LEARNING ABOUT COCKPIT AUTOMATION: FROM PISTON TRAINER TO MODERN JET TRANSPORT

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This study examines the usefulness of providing cockpit automation training to career-minded pilots using automation equipment commonly found in small training airplanes. After mastering a set of tasks and maneuvers of varying difficulty using a small-airplane GPS navigation computer, autopilot, and flight director system, eight student pilots were then tested on their ability to complete a similar set of tasks and maneuvers using a computer-based simulator of a popular jet transport aircraft. Pilots attempted the jet transport tasks with no prior exposure to the equipment, no training, and no reference materials. Pilots were told to try to apply the principles they had learned in the small airplane. The results indicate a high degree of success: pilots were able to successfully complete 77% of all tasks in the jet transport on their first attempt. An analysis of a control group that received no small airplane automation training suggests that the pilot trainees' success was attributable to the application of automation principles they had learned in the small airplane. The results cast a strong vote for the incorporation of cockpit automation training in curricula designed for pilots who will later transition to the jet fleet.

Introduction

Among the challenges of transitioning from small piston training airplanes to the modern jet fleet is the requirement of learning to use cockpit automation. Regional airline carriers continue to struggle with training new hire pilots coming from the world of general aviation training. Although the Federal aviation regulations (FARs) contain specific aeronautical knowledge and flight experience requirements for other topics such as aerodynamics, weather, regulations, and other aircraft systems, there are no such requirements for cockpit automation. Consequently, it is typically the case that pilots come to initial training with little or no experience with cockpit automation.

This work aims to bridge the gap between primary flight training and airline carrier training by taking advantage of the advanced cockpit automation that is now available in small training airplanes. Using modern GPS navigation computers, autopilots, and flight director systems available in piston training airplanes, a cockpit automation curriculum has been designed that teaches fundamental cockpit automation concepts and skills to the student pilot. The curriculum presents the student with opportunities to develop a range of cockpit automation skills, and to gain hands-on experience with the challenging job of performing pilot duties in concert with computers in the cockpit.

A Small-Airplane Cockpit Automation Curriculum

The curriculum we used to teach cockpit automation concepts and skills in the small airplane is given in a textbook entitled *Cockpit Automation for General Aviators and Future Airline Pilots*. [Casner, 2002].

A summary of the curriculum used in the textbook is given in Figure 1.

Planning the Flight Route
Electronic flight planning
Knobs and dials
Reviewing the flight plan

Following the Route
Monitoring progress
Position awareness
Descent planning
Precision approaches
Non-precision approaches
GPS approaches

En Route Modifications
Direct to
Diversions

Departing & Rejoining the Route
Intercept course
Intercept leg to
Intercept radial
Early and late descents
Maintaining awareness
Holds
Procedure turns
Missed approaches

Flying with an Autopilot
Autopilot functions
Flight mode annunciator
Flight director
Autopilot maneuvers
Climbs and descents
Headings
Intercepts
Armed vs. engaged
Approaches
Disconnecting the autopilot
Mode awareness and confusion

Figure 1: Cockpit automation curriculum elements.

The aim of the present study was to take the testing of the curriculum to the next level: to measure to what extent the skills mastered using automation found in piston training airplanes could be successfully transferred by students to the operation of the cockpit automation systems found in a jet transport aircraft.

Method

Participants
Sixteen commercial instrument rated pilots were recruited from local professional flight training schools. Pilots ranged from 300 to 1,600 hours of flight experience. Pilots were told they would not be paid for their participation but would receive instrument flight experience using cockpit automation.

Procedure
The sixteen pilots were divided randomly into two groups. The experimental group would work through the cockpit automation curriculum and then be tested using the jet transport computer-based simulator. A control group would be tested on the computer-based simulator first, without the cockpit automation training. The control group would later receive a portion of the cockpit automation training, but their performance not recorded as part of the experiment.

The purpose of the control group was to factor out any successes that might be enjoyed due to what Irving, Polson, and Irving [1994] refer to as *label following*. Label following occurs when a computer system provides simple cues about how it might be operated, typically in the form of labels that suggest the purpose or operation of knobs, buttons, and dials on the equipment. When using label following, operators can often succeed in completing a task without any knowledge or skill related to that task. For example, consider the task of calling up the Index page on a control display unit (CDU). A person with little or no knowledge about cockpit automation might notice the button labeled INDEX, shown on CDU in Figure 2, and correctly hypothesize that pushing this button will accomplish the task.

