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Teaching Cockpit Automation in the Classroom

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Summary

This study explores the idea of teaching fundamental cockpit automation concepts and skills to aspiring professional pilots in a classroom setting, without the use of sophisticated aircraft or equipment simulators. Pilot participants from a local professional pilot academy completed eighteen hours of classroom instruction that placed a strong emphasis on understanding the underlying principles of cockpit automation systems and their use in a multi-crew cockpit. The instructional materials consisted solely of a single textbook. Pilots received no hands-on instruction or practice during their training. At the conclusion of the classroom instruction, pilots completed a written examination testing their mastery of what had been taught during the classroom meetings. Following the written exam, each pilot was given a check flight in a full-mission Level D simulator of a Boeing 747-400 aircraft. Pilots were given the opportunity to fly one practice leg, and were then tested on all concepts and skills covered in the class during a second leg. The results of the written exam and simulator checks strongly suggest that instruction delivered in a traditional classroom setting can lead to high levels of preparation without the need for expensive airplane or equipment simulators.

Cockpit Automation Training for Aspiring Professional Pilots

The recent modernization of aircraft operated by regional, major, and charter operators has placed a new requirement on aspiring professional pilots, as well as on the learning institutions who must educate them. In addition to a sound base of instrument flying skills, pilots must now also be prepared to exercise those skills in a modern cockpit that features a suite of sophisticated cockpit automation systems. These systems include flight management computers, autopilot flight director systems, electronic flight instrument systems, and many others.

Until recently, many institutions have elected to not respond to the need for cockpit automation skills, thus placing the burden of training on the carrier companies that choose to hire the students they produce. For both learning institutions and individual pilots, there are a number of problems with this approach. First, carrier companies continue to struggle with training pilots to work in the new high-tech cockpit (refs. 1–8). Most of the regional airlines we surveyed indicated that significant numbers of new-hire pilots fail their initial training due to difficulties they experience in learning to use advanced cockpit automation systems. Second, cockpit automation skills are already becoming a competitive bargaining chip. Pilot candidates who walk into job interviews with training and experience with cockpit automation are often viewed more favorably than candidates who have no such experience.

Alternatives For Providing Cockpit Automation Training

A NASA research effort aimed at promoting cockpit automation learning among professional pilot education programs has investigated two alternatives for teaching cockpit automation to aspiring professional pilots.

Teaching Cockpit Automation in Small Airplanes

Casner (ref. 9) describes a teaching program in which students receive cockpit automation training, as well as hands-on experience, using cockpit automation systems that are now readily available in small piston training airplanes. In a controlled study, students who completed the small-airplane cockpit automation training were given a check flight using a simulator of a popular regional jet. Pilots who received the small-airplane training were able to successfully demonstrate 75% of the maneuvers in the jet, versus the 25% success rate of a group of pilots who did not receive the small-airplane training. The results clearly demonstrate that taking the time to acquire basic cockpit automation skills in a small training airplane is a sound investment for the career-minded aviator.

Teaching Cockpit Automation in the Classroom

This article describes an alternative approach to teaching cockpit automation concepts and skills. In this study, we test the idea of teaching cockpit automation skills and concepts in a traditional classroom setting, without the use of sophisticated flight or equipment simulators.

A group of pilots at a local professional pilot academy completed an eighteen-hour classroom instructional course on the cockpit automation systems found in a large transport-category jet airplane. Pilots were trained not only on the procedures used to operate the cockpit automation systems but also on the underlying principles of how the automation works, and how to manage the automation as it performs its assigned duties. During the classroom training, pilots did not have hands-on access to any type of simulation or facsimile of the automation equipment.

Following the classroom training, pilots completed a written exam as well as a check flight in a Boeing 747-400 Level D flight simulator.

The results of both the written exam and the simulator check flights suggest that classroom training is indeed a viable alternative for providing instruction in this needed area of proficiency.

Method

Participants

Eight pilots were recruited from a local professional pilot academy. Pilots were paid the current rate for flight instructors for each hour of participation in the study.

Procedure

The teaching paradigm used was traditional classroom instruction, followed by a comprehensive written examination, followed by a check flight in a Boeing 747-400 Level D flight simulator.

