THE EFFECT OF FLIGHT DECK AUTOMATION AND AUTOMATION PROFICIENCY ON COCKPIT TASK MANAGEMENT PERFORMANCE

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AUTOMATION AND COCKPIT TASK MANAGEMENT

The fact that flight deck automation has improved aircraft performance and reliability is welcome. But although automation has generally been well received by pilots, the advent of advanced technology (so called "glass cockpit") aircraft has raised several concerns. For example, Wiener (1989) argued that the promise of automation in reducing overall flight crew workload has not been realized. Workload appears to have decreased during low workload periods (e.g., in a cruise phase of flight), but to have increased during high workload periods (e.g., in the approach and landing phases of flight).

Although Funk et al's (1999) meta-analysis of flight deck automation issues failed to identify this "clumsy workload" issue as a significant problem, it did reveal substantial evidence to support the related claim that the attentional demands of pilot-automation interaction may significantly interfere with performance of safety-critical tasks. That is to say that automation may interfere with what we call Cockpit Task Management (CTM).

CTM is the process by which pilots selectively allocate human and machine resources to and perform multiple, concurrent tasks to achieve mission goals. Satisfactory CTM requires the correct prioritization of tasks based on their importance to mission safety, how urgent the tasks are, and how well the tasks are actually being performed. A task prioritization error occurs when the pilot compromises a higher priority task – i.e., one more important to flight safety, one that is more urgent, or one that is currently not being performed at a satisfactory level – by attending to a lower priority task – i.e., one less critical to safety, one less urgent, or one that is already being performed quite well and is not in need of immediate attention.

Wilson (1997) conducted an Aviation Safety Reporting System (ASRS) incident report study to examine the effect of the level of automation on the rate of task prioritization errors on the commercial transport flight deck. A total of 420 randomly selected ASRS reports were reviewed for task prioritization errors. Two hundred ten of these reports were selected from aircraft classified as advanced technology (high automation aircraft), and the other 210 from conventional technology, or low automation aircraft. All of these reports were constrained to reports submitted during the period of 1988 to 1993 and were limited to large transport commercial jets with two-pilot flight decks.

Not surprisingly, she found that task prioritization errors occurred in both advanced technology and traditional technology aircraft. But of great interest is the fact that the frequency of task prioritization errors in the advanced technology aircraft was higher than the frequency of task prioritization errors in traditional technology aircraft. To explore these findings more fully, we conducted a part-task simulator study.

OBJECTIVES

The main objectives of the simulator study were to investigate the effect of flight deck automation level on CTM performance and also to determine the effect of pilot automation proficiency, measured by 'glass cockpit' hours, on CTM performance.

METHOD

We used the NASA "Stone-Soup Simulator" version 4.1 obtained from NASA-Ames Research Center. The simulator models a generic, twin-engine turbojet transport with an advanced autoflight system. The subject interface consists of a Primary Flight Display (PFD), Horizontal Situation Indicator (HSI), Mode Control Panel (MCP), Engine Indication and Crew Alerting System (EICAS), menu-selectable synoptic pages for aircraft system monitoring and control, navigation and communication radio interfaces, and other system displays and controls.

The hardware consisted of 2 SGI Indigo 2 workstations, running the IRIX 6.2 operating system. The workstations were networked, with one serving as
the experimenter’s station and the other displaying the simulator interface for the pilot. The simulator flight control was performed with a BG Flybox and a mouse connected to the pilot’s workstation. Video equipment included a video camera, videocassette recorder, and a video monitor.

All participants in the study flew three different flights with three different flight deck automation levels, i.e. low, medium, and high. Each of these levels of automation was designed to be similar to automation functionality that one could find in a real flight deck. The differences and the availability of flight deck equipment among the three levels of automation are described as follows.

In the low level of automation, subjects flew the aircraft with the use of the joystick, using ‘raw data’ procedures. Raw data flying means the pilot flies and controls lateral and vertical movement of the aircraft with a joystick and throttles and navigates using a VOR/DME display on the HSI.

