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Human Factors Implications of UAVs in the National Airspace

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INTRODUCTION

Unmanned aerial vehicles (UAVs) are quickly becoming a part of the national airspace system (NAS) as they transition from primarily military and hobbyist applications to mainstream flight applications such as security monitoring, satellite transport, and cargo hauling. Before the full potential of UAV flight in the NAS can be realized, however, FAA standards and regulations for UAV operations must be established. Given the experience of the U.S. military that mishap rates for UAVs are several times higher than for manned aircraft (Williams, 2004)—over thirty times higher, in some cases (Department of Defense, 2001)—the importance of carefully designed standards and regulations is clear.

Issues related to human factors are likely to be of particular concern in establishing guidelines for UAV flight. As noted by Gawron (1998), UAV flight presents human factors challenges different from and in some ways greater than those of manned flight. These arise primarily from the fact that operator and aircraft are not co-located. As discussed in more detail below, the separation of operator and vehicle imposes a number of barriers to optimum human performance, including loss of sensory cues valuable for flight control, delays in control and communications loops, and difficulty in scanning the visual environment surrounding the vehicle. Unmanned flight also allows the possibility that a single operator might control multiple vehicles simultaneously, a task likely to impose unique and heavy workload demands.

The goal of the current work was to examine the existing research literature on the human factors of unmanned flight, and to delineate issues for future research to address. The topics discussed below are divided into the categories *Automation*; *Perceptual and Cognitive Aspects of Pilot Interface*; *Air Traffic Management Procedures*; and *Crew Qualifications*. As will be clear, however, the issues covered within the various categories are highly interrelated. Answers to questions about crew complement, for example, will be contingent on the nature and reliability of automation provided to support UAV operators. Likewise, decisions about interface design will depend on the extent to which flight control is automated, with manual flight mode demanding traditional stick-and-rudder controls and automated flight mode allowing for point-and-click menu-based control or other forms of non-traditional interface.

It is also important to note that unmanned aircraft will likely serve a range of purposes in civilian airspace, and that the demands placed on human operators will vary with characteristics of the flight mission. Proposed uses for UAVs include agricultural, geological, and meteorological data collection; border surveillance; long distance transport; search and rescue; disaster monitoring; traffic monitoring; and telecommunications relay. Furthermore, military UAVs will increasingly be required to transition through civilian airspace en route to their missions. In some of these cases, the vehicle is likely to operate solely within line-of-sight communications range and only over relatively short periods of time (i.e., on the time scale of several hours or less). In other cases, the vehicle will operate at distances demanding over-the-horizon communications, and will potentially remain airborne for many days on end. These mission characteristics will modulate concerns about communications delays between ground control station and vehicle, and about the need for transfer of vehicle control between crews. For some applications, additionally, operators will likely be required to make frequent control inputs, adjusting flight parameters or selecting new waypoints “online” in response to changing task demands or conditions. For other applications, flight path will be predetermined and less susceptible to modification, reducing the immediacy and frequency with which operators are required to intervene in flight control and allowing for a heavier reliance on automated vehicle guidance.

TECHNICAL APPROACH

Our technical approach involved three parallel efforts. (1) We acquired a large body of literature, both in published sources and in technical reports, that addressed any aspects of human factors in UAVs. This literature is documented in an annotated bibliography in Appendix A. (2) We identified laboratories where UAV human factors work is in progress. These laboratories, and points of contacts, are listed in Appendix C. (3) We became acquainted with UAV human factors issues in civilian airspace by familiarizing ourselves with Access 5 documents. (4) We applied our own subject-matter expertise of both aviation human factors in general, and UAV operations in particular, to identify 18 key human factors research topics, that we believed were **relatively unique** to UAV operations. This uniqueness constraint is critical. There are for example numerous human factors issues that should be applied equally to manned as well as to unmanned aircraft, relating to topics such as display legibility, CRM and communications, checklist design, etc. We did not include these in our effort, but note their enduring importance for UAV certification. Research topics are described in the text below, and in Appendix B are cross-indexed with relevant sources from the research literature described in Appendix A.

Having identified issues, and examined written documents that described human factors research, our final product was to map research needs against existing research documents, where such documents contained empirically valid findings. This material, contained in table 1 of the report below, provides an identification of the key research areas that we believe should be funded, in order to proceed on the path toward safe certification of UAVs in civilian airspace. We have not explicitly prioritized these areas in terms of their importance.

AUTOMATION ISSUES

1. To what extent should en route flight control be automated?

Current UAV systems vary in the degree to which en route flight control is automated. In some cases the aircraft is guided manually using stick and rudder controls, with the operator receiving visual imagery from a forward looking camera mounted on the vehicle. In other cases control is partially automated, such that the operator selects the desired parameters or behaviors through a computer menu or rotary dial interface in the ground control station. In other cases still control is fully automated, such that an autopilot maintains flight control using preprogrammed fly-to coordinates. At least one system (Pioneer), finally, allows the operator to switch between full manual, hybrid, and full automation control modes.

These various modes of flight control each present benefits and drawbacks (Mouloua et al., 2003). Full manual control would seem to impose the highest and most continuous level of cognitive workload on UAV operators. Moreover, manual control will be degraded by communication delays between UAV and GCS (see #8, #13). Conversely, fully automated control can prevent an operator from rapidly intervening when necessary, (e.g., upon loss of communications) and by leaving the operator largely “out of the loop” (Wickens & Holland, 2000), can produce degraded situation awareness (e.g., noticing a change of handling qualities due to icing). Flight planning can also be excessively time consuming for fully automated systems, sometimes requiring many weeks (Williams, 2004).

For reasons like those described above, Mouloua et al. (2003) recommended hybrid manual/automated control systems for military UAVs. A blanket recommendation, however, may not be appropriate for UAV flight in civilian airspace. Rather, the optimal flight control system seems likely to vary with the characteristics of the flight operation, either within or across flights. UAV operations that entail primarily long-endurance station-keeping (ACCESS 5, 2003), for example, are not likely to impose especially high demands on operator situation awareness. Fully automated control might therefore be more appropriate for such operations that either hybrid or manual automation. The optimal level of automation may also depend on the number of UAVs that a single operator is required to control, the communication delays between operator and UAV, and the quality of visual imagery and other sensory information provided to the operator from the UAV.

A number of questions related to the method of UAV flight control thus remain to be addressed. Research is recommended to:

- Determine the circumstances under which various modes of UAV flight control—fully automated, partially automated, manual—are appropriate.
- Determine whether or not the level of automated flight control should be reconfigurable, such that the operator can alternate between levels of control when he/she deems appropriate.
- Determine whether the reconfiguration of flight control should itself be adaptively automated, such that the UAV system adjusts the level of automated flight control to match the current circumstances (e.g., the current communications delay between UAV and GCS).
- Determine how and when the UAV operator will be allowed to override the automated flight control system.

The output of this work would be a set of rules advising what level of automation should be available/required, during what phases of flight and types of operations.

2. What are the consequences of degraded reliability of automated UAV functions for performance of the automated task and of concurrent tasks?

As the discussion in #1 above makes clear, UAV operations are likely to be highly automated. It is widely acknowledged, however, that often the effect of automation is not to reduce the human operator’s task demands but rather to change them, imposing new forms of cognitive workload and modifying the operator’s performance strategies (Parasuraman, 2000). Such changes, and occasional increases in cognitive workload, often result in circumstances when automation is imperfect. This imperfection does not refer to issues such as software reliability (e.g., “10^{-5} requirements”), but rather, to circumstances where correctly functioning automation is incapable of perfectly carrying out the functions asked of it. Examples include on-board conditions (e.g., icing) for which stability control cannot fully compensate, diagnostic systems based on imperfect cues, or conflict detection/avoidance algorithms based upon future trajectory estimates in a probabilistic environment (Xu et al., 2002; Kuchar, 2001). Past work has indicated that imperfect automation at a reliability level greater than around 0.80 can continue to support performance on the automated task as well as concurrent tasks (Dixon and Wickens, 2004; Wickens & Dixon, 2005), although this “threshold” estimate remains far from an absolute value, and other factors, such as the nature and priority of the automated task, appear to modulate pilot tolerance for imperfection. To allow the optimal design of automated support systems for UAV operators, research is thus recommended to:

- Determine the minimum acceptable reliability levels for automated functions that relatively unique to UAV operations.

- Anticipate potential forms of system failure, and delineate their likely consequences.
- Estimate the means and standard deviations of operators' response times to various failures.

Techniques such as Failure Modes Effects Criticality Analysis can be used in these endeavors.

3. How will see and avoid requirements be addressed in UAV flight? Can automated detect, see, and avoid (*DSA*) technology allow a UAV operator to maintain acceptable levels of separation? What are the consequences of imperfectly reliable DSA automation on conflict detection and on performance of concurrent tasks?

The ability to maintain adequate separation between aircraft is a prerequisite for the safe integration of unmanned vehicles into the NAS. While safe separation from other aircraft can generally be assured through standard ATC operations in operations under IFR and IMC (but see issue #13 below), there will be times in which UAVs may be flying under VFR (or a corresponding designation) in which detect, see and avoid (DSA) capabilities are essential. In such circumstances, separation may often be maintained through emerging CNS (communications, navigation, surveillance) technology supported by GPS navigation and ADS-B communications. However, these conditions do not accommodate unequipped (non-cooperating) air vehicles that are unable to accurately transmit (or transmit at all) their position and trajectory through the 3D airspace, and which may be uncooperative or non-responsive in negotiating conflict avoidance maneuvers. It is for this reason that automated DSA functions are required. The need for such functions raise two critical human factors concerns.

First, operators will be asked to interact with error prone systems. It is likely that automatic target recognition capabilities will be fallible, particularly if they are asked to generate early alerts (i.e., at sufficient distance that avoidance maneuvers are possible). As a consequence, this form of automation will be imperfect (see # 2 above; Thomas, Wickens, & Rantanen, 2003), leading to either misses (late alerts) or false alerts. Given the high costs of misses, and low base-rate of events (Parasuraman, Hancock, and Obofinbaba, 1996), the false alarm rate will be potentially quite high (Krois, 1999). The effects of such automation errors will have to be considered in designing DSA systems. Second, operators will be required to interact with the imperfectly reliable DSA system while also maintaining responsibility for airframe and payload control. These concurrent responsibilities will determine the degree to which the operator can be expected to oversee the DSA, monitoring the raw data of the UAV sensor images of the 3D airspace upon which the DSA algorithms are based. In light of these concerns, research is recommended to:

- Determine how operators will respond to alert imperfections in DSA.
- Delineate the conflict geometries and visibility conditions that are likely to degrade the reliability of DSA automation.
- Establish procedures by which the output of human perception and automated target analysis can be combined to maximize the sensitivity of the two component (pilot and algorithm) system given the pilot's concurrent responsibility for flight control.

4. To what extent should takeoff and landing be automated?

Current UAV systems differ in their manner of takeoff and landing. Some (e.g., the Hunter and Pioneer) are controlled by an on-site external pilot. Others (e.g., the Predator) are controlled by an air vehicle operator within the GCS. For others still (e.g., the Global Hawk) takeoff and landing are fully automated. These differences appear to be consequential; takeoff and landing errors constitute a higher proportion of human factors-related accidents for the Hunter (67%) and Pioneer (78%) systems, both of which are controlled by an external pilot, than for other systems (Williams, 2004). Research is therefore recommended to:

- Determine what method of UAV control during takeoff and landing is appropriate for aircraft in civilian airspace.
- Delineate the responsibilities that the human operator can and will be expected to assume in the case of automation failure.
- Establish guidelines to for how and how will the human operator will be allowed to override automated control systems.

PILOT INTERFACE: PERCEPTUAL AND COGNITIVE ISSUES

5. Through what form of control interface should internal and external pilots manipulate a UAV?

As noted above, UAV systems will vary in the degree to which airframe control is automated either en route or during takeoff and landing. For any system that is not fully automated—including systems that allow for a human operator to intervene in vehicle control by overriding automation—it will be necessary to provide operators with a control interface through which to manipulate the vehicle. The form of this interface will differ for internal pilots, those who interact with the vehicle through an interface of sensor displays and controls inside a ground control station, and external pilots, those who interact with the vehicle while in visual contact with it at the site of takeoff or landing. In the case of full manual control by an internal pilot, the seemingly obvious choice of control design is a stick and rudder interface like that used for control of manned aircraft. In cases of partially automated flight control, or of fully automated flight control where the pilot is provided authority to override the automation when deemed necessary, the optimal design of control interface is less clear. Current UAV systems vary in control design, with some systems allowing interaction through knobs or position switches and others through mouse-driven point-and-click computer menus (Williams, 2004). Alternative designs may be possible, however, and should be explored. Additionally, it is important to ensure that any interface be tailored according to established human factors guidelines; data suggest that some existing UAV system interfaces are poorly designed for human interaction.

Similarly, research is necessary to assess and improve the design of controls for external pilots. Currently, an external pilot manipulates the UAV using joystick controls similar to those used by radio-controlled aircraft hobbyists (Williams, 2004). These designs are problematic, however, in that the mapping of vehicle movement to control input varies depending on the heading of the vehicle relative to that of the EP. When the heading of the vehicle and pilot are the same, a rightward input to the joystick control produces rightward motion from the aircraft relative to the pilot. When the heading of the aircraft and pilot deviate, however, this is no longer true. In the most extreme case, where the heading of the UAV and pilot differ by 180°, a rightward input on the joystick produces leftward motion of the vehicle relative to the pilot. Joystick controls for external pilots are thus not designed to conform consistently to the well-established human factors principle of *motion compatibility* (Wickens & Holland, 2000; Wickens, Vincow, & Yeh, 2005). Not surprisingly, this violation appears to be contributing factor in a high number of UAV mishaps (Williams, 2004). Quigley and colleagues (Quigley, Goodrich, & Beard, 2004) have designed and tested a variety of control interfaces to address this problem. Further is now necessary to:

- Explore and optimize the design of control interfaces for internal and external pilots' control of UAVs.
- Delineate the performance benefits and drawbacks of various forms of UAV control interface so as to determine which design should be adopted.

6. What compromises should be adopted between spatial resolution, temporal resolution, time delay, and field-of-view (FOV) in the display of visual imagery for flight control and/or conflict detection?

