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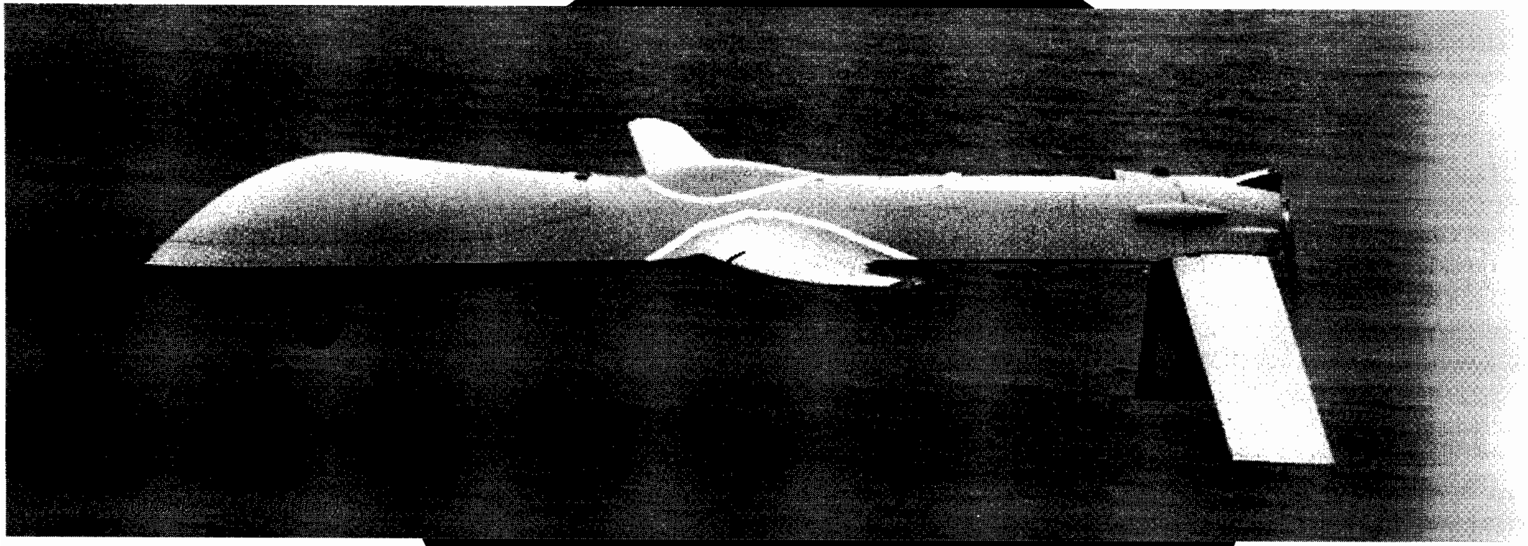

HUMAN-CENTERED DESIGN OF

BY MUSTAPHA MOULOUA, RICHARD GILSON, & PETER HANCOCK

Technology advances and increased application of UAVs will demand greater attention to human factors concerns in design, deployment, and training.

Rarely do human factors practitioners have opportunities to provide input to the design of revolutionary interfaces during the first, conceptual phases of development. However, interactive pilotless aircraft, or unmanned aerial vehicles (UAVs), have provided just that opportunity. From humble beginnings more than 50 years ago, UAVs are being put to increasing use for new missions and roles in contemporary and future aviation. According to Frost and Sullivan (www.frost.com), world markets for military, civil, and commercial UAVs will see remarkable growth in revenue during the coming decade. In 1997 alone, over $2.3 billion was spent in the UAV market, and this figure is expected to increase substantially as technological and airspace regulatory issues are resolved.

Because of their successful military operations overseas, remotely piloted vehicles are increasingly being considered for homeland security. According to a recent report by *The Times-Picayune*, unmanned aerial vehicles could provide constant, round-the-clock surveillance of pipelines and ports, safely investigate disasters involving hazardous and radioactive materials, and easily gauge damage to bridges, buildings, and hard-to-access areas if their safety and reliability issues can be resolved.