In the medium level of automation, subjects no longer flew the aircraft with the joystick and throttles. Instead, they utilized the altitude selector, vertical speed selector, and heading selector on the MCP to control lateral and vertical movement of the aircraft. Although subjects were required to use the autopilot systems (i.e., heading hold, altitude hold, or vertical speed hold modes), they used VOR/DME navigation as before. Cockpit displays were the same as in the low automation condition. In summary, the only difference between low and medium automation was the use of the autopilot system to control altitude, heading, and vertical speed on the MCP as opposed to using a joystick.

In the high level of automation, subjects were asked to use the FMS to program a flight path and modify the plan as necessary. Subjects were also provided with a moving map display on the HSI to help them navigate. Generally, the subject acted as a ‘button-pusher’ due to the highly automated environment. Unlike the other two levels of automation, there was an additional display of the FMS Control Display Unit (CDU).

Regardless of the level of automation used, all subjects experienced unexpected aircraft equipment malfunctions initiated by the experimenter. These malfunctions included electrical system malfunctions, pack malfunctions, fuel boost pump failures, and fuel imbalances. Pilots utilized non-normal checklists to guide them in performing fault correction procedures.

The experiment was designed to determine whether different levels of automation and automation proficiency affect CTM performance. The number of errors committed by each subject in a scenario, expressed as a fraction, was the dependent variable. The level of automation was defined as a factor or an independent variable for analysis using analysis of variance (ANOVA). In order to avoid a learning effect that could bias the results of the study, three different scenarios were created. The subject’s automation proficiency was assessed by recording his total flying hours in a ‘glass cockpit’ or FMS-equipped aircraft. Extraneous variables were also important to this study. They were the fidelity of the simulator, the complexity of the scenarios, the static condition of the simulator, and the subject’s level of motivation to participate in the study. Both the fidelity of the simulator and the static conditions of the simulator were ignored in the experimental model.

Three different scenarios were included in the model by choosing three familiar routes with a similar number of flight tasks, a similar number of aircraft subsystem malfunctions, a similar length of flight path, a similar number of waypoints, and a similar number of turning angle degrees.

The level of automation, scenario, and the order of the experimental runs were randomized. Each of the nine subjects performed the experiment runs according to a randomly assigned subject number. The purpose of randomly assigning the subjects was to randomize the combination of the automation level factor with the scenario factor to each of the subjects.

A total of nine airline transport pilots (ATPs) served as subjects. One general aviation (GA) pilot served as a ‘test’ subject to fine-tune the scenarios and data collection/training procedures. All subjects except the GA pilot had at least 200 hours in an FMS-equipped transport aircraft and at least 1500 hours of total flying time.

Throughout all experimental runs, the experimenter acted as an ATC controller giving clearances to the subjects. There were three scenarios in the northwestern United States airspace and one training scenario in California airspace. None of these scenarios required the subjects to take off or to land the aircraft; in other words, all flights started in the air and ended in the air. The training scenario was created to get subjects familiar with the flight simulator and to introduce them to all possible aircraft equipment malfunction events. It was a flight from San Luis Obispo, California (MQO) to San Francisco, California.
The first scenario was a flight from Eugene, Oregon (EUG) to Seattle, Washington (SEA). The initial aircraft position was in the air, on Victor airway 481 (V481) out of Eugene to Corvallis. About 5 miles before Corvallis, the ATC controller (i.e., the experimenter) unexpectedly re-routed the aircraft to a fix/waypoint called CRAAF, continuing to Newberg, Oregon (UBG) and finally to Portland, Oregon (PDX) as a new destination. Equipment malfunction events included in this scenario were as follows: line contactor malfunction, right pack malfunction, line contactor and bus tie contactor faults, boost pump failure, and fuel imbalance.

The second scenario was a flight from Pasco, Washington (PSC) to Seattle, Washington (SEA) with an unexpected en-route diversion at Yakima, Washington (YKM) to a fix/waypoint called THICK. Other than a 270V DC fault, all aircraft malfunctions in this scenario were similar to the ones in the first scenario.