A UAV operator generally relies on imagery from onboard sensors for manual control of vehicle and payload and for visual target detection. The quality of this visual information, however, may be degraded due to datalink bandwidth limits and transmission delays. Specific degradations include poor spatial resolution, limited FOV, low update rates, and delayed image updating (Van Erp, 2000). These conditions will impair both vehicle control and the visual detection of air traffic. For example, low image update rates will degrade perception of motion information that is useful for drawing attention to air traffic in the visual field. Low update rates and long communication delays, likewise, will produce discontinuous and slow visual feedback in response to operator control inputs, leading to instability of manual UAV control or camera image control and encouraging operators to adopt a "go-and-wait strategy" in manual control (Van Erp & Van Breda, 1999). Poor spatial resolution, obviously, will impair detection of objects that occupy only a small visual angle within an image, reducing stand-off distance in detection of potential traffic conflicts (see 4 above). A small field of view (FOV) will not only eliminate ambient visual information useful for assessing ego-motion necessary at low level flight (Gibson, 1979; Wickens & Holland, 2000), but will also impose a demand for greater amounts of camera scanning for successful traffic detection. A well-designed system for display of sensory imagery will be required to balance the benefits and costs of temporal resolution, spatial resolution, and FOV. To guide the design of visual information displays, research is recommended to:

- Determine what information is "task-critical" in manual airframe control, payload sensor control, and visual traffic detection (Van Breda, 2000).
- Establish the optimal compromise between spatial resolution, temporal resolution, and FOV in the display of visual imagery.

As part of this work, it will be important to establish a catalogue of mission payload requirements that may compromise the quality of visual information for flight, and establish the minimum necessary information (time delay and image quality) for manual control. For different functions, sensitivity curves should be established to show performance quality or function degradation as a function of spatial and temporal resolution.

7. Can augmented reality displays or synthetic vision systems successfully compensate for the degraded visual imagery provided by onboard sensors?

As noted above (#6), low temporal resolution and delayed updating of visual imagery received from onboard sensors will degrade manual control of airframe and payload tasks. The judicious choice of spatial and temporal image parameters may attenuate these effects, but is unlikely to mitigate them in full. An alternative approach to improving visual information display may be through the use of "augmented reality" (Milgram & Colquhoun, 1999) or "synthetic vision" (Draper et al., 2004), in which the real-world imagery provided by a sensor is embedded within a display of computer-generated landmarks or objects representing the same scene. The virtue of augmented reality in the context of UAV flight is that the computer-generated component of a display can be updated immediately in response to control inputs from a UAV operator, providing rapid feedback to improve manual tracking. For example, Van Erp & Van Breda (1999) provided subjects in a simulated payload sensor control task camera imagery overlaid by a computer-generated grid of perpendicular lines, oriented so as to conform to the imaged scene. The synthetic grid shifted in real time following input from the operator, giving visual feedback as to the direction and magnitude of camera movement. As compared to a control condition with no virtual grid, augmented displays significantly improved target tracking at low camera update rates (i.e., long sensory delays). A study by Veltman and Oving (2002) produced similar benefits by embedding current and predicted camera footprints within a larger map (either 2D or 3D) of the terrain to be scanned. A still more sophisticated form of display is a fully virtual synthetic vision system, in which terrain information is stored in databases and rendered based on GPS position. An important issue here concerns the degree of realism with which synthetic imagery should be presented, whether minimalist (e.g., the grid used by Van Erp and Van Breda), or highly realistic, such as employed in current SVS systems (Prinzel et al., 2004). The danger of the latter is that pilots may place undue trust in the imagery, leading to cognitive tunneling and neglect of information not available within such a high imagery display (e.g., a "transponder off" aircraft; Thomas and Wickens, 2004). Augmented displays thus present a promising method of enabling good UAV operator performance, but are not without potential costs. Research is thus recommended to:

- Further develop and test predictive augmented displays to improve airframe and payload sensor control.
- Determine the effects of display format/fidelity on the UAV operator's level of trust in the automated system.

8. Can multimodal display technology be used to compensate for the dearth of sensory information available to a UAV operator?

One of the primary consequences of the separation between aircraft and operator is that the operator is deprived of a range of sensory cues available to the pilot of a manned vehicle. Rather than receiving direct sensory input from the environment in which his vehicle is embedded, the UAV pilot receives only that information provided by onboard sensors via datalink. As noted above, this consists primarily of potentially degraded visual imagery covering a relatively small FOV. Sensory cues that are lost thus include ambient visual input, kinesthetic/vestibular information, and sound, all of which are valuable in maintaining operator awareness of the environmental and system conditions (e.g., turbulence, icing). As compared to the operator of a manned aircraft, therefore, a UAV operator can be said to function in relative "sensory isolation" from the aircraft under his control. It is critical in light of this for UAV system developers to design displays and alarms to keep operators well-informed of system status and aware of potential system failures.

Visual displays provide one method of presenting a UAV operator with sensor information beyond that conveyed by imagery from a vehicle-mounted camera. Data suggest, however, that UAV operators may not optimally modify their visual scanning strategies to compensate for the absence of multisensory cues (Tvaryanas, 2004). Moreover, the task of creating an "ecological", intuitively-interpreted visual representation for such information is often difficult. An alternative way to compensate UAV operators for the lack of direct sensory input from the vehicle's environment could be through the use of multimodal (e.g., tactile or auditory) information displays. For example, fly by wire controls have long been equipped with augmented force feedback mimicking the forces experienced on the air surfaces of manned aircraft, and roughly capturing the changes in handling quality. Ruff et al. (2000) examined the value of haptic displays for alerting UAV operators to the onset of turbulence. Their data revealed that haptic alerts, conveyed via the UAV operator's joystick, could indeed improve self-rated situation awareness during turbulent conditions in a simulated UAV approach and landing task. Interestingly, this was true despite the fact that the haptic signals were not designed to closely simulate or mimic the veridical haptic information experienced by the pilot of a manned vehicle. The benefits of haptic displays, however, were obtained only under limited circumstances (specifically, only when turbulence occurred far from the runway), and were offset by an increase in the subjective difficulty of landing. These results suggest some value of multi-modal displays as a method of compensating for sensory cues typically denied to a UAV operator, but also indicate that such displays may not be universally valuable and may carry costs as well as benefits.

A related point is that multimodal displays may be useful not simply as a means to compensate for the UAV operator's impoverished sensory environment, but more generally to reduce cognitive-perceptual workload levels. Studies by Calhoun et al. (2002), Sklaar and Sarter (1999), and Wickens and Dixon (2002; Dixon & Wickens, 2003; Wickens, Dixon, & Chang, 2003), for example, have found that auditory and tactile displays can improve aspects of flight control and system monitoring.

In sum, research is necessary to:

- Further develop techniques for multimodal information display.
- Assess the value of multimodal displays in countering UAV operators' sensory isolation.
- Assess the more general value of multimodal displays in distributing workload optimally across cognitive-perceptual channels.

9. To what extent can displays and controls be standardized across UAV systems? What level of standardization should be mandated? (Basic T instrument panel? HUD overlay?)

We anticipate a tendency for vendors to produce novel designs for the interface, particularly, given the diversity of specialized payload missions for which UAVs may be designed. It is essential to establish certain commonalities across all interfaces. Exactly what these should be remains a question for research. Questions to be considered include, but are not limited to:

- Should the "basic T" always be maintained?
- Is an inside-out attitude display necessary, given that the pilot is no longer inside the vehicle?
- Should certain information always be visible (never hidden to be retrieved by menu navigation)?
- Should all aspects of the payload display be kept spatially separated from the primary flight display, or are HUD overlays advisable?
- Should certain controls (e.g., a joystick) be mandatory for certain functions, and should others be prohibited (e.g., mouse for flight control)?

Identification of these issues recognizes that no single display layout or control assignment is optimal for all tasks, but also recognizes that certain cases of inconsistency can lead to negative transfer and pilot error, as pilots transfer from one interface to another. Similar issues have been addressed in assigning common type ratings and differences training in commercial manned aircraft.

10. What are the consequences for system safety of pilot judgment when the pilot no longer has a "shared fate" with the vehicle? Will there be subtle shifts in risk taking that might affect overall airspace safety?

UAV pilots will not be at risk for injury or death if their aircraft crashes, in contrast to the circumstances of manned aircraft pilots, who "share fate" with their aircraft. This difference could, in theory, impose a substantial difference in risk taking tendencies, in such areas as the decision to carry out a flight into bad weather (Goh & Wiegmann, 2001; Wiegmann, Goh, & O'Hare, 2002). Such differences may be further amplified by the sensory isolation described previously. Research is thus recommended to:

- Determine how the UAV operator's risk perception and risk taking behavior are affected by absence of shared fate with his/her vehicle.
- Determine how the UAV operator's risk perception and risk taking behavior are affected by the absence of sensory/perceptual cues.

AIR TRAFFIC MANAGEMENT PROCEDURAL ISSUES

11. How will hand-offs between crews be accomplished during long-endurance flights?

Long-distance and/or long-endurance UAV flight will require the frequent transfer of control between operators, generally taking one of three forms (Kevin Williams, personal communication). First, control may be passed from one ground control station to another. Second, control may be passed from one crew of operators to another within the same ground control station. Finally, control may be passed from one operator to another within a crew. The transfer of control will likely constitute a critical and high-workload phase of UAV operations. Indeed, a number of military UAV accidents have occurred during transfer of control from one team of operators to another, generally because the station receiving control was not properly configured (Williams, 2004). Research is necessary to establish procedures for the safe handoff of control between UAV crews. More specifically, this work should:

- Develop and test formal procedures for handoff of UAV control between teams of operators.
- Develop and test displays, automation, and procedures to ensure that the operators receiving UAV control are adequately informed of system status and are alerted to discrepancies in system configuration between control stations relinquishing and assuming vehicle control.

12. What are the effects of variable total loop time delays on response to ATC instructions?

Datalink delays may be expected to add as many as several seconds to the communications loop between UAV operators and ATC. The magnitude of these delays, however, will be variable, and may not always be predictable to human operators. Thus, controllers may have greater difficulty in compensating for these delays than they do in compensating for the fixed response characteristics of a given class of aircraft. Potential compensatory responses to communication delays are changes in the timing with which ATC commands are issued and acted upon, and changes in the communications flow between ATC and UAV operators (Kiekel, Gorman, & Cooke, 2004; Rantanen McCarley & Xu, 2004). To anticipate and accommodate the effects of communications delays, it will be necessary to understand and take account of these compensatory behaviors and their consequences for system performance. Research should thus be conducted to:

- Determine what compensatory behaviors, if any, air traffic controllers' and UAV operators' adopt in response to communication delays.
- Determine the effects of communications delays on the flow of air traffic.

Computer simulation models of communications may be particularly effective tools here, so long as such models are based on empirically validated estimates of human response time, variability, and reliability (probability of communications error).

13. What form of predictable autonomous behavior should a UAV adopt following a loss of ground-to-air communications? How should the UAV operator be alerted to a loss of ground-to-air communications?

One particularly disruptive scenario of UAV automation failure is a total severing of the GC-UAV control loop. It is important that the vehicle behave predictably under such circumstances. This is a human factors issue because such default rules are of critical importance to the ATC/ATM who must manage traffic based on the knowledge of these rules (Shively, 2004). It is also important, clearly, that the UAV operator become aware of the communications loss as rapidly as possible. Research is therefore necessary to:

- Determine what behavior UAV be programmed to adopt by default in case of a total communications loss with ground control station (Continue to fly on a straight path? Descend? Fly toward the nearest equipped airfield?).
- Develop displays, automation, and/or procedures by which the UAV operator can be made aware of a communications loss, and be provided estimates of its potential causes and consequences.

CREW QUALIFICATIONS

14. How many members will each crew comprise, and what will be each crewmember's responsibilities? Can an operator supervise multiple UAVs simultaneously while maintaining an acceptable level of performance?

Military UAV crews for reconnaissance missions typically include both an air vehicle operator and a mission payload operator (Draper et al., 2000; Mouloua et al., 2003). Such crew structure is reasonable in light of findings that the assignment of airframe and payload control to the same operator can substantially degrade performance (Van Breda, 1995, cited in Van Erp & Van Breda, 1999). For UAV flight in civilian airspace, however, the size of the crew complement necessary for each vehicle is likely to be contingent on the nature and goals of the flight task (e.g., surveillance vs. long-distance transport vs. station keeping for telecommunications). Although some research has demonstrated possibility of single pilot-multiple UAV (1-to-many) control (Cummings and Guerlain, 2004; Galster et al., 2001; Wickens et al., 2003), these successes pre-suppose three circumstances: (1) closely coordinated and correlated activities among the multiple UAVs (Cummings & Guerlain, 2004), (2) operation in a disturbance free (closed) environment, such as very high altitudes, (3) high levels of reliable automation (Dixon and Wickens, 2004). When any of these three characteristics are not in force, and, in particular, when one UAV enters a failure mode, the ability of the pilot to monitor others in a 1-to-many configuration is severely compromised. Furthermore, even in a 1-to-1 configuration, performance of concurrent tasks is dramatically degraded when heavy demands are imposed on the single operator by complex payload operations (e.g., manipulating camera imagery) (Dixon and Wickens, 2004). In light of this, research is necessary to:

- Delineate circumstances under which multiple responsibilities (e.g., flight control, conflict detection, payload control) be safely assigned to a single UAV operator, and circumstances under which such responsibilities should be distributed across two or more crew members.

And, by extension:

- Delineate circumstances under which a single operator can safe hold responsibility for multiple UAVs simultaneously.

It is crucial that such research consider circumstances under which automation is imperfect (#2), and that it address the potential cost of communications and teamwork between multiple operators (Kiekel et al., 2004).

15. What are the core knowledge, skills, and abilities (KSAs) that should be required for UAV pilot certification? What KSAs should be required for certification to fly particular UAV systems or classes of systems?

Research is necessary to:

- Determine the general KSAs that will be required of all UAV operators.
- Determine KSAs required for certification to operate specified classes or systems of UAV.

16. How should UAV operators be trained? What constitutes an appropriate regimen of ground school, simulator, and flight experience for UAV flight certification?

Safe flight of unmanned vehicles in the national airspace will demand effective procedures for UAV pilot training. Ryder et al. (2001) note that because the task demands of operating a UAV from a ground control console are similar during simulated and real flight, simulator experience is likely to constitute a greater portion of training for pilots of unmanned vehicles than for pilots of manned aircraft. As noted below (#17), furthermore, experience piloting manned aircraft appears to produce positive but imperfect positive transfer to UAV flight (Schreiber et al., 2002). Research is needed to:

- Optimize simulation systems for UAV pilot training and test their adequacy
- Establish requirements for flight training outside the simulator.
- Determine to what extent manned pilot experience should offset training requirements for UAV certification.