Classroom Instruction

A classroom setting was used to provide eighteen hours of lecture-style instruction about cockpit automation to the eight pilots. The class met six times, each session lasting three hours including breaks. The only equipment used for the classroom sessions were an overhead projector and a textbook that contained the same material that was presented on the overhead projector.

Pilots were also given a mock practical test standard (PTS) similar to the ones made available to applicants for FAA pilot certificates and ratings. The practical test standard describes the concepts and skills that pilots were charged with mastering. In addition to the button-pushing procedures required to operate the automation equipment throughout each required maneuver and phase of flight, the practical test standard also requires the pilot to demonstrate an understanding of how each function of the automation accomplishes the tasks delegated to it. Furthermore, the practical test standard requires the pilot to be able to point out which automation functions are handling which flight tasks at any given time, and to be able to explain what the airplane would do given no further input from the flight crew. A copy of the practical test standard is given in Appendix A.

Written Exam

At the conclusion of the classroom instruction, pilots were given a 50-question multiple-choice written examination covering the material that had been presented during the five class meetings. Questions and answers appearing on the exam were not made available prior to the test. A copy of the written examination is given in Appendix B.

Level-D Simulator Check Flight

Each pilot was given a check flight in a Level D Boeing 747-400 simulator. The check flight consisted of a line-oriented flight scenario between San Francisco and Los Angeles International airports. During the check flight, the pilot sat in the left seat and was responsible for operating all aircraft controls and systems. The experimenter rode in the right seat and handled radio communications and checklists. The pilot and experimenter communicated with an in-house staff of air traffic controllers who presented the series of clearances and amendments that made up the line-oriented scenario. It was the pilot's job to comply with all of the ATC requests using the skills he or she had learned in class.

In addition to the requests made by ATC, the experimenter presented each pilot with a series of questions throughout the flight. This script of questions, the same for all pilots, was designed to test the pilots' overall awareness and conceptual understanding of the procedures they carried out using the automation equipment.

Paper and pencil were used by the experimenter to record any interventions required during any maneuver, and for any help required when answering any of the questions. 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. Appendix C presents the complete script of tasks.

Prior to the check flight, each pilot had the

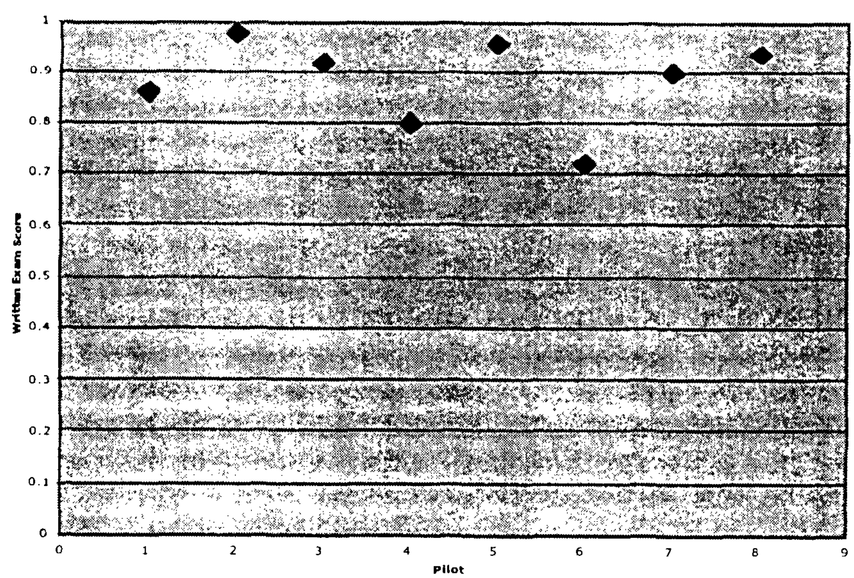

Figure 1. Scores for the written exam.

