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An Investigation of Multiple Unmanned Aircraft Systems Control from the Cockpit of an AH-64 Apache Helicopter

by Jamison S Hicks and David B Durbin

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14. ABSTRACT

The US Army Research Laboratory's Human Research and Engineering Directorate assesses crewstation design for new and upgraded US Army Aviation aircraft during simulations and operational testing. The assessments are conducted to identify and eliminate human factors design problems. As part of these evaluations, the AH-64 Apache attack helicopter has been a primary focus with respect to crewstation design changes. One of the significant design changes for the Apache crewstation is the integration of unmanned aircraft system (UAS) control. This study investigates the feasibility of controlling multiple UASs from the cockpit of an AH-64 Apache helicopter by examining scientific studies conducted on multi-UAS control that relate to operator and pilot mental workload.

15. SUBJECT TERMS: unmanned aircraft systems, AH-64 Apache, workload, simulation, Army aviation

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1. Introduction

1.1 Background

The US Army Research Laboratory's Human Research and Engineering Directorate (ARL/HRED) evaluates cockpit design for new and upgraded Army aircraft during simulations and operational testing. These cockpit evaluations are used to identify and eliminate human factors engineering design problems.

ARL/HRED has evaluated several AH-64 Apache attack helicopter cockpit design changes. One of the significant design changes evaluated by ARL/HRED is the integration of unmanned aircraft system (UAS) control into the Apache. Information about the evaluation methodology and results can be found in Hicks and Durbin (2013).

The AH-64 Apache (Fig. 1) is a tandem-seat twin-engine aerial weapons platform built by Boeing. The aircraft carries Hellfire missiles, 2.75-inch rockets, and a 30-mm chain gun and includes a fire control radar and modernized target acquisition designation sight/pilot night vision sensor (MTADS/PNVS) integrated sensor system. There are 2 multipurpose displays in each cockpit and an MTADS electronic display and control in the copilot-gunner (CPG) cockpit (Fig. 2).

Fig. 1 AH-64 Apache (courtesy of Boeing)

Fig. 2 Apache Risk and Cost Reduction System CPG cockpit (courtesy of Camber Corporation)

Modern UASs (Fig. 3) typically consist of an aircraft host platform, a payload (sensors), weapons when applicable, and a data communications suite to allow for external (teleoperated) control from an operator and data/imagery streaming to command consoles. Depending on the scenario and the UAS type, operators could consist of infantrymen, aircraft pilots, or dedicated UAS ground control station (GCS) operators. The purpose of the UAS is to allow for longer and more discrete reconnaissance loitering, air support, remote sensor deployment, and target engagements without endangering the UAS operators. Teleoperation and interaction with a UAS can be divided into the following general levels of interaction (automation) describing the operations that can be performed by the operator:

- Level 1: Receipt and transmission of secondary imagery or data
- Level 2: Receipt of imagery or data directly from the UAS
- Level 3: Control of the UAS payload
- Level 4: Control of the UAS, except takeoff and landing
- Level 5: Full function and control of the UAS to include takeoff and landing

Fig. 3 Gray Eagle UAS (courtesy of General Atomics)

According to an article in *Military and Aerospace Electronics* (Howard 2013), UAS spending is expected to double over the next decade. These expenditures will be due to technological improvements to the UAS (e.g., flight characteristics and sensors) and from integration with other assets (e.g., ground stations, aircraft, and other UASs).

1.2 Purpose

The purpose of this study was to investigate the feasibility of controlling multiple UASs from the cockpit of an AH-64 Apache helicopter. ARL/HRED has conducted simulations and operational testing to assess operation of a single UAS from the cockpit of an AH-64. Employment of a single UAS by AH-64 crews during unit training and subsequent theater operations has validated the simulation and testing results. However, no simulation or testing has been conducted that investigated the control of multiple UASs from the Apache cockpit.

The control of multiple UASs from the Apache cockpit can help crews locate and identify targets during reconnaissance and attack missions. For example, Apache crews could use one UAS to clear their route to an engagement area while using another UAS to maintain visual contact on a target in the engagement area. The primary human factors concern for Apache crew control of UASs is excessive mental workload that could degrade flight and mission task performance. Identifying and integrating the appropriate levels of UAS control automation is important to ensure safe and effective mission accomplishment.

This report will summarize the workload ratings collected during single UAS cockpit simulations and compare the ratings to a sample of ground-based and flight simulations and test events that have evaluated control of multiple UASs by operators. Additional research will be summarized for decentralized control and goal/task-oriented operations of UASs to investigate the use of these methods as options for Apache-UAS teaming. The intent is to suggest whether or not multiple-UAS control by an Apache crew would be feasible with respect to pilot workload and to identify potential solutions (e.g., interface design, operator feedback, and UAS automation requirements) that should be investigated to reduce workload.