17. Should experience piloting a manned aircraft be prerequisite for UAV pilot certification?

Past research has come to conflicting conclusions as to whether UAV operators will benefit from experience piloting a manned aircraft. Schreiber et al. (2002) examined the effects of prior flight experience on novice operators' skill acquisition and transfer in a Predator UAV simulation. In general, flight experience reduced the number of training trials required for operators to reach a criterion level of performance on a set of basic maneuvering and landing tasks, and improved operator performance on a subsequent reconnaissance task. Other findings, however, have suggested that UAV operators need not be rated aviators. Using the Army's Job Assessment Software System (JASS), Barnes et al. (2000) elicited Hunter UAV operators ratings of the relative importance of various cognitive skills in UAV air vehicle operators. Ratings indicated that outside of communication skills, raters did not consider flight-related skills of great importance to UAV operations, leading the authors to conclude that selection of rated aviators as air vehicle operators would be of little value.

The apparent discrepancy in the conclusions reached by Schreiber et al. (2002) and Barnes et al. (2000) may be due, at least in part, to differences in the operation of the UAV systems under consideration; while the Predator is piloted manually via a stick and rudder interface similar to that of a manned aircraft, the Hunter is guided by automation that allows the operator to select flight parameters using knobs on the GCS console. The value of prior flight experience to a UAV operator, that is, may depend in part on similarity between the manned and unmanned systems. Research is necessary to:

- Determine whether and how much experience piloting a manned system should be required for UAV pilot certification.
- Determine whether prerequisite levels of flight experience, if any, should vary across UAV platforms.

18. What medical qualifications should a UAV operator be required to meet?

Although issues of high altitude physiology and medication induced vestibular disruption are not relevant to UAV pilots, some forms medical qualifications are likely to remain necessary. Research is necessary to:

- Determine whether medical standards for UAV operators should be in any ways less or more strict than for pilots of manned aircraft.
- Establish special duty limits for long duration missions.

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Appendix A

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The paper uses an ACT-R model to examine expert/novice differences and effects of control strategy on Predator UAV flight. Three models were developed. Model P (performance only) lacked the knowledge of control instrument settings that is characteristic of expert pilots, and therefore could only rely on performance indicators in maneuvering the aircraft. Model CP (Control + Performance) had knowledge of control and performance settings needed to achieve aircraft behavior, and therefore could rely on a control and performance strategy. However, the model did not remain focused on control indicator after making adjustment to it, but continued with normal crosscheck and checked to see if manipulation had its intended when attention eventually returned to the indicator. Model CFP (Control Focus & Performance) was similar to model CP, except that it remained focus on control instrument until it was properly set. This was in addition to normal crosscheck.

To examine expert/novice differences, the authors compared Model P to Model CP. To examine strategic effects, they compared Model CP to Model CFP.

Results

Performance was better for Model P than for Model CP on 6 of 7 maneuvers. Model P was better on the most complex (three-axis) maneuver, though its not clear why. Performance was better for Model CFP than for Model CP on 5 of 7 maneuvers. Performance on other two maneuvers was similar. Overall, Model CFP performed the most like human subject matter experts.

2) Barnes, M.J., Knapp, B.G., Tillman, B.W., Walters, B.A., Velicki, D. (2000). *Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments (Technical Report ARL-TR-2081)*. Aberdeen Proving Ground, MD: Army Research Laboratory.

Experiment 1

Assessed the importance of using rated aviators for air vehicle operator (AVO) and external pilot (EP) positions in the Hunter UAV. The AVO tasks are to design mission plans in collaboration with commander, fly the UAV after take-off, and set course to waypoints. The AVO must be able to read the instruments, understand flight status, coordinate with the mission payload operator (MPO) when reaching target area, and respond to emergencies and make course changes when necessary. However, the AVO does not fly the vehicle using stick-and-rudder controls, in the manner of a typical pilot. The EP is responsible for take-off and landing, using a controller similar to that for model airplanes. Most flight safety problems occur during the times that the EP is in control, primarily because take-off and landing are inherently difficult.

The study used the Army's Job Assessment Software System (JASS) to determine what cognitive skills are important for the AVO and EP positions. JASS collects ratings about the degree to which various skills and abilities are necessary to perform a given task. The skills/abilities rated by JASS fall into six categories: communication, speed-loaded, reasoning, visual, auditory, and psychomotor. JASS data were supplemented with enhanced computer-aided testing (ECAT) data from an earlier study. The ECAT data were one- and two-handed tracking scores, which were correlated with failure rates for EP training.

21 subjects were AVO & MPO designated; 11 gave ratings of AVO task structure, 10 gave ratings of MPO task structure. 9 subjects were certified EPs, and gave ratings of EP task structure. 16 fixed- or rotary-wing Army aviators also rated EP skills. ECAT data came from a sample of 28 students in Pioneer and Hunter UAV EP training courses. Six of these failed the course.

Results

AVO raters did not rate flight-related tasks as overly demanding on any of the six skill sets except communication. The EP task was rated as more demanding than AVO task on all skill sets. EP subjects were broken into 4 groups: EP low experience, EP high experience, fixed-wing aviators, and rotary-wing aviators. Aviators gave slightly higher ratings to reasoning skills than did EPs. The EP low experience group gave especially high ratings to vision, audition, and psychomotor skills. Experienced EPs reported using mostly conceptual skills during emergency situations. Inexperienced EPs reported relying on visual & psychomotor skills.

ECAT tracking data were correlated with EP course success rates; 5 of the 6 students who failed had tracking data near bottom of sample distribution. These findings are consistent with the finding (noted above) that inexperienced EPs find visual and psychomotor skills to be particularly important.

Experiment 2

Examined the potential value of imagery and intelligence analysts as components of the UAV. The method used was to measure overlap between JASS ratings for imagery analysts, intelligence analysts, and UAV crew task duties. Imagery analyst skill rankings were significantly correlated with those for 2 out of 16 UAV crew duties, intelligence analyst skill rankings were correlated with those for 14 out 16 UAV crew duties. Results suggest that imagery analysts would complement UAV crew skill sets.

Experiment 3

Used a computational model of human cognition (Micro Saint) to investigate workload throughout the course of a simulated Outrider UAV flight mission. Also considered remarks from subject matter experts (SMEs). Results suggest that candidate tasks for automation included pre- and post-flight procedures & checks, verification of system settings, and computer checks of mission plans. SMEs reported that they did not want full automation, but preferred instead to retain decision making authority themselves. To reduce workload, they suggested making the computer interface faster and letting the automation provide backup check for safety problems.

3) Bell, B., & Clark, J.G. (2002). Bringing command and control of unmanned air vehicles down to earth. *Proceedings of the 21st Digital Avionics Systems Conference (DASC)*, Irvine, CA.

Describes an automated system to assist in UAV search area planning. System is called the Automated Search Area Planning System (ASAPS), and is meant to reduce search area by modeling terrain and target mobility then helping operator to plan a search route focusing on areas where target is most likely to be found.

4) Calhoun, G.L., Draper, M.H., Ruff, H.A., & Fontejon, J.V. (2002). Utility of a tactile display for cueing faults. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 2144-2148.

Subjects performed a compensatory tracking task in conjunction with a monitoring task. Study compared the value of visual, tactile, and combined visual/tactile alerts for identifying which of four scales exceeded normal range in the monitoring task. In the visual condition, subject was required to monitor the scales. In the tactile condition, subject received pulse train alert of fault, with location and frequency of train indicating which scale was beyond normal range of values.

Results

Response time to faults was faster and RMS tracking error was reduced with tactile cues compared to visual cues. Subjective ratings also strongly preferred the tactile cues.

5) Calhoun, G.L., Fontejon, J.V., Draper, M.H., Ruff, H.A., & Guilfoos, B.J. (2004). Tactile versus aural redundant alert cues for UAV control applications. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 137-141.

Experiment 1

Examined the value of aural and tactile alerts, presented redundantly with visual cues, to signal warnings during a simulated UAV control task. Subjects performed a continuous UAV control task. While doing this, they were required to respond to occasional (3-4 per minute) data entry tasks. Two kinds of data entry task were used:
1) Warning response task Subject determined whether warning level was caution (20-24 per trial) or critical (3 per trial), then responded by entering an appropriate sequence of keys.
2) Radio frequency task Subjects heard call signs, followed by a combination of color & number. On events with call sign Eagle, subject was required to select the appropriate color/number coordinate on the HDD using a mouse. On low auditory load trials, only the call sign Eagle events were used. On high auditory load trials, distractors events with different call signs were interposed.
3) Data query task Simultaneous visual/voice commands specified data for subject to retrieve from HDD and enter via keypad.

Primary manipulation of interest was in the warning response task. In baseline condition, caution signals were specified by yellow visual cue and redundant Type I aural cue, critical signals were specified by red visual cue and the Type I aural cue. In +2nd aural condition, caution signals were specified by yellow visual cue and redundant Type I aural cue, critical signals were specified by red visual cue and the Type 2 aural cue. In +Tactile condition, caution signals were specified by yellow visual cue and redundant Type I aural cue, critical signals were specified by red visual cue and tactile cue.

Results
+2nd aural and +Tactile conditions produced shorter RTs than baseline condition ($p < .05$ and $p < .10$). Baseline was also subjectively rated as less salient than the other two conditions. +2nd aural and +Tactile were not significantly different. +2nd aural and +Tactile improved performance in the radio frequency task under high auditory load conditions. Flight performance was not affected by alert condition.

Experiment 2
The second experiment was conducted to examine the interaction of cue format and auditory load more closely. Method was similar to that the Experiment 1, except that 1) no auditory cue was used in the baseline condition, 2) only critical cues (no caution cues) were used, 3) high auditory load was more difficulty, 4) aural and tactile cues were matched for salience by a pilot study, 5) a visual IFF status probe task was added.

Results
+Aural and +Tactile conditions produced shorter RTs than baseline condition, and were rated as more salient. No differences obtained between +Aural and +Baseline conditions. Baseline condition also produced higher subjective workload. Low auditory load in general produced better self-rated SA and task performance and lower workload, but did not interact with cue format, contrary to findings of Experiment 1.

6) Cooke, N.J., & Shope, S.M. (2004). Synthetic task environments for teams: CERTT's UAV-STE. *Handbook on human factors and ergonomics methods*. Taylor Francis.
Details steps involved in creating a synthetic task environment, and illustrates the process by describing the development of CERTT's Predator UAV STE.

7) Cummings, M.L. (2004). Human supervisory control of swarming networks. *Paper presented at the Second Annual Autonomous Intelligent Networked Systems Conference*.
Discusses issues related to supervisory control of swarming UAVs, i.e., groups of UAVs with some level of autonomous inter-vehicle collaboration. Collaboration between UAVs introduces another layer of automation into UAV control task. At the minimum level of network autonomy, there is no collaboration between UAVs. At the maximum level, vehicles are in full collaboration and there is no need for human intervention in emergent situations.

Increasing inter-vehicle collaboration does not necessarily increase automation level for the system as a whole. At the lowest level of inter-vehicle collaboration, automation can range from SV levels 1-10. At highest levels, it can range from levels 7-10. The effects of automation of full system and of inter-vehicle communication must be considered in system design.

DOD recognizes the need for a standard UAV interface that provides critical SA and location data to support airspace integration. Swarming UAVs will be tasked to optimize multi-objective cost functions, and central issue in maintaining SA will be to provide visualization tools that communicate cost function info to UAV operator. It will also be necessary to provide interactive sensitivity analysis tools to determine how human adjustments of variables could change overall cost function.

8) Cummings, M.L., & Guerlain, S. (2004). ***Developing operator capacity estimates for supervisory control of autonomous vehicles*****. Manuscript under review.**
An experiment assessed operators' ability to control multiple autonomous aircraft. Subjects performed a supervisory task that required them to control and occasionally re-target multiple Tomahawk missiles. Commands and occasional queries were presented in an onscreen chat box. Chat box responses served as a secondary task measure of workload. Retargeting was done with a decision matrix (looks like a spreadsheet) that allowed subjects to view information on all retargetable missiles, including how long it would take missiles to get to target and the time remaining for the operator to retarget the missile. Available missiles were listed in rows, potential targets were listed in columns. Cell at the intersection of a given row and column gave info about that missile/target pairing. Retargeting commands arrived at two tempos, low (one event every 4 minutes) and high (one event every 2 minutes). Difficulty of task scenarios was easy, medium, or hard.

Dependent variables were decision time for retargeting; Figure of Merit (FOM), a weighted measure of overall performance; utilization, an objective workload measure given by % busy time; and NASA-TLX ratings. Participants were 42 active and retired duty Navy personnel.

Results
Decision time, FOM, and utilization scores were similar with 8 and 12 missiles, but were degraded with 16 missiles. The effect of number of missiles on decision time was larger as the scenario became more difficult. Subjective workload scores were not affected by number of missiles. Results suggest that operators can manage up to 12 missiles with no degradation. See papers by Galster et al. (2001) and Hilburn et al. (1997) for similar conclusions from ATC domain.

9) de Vries, S. C. (2001). ***Head-slaved control versus joystick control of a remote camera (TNO-report TM-01-B008)*****. Soesterberg, The Netherlands: TNO Human Factors Research Institute.**
Experiment compared benefits of head-slaved HMD control of UAV camera vs. joystick control. Camera joystick was either passive, active (force feedback), or combined with UAV control joystick. Dynamics of the joystick were either position or velocity control. In some conditions, reference marks were included to aid perception of camera orientation.

Results
Analysis of joystick manipulations indicated that best performance came from a passive joystick providing position control without vehicle references. Performance on almost all measures was superior with joystick control relative to head-slaved control.

10) de Vries, S.C., & Jansen, C. (2002). Situational awareness of UAV operators onboard moving platforms. *Proceedings HCI-Aero 2002*.
An experiment examined spatial awareness of operators controlling a UAV from onboard a moving helicopter. Displays presented a 2-D electronic map of terrain including the UAV, helicopter, football stadium, and a column of tanks. In some conditions, a 3-D map was presented to provide self-motion info from perspective of operator inside the helicopter. 2-D maps varied in their center (heli-centered vs. UAV centered) and orientation (north up vs. helicopter heading up vs. UAV heading up). The subject's task was to monitor displays through a 40-60 s automated flight period then answer questions about locations of various items. Questions could ask about either absolute (world-centered) orientation or relative positions of the four items onscreen.

Results
North-up displays were better for absolute orientation questions, as assessed by angular judgment errors and by RTs. In general, absolute judgments were slower than relative judgments, except in case where map is north-up and there was no 3-D self-motion. 3-D self motion increased errors in most conditions (perhaps producing an SAT in some cases) but improved judgments of relative direction from helicopter, and had no effect on judgments relative to the UAV.