The third scenario was a reverse flight path of the first scenario. The flight plan was from Seattle, Washington (SEA) to Eugene, Oregon (EUG) with a starting point between Portland, Oregon (PDX) and OSWEG.

Each scenario contained six CTM challenges. A CTM challenge was an effort to give the pilot two or more tasks that he/she could not perform concurrently and satisfactorily and therefore required prioritization (i.e., to perform CTM). An example of a CTM challenge appeared in scenario 1, where the subject was cleared to climb to 14,000 feet when, at the same time, a right pack malfunction occurred. Also, in scenario 2, the subject experienced a failure of the 270 DC power supply at the moment a clearance to slow to 240 knots was given.

To assess pilot performance associated with a CTM challenge, we defined task status as follows:

- **Satisfactory**: A state where a task's goal has been established and task goal condition(s) are satisfied or significant progress is being made toward satisfying goal condition(s).

- **Unsatisfactory**: A state where conditions for satisfactory task status are not fulfilled.

A CTM error occurred when a lower priority task was performed satisfactorily while a higher priority task was being performed unsatisfactorily. For example, suppose that ATC cleared a flight to climb to 15,000 ft and the climb was in progress. Near the top of climb a pack malfunction occurred. If the pilot corrected the pack malfunction and in so doing overshot 15,000 ft (“busted” the altitude), a CTM task prioritization error had occurred.

The only performance measure for the study was the number of task prioritization errors committed. This number was obtained by carefully examining the aircraft's parameters as recorded by the simulator and carefully reviewing activities performed by the subjects during the runs as recorded on videotape. Since each of the scenarios had a total of six CTM challenges, the maximum number of errors that a subject could commit was six.

To find out the effect of flight deck automation on CTM performance, the mean number of task prioritization errors for each level of automation were compared and differences tested for their significance. The same method was used to see the effect of pilots' automation proficiency (measured in ‘glass cockpit’ hours) on CTM performance.

### RESULTS

Three captains and six first officers participated in this study. All of the subjects had flown a wide variety of aircraft ranging from single-engine general aviation aircraft to twin-jet-engine FMS-equipped transport aircraft. They were all instrument rated airline transport pilots and they were all very familiar with automation such as the FMS, advanced autopilots (e.g., heading, altitude, and vertical speed select), and EICAS. Their average total flying time was 5,633 hours with a standard deviation of 3,068 hours and their average flying time in 'glass cockpit' aircraft (or FMS-equipped aircraft) was 1,894 hours with a standard deviation of 1,389 hours.

A total of 11, 13, and 12 task prioritization errors were made across scenarios in nine low automation experimental runs, nine medium automation experimental runs, and nine high automation experimental runs, respectively. Each of the experimental runs in each level of automation had a total of six CTM challenges. Therefore, a total of 54 CTM challenges were presented to the subjects in each level of automation. Dividing the number of errors committed over the total number of CTM challenges resulted in the mean number of task prioritization errors...
committed in each level of automation, as shown in Table 1. A graphical representation of these mean numbers is also presented in Figure 1.

Table 1. CTM errors at three automation levels.

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Figure 1. CTM error rates at three levels of automation.

While the mean task prioritization error rates at different levels of automation seem similar to one another, the rate of task prioritization errors at different levels of 'glass cockpit' hours shows more variation. Figure 2 shows a plot of the data.

All ANOVA calculations were performed by utilizing a commercial statistical analysis software package called Statgraphics Plus. In this study, in order to determine whether a factor had a statistically significant effect on CTM performance with a confidence level of 95%, a p-value of less than 0.05 was considered to be a significant value.

Figure 2. Mean CTM error rates at different levels of automation experience, measured by 'glass cockpit' hours.

Table 1 and Figure 1 indicate that CTM error rate was not affected by automation level alone. The level of automation factor had a p-value of 0.9761, which is much greater than the reference value of 0.05. However, due to the fact that the interaction factor of level of automation and scenario was significant (p-value = 0.0276), the effect of level of automation on CTM performance was significant depending on the scenario.