In this article, we discuss human factors considerations in the design and use of interfaces and controls for UAVs and unmanned combat aerial vehicles (UCAVs).

UAV Background

Unmanned does not imply that these aircraft are uncontrolled; completely unguided lift and power have very limited use and frequently lead to short flight times and rapid destruction. Among the earliest flight vehicles were paper airplanes and rockets developed by the Chinese. However, this line of vehicles did not progress beyond this uncontrolled mode. The first fixed-wing flight with a model airplane in 1853 is credited to Sir George Cayley, who subsequently built a so-called manned glider that flew briefly carrying a boy. Otto Lilienthal followed with pioneering experiments

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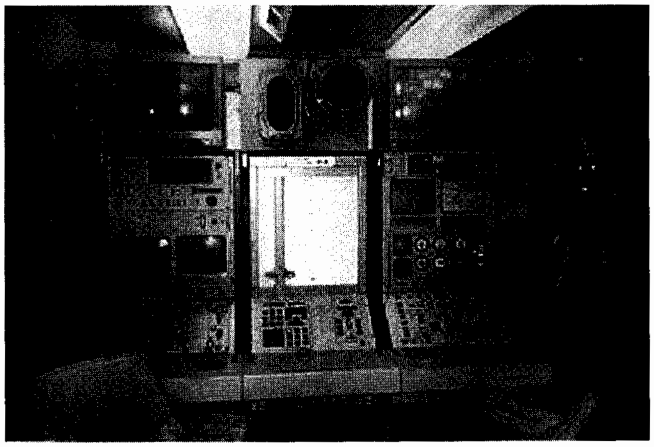
in hang gliders, making more than 2000 flights, but unfortunately he died in a crash as a result of limited flight control.

Control, more than power, was the final key element in the Wright brothers' first successful heavier-than-air flight in 1903. With control, various forms of airplanes rapidly emerged. Less than 24 years later, in 1927, Charles Lindbergh's flight to Paris opened up the possibilities of transoceanic commercial aviation, although he himself experienced significant fatigue and, because of it, nearly lost control. Today, automation and autopilots tirelessly and precisely control the bulk of routine commercial flights, placing their human crew evermore in the background as nominal supervisors.

With advanced wireless data links, UAVs can now be controlled from a range of remote locations. However, despite the events of September 11, 2001, there has been little call for remotely controlled vehicles in commercial aviation. Military aviation is another story. Often military aircraft are simply outfitted platforms for other operations ranging from surveillance to combat. Such activities can place human crewmembers in harm's way, but given the state of technology, there has often been no alternative. Now, however, technological innovation permits sophisticated remote control, and the question becomes, What missions are best suited for a UAV response? Ideally, precise maneuvering coupled with flexibility for "on-the-fly" decisions are the design objectives.

The next-generation UAVs designed by the U.S. armed forces have significantly expanded the vehicles' capability. Propeller-driven UAVs such as the Navy's Pioneer and the Army's Hunter, which have been carrying out reconnaissance/surveillance missions in Bosnia and Afghanistan, are often maneuvered manually by ground-based pilots. Their success has been tempered by a number of significant failures. For example, UAVs were brought into prominence during the 1999 NATO military campaign in Kosovo. The Hunter, Pioneer, and Air Force Predator conducted important reconnaissance operations; the Predator became the first American UAV to designate a target for laser-guided bombs launched from an A-10 ground-attack aircraft.



UAV Operator Station

NATO lost 20 to 30 UAVs during the 78-day Kosovo air operation. They were either shot down or suffered technical failure. As actual combat missions are added to long-duration, prolonged, over-the-horizon intelligence, surveillance, and reconnaissance (ISR) missions, the performance demands placed on human operators will only increase, especially because instantaneous decision making is also required. The question of whether this will be possible with current control techniques is uncertain without added reliance on computer aiding and on supervisory telerobotics. The promising benefits of the latter include superiority in flight and greater cost-effectiveness.