11) Wickens, C.D., & Dixon, S. (2003). *Imperfect automation in unmanned aerial vehicle flight control (Technical report AHFD-03-17/MAD-03-2)*. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Employed the single-UAV task of Wickens & Dixon (2002) to examine the effects of imperfect automated aids for detecting system failures and controlling UAV flight path. Subjects flew simulated UAV missions to a command target (CT) locations while concurrently searching for targets of opportunity (TOOs) and monitoring a set of gauges for system failures (SFs). In a baseline manual condition, subjects flew without automated aids. Three groups of subjects were provided an aid to signal system failures. For one group, aid was perfectly reliable. For another group, aid was 67% reliable and prone to committing false alarms. For the third group, aid was 67% reliable and prone to committing misses. Two additional groups were provided an autopilot to control UAV flight path. For one group, autopilot was perfectly reliable. For the other group, autopilot was 67% reliable (i.e., prone to going off-course). A final group was provided both forms of automation, with both being perfectly reliable.

Results
Data indicated that perfectly reliable aids improved performance relative to baseline, and that even the imperfect autopilot was beneficial. Furthermore, automated flight control improved

performance on the concurrent TOO search task. In contrast, imperfectly reliable aids for SF detection produced no gains relative to baseline, and even perfectly reliable SF detection failed to improve TOO detection. Results suggest that the benefits of later stage automation (i.e., automation of task execution) may be greater and more robust than the benefits of early stage automation.

12) Dixon, S.R., & Wickens, C.D. (2004). *Reliability in automated aids for unmanned aerial vehicle flight control: Evaluating a model of automation dependence in high workload (Technical report AHFD-04-05/MAAD-04-1)*. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Employed the single-UAV task of Wickens & Dixon (2002) to examine the effects of an imperfect automated aid for detection of system failures. Subjects flew simulated UAV missions to a command target (CT) locations while concurrently searching for targets of opportunity (TOOs) and monitoring a set of gauges for system failures (SFs). In A80 condition, automated aid was 80% reliable and was equally likely to commit a miss or a false alarm. In A60f condition, aid was 60% reliable and was 3x more likely to commit a false alarm than a miss. This should have encouraged high reliance/low compliance. In A60m condition, aid was 60% reliable and was 3x more likely to commit a miss than a false alarm. This should have encouraged low reliance/high compliance. In a baseline condition, subjects performed with no automated aid.

Results

Tracking error was unaffected by automation condition.

The number of instruction refreshes (presented visually) was higher in the A60m (M = 8.5) condition than in the baseline (M = 3). The number of refreshes for A80 (M = 5.57) and A60f (M = 5.25) conditions were marginally lower than in A60m condition, and were non-significantly higher than in baseline condition.

TOO detection rate was higher in the A80 condition than in baseline. No other differences in detection rate between groups were significant. TOO detection times were higher in the A60f and A60m conditions than in baseline. Data showed a non-significant trend toward larger decrement in A60f condition, suggesting that a high false alarm rate induced subjects to invest more visual resources in inspecting gauges in response to an alarm than a high miss rate did.

CT detection times were significantly and substantially (2 seconds) longer in A60f and A60m conditions than in the baseline and A80 conditions.

SF detection rates were higher when workload was high (i.e., during loitering/inspection), but this did not interact with automation condition. SF detection times were also higher when workload was high, and showed an interaction with condition, reflecting the fact that load increased detection times in A60f condition more than in any other condition. Effects of load were similar on all other conditions. Comparison of A60f and A60m conditions showed that in both cases, detection times were increased when automation missed the SF. Detection times when the automation detected the failure were longer in the A60f condition than in the A60m, reflecting greater compliance with alarms in the later condition.

A computational model accounted for the data well. Results of the modeling suggest that compliance and reliance are linearly related to the automation's FAR and HR, respectively, and are largely independent of one another.

13) Dowell, S.R., Shively, R.J., & Casey, D.P. (2003). UAV ground control station payload symbology evaluation. *Paper presented at the Annual AUVSI Conference,* July 15-17, Baltimore, MD.

Compared the effects of floating compass rose and heading tape symbology on mission payload operators' ability to respond to change commands and SA queries. Symbology formats also differed in their representation of sensor pitch: compass rose displays gave pitch as a digital readout, heading tape displays depicted it with a wedge representation indicating the angle of declination. Commanded changes could be to sensor heading, sensor pitch, sensor heading relative to air vehicle (sensor bearing angle), or to AV heading. MPO did not perform AV heading changes, but called them out to confederate pilot. Subjective measures of workload (NASA-TLX) and SA (SART) were also collected.

Results

Changes to sensor heading and sensor bearing angle were more accurate with heading tape than with compass rose symbology, with no SAT. Unexpectedly, changes to sensor pitch were more accurate with compass rose symbology. Post-experiment interviews with subjects suggest this might be due to size and gradient of marked increments on heading tape symbology. Control reversals were more frequent with compass rose than with heading tape. SA probes didn't show much, and no differences were found in subjective ratings.

14) Draper, M., Calhoun, G., Ruff, H., Williamson, D., & Barry, T. (2003). Manual versus speech input for unmanned aerial vehicle control station operations. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting*, 109-113.

Employed a UAV simulation to examine benefits of manual (keyboard) and speech input modalities for intermitted data entry tasks during a continuous flight/navigation control task. A manual command comprised a series of button presses. A voice command comprised a single word or short phrase. Subjects received intermittent signals to perform data entry tasks during flight task. A response to each alert was required within 10 seconds, and the task was required to be completed within an allotted amount of time thereafter. A failure to acknowledge alert was considered a miss, and a failure to complete the task was considered a time-out.

Results

Task completion times were on average 40% shorter with voice commands. Benefits ranged in magnitude from 3.14 to 21.43 seconds. Number of time-outs was almost 10 times higher with manual entry (M = .95 vs. M = .1), and the number of tasks completed incorrectly was approximately 23 times greater. Response time to alerts was faster for manual entry mode, but difference was less than 1 second. RMS airspeed error, path error, and altitude error were all smaller in speech entry conditions. Subjective data also favored speech entry.

As study was devised, speech entry mode generally required fewer commands than manual entry. Data do not indicate if speech entry would still be superior if modalities were equated for number of steps required to execute commands.

15) Draper, M.H., Geiselman, E.E., Lu, L.G., Roe, M.M., & Haas, M.W. (2000). Display concepts supporting crew communications of target location in unmanned air vehicles. *Proceedings of the IEA 2000/ HFES 2000 Congress*, 3.85 - 3.88.

UAVs for intelligence, reconnaissance, and surveillance (ISR) usually have two operators, a sensor operator (SO) and an air vehicle operator (AVO). The AVO controls the airframe, monitors subsystems, and communicates with the ground control station (GCS). The SO searches for targets using a UAV-mounted camera.

The AVO generally views scene with a larger FOV than the SO, and can therefore assist in target detection by directing the SO's attention to targets outside the SO's current FOV. Usually, the AVO attempts to communicate the target location verbally. The goal of paper was to assess a pair of display concepts meant to facilitate AVO/SO communication about target location. Two kinds of advanced displays were tested:

- Compass rose overlay on the SO's camera display Allows AVO to give direction in world-centered references (N, S, E, W), and should make translation to screen-centered references easier for the SO
- Telestrator Allows AVO to designate target location on his display using a mouse, then presents a locator line on the SO's display indicating the direction and distance in which SO should shift camera to find target

Four conditions were tested: baseline (control), compass rose, telestrator, compass rose + telestrator

Results

Telestrator reduced the time necessary to designate the target, improved camera path efficiency improved, and reduced workload. Compass rose was of little benefit.

16) Draper, M.H., Nelson, W.T., Abernathy, M.F., Calhoun, G.L. (2004). Synthetic vision overlay for improving UAV operations.

The authors discuss potential benefits of synthetic vision systems (SVSs) for UAVs. These include:

- SVS could improve SA by highlighting items of interest in camera image.
- SVS could allow operator to maintain SA if visual datalink is lost.
- SVS could facilitate communications between users who are not co-located.

17) Draper, M.H., Ruff, H.A., Fontejon, J.V., & Napier, S. (2002). The effects of head-coupled control and a head-mounted display (HMD) on large-area search tasks. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 2139-2143.

Compared effects of various head-coupled and manually-controlled camera/display configurations on ability to locate targets in a 360-degree search task in a simulated UAV. Target acquisition was better with manual joystick/stationary CRT combination than with head-coupled HMD configurations. Workload ratings, SA ratings, and simulator sickness data also generally favored the non-HMD configurations.

18) Draper, M.H., Ruff, H.A., & LaFleur, T. (2001). The effects of camera control and display configuration on teleoperated target search tasks. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 1872-1876.

Subjects performed forward-field and rear-field search tasks in a UAV simulation using either A) joystick controlled camera with stationary CRT display, B) 1.0x gain head coupled camera with HMD, C) 1.5x gain head coupled camera with HMD, or D) 1.0x gain head coupled camera with HMD in conjunction with combined with manual joystick control.

Results

Configuration A produced best performance for forward-field search. Data showed no significant differences between configurations for rear-field search.

19) Fong, T., & Thorpe, C. (2001). Vehicle teleoperation interfaces. *Autonomous Robots, 11*, 9-18.

Paper discusses various forms of interfaces for vehicle teleoperation. These include:

- <u>Direct</u> Operator manually controls aircraft, typically using controls that are similar to those of a manned vehicle. This form of control/interface is appropriate when 1) real-time human control or intervention is required, and 2) the control station and vehicle are connected by a high-bandwidth, low-delay communications link.
- <u>Multimodal/multisensor</u> Multimodal interfaces "provide the operator with a variety of control modes (individual actuator, coordinated motion, etc.) and displays (text, visual, etc.)...Multisensor displays combine information from several sensors or data sources to present a single integrated view."
- <u>Supervisory control</u> Operator specifies subtasks which the vehicle then performs on its own. This is appropriate when datalink bandwidth is low or communications are delayed.
- <u>Novel</u> These include psychophysiologically-driven control, gesture-based control, web-based interfaces, PDA-based interfaces.

20) Fontejon, J., Calhoun, G., Ruff, H., Draper, M. & Murphy, K. (2004). Tactile alerts for monitoring tasks in complex systems.

An earlier study (Calhoun et al., 2002) found that tactile alerts could speed detection of system faults in a multi-task environment. In that experiment, subjects were required to detect & identify system faults while also performing a manual tracking task. Two tactors were used to signal four possible system faults: combination of tactor location and vibration frequency signaled which of four system parameters was in fault. Performance was best (RT shortest) when one tactor was located on each arm. When both were on a single arm, performance was better with the right than the left arm.

In the study described above, all participants were right-handed. Additionally, manual tracking was performed with the right hand. The current study was conducted to determine if similar results would obtain for A) left-handed subjects, and B) when subject performed the tracking task using the left hand.

Results
RTs were shortest when tactors were located on different arms. When they were on the same arm, there was no significant difference in RTs for left & right arms. Hand used for tracking did not have any affect on RT to faults.

21) Gawron, V.J. (1998). Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles. *AUVSI '98: Proceedings of the Association for Unmanned Vehicle Systems International*, 431-438.
The author discusses a number of unique human factors concerns unique to UAV flight. These include:

- Data link drop outs may be difficult for operator to notice.
- UAV mission times may exceed human vigilance capability.
- Humans can attend to/inspect only one stream of images at a time, while some UAVs may provide multiple image streams.
- Operators are sometimes given with unprioritized lists of multiple of targets to search for. This may be especially problematic when the operator is asked to control multiple UAVs simultaneously.
- Crew coordination depends on appropriate communications flow between crew members, which can be difficult when crew is large or when crew members are not co-located.
- Visual imagery is difficult to obtain during rocket launching or UAV, and during net or cable arrest. Workload is also high during launch and recovery. Finally, small sensor FOV can reduce SA and make navigation, target acquisition, and traffic detection difficult.
- Manual control of vehicles with time delays is difficult.
- Control interface on some systems is poorly designed.
- Software is not standardized, even between instances of the same UAV system.

Proposed military uses for UAVs include special operations; point reconnaissance, cued surveillance, and target acquisition. Non-military uses are possible in the fields such as law enforcement, fire fighting, agriculture, construction, archaeology, geology, and postal delivery.

22) Gluck, K.A., Ball, J.T., Krusmark, M.A., Rodgers, S.M., & Purtee, M.D. (2003). A computational process model of basic aircraft maneuvering. *Proceedings of the Fifth International Conference on Cognitive Modeling*, 117-122.
Paper presents an ACT-R model of Predator UAV flight. The model is based on simulation used to train Air Force Predator operators. The simulation involves three tasks: basic maneuvering, landing, and reconnaissance. The modeling effort presented in this paper focuses on basic maneuvering. Pilot is required to make constant-rate changes in airspeed, altitude, and heading.

A total of seven maneuvers are involved. The first three require pilot to change one flight parameter and hold the other two constant. The second three maneuvers require pilot to change two flight parameters and hold third constant. The seventh maneuver requires the pilot to change all three flight parameters simultaneously.

The model uses a flight strategy called "Control and Performance Concept". First, the operator establishes appropriate control settings for desired performance. Next, the operator cross checks instruments to determine if the desired performance is being achieved. The rationale is that control instruments have a first-order effect on aircraft behavior, which shows up only as a second-order effect in performance instruments.

Results

RMSD for airspeed, altitude, and heading were normalized and summed to provide an overall measure of performance. Grand mean performance on this measure over 20 runs of the model was almost identical to grand mean performance of 7 subjects. Across maneuvers, r-squared for predicting human performance from model was .64. The model was also sensitive to maneuver complexity in the same way that human subjects were, showing better performance for one-axis maneuvers than for two axis-maneuvers and better performance for two-axis maneuvers than for three-axis maneuvers.

23) Gorman, J.C., Foltz, P.W., Kiekel, P.A., Martin, M. J., & Cooke, N. J. (2003). Evaluation of latent-semantic analysis-based measures of team communications. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting*, 424-428.

The authors used Latent Semantic Analysis to develop methods of assessing communications content between team members in a Predator UAV simulation. Measures used were communications density (CD), the average task relevance of the team's communications, and lag coherence (LC), a measure of task-relevant topic-shifting. Data came from two experiments in which teams of three-operators (air vehicle operator, payload operator, and navigator) flew simulated Predator UAV reconnaissance missions. In the second experiment, workload levels were manipulated (low vs. high) and some teams of operators were distributed rather than colocated.

Results

Communications density

Team performance in Experiment 1 was related to CD by a quadratic function, indicating that beyond some point performance declined with additional communication. Similar results were found for co-located and low-workload teams in Experiment 2. Under high-workload conditions, performance continued to increase as CD increased, showing no evidence of a quadratic trend or an optimal CD level. Data from distributed team conditions was too noisy to interpret clearly.

Lag coherence

Coherence was positively correlated with team performance, indicating that low-performing teams tend to shift topics more within a short window than high-performing teams.

