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Learning About Cockpit Automation: From Piston Trainer to Jet Transport

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Summary

This study explores the idea of providing cockpit automation training to airline-bound pilots using advanced automation equipment now commonly found in small piston training airplanes. This idea takes advantage of the striking similarity between the small-airplane cockpit automation systems and those found in popular jet transport airplanes. Two curricula are described designed to teach cockpit automation in airplanes big and small, exploiting the overlap between the two. Two experiments were conducted to evaluate the feasibility and effectiveness of this kind of "bridge" training that allows students to get hands-on learning and experience with cockpit automation early in their pilot training. In a first experiment, pilots mastered a set of tasks and maneuvers of varying difficulty using a small airplane GPS navigation computer, autopilot, and flight director system. Students were then tested on their ability to complete a similar set of tasks and maneuvers using a computer-based simulator of the flight management and guidance systems found in 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, rather than superficial strategies guided by words and labels that appear on the knobs and buttons of the automation equipment. A second experiment looked at two different ways of delivering small-airplane cockpit automation training: (1) a self-study method in which pilots were assigned readings in advance and were then evaluated in flight; and (2) a dual ground instruction method in which pilots received one-on-one instruction immediately prior to each flight. The results showed a slight advantage for the self-study method. Overall, the results of the two studies 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. Airline carriers continue to struggle with training pilots transitioning from the world of general aviation training, or from non-glass cockpit equipped aircraft (refs. 1 and 2). Studies of cockpit automation use continue to point to areas in which automation training should be improved (refs. 3, 4, 5, 6, and 7). Although the Federal Aviation Regulations (FAR) contain specific aeronautical knowledge and flight experience requirements for other topics such as aerodynamics, weather, regulations, and even other aircraft systems, there are no such requirements for this emerging and critical component of pilot skill. Consequently, it is typically the case that pilots come to initial job training with little or no experience with cockpit automation.

This work aims to bridge the gap between efforts to train future professional pilots 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. This curriculum has been designed to match a second curriculum aimed at teaching cockpit automation skills in jet transport airplanes. Taken together, the two curricula provide a simple, low-cost solution to the problem of teaching these important skills.

This Technical Memorandum briefly describes the two curricula and reports the results of two empirical studies. In a first study, student pilots completed the cockpit automation training curriculum in a piston-engine training airplane. Upon completion of this training, pilots were then asked to demonstrate the same set of skills using a computer-based simulation of the cockpit automation suite found in a popular jet transport airplane. Pilots' performance during the small-airplane cockpit automation training and their performance with the jet transport simulation were recorded and analyzed. In a second study, two alternatives for delivering small-airplane cockpit automation training were considered: one-on-one instruction with a ground instructor, and a self-study program in which pilots read written materials on their own time.

The results of the two studies clearly indicate that time spent learning about and gaining experience with cockpit automation in piston training airplanes pays large dividends when later confronted with the task of mastering automation found in the jet fleet.

A Big Airplane Cockpit Automation Training Curriculum

Casner (ref. 8) describes a detailed curriculum covering basic and intermediate cockpit automation skills and concepts needed to work proficiently in the modern airline cockpit. The curriculum uses the flight management computer, autopilot, and flight director systems found in most modern jet transports (see figure 1) to teach skills and concepts required to work cooperatively and proficiently with automation when performing the traditional tasks of flight navigation, guidance, and control.

The program of concepts and skills contained in the curriculum benefits from almost twenty years of laboratory and field research, along with inputs gathered from airline training departments, avionics manufacturers, and individual line pilots, instructors, and check airmen who have accumulated much experience teaching and using cockpit automation.

The curriculum goes beyond previous efforts to prescribe proficiency standards for cockpit automation in that it contains more than skills or procedures that must be memorized by rote and demonstrated by the student. This curriculum requires that the student understand the underlying principles of how the automation works and how the flight crew and automation work together as a team. Particular emphasis is placed on how the role of the flight crew is changed when automation is used, the ways in which the system of flight crew and automation can break down, and strategies for delegating work among flight crew and automation equipment. The curriculum described in the book sets the mark for the skilled and aware pilot in the modern airline cockpit.

