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SITUATION AWARENESS & LEVELS OF AUTOMATION

FINAL REPORT

Submitted By:

Mississippi State University and SA Technologies

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INTRODUCTORY MATERIAL

Legal Name of Contractor:	Mississippi State University
Address:	Sponsored Programs Administration P.O. Box 6156 Mississippi State, MS 39762
Originating Unit:	Department of Industrial Engineering
Organization Type:	Educational
Principal Investigator:	
Name:	David B. Kaber
Phone:	(601) 325-8609
Project Title:	Situation Awareness & Levels of Automation
Technical Contact:	Paul C. Schutte, Crew/Vehicle Integration Branch, Flight Dynamics and Control Division
Starting Date:	1/1/99
Duration of Project:	12 mos.

ABSTRACT

During the first year of this project, a taxonomy of theoretical levels of automation (LOAs) was applied to the advanced commercial aircraft by categorizing actual modes of McDonald Douglas MD-11 autoflight system operation in terms of the taxonomy. As well, high LOAs included in the taxonomy (e.g., supervisory control) were modeled in the context of MD-11 autoflight systems through development of a virtual flight simulator. The flight simulator was an integration of a re-configurable simulator developed by the Georgia Institute Technology and new software prototypes of autoflight system modules found in the MD-11 cockpit. In addition to this work, a version of the Situation Awareness Global Assessment Technique (SAGAT) was developed for application to commercial piloting tasks. A software package was developed to deliver the SAGAT and was integrated with the virtual flight simulator.

SITUATION AWARENESS & LEVELS OF AUTOMATION

Summary of Project Achievements:

During the first project year, the theoretical taxonomy of levels of automation (LOAs) developed by the PI and subcontractor were applied to the MD-11 autoflight systems. Specifically, existing modes of MD-11 automation were categorized in terms of the LOA taxonomy and new modes of autoflight not currently available in the aircraft were conceptualized based on function allocation schemes characterizing higher levels of complex system autonomy identified in the taxonomy. This was accomplished by assuming the utilization of an expert system in the Flight Management System (FMS) of the aircraft for flight path planning.

General direction and outcomes:

This effort was intended to describe how pilots and flight management and control computers are integrated in the advanced commercial aircraft cockpit. It also served as the basis for developing a virtual flight simulator of the MD-11. The simulator was an integration of a re-configurable flight simulator developed by the Georgia Institute Technology and new software prototypes of autoflight system modules found in the MD-11 cockpit. The virtual flight simulator was developed on a personal computer platform running the Microsoft WindowsNT® operating system.

The study of the MD-11 cockpit automation and pilot flight tasks also allowed for the development of a version of the Situation Awareness Global Assessment Technique (SAGAT) for commercial piloting. A software package was developed to deliver the SAGAT and it has been integrated with the virtual flight simulator.

Specific tasks:

Towards applying the LOA taxonomy to the MD-11 cockpit, we conducted an in-depth review of cockpit systems and flight tasks. This included:

(1) learning the Delta Pilot's Reference Manual;
(2) visiting the Delta training facilities in Atlanta, Georgia and receiving familiarization with Delta MD-11 simulators;
(3) consulting with experienced MD-11 pilots; and
(4) developing hierarchical breakdowns of MD-11 autoflight system functions.

The hierarchies established what the autoflight systems are capable of doing. They include a list of available functions and functional settings of the aircraft control systems.

Subsequently, formal descriptions of the division of flight control responsibilities among pilots and flight management and control computers were developed for each mode of automation the MD-11 is currently capable of achieving (e.g., Vertical Speed Mode, FMS Navigation Mode, Autopilot Mode, Flight Director Mode, Autothrottle System, etc.). Descriptions of the channels of communication between pilots and on-board computers were also developed along with

descriptions of triggers of different modes of automation (i.e., flight events that would cause certain modes to be engaged or disengaged).

A two-step procedure was used to categorize the modes of automation of the MD-11 in terms of the taxonomy LOAs. Initially, all flight control functions were classified according to the general stages of information processing represented in the taxonomy (i.e., monitoring, planning, decision-making and control action). Flight control function ownership under the various modes of MD-11 automation was then considered and matched to the generic function allocation schemes depicted by the taxonomy LOAs. This served to identify the LOAs of the taxonomy currently represented in the MD-11 autoflight system. It also identified the levels that needed to be conceptually modeled as part of the flight simulator development in order to study their potential effects on flight performance and pilot situation awareness (SA). As a result of this process, it was observed that the modes of MD-11 automation, in general, constitute low degrees of aircraft autonomy and often only provide pilots with assistance in implementing flight control actions.