1.3 Workload

According to Lu et al. (2013), human working memory is severely limited in its capacity duration. As the information needed for UAS control increases, the pilot's mental workload rapidly increases. There are several definitions of pilot mental workload. A useful definition is "the integrated mental and physical effort required to satisfy the perceived demands of a specified flight task" (Roscoe 1985). It is important to assess pilot workload because mission accomplishment is related to the mental and physical ability of the crew to effectively perform their flight and mission tasks. If one or both pilots experience excessively high workload while performing flight and mission tasks, the tasks may be performed ineffectively or abandoned. In general, workload assessment techniques are used to answer the following questions (Eisen and Hendy 1987):

- Does the operator have capability to perform the required tasks?
- Does the operator have enough spare capacity to take on additional tasks?
- Does the operator have enough spare capacity to cope with emergency situations?
- Can the task or equipment be altered to increase the amount of spare capacity?
- Can the task or equipment be altered to increase/decrease the amount of mental workload?
- How does the workload of a new system compare to the old system?

To assess whether the pilots are task-overloaded during a mission, the level of workload for each pilot must be evaluated. Spare workload capacity is an important commodity for pilots because they are often required to perform several tasks concurrently. For example, copilots often perform navigation tasks, communicate via multiple radios, monitor aircraft systems, and assist the pilot on the controls with flight tasks (e.g., maintain airspace surveillance) within the same time interval. Mission performance is reduced if pilots are task-saturated and have little or no spare capacity to perform other tasks (Durbin and Hicks 2009) such as UAS control.

Currently several types of subjective workload evaluation surveys are used, 2 examples of which are the Bedford Workload Rating Scale (BWRS) and the National Aeronautics and Space Administration Task Load Index (NASA-TLX).

The BWRS has been used extensively by the military, civil, and commercial aviation communities for pilot workload estimation (Roscoe and Ellis 1990). It requires pilots to rate the level of workload associated with a task based on the amount of spare capacity they feel they have to perform additional tasks. After each mission, pilots rate flight and mission tasks using the BWRS scale (Fig. 4). Roscoe and Ellis (1990) describe the BWRS and explain its use in assessing pilot workload. ARL/HRED has written the requirement, for several Army aircraft, that operation of the aircraft must not result in workload ratings of more than 5.0–6.0 on the BWRS scale. Flight and mission tasks that are rated 5.0 or higher are evaluated to determine if crewstation design problems contributed to higher workload ratings.