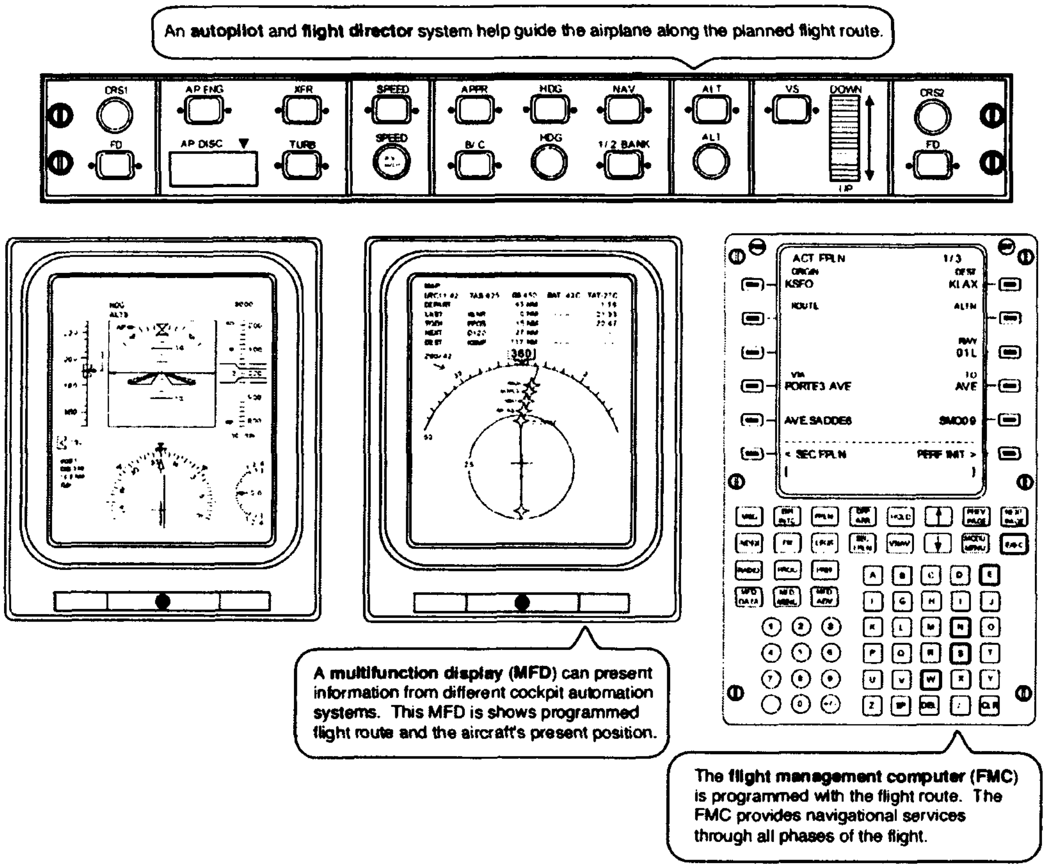

Figure 1. Cockpit automation typical of a jet transport aircraft.

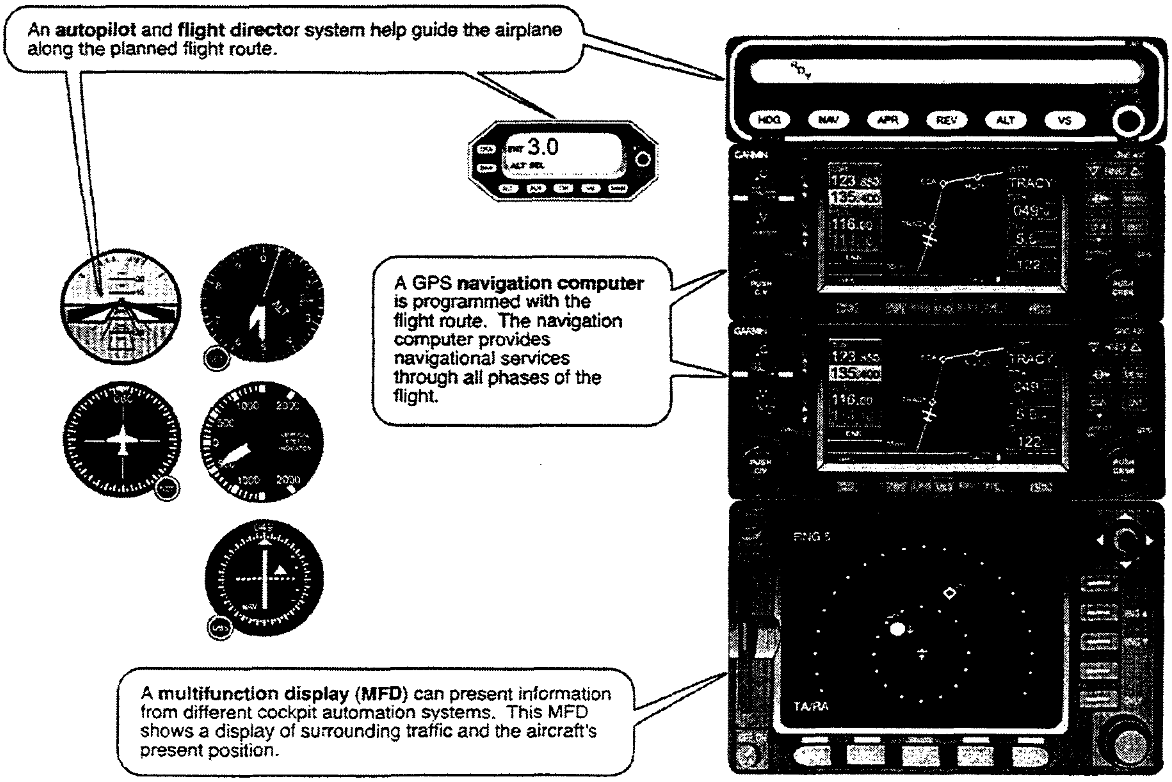

Figure 2. Cockpit automation typical of a small piston training airplane.

CONCEPT or SKILL	*PISTON*	*JET*
Planning the Flight Route		
Basics of electronic flight planning	X	X
The flight navigation computer	X	X
Learning the knobs, dials, and buttons	X	X
Entering the basics of the flight route	X	X
How the navigation computer calculates the details	X	X
Calculating the lateral portion of the route	X	X
Calculating the vertical portion of the route	Some	X
Importance of reviewing the flight plan	X	X
Mistakes humans make	X	X
Mistakes computers make	X	X
Following the Flight Route		
Monitoring progress along the route	X	X
Lateral guidance	X	X
Vertical guidance	Some	X
Staying in the loop	X	X
Descent planning	Some	X
Precision approaches	X	X
Non-precision approaches	X	X
RNAV approaches	X	X
En Route Modifications		
Direct to	X	X
Diversions	X	X
Departing & Rejoining the Route		
Intercept course	X	X
Intercept leg to	X	X
Intercept radial	X	X
Early and late descents	X	X
Maintaining awareness	X	X
Holds	X	X
Procedure turns	X	X
Missed approaches	X	X
Flying with an Autopilot and Flight Director		
Autopilot functions & targets	X	X
The flight mode annunciator	X	X
The flight director	X	X
Autopilot maneuvers	X	X
Climbs and descents	X	X
Headings	X	X
Intercepts	X	X
Armed vs. engaged	X	X
Approaches	X	X
Disconnecting the autopilot	X	X
Mode awareness and confusion	X	X

Figure 3. Common elements of the cockpit automation curricula.