UNMANNED AERIAL VEHICLES

It is expected that UAVs and unmanned combat aerial vehicles will play an increasingly significant role in military missions (Howard, Bray, & Lyons, 1996; McDaid & Oliver, 1997; Worsch et al., 1996). UAVs and UCAVs offer advantages over traditional airborne warfare equipment, including the ability to operate "fearlessly" in battle and areas contaminated by biotoxins or radiation. Further, they have the ability to withstand forces of acceleration beyond human tolerance and do not need expensive on-board environmental systems. Operationally, UAVs can locate and persistently surveil enemy activities with near impunity. UCAVs can attack targets and then provide follow-up damage assessment and identification of new target sites. Near-real-time communication from, and command of, UAVs and UCAVs is imperative for mission effectiveness (Worsch et al., 1996) – and for managing environmental difficulties, resolving unplanned events such as malfunctions or retasking after launch, and dealing with enemy countermeasures.

Command and communication is critical as the final authority link for unleashing lethal weapons, but the distinct advantage of a remote operator also provides human factors with challenges for the design of interfaces and the training of operating personnel.

Design Considerations

Analysis of a generic UAV mission reveals several critical initial considerations. First, it is important to understand that the dual concerns of mission requirements and flight control may exceed the capabilities of a single pilot and may therefore preclude a single operator from simultaneously controlling multiple vehicles. This immediately leads to considering function automation. Second, there is the need for communication in near real time, mentioned earlier. Therefore, a second design question concerns how communications timing delays (sometimes on the order of seconds)

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will be effectively managed or even designed out through user interfaces. Third, because lethal weapons are involved, target verification and assurance of collateral safety are of utmost concern. Finally, it is important that any design address the management of unplanned events, including mechanical failure and enemy countermeasures.

We consider the automation issue first because subsequent design decisions are contingent on this initial step.

The automation design dilemma. There are three major possible levels of UAV/UCAV flight control: full manual control, supervisory control, and full automation. Manual control places a continuous high workload on the pilot and is especially influenced by individual differences in attention and ability. Additionally, manual control is dramatically disrupted by time delay, such as that encountered in the transmission of data through satellites when the UAV/UCAV is "over the horizon" (beyond direct radio communications) or when there are transmission breaks. In contrast, full automation of a UAV/UCAV involves minimal operator workload, allowing for the simultaneous control of many UAVs.

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Automation decreases problems arising from time delays; on-board routines can be scripted for execution before the UAV/UCAV is launched. However, automation carries its own risks as to the release of lethal weapons. Weapon utilization decisions must be verified by a controller and should reflect up-to-the-minute tactical considerations. Therefore, we support the design strategy in which the operator exercises hybrid or supervisory control. The UAV/UCAV would certainly have many preprogrammed, event-triggered subroutines whose activation would be monitored by the operator; the operator would also be responsible for verifying targets and alerts.

To further increase operator efficiency and to decrease training time, we posit that a standardized interface should be used for all ground control units, which could then link a variety of different vehicles. If a standard operating system were developed, different types of UAVs, their modifications, and future developments could be accommodated by the same ground-based station without significant changes in operator training or manpower. Such interfaces could also ease the process of switching control to other UAVs/UCAVs in flight or between missions. Such standardization would then free developers to focus on the most vital aspects of the mission: fitting the appropriate vehicle(s) to the task(s), without diverting attention to interface, training, or manpower issues.

Further Human Factors Design Issues

Our aim was to provide design recommendations. We performed a task analysis of UAV operations to identify human factors concerns. We do not have sufficient space here to address all such issues, so we have selected the most relevant: data-link delays, control design, cognitive workload, displayed information, situation awareness, target detection, and design for training/teaming.

