS pilots (Hottman & Sortland, 2006).

UASs have been around for approximately 100 years, but it hasn’t been until recently that their capabilities have been recognized. Shortly after World War I, UAS technologies really began to develop, following the advent of automatic stabilization, remote control, and autonomous navigation advancements. Today, the military relies heavily on UAS to conduct missions that would otherwise be too boring, risky, or impractical for manned flight. These missions are often referred to as the “Dull, Dirty, or Dangerous” (Hottman & Sortland, 2006). The enormous growth of military interest towards UAS is a direct result of their proven performance and capabilities in the realm of surveillance, reconnaissance, and intelligence gathering, and more recently- attack missions (Hottman & Sortland, 2006). Furthermore, UASs accomplish this effort without putting American pilots’ lives in danger, due to the missions being remotely flown by operators residing within the U.S. borders, not in the hostile airspace. While the idea behind unmanned flight is to avoid the risk to human life, there is still a cost associated with losing a UAS; accident rates for UASs far exceed those of manned aircraft. Moreover, according to Sniezek et al., “an industry analysis has shown that over 70% of accidents can be attributed to human error” (2001). While proper pilot selection and training can greatly reduce accidents, it is by no means the only solution to reducing human error in UAS flights; effective training along with proper automation, user-friendly interfaces, and appropriate procedures can together make a positive impact in the safety record of UASs (Parush, 2006).
Within the United States, there are four different possible markets that could potentially benefit from the expansion of UAS operations: military, civil government, research, and commercial applications (Reynolds, 2009). Each market will have its own set of rules provided by the Federal Aviation Administration (FAA). Therefore it is important for the FAA to have full understanding of future implementations of UASs in those specific domains since not only will the rules change for each domain, but for the UAS operators as well. Consequently, the success of UAS operations in each market could depend on the constraints imposed on the operation.

Currently, there is no universally supported definition for modern-day UASs. In the UAS Roadmap, the Department of Defense (DoD) defines these systems as:

A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. Ballistic or semi ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles (Department of Defense, 2005).

The FAA defines an UAS as:

An airplane, airship, powered lift, or rotorcraft that operates with the pilot in command off-board, for purposes other than sport or recreation. It is also known as unmanned aerial vehicle. UASs are designed for recovered and reused. A UAS includes all parts of the system (data-link, control station, and so forth) required to operate the aircraft (American Society of Testing and Materials, 2005).
In either definition, a pilot is not co-located within the flying component of the system. For this reason, human factors concerns are raised regarding the pilot and their integration into the system for effective operations (Hottman & Sortland, 2006).

UASs come in two varieties: some are controlled from a remote location, and others fly autonomously based on pre-programmed flight plans using more complex dynamic automation systems. For both types, though, an operator has to be in the loop, where the operator interacts with the system, to either control the UAS or supervise it. In many of the supervisory instances, UASs are used as “eyes in the sky” and need someone to analyze, interpret, and make decisions about what the UASs see.

Since the pilots of these new domains of UAS operations will have different sets of rules to go by, it is important to understand how pilots are selected now and how this practice could improve for future pilot selection. Within the branches of the military, the primary users of UASs, there is no consistency when it comes to pilot selection. The U.S. Air Force, for example, select from UAS pilot candidates who have received formal military flight training, but have recently trained specifically for UAS (Brinkerhoff, 2009). They take graduates who have flown, “airplanes such as B-52, T-38, T-37, and T-1” and guide through rigorous UAV training, which results in trained pilots to be taken away from manned aircraft duties (Pedersen et al., 2006). Furthermore, the U. S. Navy and Marine Corp select UAS pilots that already hold a private pilot license, which is more of a “middle of the road” approach (McCarley & Wickens, 2004). On the other hand, the U. S. Army selects enlisted personnel at boot camp who may or may not have flight experience to fly their UASs (Pedersen et al, 2006). The lack of standardization does not stop there. There are also major differences between medical qualifications and
restrictions, not only from branch to branch, but in the general sense between manned and unmanned aircraft pilots. Although some medical qualifications in place for manned aircraft pilots, such as a certain level of fitness, may not necessarily be crucial for UAS operators considering the different operational environment, some are understandably important. Medical restrictions like the one imposed on alcoholics should be mandatory across the board since UAS operators will be in air space with manned aircraft, posing a major safety concern.

In order to understand the implications of automation, human trust, workload, time pressure on operator performance, there needs to be an understanding of the nature of the task. Operating a UAS is different from flying an aircraft. According to McCarley and Wickens (2004), “delayed control feedback, poor visual imagery, a small field of view, and a general lack of sensory cues [and feedback]” are the major differences between operating a UAS and flying an aircraft. Those extra sensory cues give the pilot extra information, which usually comes with added experience. Saying that, an experienced pilot will not necessarily effectively transfer knowledge and experience from their field to UAS operations. Tirre (1998) explains that pilots transitioning from manned aircraft to “UAS operations have faced boredom and difficulty maintaining situation awareness”. UAS operations are cognitively taxing. Weil et al. (2006) point up that operators are responsible for “controlling the flight, navigation, status monitoring, flight and mission alterations, problem diagnosis, communication and coordination with other operators and data analysis and interpretation”. They continue by saying that those tasks are similar in terms of their “locus of control” but they have different information requirements and thus, tap into different cognitive skills, which is were the cognitive
demands becomes so taxing (Weil et al., 2006). In addition, limited research in this area has concluded that there is a wide range of necessary qualifications that exist amongst UAS pilots, and more research is crucial to identify the kinds of skills, training and previous knowledge that would best fit into UAS operations, while not having a counterproductive effect (Weeks, 2000).

For any use of the UAS, three goals that are directly related to the Human Factors field stand true: the ergonomic goal dealing with minimizing physical fatigue, the cognitive goal that is preoccupied with minimizing mental fatigue and lastly, the response goal which targets minimizing UAV [operation or task] response time (Pedersen et al., 2006). The present study is particularly interested in the latter while focusing efforts on a variation of the cognitive goal as well. In this study, the cognitive goal is more about perceived workload, which may be impacted by the operator’s trust in the system. In turn, operator’s trust can be impacted by the reliability of the system and the task at hand.

