International Journal of Aviation, Aeronautics, and Aerospace

Volume 4 | Issue 2 Article 5

4-24-2017

Effects of System Reliability and Time Pressure on Autonomous Unmanned Aerial Vehicle Operator Performance and Mental Workload

Dahai Liu
Embry-Riddle Aeronautical University - Daytona Beach, eraufixliu@adoran.box.bepress.com
Rania Ghatas
NASA, rania.w.ghatas@nasa.gov
Christina Frederick-Recascino
Embry-Riddle Aeronautical University - Daytona Beach, christina.frederick@erau.edu
Dennis Vincenzi Ph.D.
Embry-Riddle Aeronautical University - Worldwide, vincenzd@erau.edu

Scholarly Commons Citation
Liu, D., Ghatas, R., Frederick-Recascino, C., & Vincenzi, D. (2017). Effects of System Reliability and Time Pressure on Autonomous Unmanned Aerial Vehicle Operator Performance and Mental Workload. *International Journal of Aviation, Aeronautics, and Aerospace, 4*(2). https://doi.org/10.15394/ijaa.2017.1168

The next generation of flight is already underway and Unmanned Aerial Systems (UASs) are in the midst of aviation's next generation. UAS's have proven themselves to be versatile, efficient, and valuable. As such, approximately 50 companies, universities, and government organizations in the United States (U.S.) alone are developing and producing some 155 unoccupied aircraft designs (Dorr & Duquette, 2010). That number has grown dramatically in recent years. The number of remote pilots in 2016 was estimated at approximately 20,362 and is forecast to increase to 281,300 in 2021 (Price, 2017).

UAS operations are multi-faceted and complex. Understanding what those operations entail and the automation behind them could help in determining how to use combinations of automation with UAS procedures in making the system a better one that not only decreases key human factors issues, such as workload on an operator, but also allows an operator to maintain full control at all times (Prevot, et al., 2005). There are many human factors issues that need further investigation, such as trust of automation, workload, situational awareness, confusion, displays and controls, crisis management and crew composition, selection, and training (McCarley & Wickens, 2004; Weil, Freeman, MacMillan, Jackson, Mauer, Patterson, & Linegang, 2006; Hobbs & Lyall, 2016).

It has been recognized that human trust of automation is closely related to the perceived reliability of system automation. An important aspect in automation reliability is realizing that often times the automation is asked to perform certain tasks that are themselves dynamic and uncertain in nature, such as weather forecasting or predicting enemy intent; therefore, it would be simply impossible for the automation to perform at a high level of reliability (Wickens, et al., 2004).

Trust is believed to be in direct proportion to perceived reliability. Too high a trust level in automation could lead to complacency, whereas too low a trust level could lead to distrust with the system going un-used. Trust in automation by an operator needs to be appropriately calibrated, as extremes could be dangerous (Parasuraman & Riley, 1997).

On the other hand, for an environment that is time sensitive, such as that of UAS operations, time pressure is a critical issue. Extensive research has been conducted on the issue of time pressure. Research has shown that the effects of time pressure, in relation to decision-making, causes operators to submit to coping processes (Boussemart, Donmez, Cummings, & Las Fargeas, 2009; Hughes, 2004). Time pressure in UAS operations is a critical factor when it comes to performance. Research has demonstrated that performance decreased as a result of an increase in workload due to time pressure, particularly in tasks that already present high levels of stress to the operator (e.g. target acquisition; Hughes & Babski-Reeves, 2005). According to Burke, Oron-Gilad, Conway, and Hancock (2007), time pressure during a target acquisition task resulted in the degradation of operator ability in distinguishing friend from foe. Situations such as these pose serious threats to military operations. Although time pressure may make a somewhat tedious and boring task more interesting and enjoyable, it could also cause higher levels of stress and mental overload, which result in poorer performance levels, increased fatigue and mental workload, and poor decision-making skills, among others (Driskell & Salas, 1996; Svenson & Maule, 1993).

The use of UAV's in military operations in recent years has been greatly expanded and discussion is now underway about how to integrate UAS's into civilian airspace. The highly versatile, efficient, valuable, and autonomous nature of the UAS has been extensively debated by researchers. Since their pre-aviation history, the environments in which UAS's operate, and the operators themselves, have been a major topic in the research field. UAS's could be successfully employed in a wide array of civilian aerial operations, including crop dusting, aerial photography, land surveying and remote sensing. However, how to use UAS's successfully in non-combat operations to optimize UAS performance and ensure civilian safety is accompanied by significant human factors questions. In order to attain the full potential of this technology, one must understand the relationship between the system and the human operator. This relationship exists through the interface in which the system and the human operator interact.

There is no doubt that UAS's are a driving force, leading aviation to the future that is NextGen. There is a long list of human factors issues with UAS automation, and many areas in which more information is needed in order to ensure safe UAS operations, including automation reliability, and optimization of operator performance and distribution of mental workload across tasks. Research in these areas is extremely limited for UASs applications. The paper examines several of these important areas in an experimental study. The objective of this study was to investigate the effects of system reliability and time pressure on UAS operator performance and mental workload in autonomous UAS operations.

