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Human Factors Considerations in Migration of Unmanned Aircraft System (UAS) Operator Control

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14. ABSTRACT
Unmanned aircraft system (UAS) operator control can be migrated within temporal, physical, and functional domains. Although such control migrations occur in current UAS operations, there are no human factors studies specifically addressing this issue in UASs. This work sought to identify reasons for migrating UAS operator control and summarize the human factors literature with inferential bearing on this topic. Migration of UAS operator control is necessary to overcome limitations of the human operator, current technology, or both. There are potential advantages to control migration to include mitigating operator vigilance decrements and fatigue, facilitating operator task specialization, and optimizing workload during multi-aircraft and payload control tasks. However, there are also significant disadvantages to include transient degraded operator situational and systems awareness and more complex and potentially distributed teams of operators. Future work should focus on improving the empirical knowledge base on UAS human factors so evidence-based recommendations can be made when incorporating control migration in UAS design and operations.

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Unmanned air vehicle, UAV, remotely piloted aircraft, RPA, remotely piloted vehicle, RPV, crew changeover, vehicle handoff, human factors

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EXECUTIVE SUMMARY

Purpose: To identify the potential human factors concerns in migration of unmanned aircraft system (UAS) operator control.

Background: UAS operator control can be migrated within temporal, physical, and functional domains. Although such control migrations occur routinely in current UAS operations, they constitute a critical and potentially high workload phase of flight. Despite this fact, there are currently no relevant human factors studies in the literature specifically addressing this issue in UASs.

Methodology: The technical approach involved identifying reasons which might necessitate the migration of UAS operator control and exploring the potential advantages and disadvantages of control migration. The existing human factors literature was reviewed for studies with inferential bearing on this topic.

Overall Assessment: There is a very limited scope of work to date on migration of UAS operator control requiring the application of findings from research in other task domains to that of the UAS environment. Based on the synthesis of the available literature:

- Migration of UAS operator control is necessary to overcome limitations of the human operator, current technology, or both.
- There are potential advantages to control migration to include the maintenance of operator performance by mitigating fatigue and vigilance decrements through optimum shift lengths (e.g., 6-10 hours) and the provision of work breaks, facilitating enhanced operator functional specialization, and allowing for the adjustment of workload during multi-aircraft and payload control tasks via control migration strategies.
- Possible significant disadvantages to control migration include transient degraded operator situational and systems awareness and more complex and potentially distributed teams of operators.
- Future work should focus on improving the empirical knowledge base on UAS human factors so evidence-based recommendations can be made when incorporating control migration in UAS design and operations.

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HUMAN FACTORS CONSIDERATIONS IN MIGRATION OF UNMANNED AIRCRAFT SYSTEM (UAS) OPERATOR CONTROL

INTRODUCTION

The advent of unmanned aircraft systems (UASs) has created a host of new human factors challenges[18] arising primarily because the air vehicle and operator(s) are no longer necessarily co-located.[26] One of the most unique of these human factors challenges concerns migration of UAS operator control. While the term migration simply implies movement, the construct of control migration used in this work is similar to that described by Kahne[20] and includes changes in the locus of control within temporal, physical, and functional domains. For example, in current long endurance UASs, control may be transferred between operators in a single control station (e.g., crew changeover), between control stations (e.g., vehicle handoff), or among members of a crew (e.g., task execution).[27,49] While the ability to migrate operator control adds a new dimension of flexibility in operating UASs, it also comes at a cost in terms of increased complexity and has been a factor in several UAS mishaps.[51,66] Additionally, there are currently no relevant human factors studies in the literature specifically addressing this issue in UASs.[27] For autonomous UASs requiring only supervisory control, studies of air traffic control (ATC) might serve as an analog supervisory control domain.[6] However, an important distinction is the fact ATC's instructions to aircraft are ultimately advisory rather than mandatory since legal responsibility for the safety of an aircraft rests with the pilot.[19] Nevertheless, issues related to the human factors of migration of operator control are likely to be of particular concern in the near future in establishing guidelines for the certification and safe operation of UASs in civil airspace. The goal of the current work was to examine the existing human factors literature and summarize the state of knowledge which might have inferential bearing on the discussion of migration of UAS operator control. The technical approach involved identifying reasons which might necessitate the migration of UAS operator control and exploring the potential advantages and disadvantages of control migration.