A Small Airplane Cockpit Automation Training Curriculum

Casner (ref. 9) describes a second cockpit automation curriculum designed to teach the same set of concepts and skills using cockpit automation systems now common in many small training airplanes. In the place of the flight management computer, autopilot, and flight director systems found in jet transport airplanes, this curriculum makes use of the GPS navigation computers, autopilots, and flight director systems (see figure 2) found in small training airplanes.

Although there are many cosmetic differences between the two systems, the underlying operating principles, as well as the human factors issues of working with computers in the cockpit, are fundamentally the same.

Comparing the Two Cockpit Automation Curricula

Figure 3 summarizes the elements of the two cockpit automation curricula, highlighting the similarities between the two.

Figure 3 shows that most of the concepts and skills covered in the jet transport airplane curriculum are also covered in the small airplane curriculum. The small airplane 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 cockpit duties in concert with sophisticated automation systems.

EXPERIMENT 1

The aim of the first experiment was to answer the most basic question about cockpit automation training in airplanes big and small: To what extent can cockpit automation concepts and skills acquired in a small piston training airplane be successfully transferred to the operation of the cockpit automation systems found in a jet transport aircraft?

In this experiment, we used a simulation of a popular jet transport airplane to compare the performance of two groups of pilot participants. One group of pilots completed a cockpit automation training program taught in a small piston training airplane. A control group of pilots received no such training.

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 with a mean of 1106 hours. 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 small airplane 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 small-airplane cockpit automation training. The control group would later receive a portion of the small-airplane cockpit automation training, but their training or performance was 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 (ref. 10) 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 4, and correctly hypothesize that pushing this button will accomplish the task.

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.

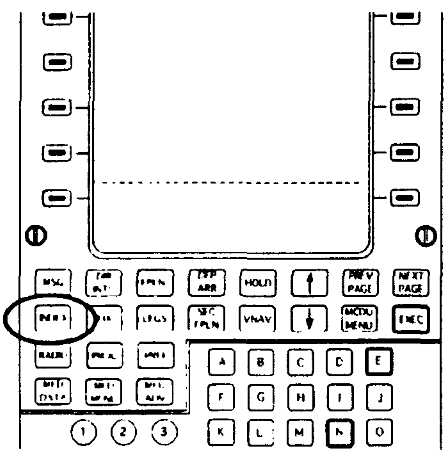

Figure 4. An example of a task that offers label following.

The small airplane cockpit automation training program

For the eight pilots participating in the treatment group, the small airplane cockpit automation training occurred in five scheduled sessions. Prior to each session, each pilot was assigned a chapter to read in the small airplane cockpit automation book (ref. 9) 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, provided 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 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 the same set of scripted tasks. A palmtop computer was used to record any interventions required by the experimenter for each task, errors made by the pilot on any task, 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

Flight 1	***Flight 3***
Check navigation database	Missed approaches
Enter waypoints and procedures	Holds
Review route	
Monitor active waypoint and progress	
Plan a descent w/crossing restriction	***Flight 4***
Direct to	Autopilot: Heading
Add and delete waypoints	Autopilot: Constant-rate climbs and descents
GPS approach to minimums	Autopilot: Intercepts
	Flight 5
Flight 2	Check proficiency on all maneuvers
Intercept course	
Vectored GPS approaches	

Figure 5. Breakdown of the five small airplane cockpit automation training flights.

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. Appendix 1 presents the complete script of tasks for each of the five sessions.

The topics introduced during the five flight sessions are summarized in figure 5. It is important to note that the first four flights gradually introduce new skills, while providing opportunity to practice skills learned on the previous flights. 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.

The jet transport simulator evaluation

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 treatment 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. As in Experiment 1, if a pilot was unsuccessful on a particular task, the experimenter demonstrated the task before moving on to the next 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

