Chapter 7

Human Systems[9] and Enabling Technologies

7.1 Role of the Human in Unmanned Aircraft Operations

The role of the pilot in traditional aircraft is fundamentally to "aviate, navigate, communicate, and operate." That is, the pilot is responsible for maintaining the aircraft thrust and attitude to remain in flight or transition to takeoff and land, directing the aircraft on the intended path to get to the desired destination, communicating his intentions and receiving information from others, and performing actions necessary to maintain the subsystems in the appropriate state. Some people have tended to lessen the importance of human operators with respect to UAVs because many, if not most, of the functions will be automated. Several considerations indicate that rather than being reduced in importance, the human and the design of systems for human use are every bit as important, perhaps more important, with automation. Among the arguments supporting this contention are the following:

- No one can anticipate all events that may occur during flight. Malfunctions, retasking, enemy actions and countermeasures, intrusions by friendly forces, and other events may call for mission replanning or other intervention by the controller.

- The human may have a limited time to respond. Unless situation awareness has been maintained, the ability to make the appropriate response in the time available could be compromised. Moreover, the operator will be missing many of the cues present in manned aircraft.

- Automated systems customarily handle the easy tasks, leaving the more difficult ones for the human.

- Experience with other automated systems (such as commercial aviation, nuclear power plants, oil refineries, and other endeavors) indicates that a human operator is still required to make automation effective, although the nature and frequency of the tasks required to meet the objectives may differ.

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[9] Some definitions are in order for clarity:
Human Systems - The elements of a system, including airborne and ground hardware, software, environmental control, and procedures for which design should consider human characteristics such as workplaces, communications systems, environmental control, maintainability features, personnel selection processes, training, etc.
Human Factors (also Human Factors Engineering) - The multidisciplinary vocation or field dedicated to discovering, understanding, and applying information about human characteristics, including strengths and weaknesses, to the design of a system. May include psychologists, physicians, physiologists, anthropologists, sociologists, engineers, and mathematicians. Involves physical size and strength, motivational factors, effects on emotion, etc.
Human System Interfaces - Those facets of a system with which the human directly interacts, such as displays and controls, seating, protective garments, etc.

- Inevitably, the human is still responsible for the successful accomplishment of the mission.

In short, the human is not replaced by automation but is freed from simple and boring tasks to accomplish those functions most suited to human intellect.

UAVs now in operation or in development have few similarities in the allocation of tasks to the human and the degree of autonomy allocated to the automatic systems. The DarkStar program philosophy is to automate everything from taxi through the entire mission. Predator requires manual landings and takeoffs. Some systems were designed to require a trained pilot; others made the assumption that automation would enable a relatively untrained person to operate the system, with analogies to a truck that any soldier could operate. These decisions were based on the assumptions of designers and other decision makers.

There are many good reasons automation should be implemented. Elimination of the human from an important role in UAV operation is not one of them. The human has many capabilities that are unmatched by any automatic system currently foreseen. Automation will not eliminate human error but will relocate it to preflight activities and the remote human operator position.

The reliability of digital systems is uncertain in benign environments, let alone in a war in which an intelligent enemy is trying to thwart the mission. Although failure mode and effects analyses can be conducted, they are impossible to perform on multiple failures because the number of possible events (and combinations) rapidly becomes prohibitive. As mission complexity increases to include combat missions, flying mixed fleets, and multiple UAVs the potential for automation error grows. The human's flexibility and capability for inductive reasoning are desirable attributes that justify the retention of a significant supervisory and intervention capability during UAV operations for the foreseeable future.

For the reasons stated above, the study group concluded that trained and proficient pilots should man the mission control elements and have the capability to intervene in mission and flight operation. This approach should be reviewed as experience in automated flight/mission operations is gained.

Table 7-1 lists several categories of human-machine interaction. Too often, the assumption is made that everything that can be automated should be fully automated to reduce human workload and error. Little emphasis is placed on making carefully considered decisions based on well-defined criteria and data to establish the degree of automation as shown in the table, function-by-function. In the UAV aircraft programs reviewed during this study, there was little evidence that human factors specialists had participated substantially in the design phase of any of these programs.