REASONS FOR CONTROL MIGRATION

Temporal

Many current human-machine operations are continuous in character and the nature of these operations often preclude a temporary shutdown because of economical, operational, or other constraints.[21] Such operations have the potential to create situations in which people are driven to work continuously. This has certainly been the case in military operations where technological advances in night vision devices and other sensors coupled with a global battle space has led to a doctrine of continuous, around-the-clock operations.[3,23] Therefore, current military medium and high altitude endurance UASs have been designed to operate at distances requiring beyond line-of-sight (LOS) communications and remain airborne for nearly 1-2 days. Future military and civil UASs are projected to operate for even longer durations of time on the order of days to months.[8,27,36]

A critical problem for endurance UASs is the predictable decrements experienced by individuals continuously performing cognitive tasks for sustained periods.[21,23] In a study comparing the effects of fatigue versus alcohol intoxication, Dawson and Reid[10] found the hourly performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004 percent rise in blood alcohol concentration. After 17 hours of sustained wakefulness, cognitive psychomotor performance decreases to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05 percent. This is the proscribed level for alcohol intoxication in many western industrialized countries[3,10] and exceeds the 0.04 percent limit established by the Federal Aviation Administration (FAA) for aircrew.[16] Mullaney et al[33-35] conducted several studies of continuous performance on monotonous tasks requiring sustained attention and found such performance produced rapid fatigue effects after only six hours. More than half of the study participants experienced psychological disturbances such as mild hallucinations, illusions, disorientation, and derealizations, mostly after 18 hours. Beyond the laboratory environment, an Air Force Safety Center study found fatigue-related performance decrements were present in 12.7 percent of the most serious class of Air Force mishaps occurring during fiscal years 1972-2000,[56] costing the Air Force an estimated 54 million dollars each year.[3]

While it is obviously unreasonable to expect a single operator to control a UAS with an endurance greater than one day, it is also evident operators will need to be changed during UAS operations spanning more than the majority of a day. Summarizing NASA's experience testing UASs, Del Frante and Cosentino[11] stressed the importance of adhering to established crew rest requirements, implying UAS operations are not immune to fatigue-related operator performance decrements. Additionally, studies of personnel working 8, 10, and 12 hour shifts[39-43] have shown increased fatigue and poorer performance with 12-hour versus eight or ten hour shifts. Collectively, these studies suggest migration of operator control is desirable as UAS endurances routinely exceed 12 hours, although more optimally it should be considered after 6-10 hours.

Physical

As previously mentioned, some military endurance UASs operate at great distances from the control station, necessitating beyond line-of-sight (LOS) communications.[27,36] As satellites or other UASs are used to relay signals over the horizon, variable time delays or latencies of one or more seconds are introduced. However, latencies greater than one second mean real-time feedback necessary for effective manual control is not available.[64] Additionally, many UAS operators are dependent on real-time imagery from cameras mounted on the remote vehicle in order to manually control the vehicle.[59] This requires data transmission links between the vehicle and control station with high bandwidths and low latencies. However, increasing distance between the vehicle and control station, especially beyond LOS, necessarily forces constraints on data link bandwidth and increases latency.[26,31,59] Such data link constraints can result in limited temporal resolution, spatial resolution, color, and field of view of imagery irrespective of onboard sensor capabilities.[59,60] With great enough distance, the frequency and immediacy of transmitted images may decrease to the point where direct manual control of the vehicle is significantly degraded.[26,31] Besides vehicle control, experimental evidence has also shown visual tasks such as target detection and identification, tracking, and orientation are adversely affected by degraded image quality, slow update rates (< 2 Hz) and high latency (> 2 sec).[59,61]

Increased automation (e.g., supervisory control) and predictive displays have been utilized to mitigate the effects of control latency,[31,64] but there are situations where manual control modes may be preferred over supervisory control or a fully automated vehicle.[59] In such situations, an alternative strategy may be to handoff control to more proximate control stations. This approach has relative merit over supervisory control in situations where concerns over control latency and quality of visual imagery or sensor information are critical, such as in highly dynamic and changing environments where near-real time data is required for complex decision-making.[26,59] Such situations might include weapons employment[31] when there is a risk for fratricide or responding to a malfunctioning or damaged remote vehicle. Additionally, some current military UASs by design must be manually controlled during takeoff and landing.[26,27,59] In these circumstances, a control station needs to be located in LOS distance of the airfield to minimize data transmission delays and optimize manual control. However, once airborne, control can be handed off to a geographically remote control station where the UAS is then operated via supervisory control, minimizing the equipment and personnel which must be sent to a potentially vulnerable forward base of operations.