It can be inferred from Figure 2 that automation proficiency, at least roughly measured by 'glass cockpit' hours, does not affect the task prioritization error rate. The p-value for this factor was 0.4876. The p-value was greater than 0.05 and therefore, statistically speaking, the effect of automation proficiency on CTM performance was not significant.

A treatment combination of level of automation and scenario did have a significant effect on the CTM performance (p-value = 0.0276). It is very interesting to see the fact that the scenario factor (p-value = 0.1310) did not affect the CTM performance significantly while the combination of scenario and flight deck automation affected CTM performance significantly. What does it tell us?

Figure 3 is an interaction plot, showing transformed CTM error rate (arcsin(sqrt(error rate))) by scenario as a function of automation level. This transformation was applied because the original data were binary (error present/absent) and followed a binomial distribution. The three lines in the plot represent the three automation levels for each of three different scenarios, as a function of automation level. The graph shows that subjects performed better, that is committed fewer CTM errors, when they flew scenario 1 with medium automation and performed less well when they flew scenario 1 with high automation. An inverse condition was shown in scenario 2, where subjects performed better with high automation and performed more poorly with medium automation. The fact that scenario 1 involves a greater proportion of time in the climb/descent phase of flight and less in the cruise phase of flight than those in scenario 2 indicates
that automation could improve pilots' CTM performance under certain conditions and also could reduce CTM performance under other conditions.

Further examination of the data suggested that CTM performance could also be affected by either subjects’ total flying hours or subjects’ single crew hours. Subjects’ single crew hours refers to the total flying time spent in a single-pilot environment. In exploring this possibility, two additional parameters, subjects’ single crew hours and their total flying hours were also analyzed for their effect on CTM performance. A significant effect of the single crew hours factor on CTM performance was shown in ANOVA by a p-value = 0.0126. On the other hand the total flying hours factor did not have a significant effect on CTM performance (p-value = 0.1690). By looking at these p-values, a correlation coefficient value was also computed to describe the degree of linear association between the 'glass cockpit' hours factor and the total flying hours factor. It turned out that the correlation coefficient value of the two factors was 0.579. The positive value indicates that the 'glass cockpit' hours factor was directly proportional to total flying hours factor. Since we knew that the 'glass cockpit' hours factor did not have a significant effect on CTM performance, the ANOVA calculations were modified to include the single crew hours factor only.

After removing the 'glass cockpit' hours data and the total flying hours data from the ANOVA calculations, the single crew hours factor had a p-value of 0.0044. It appeared that the single crew hours factor affected CTM performance and that effect was statistically significant. In order to see the effect of single crew hours towards CTM performance, a plot of task prioritization errors rate vs. single crew hours is presented in Figure 4.

DISCUSSION

One of the main objectives of this study was to find the effect of flight deck automation on CTM performance. The results suggest that the level of flight deck automation does affect CTM performance, but only depending upon scenario.

Another main objective of this study was to find the effect of pilots’ automation proficiency, measured in ‘glass cockpit’ hours, on CTM performance. This had no significant effect on CTM performance. However, many other factors should should have been taken into consideration in determining a pilot's automation proficiency: type of automation training received, type of automation experience obtained, etc. But what can be concluded with confidence is that ‘glass cockpit’ hours cannot be used to predict a pilot's performance in managing tasks.

