Uninhabited Military Vehicles: What Is the Role of the Operators?

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SUMMARY

The role the operator in future uninhabited military vehicles (UMVs) will be quite different from that of the operators of current vehicles such as the Predator. Future UMVs will contain associate systems that will incorporate varying levels of autonomy and dynamic function allocation as basic operating principles. These principles will enable the UMV operator and the associate to form a team consisting of two crewmembers – one human and one electronic (although teams of multiple humans and multiple electronic crewmembers are certainly possible).

1.0 INTRODUCTION

Uninhabited aerial vehicles (UAVs) played a very important role in the latest events in Afghanistan. They served to give the command and control authorities continuous pictures of possible targets and also enabled a dramatic reduction in the time from which the target was identified until it could be engaged. Not only have uninhabited vehicles played a significant role in the air, but they also have performed important tasks on the land and in the sea (Figure 1). Taken as a whole, they are called Uninhabited Military Vehicles.

Figure 1: Examples of an Uninhabited Aerial Vehicle, Uninhabited Ground Vehicle, and Uninhabited Undersea Vehicle.

A number of NATO countries are now using UMVs to augment their manned forces, especially in performing tasks that are dull, dirty, or dangerous. Force augmentation issues relevant to the human operator exist on several levels, including individual UMV control station design, vehicle interoperability, and integration of UMVs with manned systems. Human interface issues associated with individual UMV control station design

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include guaranteeing appropriate situational awareness for the task, minimizing adverse effects of lengthy system time delays, establishing an optimum ratio of operators to vehicles, incorporating flexible levels of autonomy (manual through semi-autonomous to fully automatic) and providing effective information presentation and control strategies. UMV interoperability requires development of a standard set of control station design specifications and procedures to cover the range of potential UMV operators and applications across military services and countries. Finally, for UMVs to be successful, they must be fully integrated with manned systems so as to enhance the strength of the overall force. Human factors considerations in this area include how manned systems should best collaborate with UMVs, deconfliction concerns, operation with semiautonomous systems, and command and control issues. The essence of this paragraph can be summarized by the following statement – What is the proper role for the operator of UMVs?

The operators' stations for the U.S. Air Force's Predator and Global Hawk UAVs are mounted in vans with the operator sitting at command and control stations. In contrast, the operator station for the U.S. Marine Corps's Dragon Eye UAV is the size of a small suitcase which makes it easily transportable (Figure 2).

Figure 2: Predator Operator Station (left) and Dragon Eye Operator Station (right).

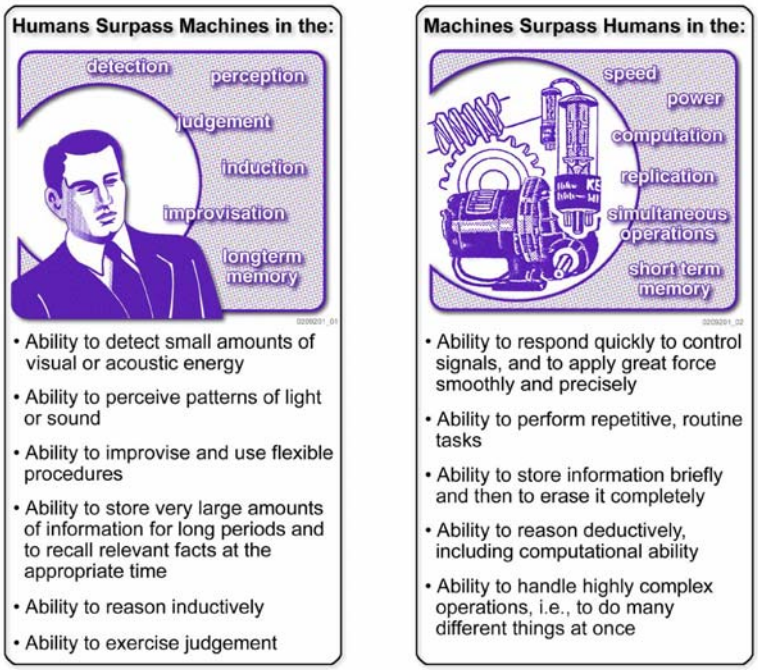
These examples serve to illustrate the wide range of operator console designs. These and other aspects of operators' consoles were discussed in a recent conference (AUVSI, 2002). One recurring theme was a strong desire to move away from teleoperation of the UMVs and progress towards a combination of semiautonomous and fully autonomous operation of these vehicles – regardless of the type of operator console. In order to achieve this goal, a significant amount of automation will be required, especially, when coupled with the desire, in the case of UAVs, to move from situation where a number of operators control one vehicle to one operator controlling a number of vehicles. A key factor in having the operator interact with the vehicles at different levels of automation depends upon what philosophy is used in building the automation.