In order to model higher LOAs in the context of the MD-11 cockpit, such as supervisory control or full automation of aircraft flight control, the integration of an expert system in the Flight Management Computer (FMC) was assumed for flight path planning tasks. The system was conceptualized as being capable of:
(1) automatically generating flight plans;
(2) evaluating the safety and efficiency of flight plans, including plans generated by pilots; and
(3) deciding on an optimal flight plan among several alternatives.
By considering the aspects of high LOAs as part of the theoretical taxonomy, we identified the existing MD-11 autoflight systems that would need to be active in conjunction with the expert system to facilitate a particular LOA (e.g., supervisory control, etc.). We also defined who (the pilot or FMC) was to be responsible for specific flight tasks and control systems based on the generic function allocation schemes presented in the taxonomy.

Deliverables:

Description of Endsley & Kaber's (1999) taxonomy of LOAs in terms of MD-11 autoflight systems and the operational roles of the pilot and flight management and control computers was submitted to the technical contact as part of a technical report entitled, "Situation Awareness & Levels of Automation," on March 6, 2000. The report also presented comprehensive reviews of the MD-11 Pilot's Flight Manuals, including "Aircraft General," "Automatic Flight System," and "Flight Control." These reviews are important because they are essentially translations of pilot references, which use cryptic terminology, into laymen's terms. It is possible that the reviews could be used by McDonald Douglas Corporation, Boeing Corporation and other commercial aircraft manufacturers to determine what information is actually being conveyed to new MD-11 pilots through the autoflight system manuals. The reviews could also serve as a guide to McDonald Douglas Corporation safety for improving aircraft manuals to prevent piloting errors due to a lack of adequate system understanding.

Beyond these reviews, the technical report also included the hierarchical analyses of the functions of the various MD-11 autoflight system functions (i.e., mode trees of automatic flight

system functions). These mode trees very clearly define the capabilities of the current modes of automation of the aircraft. They also provide insight into how pilots and the FMS and the FMC communicate during autoflight and flight events that may causes changes in the mode of aircraft automation.

Other Research Outcomes:

At this point in time, the project has generated four publications, including a refereed conference proceedings paper, an archival journal article and two software applications with commercial market potential. Current references for these publications include:

(1) Endsley, M. R. (2000). Situation awareness global assessment technique for commercial piloting©. Atlanta, GA: SA Technologies Inc..
(2) Kaber, D. B., Tan, K-W., Riley, J. and Endsley, M. (in review). Design of adaptive automation for complex systems. Submitted to the International Journal of Cognitive Ergonomics.
(3) Tan, K-W, Butts, D. and Song, D. (2000). Virtual MD-11 flight simulator©. Mississippi State, MS: Mississippi State University.
(4) Tan, K-W., Kaber, D. B., Riley, J. M. and Endsley, M. R. (in press). Human factors issues in implementation of AA to complex systems. In the Proceedings of the 14th Triennial Congress of the International Ergonomics Association and the 44th Annual Meeting of the Human Factors & Ergonomics Society. Human Factors & Ergonomics Society: Santa Monica, CA.

The proceedings paper is to be presented at the "International Ergonomics Association/Human Factors & Ergonomics Society 2000 Meeting" this Summer in San Diego, California. It is anticipated that the journal article will be published during the winter of 2000. It is also expected that revisions will be made to both software packages during the second project year to enhance the simulator capabilities for recording data on pilot performance and to expand the query base of the SAGAT application.

References:

Endsley, M. R. and Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics, 42(3), 462-492.

Personnel:

Biographical Sketch: Mica R. Endsley, Ph.D., P.E., CPE

Mica Endsley is President of SA Technologies in Marietta, Georgia where she specializes in situation awareness issues in advanced aviation systems. She recently left her post as a Visiting Associate Professor at MIT in the Department of Aeronautics and Astronautics and Associate Professor of Industrial Engineering at Texas Tech University. Prior to joining Texas Tech she was an Engineering Specialist for the Northrop Corporation, serving as Principal Investigator of a research and development program focused on the areas of situation awareness, mental workload, expert systems and interface design for the next generation of fighter cockpits. She received a Ph.D. in Industrial and Systems Engineering from the University of Southern California. Dr. Endsley has been conducting research on situation awareness, decision making and automation in aircraft, air traffic control and aviation maintenance for the past twelve years. She is the author of over 90 scientific articles and reports on numerous subjects including the implementation of technological change, the impact of automation, the design of expert system interfaces, new methods for knowledge elicitation for AI system development, pilot decision making, and situation awareness.