In the following sections, we will explore and explain some of the most important questions regarding UAS pilots, their performance and the factors that are likely to negatively impact it. Due to the nature of the UAS task, the following factors are usually involved: decision-making under uncertainty, time pressure and stress, system reliability issues and the operator’s trust in the system, and overreliance in automation. The study strives to focus particularly on those areas to better understand the UAS operator’s task, how to improve their experience and better address concerns for the future implementations of UASs.
Decision-Making under Uncertainty

Uncertainty is a major stressor that is likely to have a negative impact on decision-making. Decision-making under uncertainty is an essential part of UAS operations, especially in military applications. In military operations, UAS pilots have to differentiate between targets and distracters when they are in the field, all while staring at a very small screen. These screens may not have the best resolution and may lack additional cues to allow the operator an easy discrimination. With the lack of external cues and only relying on what the small screen gives them, uncertainty can increase the operator’s workloads and stress levels while delaying their response to complete a certain task; that in turn, can increase their perceived time pressure and thus contribute to poor performance.

Several studies of decision-making, “suggest that judgment depends on processing a memory store ‘schemata’, stereotypical representation of situations experienced previously” (Boreham, 1989). Uncertainty has been defined extensively. Lawrence and Lorsch (1967) defined uncertainty as consisting of three components: 1) the lack of clarity of information, 2) the long time span without definite feedback and 3) the general vagueness of causal relationships. Moreover, uncertainty can be classified into two quite distinct categories. According to Rastegary and Landy (1993), these two categories are: 1) the variability of a given situation and 2) the character of information regarding that situation. For the purposes of this study, uncertainty is defined as the second category; uncertainty tends to “emphasize the completeness (or lack thereof) of
the information a decision maker possesses regarding a given situation” (Rastegary & Landy, 1993).

There are several decision-making models that could illustrate the way a UAS operator manages to make decisions under a degree of uncertainty. The ‘fast-and-frugal’ method is a variation of the Probabilistic Mental Models (PMM) (Newell, Weston & Shanks, 2003). The authors explain that the ‘fast-and-frugal’ approach to decision making argues that “people ‘satisfy’ or look for ‘good enough’ solutions that approximate the accuracy of the optimal algorithms without placing too heavy a demand on the cognitive system; this aspect of the model may not apply to military operations since ‘good enough’ is not quite enough to complete a mission where lives are at stake. In military operations, the UAS operator must be very certain when discriminating between targets and friendlies. The ‘good enough’ idea will likely be applicable to border patrol, or other civilian applications that not require critical discrimination in behalf of the operator. Another part to that idea is called the “take-the-best” heuristic, which will better encompass UAS operations in a military domain. This heuristic has three aspects: the search rule (search for cues to validate a decision), the stopping rule (stop after the first discriminating cue is discovered) and the decision rule (choose the outcome pointed to by the first cue that discriminates). The problem comes, as Newell and colleagues found, when people do not stop after finding the discriminating cue. Some people tend to seek additional information to support their decisions. This could be of critical importance in a UAS task considering the lack of time facing a UAS operator. If a UAS operator looks for additional, unnecessary information to decide whether or not to do something, they could waste precious time.
Furthermore, Jha and Bisantz (2001) suggest that a Dynamic Decision Making (DDM) task is "a task where the decision maker must make decisions in an uncertain, changing and time-pressured environment". These tasks involve a recognition process, where decisions are made based on previous experience. Additionally, dynamic decisions are defined as having four distinct characteristics:

1) A series of decisions is required to reach one goal;

2) Decisions are interdependent. Each decision needs to be understood in the context of the other decisions in the series either because they are constrained by the earlier decisions, or because they may constrain later decisions;

3) The state of the decision problem changes over time, either autonomously, because of the system makes the decision, or as a consequence of decision makers’ actions;

4) Decisions occur in real time. The decision maker must make a decision when the environment requires it, not in her or his own time. This is a stress generator, which hinders decision performance, since the decision maker under stress reverts to simple, more task-oriented modus operandi (Bullen & Sacks, 2003).

Time Pressure and Stress

Another important aspect of UAS operations is operator’s perceived time pressure to successfully complete a task and the stress that they can experience if the pressure becomes overwhelming. Controlling a UAS can become quite stressful considering the small visual system given to operators to make decisions; it is easy to imagine that the
task of discriminating between images can rapidly become taxing if there is a time constrain to complete the task. In addition, the lack of sensory cues, such as visual and tactile, to inform the operator of current system or task status that could potentially aid the operator in making a decision are not available like they are in other aircraft. It is important to understand how time pressure affects UAS operators in their ability to make correct decisions of critical importance and how stress plays a role in their overall experience.

In an environment with time sensitive decisions such as UAS operations, operators are not “free to make decisions when they feel ready to do so. Instead, they have to make decisions when the environment demands decisions from them, [which] introduces a level of stress” (Brehmer, 1992). Time pressure is a simple concept. Time pressure is the perceived demand between the available time and the amount of time required to complete a given task. Time pressure affects people in different ways. Some people may cope with high time pressure to make a decision by rushing through other activities; this will likely end in information overload ultimately resulting in increased stress levels. According to Maule et al. (2000), this adaptation in known as acceleration, which they explain as, “increasing the speed or tempo of information processing” and add that another adaptation strategy is known as filtration, which dictates, “increased selectivity of processing”. Since the operator is aware of the need to work harder and faster, it will lead to increased anxiety and stress (Maule et al., 2000).

Perceived time pressure can also prove critical to performance by increasing workload and completely overwhelming the operator. Time pressure becomes an important factor to be considered in a dynamic environment such as UAS Operations
because decisions have to be made immediately. Brehmer (1992) expresses that, “it [is] not sufficient to make correct decisions and to make them in the correct order; the decisions have to be made at the correct time...dynamic decisions are decisions in context and in time”. Not all time pressure is bad. People have been found to feel more energetic after brief periods of increased workload (Brehmer, 1992). Furthermore, giving people deadlines can keep them focused on the task while motivating them to successfully bring the task to completion; this can translate in job satisfaction.