2.0 PHILOSOPHY OF AUTOMATION

Early Automation Philosophy. "... It appears that the best arrangement is one in which inanimate components work as a team with human operators to provide safe and accurate control and guidance" (Draper, Whitaker, and Young, 1964, p.5). The key concept in this philosophy is that the operator and machine form a team. The active participation of the operator, a vital component of the teaming arrangement, was a key philosophy of the Air Force Flight Dynamics Laboratory. The essence is that one cannot expect operators, in an emergency, to cope with a problem which they have not been following. By monitoring only and not performing, they will fail to notice important information and, consequently, will not react properly. Automation is desirable, and should exist, not as a conflict, but as an aid, an adjunct to the operator.

For several years (early to mid sixties) the Air Force research and development community pursued a technically sound and logical solution to the pilot/autopilot integration problem. The concept was first evaluated by the Germans during World War II and then introduced in the U.S. with names such as “pilot control force steering” and “force wheel steering”. The system linked pilots to the control surfaces through the autopilot by placing electronic force sensors in the control column and rudder pedals of the aircraft. The control pressures applied by pilots were converted to electronic signals which were sent to the autopilot computer where they were summed with the commands being provided by the basic flight director system to, in turn and accordingly, move the control surfaces. This system provided the means for the pilot, in an emergency or otherwise, to assume control of the aircraft smoothly and in a conventional fashion without having to uncouple or disengage the autopilot. To a certain extent, this concept has been overcome by the introduction of computer controlled “fly-by-wire” flight control systems in which the pilot provides inputs to the flight control computer which sums them with inputs from the aircraft’s attitude sensors and manipulates the control surfaces to provide the required flight vector. However, this does not provide the pilot with the degree of autopilot control visualized in the original “force wheel steering” concept.

Today’s Automation Philosophy. Despite the work in the early 60’s, the team arrangement design philosophy has rarely, if ever, been carried out in implementation of automation in today’s aircraft systems. In order to create teamwork, the designer must examine the roles of human and machine in the system (Gagne, 1962). One of the key components in this process is functional allocation between the human and the machine. Ideally this division of responsibilities between the two “teammembers” occurs by taking into account the strengths and weaknesses, workload limitations, etc., of each and then assigning roles accordingly. The idea of function allocation has been around since the 1950s (Fitts, 1951), Figure 3.



Humans Surpass Machines in the:

- Ability to detect small amounts of visual or acoustic energy
- Ability to perceive patterns of light or sound
- Ability to improvise and use flexible procedures
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time
- Ability to reason inductively
- Ability to exercise judgement

Machines Surpass Humans in the:

- Ability to respond quickly to control signals, and to apply great force smoothly and precisely
- Ability to perform repetitive, routine tasks
- Ability to store information briefly and then to erase it completely
- Ability to reason deductively, including computational ability
- Ability to handle highly complex operations, i.e., to do many different things at once

Figure 3: Capabilities of Humans and Machines (from Hancock and Scallen, 1996, pp. 25-26).

However, in actual system design, that is not how the process usually occurs; functional allocation is largely a myth and rarely applied in system design and development (Fuld, 1993). What basically happens is that everything possible is automated, and the human operator gets left with doing what the machine cannot do, or fails to do, because of a malfunction.