Functional

Migration of control within a crew may occur when a UAS is designed such that control is functionally divided between non-equivalent operators. Current military UASs are typically operated by at least two operators with one responsible for vehicle control and the other for payload control.[26,59] While the payload operator usually does not directly control the vehicle, it may be possible for this individual to exercise indirect control of a UAS if the program logic automatically adjust the flight path to stabilize camera or sensor images. For example, current MQ-1 Predator UAS multi-aircraft control (MAC) ground control station design allows sensor operators limited control of the vehicle within a senor operator container (SOC) predefined by the pilot.[46] Functional migration of control also occurs in some small military tactical UASs where responsibility for takeoff/landing and en route control is divided between two operators. In this situation, the external pilot (EP) interacts with the UAS while in direct visual contact at the site of takeoff or landing. In contrast, the air vehicle operator (AVO) is inside a control station and interacts with the UAS through an interface of sensor displays and controls during the

en route phase of flight.[1,27,66] While control is functionally divided out of necessity because of task-specific human-machine interfaces (HMIs), Barnes et al[1] also demonstrated differences between EPs and AVOs with regards to operator abilities across multiple cognitive skill sets.

ADVANTAGES OF CONTROL MIGRATION

Vigilance and Fatigue

Much of an operator's task load in highly automated systems such as UASs is supervisory in nature, consisting mainly of passive monitoring of system parameters and remaining alert for malfunctions.[32,59] This trend towards placing the operator in the role of passive monitor has continued despite years of vigilance research demonstrating such roles make maintaining a constant level of alertness exceedingly difficult[9,25,37,65] and predispose to "hazardous states of awareness."[38(p. 449)] Studies of vigilance tasks have consistently demonstrated a vigilance decrement beginning as early as 20-35 minutes after task initiation and characterized by declining numbers of correct responses, increasing response times, or both.[9,23,64] One study found declining response rates after only 2-3 minutes of task performance, with response rates eventually plateauing at 70-80 percent of initial rates.[24] Prolonged vigilance work generally invokes subjective feelings of boredom and monotony and invariably induces decreased levels of physiologic arousal. Boredom in particular can become apparent within minutes of the onset of a monotonous task and is associated with decreased performance efficiency and increased drowsiness. However, when coupled with the need to maintain high levels of alertness, boring vigilance tasks can be perceived as quite stressful.[23,47] This stress predisposes to short term fatigue which typically manifests as long response times, missed signals, and brief interruptions in performance due to gaps or lapses in attention[44] as well as increased decision errors or decreased throughput.[23] This was born out in a study of U.S. Air Force MQ-1 Predator UAS operators which found a 7.1-17.8% increase in reaction times associated with more frequent lapses in attention as well as increased subjective ratings of fatigue and decreased ratings of alertness over the course of an 8-hour shift. Ninety-two percent of these operators also reported "moderate" to "total" boredom.[55] Thus, it should be expected

tasks requiring the sustained attention of UAS operators will be susceptible to degraded performance and increased risk for operator error.[32]

Although initial research[21,45] with complex monitoring tasks typical of the ATC task environment suggested vigilance decrements did not occur, more recent studies are supportive of the vigilance decrement in both simple and complex monitoring tasks.[9,30,44,48] The validity of these concerns in the UAS task environment was demonstrated in a study of Army UAS operator performance under two experimental conditions involving 8-10 hour versus three hour flights.[2] Target detection and recognition performance as well as crew reaction times were significantly degraded during nocturnal operations involving the longer flights while no nocturnal changes were observed for the shorter flights. Likewise, two studies[44,48] using an ATC task found the time to detect and the frequency of missed traffic conflicts increased significantly over the course of just two hours. These vigilance decrements were attributed to increasing lapses in attention rather than a generalized fatigue effect.

One of the best ways to overcome these effects is change, whether using work breaks, rest pauses, or split shifts, although the benefits of rest pauses may derive more from subjective factors such as relief of boredom.[23] Warm[62] in particular recommended continuous vigilance monitoring tasks be kept to less than four hours in duration. Irregardless of the method of change, it will necessarily involve the migration of control to another operator, whether in the same or another control station. Thus, control migration plays a potentially critical role in the maintenance of optimum operator performance and in decreasing the risk for operator errors.