Method

Participants

Twenty-four college students from Embry-Riddle Aeronautical University were recruited for this study. For their engagement in the study, participants received extra credit in an undergraduate course and had the opportunity to win $50 for best overall performance.

Apparatus

This study utilized a generic UAS human factors test bed, named Multi-Modal Immersive Intelligent Interface for Remote Operation (MIIIRO) system. The MIIIRO system was developed by IA Tech, Inc., with support from the Air Force Research Laboratory, to perform or simulate the operations of a number of autonomous UASs, providing a synthetic task environment that allows for simulations of multiple autonomous unmanned aerial vehicles (Galster, Nelson, & Bolia, n.d.; Tso, Tharp, Tai, Draper, Calhoun, & Ruff, 2003).

The apparatus consists of a desktop PC installed MIIIRO with two PC monitors. The first monitor (Figure 1) portrays the Tactical Situation Display (TSD), which provides a plan view of the mission environment, including waypoints, flight segments, targets, and threats, in addition to icons showing the positions and status for each of the unmanned vehicle. The Mission Mode Indicator (MMI), which displays a series of lights (green, yellow, and red), is also displayed at the top of the TSD (Tso, et al., 2003). MMI indicates the status of the vehicle, which requires operator attention if MMI is not green. The second monitor (Figure 2) is used for image processing and shows the Image Management Display (IMD) that includes an image cue and image display.

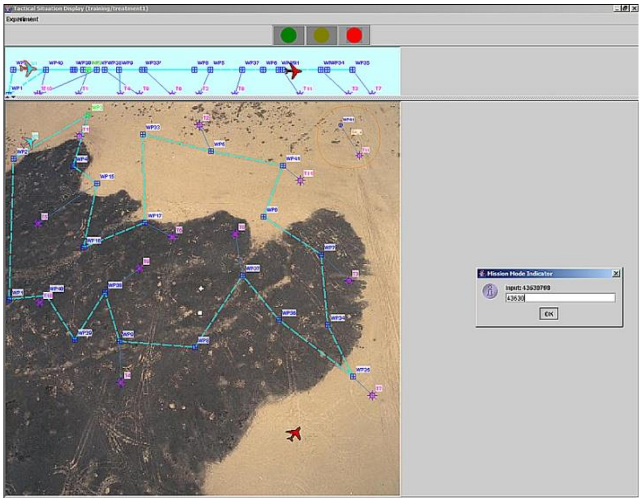

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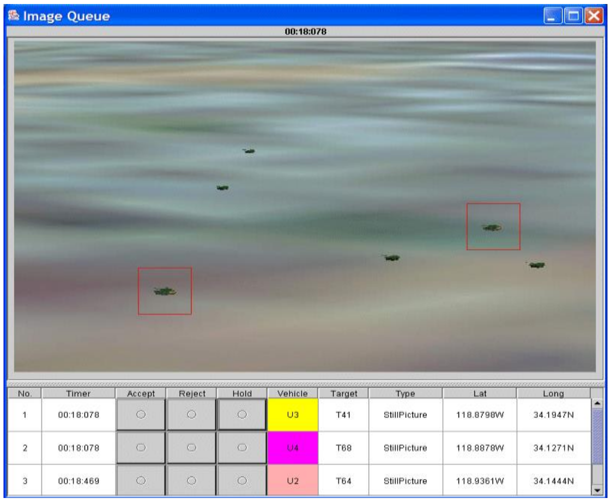
Figure 1. MIIIRO Tactile Situation Display (TSD)



No.	Timer	Accept	Reject	Hold	Vehicle	Target	Type	Lat	Long
1	00:18:078	○	○	○	U3	T41	StillPicture	118.8798W	34.1947N
2	00:18:078	○	○	○	U4	T68	StillPicture	118.8878W	34.1271N
3	00:18:469	○	○	○	U2	T64	StillPicture	118.9361W	34.1444N

Figure 2. MIIIRO Image Management Display (IMD)

Design

A 2x2 within subjects, fully factorial design was used for this study. The study consisted of two IVs; system reliability was defined as the percentage of automation correct response, i.e. percentage of time that automation identifies the correct target image, set at two levels (80% and 40%), and time pressure for target acquisition also set at two levels (5 seconds and 10 seconds). A 4x4 Latin Square (LS) design (Table 1) was used to determine the order of trials in order to counter balance any learning effects. The dependent variables (DVs) that were collected were operator performance and mental workload. Mental workload was subjectively reported by the participants using the NASA-TLX standardized subjective workload scale after each of the four scenarios. Operator performance was operationalized using a set of variables including image processing time, target acquisition accuracy, MMI processing time, re-route processing time for pop-up threats, and Intruder Aircraft (IA) processing time. These performance variables were captured by the MIIIRO system.