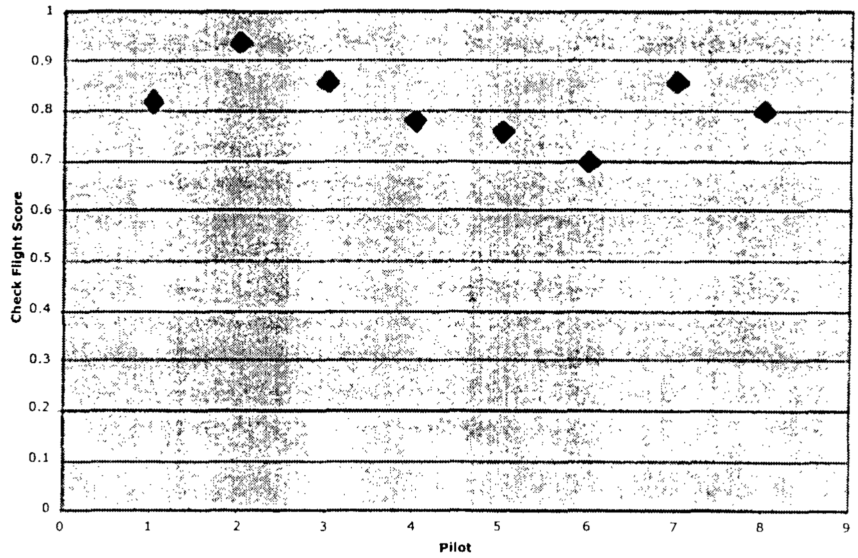

Figure 2. Scores for the simulator check

opportunity to fly a practice leg, over the same route in the reverse direction, before being tested. During the practice leg, two pilots from the class occupied the two pilot seats while the experimenter sat in the jump seat.

Results

The written exam scores for the eight pilots are shown in Figure 1. The mean score was 91% with a standard deviation of 7%.

The overall simulator check flight scores for the eight pilots are shown in Figure 2. The mean score was 82% with a standard deviation of 7%.

The scores in Figure 2 represent the proportion of tasks and questions that each pilot successfully completed with no intervention on the part of the experimenter.

There was a fairly strong correlation between performance on the written exam and performance during the simulator check flight (R = 0.52).

Recall that each pilot was scored on two kinds of tasks during the check flight. First, pilots were asked to comply with air traffic control requests to perform various maneuvers and flight plan modifications. These tasks were designed to test pilots' procedural skills. Second, pilots were presented with a battery of questions aimed at probing their understanding of the procedures they carried out. It is interesting to look at the results for these two types of tasks separately.

Procedural Tasks

Figure 3 shows the results for maneuvers performed by pilots during the check flight. The scores shown in Figure 3 reflect pilots' success at performing the procedural (button-pushing) steps required to complete the clearances issued by air traffic control during the flight.

By Maneuver	
Enter flight route	0.78
Review route	0.75
Execute modifications	0.75
Direct to	1.00
Hold	0.75
Descend pilot's discretion	0.88
Descend now	0.63
Constant-speed descents	0.69
Heading	0.88
Intercept course	0.50
Average	**0.76**

Figure 3. Breakdown of scores for procedural tasks during the simulator check flight.

By Question Type	
Mode and target awareness tasks	0.96
No further input	0.81
How it works	0.88
Position awareness	0.90
Average	**0.89**

Figure 4. Breakdown of scores for question-answering tasks during the simulator check flight.

Question-Answering Tasks

Figure 4 shows the results for four types of questions answered by pilots during the check flight. The scores in Figure 4 reflect pilots' conceptual understanding of the procedures they were performing when complying with air traffic control clearances.

Conclusion

The most striking outcome of the study was how well a group of piston-engine airplane flight instructors were able to fly a large transport-category aircraft after eighteen hours of classroom instruction and one practice trial. The results strongly suggest that: (1) the idea of teaching cockpit automation concepts and skills as part of pilots' early development is indeed a viable one; (2) that successful learning can be accomplished using traditional classroom training; and (3) while the adage 'practice makes perfect' likely still holds true, significant learning can take place absence of sophisticated flight simulator equipment.

The average score of 76% on the procedural tasks casts a strong vote for the value of teachings that focus on student mastery of procedural skills as well as student understanding of underlying concepts. This finding is consistent with other studies comparing 'procedures-only' and 'procedures-plusunderstanding' approaches to learning (refs. 10–13). Students that understand procedures they learn are significantly more able to solve problems that differ from those they learned during their instruction, and are better able to reconstruct solutions to problems when procedural steps are forgotten.