List of Principal Publications

Endsley, M. R. and Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics, 42(3), 462-492.

Endsley, M. R., & Robertson, M. M. (in press). Situation awareness in aircraft maintenance teams. International Journal of Industrial Ergonomics.

Endsley, M. R., & Rodgers, M. D. (1998). Distribution of attention, situation awareness, and workload in a passive air traffic control task: Implications for operational errors and automation. Air Traffic Control Quarterly.

Endsley, M. R. and Smolensky, M. (1998). Situation Awareness in Air Traffic Control: The Picture. In M. Smolensky and E. Stein (eds.) Human Factors in Air Traffic Control (pp. 115-154). New York: Academic Press.

Endsley, M. R., Mogford, R. H., & Stein, E. S. (1997). Controller situation awareness in free flight. In Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting (pp. 4-8). Santa Monica, CA: Human Factors and Ergonomics Society.

Endsley, M. R. (1996). Situation Awareness Measurement in Test and Evaluation. In T. G. O'Brien & S. G. Charlton (Eds.), Handbook of Human Factors Testing & Evaluation (pp. 159-180). Mahwah, NJ: Lawrence Erlbaum.

Jones, D. G. and **Endsley**, M. R. (1996). Sources of situation awareness errors in aviation. Aviation, Space and Environmental Medicine, 67(6), 507-512.

Endsley, M. R. and Kiris, E. O. (1995) The Out-of-the-Loop Performance Problem and Level of Control in Automation, Human Factors, 37(2), 381-394.

Endsley, M. R. (1995) Towards a Theory of Situation Awareness, Human Factors, 37(1), 32-64.

Endsley, M. R. (1995) Measurement of Situation Awareness in Dynamic Systems, Human Factors, 37(1), 65-84.

Biographical Sketch: David B. Kaber, Ph.D., E.I.T.

David Kaber is an Assistant Professor in the Department of Industrial Engineering at Mississippi State University and Director of the Cognitive Engineering and Systems Laboratory. Prior to joining Mississippi State, he worked as an instructor of Engineering Science and Mathematics at Amarillo College. He received his Ph.D. in Industrial Engineering at Texas Tech University, with a specialization in cognitive ergonomics. While completing this degree, he received the Air Force Office of Scientific Research Fellowship in Human Factors. He received his Masters and Bachelors degrees in Industrial Engineering with specializations in human factors and occupational safety from the University of Central Florida. Dr. Kaber's research interests include cognitive engineering, adaptive systems and modes of automation in complex systems, teleoperations and virtual reality systems. He has published several refereed papers in technical journals and conference proceedings concerning these interests. His current projects include advanced interface design for teleoperation systems, investigation of the role of telepresence (the sense of being present at a remote site) in teleoperation performance, virtual environment design for scientific data visualization tasks including meteorological and oceanographic model analysis, and assessment of the impact of modes of automation and adaptive automation on human operator workload and situation awareness in complex system control tasks.

List of Principal Publications

Kaber, D. B. and Endsley, M. R. (1997). Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety. Process Safety Progress, 16(3), 126-131.

Kaber, D. B. and Endsley, M. R. (1998). Team situation awareness for process control safety and performance. Process Safety Progress, 17(1), 43-48.

Kaber, D. B., Endsley, M. R. and Onal, E. (in press). Design of automation for telerobots and the effect on performance, operator situation awareness and subjective workload. Submitted to the International Journal of Human Factors in Manufacturing.

Kaber, D. B. and Endsley, M. R. (1997). Level of automation and adaptive automation effects on performance in dynamic control environments. Proceedings of the 13th Triennial Congress of the International Ergonomics Association (pp. 202-204).

Kaber, D. B. and Endsley, M. R. (1997). The combined effect of level of automation and adaptive automation on human performance with complex, dynamic control systems. In the Proceedings of the 41st Annual Meeting of the Human Factors and Ergonomics Society (pp. 205-209). Human Factors and Ergonomics Society: Santa Monica, CA.

Kaber, D. B., Onal, E. and Endsley, M. R. (in press). Level of automation effects on telerobot performance and human operator situation awareness and subjective workload. In Proceedings of the Third Automation Technology and Human Performance Conference. Lawrence Erlbaum Associates: Mahwah, NJ.

Kaber, D. B. and Riley, J. (in press). Adaptive automation of a dynamic control task based on workload assessment through a secondary-monitoring task. In Proceedings of the Third Automation Technology and Human Performance Conference. Lawrence Erlbaum Associates: Mahwah, NJ.