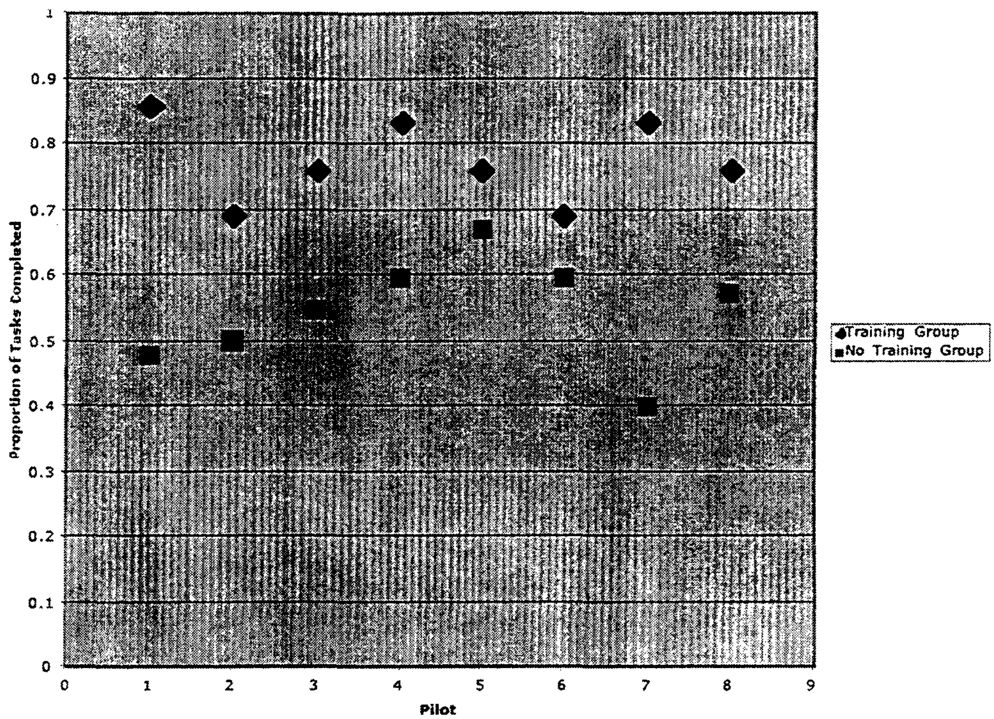

Figure 6. Percentage of tasks completed correctly for the individual pilots in the training and no training groups.

needed interventions. A scorecard similar to the one used during the cockpit automation training was used to record interventions made by the experimenter. The complete script of tasks for the jet transport sessions is presented in Appendix 2.

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 6 shows a graph of the percentage of tasks completed correctly by each pilot using the jet transport automation. The dots in figure 6 represent individual scores (on all tasks combined) for the sixteen pilots. The pilots who received the small airplane cockpit automation training performed significantly better than the control group ($df = 14$, $t = 6.23$, $p < .001$).

The overall performance of the experimental group casts a vote for the usefulness of cockpit automation training in small airplanes. These 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 mean success rate of 54% for 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 7 shows the results for the experimental and control groups on label-cued and non-label-cued tasks.

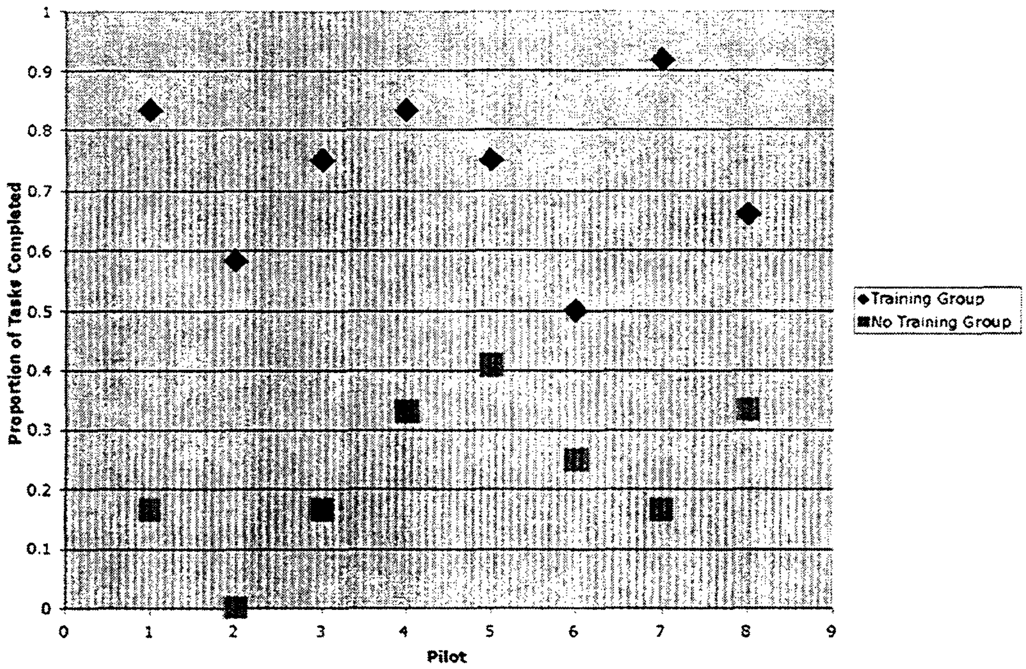

Figure 7. Breakdown of scores for tasks completed with and without presence of label cues.

A 2-way analysis of variance reiterated the main effect of the advantage due to receiving the small-airplane 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 small-airplane 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 cockpit automation training performed well when label cues were present but poorly in the absence of label cues. This suggests that their success occurred in the absence of understanding of how to operate the systems. Lastly, the pilots who received the small-airplane cockpit 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 Procedure

A second interesting way to look at pilot performance is to consider the particular tasks that pilots were asked to perform using the jet transport automation. Since the list of tasks is quite lengthy (see Appendix 2) and many of the tasks are related, figure 8 organizes the tasks into groups that pilots typically refer to as *procedures*. A procedure is defined as a collection of tasks that lead to the accomplishment of a goal. For example, the `Enter waypoints and procedures` procedure is composed of six tasks that accomplish the goal of entering a flight route into the flight computer.

When looking at the data in figure 8, it is important to note that the scores for the procedures listed in figure 8 represent the scores recorded for all of the component tasks in each procedure. For example, if a pilot successfully completed the first three tasks in the `Enter waypoints and` `procedures` procedure but failed to complete the last three, a score of .5 would result.