The average score of 89% on the question-answering tasks indicates that pilots were successful in achieving an in-depth understanding of the procedures they had learned as a result of the classroom instruction. The curriculum and practical test standard we used strongly emphasized the importance of maintaining an understanding of what pilot tasks are delegated to the automation, how the automation works to achieve those tasks, and what the airplane is configured to do at all times.

Clearly, it is likely that the successes we saw could be improved upon given the availability of flight simulation equipment for pilots to practice their newly-learned skills. Learning institutions with the resources to obtain such equipment are highly encouraged to do so. There are several companies now manufacturing inexpensive simulators designed for desktop computers. Aerowinx's Precision Simulator 744 is a low-cost and high-fidelity simulation of the Boeing 747-400 airplane. More information about this product is available at www.aerowinx.com. Project Magenta (www.projectmagenta.com) offers PC-based simulators for the avionics found in most popular transport category airplanes.

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Appendix A

Cockpit Automation: Practical Test Standard Used for the Experiment

I. AREA OF OPERATION: PREFLIGHT

A. TASK: FLIGHT PLANNING

Objective: To determine that the applicant:

1. Exhibits knowledge of how the flight crew and flight management system work together to plan a flight.

   a. Exhibits knowledge of the roles, capabilities, and limitations of the flight crew and the FMC in the flight planning process.

   b. Exhibits knowledge of the potential errors that can arise when the flight crew and FMC work together to plan a flight.

2. Exhibits knowledge of the information needed by the flight management computer to define a flight route, and the devices and procedures that the flight crew must use to enter the information, including -

   a. control display unit (CDU)
   b. current navigation database
   c. an accurate initial position
   d. a series of airways and fixes defining a route
   e. a departure procedure
   f. a departure runway

g. a gross weight or zero fuel weight
h. fuel reserves
i. a cost index
j. a cruising altitude
k. winds and temperature aloft
l. outside air temperature

3. Exhibits knowledge of how the flight management computer uses the information provided by the flight crew to construct a flight route, including -

   a. calculating great circle bearings and distances between fixes.
   b. calculating economical climb, cruise, and descent speeds.
   c. predicting the top-of-climb point, with and without altitude and speed constraints.
   d. calculating a top-of-descent point, with and without altitude and speed constraints.
   e. calculating altitude and speed predictions for each fix.
   f. calculating ETAs for each fix.
   g. calculating fuel remaining at each fix.
   h. calculating takeoff thrust.

5. Exhibits knowledge of how to review the flight route that has been constructed by the flight management computer, including -

   a. the electronic horizontal situation indicator (EHSI).
   b. the Route page.
   c. the Route Legs page.
   d. the Route Data page.
   e. the Progress page.
   f. the Climb page.
   g. the Cruise page.
   h. the Descent page.

II. AREA OF OPERATION:
AUTOMATED NAVIGATION, GUIDANCE, AND CONTROL

A. TASK: FUNDAMENTALS OF AUTOMATED GUIDANCE

Objective: To determine that the applicant:

1. Exhibits knowledge of the importance of enumerating the responsibilities associated with each phase of flight.

2. Exhibits knowledge of how responsibilities associated with each flight phase relate to the flight plan stored in the flight management computer.

3. Exhibits knowledge of the concept of a target.

4. Exhibits knowledge of how the flight management computer translates the fixes in the flight route into lateral, vertical, and speed targets.

5. Exhibits knowledge of the basic functions of lateral navigation (LNAV) and vertical navigation (VNAV) modes: how the FMC sends targets to the flight control computer.

6. Exhibits knowledge of how the flight control computer (FCC) generates guidance commands.

7. Exhibits knowledge of the three ways in which guidance commands generated by the FMC/FCC can be carried out.

   a. Autopilot and autothrottle.
   b. Flight director and autothrottle.
   c. Flight director and N1 gauges.

8. Exhibits knowledge of the flight mode annunciator (FMA) and how it is used to monitor which autoflight modes are armed or engaged.