Functional Specialization

Unlike traditional manned aircraft where crew size is limited by vehicle payload constraints and all human functional capabilities must be resident in the onboard crew, UASs offer the advantage of allowing these functional capabilities to be distributed over a multitude of potentially geographically dispersed specialists. In essence, a UAS crew is limited only by data transmission link accessibility. Given the massive amounts of information currently down-linked from UASs[32] and the information processing constraints imposed by the sequential

decision-making of human operators,[20] it is key to distribute this information so it can be more efficiently processed for mission accomplishment.[32] This point was highlighted by a study of human systems integration (HSI) issues in military UAS mishaps which found an association between failures in the cognitive domain and operator errors.[53]

Beyond the issue of information processing, UASs offer the opportunity to employ task specialization beyond the level hereto seen in manned aircraft. The potential need for task specialization in UAS operations may be appreciated given the current military experience with UASs in which training and attentional issues are frequent causal factors in human error-related mishaps.[54] As noted by Barnes et al[1] in their study of Army UAS operators, experience improves operators' cognitive throughput, allowing them to devote limited attentional resources to future problems while automatically attending to immediate perceptual and motor tasks. This was echoed in NASA's lessons learned testing UASs that "even more important than practicing the emergency procedures is practicing the normal procedures to the point that they are second nature." [11(p. 8)] Thus, experience serves to increase an operator's cognitive efficiency in problem solving by effectively increasing available attentional resources.[64] Unfortunately, the cognitive efficiency obtained via experience is specific to the tasks experienced and not broadly generalizable.[1]

Given the task-centric nature of expertise, consideration should be given to the creation of specialty teams to intervene and handle uncommon or off-nominal events. Such teams could rehearse infrequent tasks and explore potential outcomes, thereby developing proficiency in situational problem solving prior to encountering the actual event. For example, rather than training all operators to handle emergencies, specialty teams could be trained to take control and troubleshoot a malfunctioning or damaged UAS. These emergency teams could operate from remote control stations equipped with enhanced displays to aid diagnosis and allow predictive simulation. Such methods have been used successfully in the U.S. space program.[32]

Functional specialization could also be utilized in non-emergent, nominal situations to optimize the central role of the human decision-maker within the system. In traditional manned combat aircraft, the pilot has the responsibility to authenticate targets and trigger weapons

because they are presumed to be in the best position to assess the situation and make timely decisions. However, UASs allow this function to be migrated to other team members possessing higher levels of technical or combat expertise such as a target detection specialist or experienced mission commander, thereby improving the confidence level of information presented to higher authorities.[32] Additionally, functional specialization allows for increased training program efficiency since all personnel don't necessarily need to receive equal training given non-uniform task environments across worksites. The FAA has explored this issue with regards to training air traffic control specialists (ATCS)[50] and the U.S. Air Force has adopted this approach in training MQ-1 Predator UAS operators on takeoff and landing.

Workload and Multiple Vehicle Control

There currently is limited human factors research suggesting one operator may control more than one UAS under relatively idealized conditions to include closely coordinated and correlated vehicle activities, a stable environment, and reliable automation.[6,13,14,27] Other research has demonstrated operator performance controlling even a single vehicle is significantly degraded when heavy demands are imposed by payload operations.[2,61,63] This would suggest the ability of an operator to attend to multiple UASs may be severely compromised under non-idealized conditions, especially if one vehicle is malfunctioning or damaged.[27] Feedback from testing of the MQ-1 Predator UAS MAC ground control station which utilizes one pilot and four sensor operators to control four UASs found dynamic taskings may require two pilots.[46] Additional human factors research is available examining situational awareness in ATC, an analog for supervisory control of multiple vehicles. Endsley and Rodgers[15] found ATCS accuracy was significantly impacted by the number of aircraft being controlled and situational awareness declined dramatically when the number of aircraft exceeded 8-10. This is consistent with the magic number "7 ± 2" in memory research,[29] suggesting there are finite limits on human information processing beyond which people tend to forget. Two studies[17,28] examining ATCS performance while passively monitoring aircraft under free flight conditions found a significant decrement in situational awareness when controllers had to handle 17 versus 11 aircraft. Another study examining control of multiple retargetable missiles[6] found operators could effectively control 8-12 missiles, but performance degraded with 16 missiles. Overall, the

preponderance of evidence suggests greater than 12 vehicles potentially represents a cognitive saturation state for operators interacting with semi-autonomous vehicles requiring only the setting of new goals.[7]