Data-link delays. Full manual control of UAVs over the horizon is unlikely because of inherent data-link delays. Satellite communications can lag real time by seconds, as illustrated by prominent gaps in televised interviews through satellite links. Empirical evidence from many behavioral studies (e.g., Bates & Hilliard, 1997; Worsch et al., 1996) show that response delays beyond about 1 second (or even less) do not allow for satisfactory manual control of aircraft. Therefore, if satellite or UAV-to-UAV relays are used, even as occasional backups, variable time delays of 1 second or more will be introduced. Signal delays to and from UAVs/UCAVs mean that real-time feedback for control response is not available, and this variability contributes to temporal and spatial uncertainty.

A workable solution is operator-initiated, semiautomated flight, search, and attack routines, which overcome data communication delays. Supervisory control of onboard automation – specifically, enacting subroutines of preprogrammed software – can permit safe and functional semiautonomous flight, especially during data-link delays or outages.

Control design. Machine precision and human flexibility together are expected to provide the best combination for hybrid UAV control, even for direct line-of-sight applications. Consistent and accurate operator control regardless of the vehicle's communication link is key to UAV success. There is a design imperative to focus on how such control can be

UAV Ground Station and Airborne Vehicle (Pioneer) maintained when data links exhibit variable time delays and inevitably are subject to periodic interruption. As a point of departure for design, the on-board flight management systems (FMS) of many of today's advanced commercial and military aircraft provide a proven basis for UAV supervisory control.

Design considerations should include a means for operator lead-compensated feedback. One possibility is the creation of a virtual environment that provides pseudo-real-time feedback for the control of distant UAVs. Parallel simulation can anticipate vehicle responses for specific commands and allow for corrective intervention even before the actual command occurs. This predictive virtual reality strategy could play an increasingly important role as the complexity of systems and tasks increases and the telecommunications time delays caused by relay switching lengthen.

Cognitive workload limitations. Next to safety, productivity is the prominent concern for UAV designers. Control of more than one vehicle per operator creates the potential for dramatic increases in efficiency and cost-effectiveness. With semiautonomous control, the workload for any individual operator could be reduced, thereby allowing simultaneous supervision of multiple vehicles. For example, the use of on-board flight automation, automatic target recognition systems, and a variety of sensor alerts could call for operator intervention only when strictly necessary.

At least five factors will affect operator workload and vigilance in most UAV/UCAV scenarios:

1. Number of flight parameters controlled by a single operator
2. Degree of operator involvement in obstruction and threat avoidance
3. Number of UAVs controlled by a single operator
4. Difficulty of target search and recognition
5. Difficulty of situation assessment (nearby friendly forces, human shields, etc.)

The level of available operator resources will depend on at least five key issues:

1. Level of training and experience
2. Time on each task
3. Attentional skills
4. Support by backup personnel or systems
5. Situation awareness

The particular combination and degree of load factors and operator resources is dependent on the level of automation employed in the UAV/UCAV operation.

Displayed information. High-resolution displays for target verification and situation assessment are essential for successful UAV/UCAV missions. However, as in many other information-rich environments, too much unfiltered data can obscure relevant ones. The key is converting data into a meaningful information array to allow for timely operator decisions (e.g., attack, bypass, loiter, return). Massive amounts of bandwidth-straining data are available from UAVs and are often necessary to uncover such areas of interest as camouflaged targets. However, data interpretation is needed for valid decision making.

We support the design strategy in which the operator exercises hybrid or supervisory control.

Appropriate formatting and editing of data can provide efficient coding for interpretation. For example, the judicious use of color, movement, and feature highlighting for coding are technically feasible, but how they will actually be used is a question for human factors specialists armed with knowledge of perceptual capabilities and limitations. Pattern perception of graphical images is usually better when they are filtered or enhanced, but how? Meaningful representational icons or isomorphic symbols usually provide faster recognition than detailed textual descriptions, but in what form?

Specific display issues include a determination of the type of presentation, viewpoint angle, eyepoint location, wide-angle panorama, focused telescopic views, or combinations of each depending on operator selection. Sensor presentations of the same areas of interest may be available on separate displays or overlaid on scene presentations. Further, it may be necessary to "overengineer" displays beyond even the acuity of humans so that additional information may be used by other automated sensors such as infrared displays.