"Somewhat paradoxically, machines that can do more, and do it faster, provide the basis for systems that are increasingly demanding of the human operator, particularly in terms of cognitive requirements" (Howell, 1993, p.235). The demand comes about because the operator is "not in the loop", but rather is a bystander – so long as the system functions normally. When emergencies occur, the operator is expected to take control of the system, diagnose the problem, and bring the system back to its nominal state. However, as was discussed previously, a design driver should be to make the operator an integral part of an automated system and not just an observer.

Future Automation Philosophy. It is interesting to note that over thirty years after the teamwork automation philosophy was espoused, it has once again come to the forefront. The current term used is Human-Centered Automation (Billings, 1991), which starts with the operator as the heart of the system and then incorporates the automation. From the operators' point of view automation is designed as it should be – to augment or assist operators in areas where they show limitations (Wickens, 1992). Although this automation philosophy is consistent with earlier years, the implementation is much more difficult because many more avionics systems are contained aboard modern combat aircraft. In the case of the UAV, the avionics will be partly contained in the flying platform and partly incorporated into the operator's console, whether airborne or ground based. On the other hand, because of present day capabilities in computers and software, the resulting product can be much closer to a true team. Operator-machine relationships are being created which emulate those occurring between two human crewmembers – mutual support and assistance. A major component in achieving this mutual support and assistance is through software entitled associate systems. "Associate systems are computer-based aiding systems that are intended to operate as an associate to the human user". (Geddes, 1997, p.221) Following from his definition, Geddes goes on to list three very important rules for associate systems and their relationship with the human operator.

- Mixed Initiative – both the human operator and decision aid can take action.
- Bounded Discretion – the human operator is in charge.
- Domain Competency – the decision aid has broad competency, but may have less expertise than the human operator.

Because of the mixed initiative aspects of an associate system, function allocation has to be looked at an entirely new light. As mentioned in a previous section, the idea of function allocation has been around since the 1950s (Figure 3) and had as its basic premise that the role of operator and the machine (computer) would stay relatively constant during the operation of the system. However, this premise does not hold for modern systems since they contain associates systems which can have varying levels of automation and, therefore, static function allocation is no longer applicable (Hancock & Scallen, 1996). Rather, *dynamic* function allocation is a key feature of associate systems with varying levels of automation.

Another way to understand how the operator and electronic crewmember will interact is to show how the relationship between the human and the machine changes as a function of organizational structure. Taylor, (1993) illustrates this changing relationship in Figure 4.