Given the limits of an operator's ability to manage multiple UASs, migration of control may need to be utilized as a workload mitigation strategy. For example, an operator controlling multiple UASs under high workload conditions (e.g., multiple vehicle requests for operator attention) could transfer control of one or more UASs to other operators under low workload conditions, even as part of normal operations. In cases where a single UAS requires sustained attention because of a backlog of vehicle requests for operator attention or off-nominal operating conditions, control of this high workload UAS could be transferred to an on-call operator or supervisor akin to current ATC practices. The ability to transfer control of UASs based on workload prevents a single operator controlling multiple UASs from having to adopt triage-like procedures for handling multiple attentional demands.[32]

Payload Control

As already alluded to during the discussion of multiple vehicle control, performing payload tasks can significantly increase operator workload and degrade operator performance. In current military reconnaissance UASs, vehicle and payload control are typically divided between a vehicle operator and a payload operator.[26,61] Van Erp and Van Breda[61] concluded such a crew structure was reasonable in light of findings that consolidating vehicle and payload control within a single operator substantially degraded performance. Likewise, Barnes and Matz[2] studied a prototype UAS control station configuration which allowed a single operator to perform both vehicle control and target acquisition functions. They found operators became focused on the targeting function to the detriment of situational awareness and vehicle control, leading the authors to question the wisdom of using a single operator. Two additional studies demonstrated attentional fixation and cognitive tunneling during target analysis which degraded performance on other tasks irrespective of level of automation or use of auditory cueing.[13,63] The task of manipulating a camera image, analyzing targets, and keeping track of cardinal directions appears to be sufficiently challenging that timesharing with other tasks such as vehicle control

becomes virtually impossible. Van Breda and Passenier[58] also noted operator performance was poor when utilizing "double-stick" controls where one joystick controls airframe heading and speed and the other camera heading and pitch. However, this is not surprising given such control arrangements predispose to perceptual confusion which increases the potential for action slip errors.[64]

Nevertheless, for optimal flexibility and cost effectiveness, it is desirable to allocate both vehicle and payload control to one operator.[58] It may therefore be necessary to delineate circumstances under which vehicle and payload control can be safely performed by a single UAS operator and when control of the payload should be transferred to another operator.[27] This may be decided prior to a mission or payload control may need to be transferred during a mission in response to a dynamically evolving situation. As previously discussed, a UAS operator's ability to perform payload-oriented visual tasks such as target detection and identification, tracking, and orientation is impaired by low temporal update rates and long transmission delays.[59,61] If vehicle control is adequate for the task using some form of supervisory control, it may only be necessary to handoff payload control to a more proximate control station, potentially eliminating the need for full control stations in forward locations. Additionally, the ability to handoff payload control to those directly requesting the camera imagery or sensor data (e.g., target detection specialists or fielded forces) could increase the efficiency of data collection and eliminate the need for coordination with an intermediate payload operator. At the extreme, control of weapons could be transferred to the forces requesting their employment, hopefully decreasing the risk for fratricide.

DISADVANTAGES OF CONTROL MIGRATION

Situational Awareness

While there are good reasons to consider utilizing migration of operator control in UASs, it is important to also explore the potential pitfalls. Indeed, migration of control may well constitute a critical and potentially high workload phase for UAS operators.[27] For example, several military UAS mishaps have occurred either directly during or indirectly as the result of

changeovers or handoffs.[27,51,66] In handing off control between stations, mishaps have resulted when the station receiving control was improperly configured.[66] During changeovers, mishaps have resulted because of the new operator's decreased systems awareness.[51] More broadly, there is concern for an acute decrement in crew situational awareness when control is transferred to a crew not currently involved in the ongoing mission. Kidd and Kinkade[21] demonstrated the existence of such an operator change-over performance decrement in the ATC environment. Controller performance was markedly decreased over the first five minute period following assumption of controller duties. This change-over performance decrement was mitigated by about 50 percent if either parallel control or auditory-plus-visual monitoring was employed as a pretransition condition. Another study examining operational errors in ATC[12] found errors were most frequent during the first 15 minutes after assuming controller duties and nearly half occurred within the first 30 minutes on position. An analysis of U.S. Air Force MQ-1 Predator UAS mishaps revealed a similar predominance of operator error-related mishaps relatively early in the duty period suggestive of a changeover effect.[52] Likewise, a study of Army UAS operators[2] found operators preferred longer over shorter rotations because they perceived the longer rotations allowed for better situational awareness of the tactical environment.

