Towards a New Paradigm for Automation: Designing for Situation Awareness

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TOWARDS A NEW PARADIGM FOR AUTOMATION: DESIGNING FOR SITUATION AWARENESS

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Abstract: Automation is being implemented in a variety of systems in an effort to improve performance and overcome high operator workload. In examining accidents with automated systems, it becomes apparent that current automation approaches may underlie these problems by reducing operator situation awareness. Furthermore, evidence suggests that in many ways current automation approaches fail to achieve the desired reduction in workload, yet the prevailing approach to system design is still to automate to reduce workload. An alternate design approach is presented that focuses on enhancing situation awareness.

Keywords: automation, failure detection, human error, aircraft, human centered design

1. INTRODUCTION

For the past several decades automation has been heralded as a panacea for the ills of complex systems. Its goal has been to improve system reliability and performance by removing error prone humans from direct control and by aiding humans with difficult tasks. In an effort to improve system performance, some form of automation has become embedded in almost every type of system from process control to manufacturing systems, from aircraft to automotive systems.

1.1 Advantages of automation

In many cases, automation additions to systems have performed admirably, significantly improving system performance. For instance, Norman and Abbott (1988) show decreased crew-caused accident rates associated with aircraft containing higher levels of automation. Although this data may be highly confounded (with age of the aircraft for instance), improvements in system performance can be found with many specific automation implementations. The incidence of controlled flight into terrain accidents, for example, has significantly decreased since the introduction of ground proximity warning systems in transport aircraft (Billings, 1991).

1.2 Problems with automated systems

Despite the advantages of automated systems, significant problems remain in the integration of automated systems and the human operator. With many systems, automation has only been applied piece-meal, to tasks for which problems are identified and technological solutions available. This has been dubbed the technology-centered approach to automation. In addition to performing tasks not easily automated, the human operator usually remains in the system as a monitor to insure that the automated systems perform properly and to detect the occurrence of aberrant conditions.

Unfortunately, this places human operators into a role they are ill-suited for — that of monitor — and sets up a situation in which different *types* of errors are likely to occur. An increase in the complexity level of the system and, correspondingly, an increased propensity for catastrophic failures has been associated with the incorporation of automation (Wickens, 1992; Wiener, 1985). The occurrence of more frequent small errors in a non-automated system is replaced by an automated system with fewer large errors with significant consequences (Billings, 1988; Wiener, 1985).

The out-of-the-loop performance problem is a major issue associated with automation. Human operators acting as monitors have problems in detecting system errors and performing tasks manually in the event of automation failures (Billings, 1988; Wickens, 1992; Wiener and Curry, 1980). In addition, they have a more complex system to monitor. In a review of automation problems, Billings (1988) noted six major aircraft accidents that could be traced directly to failures to monitor automated system or the parameters controlled by the automated systems.

In addition to delays in detecting that a problem has occurred necessitating intervention, operators may require a significant period of time to develop a sufficient understanding of the state of the system to be able to act appropriately. This delay may prohibit operators from carrying out the very tasks they are there to perform or diminish the effectiveness of actions taken. In 1989, a US Air flight failed at take-off at LaGuardia Airport landing in the river and killing two passengers when an autothrottle was accidentally disarmed (National Transportation Safety Board, 1990). The time taken for the crew members to attempt to gain control of the aircraft without understanding the problem resulted in delaying the decision to abort the take-off until too late.

1.3 Impact on situation awareness

These highly reported problems with automated systems can be directly attributed to lower levels of operator *situation awareness* (SA) that can occur with automation approaches that place people in the role of passive monitor. Situation awareness, a person's mental model of the state of a dynamic system, is central to effective decision making and control, and is one of the most challenging portions of many operator's jobs. In a study of aircraft accidents involving major air carriers over a five year period, it was found that 88% of accidents citing human error could be attributed to problems with SA (Endsley, 1994). Hartel, et al. (1991) reported poor SA to be the leading causal factor in military aviation mishaps.

Situation awareness is formally defined as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (Endsley, 1988). The development of SA first involves perceiving critical data, (e.g. the state of flight parameters, system status, location of other aircraft and ground features, etc....) comprising Level 1 SA – *perception*. Shortcomings in perceiving the status of the automated system and the parameters it controls are classic problems with SA at this level.