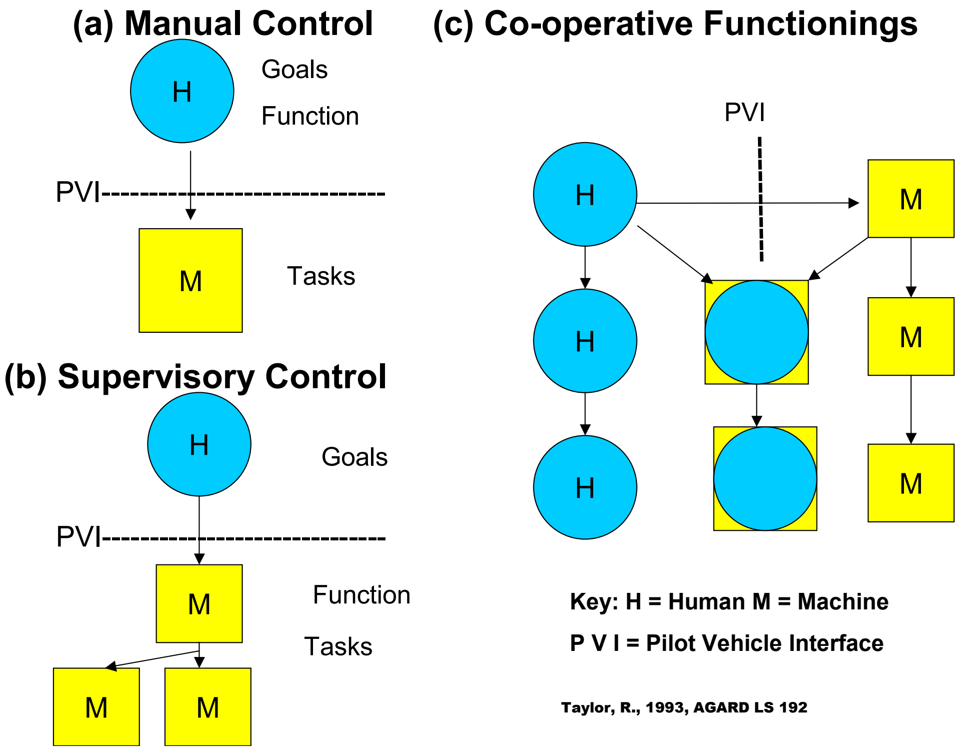


Figure 4: Systems Authority Concepts (from Taylor, 1993, pp. 2-17).

This figure shows a summarization of different control philosophies, (specifically manual, supervisory, and co-operative) depicting the various interactions between the operator and the automation. The portion of the chart labeled Co-operative Functionings indicates how the operator and automation would work together in an associate system. In manual control [Figure 4 (a)], the human specifies the goals and functions to be accomplished and the machine carries out the tasks. In the next level, supervisory control [Figure 4 (b)], the human still specifies the goals, but the machine carries out both the tasks and functions. In the co-operative functionings (associate system), [Figure 4 (c)], the human and machine interact at all levels, and *either* can perform the goals, functions and tasks. It is through this dynamic sharing of authority that the operator and the associative can begin to operate as a team – an operator and a type of electronic crewmember (EC).

Human and Electronic Crewmembers are a Team. In order to function effectively, the operator and the EC must work together as a close-knit team. The ideal relationship within this team can be likened to that of good managers and their staff. The manager must be sufficiently aware of the work of the staff to be able to predict problems, but not so involved that their work is hindered. The manager must be involved enough to be able to offer assistance when called upon, and yet must not micromanage and risk becoming overloaded and prevented from making strategic decisions. The good manager will know which staff members can be relied on to act without supervision, just as operators will form opinions of which of the systems do not require frequent attention. As in the conventional management situation, the UMV system must maintain a knife-edge balance of providing sufficient data exchange without swamping the system manager, and achieving sufficient autonomy without alienating the manager. But to function effectively as a team, both parties must be able to trust the other. Since it is not clear how the EC could or could not trust the human operator, the crucial aspect of teambuilding is that the operator must be able to trust the EC.

3.0 TRUST GUIDELINES

Guidelines for building up trust within the operator-EC Team have been previously presented (Emerson and Reising, 1990; Reising, Emerson, & Munns, 1993). Two of the most important guidelines were the establishment of Prime Directives and Levels of Autonomy. Prime Directives are overall governing rules which bound the behavior of the EC so that the operator does not experience any surprises. Levels of autonomy also bound the behavior of the EC by limiting its decision authority to a level specified by the operator. These and other guidelines are discussed in more detail in the following sections.

3.1 Define the EC's Prime Directives

One essential feature of a successful team is trust in the other partner. This, in turn, implies that the partner behaves in a rational and reliable manner. One partner cannot initiate actions which, even though they are logical to it, appear to be illogical to the other. In order to avoid arbitrary actions, there must be some overall governing rules which provide the logical structure under which both members operate. As examples of explicitly stated governing rules, consider the three laws of robotics (Asimov, 1950).

1. A robot may not harm a human being, or through inaction, allow a human being to come to harm.
2. A robot must obey the orders given to it by human beings except where such orders would conflict with the first law.
3. A robot must protect its own existence as long as such protection does not conflict with the first or second law.

These rules provide the guidance required to allow the robot to perform its job in a reasonable and consistent manner. If the word "operator" is substituted for the word "human" in the above example, a possible basis for governing the behavior of the EC exists. The three laws stated above are only examples of governing rules, and they would require major changes to be applicable in a military setting. For instance, without modification, the ideal robot would not allow the operators to function within a combat zone, knowing that they were deliberately going in harm's way.

In the 1980s the US Air Force along with the Defense Advanced Research Projects Agency undertook the task of building such a team. The project was called the Pilot's Associate Program. This Program created a number of governing rules called Design Commandments which were used to bound the behavior of the electronic crewmember so that predictable behavior would result. One of these rules – "The pilot's associate is required to monitor the pilot, not the other way around." – uses the strengths of automation in that it never get bored or fatigued in monitoring the behavior of the pilot.