Table 1.
LS-4 Experimental Design

Order of Treatment Scenarios				
Group 1	1	2	4	3
Group 2	2	3	1	4
Group 3	3	4	2	1
Group 4	4	1	3	2

Primary task. The primary task in this study was target acquisition. Waypoints were preset for the autonomous vehicle. Additionally, 10 image capture locations were preset along the Unmanned Aerial Vehicle (UAV) flight path. Participants were asked to view the images and to decipher whether or not the Automatic Target Recognition (ATR) tool—the part of the IMD on the second computer monitor that recognizes targets or objects based on data obtained from the MIIIRO software—had correctly selected the targets at the waypoint at which the UAV was located. Each waypoint contained at least one terrain vehicle, which may or may not have been a target, in addition to distracters that were randomly present at certain waypoints. The ATR, which had two preset reliability percentages at 40% and 80%, placed a red box around what it recognized as a target. The ATR was not always be correct and sometimes placed the red box around non-targets and/or distracters; the frequency of which was determined by the reliability percentages. If such a mistake was made, the participant was required to deselect the incorrect images, select the correct ones, and click “accept” on the IMD using the standard computer mouse. In the cases where the ATR recognized all the correct targets, the participants were instructed to click on “accept”; however, if the ATR recognized non-targets and/or distracters and no targets were present, the participant was told to instead click on “reject.” If no action was taken by the participant in the allotted time, the automation processed and “accepted” the red boxed images ‘as is’. The task described above measured acquisition accuracy and image processing time.

Secondary tasks. There were three secondary tasks in this study, which included: (1) processing IA, (2) responding to automation-made flight path change recommendations, and (3) monitoring the MMI.

The first secondary task consisted of processing IA that entered the operational airspace. The objective of including this task was to imitate the occurrence of unexpected IA that may enter into the airspace, requiring a quick and attentive response from the participant, as it is considered to be a highly critical situation in typical UAS operations. In order to distinguish between the UAV in the study and the unexpected aircraft, the IA resembled a red aircraft (Figure 3) and was be displayed three times at random intervals throughout the course of the simulation. In order to resolve the IA conflict, participants were required to click on the red aircraft using the standard computer mouse and then entered a predetermined code that was made available to them on a piece of paper in front of each participant.

The second secondary task was responding to recommendations, made by the automation, to change the UAV flight path (Figure 4). Participants were required to respond to these recommendations when “pop-up threats” were encountered by the UAV. These so-called “pop-up threats” were designed into the flight path; yet, were undetectable to the participant until the UAV encountered them at different waypoints. At the time when the threats were encountered, the automation made a recommendation to change the route of the flight path in order to avoid the “pop-up threat.” However, not all of the recommendations that were made by the automation were necessary. As a result, the participant was required to acknowledge the recommended change and either “accept” or “reject” the route change.

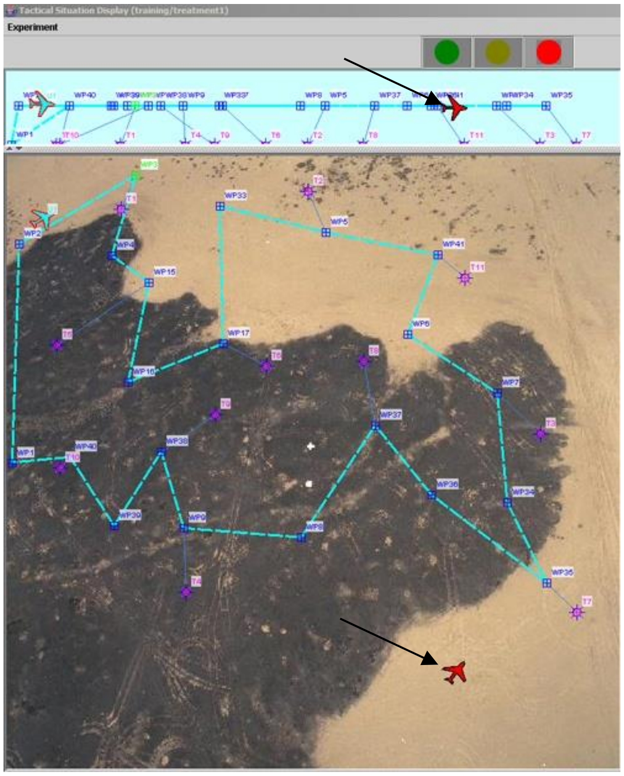


Figure 3. Intruder Aircraft (IA) displayed as red aircraft

The third and final secondary task involved the MMI (Figure 5) that is displayed at the top of the TSD. The MMI was represented by a series of three round lights (green, yellow, and red) organized in a horizontal line, similar to a horizontal traffic light. These series of lights indicated the status of the UAV; green represented a state of good health, yellow indicated that action was needed, and red indicated that an urgent action was needed. If the status of the UAV was green, the participant did not need to take any action; on the contrary, if the status of the UAV was either yellow or red, the participant needed to take immediate action by clicking on the illuminated yellow or red light and correctly typing in a string of text that appeared on the screen of the first computer monitor (Figure 6). Once the participant typed in the correct text string, the MMI went back to the color green, indicating that it had returned to a state of good health.