System Reliability

Complexity in technology has been on the rise for many years. In an effort to help the operator, many tasks have been automated to prevent the user from getting overwhelmed. As a result of an increase in computer usage, special attention must be paid to the human-computer team and its performance.

With the human-computer team, a mutual reliance exists. The human will have assistance from the computer automation, while at the same time the automation relies on the human to make ultimate decisions based on its suggestions; but having a computer in the loop is not the end of it. It is not just necessary to have the automation take some of the work; the automation has to be reliable. Otherwise, instead of reducing operator workload, the automation can increase it. The reliability of the automation system is the usual sense of proper, consistent and effective functioning (Luz, 2009). Also, “one strategy used to optimize human–computer performance has been to call on system designers to create automated aids that are increasingly more reliable”, expecting that the new found assistance can prove beneficial to the operator of the complex system
(Dzindolet, Peterson, Pomranky, Pierce, & Beck, 2003). The authors explain that even though increased reliability is assumed to lead to increased human–computer “team” performance, it may not be the case every time. Just like with human teams, increasing the reliability of one member's performance will not necessarily translate into better team's performance.

Operators depend on the system’s reliability to properly aid them in their task. As UAS use continues to proliferate, “the technology involved with the flight control system continues to become more and more sophisticated” as if the goal of system designers was to removed the human operator al together (Williams, 2006) but the rationale for continuing to use a human in the UAS loop, is the “the flexibility that the human brings to the human-machine combination” (Oron-Gilad, Chen & Hancock, 2006). In addition, human-automation interaction research has shown that automation does not eliminate human cognitive demands in their entirety, set up and supervision of that automation is still required, with supervision being quite important due to automation being less that 100% reliable (Wickens et al., 2006). For that reason, system reliability and the ability of the operator to trust the system is crucial. The proper use of such automation is directly derived from the reliability of the system and the trust the operator can build from using that system. Experiments have shown that automation is beneficial when it is perfect and it is also detrimental to operator performance when it is unreliable because it degrades performance and increases workload (Wickens et al., 2006). The authors indicate that, “people generally tend to treat diagnostic automated tasks as ‘secondary’, buffering the ‘primary;’ concurrent tasks from whatever resource demands are imposed by decreasing reliability” (Wickens et al., 2006). The finding in the study conducted by Wickens et al.
(2006) also showed that pilots might be able to tolerate less than perfect system reliability. They suggested that pilots may even be able to tolerate reliability as low as 80%, but they disclosed that this might only be achievable if the pilots are made aware of the reliability level and the source of the imperfection. This is important for the present study since participants were not aware of the low reliability or the source of the imperfection while at the same time, system reliability being well below the 80% level Wickens and others have discussed.

_Human Trust and Overreliance in Automation_

Since studies have shown reduced perceived operator’s workload when automation is used for a UAS flight, the use of automation in this field has grown significantly (Parush, 2006). UASs are heavily automated systems where the operator does more of a supervisory job as opposed to actually operating the aircraft. With this increase in functionality, consequences such as reduced situational awareness due to inactivity and lack of operator involvement in the task, over or under reliance in automation, and misunderstanding of automation modes can all occur in the human-automation interaction if not considered up front (Weil et al., 2006). According to Peterson (2010), “The level of automation implemented in the UAS then becomes an important factor in determining how safely and efficiently the system will operate in general, which is why special attention must be paid to the human-machine team. Just like in any team, there are several issues that can arise from the interaction between automation and a human operator. According to Luz (2009), if people don’t trust (under-trusting) automation support, they will not use it (disuse). On the other hand, when there is too much trust by the operator (over-trusting), the operator incurs in lack of attentive monitoring of the
system which will likely lead to missing faults in automation (misuse). It is important that
operator to evaluate the system reliability correctly and build trust on the system
thereafter.

In general, trust can be increased when the operator realizes the benefits of using
automation and understands the functionality and constraints of its tools. The relationship
of system reliability and trust in automation is illustrated in Figure 1.

![Figure 1 The Relationship Between System Reliability and Trust in Automation](image)

Automation can be a very powerful tool for a human operator but if not handled
carefully, it can hinder the ability of the user in executing the correct response under
time pressure or an emergency situation as well as increasing their workload. The
interaction between an autonomous system and the operator is an interesting one, “a
common paradigm in human-automation interaction requires a human to make a
judgment in parallel with an automated system, and then consider, accept, or reject the automated output as appropriate” (Bisantz & Pritchett, 2003). This becomes a problem when the operator becomes over reliant on the system and goes from an active operator to a monitor. If the system takes too many responsibilities away from the user, making them less involved in what is going on, when an emergency situation happens the operator is less equipped to manage it properly. This, in turn, elevates the levels of workload immensely and performance usually decreases. Overreliance on automation can be extremely critical for UAS missions since important, time-constrained decisions can happen in an instant and the operator must be alert, in the loop and able to make the right decision.

In UAS operations, research about workload, trust in automation and system reliability and how they affect operator’s performance is limited. This study will add to the body of knowledge that currently exists about these systems. The expansion that the UAS usage will have in the upcoming years will greatly benefit from a better understanding of the dynamics between system reliability and human trust and their impact of workload and performance when time pressure is added to the mix.

Research Objective

The purpose of the study is to broaden the understanding of the effects of system reliability and task uncertainty on UAS operator performance. Due to the vast number of UAS applications, concerns such as: Are pilots able to use the automation properly when it is less than perfect? Does low reliability affect their performance? Can reliable automation really have a positive impact on operator’s performance? Does low reliability
hinder the operator's positive perception of the system automation, therefore affecting their performance? Can time pressure become critical when the uncertainty of the discrimination task is high?

The objective is for the study is to find out if under a high time pressure, UAV operators are able to correctly discriminate between distracters and threats while properly accepting correct automation data or rejecting faulty data based on the two levels of system reliability. The uncertainty encompassed in the study, is threat detection; the ease of looking at an image with all threats, mixed threats and distracters or all distracters and correcting the action the automation has suggested. The effect of system reliability and different uncertainty levels on human UAS operators were investigated in this study.