In the 1990s, the U.S. Army conducted a follow on program to the U.S. Air Force effort called the Rotorcraft Pilot's Associate (RPA). Many of the overall design philosophies were carried over from the Pilot's Associate Program, including a series of prime directives. Two examples showing the role of the associate are presented below:

- Monitors crew actions/reactions to predict information required for the situation.
- Presents information to crew, when needed, and in a form most easily understood.

Note that the first rule follows very closely from the Pilot's Associate rule of monitoring the pilot. The RPA Program also brought in the idea of the associate's trying to predict the crew's intention. The idea of using pilot intention as means of knowing the crew's state is contained in the rule "Understands Commanders Intent; Infers Pilot Intent and Plans Accordingly".

The point is that rules of this type provide the basis for consistent behavior for the EC and thereby provide a basis of trust for the operator. It is through this trust that an effective team can be built. Trust, however, is not acquired instantaneously; it must be built up gradually. Trust can be envisioned to develop in three stages. At first, trust is based on the predictability of individual behaviors. In the second stage, trust is based on dependability. "... Dependability may be thought of as a summary statistic of an accumulation of behavioral evidence, which expressed the extent to which a person can be relied upon." (Muir, 1987, p.532). In the third stage of trust, faith is the major component because one team member is willing to bet that the other member will be dependable in the future.

3.2 Specify the EC's Levels of Autonomy

Another means of establishing operator trust in the EC is to allow the operator to decide how much authority or levels of autonomy (LOA) to give the EC. "LOA defines a small set ('levels') of system configurations, each configuration specifying the degree of automation or autonomy (an 'operational relationship') at which each particular subfunction performs. The pilot sets or resets the LOA to a particular level as a consequence of mission planning, anticipated contingencies, or inflight needs" (Krobusek, Boys, & Palko, 1988, p. 124). One question that must be answered is how many levels of automation should be assigned to the associate? A number of researchers have examined this issue. The result is as many as 10 (Sheridan, 1980) and as few as 5 (Endsley, 1996). An associate with 5 levels of automation is shown in Figure 5. This model allows for complete autonomy for either the operator or the associate with three levels of authority sharing in between. In levels 3 and 4, AI is an abbreviation for Artificial Intelligence.

Level of Automation	**Human Role**	**System Role**
1. None	**Decide, Act**	**----------**
2. Decision Support	**Decide, Act**	**Suggest**
3. Consensual AI	**Concur**	**Decide, Act**
4. Monitored AI	**Veto**	**Decide, Act**
5. Full Automation	**---------**	**Decide, Act**

Figure 5: Levels of Control and Automation (from Endsley 1996, pp. 174).

Using these levels, the operators could establish a "contract" with the EC in the pre-mission phase. They could, through a dialogue at a computer workstation, define what autonomy they wish the EC to have as a function of flight phase and system function. As an example, weapon consent would always remain exclusively the operator's task, but reconfiguration of the UAVs flight control surfaces to get the best flight performance in the event of battle damage would be the exclusive task of the EC. One architecture (Figure 6) illustrating how contracts can be establish between the operator and the associate at various levels of autonomy is called the pilot authorization and control of tasks (PACT).