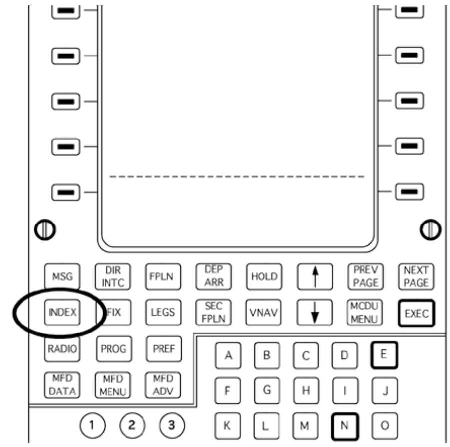

Figure 2: An example of a task that offers label following

Although label following cues are legitimate components of expert knowledge, we would like to distinguish between success attributable to true understanding of the system, and success due to label following.

Small-airplane automation sessions
The cockpit automation training occurred in five scheduled sessions. Prior to each session, each pilot was assigned a chapter to read in the cockpit automation book. Pilots were told to master the material as best as they could, and that during the upcoming session, they would have the opportunity to demonstrate and practice their newly learned skills in flight. It was emphasized that pilots' should attempt to master the skills such that they could demonstrate them without the need for intervention by the experimenter, although intervention would be available if needed.

During each session, the experimenter briefly reviewed the skills that would be covered during the flight, provide the pilot with charts covering the routes and approaches to be flown, and answered any questions the pilot had about the reading. The airplanes used for the flights contained the same GPS navigation computer, autopilot, and flight director system described in the cockpit automation book read by the pilots.

During the flight, the experimenter rode in the right seat and did not operate the controls. A script/checklist for each flight was prepared in advance and used by the experimenter to ensure that each flight proceeded in accordance to a set plan, and that each pilot was presented with exactly the same tasks. A palmtop computer was used to record any interventions required by the experimenter, errors made by the pilot, or assistance requested by the pilot for any task. A scorecard was kept for each pilot and flight. For each task, if the pilot was able to complete the task with no intervention on the part of the experimenter, the pilot received a score of 1. If an intervention of any form, regardless of how subtle (e.g., words, gestures, sounds), was required, a score of 0 was recorded for that task.

The topics introduced during the five flight sessions are summarized in Figure 3. It is important to note that the first four flights gradually introduce new skills, while providing opportunity to practice previously learned skills. The fifth flight was intended as a "check" flight. No new skills were introduced and the aim was to measure the pilots' current level of proficiency.

Flight 1
Check navigation database
Enter en route waypoints and procedures
Review route
Monitor active waypoint and progress
Plan a descent w/crossing restriction
Direct to
Add and delete waypoints
GPS approach to minimums

Flight 2
Intercept course
Vectored GPS approaches

Flight 3
Missed approaches
Holds

Flight 4
Autopilot: Heading
Autopilot: Constant-rate climbs and descents
Autopilot: Intercepts

Flight 5
Check proficiency on all maneuvers

Figure 3: Breakdown of the five small airplane cockpit automation training flights

<u>Jet transport automation sessions</u>
Following the conclusion of the small airplane training sessions, all sixteen pilots participated in a test session in which they were asked to perform a series of tasks using a computer-based simulation of the cockpit automation systems found in a popular jet transport airplane. Eight of the pilots had received the small airplane cockpit automation training and eight had not. It was explained that pilots would receive no training on the jet transport systems or have the opportunity to access any reference materials for the systems. The aim of the study was to determine to what extent their existing knowledge could help guide them through the tasks. The experimental group had their instrument flying skills together with their small-airplane cockpit automation training. The control group had their instrument flying skills to guide them, together with any label following cues present on the jet transport automation equipment

During the jet transport systems session, the same data collection procedure was used. Pilots were presented with tasks and asked to do their best to perform them without asking for intervention from the experimenter. If an impasse was encountered, pilots could ask for intervention, these interventions were recorded, and a score of 0 was recorded for that task. Since the jet transport travels as much as five times faster than the piston airplane, the simulation was frozen while the experimenter took the time to provide the needed help. A scorecard similar to the one used during the cockpit automation training was used to record interventions made by the experimenter.