24) Gugerty, L. & Brooks, J. (2004). Seeing where you are heading: Integrating environmental and egocentric references frames in cardinal direction judgments. *Journal of Experimental Psychology: Applied, 7*, 251-266.
Navigational tasks often require operators to make cardinal direction judgments, which data suggest are difficult. The goal of the experiments reported here was to examine the strategies by which people make cardinal direction judgments.

<u>Experiment 1</u>
Subjects performed a static judgment task. Stimuli each trial were A) a north-up map showing their aircraft and a footprint of a forward-facing vehicle-mounted camera, and B) a 3-D view of the terrain as seen through the vehicle-mounted camera. The view presented each trial contained a building with a parking lot on each side (N, S, E, W). One of the parking lots contained vehicles while the others were empty. The subjects' job was to indicate the cardinal direction of the occupied parking lot, relative to the building.
Results
Three noteworthy effects were evident in both the error rate and the RT data. The first was a misalignment effect, whereby performance declined as camera heading deviated from north-up. The second was a south-advantage effect, whereby performance was substantially better when camera was oriented south than when it was at nearby orientations. The third was cardinal-direction advantage effect, whereby judgments were more slightly accurate when the camera was oriented east or west than when it was at nearby orientations.

<u>Experiment 2</u>
The goal of experiment 2 was to determine if dynamic spatial information, such as that provided by controlling a vehicle, improves cardinal direction judgments. The dynamic task used was a simulated UAV mission. Subjects were provided three visual channels, A) a north-up map similar to that used in Experiment 1, B) a 3-D view of terrain from a rotatable vehicle-mounted camera, similar to that used in Experiment 1, and C) a standard flight display. The subjects' task was to pilot the UAV to a 10 target objects and answer questions about each one. Three of the 10 questions required cardinal direction judgments.

Subjects also performed a static judgment task identical to that of Experiment 1.

Results
Static judgment task replicated the results of the first experiment. Cardinal-direction judgments in the dynamic task showed effects similar to those of the static task, though the cardinal direction advantage was weaker.

<u>Experiment 3</u>
Subjects performed the cardinal direction task of Experiment 1 and 2 while providing verbal protocols.

Results
Protocols gave evidence for final strategies. The first was a mental rotation strategy, whereby subjects mentally transformed images to be in alignment with one another and north-up. The second was a heading referencing strategy, whereby subjects assigned the current heading to the

forward view in the camera, then making judgments relative to that heading ("If forward is northeast, then this is north [pointing to the upper left lot], and this is east [pointing to the upper right lot]." The third was a south-reversal strategy, whereby subjects noted that camera heading was south and then reversed the answers they would have given for a northward heading (this was possible only when camera was oriented toward the south, obviously). The final strategy was a north-heading strategy, whereby subjects noted that camera was oriented to the north and then simply made judgments within a canonical north-up frame.

25) Gunn, D.V., Nelson, W.T., Bolia, R.S., Warm, J.S., Schumsky, D.A., & Corcoran, K.J. (2002). Target acquisition with UAVs: Vigilance displays and advanced cueing interfaces. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting,* 1541-1545.

The authors note that UAV operators will probably spend much of their time in supervisory control mode, but will be required to switch to manual control suddenly in response to system malfunctions, target acquisition, enemy actions, and other intermittent events. As such, UAV operation will be a form of vigilance task. The goals of study were A) to examine value of display type (cognitive or sensory) on performance in a vigilance task and in subsequent manual control mode, B) to compare the effects of visual, auditory, and haptic cueing of target location in a 360 degree target acquisition task.

Subjects flew simulated UAV missions. In supervisory control mode, they were required to monitor a stream of digit pairs for a threat warning indicating the presence of an enemy aircraft. In the sensory task, the threat warning was signaled by a size difference between the two digits. In the cognitive task, the threat warning was signaled by an even-odd digit pairing. After detecting a threat warning, the subject was required to target the hostile aircraft with a joystick-controlled crosshair. In the visual cueing condition, a locator line on the bottom right of screen indicated the direction of the target. In the auditory cueing condition, broadband noise pulses were presented from the target location. In the haptic cueing condition, force feedback on control stick guided the subject toward the target. In the control condition, no cueing was provided.

Results

Hit rates for warnings showed no effect of signal rate, but a significant benefit of sensory display format relative to the cognitive format. False alarms were lower for cognitive than for sensory displays. Target acquisition times were shorter for sensory displays than for cognitive. Visual, auditory, & haptic cue conditions produced similar benefits in target acquisition times, all of which were shorter than in control condition. Subjective workload was higher with cognitive than with sensory displays.

26) Hansman, R.J., & Weibel, R.E. (2004). Panel 1: UAV classification thoughts. *Paper presented at NRC Workshop on UAVs*.

Proposes a classification scheme for UAVs in NAS.

<u>High altitude, long endurance</u>

- Above FL 500, above majority of commercial air traffic

- Potential applications include long-dwell missions such as communications relay, precision mapping/imaging, and atmospheric research

Medium altitude endurance

- FL 180 - FL 500, Class A airspace
- Potential applications include meteorology, disaster monitoring, border patrol, and regional mapping

Tactical

- 1000 to FL 180/10,000 ft., mixed airspace
- Potential applications include law enforcement surveillance, pipeline/rail monitoring, search and rescue, agriculture

Mini

- Below 1200/700 ft. AGL
- --Potential applications include law enforcement, local imagery, and cinematography

Micro

- Below 1200/700 ft. AGL
- Potential applications include recreation, and local imagery

Rotorcraft

- Up to 2000 ft. AGL
- Potential applications include search & rescue, law enforcement, traffic monitoring, cinematography, and agriculture

27) Hansman, R.J., & Weibel, R.E. (2004). Panel 2: Operating and flight rules. *Paper presented at NRC Workshop on UAVs*.

Presents safety analyses of UAV, deriving acceptable failure rates (mean numbers of hours until failures) for varying classes of UAVs. Note a number of safety issues for UAVs operating under instrument and visual flight rules.

IFR

- Control latency
- Communication paths
- Controller workload and representation
- Separation standards
- Traffic load
- Flight plan filing
- Cost recovery

VFR

- See and be seen equivalence
- Rules of the road

- Operation at controlled and uncontrolled airfields

28) Kiekel, P.A., Gorman, J.C., & Cooke, N.J. (2004). Measuring speech flow of co-located and distributed command and control teams during a communication channel glitch. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting,* 683-687.
An experiment used communication flow measures developed by the authors in earlier papers to examine effects of co-location and communication channel disruptions on team communications in a simulated UAV recon task. Teams of three members flew a simulated UAV, taking pictures of target items. Each team comprised three members: the data exploitation, mission planning and control (DEMPC) member planned the route, air vehicle operator (AVO) flew the aircraft, and the payload operator (PLO) controlled the camera and took pictures. Manipulations were A) teams colocated vs. teams distributed, B) workload high vs. low (workload effect not further discussed in this paper), and C) communications normal or disrupted by glitch in channel from DEMPC to AVO.

Three types of analysis were conducted. The first used Pathfinder algorithm to identify common sequences of communications events: XLoop (person X begins and ends a communication, then begins another), XYcycle (person X produces a complete communication, then person Y does), and XiY (person X interrupts person Y). CHUMS analysis measured the stability of communications, as reflected in the relative proportion of speech produced by each member in a one-minute window. Analysis of dominance measured the influence that each team member's communications had over other member's.

Expectation was that occurrence of glitch would modify communication pattern, that DEMPC should have high dominance score, and that dominance of DEMPC should drop in distributed teams and when glitch occurs.

Results
Pathfind analysis found that colocated teams produced more utterances in general than distributed teams. Glitch causes decrease in DAcycles (communications between DEMPC and AVO), increase in DPcycles, increase in PAcycles, and decrease in PDcycles. This is generally what would be expected if communications that normally would have gone from DEMPC to AVO were re-routed through the PLO following the glitch.

CHUMS analysis produced more models for distributed teams, suggesting less stable communications patterns. The communications glitch also reduced stability.

Analysis of dominance found that in co-located teams under normal conditions, the DEMPC is moderately dominant and the AVO is reactive. In distributed teams under normal conditions, AVO is distributed and DEMPC is reactive. During the communications glitch, co-located teams become AVO dominant and PLO reactive.

29) LaFleur, T., Draper, M.H., & Ruff, H.A. (2001). Evaluation of eye-dominance effects on target-acquisition tasks using a head-coupled monocular HMD. ***Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*****, 1433-1437.**
Subjects performed a target acquisition task in a UAV simulation. A large FOV display was presented with a monocular HMD. Image was provided by the UAV's gimbaled camera, with camera control by operator's head movements. After spotting a potential target in the HMD, the operator was required to ID and designate it on a high-resolution, small FOV CRT display with camera view controlled by joysticks. Several dependent variables recorded. Of primary interest were effects of dominance of HMD viewing eye on performance.

Results
Eye-dominance had no effect.

30) Miller, C.A., Funk, H.B., Goldman, R.P., & Wu, P. (2004). A "playbook" for variable autonomy control of multiple heterogeneous unmanned air vehicles. ***Proceedings of the Second Human Performance, Situation Awareness, and Automation Conference (HPSAA II),*** **Daytona Beach, FL, March 22-25.**
Discusses "delegation" as a technique for control of multiple UAVs. Characteristics of delegation are that supervisor sets agenda for subordinates, but subordinates are given authority to decide exactly how to carry out commands. The authors note five manners/components of delegation that can be employed in varying combinations:
1. Stipulation of goal
2. Stipulation of a plan to perform
3. Stipulation of constraints (via specification of actions or states that should be avoided)
4. Stipulation of actions or states to be achieved (i.e., subgoals)
5. Stipulation of an objective function that will allow the subordinate to assess the desirability of various states and actions

The authors describe their work on developing a "playbook" architecture for delegating to UAVs. Playbook would involve assigning a name to complex behavior patterns, then allowing UAVs to autonomously implement a play when it is called. The Playbook system would assess the feasibility of a commanded behavior before attempting to perform it. When given a high-level command, Playbook would assess various methods of achieving goal, then would issues specific commands to vehicles under its control. When given more highly-specified lower-level commands, Playbook would report to the human operator if the commands were infeasible, or would issues the commands to the vehicles if they were feasible, filling in additional details as necessary.

31) Morphew, M.E., Shively, J.R., & Casey, D. (2004). Helmet mounted displays for unmanned aerial vehicle control. ***Paper presented at the International Society for Optical Engineering (SPIE) conference*****, April 12-16, Orlando, FL.**
Compared performance on a target search & ID task when subjects used a conventional CRT display & joystick control versus when they used a head-slaved HMD. UAV flight was automated. Subjects' task was to search for items in the virtual world display and ID them as

target, non-target, or distractor. After spotting a target or non-target, subject was to center crosshairs on the item and press a button on control box to classify it. Independent variables were method of display/control (CRT/joystick vs. HMD/head-slaved), virtual world search width (2500 vs. 5000 ft.), and mission duration (3 vs. 9 minutes). Dependent variables were target detection accuracy (HR, CRR), cursor distance (distance of crosshairs from center of object when object was classified), slant range (distance from aircraft at which subjects were able to classify target),

Results

Accuracy was high (>98%) for both forms of display/control. However, cursor distance was smaller and slant range was larger (i.e., performance was better in both cases) for the CRT/joystick configuration. HMD configuration also produced higher levels of nausea, eyestrain, disorientation, and over simulator sickness rating than the CRT configuration.

Wide search width produced smaller cursor distance than did narrow width, but effect did not interact with any others.

32) Mouloua, M., Gilson, R., Daskarolis-Kring, E., Kring, J., & Hancock, P. (2001). Ergonomics of UAV/UCAV mission success: Considerations for data link, control, and display issues. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 144-148.

Lists a number of considerations and recommendations for optimal design of UAV/UCAV system interface and data transfer.

Data-link timing

If satellite-UAV or UAV-UAV relays are used, variable time delays of 1 second or longer are possible. This eliminates real-time feedback to controls inputs. One way of circumventing this problem is to task operator with supervisory monitoring of on-board automation using pre-programming flight parameters such as speed, altitude, direction. Predictive graphics displays may also be useful.

Controls

Neither full automated control nor full manual control is practical. Full automation prevents the operator from intervening in flight control when necessary, while full manual control can produce excessive workload and make control susceptible to communications delays. The authors recommend hybrid control in which human operator supervises automation by calling subroutines of pre-programmed software.

Display/control interfaces should be based on a standardized group of core functions described with common terminology. Keyboards, touchscreens, pointing devices, and joysticks/pedals are appropriate controls, but must be designed to resist dirt, damage, etc., especially for field operations. Keyboard inputs should be replaced with menu- or speech- inputs for on-line vehicle control.

Assuming semi-automatic flight, flight-management systems and terminology should emulate that of ARINC and DOD. Since commands are anticipatory, this approach allows for preview and escape actions. If manual flight control is used, a GCS with full-time joystick/pedal/power controls will be necessary, and real-time communication with UAV/UCAV will be required.

If menus are used for in-flight supervisory control, it will be necessary to determine optimal number of menus and menu items. Five seems like reasonable starting point, based on Miller's magic number.

Displays

Displays need to reduce and format data for easy interpretation. Other principles to follow include minimizing scene movement & unnecessary changes in viewpoint; using high-quality displays to help ID areas of interest; employing alerts/alarms for system faults; providing mechanisms of selection, comparisons, parsing, scaling of displayed info.

In addition to high-quality sensor-image displays, content should include:

- system conditions and communications status
- flight data
- threat advisories
- weapons status

33) Mouloua, M., Gilson, R., Kring, J., & Hancock, P. (2001). Workload, situation awareness, and teaming issues for UAV/UCAV operations. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 162-165.

The authors discuss UAV design considerations relevant to workload, SA, and teaming. Some of these issues pertain specifically to combat UAVs.

Physical & cognitive workload

Assuming that the UAV control will be highly automated, then the operator's task will consist primarily of supervisory monitoring and making small course adjustments. This is likely to be tedious, producing vigilance failures. UAV systems must therefore be designed not just to avoid overload, but underload as well. This might be done by combining manual and automated control. Operator would be responsible for higher-order tasks (target recognition, munitions deployment) and automation would be responsible for lower-order tasks (flight control, obstacle avoidance). On-board automation should require operator action only as needed.

Situation awareness

Poor SA is likely to contribute to UAV mishaps. One way to help maintain SA is to provide displays that keep the operator aware of the processes being controlled by the automation, with the goal "to make the deep relational structure of the system environment visible to operators and help to identify options for action and indicate the boundaries for successful performance." UAVs may also be able have and advantage relative to manned systems in providing good SA since large numbers of on-board and off-board sensor data streams are available.