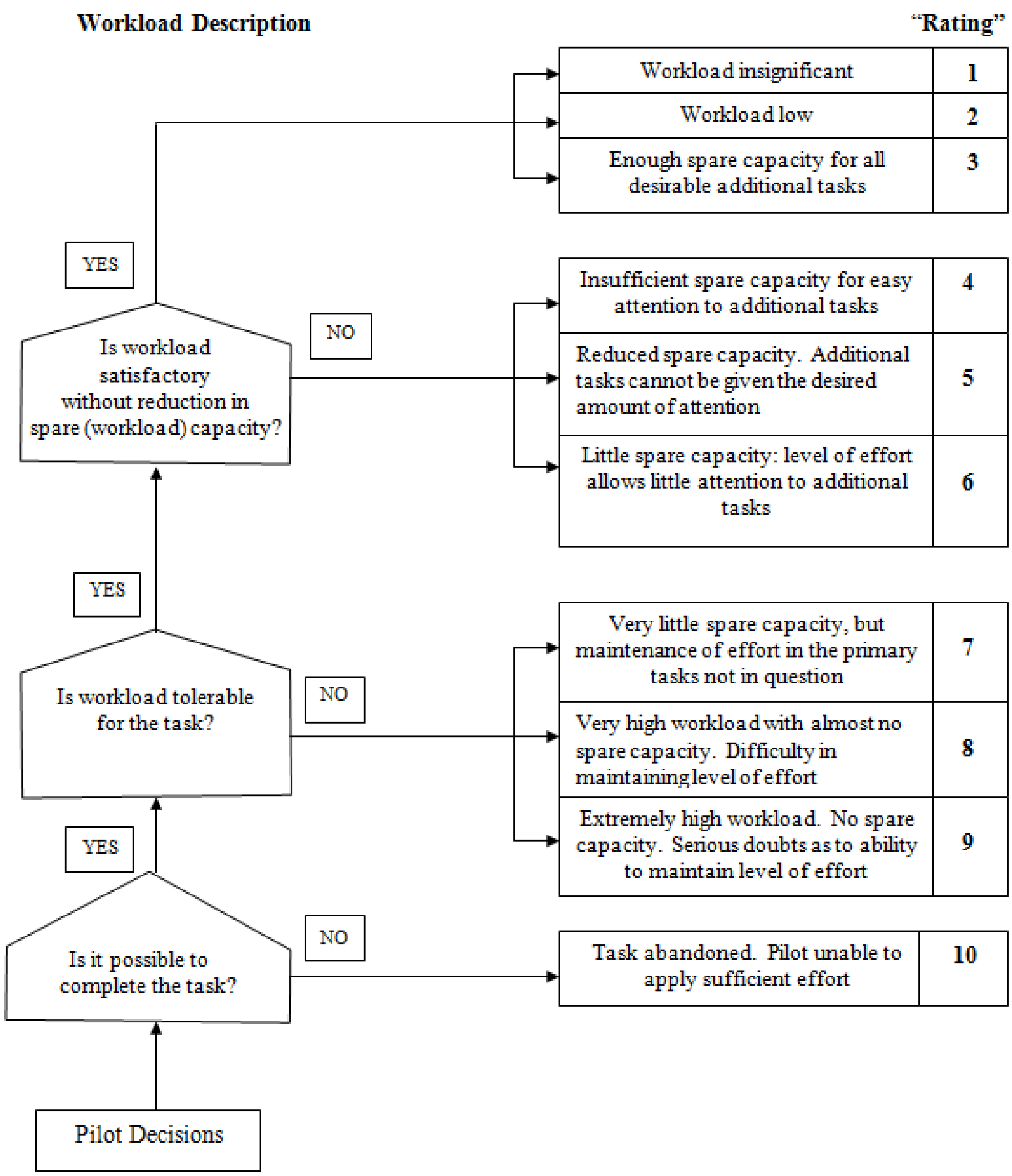
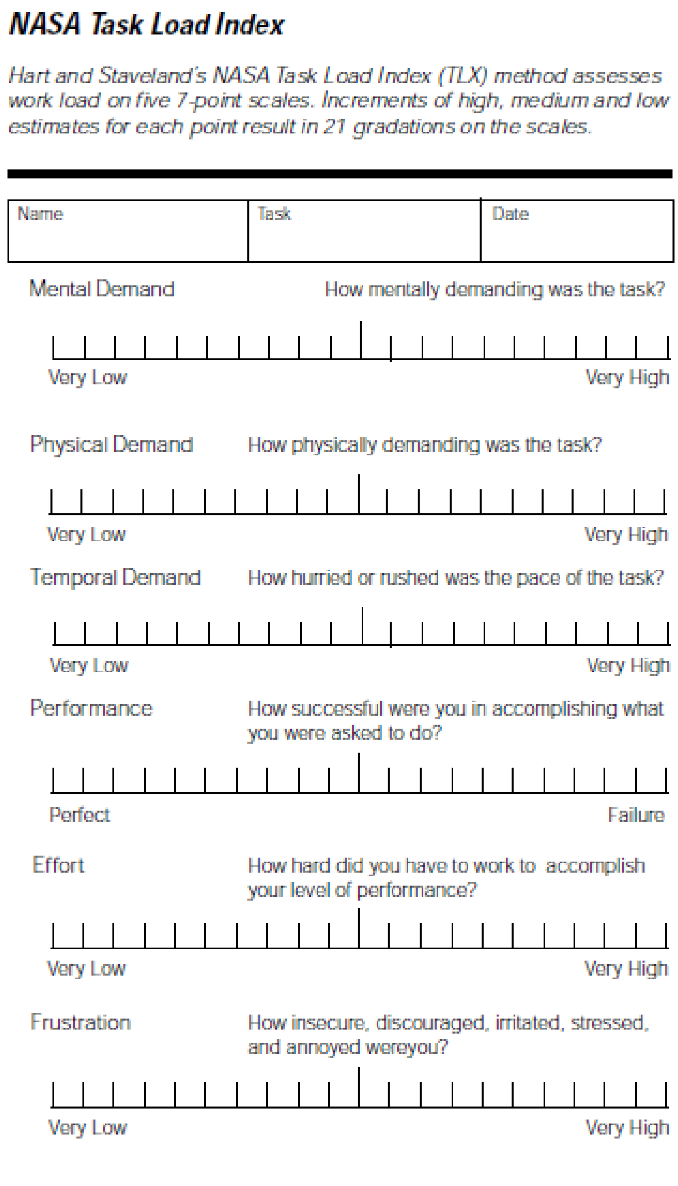


Fig. 4 Bedford workload rating scale

The NASA-TLX (Hart 2006) consists of 6 subscales that represent somewhat independent clusters of variables: mental, physical, and temporal demands plus frustration, effort, and performance (Fig. 5). The assumption is that some combinations of these dimensions are likely to represent the “workload” experienced by most people performing tasks. A weighting scheme is used to derive the overall workload score based on the 6 subscales. More information about the development of the NASA-TLX can be found in Hart and Staveland (1988). NASA-TLX has been used extensively in documenting user-based task-oriented workload.


NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Fig. 5 NASA-TLX assessment

1.4 Level of Automation

Level of automation (LOA) refers to the level of task planning and performance interaction maintained between a human operator and computer (robot) in controlling a complex system (Billings 1991, Kaber and Endsley 2004). Identifying the LOA necessary for successful human-robot interaction is vital for overall safety, efficiency, and mission success. If the LOA is too low, operator workload can become excessive. If the LOA is high, it is important to ensure that the UAS is initiating and conducting proper actions; otherwise, the operator could lose trust in the system and choose not to employ it. A balance must be formed where the UAS-operator interaction does not result in excessive operator workload but still provides enough confidence that ordered tasks could be successfully completed. There has been significant work done in the development of LOA taxonomy, although different applications employ different taxonomies for describing the automation. A proposed LOA taxonomy (Endsley and Kaber 1999, Kaber and Endsley 2004) shows the relationship between the operator interface and the responsibilities of the human and computer as follows:

- Manual: Human performs all tasks.
- Action Support: System assists the operator with performance of a selected action.
- Batch Processing: Human selects options to be performed and the system carries the actions out automatically.
- Shared Control: Human and computer generate possible decision options, human selects options, and actions are shared between human and the system.
- Decision Support: Computer generates a list of decision options that the human can select from. Once the option is selected, the computer performs the action.
- Blended Decision Making: Computer generates a list of decision options, which it selects and carries out if the human consents. The human can modify the options if necessary.
- Rigid System: Presents only a limited set of options to the operator. The operator must select from these options; no modifications are allowed.
- Automated Decision Making: System selects the best option to implement and carries out that action, based on a list of alternatives it generates (or the human operator).
- Supervisory Control: System generates options, selects the option to implement, and carries out the action. The human monitors the system and intervenes if necessary.
- Full Automation: System carries out all actions; the human is out of the loop and cannot intervene.

These operator-system LOAs can be dynamic and change depending on the type of system and operational scenario. In this case, the term adaptive automation (AA) is used to describe the variation of LOAs to meet operator workload requirements and assist in the decision-making process. The study conducted by Kaber and Endsley (2004) describes AA as the process by which control must pass back and forth between the human and the automation over time, depending on situational demands, and seeks to find ways of exploiting this process to increase human performance and reduce high levels of operator workload.

The studies presented in the following sections examine research conducted on the operator-UAS interface at varying LOAs ranging from full manual control to full automation.

2. Literature Review of Control Methods and Findings

2.1 Overview

The following subsections summarize data collected from literature reviews of select UAS control reports and their results. Experimental methodology is generalized and overall results provided for each identified test and experiment. The data will be used to develop conclusions and recommendations in the follow-on section regarding control of multiple UASs by Apache helicopter crews.

2.2 ARL/HRED Simulation and Operational Testing

Previous workload data collected by ARL/HRED related to single UAS-cockpit operation has been documented in simulation and operational test reports. Workload data collected for nonintegrated Apache-UAS teaming was published in a report by Hicks et al. (2009) entitled *AH-64D Apache Longbow/Video from UAS for Interoperability Teaming Level II (VUIT-2) Aircrew Workload Assessment*. During this simulation, the pilots conducted realistic mission scenarios while teaming with the UAS and an associated GCS operator. Level 2 UAS (imagery data only) was provided to the CPG. As missions were conducted, the CPG would instruct the GCS operator where to position the UAS and what terrain, personnel, and cultural features to identify with the UAS sensor. BWRS data were collected at the end of each mission; the average workload rating for VUIT-2 missions for CPGs was 3.3 and 3.0 for non-VUIT-2 missions. The pilot-on-the-controls (PI) workload ratings for the VUIT-2 missions were 2.6 and for non-VUIT-2 missions were 3.7. These workload ratings showed that it was feasible to incorporate UAS level 2 imagery data into the Apache cockpit during representative mission scenarios without causing excessive crew workload.

A simulation was conducted on an integrated system that allowed the Apache crew to interact with the UAS up to control level 4 (full control, except takeoff and landing). The simulation methodology and results were published in a report, *AH-64D Apache Longbow Aircrew Workload Assessment for Unmanned Aerial System (UAS) Employment*, by Durbin and Hicks (2009). As missions were conducted, the CPG would operate the UAS sensor (level 3), control the UAS flight path (level 4), or instruct the GCS operator where to position the UAS and what features to identify with the UAS sensor (level 2). BWRS data were collected at the end of each mission and the average workload rating for UAS missions for CPGs was 2.9 while that for non-UAS missions was 3.0. PI average workload for UAS missions was 2.6 and that for non-UAS missions was 2.8. These workload ratings showed that it was feasible to incorporate UAS control levels 2–4 into the Apache cockpit during representative mission scenarios without causing excessive crew workload. In general, pilots commented that UAS control workload is slightly higher than "normal" missions but manageable, and the situational awareness benefits gained by external sensors outweighed the slight increase in workload.