9. Exhibits knowledge of the inertial reference system (IRS), navigation radios, and digital air data computer (DADC), and how they help track the position of the aircraft.

10. Exhibits knowledge of the flight crew's roles and the human factors issues that arise when automated guidance functions are used, including -

    a. situation awareness
    b. potential of undetected errors
    c. automation trust
    d. communicating intentions

11. Exhibits good judgement when deciding when to use automated guidance functions with and without the autopilot and autothrottle.

B. TASK: LNAV/VNAV CLIMB

Objective: To determine that the applicant:

1. Explains the responsibilities associated with the climb phase of flight.

2. Explains when LNAV and VNAV can be armed and engaged.

3. Explains what pitch, power, and roll modes are engaged by LNAV and VNAV during the climb.

4. Explains what targets each roll, pitch, and power mode is pursuing.

5. Explains how to check the appropriateness of each target that the FMS is pursuing.

6. Explains where each target can be seen by the flight crew.

7. Demonstrates how the crew can monitor the progress of the aircraft toward achieving the targets.

8. Explains what the aircraft would do given no further input from the flight crew at any time during a flight.

C. TASK: LNAV/VNAV CRUISE

Objective: To determine that the applicant:

1. Explains the responsibilities associated with the cruise phase of flight.

2. Explains what pitch, power, and roll modes are engaged by LNAV and VNAV during cruise phase.

3. Explains what target each roll, pitch, and power mode is pursuing.

4. Explains how to check the appropriateness of each target that the FMS is pursuing.

5. Explains where each target can be seen by the flight crew.

6. Demonstrates how the crew can monitor the progress of the aircraft toward achieving the targets.

7. Explains what the aircraft would do given no further input from the flight crew.

8. Demonstrates how the FMC can be used to find the most optimum cruising altitude.

D. TASK: LNAV/VNAV DESCENT

Objective: To determine that the applicant:

1. Explains the responsibilities associated with the descent phase of flight.
2. Explains what pitch, power, and roll modes are engaged by LNAV and VNAV during the descent.
3. Explains what target each roll, pitch, and power mode is pursuing.
4. Explains how to check the appropriateness of the FMC-computed top-of-descent point and the appropriateness of each target that the FMS is pursuing.
5. Explains where each target can be seen by the flight crew.
6. Demonstrates how the crew can monitor the progress of the aircraft toward achieving the targets.
7. Exhibits knowledge of the effects of winds and pressure on descent performance and the FMS's ability to remain on the descent path.
8. Explains what the aircraft would do given no further input from the flight crew.
9. Exhibits knowledge of the principles of energy and energy management.

III. AREA OF OPERATION: ENROUTE FLIGHT PLAN MODIFICATIONS

A. TASK: ALTITUDE RESTRICTIONS

Objective: To determine that the applicant:

1. Exhibits knowledge of the procedures used to comply with enroute altitude restrictions issued during climb and descent phases of flight.

2. Exhibits knowledge of how altitude restrictions affect other aspects of the FMC route, and the aircraft's ability to follow the FMC route.

3. Exhibits knowledge of the procedures used to delete an altitude restriction.

B. TASK: SPEED RESTRICTIONS

Objective: To determine that the applicant:

1. Exhibits knowledge of the procedures used to comply with enroute speed restrictions issued during climb, cruise, and descent phases of flight.

2. Exhibits knowledge of how speed modifications affect other aspects of the FMC route, and the aircraft's ability to follow the FMC route.

3. Exhibits knowledge of the procedures used to delete a speed restriction.

C. TASK: DIRECT TO

Objective: To determine that the applicant:

1. Exhibits knowledge of the procedures used to comply with direct to clearances.

D. TASK: HOLDS

Objective: To determine that the applicant:

1. Exhibits knowledge of the procedures used to comply with hold clearances.

2. Exhibits knowledge of the procedures used to continually monitor adjustments made in ETA and fuel remaining during a hold procedure.