Data perceived also must be integrated and compared to operational goals to provide an understanding of what it really means, forming Level 2 SA - *comprehension*. At the highest level, operators have a well developed enough understanding of the situation to be able to predict the future actions of the system (Level 3 SA - *projection*), allowing them to behave proactively instead of reactively in dealing with the environment to achieve their goals.
With many automated systems, forming the higher levels of SA can pose a significant difficulty. Empirical evidence of lower Level 2 SA under automated conditions has been found in experimental studies (Carmody and Gluckman, 1993; Endsley and Kiris, 1994). The accident at Three Mile Island is a classic example of a situation where the operators received needed data, but did not correctly understand the meaning of that data. Nor do operators appear to have a high level of understanding regarding the future behavior of automated systems.

Problems with situation awareness under automation have been directly linked to several major factors (Endsley and Kiris, in press): 1.) Vigilance decrements associated with monitoring, complacency due to over-reliance on automation, or a lack of trust in automation can all significantly reduce SA as people may neglect monitoring tasks, attempt to monitor but do so poorly, or be aware of indicated problems, but neglect them due to high false alarm rates. 2.) Passive processing of information under automation (as opposed to active manual processing) can make the dynamic update and integration of system information more difficult. 3.) Changes in form or a complete loss of feedback frequently occur either intentionally or inadvertently with many automated systems.

In addition, problems with Levels 2 and 3 SA can be partially attributed to the increased level of complexity associated with many automated systems, poor interface design and inadequate training (Endsley, in press-a). As system complexity increases, achieving a good mental model of the system can be more difficult. There are more parameters that may interact in more complex ways, and many combinations of circumstances may rarely be seen. Pilots have reported significant difficulties in understanding what their flight management systems are doing and why (Wiener, 1989). Although this understanding tends to increase with experience (McClumpha and James, 1994), there is also an indication that the interfaces of these systems are frequently not well designed to meet operator information needs (Billings, 1991; Norman, 1989) yielding significant difficulties in achieving the higher levels of SA with many automated systems.

1.4 Summary

Significant decrements in the SA of operators of automated systems exist creating many problems in controlling and monitoring these systems; Yet, automation is felt to be necessary to provide operators with manageable workload levels and reduced error rates. At present, it appears that this state of affairs has been largely accepted as something to be tolerated until further automation can be added to solve each new human failure. Successive levels of automation only add to the level of complexity and remove the operator further from active control of the system, however, exacerbating the very problem these efforts attempt to solve. The answer to this conundrum lies in examining the underlying assumptions of automation and devising a different approach to the problems automation attempts to solve.

2. THE TRADITIONAL AUTOMATION PARADIGM

Traditional human factors design has focused on function allocation — the division of tasks between man and machine. In the era of automation, the focus has been on determining high workload tasks that operators need assistance with. These tasks are then allocated to automation in order to reduce the human's tasks to more manageable levels.

2.1 Reduce workload through automation

This strategy is well ensconced in the aircraft design process and underlies much of the thinking within the human factors community. The Air Force Studies Board of the National Research Council (1982 , pp. 36-39) advocated automation as a desirable means of dealing with the high workload brought on by previous piecemeal automation and increases in system complexity. The underlying assumption of workload reduction has been implicit in automation projects. The Boeing 767, like many newer aircraft, was designed with the specific objective of "increasing cockpit automation and decreasing cockpit workload" (Ropelewski, 1982).

Current automation programs, featuring advanced artificial intelligence or expert systems, are also frequently aimed at dealing with workload problems. Even programs that recognize the need for automation that is better integrated with the needs of the human operator recommend basing this integration around workload, dynamically allocating tasks in real-time during the course of a mission based on the workload level of the pilot (Emerson and Reising, 1992; Morrison and Gluckman, 1994). In attempting to implement this approach, however, Pilot's Associate noted significant difficulties in implementing a workload based strategy for adaptively allocating functions (Hammer and Small, in press).