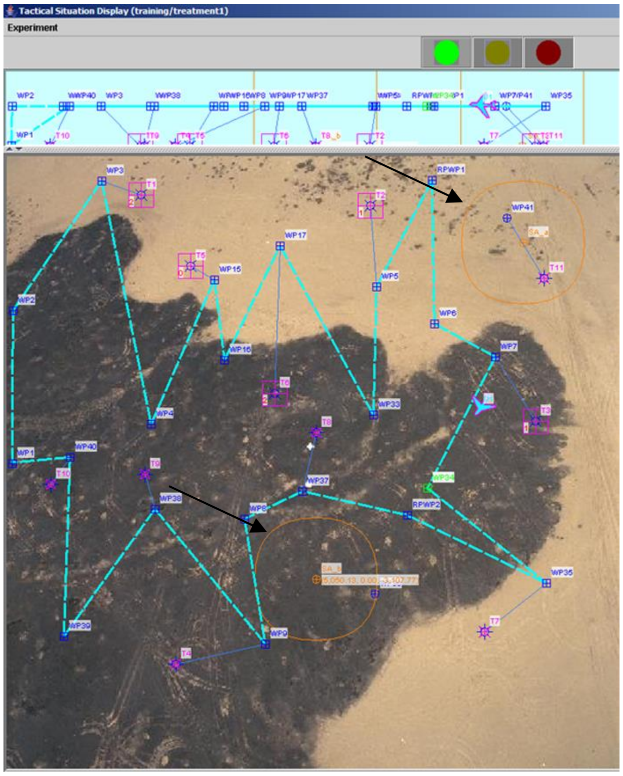


Figure 4. Flight path change recommendations for “pop-up threats”

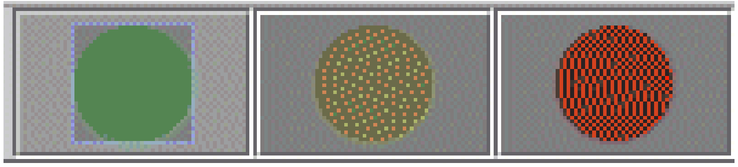


Figure 5. Mission Mode Indicator (MMI)

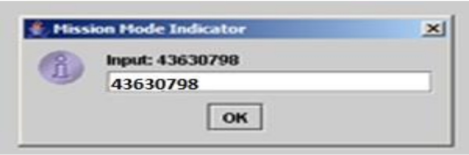


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Figure 6. MMI pop-up “input code” screen

The MIIIRO software automatically measured the results of the three secondary tasks. These measures consisted of the number of events and response times for the IA, the "pop-up threats," and the MMI. In order to subjectively measure the participants' mental workload, the NASA-TLX standardized subjective workload scale was used following the completion of the primary and secondary tasks in each of the four scenarios. The NASA-TLX measure provided an overall mental workload scale based on a weighted average of the following six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration.

Procedure

Once the participants arrived at the lab, they were asked to fill out a biographical questionnaire. The participants were then introduced to the paper-pencil version of the NASA-TLX standardized subjective workload scale; the proper method of filling out the form was explained at that time. In order to allow for familiarization with the operation of the MIIIRO simulator, each participant went through a five-minute training session that included an instructional hands-on training session, which included presentation of all possible scenario events that occur during the actual study session. During the training, two differences existed between the training and the actual study. First, system reliability was set at 50% and, in addition, a 15-second time limit was used to avoid any learning effects. After the training process, the participant was given the opportunity to ask questions or comment on any concerns he or she may have had. Once any questions or concerns had been addressed, the participant began with the actual data collection phase of the study.

Each participant received four treatment scenarios using the Latin Square Design in order to avoid any learning effects. These four treatment scenarios included, in no particular order: (1) 40% system reliability with 5 seconds of time pressure, (2) 40% system reliability with 10 seconds of time pressure, (3) 80% system reliability with 5 seconds of time pressure, and (4) 80% system reliability with 10 seconds of time pressure. Participants were not notified of the reliability levels. These levels of uncertainty/reliability and time pressure were selected on the basis of previous research studies that utilized similar variables (Liu and Reynolds, 2011; Liu, Wasson, and Vincenzi, 2009; Liu, Peterson, Vincenzi, and Doherty, 2011). Each of these treatment scenarios lasted about seven minutes, with a five-minute break after the second treatment scenario. After the completion of each treatment scenario, participants were asked to fill out the NASA-TLX standardized subjective workload scale, resulting in four separate forms for the NASA-TLX workload scale for each participant. Each participant was then verbally notified of his/her performance during the debriefing phase of the study and any further questions or concerns were addressed at that time. Once all participants had completed the study, the participant with the best performance on the primary tasks was contacted and received $50.

Results

The purpose of this study was to analyze the effects of system reliability and time pressure on UAS operator performance and mental workload. A repeated measures analysis of variance (ANOVA) was used to analyze the effect of each independent variable on the following dependent variables: image processing accuracy, image processing time, MMI processing time, pop-up threats re-route processing time, IA processing time, and mental workload. It is included in the outcome of the results described in this section. For all analyses, an alpha value (α) of 0.05 was used to determine significance.

Primary Task

There were two primary task performance measures collected during this study, image processing time, and target acquisition accuracy. Repeated measures ANOVA's were conducted to analyze the hypotheses made regarding each primary task performance measure.

Image processing time. Image processing time was the first primary task performance dependent measure to be tested. The means and standard deviations for image processing time are presented in Table 2. The results of the ANOVA for image processing time are shown in Table 3.