IV. AREA OF OPERATION: SEMI-AUTOMATED GUIDANCE AND CONTROL

A. TASK: SIMPLE AUTOFLIGHT GUIDANCE AND CONTROL FUNCTIONS

1. Exhibits knowledge of the simpler autoflight guidance and control functions, including:

    a. Heading Select
    b. Speed
    c. Level Change
    d. Vertical Speed
    e. N1
    f. VOR/LOC
    g. Approach
    h. Takeoff

For each autoflight function, exhibits knowledge of:

a. the procedures used to set and achieve simple targets using each autoflight function.

b. how each autoflight function achieves its target(s).

c. the situations in which each autoflight function is most useful.

B. TASK: MODE AWARENESS

1. Exhibits knowledge of the combination of autopilot and autothrottle modes that make up each autoflight function.

2. Exhibits knowledge of the flight mode annunciator (FMA) and the annunciations for each autofight function.

3. Demonstrates at all times an awareness of which modes are engaged, the targets each mode is pursuing, how each mode functions, and the future behavior of the aircraft given the currently engaged modes and targets.

V. AREA OF OPERATION: ADVANCED MANEUVERS

A. TASK: LEG AND RADIAL INTERCEPTS

1. Exhibits knowledge of the procedures used to accomplish leg and radial intercepts.

2. Exhibits knowledge of how control is between autoflight functions during leg and radial intercepts.

3. Exhibits knowledge of the relationship between the present position of the aircraft and the FMC route at all times during intercept maneuvers.

B. TASK: EARLY DESCENTS

1. Exhibits knowledge of the energy management problem presented by early descents.

2. Exhibits knowledge of the procedures used to accomplish early descents.

3. Exhibits knowledge of how control is passed between autoflight functions during early descents.

4. Exhibits knowledge of the relationship between the present position of the aircraft and the FMC route at all times during early descent maneuvers.

C. TASK: LATE DESCENTS

1. Exhibits knowledge of the procedures used to accomplish late descents.

2. Exhibits knowledge of the procedures used to accomplish late descents.

3. Exhibits knowledge of how control is passed between autoflight functions during late descents.

4. Exhibits knowledge of the relationship between the present position of the aircraft and the FMC route at all times during late descent maneuvers.

Appendix B

Cockpit Automation: Written Exam Used for the Experiment

This exam contains 50 questions.

There is a 3-hour time limit for this exam.

For each question, circle the letter (A, B, or C) that corresponds to the best answer.

Do not write your name on the exam. Your answers and score will be kept anonymous.

DO NOT TURN THE PAGE UNTIL INSTRUCTED
TO DO SO BY THE EXAMINER.

1. Box prompts appearing on a CDU page are used to indicate

A - optional entries that can be made by the crew.
B - mandatory entries that must be made by the crew.
C - entries that will be filled in by the FMC after certain other crew entries have been made.

2. The Route page provides

A - a detailed description of your planned flight route, including each fix and airway.
B - an overview of your route, including terminal area procedures, and interchanges between airways.
C - a detailed description of your planned flight route, including each terminal area, procedure, airway, fix, and waypoint.

3. When specifying aircraft weight information on the Perf Init page, the crew can

A - enter a gross weight and let the FMC automatically calculate the zero fuel weight (ZFW).
B - enter a zero fuel weight (ZFW) and let the FMC automatically calculate the gross weight.
C - either A or B

4. The Reserve fuel entered by the crew on the Perf Init page

A - indicates that portion of the fuel displayed at line 2 Left that will be considered reserve fuel by the FMC.
B - must be added to the fuel weight displayed at line 2 Left to determine the total amount of fuel on board.
C - when added to the fuel weight displayed at line 2 Left equals usable fuel.

5. Which of the following best describes what is computed by the FMC once the required crew entries have been made?

A - Distances between all fixes; the time required to reach each fix; and climb, cruise, and descent speeds.
B - Distances between all fixes; the time required to reach each fix; climb, cruise, and descent speeds; geographic coordinates of the points at which the aircraft will reach its top-of-climb and top-of-descent.
C - Distances between all fixes; the time required to reach each fix; the predicted fuel remaining at each fix; climb, cruise, and descent speeds; geographic coordinates of the point at which the aircraft will commence its descent.

6. (Refer to Figure 1.) Which top-of-descent point would most likely result after a high cost index has been entered by the crew?