Despite the fact that the 'glass cockpit' hours factor shows no significant effect on CTM performance, Figure 2 indicates that fatigue or knowledge about the FMS may affect CTM performance. The two subjects who committed more errors compared to the other subjects were pilots who were between flights at the time they participated in the study. Thus the fatigue factor may have contributed to their poorer CTM performance. On the other hand, the two subjects who committed the fewest errors compared to the other subjects were instructor pilots who teach FMS classes. Hence, automation proficiency in terms of the knowledge about the FMS may have contributed to their CTM performance. However, this speculation cannot be justified without further research.
Although the effect of the interaction between the level of flight deck automation and scenario on CTM performance was not the objective of this study, it is an additional important result that needs to be examined. In this study, scenario 3 had rates of task prioritization errors for all three levels of automation use about equal to the overall mean. Scenario 1 had a higher rate of task prioritization errors when flown in high automation, whereas scenario 2 had a higher rate when flown in lower (i.e., medium) automation. In the first 5 to 10 minutes of flight in both scenarios with high automation, subjects made more errors in the climb phase in scenario 1, while on the contrary they made fewer errors in the cruise phase in scenario 2. It is also important to realize the fact that there were 10, 7, and 19 task prioritization errors made in climb, cruise, and descent respectively. Furthermore, of the 19 errors made in descent phase of flight, 7 were committed in high automation runs, 8 were committed in medium automation runs, and 4 were committed in low automation runs. This finding appears to be consistent with Wiener’s “clumsy automation” hypothesis. Wiener’s (1989) study suggested that flight deck automation may actually increase workload during phases of flight already characterized by high workload (e.g., climb or descent) and decrease workload during phases of flight already characterized by low workload (e.g., cruise). To the extent that CTM errors are positively correlated with workload, which has been shown (Chou et al, 1996), our findings agree with Wiener’s.

This also serves to emphasize the idea that current automation is not always appropriate in every phase of flight. This may be relevant to training on when, where, and why pilots should or should not use automation.

In this study, the single crew flying hours factor had a significant effect on the CTM performance. Figure 4 shows that subjects who had high single-crew flying hours tended to manage their tasks better compared to subjects who had low single-crew flying hours. However, this result may be explained by the fact that the flight simulator used for this study is a single-pilot part-task simulator. Further research is required to determine if single crew flying hours indeed plays a critical role in affecting CTM performance on a two-pilot flight deck. Nonetheless, this finding suggests that CTM performance might be improved through more single-pilot time both in the simulator and in the air.

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REFERENCES


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Program
11th International Symposium on Aviation Psychology

Sponsored by

The Department of Aerospace Engineering and Aviation of The Ohio State University
The US Association of Aviation Psychologists
The International Journal of Aviation Psychology

Columbus, Ohio, USA
March 5-8, 2001

Introduction

The Eleventh Biennial International Symposium on Aviation Psychology is being held at the Hyatt Regency in Columbus, Ohio, USA on March 5-8, 2001, sponsored by The Ohio State University’s Department of Aerospace Engineering and Aviation, The International Journal of Aviation Psychology, and the Association of Aviation Psychologists. AVIATION PSYCHOLOGY is the field of study concerned with the development and operation of safe, effective aviation systems from the standpoint of the human operator(s) who is (are) responsible for 70 to 80 percent of aircraft accidents. This Symposium series is offered for the purposes of 1) exposing current and potential human related problems in the international aviation community and 2) presenting the latest research findings aimed at the solution of these problems. The Symposium brings together both scientists, research sponsors, and operators in an effort to bridge the gap between research and application.

History/ Purpose/ Results

This biennial symposium series was first convened by the Aviation Psychology Laboratory in 1981 and has continued to grow internationally since that date. The objective of this meeting is to provide a forum for the critical examination of the impact of high technology on the role, responsibility, authority, and performance of human operations in modern civil and military aircraft and air traffic control systems all over the world. The symposium is aerospace safety oriented, though the symposium would be of value to anyone with an interest in human performance and behavior.

Theme

The theme for the Eleventh Symposium is “Focusing attention on aviation safety” among humans and between humans and their instruments and computers. Papers will be presented on this and other topics in aviation psychology including cockpit design, pilot selection, cockpit resource management, pilot judgment, stress, fatigue, automation in air traffic control accident investigation, and pilot workload.
11th International Symposium On Aviation Psychology