**Hypotheses**

The following hypotheses were tested:

**Hypothesis 1:** When participants are exposed to high uncertainty targets, that is, all threats or all distracters, they will have a lower accuracy score than when presented with low uncertainty targets.

**Hypothesis 2:** When participants are exposed to low uncertainty, their primary task processing time will be lower than when presented with high uncertainty targets.

**Hypothesis 3:** When participants are exposed to high system reliability, their primary task accuracy scores will be higher than when they are presented with low reliability.

**Hypotheses 4:** When participants are exposed to high system reliability, their
primary task processing time will be lower than when they are presented with low system reliability.

Hypotheses 5: There is an interaction between reliability and uncertainty for the primary task accuracy scores

Hypothesis 6: There is an interaction effect between reliability and uncertainty for the primary task processing time

Hypothesis 7: When participants are exposed to low uncertainty targets, their secondary task time, mission mode indicator MMI processing time will be lower than when presented with high uncertainty targets.

Hypothesis 8: When participants are exposed to high reliability, their secondary task time, MMI processing time will be lower than when presented with low system reliability.

Hypothesis 9: When participants are exposed to low uncertainty, their secondary task time, pop-up threats processing time will be lower than when presented with high uncertainty targets.

Hypothesis 10: When participants are exposed to high reliability, their secondary task time, pop-up threats processing time will be lower than when presented with low system reliability.

Hypothesis 11: When participants are exposed to low uncertainty, their secondary task time, Intruder Aircraft (IA) processing time will be lower than when presented with high uncertainty targets.

Hypothesis 12: When participants are exposed to high reliability, their secondary task time, Intruder Aircraft (IA) processing time will be lower than
Hypothesis 13: There is an interaction between reliability and uncertainty for the secondary task time.

Methods

Participants

Twenty-five undergraduate and graduate students from Embry-Riddle Aeronautical University, 15 males (60%) and 10 females (40%) were recruited to participate in this study. They were briefed prior to their participation and asked to sign an informed consent form.

Apparatus

This study used a standard PC running a UAS software test bed simulation device called MIIIRO (Multi-modal Immersive Intelligent Interface for Remote Operations). The software was designed by IA Tech with support from the Air Force Research Laboratory, and is used to conduct research for simulate long range, and high endurance UASs (Tso et al., 1999). The setup includes two monitors; the one on the left displayed the Tactical Situation Display (TSD). The TSD included a topographical image of the operating environment, highlighted routes including waypoints, critical targets, other intruding aircraft, and the Mission Mode Indicators (MMI). The secondary monitor displayed the Image Management Display (IMD), which included an image cue and
image display used for image processing, as shown in Figure 2.

Figure 2 The TSD and IMD using the MIIIRO interface

Design

The design utilized a 2x2 within subjects, fully factorial design (Table 1). The two independent variables were reliability of the automation and uncertainty of the data presented. Five dependent measures were collected in the study across two tasks.

Table 1

<table>
<thead>
<tr>
<th>Reliability</th>
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</tbody>
</table>

*Primary task:* For this study, the primary task was image processing. Participants did not need to control flight directly due to the high level of automation used by the system. Waypoints made up the flight path of the UAS. Along the flight path, 10 image capture locations were preset to represent each location. Once the UAS reached a
waypoint, the designated image was presented to the participants. Each image contained at least one terrain vehicle that may have or may have not been a target. Distracters may have also been present. The participants were to view the images captured by the aircraft onboard camera, and verify that the Automatic Target Recognizer (ATR) had correctly selected the targets. The ATR placed a red box around the vehicles it had recognized as targets, although the ATR was not always correct. For example, the ATR placed red boxes around distracters while not placing them around the targets. In cases where the ATR had incorrectly identified distracters as targets or had not recognized a target as one, the participant was required to manually select the target and/or deselect the distracter by clicking on the images with the mouse. The automation processed the automation’s suggested action as is, if no input from the operator was received within the 5 seconds time limit. The reliability of the ATR was set to 90% and 50% for the two levels of reliability.

The MIIIRO software automatically collected primary task performance measures for analyses. These measures included: image processing time, target selection accuracy, manual accepts/rejects, and automatic accepts/rejects.

Secondary task. There were three secondary tasks that the participants needed to perform during this study. The first task was the Mission Mode Indicator (MMI). The MMI had three round lights organized in a line like a sideways traffic light. It indicated the status of the UAS by lighting up the green, yellow, or red light. The lights depicted the estate of the system: good health (green), action needed (yellow), and urgent action needed (red). The participants needed to click on the light panel when the MMI lighted up yellow or red. They then needed to correctly type in a text string that popped up in a
window after initiating the action. Once the participants had successfully entered the text string presented to them, the MMI lighted up green indicating the new state of the system as being in good health.

The second task in this experiment required the participant to respond to flight path changes recommendations made by the automation. Pop-up threats were designed into the flight path, but were not visible to the participant until the aircraft had encountered them. When the UAS encountered the threats, the automation provided an alternate route. The alternate route provided was not always ideal and the participant had to choose to accept the new route before it was put in effect or rejected it and continue with the original flight plan.

Lastly, the third task to increase pilot workload consisted of processing an Intruder Aircraft (IA), which entered the operational airspace. This task was used to imitate unexpected aircraft that may enter airspace during typical UAS operations. This was a highly critical situation and required a quick and attentive response. A red aircraft shaped icon depicted as the intruder, appeared on the display at random times during the experiment. Participants were required to click on the aircraft and enter a predetermined code to alleviate the situation. This event occurred twice in each trial.

Data from all three tasks was automatically collected by the MIIIRO software and included the number of events and response times for the MMI and the IA, as well as the pop-up threat reroute occurrences.

