

# HUMAN FACTORS CONCERNS IN UAV FLIGHT

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Unmanned aerial vehicles have potential to serve a range of applications of civil airspace. The UAV operator's task, however, is different from and in some ways more difficult than the task of piloting a manned aircraft. Standards and regulations for unmanned flight in the national airspace must therefore pay particular attention to human factors in UAV operation. The present work discusses a number of human factors issues related to UAV flight, briefly reviews existing relevant empirical data, and suggests topics for future research.

## Introduction

System developers have proposed a wide range of government, scientific, and commercial applications for unmanned aerial vehicles (UAVs), including border and port security, homeland surveillance, scientific data collection, cross-country transport, and telecommunications services. Before these possibilities can be realized, however, FAA standards and regulations for UAV operations in the NAS must be established. Given the military's experience that accident/incident rates for UAVs are several times higher than those for manned aircraft (Williams, 2004), the import of carefully designed standards and regulations for UAV flight is clear. Human factors issues are likely to be of particular concern in establishing guidelines for safe UAV flight. As noted by Gawron (1998), UAV flight presents human factors challenges different from and beyond those of manned flight, arising primarily because the aircraft and its operator are not colocated. The goal of the current work is to identify human factors issues in UAV operations, and to review relevant studies in the existing literature. The present document provides a preliminary summary of this work.

Issues discussed below will be grouped into the categories of *Displays and Controls*; *Automation and System Failures*; and *Crew Composition, Selection and Training*. As will be clear, however, the

topics presented within various categories are highly interrelated. Answers to questions about crew complement, for example, are likely to depend in part on the nature and reliability of automation provided to support UAV operators. The nature of automation required for safe UAV operation, in turn, is likely to depend in part on the quality of displays and controls provided to the UAV operator.

## Displays and Controls

One of the primary consequences of the separation between aircraft and operator is that the operator is deprived of a range of sensory cues that are available to the pilot of a manned aircraft. Rather than receiving direct sensory input from the environment in which his/her vehicle is operating, a UAV operator receives only that sensory information provided by onboard sensors via datalink. Currently, this consists primarily of visual imagery covering a restricted field-of-view. Sensory cues that are lost therefore include ambient visual information, kinesthetic/vestibular input, and sound. As compared to the pilot of a manned aircraft, thus, a UAV operator can be said perform in relative "sensory isolation" from the vehicle under his/her control. Research is necessary to identify specific ways in which this sensory isolation affects operator performance in various tasks and stages of flight, and more importantly, to explore

advanced display designs which might compensate for the lack of direct sensory input from the environment.

Work by Ruff, et al (2000), Calhoun, et al (2002), and Dixon, et al (2003) has begun to address to these issues by exploring the benefits of multimodal displays to UAV operators. Ruff and colleagues examined the utility of haptic displays for alerting UAV operators to the onset of turbulence. To the pilot of a manned aircraft, turbulence is signaled by visual, auditory, and kinesthetic/haptic information. To the pilot of a UAV with a conventional display, in contrast, turbulence is indicated solely by perturbations of the camera image provided by the UAV sensors. A study by Ruff, et al, found that haptic information conveyed via the joystick control improved operator's self-rated situation awareness in a simulated UAV approach and landing task. These improvements obtained, however, only under limited circumstances (specifically, only when the turbulence occurred far from the runway; no benefits to SA were observed when turbulence occurred near 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 information denied to a UAV operator with conventional displays, but indicate that such displays may carry performance costs as well. Future research is necessary to examine the costs and benefits of multimodal displays in countering for UAV operators' sensory isolation, and to determine the optimal design of such displays.

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 the cognitive and perceptual workload levels. Studies by Calhoun, et al (2002) and Dixon, et al (2003), for example, tested the value of tactile and auditory displays, respectively, as a method of alerting operators to system failures. Given the high

visual demands of the UAV flight control task, the experimenters predicted such multimodal displays would enable better human performance than would visual displays of system status (Wickens, 2000). Consistent with this prediction, system failures in these studies were detected more quickly when signaled through tactile or auditory displays than when indicated visually. Data from Calhoun, et al (2002) suggested that multimodal displays, by offloading of workload from the visual channel, can improve flight tracking performance. Additional research should further address the value of multimodal displays for offloading visual information processing demands. A related point is that multimodal operator controls (e.g., speech commands) may also help to distribute workload across sensory and response channels (Draper, et al, 2003; Gunn, et al, 2002), and should be explored.