Schedule of Main Events

Sunday, March 4  1800-2000,  Registration, County Line Hallway
Monday – Thursday  0730-1700,  Registration, County Line Hallway
Monday, March 5  0830-1700,  Workshops, Various rooms (See Schedule)
Monday, March 5  1900-2200,  Opening Reception and Poster Session, Franklin Room
Tuesday, March 6  0830-0930,  Opening Plenary Session, Ballroom
Tuesday, March 6  1030-1700,  Paper sessions, Various rooms (See Schedule)
Tuesday, March 6,  1700-2200,  Banquet, Regency Ballroom
Tuesday, March 6,  1800-2100,  AAP Reception, Peppercorn Duck
Wednesday, March 7  0800-1700,  Paper sessions, Various rooms (See Schedule)
Wednesday, March 7  1200-1300,  IJAP Editorial Board Luncheon, Morrow Room
Thursday, March 8,  0800-1630,  Paper sessions, Various rooms (See Schedule)

Tuesday, March 6, 0800 – Thursday, March 8, 1200, Exhibits open

Tuesday, March 6 - Thursday, March 8, Coffee Breaks between each session in the Exhibit Room, Delaware A, B, C


**Exhibitors**

A variety of exhibits will be on display in Delaware A, B, and C throughout the Symposium for your examination and participation. Please stop by and take a look. The coffee breaks will be provided in the exhibit area.

The following have provided exhibits at the 11th Symposium:

**Ashgate Publishing Company, Brookfield, Vermont**

**Lawrence Erlbaum Associates, Mahwah, New Jersey**

**Aero Innovation, Inc., Saint-Laurent, Canada**

**Lafayette Instrument Company, Inc., Lafayette, Indiana**

**Checkout**

If you are planning to leave on Thursday, March 8, hotel checkout will be at 12:00 noon. The hotel has an area in the lobby to store luggage. If you need transportation to the airport, be sure to make arrangements at the hotel registration desk or with the bell person.

**Cost**

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Workshop Schedule, Monday, March 5

Morning Workshops, March 5, 0830-1200
(Coffee Break 1000-1015, County Line Hall)

1) (Union A) UNDERSTANDING THE HUMAN CONTRIBUTION TO SYSTEM FAILURE: A TUTORIAL
Dr. Sidney Dekker, Linkoping Institute of Technology, Sweden

2) (Union B) THE PSYCHOLOGY OF AIR WARFARE TRAINING
Dr. Malcolm J. Cook, University of Abertey Dundee, Scotland

3) (Union C) AN OVERVIEW OF THE DANGERS OF AIRCREW FATIGUE AND THE EFFECTS OF VARIOUS FATIGUE COUNTERMEASURES
Drs. John A. Caldwell, and J. Lynn Caldwell, US Army Aeromedical Research Division

4) (Union D) COGNITIVE ANALYSIS AND MODELING IN AVIATION DOMAINS
Dr. Wayne Zachary, CHI Systems, Inc.

5) (Union E) A HUMAN FACTORS APPROACH TO ACCIDENT ANALYSIS AND PREVENTION
Dr. Scott A. Shappell, FAA CAMI and Dr. Douglas A. Wiegmann, University of Illinois

6) (Delaware D) RISK ASSESSMENT TRAINING METHODS
Capt. Richard T. Barcheski, United Airlines

Afternoon Workshops, March 5, 1330-1700
(Coffee Break 1500-1515, County Line Hall)

7) (Union A) PRM: PERSONAL RESOURCE MANAGEMENT: HOW TO TRAIN SENSORY AWARENESS
Capt. Awad Thomas Fakoussa, Awareness Training, Germany

8) (Union B) METHODOLOGIES FOR TEACHING PROFESSIONAL AIRMANSHP: WHAT TO TEACH AND HOW TO TEACH IT
Dr. Robert O. Besco, Pilot Performance Associates

9) (Union C) USING PSYCHOPHYSIOLOGICAL MEASURES IN AVIATION
Dr. Glenn F. Wilson, Wright-Patterson AFB and Dr. Jared Lambert, Systronics, Inc.

10) (Union D) PREVENTING HUMAN ERROR IN CREW OPERATIONS
Dr. Patrick Veillette, University of Utah and Dr. Al Diehl, Albuquerque

11) (Union E) SITUATIONAL AWARENESS METRICS
Dr. Valerie Gawron, Veridian Engineering