Complex Teaming Situations

Migrating operator control can create distributed crews with dynamically changing membership which may have significant associated costs in terms of the increased complexity of crew coordination and communication.[22,27] Moving from the individual to multiple operators introduces an additional layer of cognitive requirements in the form of the associated demands for working together effectively as a team. Additionally, the effects of physical dispersion on team workload and performance have not been well evaluated.[5] However, breakdowns in team performance, cooperation, and communication do occur in military UAS operations and have been a contributing factor in UAS mishaps.[54]

Studies of team dynamics in the UAS task environment are limited. Kiekel et al[22] used a UAS synthetic task environment to assess team cognition by evaluating the flow of communications among team members. They found communication patterns were less stable

when team members were geographically dispersed as compared to co-located. Cooke et al[5] also used a UAS synthetic task environment to evaluate the effects of distributed mission environments and workload on team performance, process, and cognition. While they did not find any detrimental effects of physical dispersion on team processes, knowledge, and situational awareness, the composition of their teams limits the validity of the results when extrapolated to the context of migration of operator control. Specifically, in their study a team consisted of a UAS crew comprised of three members: an air vehicle operator, payload operator, and data exploitation, mission planning, and communications (DEMPC) operator. This makes it difficult to infer how teams consisting of more than one UAS crew would function in the context of UAS handovers or handoffs, especially given the membership of such teams may not be predetermined and generally exist for only short periods of time. This is important given the findings of Cooke et al that teams generally required four 40-minute missions to reach asymptotic levels of performance and teamwork knowledge developed with mission experience. This suggests those phases of UAS operations involving migration of control may well be vulnerable to diminished team performance.

AEROMEDICAL IMPLICATIONS

Human factors issues are central to the current practice of aerospace medicine, especially with the recent increased focus on ensuring humans have the capacity to perform under conditions associated with current aerospace operations. As noted by a U.S. Air Force Scientific Advisory Board report, *Human Systems Integration in Air Force Weapons System Development and Acquisition*, "the roles of human operators are undergoing qualitative changes driven by technological changes...because of these transformational factors, the considerable base of human factors knowledge derived from cockpit experience may have limited applicability to future systems."[57(p. v)] The importance of this finding is self evident given UASs currently comprise 81 percent of all the U.S. military's aviation hours flown per year[4] and the U.S. UAS inventory is expected to grow from 250 vehicles today to 675 by 2010 and 1,400 by 2015.[36] Since UASs represent the engineering solution to such traditional aeromedical human factors concerns as barotrauma and hypoxia, acceleration, vibration, thermal stress, and those forms of

spatial disorientation associated with acceleration, human cognitive and information processing capabilities are the main limiting factor for the performance of this significant and growing subset of aerospace systems. As demonstrated in this review, there is currently a lack of aeromedical research addressing these capabilities, particularly as applied to UASs. Some initial work has been started as part of the U.S. Air Force's UAS Performance Analysis Project which will document the workflow, major accomplishments, and supporting tasks to include the knowledge, skills, and abilities associated with the roles of MQ-1 Predator and RQ-4 Global Hawk UAS pilots and sensor operators (Constable S, 311th Performance Enhancement Directorate. Personal communication; 2006). The capability to migrate operator control and potentially for operators to task specialize will have significant ramifications for future operator selection, certification, and training. Additionally, the ability to migrate control may drive new perspectives on more traditional aeromedical concerns such as fatigue, workload, and acceptable levels of risk for operator incapacitation.

CONCLUSION

Current UASs encompass a broad range of military mission capabilities and offer great promise in potentially serving a host a civil applications. Transformational technologies and operational necessity has led UAS designers and operators to step out of the one crew-aircraft-mission paradigm of traditional manned aircraft systems and allowed for the routine migration of UAS control between operators across temporal, physical, and functional domains. This has in part been driven by limitations of the human operator, the technology, or both. However, this capability also offers aerospace human factors practitioners the potential to redesign UAS operator tasks and jobs in order to capitalize on the inherent strengths of human operators while limiting the impact of their natural weaknesses. It is also equally important these same human factors practitioners identify the potential pitfalls of control migration and design appropriate administrative or engineering countermeasures. As this review has demonstrated, the limited scope of work to date on this topic requires the application of findings from research in other task domains to that of the UAS environment. The immediate challenge therefore is to verify the generalizability of existing research to UASs. However, future work should focus on improving

the empirical knowledge base regarding UAS human factors so improved cost-benefit analyses can be made when considering incorporating control migration in UAS design and operations.

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