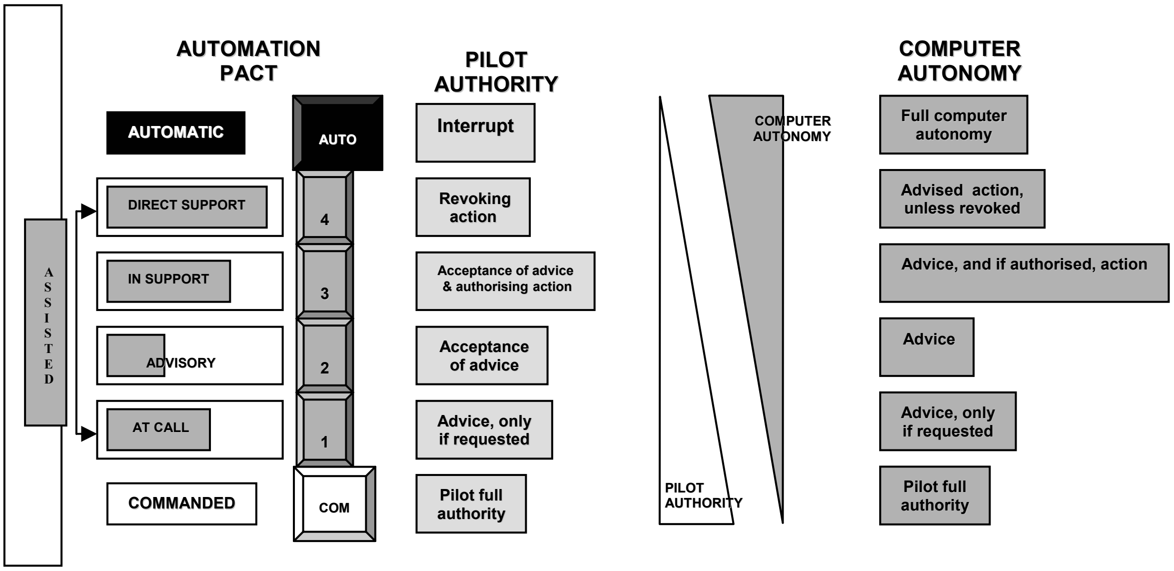


Figure 6: Pact Levels of Pilot Authority and Contractual Autonomy (from Taylor, Brown, and Dickson, 2002, p. 8).

"PACT is based on the idea of contractual autonomy. ... The contract defines the nature of the operational relationship between the pilot and the computer aiding during cooperative performance of functions and tasks. Autonomy is limited by set of contracts, or binding agreements, made between the pilot and the computer automation system governing and bounding the performance of tasks. Through PACT contracts, the pilot retains authority and executive control, while delegating responsibility for the performance of the tasks to the computer. " (Taylor, Brown, and Dickson, 2002, p. 8).

3.3 Conform to the Operator's Mental Model

The EC must not only be bounded in the overall authority it has, but also must appear to perform logically within those bounds. Mental models play an important part in the efficient operation of systems (Wickens, 1992). Since direct views of the inner workings of a system are often not possible, e.g., the flow of electrons inside the avionics system, displays are a major means of conveying information on the operation of a system. The closer the EC's display formats conform to the operators' mental model of the system, the more beneficial they will be. Operators form a mental picture of how a system should work (at a top level) and base their trust in the system according to how the system conforms to this picture or mental model. "A mental model is a representation formed by a user of a system and/or task, based on previous experience as well as current observation, which provides, (most if not all) of their subsequent system understanding and consequently dictates the level of task performance" (Wilson and Rutherford, 1989, p. 619).

Three ideas have been underlined in the above definition to stress its key aspects: representation, understanding and task performance. The operators' representation leads to their understanding of the system which in turn leads to their performance with the system. For example, if the operators' mental model of a fuel system pictures the flow valve lever in line with the flow when the fuel is moving and at right angles when the flow is shut off, then that is the way it should be portrayed. It is not important that the valves are electronic and do not have a flow valve handle to turn.

An example of a system not conforming to an operator's mental model is illustrated by the use of automation in modern commercial aircraft. If the automation is not carefully designed, keeping in mind how the operator will exercise supervisory control, problems can occur. One of the key issues is "automation surprises" experience by the pilots (Hughes, 1995). Since the operators are often in a supervisory control mode, they're not controlling aircraft directly, but rather their commands are carried out by the automation. The automation surprises arise because of the intervention of automation which "translates" their inputs. Often the operators do not know the reasons for this translation and are confused as to the exact task the automation is performing.

4.0 CONCLUSION

Future UMVs will contain associate systems that will incorporate varying levels of autonomy and dynamic function allocation as basic operating principles. These principles will enable the UMV operator and the associate to form a team consisting of two crewmembers – one human and one electronic. In order to function effectively, the operator and the EC must work together as a close-knit team. One essential feature of a successful team is trust in the other partner. Guidelines to create such trust include defining the EC's prime directives, specifying the EC's level of autonomy, and conforming the EC's functioning to the operator's mental model. By using these guidelines, a high-quality, trusting relationship can be achieved between the operator and the EC. This internal trust will, in turn, lead to an efficient and effective team.