Findings by ARL/HRED showed that integrating UAS levels 2–4 into the Apache helicopter did not significantly increase crew workload or negatively impact crew performance and mission accomplishment. During the evaluations, subject matter experts (SMEs) independently rated whether the missions were a success or failure. The criteria that the SMEs used to rate mission success or failure was whether the aircrew completed most or all of their mission objectives and did not crash or get shot down. In both evaluations, pilots completed 100% of missions successfully when operating a UAS. These independent ratings support the conclusion that crews can control one UAS during missions without experiencing excessive workload.

ARL/HRED has helped conduct operational testing for the AH-64. During operational testing, the pilots maintained UAS control levels 2, 3, and 4 at various times during missions. The workload ratings and mission success ratings collected by ARL/HRED further support the conclusion that crews can operate one UAS without experiencing excessive workload.

2.3 Human-UAS Interaction Literature Review and Past Studies

A study by Ruff et al. (2002), *Human Interaction with Levels of Automation and Decision Aid Fidelity in the Supervisory Control of Multiple Simulated Unmanned Air Vehicles*, investigated 3 LOAs—manual control, management by consent, and management by exception—to control UASs in a dynamic simulation environment. This study was used to identify techniques that may allow multiple-UAS control by a ground operator. The levels of automation were defined as the following:

- Manual Control: Automation is dormant unless initiated by the operator.
- Management by Consent: Automation proposes action but cannot act without explicit operator consent.
- Management by Exception: Automation acts without explicit operator consent and fails to act only when commanded by the operator.

This study used performance measures of efficiency, correct decision responses, and event management along with subjective NASA-TLX workload measurements to evaluate the different LOAs. The results of this study showed that manual control for a single UAS resulted in the lowest workload, and the highest workload was when 2–4 UASs were supervised during the scenario. Management by consent resulted in a lower workload than management by exception for 1 and 2 UASs but higher for 4 UASs. This article also examined "trust" of the UAS. It was found that if the UAS acted in a manner that seemed incorrect or outside of the expected actions, trust in the automation was lower. The study concluded that management by consent helped humans remain in the loop of control without requiring constant vigilance of status indicators. Increasing the automation level reduced the situational awareness of the operator and generally lowered operator trust if some form of inaccuracy occurred. The primary suggestion from this study was to examine different levels of (variable) automation depending on mission scenarios and tasks to assist the operators in accomplishing mission objectives.

An article by Cummings and Morales (2005), *UAVs as Tactical Wingmen: Control Methods and Pilots' Perceptions*, examined the use of the previously discussed control methods (manual, control by consent, and control by exception) and surveyed US Air Force pilots to obtain feedback. A simulation was set up to provide the pilots an interface that depicted the UAS as a wingman, and pilots performed a cognitive walkthrough of the interface to identify potential usability problems and characterize the problem-solving process. The results of the study indicated that Air Force (fixed-wing) pilots generally preferred management by consent as the control strategy that would allow them to avoid performing tedious functions and still allow them the final decision with respect to UAS actions during missions. The pilots did not want the UAS to make decisions about target engagement or to perform any tasks that might interfere with the manned aircraft airspace requirements. Additionally, the article suggested that the complex socio-technical cultural component of single-seat versus multicrew cockpits could have a significant effect on the acceptance of UAS technology in the cockpit.

A study conducted by Fern and Shively (2009), *A Comparison of Varying Levels of Automation on the Supervisory Control of Multiple UASs*, indicated that new concepts of operations and procedures were required for a single (ground) operator to simultaneously control multiple UASs. This study investigated the use of an interface technique called Playbook, which allowed operators to designate specific "plays" that were tied to semi-autonomous UAS tasks in an effort to reduce operator workload. A play example would be for the operator to call for "Overwatch Tango", which would provide the UAS instructions to loiter over the Tango waypoint. This experiment focused on 3 levels of automation: Playbook (multiple UAS), script (single UAS), and tools (no automation). Performance measurements collected included accuracy, speed, and target identifications. The results from this study showed that the Playbook interface resulted in better performance than the other methods, and the NASA-TLX data indicated that when using the Playbook, workload was significantly lower than using scripts or tools. The study showed the advantages of task delegation to support supervisory control of multiple UASs.