Situation awareness and assessment. Situation awareness can be considered as "perceiving and understanding the relevance of what's happening and what's to come" (Gilson, Mouloua, & Richardson, 1998). Multiple perspectives increase the potential for situation awareness, assessment, and the projection of future events by aiding decisions. An advantage of UAV "cockpit" telepresence is that it can provide multiple representations through its sensors and communication data links, often more information than from a piloted aircraft that must limit communications for its own protection. Thus, command and control decisions can be improved with more relevant information about the situation.

The concurrent use of multiple UAVs within a specific geographic area expands these possibilities. Therefore, a design issue is how to take advantage of UAVs as sensor platforms beyond a "soda straw" view, for an enhancement of the operator's or commander's perspective, allowing the

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integration of considerable information spread over space and time with other potentially meaningful knowledge. One possibility is that UAVs/UCAVs, in concert with other aircraft or satellites, could provide many scalable vantage points on demand. These vantage points could be summed into a dynamic virtual representation of the theater of interest by integration with existing three-dimensional databases of the area. Ground-based computers could provide storage, recall, and comparison of the situation from any desired location. Intranet advisories to operators could provide further up-to-date intelligence from other sources.

In combination, then, UAV/UCAV operators theoretically could have the situation awareness of a commander combined with the capability of an on-screen pilot. To achieve this goal, specific human factors issues to be considered include the level of detail needed, zooming capability, and choice of perspective.

Detecting targets. Operator vigilance is limited, although a number of factors influence effective duration (Mackworth, 1950; Matthews & Holley, 1993; Warm, Dember, & Hancock, 1996). On-board systems such as automatic target recognition systems can provide major benefits in UAV applications by tirelessly and exhaustively searching areas of interest without demanding constant operator attention. To accomplish this, UAVs can be programmed to automatically fly continuous systematic search patterns, allowing target recognition systems to identify potential targets to operators on a case-by-case basis.

On-board systems with rudimentary first filters of target characteristics can offer likely nominees while eliminating the vast majority of suspected false candidates. Once a suspected target is nominated by the target recognition system, human perception and pattern recognition can be brought to bear for refined target detection. Ground-based computers can electronically tag suspected targets, highlighting them for added attention and verification by the operator or by other surveillance specialists. Moreover, ground-based computers could add congruent graphical overlays from other sensors and databases to enhance the signal-to-noise ratio. Further possibilities include the generation of 3-D or even the 3-D cancellation of certain known nontarget information to enhance or make salient information pop out of a background (similar to noise-canceling headsets).

Designing for training and teaming. An additional feature of UAVs/UCAVs is that the interface, when detached from the airborne vehicle, may be used for embedded training that enables operators to practice on their actual interface. However, this opportunity opens the possibility that operators may fail to distinguish between virtual and real situations, particularly when called on to launch lethal weapons. Therefore, to obviate error, training conditions need to be clearly distinguishable.

A further issue in training is how teams might be fully utilized to control UAVs/UCAVs and the special considerations posed when automated systems are members of such teams. Unlike fighter cockpits, UCAVs invite more crewmembers. Accordingly, decisions need to focus on communication routing and information parsing. Massive amounts of UAV/UCAV downlinked information can be available to others via parallel networking, and operators will want to use this knowledge. Such information could best be used when shared with team members, but research is needed to further address which data are most useful for which team members and how classified information can retain its security level. Finally, there is a need to examine whether the formation of special "tiger teams" to deal with unexpected difficulties will enhance productivity.

Implementing the Design Recommendations

The recommendations we have presented suggest that a great deal of research and information relevant to the design of UAVs/UCAVs is already available. It ranges from perceptual and cognitive insights to technological advances in aircraft, sensors, and communication systems. Human factors professionals, working with designers to filter the relevance of such information, will be able to place it into a functional context. Beyond this, much more empirical research is necessary to reach maturity in UAV/UCAV design.