Results and Discussion

Overall Performance
A first question posed by the experiment is the extent to which the small-airplane cockpit automation training and experience leveraged pilot performance when presented with the jet transport airplane automation. Figure 4 shows a graph of the individual pilots' scores for the jet transport automation tasks. The pilots that received the small airplane cockpit automation training performed significantly better than the control group ($df = 14$, $t = 6.23$, $p < .001$).

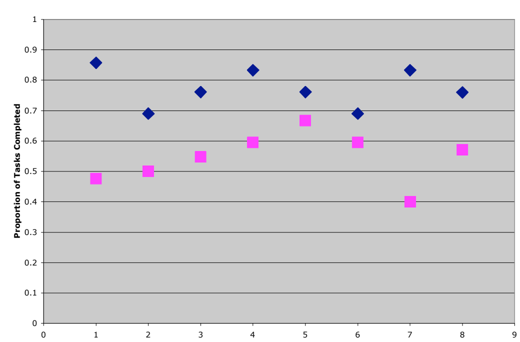

Figure 4: Percentage of tasks completed correctly for the training and no training groups.

The overall performance of the experimental group casts a vote for the usefulness of cockpit automation training in small airplanes. Pilots were able to successfully perform 77% of all tasks on the jet transport airplane on the first try.

Success Due To Label Following
The 54% mean success rate of the control group prompts the question of to what extent was their success attributable to superficial label following. To answer this, tasks were divided into two groups, those for which label cues appeared on the equipment, and those for which no cues appeared. The graph in Figure 5 shows the results for the experimental and control groups on label-cued and non-label-cued tasks

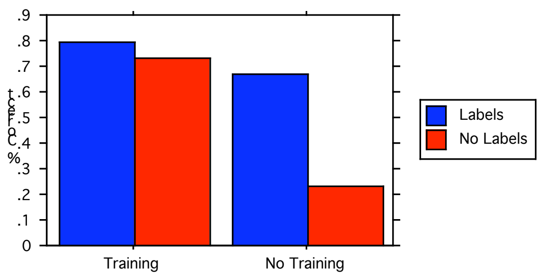

Figure 5: Breakdown of scores for tasks completed with and without presence of label cues.

A 2-way analysis of variance reiterated the main effect due to receiving the cockpit automation training (F=67.5, $p < .001$), a main effect due to the presence of label cues (F=44.5, $p < .001$), and a significant interaction between the two factors (F=25.1, $p < .001$).

For the pilots who received the cockpit automation training, there was no significant difference between the two task types, suggesting that the cues provided by their knowledge were as strong as the cues provided by the labels. The pilots who received no automation training performed well when label cues were present but poorly in the absence of label cues. This suggests that their success proceeded in the absence of understanding of how to operate the systems. Lastly, the pilot who received the small airplane automation training performed significantly better on tasks for which label following was possible, than did their control group counterparts. This suggests that the training group imparted knowledge on tasks even when label cues were present, and this knowledge led to significantly greater performance.

Breakdown By Task
A second item of interest is a breakdown of the tasks that pilots were asked to perform using the jet transport automation. Figure 6 lists the tasks along with the proportion of the tasks that were performed correctly.

Task	**Tr.**	**Cnl**	**t-Test**
Check navigation database	.88	.25	p < .01
Position initialization	.58	.54	No
Enter en route waypoints and procedures	.94	.81	No
Review route	.69	.56	No
Execute modifications	.25	.25	No
Monitor active waypoint and progress	1	.94	No
Direct to	.88	.75	No
Add and delete waypoints	.79	.37	p < .05
Hold	.81	.63	No
Enter crossing restriction	.63	.5	No
Explain purpose of entering crossing restriction	.75	.13	p < .01
Constant-rate climbs and descents	.66	.13	p < .001
Heading	.75	.75	No
Intercept course	.75	.25	p < .001
Constant-speed climbs and descents	1	1	No

Figure 6: Percentage of tasks successfully completed by pilots who did and did not receive small-airplane cockpit automation training.