**Independent variables.** The first independent variable (IV) was reliability of the system. It had 2 levels: 50% and 90%. When the reliability was set at 50%, 5 images out
of the 10 images captured by the aircraft onboard camera were correctly processed; the automation had red boxes around the targets and no boxes around distracters. This was also the case for the 90% reliability where 9 out of the 10 images were correctly processed by the automation. The second IV was task uncertainty. It too had 2 levels: Low (with comparison) and High (without comparison). For the comparison group, there was a mixture of threats and distracters and the participant had a comparison point to discriminate one from the other. For the without comparison group, participants were presented with either all threats or all distracters and they had to make decisions based on what they thought was differentiable on the screen.

**Dependent variables.** Performance from the primary task was measured based on processing time and accuracy scores and the secondary tasks were measured based on processing time.

**Procedure**

Upon arrival, each participant was given an informed consent form to sign (Appendix A). Then, they were briefed about the primary task as well as the three secondary tasks. They were also informed that they could receive extra credit in one undergraduate Human Factors class in addition to being eligible for a $50 cash prize if they were the overall top performer in the study. Before starting the sequence of scenarios, they were able to get themselves familiarized with the software and all the tasks as well as ask questions they may have had during a 5-minute trial run. After the trial run was completed, the participants were presented with a randomized sequence of the experimental scenarios. Each scenario lasted approximately 8 minutes.
and the total time to complete the study varied from 50 minutes to 1 hour, depending on individual breaks between scenarios.

Results

The present study was intended to analyze the effects of system reliability and task uncertainty on performance of UAS pilots under high time pressure. A repeated measures analysis of variance (ANOVA) was conducted for each one of the dependent variables: primary image processing accuracy, primary image processing time, MMI processing time, pop-up threats reroute processing time and IA processing time. The significance level was set at alpha = .05 and the graphs shown below include standard error bars.

Primary Task

*Primary task image processing accuracy.* For the first primary task dependent variable (DV), accuracy, an ANOVA was conducted to test hypothesis 1 and hypothesis 3. Hypothesis 1 states that when participants are exposed to high uncertainty targets, that is, all threats or all distracters, they will have a lower accuracy score than when presented with low uncertainty targets. Hypothesis 3 states that when participants are exposed to high system reliability, their primary task accuracy scores will be higher than when they are presented with low reliability. The descriptive statistics for accuracy are shown in Table 2.
Table 2

Descriptive Statistics for Primary Task Accuracy

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Reliability</td>
<td>50%</td>
<td>64.17</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>72.08</td>
</tr>
</tbody>
</table>

The main effects for system reliability and task uncertainty on accuracy were $F(1, 23)=1.056, p=.315$ and $F(1, 23)=.120, p=.733$ respectively. Both did not reach statistical significance. The interaction effect between reliability and uncertainty was found to not be statistically significant with, $F(1, 23)=2.968$, and $p=.098$. Partial Eta Square was .044 for reliability and .005 for uncertainty, which means that each factor accounted for 4.4% and .5% of the variance respectively. Also, power was low at .166 for reliability and at .063 for uncertainty. This means that for reliability, there is 83.4% chance of failing to detect an effect that is there and for uncertainty, there is a 93.7% chance. The results are shown in Table 3.

Table 3

ANOVA Source Table for Primary Task Accuracy (%)

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
<th>$\eta^2$</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>1</td>
<td>204.167</td>
<td>1.056</td>
<td>.315</td>
<td>.044</td>
<td>.166</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>1</td>
<td>37.5000</td>
<td>.120</td>
<td>.733</td>
<td>.005</td>
<td>.063</td>
</tr>
<tr>
<td>Reliability*Uncertainty</td>
<td>1</td>
<td>600.000</td>
<td>2.968</td>
<td>.098</td>
<td>.114</td>
<td>.379</td>
</tr>
<tr>
<td>Error(Reliability)</td>
<td>23</td>
<td>193.297</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error(Uncertainty)</td>
<td>23</td>
<td>313.587</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Also, Figure 3 shows that based on the data, it seems that when participants were exposed to high uncertainty targets, their accuracy scores were lower but according to the analysis, the difference was not statistically significant. Hypothesis 1 was not supported by the findings.

![Average Image Processing Accuracy](image)

**Figure 3 Average Accuracy Scores for High and Low Uncertainty**

As for Hypothesis 3, Figure 4 shows from the data, it appears that when participants were exposed to the high reliability condition, they had higher accuracy scores, but this too was not found to be statistically significant.
Primary task image processing time. A separate repeated measures ANOVA was conducted to analyze the effects of reliability and uncertainty on the second performance measure for the primary task, and image processing time. For image processing time, hypotheses 2 and 4 stated that: (2) when participants are exposed to low uncertainty, their primary task processing time will be lower than when presented with high uncertainty targets and (4) when participants are exposed to high system reliability, their primary task processing time will be lower than when they are presented with low system reliability, respectively. The descriptive statistics are shown in Table 4.
Table 4

Descriptive Statistics for Primary Task Time (ms)

<table>
<thead>
<tr>
<th></th>
<th>Uncertainty</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>95% C.I.</td>
<td>Mean</td>
</tr>
<tr>
<td>Reliability</td>
<td>50%</td>
<td>3607.96</td>
<td>1029.57</td>
<td>[3173, 4042]</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>3272.00</td>
<td>1114.72</td>
<td>[2801, 3742]</td>
</tr>
</tbody>
</table>

It was found that there was a significant main effect for system reliability with $F(1, 23)= 7.581$ and $p=.011$. There was also a significant main effect for uncertainty of the task with $F(1, 23)=8.809$ and $p=.007$. However, the interaction effect between reliability and uncertainty was not found to be statistically significant with $F(1, 23)= .063$ and $p=.804$. Partial Eta Square was .248 for reliability and .277 for uncertainty, which means that each factor accounted for 24.8% and 27.7% of the variance respectively. Also, power was relatively high at .751 for reliability and at .811 for uncertainty. This means that for reliability, there is 24.9% chance of failing to detect an effect that is there and for uncertainty, there is an 18.9% chance. The ANOVA source table is shown in Table 5.
Table 5

ANOVA Source Table for Primary Task Processing Time (ms)

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>1</td>
<td>2188292.042</td>
<td>7.581</td>
<td>.011*</td>
<td>.248</td>
<td>.751</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>1</td>
<td>3847203.375</td>
<td>8.809</td>
<td>.007*</td>
<td>.277</td>
<td>.811</td>
</tr>
<tr>
<td>Reliability*Uncertainty</td>
<td>1</td>
<td>27744.00</td>
<td>.063</td>
<td>.804</td>
<td>.003</td>
<td>.057</td>
</tr>
<tr>
<td>Error(Reliability)</td>
<td>23</td>
<td>288657.911</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error(Uncertainty)</td>
<td>23</td>
<td>436733.766</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicated significant factors

Also, Figure 5 shows that when participants were exposed to low uncertainty targets, their processing time was significantly lower. Hypothesis 2 was supported by the findings.