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 `Enter en route waypoints and procedures` and `Monitor active waypoint and progress` procedures. These procedures, along with their associated concepts, were nearly identical to the ones learned in the small airplane. Other procedures, such as `Direct to` and `Check navigation database`, were similar but not identical. Pilots experienced high degrees of success on these procedures. Some procedures, such as `Position initialization` and `Execute modifications`, were completely absent from the small airplane equipment and training. Pilots had little success in completing these procedures.

The most encouraging result is the intercept course procedure. Previous studies with experienced airline pilots have shown this task to be difficult (ref. 10). The intercept course procedure combines several advanced concepts such as the notions of departing and rejoining the planned route, and armed vs. engaged autopilot modes. Slightly less than 70% of Irving et al's airline pilots who had just completed an airline initial training course on a Boeing 737-300 were able to

Task	**Trained Group**	**Control Group**	**t-Test**
Check navigation database	.88	.25	$p < .01$
Position initialization	.58	.54	No
Enter 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 8. Percentage of procedures successfully completed by pilots who did and did not receive small-airplane cockpit automation training.

successfully complete this procedure following explicit training using the same equipment used for the test. The experimental group described here completed the task successfully 75% of the time. There is reasonable evidence to suggest that this was due to the emphasis the automation materials place on conceptual understanding of the task. In the cockpit automation textbook, pilots are taught to ask themselves two questions that are promised to guide them in any advanced route modification situation: (1) Where am I going? and (2) How am I going to get there? One pilot foundered on the procedure for about thirty seconds and then spontaneously verbalized the two questions. The pilot quickly assembled a procedure that successfully solved the problem.

Two procedures unexpectedly tripped up roughly half of the pilots. One was the constant-rate descent procedure. 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 procedure that challenged subjects was the `Enter crossing restriction` procedure. The solution for this procedure is also somewhat similar to the solution used on the small-airplane automation.

Correlating Total Flight Time and Performance with Cockpit Automation

A last interesting analysis is to look at the relationship between the total flight experience of each pilot participant and their performance with the jet transport cockpit automation. For the group that received the small airplane cockpit automation training, the correlation was –0.36. For the group that did not receive the small airplane training, the correlation was 0.15. These results suggest that there is little link between total flight time and mastery of cockpit automation. Stated in another way, total flight time does not appear to serve as a substitute for training and experience with cockpit automation. Cockpit automation proficiency appears to be a unique set of skills that must be learned in addition to basic airmanship.

EXPERIMENT 2

After demonstrating the usefulness of providing small airplane cockpit automation training, a second experiment was designed to examine the differences between delivering the small airplane cockpit automation instruction to students in two different ways. In one condition, the material was presented to students in the form of a book to be read in their own time, as was done in Experiment 1. In a second condition, the material was presented to students in a traditional one-on-one ground instruction scenario. These conditions were designed to represent two ways in which pilots might learn about cockpit automation: (1) as part of a program of instruction at a flight school; or (2) on a self-study basis as is frequently done for many aviation topics.

For this experiment, a different airplane was used that contained a different manufacturer's GPS navigation computer and autopilot. Therefore, the condition in which material was presented to students in book form was replicated to control for any differences that might exist between the two airplanes. Having two data sets for which students used two different kinds of navigation computers would also permit an informal comparison between the two kinds of navigation computers.

Method

Participants

Sixteen commercial instrument-rated pilots were recruited from local professional flight training schools. Pilots ranged from 120 to 3,700 hours of flight experience, with a mean of 790 hours. Pilots were told they would not be paid for their participation but would receive instrument flight experience using cockpit automation.

Procedure

All sixteen pilots received the small airplane cockpit automation training, individually, in the same five scheduled sessions used in Experiment 1. The sixteen pilots were divided randomly into two groups prior to the first scheduled session.

The Self-Study group received a version of the cockpit automation book described in Experiment 1. This version of the book used a different manufacturer's GPS navigation computer to explain the same cockpit automation curriculum. In the same manner as Experiment 1, these pilots were assigned readings in the cockpit automation book prior to each session. 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.

The Dual-instruction group was told to do nothing to prepare for the flight sessions. These pilots were told that the experiment would cover all of the concepts and skills needed for each flight during a dual ground instruction session immediately prior to the flight. Pilots were told that the experimenter would answer any questions the pilot might have to bring them to the level at which the pilot felt he or she could demonstrate the skills without the need for intervention by the experimenter, although intervention would be available if needed.

For both groups, prior to each flight, the experimenter briefly reviewed the skills that would be needed during the flight, provided the pilot with charts covering the routes and approaches to be flown, and answered any questions the pilot had about the material.

During the flight, the experimenter rode in the right seat and did not operate the controls. The same script used for Experiment 1 was 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 for any task, errors made by the pilot on any task, 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.

Results and Discussion

The mean and standard deviation for the Self-study and Dual-instruction groups were: 0.981 (.023) and 0.91 (.073), respectively. A two-tailed t-test yielded a significant difference between the two groups ($df = 14$, $t = 2.62$, $p < .05$).