The main effect of system reliability on image processing time was analyzed first and was found to be statistically significant with $F(1, 23) = 13.613$, $p = .001$. The significance of this effect indicated that the participants' processing times were significantly lower (better) in the primary task when they were exposed to the low system reliability (40%) than when they were exposed to the high system reliability (80%). The main effect of time pressure on image processing time and the interaction between system reliability and time pressure for primary task processing time were also analyzed, but neither one was found to be statistically significant.

Target acquisition accuracy. Target acquisition accuracy was the second primary task performance dependent measure to be tested. The means and standard deviations for target acquisition accuracy are presented in Table 4. The results of the ANOVA are presented in Table 5 and are meant to reflect percentages.

Table 2

Primary Task's Image Processing Time Means and Standard Deviations (in milliseconds)

	Mean	Standard Deviation	N
40% System Reliability / High Time Pressure	2384.500	449.459	24
40% System Reliability / Low Time Pressure	2506.125	757.080	24
80% System Reliability / High Time Pressure	2389.667	474.585	24
80% System Reliability / Low Time Pressure	2844.083	623.191	24

Table 3

ANOVA Source Table for Primary Task Image Processing Time (in milliseconds)

Source Greenhouse-Geisser	Sum of Squares (SS)	*df*	Mean Square	*F*	*p*	Observed Power
System Reliability	1990944.010	1	1990944.010	13.613	.001*	.942
Time Pressure	706408.594	1	706408.594	3.964	.059	.479
System Reliability*Time Pressure	664501.760	1	664501.760	3.223	.086	.405

* indicates *p* value < 0.05

Table 4

Primary Task's Target Acquisition Accuracy (percentage) Means and Standard Deviations

	Mean	Standard Deviation	N
40% System Reliability / High Time Pressure	84.875	16.201	24
40% System Reliability / Low Time Pressure	86.000	10.299	24
80% System Reliability / High Time Pressure	85.542	12.635	24
80% System Reliability / Low Time Pressure	77.792	19.580	24

Table 5

ANOVA Source Table for Primary Task Target Acquisition Accuracy

Source Greenhouse-Geisser	Sum of Squares (SS)	*df*	Mean Square	*F*	*p*	Observed Power
System Reliability	263.344	1	263.344	3.641	.069	.448
Time Pressure	341.260	1	341.260	6.717	.016*	.699
System Reliability*Time Pressure	472.594	1	472.594	3.622	.070	.446

* indicates *p* value < 0.05

The main effect of time pressure on target acquisition accuracy was analyzed *and* was shown to be statistically significant, $F(1, 23) = 6.717$ and $p = .016$. The significance of this effect indicated that the target acquisition accuracy of participants was higher (better) when they were exposed to the higher time pressure condition (5 seconds) than when they were exposed to the lower time pressure condition (10 seconds), as shown in Figure 7. The main effect of system reliability on target acquisition accuracy and the interaction between system reliability and time pressure were also analyzed and both were found to be statistically insignificant.

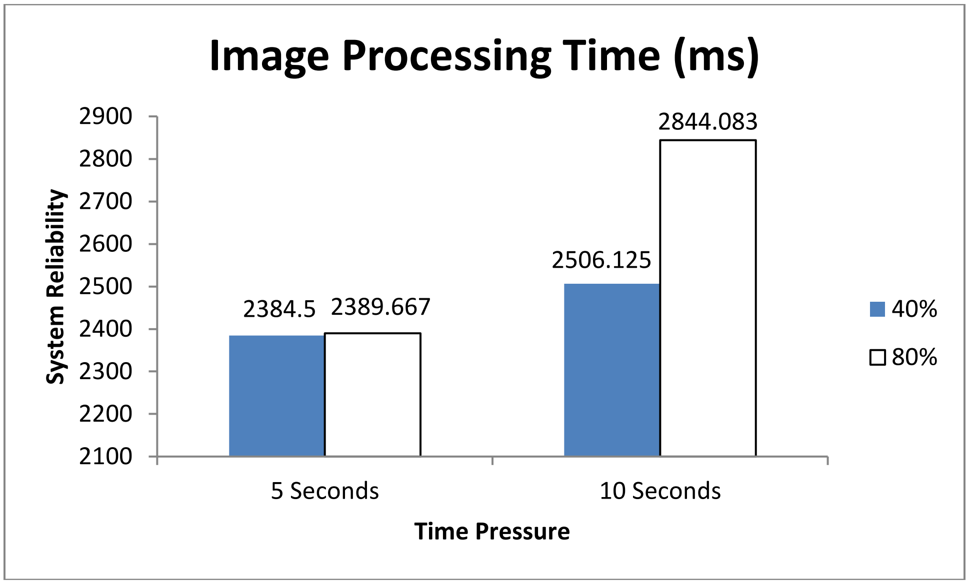

Figure 7. Effect of time pressure and reliability on image processing time

Secondary Task

In addition to the primary tasks, there were three secondary task performance measures collected during this study, which included Intruder Aircraft (IA) processing time, pop-up threats re-routing processing time, and Mission Mode Indicator (MMI) processing time. Repeated measures ANOVAs were conducted to analyze the hypotheses made regarding each secondary task performance measure.