2.2 Fallacy of the workload assumption

Evidence indicates that the under-riding principle involved in this automation strategy is flawed. Human workload does not always respond to automation as predicted. Hart and Sheridan (1984) noted that automation often replaces workload involving physical activity with workload involving cognitive and perceptual activity. "Pilots recognize that the new aircraft call for more programming, planning, sequencing alternative selection and more thinking" (Wiener, 1988b). Furthermore, pilots complained that automation requires constant scanning adding to workload. Wiener's (1985) studies in commercial aviation found a significant number of pilots reporting that automation does not necessarily reduce their workload, but actually may increase it during critical portions of the flight. Bainbridge (1983) called it the irony of automation that when workload is highest automation is often of the least assistance.

Many recent studies are beginning to confirm a lack of correspondence between workload and automation or people's use of automation. In studying adaptive automation techniques, Harris, et al. (1994) found that when operators were required to initiate task automation in response to an unanticipated increase in workload, it was accompanied by a significant increase in performance error on other manual tasks. This confirmed work by Parasuraman, et al. (1992) indicating that operator initiation of automation was likely to increase demands when they were already high. Riley (1994) investigated factors that influenced when people would choose to initiate automation. He found that a subject's choice to use automation in a task was not related to the workload level of the task, but rather to factors such as reliability, trust and risk.

Furthermore, it appears that monitoring itself may induce high workload. A series of studies have shown that in tasks where people must provide sustained attention as monitors over a period of time, it induces considerable fatigue (Galinsky, et al., 1993) and perceived workload is rated as fairly high (e.g. Becker, et al., 1991; Dittmar, et al., 1993; Scerbo, et al., 1993), contrary to characterizations of monitoring activities as boring but non-demanding.

The evidence is building that automation fails to decrease and may even increase workload. Operators indicate that under high workload they frequently turn the automation off, which Wiener (1988a) calls the paradox of automation. Even when task load is not high, the requirement to vigilantly monitor automated systems imposes its own workload.

2.3 Summary

Despite significant problems with human performance and evidence that workload does not necessarily decrease with automation, workload remains the fundamental human factors consideration in automation decisions. The overriding approach for dealing with workload is to automate. This schizophrenic mind set is firmly entrenched in today's automation projects, perhaps because no other alternative is readily apparent. As automation may not reduce workload and indications are that it can compromise SA, a new approach is needed.

3. A NEW APPROACH TO AUTOMATION

A solution to the problem posed here lies in examining when things go well in system operations. This is when operators are involved in their tasks, aware of what is going on, but not overloaded. Researchers have made the mistake of focusing on the overload problem with out taking into account the issues of involvement and awareness.

Design solutions that decrease SA increase the probability that errors will occur. Traditional automation approaches have done just that — decrease operators' SA by removing them from involvement in system operation. Using a fairly ingenious feedback paradigm, Pope et al. (1994) found an index based on EEG signals that corresponds to the degree to which subjects are "engaged" in performing a task. This index responded negatively to automation and positively to manual control, demonstrating this effect.

As a lack of SA appears to be at the heart of a large majority of human errors, it makes sense to focus on SA in the design process. Although the design community has focused increased attention on SA, this is currently being done in conjunction with the existing automation paradigm. These two approaches are not additive or even fundamentally compatible. An alternate approach focuses on system design and automation strategies that enhance SA by keeping operator involvement.

3.1 Design for situation awareness

A structured approach is required to incorporate SA considerations into the design process, including a determination of SA requirements, designing for SA enhancement, and measurement of SA in design evaluation.

SA Requirements Analysis. Designing interfaces that provide SA depends on domain specifics that determine the critical features of the situation that are relevant to a given operator. A goal-directed task analysis methodology (Endsley, 1993) has been used successfully for determining SA requirements in several different domains, including aircraft, air traffic control and remote maintenance control centers. This methodology focuses on the basic goals of operators (which may change dynamically), the major decisions they need to make relevant to these goals, and the SA requirements for each decision. SA requirements are established in terms of the basic data that is needed (Level 1 SA), required integration of the data for a comprehension of system state in light of goals (Level 2 SA), and projection of future trends and events (Level 3 SA).

The method is significantly different than traditional task analyses in that: 1.) it is not pinned to a fixed timeline, a feature which is not compatible with the work flow in dynamic systems, 2.) it is technology independent, not tied to how tasks are done with a given system, but to what information is really, ideally needed, and 3.) the focus is not just on what data is needed, but on how that data needs to be combined and integrated to support decision making and goal attainment. This last feature, defining comprehension and projection needs, is critical for creating designs that support SA instead of overload the operator with data as many current systems do.