Table 7-1. *Categories of Human-Machine Interaction*

Category	*Description*
Manual	Unaided manual activity as in assembly, maintenance, servicing, or in operational control of a vehicle or system.
Augmented	Amplification of human sensory or motor capabilities with powered assists, sensing devices, etc.
Tele-operated	Use of remotely controlled sensors and actuators allowing the human presence to be removed from the work site, e.g., remote manipulator systems, tele-operators, tele-factors, etc.
Supervised	Replacement of direct manual control or tele-operated control of system operation with computer directed functions as though maintaining humans in supervisory control.
Independent	Self-actuating, self-healing, self-learning independent operations dependent upon automation and artificial intelligence and minimizing the requirement for direct human intervention.

7.2 Human Systems Technical Issues

A number of technical issues are critical to future UAV operations. These issues must be addressed at the technology base level, as well as applying available mature technology at the UAV design level.

Allocation of Functions. Assignment of appropriate roles and functions between the human and automated components of the system is vital for successful design. The human, the software, and the hardware integrate to become one system and must interact effectively if missions are to be accomplished with the greatest efficiency and lowest cost. Criteria based on factors such as probable success, response time available, cost, and the status of technology should be established. Analyses of the relative strengths and weaknesses of alternatives can establish a baseline. For example, under normal mission circumstances authorization to release a lethal weapon may be reserved for the human. For ballistic missile intercept during the boost phase, it may be decided that the automatic system has the authority due to time constraints and the inability of the human to respond in time for a successful intercept.

This baseline can be tested in several different types of simulations, including computer modeling and human-in-the-loop, to validate or define deficiencies. The DARO/DARPA Warbreaker program has used this process and serves as a useful demonstration of a simulation-based design process (see Simulation section below). A program should be established to formalize a rational approach to guide function allocation at the earliest possible phase of concept definition. This program is anticipated to be a process for defining meaningful and useful criteria, as well as establishing a baseline for simulation to validate and support redesign.

Simulation. Simulation has many important roles in the development and introduction of UAVs to the Air Force:

- Development Tool - UAV design, crew station (mission control element) design, knowledge base development and testing, reasoning design, etc.
- Effectiveness Analysis - Utility, effectiveness, and survivability analysis for single flights, multi-UAV missions, mixed manned-unmanned aircraft missions, engagement, and campaigns.
- Training and Proficiency - Normal and emergency conditions simulation as well as response analysis, perhaps as an integral element of the mission control element.

It is important to recognize the differences as well as the similarities and synergisms between these various applications of simulation.

Most engineering disciplines rely heavily on testing during development to assure designs are acceptable and/or to optimize design. For human system design, simulation is analogous to wind tunnels for aerodynamicists or structural tests for structural designers. Human-in-the-loop simulation has been used in crew station development for many years. Simulation has been applied primarily to assessing handling qualities, display and control concepts, and crew station configuration. For piloted vehicles, concepts have involved tasks that were largely evolutionary. Although experiments conducted have been mostly part task, full mission simulation was used late in programs for demonstrations and/or for training prior to first flight.

While highly automated UAVs impose revolutionary changes on the nature of the crew tasks, effective use of simulation can help address key front-end human system issues, such as the role of the human, workload and staffing, display and control concepts, and general problems of crew station layout as well as concept of operations, command and control, etc. Several recent developments make this feasible, including:

- Rapid prototyping capabilities in which software can be in hand or quickly developed to represent and drive representations of many real world events at a relatively low cost.
- The development of Distributed Interactive Simulation (DIS) which allows many players at different sites to participate in many different scenarios involving HITL in both offensive and defensive roles.
- The availability of many already developed software programs for maps, weather, terrain, and other elements of scenarios generated for training simulations including battle management training.

The effectiveness of the human is vital to system performance. Human-centered design is worth the effort and cost. Simulation has great value in developing and validating human system design.

Its application early in the process can make important contributions to design. Although some may believe its costs are prohibitive early in design, actual cost savings may be realized by early identification of system deficiencies, resulting in fewer engineering changes (a notorious cost driver) and lowered operational costs.

The advent of battle management simulation and DIS offers the opportunity to apply simulation to analyze and experience how a new concept could affect the outcome of battle. These effectiveness simulations are crucial to assess the cost-benefits for UAV and UAV- manned air forces and to determine the best mixes.