Intruder aircraft (IA) processing time. IA processing time was the first of the three secondary task performance dependent measures to be tested. The means and standard deviations for IA processing time are presented in Table 6. The results of the ANOVA for IA processing time are shown in Table 7.

The effects of system reliability, time pressure, and the interaction between the two on IA processing time were all analyzed, but none of them were statistically significant.

Table 6

Secondary Task's IA Processing Time Means and Standard Deviations (in milliseconds)

	Mean	Standard Deviation	N
40% System Reliability / High Time Pressure	6112.583	1965.309	24
40% System Reliability / Low Time Pressure	6405.458	3631.532	24
80% System Reliability / High Time Pressure	5890.542	2210.470	24
80% System Reliability / Low Time Pressure	5902.708	1741.681	24

Table 7

ANOVA Source Table for Secondary Task IA Processing Time (in milliseconds)

Source Greenhouse-Geisser	Sum of Squares (SS)	*Df*	Mean Square	*F*	*p*	Observed Power
System Reliability	558302.510	1	558302.510	.393	.537	.092
Time Pressure	3151937.760	1	3151937.760	1.188	.287	.181
System Reliability*Time Pressure	472783.010	1	472783.010	.075	.787	.058

Pop-up threats re-routing processing time. The second of the three secondary tasks performance dependent measures to be tested was the processing time for the re-routing of pop-up threats. Table 8 presents the means and standard deviations for the pop-up threats re-routing processing time and Table 9 shows the results of the ANOVA.

The main effects of system reliability and time pressure on pop-up threats processing time were analyzed, but neither one was statistically significant. However, there was a significant interaction between system reliability and time pressure with $F(1, 23) = 6.142$ and $p = .021$. The results of this interaction are shown in Figure 8.

Table 8

Secondary Task's Pop-up Threats Re-routing Processing Time Means and Standard Deviations (in milliseconds)

	Mean	Standard Deviation	N
40% System Reliability / High Time Pressure	2568.333	646.298	24
40% System Reliability / Low Time Pressure	3078.333	924.850	24
80% System Reliability / High Time Pressure	3074.167	721.195	24
80% System Reliability / Low Time Pressure	2901.417	858.656	24

Mission mode indicator (MMI) processing time. The final secondary task performance measure, or DV, that was tested was the MMI processing time. Table 10 shows the means and standard deviations for the MMI processing time. The results of the ANOVA are presented in Table 11.

Table 9
ANOVA Source Table for Secondary Task Pop-up Threats Re-routing Processing Time (in milliseconds)

Source Greenhouse-Geisser	Sum of Squares (SS)	*Df*	Mean Square	*F*	*p*	Observed Power
System Reliability	682425.375	1	682425.375	1.345	.258	.199
Time Pressure	649117.042	1	649117.042	1.833	.189	.254
System Reliability*Time Pressure	2796885.375	1	2796885.375	6.142	.021*	.661

* indicates *p* value < 0.05

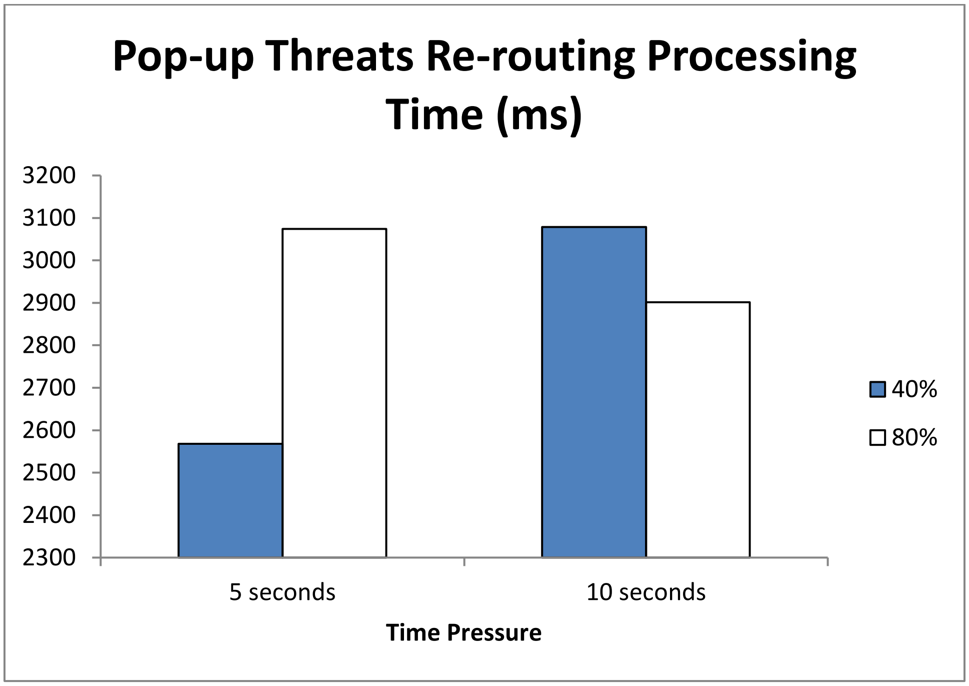

Figure 8. System Reliability and Time Pressure Interaction on Pop-up Threats Re-routing Processing Time