![Average Image Processing Time](image)

Figure 5 Average Processing Time for High and Low Uncertainty in (ms)

In addition, Figure 6 shows that when presented with high system reliability, participants processed images quicker than when they were exposed to low system reliability. The findings also support hypothesis 4.
Figure 6 Average Processing Time for High and Low System Reliability in (ms)

As for the hypotheses 5 and 6, which relate to the interaction between reliability and uncertainty for the primary task accuracy scores (5) and primary task image processing time (6), the findings do not support either one of the hypotheses.

Secondary Tasks Processing Time

The first secondary task analyzed using repeated measures ANOVA was Mission Mode Indicator (MMI) processing time and the descriptive statistics are shown in Table 6.

Table 6
Descriptive Statistics for MMI processing time (ms)

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Mean (ms)</th>
<th>SD (ms)</th>
<th>95% C.I.</th>
<th>Mean (ms)</th>
<th>SD (ms)</th>
<th>95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>8831.3</td>
<td>2336.41</td>
<td>[7845, 9818]</td>
<td>9872.75</td>
<td>2890.92</td>
<td>[8652, 11093]</td>
</tr>
<tr>
<td>90%</td>
<td>9317.79</td>
<td>2883.66</td>
<td>[8100, 10535]</td>
<td>10319.6</td>
<td>2869.78</td>
<td>[9107, 11531]</td>
</tr>
</tbody>
</table>
It was found that there was a significant main effect for uncertainty of the task, $F(1, 23)= 15.361, p<.001$. The main effect for reliability of the system was not found to be significant, $F(1, 23)= 1.697. p=.206$ and neither was the interaction, $F(1, 23)= .002, p=.969$. Partial Eta Square was .069 for reliability and .400 for uncertainty, which means that each factor accounted for 6.9% and 40% of the variance respectively. Also, power was low for reliability at .239 for reliability and high for uncertainty at .963. This means that although there is 76.1% chance of failing to detect an effect that is there for reliability, for uncertainty, there is a very low 3.7% chance of failing to detect an effect.

The results are shown in Table 7.

Table 7

<table>
<thead>
<tr>
<th>ANOVA Source Table for MMI Processing Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>$df$</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Reliability</td>
</tr>
<tr>
<td>Uncertainty</td>
</tr>
<tr>
<td>Reliability*Uncertainty</td>
</tr>
<tr>
<td>Error(Reliability)</td>
</tr>
<tr>
<td>Error(Uncertainty)</td>
</tr>
</tbody>
</table>

* indicates significant factors

Hypothesis 7 predicted that when participants are exposed to low uncertainty, their MMI processing time will be lower than when presented with high uncertainty targets. This was not supported by the findings (see Figure 7). Therefore, results suggest that participants took longer to process the MMI task when the primary task uncertainty was low. Hypothesis 8 is not supported either and states that when participants are
exposed to high reliability, their MMI processing time will be lower than when presented with low system reliability since reliability was not found to be statistically significant.

![Average MMI Processing Time](image)

Figure 7 Average MMI Processing Time under High and Low Uncertainty in (ms)

The next secondary task analyzed was pop-up threats reroute processing time. The descriptive statistics are shown in Table 8.

Table 8

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Mean</th>
<th>SD</th>
<th>95% C.I.</th>
<th>Mean</th>
<th>SD</th>
<th>95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>2834.75</td>
<td>902.854</td>
<td>[2453, 3216]</td>
<td>2852.50</td>
<td>936.908</td>
<td>[2457, 3248]</td>
</tr>
<tr>
<td>Low</td>
<td>3073.27</td>
<td>845.464</td>
<td>[2716, 3430]</td>
<td>2686.96</td>
<td>817.469</td>
<td>[2342, 3032]</td>
</tr>
</tbody>
</table>

The main effects for reliability with $F(1, 23)=.077$, $p=.784$ and for uncertainty with $F(1, 23)=1.780$, $p=.195$ were not found to be statistically significant. The interaction between reliability and uncertainty also failed to show a significance with $F(1,$
As previously stated, hypotheses 9 and 10 predicted that when participants are exposed to low uncertainty and high reliability their pop-up threats reroute processing time will be lower than when presented with high uncertainty targets and low system reliability respectively. Since the repeated measures ANOVA did not find statistical significance for either one of the IVs nor their interaction, hypothesis 9 and hypothesis 10 were not supported. The ANOVA source table is shown below (see Table 9).

Table 9
ANOVA Source Table for Pop-Up Threats Reroute Processing Time (ms)

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>1</td>
<td>31937.510</td>
<td>.077</td>
<td>.784</td>
<td>.003</td>
<td>.058</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>1</td>
<td>814937.760</td>
<td>1.780</td>
<td>.195</td>
<td>.072</td>
<td>.248</td>
</tr>
<tr>
<td>Reliability*Uncertainty</td>
<td>1</td>
<td>979498.010</td>
<td>1.850</td>
<td>.187</td>
<td>.074</td>
<td>.256</td>
</tr>
<tr>
<td>Error(Reliability)</td>
<td>23</td>
<td>413498.532</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error(Uncertainty)</td>
<td>23</td>
<td>10530000.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lastly, the Intruder Aircraft (IA) processing time was analyzed for which the descriptive statistics are shown below in Table 10.
Table 10

Descriptive Statistics for IA Processing Time (ms)

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>50%</td>
<td>5630.09</td>
<td>1721.638</td>
</tr>
<tr>
<td>90%</td>
<td>6161.18</td>
<td>2094.812</td>
</tr>
</tbody>
</table>

Similarly to the reroute processing time, the ANOVA did not find a statistically significant main effect for reliability with $F(1, 23)=2.964$, $p=.100$ or for uncertainty with $F(1, 23)=.252$, $p=.621$. The interaction between reliability and uncertainty also failed to show a significance with $F(1, 23)=.037$, $p=.850$. The ANOVA source table is shown below (see Table 11).