As expected, pilots performed best on tasks that resembled tasks that they had learned during their small airplane cockpit automation training. For example, nearly all pilots completed the Monitor active waypoint and progress, and Enter en route waypoints and procedures tasks. These concepts and procedures were nearly identical to the ones learned in the small airplane. Other tasks, such as Direct to and Check navigation database, were similar but not identical. Pilots experienced high degrees of success on these tasks. Some tasks, such as Position initialization and Execute modifications, were completely absent from the small airplane equipment and training. Pilots had little success in completing these tasks.

The most encouraging result is the intercept course task. Previous studies with experienced airline pilots has shown this task to be difficult [Irving, Polson, and Irving, 1994]. The intercept course task combines several advanced concepts such as the notions of departing and rejoining the planned route, and armed vs. engaged autopilot modes. Less than 70% of Irving et al's airline pilots successfully completed this maneuver following explicit training on the maneuver with the same equipment used to test them. The experimental group described here completed the task successfully 75% of the time. There is reasonable evidence to suggest that there suggest is due to the emphasis the automation materials place on conceptual understanding of the task. Pilots are taught to ask themselves two questions that are promised to guide them in any advanced route modification task: (1) Where am I going? And (2) How am I going to get there? One pilot foundered on the task for about thirty seconds and then spontaneously verbalized the two questions. The pilot quickly assembled a procedure that successfully solved the problem

Two tasks unexpectedly tripped up roughly half of the pilots. One was the constant-rate descent task. This procedure is almost identical to the one used in the small-airplane automation, and one for which most pilots had demonstrated mastery. When pilots were given the first step in the procedure, they were generally able to complete the remaining steps immediately.

A second task that challenged subjects was the Plan a descent w/crossing restriction task. The solution for this task is also somewhat similar to the solution used on the small-airplane automation.

Comparing Small and Jet Airplane Performance
It is also interesting to look at the relationship between pilots' performance during the small-airplane training and their subsequent performance on the jet transport equipment. Figure 7 shows a graph of pilots' performance on the final small-airplane flight together with their performance on the jet transport tasks. The correlation between the two sets of scores was R=0.73, providing further evidence that their success on the jet transport tasks was related to their exposure to the small airplane training.

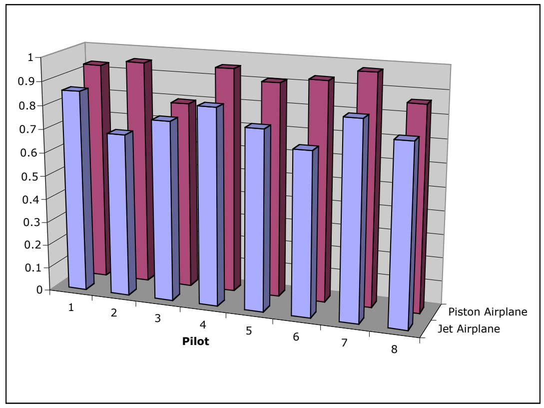

Figure 7: Percentage of tasks successfully completed on piston and jet airplanes.

Conclusion
The results of this study demonstrate that a relatively small investment made in acquiring basic skills with cockpit automation, now readily available to most any student pilot, can have a significant impact on the readiness of that pilot when later confronted with more sophisticated cockpit automation. This situation appears to provide a simple, cost-effective solution to the problem of new-hire pilots arriving to airline initial training programs with little or no cockpit automation experience.

A principle lesson learned during our study of teaching cockpit automation is the value of teaching underlying principles of automation and automation use rather than teaching simple button-pushing procedures. It must be reiterated that *neither* group received training on the jet transport airplane. The success of the training group can only be attributed to the learning and application of generalized concepts and principles acquired during their training using different automation equipment.

This result is consistent with previous studies that have demonstrated that teachings focused on knobs, dials, and procedures result in fast training times, but also tend to result in brittle skills that are typically not transferable to other aircraft, or problems and situations that are different from those learned during training [Kieras and Bovair, 1984].

Alternatively, training that attempts to provide the learner with procedures couched in deeper understanding often avoids the limitations suffered by "knobs and dials" training. This study clearly demonstrates how one properly presented skill set can be transferred and applied to new, more sophisticated equipment.

With cockpit automation now common in the piston-engine training airplanes used in flight schools across the U. S., there seem to be few obstacles to providing these much-needed skills to career-minded student pilots.

References

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