A small advantage was observed for the Self-study group. Even though the Dual-instruction group had the benefit of

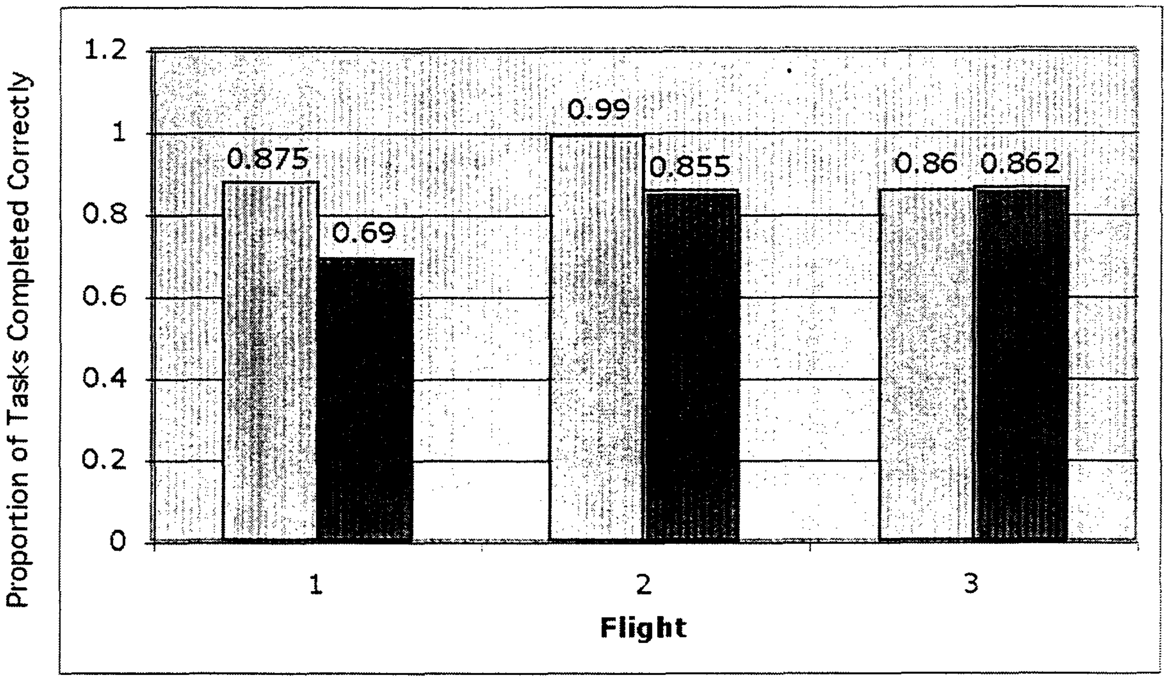

Figure 9. Percentage of tasks successfully completed by different pilots using different manufacturers' navigation computer.

having the procedures explained and demonstrated on a one-on-one basis, the Self-study group performed slightly better. There are a number of plausible explanations for the advantages of written material over verbally-delivered material that have been observed in previous studies of learning. First, users of written material are able to control the pace of instruction: they can proceed to a new sentence, paragraph, or topic when they decide they are ready. Second, users of written material have a persistent record of the instructional material that they can review as much as they wish. Listeners must rely on handwritten notes to record information they feel they may need in the future. It is interesting to note that none of the pilots in the Dual-instruction group made use of notes.

Comparing the Two Manufacturers' Navigation Computers

A direct comparison of the navigation computers used in Experiments 1 and 2 is difficult for a number of reasons. First, the airplane used in Experiment 2 contained a much more sophisticated autopilot, and this autopilot played an important role during flights 4 and 5. Therefore, a direct comparison of data including these two flights would be meaningless. We could look at the data for the first three flights only, and examine the success rates as pilots worked toward mastery of the two computers. Figure 9 shows the mean scores for the proportion of navigation computer programming tasks completed correctly by the treatment group from Experiment 1, and the Self-study group from Experiment 2.

Three t-tests showed a significant difference for the two navigation computers for Flight 1 ($df=14$, $t=2.06$, $p <$

0.05), and for Flight 2 (df=14, t=3.43, $p < 0.01$), but no significant difference for Flight 3.

These data suggest that pilots had a more difficult time mastering one computer than the other, and this result agrees with the experimenter's experience in the cockpit with the pilot participants. Although neither navigation computer is more sophisticated than the other, one of the computers contains design features that are inconsistent with human factors principles that are known to lead to errors and longer learning times. A principal problem with the navigation computer used in Experiment 2 was a lack of consistency among conventions used in the user interface. The navigation computer used in Experiment 2 sometimes requires the user to learn different procedures for accomplishing the same task under different circumstances. In other circumstances, this computer leaves the user with ambiguous displays that provide few clues about how to proceed to the next step in a procedure. These design features required pilots to memorize work-arounds for these situations, and a few flights were required before pilots reached proficiency.

Conclusion

A number of conclusions can be drawn from the research described above:

Cockpit Automation Skills Learned in Small Airplanes Transfer to Big Airplanes

A relatively small investment made in acquiring basic skills and experience with cockpit automation, now readily available to most student pilots, can have a tremendous impact on the readiness of that pilot when later confronted with more sophisticated cockpit automation. The demonstrated usefulness of cockpit automation found in small training airplanes appears to provide a simple, cost-effective way of introducing cockpit automation to pilots who are still in the formative phases of their professional aviation careers. This should greatly alleviate the problem of new-hire pilots arriving to airline initial training programs with little or no cockpit automation experience.