Human Performance Measurement. Decisions about the human role in systems should be data driven, not assumptions driven. Simulations are valuable even if only subjective opinions or observations are obtained. They can be far more valuable if data are obtained based on actual performance of the human. Performance on many psychomotor tasks can be directly measured. Since many of the tasks in automated systems will be decisions, often open-ended, it might be assumed that measurement of performance on these tasks against a rigorous standard may be impossible or at least very difficult. This may be true for some tasks particularly in the dynamic air-to-air arena.

It is believed, however, that suitable measurement methods may be devised if sufficient attention is dedicated to the task. Aircraft handling qualities, for example, consist of a number of variables that have many interactions. For years, assessments were left to vague test pilot descriptions. In the 1960s, Cooper and Harper developed a rating scale to introduce some rigor. This scale not only provided a better assessment tool but also facilitated research to foster a better understanding of system requirements. It is believed such rating scales could be developed to assist measurement for many if not all complex and/or subtle human decision making activities. Such measurement would help define human system design requirements, assuring that requirements are met and that effective training programs are developed and applied.

While the study group has strong reservations about the feasibility of totally replacing the human for many missions in the near-term, there is no denying the increasing potential for AI. The development of valid and reliable human performance measures would also further the development of AI models and provide assistance in deciding which tasks can be adequately performed by automated systems.

Command, Control, Communications, and Intelligence (C^3I). Successful utilization of UAVs requires their integration with other Air Force operations, including the associated C^3I system. Positive control of UAVs is required to assure conflict with other friendly aircraft is avoided. These concerns become increasingly serious as the role of UAVs grows into combat missions possibly involving mixed fleets and multiple UAVs. Mission planning systems are vital for mission success, and this technology needs to be enhanced if UAVs are to operate with needed C^3I connectivity. Architecture concepts such as "layered cueing" and "collaborative operations" show promise for maximizing the military effectiveness of UAVs. Complex scenario-based simulations will be a powerful tool in developing and testing such C^3I concepts.

Vulnerability - A Human Systems Perspective. The three components of the system—the vehicle, the ground station, and the data linkÑare all vulnerable to attack. Direct attack may be made against the vehicle or the ground station. Misinformation may be introduced into the onboard systems through decoys and/or camouflage. Data links may be broken or noise introduced. If the operators' situational picture or ability to intervene is too limited, they will be restricted in response alternatives. Perhaps most important is the potential inability of the human to quickly process, interpret, and appropriately distribute all of the relevant information to the warfighters. This inability should be carefully assessed and investment to overcome shortfalls should receive a high priority. The Air Force is also encouraged to assure that system vulnerabilities are identified and addressed in the ongoing development of these systems so that their effectiveness is not unnecessarily compromised by enemy action.

7.3 Human Systems Nontechnical Issues

Attention Given to Human Systems Issues. The experience of a number of study group members is that developers generally try to give the customer what is sought within the constraints imposed. Air Force directives have historically imposed a requirement for a human factors engineering effort for major programs. Too often this requirement has been compromised, either in the interest of cost savings or because firm contractual performance requirements for human system performance were not specified. A June 1994 Air Force Inspector General audit of compliance with DoD 5000.2 (Human Systems Integration) found that only 3 of 110 programs reviewed were in compliance. This suggests that the Air Force seldom receives a well-designed human systems interface.

Where performance criteria have been established, such as in handling qualities, great effort is dedicated to assuring the requirements are met. The study group believes that lack of specified performance data and rigorous adherence to implementing a comprehensive human factors program and test plan have significantly reduced the contributions of the discipline and thus operational effectiveness. Moreover, these failures have resulted in added training time to meet operational performance standards and increased maintenance and logistical costs of fielded systems.

In some respects, this is a more serious problem for UAVs than for conventional manned aircraft. If appropriate displays are not provided, the operator will be denied adequate situation awareness, as the sensory-perceptual cues provided by direct vision, motion, or sound may not be available. Even if some of these cues are provided, the remote operator will likely be restricted in other ways and may suffer from time lags. If the potential need to intervene is not recognized and designed into a UAV, the remote operator will not be able to take action unless he or she is ingenious enough to invent a "workaround" (e.g., waypoint manipulation). Situation awareness will be difficult to maintain if the crew suffers from boredom, "automation complacency," overconfidence, or if the crew is replaced during the mission to avoid fatigue.