Table 10

Secondary Task's MMI Processing Time Means and Standard Deviations (in milliseconds)

	Mean	Standard Deviation	N
40% System Reliability / High Time Pressure	9934.667	3129.013	24
40% System Reliability / Low Time Pressure	9860.667	3820.227	24
80% System Reliability / High Time Pressure	8994.500	3148.219	24
80% System Reliability / Low Time Pressure	9229.500	4649.934	24

Table 11

ANOVA Source Table for Secondary Task MMI Processing Time (in milliseconds)

Source Greenhouse-Geisser	Sum of Squares (SS)	*df*	Mean Square	*F*	*p*	Observed Power
System Reliability	155526.000	1	155526.000	.024	.879	.052
Time Pressure	1.481E7	1	1.481E7	2.960	.099	.378
System Reliability*Time Pressure	572886.000	1	572886.000	.088	.769	.059

The effects of system reliability, time pressure, and the interaction between the two on MMI processing time were all analyzed, but none of them were statistically significant.

Mental Workload

Mental workload was subjectively measured using the NASA-TLX after each trial. The subjective ratings were on a scale ranging from 0 to 100 on six different workload factors, with 100 being the highest level of workload and 0 being the lowest level and adjusted based on the pair-wise comparison among workload factors. A repeated measures ANOVA was conducted to test the hypotheses regarding mental workload. Table 12 shows the means and standard deviations for mental workload and the results of the ANOVA are presented in Table 13.

Table 12

Mental Workload Means and Standard Deviations

	Mean	Standard Deviation	N
40% System Reliability / High Time Pressure	39.139	19.910	24
40% System Reliability / Low Time Pressure	32.083	18.880	24
80% System Reliability / High Time Pressure	36.903	23.476	24
80% System Reliability / Low Time Pressure	35.862	20.305	24

Table 13
ANOVA Source Table for Mental Workload

Source Greenhouse-Geisser	Sum of Squares (SS)	*df*	Mean Square	*F*	*p*	Observed Power
System Reliability	14.281	1	14.281	.074	.789	.058
Time Pressure	393.470	1	393.470	4.292	.050	.510
System Reliability*Time Pressure	217.060	1	217.060	2.346	.139	.312

The effects of system reliability, time pressure, and the interaction between the two on mental workload were all analyzed, but none of them were statistically significant.

Discussion

The objective of this study was to examine the effect of system reliability and time pressure on UAS operator task performance and mental workload when conducting certain tasks relating to UAS operation. The results of this study are discussed here, organized into main areas of interest: primary task performance measures, secondary task performance measures, and mental workload.

Primary Task Performance Measures

There were two primary task performance measures collected during this study: image processing time and target acquisition accuracy.

Image processing time. From the results, image processing time showed significance for system reliability and no significant effect for time pressure. Additionally, no significant interaction was found for system reliability and time pressure with regards to image processing time. The significance for system reliability indicated that the participants‘ processing time scores were lower (better) when they were exposed to the low system reliability (40%) than when they were exposed to the high system reliability (80%). This contradicted predictions made about system reliability and image processing time. During low system reliability, results showed that participants did not make many clicks to fix the target recognizer thus taking less time to complete the task. Although most of the targets were not pre-selected by the ATR from the MIIIRO software in low system reliability, one explanation for these results could be that participants were more concerned with completing the task quickly rather than accurately. On the opposite side of the spectrum, another explanation could be that participants confused the distracters for targets and as a result may have thought the “targets” were correctly selected by the ATR. The latter scenario would explain why participants took less time in processing the image – they only needed to click "accept" rather than going through the process of selecting targets, or deselecting distracters, and then clicking on "accept;" it saved time, thus having a lower processing time.

The fact that the participants were under more time pressure (5 seconds) to process the images possibly led them to exceed the 5-second time limit thus having the MIIIRO system automatically answering for them. This would also explain why there was a significant effect for system reliability and not for time pressure. Essentially, the MIIIRO system could time out and move on to the next target, instead of recording the lack of response as an incorrect decision.

Target acquisition accuracy. The second primary performance measure collected in this study was target acquisition accuracy. Results showed that there was no significant effect for system reliability on target acquisition accuracy. This could be due to a number of reasons, including the reality that participants did not know the reliability of the software prior to their experience. As a result, they may have treated each trial in the same manner and took their time to make each decision. The trials were also relatively short, so participants likely didn't have enough time with the automation to develop a particularly strong sense of trust or mistrust in the system.

There was a significant effect for time pressure on target acquisition accuracy. The significance of this effect indicates that the target acquisition accuracy of participants was higher (better) when they were exposed to the higher time pressure condition (5 seconds) than when they were exposed to the lower time pressure condition (10 seconds). One possible explanation for this would be that 10 seconds was so long to make a decision that participants were not engaged enough in the task, which could cause a decrease in performance.

Secondary Task Performance Measures

Secondary task performance measures are often used as another measure of mental workload, attempting to determine how much excess capacity was available while performing the primary task. There were three secondary task performance measures involved in the current study: IA processing time, pop-up threats re-routing processing time, and MMI processing time.