A workable solution is operator-initiated, semiautomated flight, search, and attack routines, which overcome data communication delays.

Perhaps the area of interest with the highest return on investment is the evaluation of the UAV/UCAV interface. A standardized interface, if development of such an interface is possible, should work almost independently of the vehicle design. Thus, a standardized interface may be applied to new UAV designs or modification without significant change of the interface and the concomitant operator retraining.

In addition, various methods for training and evaluation – for example, through interaction in virtual reality – could use the actual interface itself, not just a simulated facility. Simulation techniques for mockups can be expensive, time consuming, and difficult to implement. Also, with mockups, programmers often have to make assumptions about dynamics, human behavior, and real circumstances that may not be entirely accurate, thereby blurring accurate prediction. However, because the interface could be the same for simulated and actual UAV/UCAV control, there should be fewer assumptions in the design, and after successful evaluation, the design could be implemented directly. Clearly, there

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are many opportunities with a standardized interface for efficient use of resources without resorting to extensive computer prototype redesigns: in the design stages, in the training of operators, and in the rapid implementation of changes or modifications.

At first blush, human interaction with UAVs might seem a very specialist area confined largely to advanced military applications. But we submit that this is not so. Indeed, as digital technologies present the opportunities for remote control of a vast spectrum of processes, the concerns and design recommendations we raise here will assume an ever-growing importance in many other application areas.

Unmanned or remote-piloted vehicles have proven to be a valuable technology for a wide variety of applications, ranging from military and rescue operations to hazard material handling. As technological systems continue to advance beyond the need for actual physical presence, likewise the boundaries and limits set by Mother Nature are no longer constraining. Therefore, certain missions and tasks that would have likely placed human beings in harm's way now can be accomplished safely and efficiently with UAV and other remotely controlled vehicles.

For example, UAVs can provide significant contributions to various missions involving emergency response operations. Remote vehicles are used in police operations such as bomb removal or hostage situations, in fire operations for searches in burning buildings, and in naval operations for the rescue and retrieval of personnel trapped in deep underwater environments. In addition, they have been and will be used in a wide range of extreme environments where the limits of human capabilities are exceeded. For example, the NASA Mars Land Rover provided valuable information that would have been otherwise unattainable, and undeniably future space exploration will depend in large part on the use of remote vehicles.

In addition, consider another example: human interaction with nanomachines. One might envisage a medical application that necessitates the injection and action of multiple entities designed to clear plaque from arteries. Although much of this process will be preprogrammed, there will still be the need for a physician/operator to monitor the activity and to provide ongoing regulation, especially in the case of unexpected circumstances. The environment of operation and vehicle dynamics may be radically different, but the fundamental interface will contain any number of convergent commonalties (see Hancock, 1996). Thus, design recommendations can – and indeed should – transfer across domains, and it may well be then that the specific emergent properties of the interface can map to the specific domain at hand (see Flach, Hancock, Caird, & Vicente, 1995) to produce seamless human-machine interaction.

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Mustapha Mouloua is associate professor of psychology, director of the Center for Applied Human Factors in Aviation, and associate director of the Center of Advanced Transportation Simulation Systems at the University of Central Florida, Department of Psychology, P.O. Box 1390, Orlando, FL 32816-1390, mouloua@pegasus.cc.ucf.edu. His research interests include automation and human performance, pilot interaction with alerting systems, simulation and training, and older driver and pilot performance. Richard Gilson is professor of psychology and associate director of the Center for Applied Human Factors in Aviation at the University of Central Florida. His research interests include human interaction with alarm/warning systems, UAV design guidelines, adaptive controls and systems design, synthetic speech, and tactile display systems. Peter Hancock is Provost Distinguished Research Professor in the Department of Psychology and the Institute for Simulation and Training, and associate director of the Center for Applied Human Factors in Aviation at the University of Central Florida. His current experimental work focuses on operator capabilities in extremes of stress, workload, and fatigue.