Teaming

Research is needed to determine the appropriate crew size and structure for UAV control, and to ensure effective communications. One particular source of miscommunication is the large amount data provided to the various UAV operators. This demands that important information be shared appropriately among operators. Ways to do this include "creating a mechanism for communicating understanding the real-time situation at a higher level across several connected teams or individuals", creating teams of specialists for target detection/authentication and for emergency operations.

34) Nelson, W. T., Anderson, T.R., McMillan, G.R. (2003). ***Alternative control technology for uninhabited aerial vehicles: Human factors considerations*****. Book chapter.**

Discusses potential alternative control technologies for UAVs. These include position and orientation tracking, eye-position tracking, speech recognition, gesture recognition, and electrophysiological measures. The authors advocate increasingly immersive environments for UAV pilots, with eventual possibility that alternative control technologies will replace traditional controls. Possible impediments to these goals include time delays in display updating, simulator sickness.

35) Nelson, J.T., Lefebvre, A.T., & Andre, T.S. (2004). Managing multiple uninhabited aerial vehicles: Changes in number of vehicles and type of target symbology. ***Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*****.**

The authors describe an experiment conducted with two goals. The first was to examine changes in performance that result from increasing the number of UAVs under an operator's supervision. Contrary to expectations, past research (Draper, Calhoun, & Ruff, 2003) found limited performance consequences when the number of UAVs under a single operator's supervision increased from 2 to 4. The present experiment compared performance using 3 and 5 UAVs, in an effort to increase the workload demands of the higher-load condition. The second was to compare performance with a novel set of stylized icons to performance with a set of standardized icons (MIL-STD_2525B). The authors hypothesized that the stylized icons, designed to have a physical resemblance to the objects they represented, would produce better performance.

After training, subjects flew two missions in the Multi-modal Immersive Intelligent Interface for Remote Operation (MIIIRO). One mission involved control of 3 UAVs, the other involved control of 5 UAVs (order of missions counterbalanced). Flight control was automated. Subjects were responsible for several additional tasks: identifying unknown aircraft, approving replans of UAV routes, identifying and selecting targets in the imagery from UAV sensors, completing tasks on a mission mode indicator, and counting symbols on the Tactical Situation Display (top-down map of terrain with UAVs and routes depicted) for later recall. Subjective workload measures were also collected.

Results

Data showed no difference between the 3 UAV and 5 UAV conditions in the number of enemy targets identified and selected. Other dependent variables showed significant effects favoring the 3 UAV condition. Specifically, the time to respond to unidentified aircraft was shorter, the number of Mission Mode Indicator tasks completed was higher, the time to check and approve UAV replan routes was shorter, and all subjective performance measures (ratings of situation awareness, perceived task difficulty, perceived performance, and perceived workload level) were better.

Recall of symbols on the TSD was better with the standardized icons than with the stylized set. The authors speculate that this might have happened because the standardized icons were easier to perceptually segregate from the background.

36) Purtee, M.D., Gluck, K.A., Krusmark, M.A., Koffe, S.A., & Lefebvre, A.T. (2003). Verbal protocol analysis for validation of UAV operator model. *Proceedings of the 25th Interservice/Industry Training, Simulation, and Education Conference*, 1741-1750.
Used concurrent and retrospective verbal reports from subject matter experts piloting a Predator UAV simulation to determine how accurately the lab's ACT-R model of Predator pilot performance represents the cognition/information processing of actual pilots.

Results
Overall, attention to performance instruments was verbalized more often than attention to control instruments during concurrent reports. However, retrospective reports suggested that SMEs were using the Control and Performance concept implemented by the model. Results also demonstrate that distribution of operator attention, as reflected in concurrent verbal reports, is influenced by goals/demands of maneuver being implemented. Ideas for improving the cognitive model include incorporating use of trim and a metacognitive awareness of passage-of-time to improve use of timing checkpoints for monitoring progress toward goal.

37) Quigley, M., Goodrich, M.A., & Beard, R.W. (2004). Semi-autonomous human-UAV interfaces for fixed-wing mini-UAVs. *Proceedings of IROS 2004,* Sep 28 – Oct 2, Sendai, Japan.

The paper describes work prototyping and testing several forms of interface for control of small (32" wingspan, in this case) semi-autonomous UAVs.

Control techniques
Numeric parameter-based interfaces provide text boxes in which operator types desired flight parameters.

PDA direct manipulation interface presents fixed-horizon wing-view representation from the viewpoint of an observer behind the UAV. Display also includes a compass and speedometer alongside the wing-view display. The user controls the UAV through drag-and-drop manipulation of the UAV icon or the compass/speedometer. Color differences (blue vs. red) are used to distinguish current state of UAV from desired state specified by user manipulation. This makes the future state of the UAV easy to predict. This interface was also tested with a laptop using trackpad and mouse.

Voice controller is allows UAV control using a grammar of twenty words (e.g., "climb", "go north"). Voice synthesizer provides immediate feedback in present progressive tense (e.g., "climbing", "going north").

Attitude joystick controller mimics a fly-by-wire controller by mapping deflection in joystick to deflection in aircraft attitude. This form of interaction is especially good for novices, non-experience pilots.

Trackpoint controller uses a trackpoint pointing device from ThinkPad laptop, with horizontal inputs mapped to UAV roll and vertical inputs mapped to UAV pitch.

The physical icon interface is a hand-held model of UAV. Orientation of model in 3-D space is tracked, and converted into pitch / roll commands for UAV. Should provide good SA since the operator is holding a representation of UAV in its actual orientation. An accompanying (optional) display helps the user distinguish actual and desired UAV states by presenting the current state in one color and the desired state (i.e., state of physical icon control) in another.

Assessments

The attitude joystick, physical icon, and trackpoint controller produce the fastest operator response times for UAV manipulations. However, these re problematic when UAV is traveling toward the operator, since they require reversal of control inputs.

Direct manipulation interfaces are useful because they don't required sustained attention. After the user has specified the desired UAV state, no further interaction is necessary until another change of state is desired. This can make these interfaces especially appropriate for control of multiple UAVs. The only difficulty is that subject must shift gaze between interface and UAV. This creates demand for frequent accommodation changes.

Voice control allows operator to maintain gaze on UAV, and, assuming commands can be issued in world-centered coordinates (e.g., "go north"), does not require mental transformation of commands depending on heading of UAV.

Parameter based interfaces are difficult because they require operator to type, and also demand mental math.

38) Ruff, H.A., Calhoun, C.L., Draper, M.H., Fontejon, J.V., Guilfoos, B.J. (2004). Exploring automation issues in supervisory control of multiple UAVs. ***Proceedings of the Second Human Performance, Situation Awareness, and Automation Conference (HPSAA II),*** **Daytona Beach, FL, March 22-25.**

Experiment 1

Examined the effects of automation on task completion time and subjective workload levels in control of 2 or 4 UAVs. Two levels of automation (LOA) were compared, management by consent (MBC) and management by exception (MBE). Automation was provided for two tasks, image prosecution and route re-plans. Time limits for overriding automation in the MBE condition were 40 s for image prosecution and 15 s for route re-plan. Automation reliability was either 75% or 98% for image prosecution, 75% or 100% for route re-plan.

Overall task involved four sub-tasks
1. Responding to unidentified aircraft
2. Route re-planning
3. Image prosecution
4. Monitoring Mission Mode Indicator (MMI)

Results
An increase in number of UAVs increased completion times for image prosecution, route re-planning, and MMI monitoring, and also increased the amount of time was spent in threat zones. Subjects were more likely to respond before MBE automation acted (i.e., subjects were more likely to carry out the automation's recommendation than to simply let the automation carry out the action itself) when there were 2 UAVs than when there were 4. Subjective workload ratings were higher for 4 UAVs than for 2.

Fewer images were prosecuted and more errors committed when automation was less reliable. Subjective trust ratings were also lower.

No consistent differences obtained between MBC and MBE . This might be because the time limit for overriding MBE automation was too long. As noted above, subjects often pre-empted the automation under MBE by carrying out the recommended action themselves. Expt 2 therefore reduced time limits for MBE.

Experiment 2
Automation reliability and LOAs were same as in Expt 1, but the time limit for overriding MBE was now included added as a dependent variable. Time limits for image prosecution were 15 and 40 seconds. Time limits for route re-plan were 10 and 15 seconds. Execution of route re-plan task was also made more difficult. Only the 4 UAV condition was used.

Results
Only one measure, the percentage of images correctly prosecuted, showed an effect of automation reliability.

With MBC, subjective ratings were similar across time limits. With MBE, shorter time limits produced higher workload ratings and poorer performance on both tasks. Subjects were faster to complete tasks in MBE/short time limit condition than in any other combination of automation/time limit, suggesting that they felt time pressure. This may have contributed to higher subjective workload. MBE automation was more likely to execute action in short time limit condition.

39) Ruff, H.A., Draper, M.H., Lu, L.G., Poole, M.R., & Repperger, D.W. (2000). Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence. *Proceedings of the IEA 2000/ HFES 2000 Congress*, 3.41 - 3.44.

UAV operators are denied many of the sensory cues available to the pilot of a manned aircraft. One instance in which this might be consequential is in detecting turbulence. During flight of a manned aircraft, the onset of turbulence typically produces kinesthetic/haptic feedback. During UAV flight, turbulence is signaled to the operator only by perturbations of camera image.

Current experiment measured value of haptic alert (via control stick) for detection of turbulence onset. Participants flew simulated UAV landings. When turbulence occurred, subjects rated their level of SA. After each trial, participants rated the difficult of difficulty, assessed their performance, and judged the strength (mild or severe) and axis of perturbation (horizontal or vertical) of the turbulence. Note that the multimodal display did not mimic the haptic signals experienced in real flight, but was simply meant as an alerting signal.

Results

Haptic feedback improved SA ratings, but if when turbulence occurred when UAV was far from the runway. When UAV was near runway, no benefit of feedback. Authors suggest that heightened alertness near runway might facilitate turbulence detection, mitigating the effects of haptic feedback. RTs for turbulence detection would have provided useful data to test this hypothesis.

Subjective ratings of landing performance were unaffected by haptic alert, but ratings of landing difficulty increased when haptic alert was provided. Perceived turbulence strength and judgments of turbulence direction were unaffected by haptic feedback.

40) Ruff, H.A., Narayanan, S., & Draper, M.H. (2002). Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. *Presence, 11*, 335-351

Subjects flew simulated UAV missions, with task of acquire four targets at unknown locations (3 enemy and 1 friendly) while avoiding enemy fire. Number of UAVs was 1, 2, or 4. Flight path was preprogrammed. Subjects were required to respond to/manage events as they occurred through course of scenario. Automation was provided to some subjects to help manage events. Two forms of automation were used, in addition to the no-automation baseline: management by consent, and management by exception. Two levels of automation reliability were used: 100% and 95%.

Results

Management by consent produced the highest level of mission efficiency (number of enemy targets destroyed divided by number of missiles fired). Management-by-exception and manual monitoring produced similar efficiency scores. Decision aid false alarms in the 95% reliability automation condition were more likely to be detected under management-by-consent than management-by-exception.

In manual condition, event management became poorer as the number of UAVs increased. Subjective workload estimated by NASA_TLX also increased with number of UAVs in the manual and management by consent conditions. SWORD ratings of workload were higher for manual control than for either form of automation, and were higher for management-by-consent than for management-by-exception when reliability was less than perfect. Sword ratings also increased as the number of UAVs increased.

Management-by-consent produced higher levels of self-rated situation awareness than did manual control or management-by-exception. Management-by-exception produced especially low ratings of SA when automation reliability was only 95%. SA ratings also decreased as the number of UAVs increased.

Trust in automation decreased as the number of UAVs increased.

41) Ryder, J.M, Scolaro, J.A., Stokes, J.M. (2001). An instructional agent for UAV controller training. *UAVs-Sixteenth International Conference,* 3.1-3.11. Bristol, UK: University of Bristol.

Describes development of an automated agent, EAGLE, to train pilots on a simulated Predator UAV landing task. The authors note that because there are minimal differences between operating a console during real missions and simulations, simulations may be ideal for UAV operator training. The current instructional agent was developed using CHI Systems' COGNET framework.

42) Schreiber, B.T., Lyon, D.R., Martin, E. L., & Confer, H.A. (2002). *Impact of prior flight experience on learning Predator UAV operator skills (AFRL-HE-AZ-TR-2002-0026).* Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Examined subjects ability to learn & perform maneuvers on a Predator UAV. Compared several groups of subjects including experienced Predator pilots; experienced USAF pilots selected to fly the Predator; students who had recently completed USAF T-38 training; students who had recently completed USAF T-1 training; students who recently completed single-engine instrument training at Embry-Riddle; students who recently completed requirements for private pilot's license; Embry-Riddle ROTC students who planned to join USAF but had no flight training or experience.

Subjects flew basic maneuvers and landings until reaching a criterion level of performance, then flew 30 reconnaissance missions. Of interest was the number of trials necessary to reach criterion performance on the training task, and the transfer of training performance to the reconnaissance task.

<u>Results</u>

<u>Training</u>

As expected, predator pilots required the fewest trials to reach criterion performance, and nonpilot ROTC students required the most. This comparison demonstrates the validity of the simulation and task. Predator selectees and civilian instrument pilots required fewer trials than T-1 grads, required fewer trials. T-38 grads and private pilots were not significantly worse than

Predator selectees/civilian instrument pilots, nor were they significantly better than T-1 grads. Results demonstrate that prior flight experience can reduce the number of trials to become proficient at maneuvering & landing the Predator simulation.

Transfer
Dependent variable was mean amount of time that sensor was focused on target during each trial. Predator pilots, Predator selectees, and T-38 grads had more time on target than other groups. ROTC nonpilots had less time on target than Predator pilots, selectees, T-38 grads, and T-1 grads. Results show that even after subjects achieved matched levels of performance on the training task, prior flight experience improved performance in the recon task. Authors suggest that good performance of T-38 grads as compared to T-1 grads may reflect the degree to which performance characteristics of the T-38 and T-1 are similar to those of the Predator.

43) Tvaryanas, A.P. (2004). Visual scan patterns during simulated control of an uninhabited aerial vehicle (UAV). *Aviation, Space, and Environmental Medicine, 75*, 531-538.

An experiment examined pilots' eye movements during a simulated Predator UAV flight task. Goals were to determine A) how efficiently operators process the moving textbox instrument displays used in the Predator HUD, B) whether workload (as determined by windiness during flight and by the difficulty of flight maneuvers) affected scan patterns, and C) whether the absence of auditory and haptic cues caused UAV pilots to increase their dwell frequency on the engine instrument (RPM) relative to pilots in a manned aircraft. Of particular interest was whether or not the moving textbox instruments would be processed as digital/quantitative displays or as analog/qualitative displays. Past data has suggested that quantitative displays are processed less efficiently (i.e., require longer dwell times) than qualitative displays.