Studies conducted by Lu et al. (2013) and Hou and Kobierski (2006) investigated human-computer interface designs that could reduce workload when controlling UASs. Lu et al.'s *Design and Test of a Situation-Augmented Display for an Unmanned Aerial Vehicle Monitoring Task* (2013) focused on using an augmented display that would provide operators with important situational-dependent UAS status information. The results of this study showed that the situation-augmented display improved operator response times to abnormalities and reduced total flight time required to complete objectives. However, at the conclusion of the study it was found that while performance was better for a situational-augmentation display, the reported workload was not significantly different from a nonaugmented display. The study further reported that UAS monitoring tasks are difficult and that providing high-level situation awareness information through visual displays may improve overall operator performance.

Hou and Kobierski's 2006 study, *Intelligent Adaptive Interfaces: Summary Report on Design, Ddevelopment, and Evaluation of Intelligent Adaptive Interfaces for the Control of Multiple UAVs from an Airborne Platform*, investigated the development and design of intelligent adaptive interfaces (IAIs) for the control of multiple UASs. Their findings showed that when using IAI automation agents and aids, UAS operators performing cognitively complex tasks with high workload were able to reduce the time required to perform critical tasks. Six system functional groups were identified for IAI (situational-based decision-making) investigation and proposed experimentation: inter-crew communications, route planning, route following, screen management, data-link monitoring, and UAS sensor selection. The results of the study showed that using an IAI to monitor and perform decision-based predefined UAS operations resulted in reduced operator workload and increased situational awareness.

A study conducted by Calhoun et al. (2004), *Tactile Versus Aural Redundant Alert Cues for UAV Control Applications*, considered the use of tactile and aural alert cues for UAS control applications. The study found that aural and tactile cues can reduce the visual workload required for UAS task monitoring, but no significant differences for response time to alerts between the aural and tactile cues were observed during the study.

2.4 UAS Autonomous Decision-making Literature Review and Past Studies

Maintaining crew workload at an acceptable level is necessary to employ multiple UASs from the cockpit. A variety of methods have been used to reduce the burden placed on operators by providing more automation capabilities to operators when interacting with a UAS network. The following studies examined multi-agent systems, task allocation architectures, and decentralized control frameworks for autonomous UAS control with minimal operator input.

A study conducted by Lian and Deshmukh (2006), *Performance Prediction of an Unmanned Airborne Vehicle Multi-agent System*, examined the use of a Markov Decision Process to determine optimal paths for UAS mission execution when considering the use of UASs as control agents in a dynamic multi-agent system. The premise of the study was to develop a decision-making process that allowed the UASs to share data with each other to accomplish a set of mission goals (e.g., avoid gunfire, successfully reach targets, negotiate paths within system constraints). The study found that when using the decentralized model, and when UASs share data and group dynamically, heuristic algorithms allowed the UASs to effectively identify optimal directions (paths) to targets.

A paper by Lemaire et al. (2004), *A Distributed Tasks Allocation Scheme in Multi-UAV Context*, proposed a completely distributed architecture where robots dynamically allocate their tasks while building their own plans. The paper investigated incremental task algorithms and parameters that would distribute and balance the workload equally among different robots. Dynamic and temporary hierarchies were developed for task auctions when time constraints between tasks were present. The study focused on token-based auctions to distribute tasks amongst the UASs. When robots were idle or their hierarchy chain allowed, they could bid on tasks (i.e., go to) created by other robots to help accomplish the overall mission requirements. An auction leading robot (one that has either been assigned a token or generated an initial token) would allow other robots to bid on the tasks that were available to the auction leader. Once all of the tasks were bid and distributed, another robot could request the token and begin auctioning their tasks to reduce single robot workload. The resulting simulation showed that simple planning algorithms using the token-based task distribution system could be used to accomplish required tasks among multi-robot systems.

A study by Cheng et al. (2013), *Cooperative Control of UAV Swarm via Information Measures*, investigated a rule-based decentralized control framework for a swarm of UASs carrying out a cooperative ground target engagement mission scenario. In this case the behaviors of the UASs were governed by rule sets that lead to system-level cooperation. Information measures were adopted to estimate the value of future actions, and a prediction model was used to enhance team performance when coupled task constraints were present. An example scenario from the simulation used data fusion where 2 UASs track a target and provide information back to an attacking UAS to help integrate and determine flight trajectories and firing constraints. The study found that highly cooperative group performance could be achieved without the use of a centralized controller. However, the performance was related to the complexity of the coupled constraints and the accuracy of the prediction model. In that case an increased number of UASs could reduce task coupling. Also, predictive modeling can help to allow agents to estimate the intentions of other agents (UASs) and allow the original agents to choose goal oriented activities that enhance overall team utility.