Manpower, Personnel, and Training (MPT). MPT issues have been largely sidestepped by the ACTD programs. Contractors have been responsible for providing operators and support personnel during the developmental phases. But in future operations, military manning will be used. For the relatively benign reconnaissance missions, the resulting problems are probably manageable. For future missions, particularly those that involve mixed fleets, combat applications, and lethal weapon release the responsibility, skill, aptitude, and training requirements may be quite different. Unless this difference is addressed during acquisition, serious disruption could result.

A number of important issues must be addressed including selection criteria, rank of the differing personnel positions, staffing, and training requirements and processes. Ideally, MPT program development should be initiated during aircraft system development to assure a timely and effective employment of the system. The rapid acceptance and employment of the Predator UAV has highlighted some personnel and training problems. Attention should be given to finding methods to establish the MPT base to facilitate the transition of ACTD programs to fielded systems.

7.4 Technology Requirements

The most pressing needs to foster effective human systems for UAVs are *process* improvements such as the following:

- Increased emphasis on human systems issues, beginning with the concept development phase with specific, measurable human performance requirements appropriately weighted and included in contracts.

- Development and implementation of effective and reliable methods, including analyses and simulation, to support decisionmaking about the role of the human, function allocation, and degree of autonomy assigned to automated systems.

- Definition and implementation of an improved transition process to facilitate rapid and effective deployment of systems developed using the ACTD approach.

- Identification of problems during the ACTD so they can be eliminated in production programs.   Many accidents and incidents have occurred, however there seems to be no central repository to organize the data and/or to develop lessons learned. Such a process should be implemented involving all of the Services and developers. (Much of the UAV information obtained during this study was anecdotal).

Desirable technology improvements involve a number of areas:

- Digital technology and sensor developments have made many relatively new display and control concepts possible for manned aircraft such as helmet mounted displays, low-light level television, pull-down menus, and “look and shoot” systems. While human systems integration (HSI) issues still need to be addressed with regard to these media—such as improving resolution or reducing weight—most of this technology can be readily adapted as required to UAVs. A new technology that may have applications for UAV requirements is Virtual Presence. Considerable effort has already been devoted to developing this technology, but its value has not been convincingly demonstrated and many technical problems remain if it is to be used in real-world applications.

- No matter what display medium is used, there is a continuing problem with developing formats that will enable the operator to quickly assimilate and integrate large quantities of sometimes disparate information to achieve full situation awareness and to make rapid, accurate decisions. Significant support is required to develop display principles to facilitate the invention of such formats.

- An improved understanding of human information processing and decision making processes and weaknesses will facilitate better display formatting, training, and development of decision aids. This area, known as cognitive science, is closely related to artificial intelligence (AI) and should be supported aggressively.

- Development of metrics for assessing human performance in complex tasks would greatly benefit not only systems development but also training.

- The importance of simulation suggests that developments to increase its fidelity and reduce costs should be supported.

- A continuing need exists to process and transmit large amounts of data. Although this is not a problem unique to human systems, advances in this area would undoubtedly benefit UAV human systems applications.

- AI offers promise for developing decision aids and assuming first-order responsibility for many low-level, rule-based decisions. It is already being applied in a number of areas; additional advances will broaden its applicability.

- C^3I is a primary concern, particularly as mixed fleets involving many UAVs become operational. Architectures must be developed that will enable the required information to be available to anyone who needs it without delay. Human systems issues abound in this area also.

- UAVs will be vulnerable to direct attack on the vehicle, to the introduction of "misinformation" into the system by various methods, and to attack of the control element. Vulnerabilities should be systematically defined and appropriate precautions taken during UAV human systems design and operation.

7.5 Human Systems Summary

The Air Force should take action to identify appropriate processes that emphasize human-systems interaction issues and performance criteria to ensure critical functions are specified as contractually obligatory. One approach might be to organize a team of Air Force operational and laboratory specialists with industry representatives during the pre-proposal phase to define key automation and human systems issues and measures.

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