It Is Important to Teach Concepts Along With Skills

A principle lesson learned during this research is the value of teaching underlying principles of cockpit automation and automation use in addition to teaching button-pushing procedures. It must be reiterated that, in Experiment 1 described above, *neither* group received training on procedures required to complete the jet transport airplane tasks. Furthermore, looking at figures 1 and 2, we can see that the knobs, dials, and procedures used to operate the devices found in each airplane are quite different. The success of the group who received the small airplane cockpit automation training 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 equipment, or problems and situations that are different from those learned during training. Teaching rote procedures helps students learn specific procedures quickly. However, if the equipment or situations encountered in the real world differ from those taught in the classroom, and challenge the student in new ways; expect poor results. Alternatively, training that attempts to provide the learner with procedures couched in deeper understanding often avoids the limitations suffered by "knobs and dials" training. Kieras and Bovair (ref. 11) demonstrated how students who received "how it works" explanations for a set of procedures they had learned were significantly more successful when presented with related problems that challenged them in different ways. Pennington et al (ref. 12) conducted a similar study. Chi et al (ref. 13) looked specifically at how students generated and successfully used their own "self-explanations" while solving problems.

This study demonstrates again how an appropriately-presented skill set can be transferred and applied to new, more sophisticated equipment.

Proficiency with Cockpit Automation is a Unique Skill Set That Must Be Learned

It appears that proficiency with cockpit automation is a separate set of skills to be acquired. Having extensive experience in airplanes not equipped with cockpit automation systems does not appear to be a substitute for explicit cockpit automation training. Working proficiently with advanced computer systems seems to be the result of training and experience working with advanced computer systems.

Both Dual-instruction and Self-Study/Practice Methods Can Lead to Successful Learning

In the U. S. aviation industry, future professional pilots come from a variety of training channels. Some pilots receive their training as partial fulfillment of a university degree program. For these pilots, aviation knowledge and skill areas that are not part of the required training for any FAA certificate or rating are introduced in the classroom, as part of course work required by the university as degree requirements. Other pilots take university degrees in other, often related, fields, and accomplish their FAA certificate flight training on their own at local flight schools and training academies. These pilots typically learn about aviation topics not required as part of the FAA certificates and ratings on their own, relying on other, more experienced pilots, and an expanding market of aviation training materials such as books, videos, and computer-based simulations.

The second experiment described above demonstrated that an appropriately-designed and appropriately-followed cockpit automation curriculum can be effectively undertaken in either of these two popular learning situations.

Learning Opportunities for Cockpit Automation Are Becoming Widely Available

A growing market for learning resources for cockpit automation presents a variety of opportunities for providing these much-needed skills to career-minded student pilots. A first category of learning aids are the books about cockpit automation that are now widely available (refs. 8, 9, 14, 15, 16, and 17).

A second type of learning resource are the computer-based simulators that provide opportunities for hands-on practice. Garmin (www.garmin.com) and Bendix-King (www.bendixking.com) offer computer-based simulations of their GPS navigation computers that can be downloaded free of charge from their web sites. Aerowinx (www.aerowinx.com) offers a fully-functional desktop simulation of a Boeing 747-400 for $250. Lastly, many small training airplanes now come equipped with GPS navigation computers, autopilots, and flight directors. Hands-on access to sophisticated cockpit automation systems may be available at your local flight school.

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Appendix 1

Script of Tasks Used for the Small Airplane Cockpit Automation Training Flights

Flight 1: SQL-O27-SQL

- SQL-O27
  - Program SQL-Sunol-Tracy-ECA-O27 on ground
  - Announce Sunol
  - Program VNAV ECA @ 3,000
  - Announce Tracy
  - Announce ECA
  - Announce Moter
  - Announce approach active mode
  - Announce Eltro
  - Aircraft control
- O27-SQL
  - Program O27 to SQL on ground
  - Insert Tracy and Sunol
  - Program diversion
  - Look up rwy length and frequency
  - Program Sunol to SQL
  - Aircraft control

Flight 2: SQL-MOD-SCK-LVK-SQL

- SQL-MOD
  - Program SQL-Sunol-Tracy-Cazli-MOD on ground
  - Set OBS 009 to Sunol
  - Set GPS to sequencing mode
  - Announce Sunol
  - Announce Tracy
  - Set OBS 018 to Awoni
  - Announce Awoni
  - Set GPS to sequencing mode
  - Announce approach active mode
  - Announce Wowar
  - Aircraft control
- MOD-SCK
  - Program MOD-SCK on ground
  - Set OBS 291 to Oxjef
  - Set GPS to sequencing mode once established

Announce Oxjef
Announce approach active mode
Announce Ipdew
Aircraft control

SCK-LVK

Program SCK-LVK on ground
Set OBS 246 to Uhhut
Set GPS to sequencing mode
Announce Uhhut
Announce approach active mode
Announce Oyahi
Aircraft control

Flight 3: SQL-STS-KDVO-O69-SQL

SQL-STS

Program SQL-STS
Set OBS 321 to Zijbe
Set GPS to sequencing mode
Announce Zijbe
Announce approach active mode
Announce Gokuw
Aircraft control

STS-DVO

Program STS-DVO on ground
Set OBS course to Oriby
Announce Oriby
Announce approach active mode
Announce Eyeji
Program direct to SGD
Set OBS 180 to SGD for hold
Program SGD-O69
Aircraft control

DVO-O69

Set OBS 268 to Ipary
Set GPS to sequencing mode when established
Announce approach active mode
Announce Ipary
Aircraft control

Flight 4: SQL-MRY-WVI-HAF-SQL

SQL-MRY

Program SQL-OSI-Sapid-Santy-Mover-SNS-Llynn-MRY on ground
Engage Heading Select
Engage VS and arm Altitude Hold
Set OBS 141 to Sapid
Arm Nav to capture course
Set GPS to sequencing mode