3. Conclusions

3.1 Summary of Findings

The data presented in this report provides an overarching look into the different test methodologies and potential system designs that could be used to facilitate the implementation of multiple UAS control from an Apache cockpit. Two primary concerns that are present throughout the literature are the appropriate LOA for system control and cognitive workload concerns for the operator. While a direct comparison of ARL/HRED UAS workload data and other workload study data cannot be accomplished because of different collection and test methodologies, trends can be identified among all of the studies. Generally, as fully manual operation of UASs decreases, operator workload decreases as well, which is to be expected when automatic control is present in the system and the automation is increasingly taking over operator tasks. However, in some instances, operators reported that workload can increase if the information presented for supervisory control acknowledgements is not presented in an appropriate manner. Operators can become overloaded with supervisory control tasks while trying to perform other tasks.

Studies that dealt with the human-robot interface and relationship found that most operators preferred to have some control over the situation. Whether the control was management by supervision or the Playbook interaction, operators needed to feel that they had control over the actions of the UAS to trust the system. Other studies examined the adaptive and intuitive interface designs to reduce workload and enhance situational dependent decision-making for the operators. In all cases, operator workload was reduced by using a decision-making tool or interface to assist in multiple UAS control.

The studies that examined the interaction of multiple autonomous UASs found that multi-agent systems, data fusion, and goal-oriented decision-making made it possible for multiple UAS systems to perform tasks collectively. The development of data-sharing and task-allocation algorithms allows the UASs to self-determine flight task plans, avoid interference, and trade off tasks amongst each other. In these cases, the UASs operated mostly independently and accomplished tasks without significant user inputs past the beginning of the mission.

3.2 Discussion

An examination of the studies presented provides insights into future development of multi-UAS control from a multi-UAS systems level and an operator-UAS interface domain. It is clear from the research that operating multiple UASs can induce high cognitive workload requirements for operators when some form of interface assistance or autonomous programming is not used. Tasks that require significant operator vigilance increase the cognitive demands required during missions. For UAS ground control operators, high workload can reduce performance during missions. For crews (i.e., pilots and copilots), high workload can reduce their performance and increase the probability of a crash or engagement by the threat.

A combination of automation processes and levels of automation must be used to fully integrate multi-UAS control into an Apache helicopter. Single UAS–Apache control with cooperation from a GCS has been proven to be effective, but a significant increase in workload would likely occur when adding additional UASs. A multi-agent approach that increases the amount of automation and data fusion used between UASs would require the least amount of human vigilance and task monitoring during operations. However, the system would need to be demonstrated extensively to ensure that a level of trust between the UASs and pilots is established. As the control algorithms and UAS technology improve, having a UAS wingman and controlling multiple UASs during mission scenarios appears to be viable from a workload perspective. However, in the immediate future, determining the correct amount of automation from a supervisory perspective will be a key factor in providing multi-UAS capability to the Apache as soon as possible.

Using the conclusions drawn from the literature review, a combination of supervisory control interfaces (i.e., Playbook) and adaptive interfaces to present key UAS and mission parameters depending on the situation or workload of the pilot would be beneficial when providing multiple UAS control capability to Apache crews. Additionally, an investigation into integration of tactile and aural cues should be conducted to assist in UAS-pilot operation. Past studies have shown that tactile cueing and aural alerts can supplement visual systems by alerting the pilots to information being presented. The use of these augmentations must also be implemented with caution to ensure that only pertinent information is presented so as not to overload the pilot with unnecessary cues. Pilots would need adequate training on the capabilities and limitations of the various LOAs with respect to UAS control and the appropriate amount of automation required for different mission scenarios. Pilot workload should be assessed to identify whether the pilot is capable of making automation decisions for multi-UAS control in high-workload environments. In a case where workload becomes overwhelming, the UASs should employ adaptive automation to ensure safe operations throughout a mission scenario.

The dynamic flight and mission environment is a significant challenge when designing for the UAS-pilot interaction. Multi-UAS control could occur in cooperation with a GCS operator. In these instances a multi-UAS system could be split to share command authority between the GCS operator and pilot. During this scenario the pilot would not have to maintain awareness of all UASs; rather, just the ones that were related to the pilot tasks. To reduce the workload in dynamic environments, multi-UAS employment should be limited to goal-oriented automation, where the UAS teams accomplish well-defined goals automatically and independent of the pilot (i.e., monitor waypoint, track target, update plan) and the pilot has the ability to monitor video feeds or imagery results from those actions. In these instances, expected workload would be similar to single UAS tasks. Using the UAS teams as extended sensors (controlling only the payloads) is another option. A GCS operator could place the UAS teams in appropriate locations, and the pilots could take control over the payload for reconnaissance and targeting tasks. Once the pilot was done, he could hand the task back to the GCS operator or provide a command to the UAS to carry out a predefined action.