Table 11

ANOVA Source Table for IA Processing Time (ms)

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$p$</th>
<th>$\eta^2$</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>1</td>
<td>5052013.92</td>
<td>2.964</td>
<td>.100</td>
<td>.124</td>
<td>.376</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>1</td>
<td>1704728.44</td>
<td>.252</td>
<td>.621</td>
<td>.012</td>
<td>.077</td>
</tr>
<tr>
<td>Reliability*Uncertainty</td>
<td>1</td>
<td>59228.284</td>
<td>.037</td>
<td>.850</td>
<td>.002</td>
<td>.054</td>
</tr>
<tr>
<td>Error(Reliability)</td>
<td>21</td>
<td>1704728.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error(Uncertainty)</td>
<td>21</td>
<td>2853774.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Hypotheses 11 and 12 predicted that when participants were exposed to low uncertainty targets and high system reliability, IA processing time was going to be lower
than when presented with high uncertainty targets and low system reliability respectively. Since the findings do not support those predictions, we reject hypothesis 11 as well as hypothesis 12. As for hypothesis 13 that deals with the interaction effect between reliability and uncertainty and it affecting secondary task time, we reject this hypothesis because none of the three secondary tasks processing times showed a statistically significant interaction effect. In the next section, the major findings of the study are discussed.

Discussion

The objective of this study was to examine the effects of system reliability and task uncertainty on performance under high time pressure when conducting unmanned aerial vehicle operations. The aim of the study was to further the understanding of how system reliability and uncertainty of the task can impact performance in highly autonomous UASs and use that knowledge to improve future designs as well as operators' experience. According to the findings, both system reliability and task uncertainty had a significant effect on primary image processing time but not their interaction. Furthermore, reliability and uncertainty did not show a statistically significant main effect on primary task accuracy and neither did their interaction. Similarly, no significance was found for reliability and uncertainty or their interaction, on secondary task processing time for intruder aircraft or pop-up threat reroute. Lastly, uncertainty was found to have a main effect on MMI processing time but reliability was not found to be statistically significant, and neither was the interaction between reliability and uncertainty. The results of the performance measures are discussed in two separate sections, primary task and secondary tasks.
Primary Task

*Primary task performance measures.* For the primary task, two different performance measures were recorded: image processing accuracy and image processing time. System reliability was not found to be significant for primary task accuracy, which may be derived from the participant’s understanding of the task at hand. Part of the briefing explained that the system would be unreliable at least once. Participants knew there were two levels of reliability on which they would be tested and that neither of which was set up at 100% reliability, but they were not aware of what each level was. A possible explanation of the lack of significance of reliability on accuracy is that participants were even more careful when identifying targets and distracters and processing images in each scenario because they were aware that the system was not set up to be 100% reliable at any point in the study. Surprisingly and contrary to the hypothesis, uncertainty of the task had no significance on accuracy either. Processing both, images where targets and distracters were both present and images where only targets or distracters were present, had statistically similar accuracy scores. Participants seemed to have had no added difficulty differentiating targets from distracters when processing images correctly. The feature difference between targets and distracters was only color, not shape or size.

Moreover, primary task image processing time showed statistical significance for both system reliability and task uncertainty but not their interaction. The findings support the claim that when the reliability of the system is high participants take less time processing the images; not only is there a higher percentage of images correctly processed by the automation but there is also less mouse-clicking involved for the
incorrect images to be corrected therefore saving the participant some time processing the image. That also holds true that when the task uncertainty is low; when participants have a way to compare between targets and distracters in an image, they can better differentiate between distracters and targets and thus process the image faster. On the other hand, the interaction between reliability and uncertainty was not significant, which did not support the predictions stipulated. This may be due to the small number of targets in each imaged captured. It may be possible that the task was not demanding enough to show a significant interaction and increasing the task demand might show an interaction. In the next section, the processing times for all three secondary tasks are discussed.

Secondary Tasks

Secondary tasks performance measures. Response time data was collected as the performance measure for all three secondary tasks and each of which are discussed in the following order: mission mode indicator (MMI), pop-up threats reroutes and intruder aircraft (IA). In all the secondary tasks the processing times are a reflection of the workload experienced by the participants due to system reliability and uncertainty for their primary task given that participants used their spare capacity. Since participants had to focus primarily on target/distracter image processing when the task was active, their processing time with their primary task impacted their processing time for subsequent secondary tasks.

The MMI processing time only showed that it was significantly affected by uncertainty; more specifically low uncertainty resulted in higher processing time. This finding directly contradicts the prediction that stated that MMI processing time would be lower when participants were exposed to low uncertainty since it would be easier for
participants to differentiate the targets. The findings showed that MMI processing time did not reduce when participants were presented with low uncertainty. A possible reason for this could be that because participants had accomplished the primary task quicker, they did not feel rushed to input the numeric string presented to them in the pop-up window to bring the system back to “good health” status. Participants knew that their primary task was completed; they took their time to complete the secondary task. In contrast, if participants were presented with high uncertainty on their primary task, and they had to rush to make a decision quickly in order to successfully complete that task, they may have carried over some of that sense of urgency to the MMI task, hence completing it faster. Moreover, system reliability did not show significance in MMI processing time. Given that participants knew the automation would be unreliable at least once, they may have taken similar care in their primary task image processing across all four scenarios, resulting in similar spare time to complete the MMI task. Also, the interaction between system reliability and task uncertainty did not show statistical significance for similar reasons. The trend of lack of significance continued with the last two secondary tasks.