Subjects were 5 instrument rated pilots. Subjects flew an eight-leg flight plan twice, once in no-wind conditions and once in windy conditions (order randomized). Different segments of the flight profile included changes in heading, altitude, and airspeed, sometimes singly and sometimes in combination. Changes involving multiple parameters were presumed to impose higher workload, as were windy flight conditions.

Results
Dependent variables were dwell times and dwell frequencies. Independent variables were flight conditions (no wind vs. windy), flight segment (one, two, or three parameters changed), and instrument. Both dwell times and dwell frequencies showed a significant main effect of instrument, and neither showed any other main effects or interactions.

Dwell frequency was highest for the ADI, followed by the VSI, AS, HI, ALT, RPM, and AOA.

To determine whether moving textboxes were processed as qualitative or quantitative displays, dwell times for these instruments were compared to dwell time for the heading indicator, an instrument that is clearly quantitative. If moving textboxes are processed as qualitative displays, they should have dwell times shorter than those for the HI. Only the AOA and RPM had significantly shorter dwell times, suggesting that other moving textboxes were processed as quantitative displays.

The author also compares the current data to the results of earlier studies of instrument scanning in manned aircraft. In the present study, ADI was the most frequently fixated instrument, but still accounted for only 30% of all dwells. In contrast, previous research has found that the ADI can account for over 50% of all dwells in manned flight. Conversely, VSI was fixated more often in the present study (16% of all dwells) than in studies of manned flight (22%). The author suggests two possible reasons for these differences. First, ADI in the Predator HUD was very simple, showing only a horizontal line without any pitch or bank scale. VSI scanning might therefore be necessary to acquire or verify climb and descent rates. Second, pilots might rely on the VSI more heavily in UAV given the inherent system delays. In other words, delays in the system responses to control inputs might require operators to rely more heavily on the predictive VSI instrument than in manned flight.

Data also suggest that the engine instrument was not scanned more heavily in the current task than in previous studies of scanning in manned flight. This suggests that operators did not use the RPM to compensate for the absence of auditory and haptic information, and may indicate a sub-optimal performance strategy.

The author speculates that the high skill level of the participants in the current experiment might explain the null effect of workload on scanning behavior.

44) Van Erp, J.B.F. (2000). Controlling unmanned vehicles: The human factors solution. *RTO Meeting Proceedings 44 (RTO-MP-44)*, B8.1-B8.12.

The author notes that bandwidth constraints on the datalink between a ground control station and UAV will limit the quality of sensor information displayed to UAV operators. Two remedies to this problem are possible. The first is to reduce bandwidth needs by identifying task-critical sensor information and ensuring that only this is transmitted. The second is to design advanced interfaces that assist the operator in compensating degradations or limits in sensor imagery.

Several specific ways in which the information provided to a UAV operator is degraded are described. First, this information typically includes only imagery from an on-board camera. Input from other sensory modalities (audition, kinesthesia) is lost. Second, the sensor imagery provided to the operator is often of low resolution, achromatic, and limited to a small FOV. Third, sensor imagery is often of low temporal resolution. Fourth, the control devices used to manipulate sensor cameras do not provide proprioceptive/kinesthetic feedback similar to that obtained in using the scanning through head and eye movements.

The author next delineates a variety of sensor image characteristics that contribute to vehicle control: field size, magnification factor, chromaticity, temporal resolution, spatial resolution, monoscopic vs. stereoscopic presentation, fixed vs. variable viewing direction, and placement/aiming. To optimize performance, operator can be given the capability to manually adjust the temporal and spatial display resolution, reduce the image field size, and toggle between color/grayscale and between stereoscopic/monoscopic display modes.

The UAV operator is also confronted with difficulties in payload sensor control. First, controls do not provide feedback on camera responses to user inputs. Second, the operator does not receive vestibular feedback to specify vehicle attitude. Third, the operator has no proprioceptive feedback to indicate viewing direction. Fourth, control inputs do not produce immediate changes in sensor imagery. Fifth, spatial information within the sensor imagery is low in resolution. Sixth, the sensor FOV is often small, imposing the need for additional control inputs to scan a scene and degrading the operator's ability to integrate sensor images into a coherent and veridical mental representation. Seventh, camera imagery may be zoomed-in, disturbing the normal relationship between camera translation and image motion. Finally, image update rates may be low, degrading the temporal resolution necessary for dynamic tracking tasks. The author discusses a number of advanced display designs to address the difficulties in camera control produced by these degradations. Two of these involve computer-synthesized imagery superimposed upon or embedding the camera imagery. The value of such "augmented reality" displays is that they computer-generated components can be updated immediately in response to user inputs, even if the sensor imagery itself is not updated until after a delay. The computer-generated components thus can provide real-time feedback to assist in guiding the sensor footprint. The third novel display discussed is a radar image that includes actual and predictive sensory footprints. Thus, motion of the computer-generated predictive sensor footprint again provides operator with immediate feedback to aid camera targeting, despite delays in camera update rate. Head-coupled camera control, the author notes, does not improve camera control in a search task (effect of the head-coupled control is a speed-accuracy tradeoff), and may degrade performance because of mismatches in proprioceptive and visual information produced by sensor delays.

45) Van Erp, J.B.F., & Van Breda, L. (1999). *Human factors issues and advanced interface design in maritime unmanned aerial vehicles: A project overview. TNO-report TM-99-A004*. Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Report presents a summary of human factors issues in UAV control, and an overview of relevant research conducted at TNO.

<u>Human factors concerns</u>

The authors assume that vehicle control will generally be highly automated, and so focus their discussion of on manual control of payload camera. The studies reported assume that the most important source of information for camera control will be the imagery from the on-board camera.

The authors note that the perceptual information the operator receives from the remote environment is likely to be degraded in several ways:
--no proprioceptive feedback from controls
--no vestibular input based on attitude
--no proprioceptive feedback based on viewing direction
--limited spatial orientation
--no direct feedback (i.e., feedback delayed) in response to control inputs

--no auditory input
--limited resolution of camera images
--limited geometrical field of view
--zoomed-in camera image
--few points of reference at sea
--limited image update rate

Possible consequences for human performance include poor tracking; difficulty in judging camera, platform, and target motion; confusion about direction of platform flight; confusion about viewing direction of camera; disorientation; degraded situation awareness.

Experiments

Experiment 1

Examined the benefits of synthetic visual motion in guiding payload camera. A computer-generated grid of perpendicular lines was overlaid on camera image, and moved in response to camera inputs. In the first experiment, subjects had to track a moving ship with a simulated UAV sensor camera. Performance was improved by synthetic image augmentation, and benefits were largest when the update frequency of the camera was low. In a second experiment, subjects saw a target ship, then had to point camera at after a 15 s delay that included several translations and rotations of the MUAV. Again, performance was improved by the synthetic image overlay.

Experiment 2

Asked whether a computer-synthesized world embedding the camera image (called an ecological display, based on the notion that visual cues provided by embedding world are directly perceived) can aid in guiding camera. Subjects had to search for target ships with camera. Performance with ecological display was compared to performance with heading/pitch indicators adjacent to camera image. Such indicators require cognitive inference, in contrast to ecological display. Ecological display reduced search time and total number of camera motions. Indicators did not significantly improve performance relative to baseline.

Experiment 3

Asked whether an ecological display can allow an operator to control UAV airframe and camera simultaneously. The task required the subject to track a target ship while circling it. Four display types were used: two without augmentation (north up & track up), and two with augmentation (2D synthetic world and a 3D synthetic world). Data showed that augmented displays aided airframe control without degrading tracking. Augmented displays also allowed effective manual control with high airframe speeds.

Experiment 4

Experiment examined manual control of sensor under conditions of low update rates and delayed visual feedback, and measured the benefits of a predictive camera footprint. Data showed that update rates below 2 Hz and delays longer than 2 seconds degraded tracking performance. Predictor display eliminated costs of slow update rate and time delay except at the most extreme values.

Experiment 5

Examined the effects of head-slaved camera control, time delays, and advanced interface design on situational awareness. The authors speculate that proprioceptive feedback from head-slaved control may aid SA. However, helmet-mounted displays might be uncomfortable, and transmission delays could make the perception of spatial information difficult. In the experiment, HMD was compared to head-slaved dome projection. To overcome the problems of delayed image transmission, a method of compensation called delay handling was introduced. Delay handling preserves spatial relationships between input images by presenting them in the viewing direction of the camera at the moment image was recorded, rather than the moment at which image transmission is received. Data indicate that delay handling improves SA. No benefit was found for dome projection relative to helmet-mounted display.

Experiment 6

Compared head-coupled control/helmet-mounted displays to manual control of camera. Subjects had to locate five target ships as quickly as possible. In manual control condition, imagery was projected on a dome, so that proprioceptive info was available in both conditions. Head-slaved camera control increased search speed but enlarged the search path as compared to manual control.

46) Veltman, J.A., & Oving, A.B. (2002). Augmenting camera images for operators of unmanned aerial vehicles. *RTO Meeting Proceedings (RTO-MO-088)*.

UAVs flight path is often pre-programmed, but camera must still be steered manually. This can be difficult because of low camera update rates and communication time delays between GCS and vehicle. One method of addressing these difficulties is to provide current and predictive camera view footprints on a 2D map. This provides motion feedback when camera moves, along with information preview of where the camera will be shifting. The authors note that a 2D map provides primarily exocentric (authors use the term "local") spatial information, while a 3D map provides egocentric ("global") info. Authors speculate that providing a predictive camera footprint within a 3D map might therefore improve camera steering performance beyond that observed with a 2D map. The goal of the experiment was to test this speculation.

Subjects flew a simulated UAV recon mission which required them to search for military vehicles along roads and edges of woods. Two side-by-side displays were used. On the left was a 2D map which presented waypoints and route plan; flight direction; and actual and predicted camera footprints. On the right (in some conditions) was a 3D map which presented an immersed view from vantage point of UAV camera, along with actual and predicted footprints. In experimental conditions, subjects were provided the 3D display in addition to the 2D map. In control conditions, only the 2D map was provided. The camera image was presented in lower right display. Camera image quality had three levels: normal, 3 Hz update rate, 1 second delay. In some conditions, subjects also performed a secondary monitoring/memory task.

Results

When camera quality was normal, 3D camera produced a small increase in the percentage of roads and wood edges that were inspected (~35% vs. ~40%). When camera image quality was degraded, the benefits of the 3D map were larger (~20% vs. ~30%). Secondary task performance was better with 3D map, suggesting that map produced spare mental capacity, and subjective workload ratings were lower with 3D camera than without. EOGs indicated that subjects inspected 3D map frequently, especially when camera quality was low.

47) Walters, B.A., Huber, S., French, J., & Barnes, M.J. (2002). *Using simulation models to analyze the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles (TUAVs) (ARL-CR-0483)*. Aberdeen Proving Ground, MD: Army Research Laboratory.

A study used simulation modeling to determine how fatigue, crew size, and rotation schedule affect operator workload and performance on a TUAV control task. Simulations were conducted using MicroSaint modeling architecture, from Micro Analysis and Design. 18 subject matter experts (SMEs) provided A) a list of tasks that are involved in controlling a TUAV during normal operations and during emergencies, B) the order in which the tasks are performed, C) the visual, auditory, cognitive, and psychomotor workload imposed by tasks, D) the types of emergencies that can occur during missions, and E) the probabilities of mishaps occurring during emergencies when soldiers are fatigued.

The fatigue algorithm used by simulation predicts human response capability for tasks over an extended period of sleep deprivation. The focus of algorithm is the interaction of sleep deprivation with circadian rhythms.

The model used simulates the tactical operations center (TOC) and launch/recover station (LRS) (including mission commander [MC], aerial vehicle operator [AVO], and mission payload operator [MPO] duties), and several functions: launch, transfer, recovery, mission support, emplacement, displacement, emergencies, mishaps, and maintenance during emplacement. The model was used to simulate 12- and 18-hr missions over a 24-hr period under 15 different conditions for three consecutive days. During the missions, there were times with 2 UAVs in-flight: one observing the targets, and one flying to assume control of search. Soldiers were modeled to work 2-, 3-, 4-, or 6-hr rotation schedules. The model does not simulate soldier activity in between shifts.

Models simulate one move (jump) per day for the TOC and one move every other day for the LRS. Each move comprises a 1/2 break-down, 1/2-hr move, and a 1-hr setup. The TUAV spends 5 hrs of simulation time in the air: 4 hrs of surveillance and 1 hr in transit to/from destination. The output of model includes performance times, target detection rates, and AV mishaps under each simulated condition. Several crew configurations (different numbers of MCs and AVOs/MPOs) were tested.

Some conditions that can affect a TUAV mission include
--type of search: area search, person search, airfield, tanks, building, road search, bridge, missile site, command post, air defense artillery, check points, battle damage assessment on SAM, artillery search

--emergencies: icing, generator failure, signal degradation or intermittent link loss, payload failure, AVO or MPO console failure, GPS failure
--weather: humidity, sun, gusting winds, crosswinds, flat clouds, ragged clouds
--terrain: high vegetation, desert (sand), high desert, city, town, village

Workload estimates were obtained from SMEs using a scale developed to be compatible with Wickens' (1984) multiple resources theory of attention. Four resource pools were assumed: visual, auditory, cognitive, and psychomotor.

The model simulates 5 TUAV launches per day for an 18-hr mission. Each launch, three types of target search were performed. Missions were repeated every day for 3 days for each crew rotation schedule.

Results
Decreasing crew size decreased target hit rates and increased target detection times.

Workload estimates suggested that when there was no MC in the LRS, the TOC MC was interrupted ~50% of the time to perform tasks that the LRS MC would otherwise have performed. When there was 1 MC in the LRS, the TOC MC was interrupted ~20% of the time with LRS MC tasks. Adding a third AVO to the LRS (compared to baseline condition of 2 AVOs) did not improve performance.

The model was adjusted to simulate 12-hr mission profiles with and without 1-hr gaps between flights. Three launches were simulated per day instead of 5. Results were similar to those from 18-hr mission conditions. No performance differences were produced by 1-hr gaps between missions.

48) Weeks, J.L. (2000). *Unmanned aerial vehicle operator qualifications (AFRL-HE-AZ-TR-2000-0002)*. Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Report compares selection criteria for UAV operators across branches of the U.S. military and British army.

Pioneer, USNL EP candidates go through a 24-week training course. Payload operator and AVO compete different 8-week courses. Mission commander has to be a flight officer. Health conditions related to hypoxia or pressure changes are not disqualifying. Health standards include corrected visual acuity of 20/20 in each eye, normal color vision, normal hearing, clear & distinct speech, and voice well modulated. EP requires normal depth perception.