4. Proposed Solutions, Evaluation Plan, and Future Integration

4.1 Proposed Solutions

The use of adaptive automation and supervisory controls plays a central role in the sample of UAS management methodologies discussed in this report. Using the Playbook style of goal-oriented task direction and adaptive automation for high-workload environments should allow Apache helicopter pilots to control multiple UASs during missions. In addition, using different sensory inputs (i.e., visual, auditory, tactile), as described by Wickens's (1984) Multiple Resource Model, could reduce workload by not overloading any single sensory channel.

In the near term, multiple-UAS control by Apache pilots could be accomplished by allowing pilots to alternate UAS sensor video feeds inside the cockpit in a very controlled method. This would allow multiple battlefield sensors to be accessed through quickly changeable video feeds on the pilot displays. Conceptually the workload should be somewhat similar to the operation of a single UAS sensor from the cockpit. The additional task of swapping UAS sensors and gaining situational awareness has potential to raise pilot workload but could easily be evaluated in a simulation environment. Most of the solutions presented in this report deal with long-term automation solutions, but the first step is to evaluate low level automation control of manipulating UAS sensors and receiving imagery data. Once the initial evaluations are completed, advancing the automation levels and overall fidelity of system control can be conducted to improve the UAS control by pilots.

It is proposed that experimentation should be conducted to use goal-oriented decision-making in conjunction with adaptive automation and visual, auditory, and tactile cueing to examine the appropriate levels of automation required for control of multiple UASs by Apache helicopter crews. The use of multiple decision aids and cues should help to reduce pilot workload by providing information to multiple human input channels, rather than only using the visual system. The combination of these techniques should provide an effective system for controlling multiple UASs from the cockpit of an Apache. Also, as UAS designs and software become more advanced, continued testing should be conducted to examine the UAS-pilot interactions. As UAS intelligence and autonomy increases, more mission tasks could be carried out by the UAS with less input from pilots. The optimal design solution should be determined though simulation and operational testing. An ideal solution would likely consist of highly autonomous UASs with some goal-oriented inputs from pilots.

4.2 Evaluation Plan

To assess the feasibility of multiple UAS control by Apache pilots based on the sample of research summarized in this report, an evaluation approach is proposed. The first step in the evaluation is to interview SMEs on the proposed control tasks that Apache pilots would potentially use during representative missions to ensure that the levels of automation proposed for further research are reasonable and feasible for mission types. SMEs can provide valuable input on the use and employment of the aircraft and UAS use. Once the mission is understood, simulations can be conducted using modeling software (e.g., Improved Performance Research Integration Tool, or IMPRINT) to analyze mission tasks and workload interactions between the aircraft-UAS-mission goals. These simulations can be adjusted for sensitivity and the number of UASs controlled can be adjusted to represent high-level task performance. A more detailed look at multi-UAS control requires integration of the proposed solutions into a manned simulator to evaluate pilots interacting with various design solutions and receiving pilot feedback and objective data collection (i.e., task time and button presses). The final evaluation of the proposed solutions would be to take the solutions that perform best in simulation and integrate them into the actual aircraft for full operational testing and evaluation. As data are collected during operational testing, incremental improvements can be added and retested to arrive at a preferred solution.

4.3 Future Integration

The future integration of multi-UAS control into an Apache cockpit must be investigated carefully. Controlling multiple UASs can provide a tactical advantage to pilots by increasing situational awareness and reducing the probability of detection and engagement on the battlefield. Operating multiple UASs from an Apache has potential to benefit the crew if the following are achieved:

- The appropriate levels of automation are identified.
- The automation supports high levels of trust.
- Proper controls are implemented for adaptive automation in high-workload environments.
- Consideration is given to multi-agent systems and data fusion.
- The pilot-UAS control interface is developed using accepted human factors design standards and practices.
- The automation is focused on minimizing pilot workload.
- Appropriate tactics, techniques, and procedures are developed for aiding the crew when controlling multiple UASs.

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List of Symbols, Abbreviations, and Acronyms

AA	adaptive automation
ARL	US Army Research Laboratory
BWRS	Bedford workload rating scale
CPG	copilot/gunner
GCS	ground control station
HRED	Human Research and Engineering Directorate
IAI	intelligent adaptive interfaces
LOA	level of automation
MTADS	modernized target acquisition designation sight
NASA-TLX	National Aeronautics and Space Administration Task Load Index
PI	pilot on the controls
PNVS	pilot night vision sensor
SME	subject matter expert
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
VUIT-2	video from UAS for interoperability teaming level II

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