An additional concern imposed by the separation between vehicle and operator is that the quality of visual sensor information presented to the UAV operator will be constrained by the bandwidth of the communications link between the vehicle and its ground control station. Data link bandwidth limits, for example, will limit the temporal resolution, spatial resolution, color capabilities and field of view of visual displays (Van Erp, 1999), and data transmission delays will delay feedback in response to operator control inputs. Research is necessary to examine the design of displays to circumvent such difficulties, and the circumstances that may dictate levels of tradeoffs between the different display aspects (e.g., when can a longer time delay be accepted if it provides higher image resolution). Research has found, not surprisingly, that a UAV operators' ability to track a target with a payload camera is impaired by low temporal update rates and long transmission delays (Van Erp & Breda, 1999). Additional research should be conducted to determine the effects of lowered spatial and/or temporal resolution and of restricted field of view on other aspects of UAV and payload sensor control

(e.g., flight control during takeoff and landing, traffic detection). Of further interest is the possibility of augmented reality and/or synthetic vision systems (SVS) to supplement sensor input (Draper, et al, 2004). Studies by Van Erp & Van Breda (1999) have found that such augmented reality displays can improve the accuracy and reduce the cognitive demands of target tracking with a payload sensor, and by extension improve UAV flight control.

### **Automation and System Failures**

Current UAV systems differ dramatically in the degree to which 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 through an 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. The manner of flight control used during takeoff and landing, further, often differs from the manner of control used en route. The relative merits of each form of flight control may differ as a function of the time delays in communication between operator and UAV and the quality of visual imagery and other sensory information provided to the operator from the UAV. Research is needed to determine the circumstances (e.g., low time delay vs. high time delay, normal operations vs. conflict avoidance and/or system failure modes) under which each form of UAV control is optimal. Of particular importance will be research to determine the optimal method of UAV control during takeoff and landing, as military data indicate that a disproportionate number of the accidents for which human error is a contributing factor occur during these phases of flight (Williams, 2004).

Research will also be necessary to examine the interaction of human operators

and automated systems in UAV flight. A study by Dixon & Wickens (2003) found that allocation of flight control to an autopilot freed attentional resources and improved performance on a concurrent visual target and system fault detection tasks. This effect obtained even if the autopilot was not perfectly reliable but occasionally drifted off course. The converse effect, however, did not hold; automated auditory alerts to signal the occurrence of system faults produced no benefit to flight tracking performance. The benefits of automation are also likely to depend on the level at which automation operates (Mouloua, et al, 2001; Parasuraman, et al, 2000). For example, Ruff, et al (2002) found different benefits for automation managed by consent (i.e., automation which recommends a course of action but does carry it out until the operator gives approval) and automation managed by exception (i.e., automation which carries out a recommended a course of action unless commanded otherwise by the operator) in a simulated UAV supervisory monitoring task. Research is thus needed to determine which of the UAV operator's tasks (e.g., flight control, traffic detection, system failure detection) should be automated and what levels of automation are optimal. A corollary of these recommendations is that research will be necessary to establish and optimize procedures for responding to automation or other system failures. For example, it will be important for the UAV operator and air traffic controllers to have clear expectations as to how the UAV will behave in the event that communication with the vehicle are lost.

### **Crew Composition, Coordination, Selection, and Training**

A third set of human factors-related issues pertains to the composition, selection, and training of UAV flight crews. UAV flight crews for military reconnaissance missions typically comprise two operators, with one responsible for airframe control and the other for payload sensor control.

Such crew structure is merited in light of findings that the assignment of airframe and payload control to a single operator with conventional UAV displays can substantially degrade performance (Van Breda, 1995). Data also suggest, however, that appropriately designed displays and automation may help to mitigate the costs of assigning UAV and payload control to a single operator (Dixon, et al, 2003; Van Erp & Van Breda, 1999). It may even be possible for a single UAV operator to monitor and supervise multiple semi-autonomous vehicles simultaneously. Study is necessary to determine crew size and structure necessary for various categories of UAV missions in the NAS, and to explore display designs and automated aids that might reduce crew demands and potentially allow a single pilot to operate multiple UAVs simultaneously. Research is necessary on techniques to understand (Gorman, et al, 2003) and facilitate (Draper, et al, 2000) crew communications, with perhaps particular focus on inter-crew coordination during the hand off of UAV control from one team of operators to another (Williams, 2004).

Finally, study is necessary to examine standards for selecting and training UAV operators. There are currently no uniform standards across branches of the US military for UAV pilot selection; while the Air Force exclusively selects military pilots as UAV operators, Navy and Marine UAV operators are required only to have a private pilot's license, and operators of the Army's Shadow UAV generally are not rated pilots. Thus, while data from Schreiber, et al (2002), indicate significant positive transfer from manned flight experience to Predator UAV control, research is needed to determine whether such experience should be required of UAV operators. Efforts are also necessary to determine the core content of ground school training for UAV operators, and to explore flight simulation techniques for training UAV pilots (Ryder, et al, 2001).

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