Intruder aircraft (IA) processing time. The secondary task of IA processing required the participants to respond to a red aircraft icon by clicking on the icon and typing in a given code, which appeared on the TSD. IA processing time yielded no significant differences for the effects of system reliability, time pressure, and their interaction. A possible explanation for this lack of significance is the number of IA events that took place during each treatment scenario; only two IA events occurred per treatment. With such few opportunities for the different tasks to conflict, the system reliability and time pressure effects placed on the primary task had little chance to affect performance on IA processing time.

Pop-up threats re-routing processing time. The secondary task measure for pop-up threats re-routing processing time required the participants to either accept or reject a recommended flight path change made by the automation in order to avoid a threat that had appeared during the simulation. Pop-up threats re-routing processing time yielded no significant differences for the effects of system reliability and time pressure. A possible explanation for this lack of significance is the number of pop-up threats that took place during each treatment scenario; only two events occurred per treatment. In addition, the automation automatically "accepted" the flight path change if the participant missed his or her time frame to "accept" or "reject;" the time out period would impact the significant results. The interaction between system reliability and time pressure, however, was shown to be significant. This suggested that it took significantly longer to respond to a pop-up threat in the higher time pressure condition (5 seconds) when the system was at 80% reliability, as opposed to 40% reliability. Although from a qualitative standpoint, this difference might not matter much, as the means only differed by approximately 0.5 seconds. However, one might argue that this difference *is* important for a safety critical system like a UAS.

Mission mode indicator (MMI) processing time. The processing time for MMI showed no significant results for the main effects of system reliability and time pressure, as well as no significant results for their interaction. An explanation for this lack of significance could be due to the participants being more concerned with image processing than with secondary tasks; it is evident that when participants take longer to process the images, as in the case of the low system reliability images, secondary task performance is affected. As MMI is another secondary task, its priority is of less importance in comparison to primary tasks. In addition, changes in this task are not easily detected unless they are looked at specifically.

Mental workload. Mental workload was measured using the NASA-TLX after each treatment scenario, resulting in four NASA-TLX forms for each participant. The results for mental workload showed no significant results for the main effects of system reliability and time pressure, as well as no significant results for their interaction. Due to subjectivity and a relatively small sample size, individual differences may have limited the sensitivity of the results. In addition, the results of mental workload are in correspondence with the results of the secondary task performance measures in terms of their insignificance. An explanation for this could be that due to the insignificance of the secondary tasks, mental workload was not perceived to be at an increased level to the participants and thus resulted in insignificant results.

Practical Implications and Recommendations for Future Research

The next generation of flight is already underway and UAS's are thought to be a critical element in the future of military and civil air operations. . These highly autonomous aerial vehicles can open many doors and broaden many horizons on how operators perform crucial and time sensitive tasks. Research and development on issues relating to UAS operator performance can open doors for understanding what is needed, or not needed, for one operator to supervise multiple vehicles at the same time.

This study demonstrated a significant effect of system reliability on processing times for images. A significant effect of time pressure on target acquisition accuracy was also found in the primary task performance measures. The time pressure differences for image processing time, however, were small enough that they may not require any design changes. Although time pressure was found to be statistically insignificant for many of the secondary tasks, the time differences may be not negligible when dealing with real-life situations. The topics of system reliability, time pressure, and other factors that could impact performance should be researched further before implementing design strategies, in order to avoid any potential safety hazards.

Due to the operator being separated from the UAV and the environment surrounding it, it is necessary to have reliable systems and designs. By further understanding system reliability and uncertainty when conducting UAS operations, UAS designs can be implemented to reduce the uncertainty that contributes to higher levels of mental workload and lower levels of performance. This would allow for an operator who is comfortable enough to rely on the system, yet knowledgeable enough to know when it is necessary to take manual control. One of the limitations of the study is that limited sample size of the participants recruited. From the results, it can be seen that some of the standard deviation was relatively high. It was believed that with more sample size the power of the tests could be improved. Another limitation of the study is that participants recruited were not UAS operators, although it is believed that the pilot experience is not necessary for the tasks measures for this particular experiments, in the future, UAS pilots could be recruited to see if any further insights can be obtained for UAS human performance.

Another research effort could include the manipulation of participants' knowledge regarding the reliability of the system. The manipulation could be studied many ways, including having two groups, one with prior knowledge of the effects and another group with no knowledge. Feedback could be given to the participants following each trial, as well, in order to give them the chance to improve in the remaining trials of the study. Such a design could reveal valuable information about the effects of trust and feedback on UAS operator performance, further contributing to UAS efficiency and safety.

Conclusion

UAS's play a crucial role within military and security operations. Their use has grown considerably in the last decade and continues to grow; making UAS's an important part of NextGen and the future of the national airspace. UAS's have a wide range of capabilities that allow them to provide a much safer and efficient method for performing a number of tasks, while not putting an operator's life in jeopardy. Although considerable research and development has taken place within the history of UAS operations, a number of concerns still exist with regard to UAS flight safety within the NAS and abroad. Designing this technology with the human in mind is necessary, as understanding the human component of these systems would help resolve many human factors and safety concerns, such as operator performance and mental workload. Once the human component is understood, issues of concern can be resolved through design, providing the ability for all system components to perform at optimum levels.

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