The findings did not support the claims that high system reliability, low uncertainty and their interaction would have an effect on pop-up threats reroute processing time and IA processing time. Results showed that pop-up threats reroute processing times were similar across the board and participants were not affected by the reliability of the system, the tasks uncertainty or the interaction of the two, when it came to processing reroutes. A reason for this could be that since they were aware that the reroute was a time sensitive task, the participants devoted the same amount of resources
to it regardless of how they reacted to the primary task and the different levels of reliability and uncertainty presented to them. The IV that affected the primary task had no impact on secondary tasks resulting in similar spare capacity.

In addition, the IA processing time was not impacted by the independent variables either. The IA occurred randomly in each scenario, leaving the participant less room to respond in advance or plan ahead. Since IA requires the same code input, there might be some learning transferred from the second scenario they were presented with to the third and fourth. Thus, for IA processing time, the findings did not support the claims that high system reliability, low uncertainty and their interaction would have an effect. In the next section, the study limitations are explored.

Study Limitations

In the present study, uncertainty was measured more effectively for the primary task. However, the secondary tasks did not reflect conclusive results and part of that might come from secondary tasks processing times being dependent on the primary task processing time. In addition, the partial eta squared for the primary task processing time was low, showing that only about 20% of the variance could be accounted for by the factors. In turn, the observed power for the primary task processing time was not as high, leaving room for failure to detect an effect when there is one. Moreover, there were no significant interactions in the study, which could have resulted from the primary task not being demanding enough to challenge participant’s perceived mental workload capacity. In addition, due to the nature of the study, where participants are exposed to all levels, there may be some learning effects associated with some aspects of the primary task and all secondary tasks. Lastly, confounds such as video game proficiency or previous exposure to similar UAS software, may have impacted participant’s response times and
accuracy scores. Some suggestions are explored in the next section, which provides recommendation for future research.

**Recommendations for Future Research**

For research in UAS pilot performance, it is usually helpful to evaluate the level of perceived workload. The original intention of this study was to also analyze and evaluate workload. Due to corrupted data, the current study was not able to evaluate how system reliability and task uncertainty may affect perceived workload. Recommendations for future studies would be to use NASA-TLX after each on of the scenarios to help understand if and how reliability and uncertainty affect perceived workload.

Also, increasing task fidelity to be more of what UAS pilots experience in their stations could shed more light on pilot performance and how to increase it based on system reliability and task uncertainty understanding. Providing pilots with a continuous visual feedback and not just image captures when they approach a coded waypoint. If a flight path provides video-like feedback, the pilot may feel more involved in the task and thus processing images more accurately. Their perceived workload levels may increase just enough to where they feel they are in the loop, not over relying on the automation and keeping a high job satisfaction.

Furthermore, if at all possible, something that would be interesting to investigate would be if adding visual aids to the workstation versus not having visual aids could affect the uncertainty of the task, if the visual aid makes the distinction between a target and a distracter. Since the findings suggest that having comparison present, that is at least one target and one distracter in an image, allows the pilot to make decisions faster.
Having something to compare the images the pilot is presented with, can improve their accuracy and processing time because they are not likely to have both, targets and distracters, present in every one of the images they have to process.

This type of research will add to the body of knowledge that exists about UAS operations. Reporting findings that will improve the pilot experience and their performance will increase the usability of these very efficient and effective systems. By understanding the implications of system reliability and uncertainty on pilot performance, we can better design for the future implementations of UASs.

Conclusion

Due to the vast use of UASs in the military, the rapid growth of UAS applications in many different domains and the imminent integration into the NAS, it is important to broaden the body of knowledge regarding the UAS pilots' mental processes and what kind of things affect their performance. The aim of human factors is to foresee areas of concern and come up with plausible solutions before those areas become serious problems. Performance, job satisfaction, pilot selection and workload are amongst the areas of interest for UAS operations research. This experiment expands on how system reliability and task uncertainty affect one of those, performance.

The present study has found that pilots processing time is affected by system reliability and task uncertainty. The task uncertainty portion may provide important clues as to what kind of training pilots should be given. In regards to reliability, the study supports what the literature says; when the reliability is high, processing time goes down. This indicated that it is important for the reliability of the system to be as good as it can
be, but something interesting came out of this study. The accuracy was not significantly affected by the reliability because, like it was mentioned before, the participants were told that the system was wrong at least once. That made them more involved with the system and more aware of what they had to do. Pilots may benefit from some kind of warning that their system will be wrong so that they can perform better instead of overrelying on the automation and going from being a significant part of the human-system team, to playing a passive role.
References


Appendix A
IRB Number: 10-135

Informed Consent Form
For the study:

The Effects of System Reliability and Task Uncertainty on Unmanned Aerial Vehicle Operator Performance under High Time Pressure

Conducted by Manuela Jaramillo
Advisor: Dr. Dahai Liu
Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd, Daytona Beach, FL 32114

The purpose of this study is to examine the effect of System Reliability and task uncertainty on performance and workload. This experiment consists of one session that will last approximately forty five minutes. During this session, you will be asked to complete four computer-based UAS simulations, fill out a short survey after each one and fill out a questionnaire regarding your perceived feeling of workload at the end of the session.

Your participation in this study will help us determine an appropriate level of automation and help distinguish potential pilot candidates for future UASs. There are no known risks associated with this experiment. The data collected from your participation will remain confidential. You will be compensated for your participation with extra credit in an undergraduate course and will be eligible to receive a $50.00 cash prize for best overall performance. You may terminate your participation at any time.

Thank you for your participation. If you have any questions, please ask during the experiment, or call Manuela Jaramillo at 863.458.2758 or Dr. Dahai Liu at 386.226.6214.

Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time. I have been informed as to the general scientific purposes of the experiment and that I will receive extra credit for participation in this study and will be eligible to receive $50.00 in the event that I have the best overall task performance in the entire study. Prize money is contingent on completion of the study.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction.

I have read and fully understand the consent form and I sign it freely and voluntarily.

Participant’s Name: _______________________________ ID# ______________

Participant’s Signature: _______________________________ Date ______________

Experimenter Signature: _______________________________ Date ______________