SA-Oriented Design. The development of a system design for successfully providing the multitude of SA requirements that exist in complex systems is a significant challenge. A set of design principles have been developed based on a theoretical model of the mechanisms and processes involved in acquiring and maintaining SA in dynamic complex systems (Endsley, in press-c). These guidelines are focused on a model of human cognition involving dynamic switching between goal-driven and data-driven processing and feature support for limited operator resources, including: 1.) direct presentation of higher level SA needs (comprehension and projection) instead of low level data, 2.) goal-oriented information display, 3.) support for global SA, providing an overview of the situation across the operator's goals at all times (with detailed information for goals of current interest), enabling efficient and timely goal switching and projection, 4.) use of salient features to trigger goal switching, 5.) reduction of extraneous information not related to SA needs, and 6.) support for parallel processing. To date, an SA-oriented design has been successfully applied as a design philosophy for systems involving remote maintenance operations and flexible manufacturing cells.

Evaluation. Many concepts and technologies are currently being developed and touted as enhancing SA. Prototyping and simulation of new technologies, new displays and new automation concepts is extremely important for evaluating the actual effects of proposed concepts with in the context of the task domain and using domain knowledgeable subjects. If SA is to be a design objective, then it is critical that it be specifically evaluated during the design process. Without this it will be impossible to tell if a proposed concept actually helps SA, does not effect it, or inadvertently compromises it in some way. The Situation Awareness Global Assessment Technique (SAGAT) has been sucessfully used to provide this information by directly and objectively measuring operator SA in evaluating avionics concepts, display designs, and interface technologies (Endsley, in press-b).

3.2 New roles for automation

In addition to supporting SA through system design, automation strategies must maintain or enhance SA. Many of the negative impacts of automation on SA and human performance may be attributable to the way that automation has traditionally been implemented. New approaches are currently being explored that challenge the relegation of the operator to passive monitor. These approaches redefine the assignment of functions to people and automation in terms of an integrated team approach that maintains operator involvement. One approach seeks to optimize the assignment of control between the human and automated system by keeping both involved in system operation. The other recognizes that control must pass back and forth between the human and the automation over time, and seeks to use this factor to increase human performance.

Adaptive Automation. Adaptive automation has been found to aid in overcoming the out-of-the-loop performance problem (Parasuraman, 1993). Adaptive automation attempts to optimize a dynamic allocation of tasks by creating a mechanism for determining in real-time when tasks need to become automated (or manually controlled) (Morrison and Gluckman, 1994). In direct contrast to historical efforts which have featured fixed task allocations, adaptive automation provides the potential for improving operator performance by keeping them in the loop. Carmody and Gluckman (1993) found SA to be impacted by adaptive automation of certain tasks. A concern associated with this technique, however, is that it may impose an additional task management load, requiring operators to keep up with who is doing what as the allocation changes. Research is needed to examine the full consequences of this approach for operator SA.

Level of Control. A second, complementary approach maintains operator involvement by identifying an optimal level of automation that keeps the operator in the loop, thus maintaining SA. In automating cognitive tasks via expert systems, five levels of automation (or control) can be considered. Decisions can be made: (a) manually with no assistance from the system, (b) by the operator with input in the form of recommendations provided by the system, (c) by the system, with the consent of the operator required to carry out the action, (d) by the system, to be automatically implemented unless vetoed by the operator, or (e) fully automatically, with no operator interaction.

Endsley and Kiris (in press) implemented automation of an automobile navigation task at each of these five levels. They found that the out-of-the-loop performance problem was significantly greater under full automation than under intermediate levels of automation. This corresponded with a greater decrement in SA under full automation than under intermediate levels, as compared to manual control. By implementing functions at a lower level of automation, keeping the operator in the decision loop, SA remained at a higher level and subjects were more able to assume manual control when needed.

Thus, even though full automation of a task may be technically possible, it may not be desirable if the performance of the joint human-machine system is to be optimized. Intermediate levels of automation may be preferable for certain tasks, in order to keep human operators' SA at a higher level and allow them to perform critical functions.

3.3 Summary

Following a structured approach from analysis to design to testing, SA can be incorporated as a significant and attainable design goal. It is important that such procedures are applied in the design process and automation strategies that maintain operator involvement exploited if the SA and performance of operators in complex settings are to be improved.