Announce Sapid
Engage VS and arm Altitude Hold
Announce Santy
Engage Heading Select
Set OBS 286 to Raine
Arm Approach to capture course
Set GPS to sequencing mode when established
Announce approach active mode
Announce Raine
Announce 7.2NM waypoint

MRY-WVI

Program MRY-WVI on ground
Engage VS and arm Altitude Hold
Set OBS 314 to Dyner
Arm Approach to capture course
Set GPS to sequencing mode when established
Announce approach active mode
Announce Dyner

WVI-HAF

Program WVI-HAF on ground
Announce Giruc
Set GPS to OBS mode for hold
Set GPS to sequencing mode
Engage Approach to capture course
Announce approach active mode
Announce Wohli

Flight 5: SQL-O27-SCK-1O3-LVK-SQL

SQL-O27

Program SQL-Sunol-Tracy-ECA-O27 on ground
Announce Sunol
Engage VS and arm Altitude Hold
Program VNAV ECA @ 3,000
Engage VS and arm Altitude Hold
Announce Tracy
Set OBS 090 to Moter
Engage Heading Select and arm Approach
Set GPS to sequencing mode
Announce Moter
Announce approach active mode
Announce Eltro
Program direct Wraps
Use autopilot to accomplish missed approach
Set OBS 180 Wraps for hold
Announce Wraps

Wraps-SCK

Program Wraps-SCK
Set OBS 234 to Oxjef

Engage VS and arm Altitude Hold
Engage Heading Select and arm Approach
Set GPS to sequencing mode when established
Announce approach active mode
Announce Ipdew

SCK-1O3

Program SCK-1O3
Set OBS 285 to Quads for PT
Use autopilot to accomplish PT
Announce Quads
Set GPS to sequencing mode inbound to Quads
Engage approach function
Announce approach active mode
Announce Quads

1O3-LVK

Program 1O3-LVK
Engage VS and arm Altitude Hold
Set OBS 246 to Uhhut
Engage Heading Select and arm Approach
Set GPS to sequencing mode when established
Announce Uhhut
Announce approach active mode
Announce Oyahi

Appendix 2

Script of Tasks Used for the Jet Transport Cockpit Automation Training Flights

1. Basic Data Entry and Access
    a. Access page using page button
    b. Access page using line button
    c. Find information on page
    d. Make line entry
    e. Copy and paste line entry
    f. Select page line option
    g. Scroll to next page

2. Check Navigation Database
    a. Access Status page
    b. Check effective dates

3. Position Initialization
    a. Enter identifier to lookup coordinates of KSFO
    b. Enter KSFO coordinates to set position

4. Program Route
    a. Enter KSFO as origin airport
    b. Enter KLAX as destination airport
    c. Install PORTE3 departure procedure and AVE transition
    d. Install SADDE6 arrival procedure and AVE transition
    e. Install ILS Runway 24L approach

5. Execute modifications

6. Performance Initialization
    a. Enter fuel on board
    b. Enter cruising altitude
    c. Enter gross weight

7. Review Route
    a. Check Legs page
    b. Check Route page
    c. Check multifunction display

8. Follow Route
    a. Point out the active waypoint

b. Report time and distance to active waypoint

9. Direct To
   a. Program direct to assigned waypoint

10. Add/Delete Waypoint
    a. Delete waypoint
    b. Delete route discontinuity
    c. Add waypoint
    d. Delete route discontinuity

11. Different approach or transition
    a. Select new approach

12. Hold
    a. Select hold waypoint
    b. Program course, turns, leg length, and EFC
    c. What will happen when the airplane reaches the hold fix?
    d. Exit the hold

13. Plan and Execute Descent
    a. Enter crossing restrictions for SYMON and BAYST
    b. How do you know when to start down?
    c. At the top-of-descent point, dial down altitude
    d. Engage vertical speed function
    e. Determine and dial the required vertical speed
    f. Determine whether or not you will meet the restriction
    g. How is the airplane maintaining this constant-rate descent?
    h. What will happen when the airplane reaches 12,000 feet?

14. Fly Heading / Intercept Leg To
    a. Fly heading 130
    b. How do you know that HDG is engaged?
    c. Make assigned waypoint the active waypoint
    d. Program the desired intercept course
    e. Arm the Nav function to capture
    f. What will the airplane do once it reaches the course?

15. Constant-Speed Descent
    a. Engage the Speed function
    b. Dial assigned speed
    c. How does the airplane maintain the 280 knots?

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13. ABSTRACT *(Maximum 200 words)*

Two experiments explored the idea of providing cockpit automation training to airline-bound student pilots using cockpit automation equipment commonly found in small training airplanes. In a first experiment, pilots mastered a set of tasks and maneuvers using a GPS navigation computer, autopilot, and flight director system installed in a small training airplane. Students were then tested on their ability to complete a similar set of tasks using the cockpit automation systems found in a popular jet transport aircraft. Pilots were able to successfully complete 77% of all tasks in the jet transport on their first attempt. An analysis of a control group suggests that the pilots' success was attributable to the application of automation principles they had learned in the small airplane. A second experiment looked at two different ways of delivering small-airplane cockpit automation training: a self-study method, and a dual instruction method. The results showed a slight advantage for the self-study method. Overall, the results of the two studies cast a strong vote for the incorporation of cockpit automation training in curricula designed for pilots who will later transition to the jet fleet.

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