5.0 REFERENCES

Asimov, I. (1950). I, Robot. New York: Fawcett.

Association of Unmanned Vehicle Systems International: Unmanned Systems in a New Era, AUVSI Second Annual Ground, Sea and Air Conference, February 12-14 2002, Washington, D.C.

Billings, C. (1991). Human Centered Automation (NASA Technical Memorandum 103885). Moffett Field, CA: Ames Research Center.

Draper, C.S., Whitaker, H.P., & Young, L.R. (1964, September). The Roles of Men and Instruments in Control and Guidance Systems for Spacecraft. Proceedings of the XVth International Astronautical Congress, Warsaw, Poland.

Emerson, T.J. and Reising, J.M. (1990). The Effect of an Artificially Intelligent Computer on the Cockpit Design Paradigm. In Proceedings of the Human – Electronic Crew: Is the Team Maturing? [pp. 1-5] (Tech. Report WL-TR-92-3078). Wright-Patterson Air Force Base, OH: Cockpit Integration Directorate.

Endsley, M.R. (1996). Automation and Situational Awareness. In Parasuraman, R. and Mouloua, M. (eds.) Automation and Human Performance: Theory and Applications (163-181). Mahwah, New Jersey: Earlbaum.

Fitts, (1951). Human Engineering for an Effective Air Navigation in Traffic Control System. Washington D.C.: National Research Council.

Fuld, R.B. (1993, January). The Fiction of Function Allocation. Ergonomics in Design, pp. 20-24.

Gagne, R.M. (1962) Psychological Principles in Systems Development. New York: Holt, Rinehart, & Winston.

Geddes, N. (1997). Associate Systems: A Framework for Human-Machine Cooperation. In Smith, M., Salvendy, G. and Koubek, R. (Eds.) Designing of Computing Systems: Social and Ergonomic Considerations. Amsterdam: Elesvier.

Hancock, P.A. and Scallen, S.F. (1996). The Future of Function Allocation. Ergonomics in Design, pp. 24-29.

Howell, W.C. (1993). Engineering Psychology in a Changing World. Annual Review of Psychology, 44, 231-263.

Hughes, D. (1995). Studies Highlight Automation ‘Surprises’. Aviation Week & Space Technology, February 6, 1995.

Krobusek, R.D., Boys, R.M. and Palko, K.D. (1988). Levels of Autonomy in a Tactical Electronic Crewmember. In Proceedings of The Human – Electronic Crew: Can They Work Together? [pp. 124-132] (Tech. Report WRDC-TR-89-7008). Wright-Patterson Air Force Base, OH: Cockpit Integration Directorate.

Muir, B.M. (1987). Trust between Humans and Machines, and the Design of Decision Aids. International Journal of Man-Machine Studies, 27, 527-539.

Reising, J.M., Emerson, T.J. and Munns, R.C., (1993). Automation in Military Aircraft. In Proceedings of HCI International ‘93: 5th International Conference of Human-Computer Interaction, Orlando, Florida, August.

Sheridan, T.B. (1980). Computer Control and Human Alienation. Technology Review, October, 61-73.

Taylor, R. (1993). Human Factors of Mission Planning Systems: Theory and Concepts. In AGARD LS-192 New Advances in Mission Planning and Rehearsal Systems, pp. 2-1 – 2-22.

Taylor, R., Brown, L and Dickson, B. (2002). From Safety Net to Augmented Cognition: Using Flexible Autonomy Levels for On-Line Cognitive Assistance and Automation. Paper No 27, NATO RTO Human Factors and Medicine Panel, Symposium on “Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures”, La Coruna, Spain, 15-17 April 2002.

Wickens, C. (1992). Engineering Psychology and Human Performance. (2nd ed.) New York: HarperCollins.

Wilson and Rutherford (1989). Mental Models: Theory and Application in Human Factors, Human Factors, pp. 617-634.