REFERENCES

Air Force Studies Board, Committee on Automation in Combat Aircraft, National Research Council. (1982). *Automation in combat aircraft.* National Academy Press, Washington D.C.

Bainbridge, L. (1983). Ironies of automation. *Automatica*, **19**, 775-779.

Becker, A. B., J. S. Warm and W. N. Dember (1991). Effects of feedback on perceived workload in vigilance performance. In: *Proceedings of the Human Factors Society 35th Annual Meeting*, pp. 1491-1494. Human Factors Society, Santa Monica, CA.

Billings, C. E. (1988). Toward human centered automation. In: *Flight deck automation: Promises and realities* (S. D. Norman and H. W. Orlady (Eds.)), pp. 167-190. NASA-Ames Research Center, Moffet Field, CA.

Billings, C. E. (1991). *Human-centered aircraft automation: A concept and guidelines* (NASA Technical Memorandum 103885). NASA Ames Research Center, Moffet Field, CA.

Carmody, M. A. and J. P. Gluckman (1993). Task specific effects of automation and automation failure on performance, workload and situational awareness. In: *Proceedings of the Seventh International Symposium on Aviation Psychology* (R. S. Jensen and D. Neumeister (Eds.)), pp. 167-171. Department of Aviation, The Ohio State University, Columbus, OH.

Dittmar, M. L., J. S. Warm, W. N. Dember and D. F. Ricks (1993). Sex differences in vigilance performance and perceived workload. *J. of Gen. Psych.*, **120(3)**, 309-322.

Emerson, T. J. and J. M. Reising (1992). The effect of an artificially intelligent computer on the cockpit paradigm. In: *The human-electronic crew: Is the team maturing?* (T. Emerson, M. Reinecke, J. Reising and R. Taylor (Eds.)), pp. 1-5. Wright Laboratory, Air Force Materiel Command, Wright-Patterson AFB, OH.

Endsley, M. R. (1988). Design and evaluation for situation awareness enhancement. In: *Proceedings of the Human Factors Society 32nd Annual Meeting*, pp. 97-101. Human Factors Society, Santa Monica, CA.

Endsley, M. R. (1993). A survey of situation awareness requirements in air-to-air combat fighters. *Int. J. of Av. Psych.*, **3(2)**, 157-168.

Endsley, M. R. (1994, March). *A taxonomy of situation awareness errors.* Paper presented at the Western European Association of Aviation Psychology 21st Conference, Dublin, Ireland.

Endsley, M. R. (in press-a). Automation and situation awareness. In: *Automation and human performance: Theory and applications* (R. Parasuraman and M. Mouloua (Eds.)). Lawrence Erlbaum, Hillsdale, NJ.

Endsley, M. R. (in press-b). Measurement of situation awareness in dynamic systems. *Human Factors*.

Endsley, M. R. (in press-c). Towards a theory of situation awareness. *Human Factors*.

Endsley, M. R. and E. O. Kiris (1994). The out-of-the-loop performance problem: Impact of level of control and situation awareness. In: *Human performance in automated systems: Current research and trends* (M. Mouloua and R. Parasuraman (Eds.)), pp. 50-56. Lawrence Erlbaum, Hillsdale, NJ.

Endsley, M. R. and E. O. Kiris (in press). The Out-of-the-Loop Performance Problem and Level of Control in Automation. *Human Factors*.

Galinsky, T. L., R. R. Rosa, J. S. Warm and W. N. Dember (1993). Psychophysical determinants of stress in sustained attention. *Human Factors*, **35(4)**, 603-614.

Hammer, J. M. and R. L. Small (in press). An intelligent interface in an associate system. In: *Human/technology interaction in complex systems* (W. B. Rouse (Ed.)). JAI Press, Greenwich, CT.

Harris, W. C., P. N. Goernert, P. A. Hancock and E. Arthur (1994). The comparative effectiveness of adaptive automation and operator initiated automation during anticipated and unanticipated taskload increases. In: *Human performance in automated systems: Current research and trends* (M. Mouloua and R. Parasuraman (Eds.)), pp. 40-44. LEA, Hillsdale, NJ.

Hart, S. G. and T. B. Sheridan (1984). Pilot workload, performance, and aircraft control automation. In: *Human factors considerations in high performance aircraft (AGARD-CP-371)*, pp. 18/1-18/12. NATO-AGARD, Neuilly Sur Seine, France.