Pioneer, USMC AVO and PO complete the same 8-week training course. Candidates for EP have to demonstrate satisfactory as AVO or PO, demonstrating good 3-D cognition/perception, then complete a 19-week training course. MC has to be an aviation officer. Physical standards are the same as for UAN UAV operators.

Hunter, USA AVO and PO have to complete a 23-week training course. Candidates for EP have to demonstrates satisfactory performance as AVO or PO, and are screened by interview and by performance using a radio-controlled model airplane. If selected, they must complete a 16-week training course. The AVO and PO are required to pass a class IV flight physical, which includes requirements for medium physical demands, a normal physical profile, and normal color vision. The EP is required to pass a class III physical, similar to that required for air traffic controllers.

Phoenix, British Army AVO is required to take a 3-week course. Flight crews are not required to take physicals.

Predator, USAF AVO candidate has to be a pilot of a fixed-wing aircraft or a navigator with FAA instrument rated commercial license. Beyond undergraduate flight training, follow-on training, then 9 weeks of Predator basic training. DEMPC and SO complete 24 weeks of initial-skills training as an Imagery Interpretation Apprentice, then 9 weeks of Predator basic training. AVO has to pass a Class I physical. DEMPC and SO have to pass a Class III flight physical, but with visual acuity and depth perception standards equivalent to Class I standards.

49) Wickens, C.D., & Dixon, S. (2002). ***Workload demands of remotely piloted vehicle supervision and control: (1) Single vehicle performance (Technical report AHFD-02-10/MAD-02-1)***. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Examined the benefits of offloading tasks from visual channel in a single-UAV control task, and compared the results to the predictions of single-channel theory (SCT), single-resource theory (SRT), and multiple-resource theory (MRT) of attention. Subjects each flew a series of missions involving three tasks: mission completion (flight path tracking), inspecting command targets (CTs) / searching for targets of opportunity (TOOs), and monitoring system gauges for system failures (SFs) (i.e., out of bounds values). Flight instructions (fly-to coordinates of next target and a question about the target to be answered) were provided during the task. Instructions could be refreshed with a button press. In baseline condition, pilots flew with all manual flight controls and all visual displays. In auditory condition, SF alerts and flight instructions were provided aurally. In an automation condition, flight control was offloaded to an automated system. All alerts/instructions/automation were perfectly reliable.

Results
Flight path tracking was unaffected by auditory offloading.

Button-press refreshes of instructions were reduced in both the auditory offloading and the automation conditions. In auditory condition, this might have been because aural presentation reduced visual conflict during time that instructions were first presented. In automation condition, it may have been because the subject was not required to remember target coordinates.

TOO detection rates improved under autopilot flight control both for single and dual-UAV tasks. This was in part due to the fact that the autopilot flew directly over each target, while the human operator sometimes did not. However, an autopilot benefit was evident even restricting analysis to those trials on which the TOO appeared in the 3D display. This suggests a role for the autopilot in improving cognitive/attentional performance in TOO detection.

Auditory alerts significantly improved SF detection rates and SF response times compared to baseline, except in cases where the subject was loitering/inspecting a target at time of SF occurrence. This suggests that difficult image interpretation produced cognitive tunneling. Automation condition also improved SF detection rates (though not under all circumstances), but did not affect SF response times.

50) Wickens, C.D., Dixon, S., & Chang, D. (2003). *Using interference models to predict performance in a multiple-task UAV environment-2 UAVs (Technical report AHFD-03-09/MAAD-03-1)*. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Examined the benefits of task offloading to pilots performing single- and multiple-UAV tasks and compared the results to predictions of single-channel attention theory (SCT), single-resource theory (SRT), and multiple-resource theory (MRT) of attention. Subjects each flew a series of missions involving three tasks: mission completion (flight path tracking), inspecting command targets (CTs) / searching for targets of opportunity (TOOs), and monitoring system gauges for system failures (SFs). Flight instructions (fly-to coordinates of next target & a question about the target to be answered) were provided during the task. Instructions could be refreshed with a button press. In the baseline condition, pilots flew with all manual flight controls and all visual displays. In the auditory condition, SF alerts and flight instructions were provided aurally. In the automation condition, flight control was offloaded to an automated system. All alerts/instructions/automation were perfectly reliable.

Results

Flight path tracking was unaffected by auditory offloading. Button-press refreshes of flight instructions were reduced in both the auditory offloading and the automation conditions, suggesting that these conditions freed up processing resources. The number of refreshes was higher in dual-UAV conditions, but the effect was primarily in the baseline & auditory offloading conditions, not in the automation condition. TOO detection rates improved under autopilot flight control both for single and dual-UAV tasks. This was in part due to the fact that the autopilot flew directly over each target, while the human operator sometimes did not. However, an autopilot benefit was evident even restricting analysis to those trials on which the TOO appeared in the 3D display. This suggests a role for autopilot in improving cognitive/attentional performance in TOO detection.

Auditory alerts improved SF detection rates and reduced detection times. Autopilot had no effect. Dual-UAV costs to SF detection time obtained in the baseline and autopilot conditions, but not in the auditory alert condition. SF detection times were longer for faults that occurred during target inspection than for faults that occurred under normal flight, lending some support to CST and SRT. However, this effect was mitigated somewhat by auditory alerts, consistent with MRT.

51) Williams, K.W. (2004). A summary of unmanned aircraft accident/incident data: Human factors implications.

Examines military UAV accident/incident data for various UAV systems.

Army

Hunter

Hunter takes off & lands using an external pilot (EP) in visual contact using controller similar to that used for remote controlled hobby planes. After takeoff and climb, internal pilot (IP) assumes controls from GCS. The IP controls the aircraft using knobs to select altitude, heading, & airspeed. 47% of accidents were HF related. The largest percentage (47%) of HF issues arose during landing. An additional 20% arise during takeoff. Control difficulties are caused in part by the need for the operator to reverse control inputs when aircraft is headed toward him/her. Other problems include:

--pilot-in-command issues
--failure of alerts/alarms to inform operator of non-normal conditions
--mode display errors
--crew failure to follow proper procedure

Shadow

The Shadow uses a launcher for takeoff and an automated system, the tactical automated landing system (TALS), for recovery. Landing generally does not require intervention from the operator in the GCS. In flight, the aircraft is controlled through a menu-based interface that allows operator to select altitude, heading, & airspeed. During landing, operator in GCS has no visual contact with aircraft, and receives no data from onboard sensors. An external observer is required to communicate to the operator when the craft has touched down, at which time the operator gives a command to stop the engine. HF errors were less frequent with Shadow than with Hunter.

Navy

Pioneer

The Pioneer requires an EP for takeoff & landing. After takeoff, IP controls the vehicle from the GCS in one of three modes: autonomously using preprogrammed waypoint coordinates; semi-autonomously using airspeed, altitude and heading values specified with rotary knobs; manually, with a joystick. There are plans to implement an automated system for ship-based landings. 28% of accidents were HF related. Of these, 68% occurred during landing and 10% during takeoff. An additional 13% were due to aircrew coordination lapses (procedural & communication errors) and 10% were weather related errors resulting from errors in pilot decision making.

Fire Scout

A vertical takeoff & landing vehicle, the Fire Scout was involved in one accident. Antenna was damaged during ground handling (human error), causing incorrect altimeter reading when vehicle was airborne.

Air Force

Predator

The Predator is flown from a GCS using a joystick and rudder pedals and a forward looking camera with a 30-deg FOV. The camera is also used for takeoffs and landings. Human factors lapses contributed to 67% of accidents. A majority of these (75%) were procedural errors, including a failure to follow checklist steps during handoff between crews and an accidental activation of a program that erased the aircraft computer's internal RAM.

Interface issues are discussed in 89% of Predator accidents, and are cited as a contributing factor in 44%. Four categories of interface issues: design of HUD; design of HDD; alerts and alarms; functioning of the autopilot.
--HUD problems: FOV (30 degs) is too narrow; attitude indicator is inadequate; RPM indicator needs improvement; symbology obscured during low-link conditions; symbology contrast too low; symbology inadequate.
--HDD problems: too many levels to maneuver through to reach needed info; info display unintuitive; critical commands unprotected or unemphasized; operational value ranges inconsistent within display.
--Alerts/alarms problems: do not capture attention; audio warnings insufficient or absent; info provided inadequate or poorly prioritized; info provided invalid; data that need to be compared not always collocated on same display page.
--Autopilot problems: no indication of autopilot status on HUD; flight controls are disabled while autopilot is engaged (i.e., no override capability) and four separate menus have to be traversed in order to deactivate autopilot (requires about M = 7 seconds); autopilot tends to command extreme measures and overstress aircraft; autopilot functionality does not conform to AF standards.

Global Hawk

Global Hawk is the most fully automated of UAV systems. All phases of flight are automated, including takeoff & landing. The crew's task is to monitor the aircraft and control payload. This makes flying the relatively easy, but makes mission planning exceedingly difficult. Mission planning process begins up to 270 days prior to mission. Once the target set is finalized, 3-5 weeks are required to write and validate mission plan. Of three accident reports available for Global Hawk, only one involved HF issues. Aircraft was forced to perform an emergency landing at a preprogrammed alternate airport. At point of airport, a taxi speed of 155 knots had been set due to software bug during preprogramming. When aircraft was commanded to begin taxiing for takeoff, it reached a speed where it was unable to turn at appropriate point and ran off the runway. Fundamental HF problem with the Global Hawk is that the system does not encourage close monitoring by operators, resulting in reduced SA. An additional problem is that status reports are provided in hexadecimal and do not include trend data.

52) Wilson, G.F., & Russell, C.A. (2004). Psychophysiologically determined adaptive aiding in a simulated UCAV task. *Proceedings of the Second Human Performance, Situation Awareness, and Automation Conference (HPSAA II)*, Daytona Beach, FL, March 22-25.

An experiment tested the benefits of adaptive aiding based on psychophysiological assessment of operator workload. The task required subjects to monitor 4 vehicles flying preplanned routes. When vehicles reached designated points, radar images of target area were presented to subject. Subject searched target area then selected targets for bombing. The search/target designation task was conducted under time stress. The subjects chose the order in which images from the vehicles were presented. Images were presented at two levels of difficulty. The more difficult level included more distractors and required more difficult decisions regarding target priority.

Subjects were also required to monitor vehicles for potential emergencies (e.g., loss of communication). Memory load was manipulated by having subject hold up to 4 aircraft/problem combinations simultaneously until a command was given specifying which problem to address.

EEG, ECG, and EOG data were recorded. An artificial neural network was trained to recognize periods of low and high task difficulty using these data. During criterion task performance, three levels of adaptive aiding were used: 1) no aiding, 2) aiding during times of high workload, and 3) random aiding. Aiding involved decreasing velocity of vehicle so that time stress was reduced. Subjective workload was measured with NASA-TLX.

Results

The neural net was 70% accurate at classifying high/low task difficulty levels during task performance. For all conditions, the number of correctly selected targets was lower when the task was difficult. The number of designated points of impact was lower for the difficult task level in the unaided and the randomly-aided conditions, but was unaffected by task difficulty in the adaptively-aided condition. Similarly, the number of missed weapons releases was higher in the difficult level for the unaided and randomly-aided conditions but was unaffected by difficulty in the adaptively aided condition. Differences in subjective workload were marginal and inconsistent.

Appendix B

Research Matrix

This appendix provides a cross-index of the research issues discussed in the main body of the text with the research literature described in Appendix A. Only those articles deemed directly relevant to each question are included. Bold-faced italics indicate research articles that present empirical data.

1. To what extent should en route flight control be automated?
Relevant articles: ***2,*** 7, 19, ***25***, 32, 33, ***38***, 40, ***49***, 50, 51, ***52***

2. What are the consequences of degraded reliability of automated UAV functions for performance of the automated task and of concurrent tasks?
Relevant articles: ***11***, ***12***, 40

3. How will see and avoid requirements be addressed in UAV flight? Can automated detect, see, and avoid (*DSA*) technology allow a UAV operator to maintain acceptable levels of separation? What are the consequences of imperfectly reliable DSA automation on conflict detection and on performance of concurrent tasks?
Relevant articles: 27

4. To what extent should takeoff and landing be automated?
Relevant articles: ***2***, 51

5. Through what form of control interface should internal and external pilots manipulate a UAV?
Relevant articles: ***37***, 51

6. What compromises should be adopted between spatial resolution, temporal resolution, time delay, and field-of-view (FOV) in the display of visual imagery for flight control and/or conflict detection?
Relevant articles: ***10***, 32, 44, ***45***, ***46***, 51

7. Can augmented reality displays or synthetic vision systems successfully compensate for the degrade visual imagery provided by onboard sensors?
Relevant articles: 3, ***13***, ***15***, 16, ***17***, ***18***, ***29***, 44, ***45***, ***46***

8. Can multimodal display technology be used to compensate for the dearth of sensory information available to a UAV operator?
Relevant articles: ***4***, ***5***, ***11***, ***12***, ***14***, 19, ***20***, ***25***, *32*, 34, ***39***, ***43***, 44, ***49***, ***50***, 51

9. To what extent can displays and controls be standardized across UAV systems? What level of standardization should be mandated? (Basic T instrument panel? HUD overlay?)
Relevant articles: 21

10. What are the consequences for system safety of pilot judgment when the pilot no longer has a “shared fate” with the vehicle? Will there be subtle shifts in risk taking that might affect overall airspace safety?
Relevant articles: none

11. How will hand-offs between crews be accomplished during long-endurance flights?
Relevant articles: none

12. What are the effects of variable total loop time delays on response to ATC instructions?
Relevant articles: 19, 27, 32, ***43***, 44, ***45***

13. What form of predictable autonomous behavior should a UAV adopt following a loss of ground-to-air communications?
Relevant articles: none

14. How many members will each crew comprise, and what will be each crewmember’s responsibilities? Can an operator supervise multiple UAVs simultaneously while maintaining an acceptable level of performance?
Relevant articles: 7, ***8***, ***15***, 21, ***23***, ***28***, 30, 33, ***38***, ***47***, 51, ***52***

15. What are the core knowledge, skills, and abilities (KSAs) that should be required for UAV pilot certification? What KSAs should be required for certification to fly particular UAV systems or classes of systems?
Relevant articles: ***2***, 26, 48

16. Should experience piloting a manned aircraft be prerequisite for UAV pilot certification?
Relevant articles: ***2***, ***42***, 48

17. What medical qualifications should a UAV operator be required to meet?
Relevant articles: ***25***, ***47***, 48

Appendix C

Contact Information

This appendix provides available contact information for first and/or senior authors on the research articles summarized in Appendix A.

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