Hartel, C. E., K. Smith and C. Prince (1991, April). *Defining aircrew coordination: Searching mishaps for meaning*. Paper presented at the Sixth International Symposium on Aviation Psychology, Columbus, OH.

McClumpha, A. and M. James (1994). Understanding automated aircraft. In: *Human performance in automated systems: Current research and trends* (M. Mouloua and R. Parasuraman (Eds.)), pp. 183-190. Lawrence Erlbaum, Hillsdale, NJ.

Morrison, J. G. and J. P. Gluckman (1994). Definitions and prospective guidelines for the application of adaptive automation. In: *Human performance in automated systems: current research and trends* (M. Mouloua and R. Parasuraman (Eds.)), pp. 256-263. Lawrence Erlbaum, Hillsdale, NJ.

National Transportation Safety Board (1990). *Aircraft accidents report: USAIR, Inc., Boeing 737-400, LaGuardia Airport, Flushing New York, September 20, 1989* (NTSB/AAR-90-03). Author, Washington, D.C.

Norman, D. A. (1989). *The problem of automation: Inappropriate feedback and interaction not overautomation* (ICS Report 8904). Institute for Cognitive Science, U. C. San Diego, La Jolla, CA.

Norman, S. and K. Abbott (1988). Current flight deck automation: Airframe manufacturing and FAA certification. In: *Flight deck automation: Promises and realities* (S. D. Norman and H. W. Orlady (Eds.). NASA-Ames Research Center, Moffett Field, CA.

Parasuraman, R. (1993). Effects of Adaptive Function Allocation on Human Performance. In: *Human factors and advanced aviation technologies* (D. J. Garland and J. A. Wise (Eds.)), pp. 147-158. Embry-Riddle Aeronautical University Press, Daytona Beach, FL.

Parasuraman, R., T. Bahri, J. E. Deaton, J. G. Morrison and M. Barnes (1992). *Theory and design of adaptive automation in aviation systems* (AWCADWAR-92033-60). Naval Air Warfare Center, Aircraft Division, Warminster, PA.

Pope, A. T., R. J. Comstock, D. S. Bartolome, E. H. Bogart and D. W. Burdette (1994). Biocybernetic system validates index of operator engagement in automated task. In: *Human performance in automated systems: Current research and trends* (M. Mouloua and R. Parasuraman (Eds.)), pp. 300-306. Lawrence Erlbaum, Hillsdale, NJ.

Riley, V. (1994). A theory of operator reliance on automation. In: *Human performance in automated systems: Current research and trends* (M. Mouloua and R. Parasuraman (Eds.)), pp. 8-14. Lawrence Erlbaum, Hillsdale, NJ.

Ropelewski, R. R. (1982). Boeing's new 767 eases crew workload. *Aviation Week & Space Technology*, **August 23**, 41-53.

Scerbo, M. W., C. Q. Greenwald and D. A. Sawin (1993). The effect of subject-controlled pacing and task type on sustained attention and subjective workload. *J. of Gen. Psych.*, **120(3)**, 293-307.

Wickens, C. D. (1992). *Engineering Psychology and Human Performance* (2nd ed.). Harper Collins, New York.

Wiener, E. (1988a). Field studies in automation. In: *Flight deck automation: Promises and realities* (S. D. Norman and H. W. Orlady (Eds.)), pp. 37-55. NASA-Ames Research Center, Moffett Field, CA.

Wiener, E. L. (1985). Cockpit automation: In need of a philosophy. In: *Proceedings of the 1985 Behavioral Engineering Conference*, pp. 369-375. Society of Automotive Engineers, Warrendale, PA.

Wiener, E. L. (1988b). Cockpit automation. In: *Human Factors in Aviation* (E. L. Wiener and D. C. Nagel (Eds.)), pp. 433-461. Academic Press, San Diego.

Wiener, E. L. (1989). *Human factors of advanced technology ("glass cockpit") transport aircraft* (NASA Contractor Report No. 177528). NASA-Ames Research Center, Moffett Field, CA.

Wiener, E. L. and R. E. Curry (1980). Flight deck automation: Promises and problems. *Ergonomics*, **23(10)**, 995-1011.