A - A
B - B
C - C

7. Descents that are planned by the FMC are

A - geographically fixed in space.
B - not geographically fixed but referenced to the airmass through which the aircraft will descend.
C - open-ended like the climbs that are planned by the FMC.

8. Which sentence best describes a conditional waypoint?

A - A waypoint that may or may not be crossed during flight when LNAV and VNAV are being used.
B - A waypoint that has no fixed geographic position.
C - An optional waypoint that can easily be deleted by the crew.

9. The electronic horizontal situation indicator when set to Map mode

A - provides the most detailed and accurate description of the programmed flight route.
B - provides a big picture display of the flight route but is not as accurate as the description given on the Route Legs page.
C - is the primary instrument for the lateral control of the aircraft.

10. The flight management computer gets information about the aircraft's present position (i.e., latitude and longitude) from

A - the digital air data computer.
B - LNAV.
C - the inertial reference system.

11. Which best describes the difference between the way VNAV works during climb, versus the way VNAV works during cruise or descent?

A - During cruise or descent, VNAV performs an airmass descent; during climb VNAV performs an earth-referenced descent.
B - During cruise or descent, VNAV uses pitch to control airspeed; during climb VNAV uses engine thrust to control airspeed.
C - During cruise or descent, VNAV provides guidance along a fixed "wire-in-the-sky"; during climb, VNAV is more open-ended.

12. If you are high during a descent, VNAV will

A - obey the planned descent speed, and remain high of the path if necessary.
B - descend down to the path, exceeding the planned descent speed if necessary.
C - avoid overcontrolling and maintain the present aircraft trajectory since atmospheric conditions will likely cause the aircraft to drift back down to the path later in the descent.

13. (Refer to Figure 2.) Which flight mode annunciator depicts an airplane in a VNAV climb?

A - A
B - B
C - C

14. (Refer to Figure 2.) Which flight mode annunciator depicts an airplane in a VNAV cruise?

A - A
B - C
C - D

15. (Refer to Figure 2.) Which flight mode annunciator depicts an airplane in a VNAV descent?

A - B
B - C
C - D

16. Which is the best way to determine whether or not VNAV is currently engaged?

A - Check to see that the VNAV button is lit on the mode control panel.
B - Check to see if VNAV PATH or VNAV SPD is annunciated as the pitch mode on the flight mode annunciator.
C - Check to see that the VNAV button is lit and cross check the altimeter and electronic horizontal situation indicator (EHSI).

17. Which of the following is NOT an advantage of manually controlling the aircraft in response to flight director commands?

A - It allows the crew to remain close to the controls of the aircraft during critical phases of flight.
B - It gives the crew more time to review the programmed flight route.
C - It allows the crew to change the path of the aircraft more quickly.

18. It is customary to activate the autopilot and allow the aircraft to perform fully automated guidance

A - whenever possible.
B - only in the terminal area.
C - outside of the terminal area and above critical altitudes.

19. When manually steering the aircraft using the flight directors, why is it important for the crew to monitor other displays as well?

A - The flight directors sometimes "drift" and provide slightly inaccurate information.
B - The flight directors don't really tell you what the aircraft control surfaces are doing.
C - The flight directors provide information about what the aircraft is currently doing, but do not provide information about the future behavior of the aircraft.

20. During cruise phase, the planned descent speed

A - can be seen on the Descent page.
B - can be seen on the Speeds page.
C - can only be seen on the airspeed indicator.

21. (Refer to Figure 3.) At what time is the aircraft predicted to reach the top-of-climb point?

A - 1634 Z.
B - 1637 Z.
C - 1619 Z.

22. (Refer to Figure 3.) How much fuel will likely be burned between PESCA and WAGES?

A - 8 thousand gallons.
B - 8 hundred pounds.
C - Present fuel minus 1.2 thousand gallons.

23. (Refer to Figure 3.) How long will it likely take the aircraft to fly between PESCA and WAGES?

A - Insufficient information.
B - 10 minutes.
C - 25 minutes.

24. (Refer to Figure 4.) The planned top-of-descent point is located

A - between WAGES and AVE.
B - between PESCA and WAGES.
C - after FIM.

25. If the crew does not enter wind direction and velocity for the waypoints listed on the Route Data page, the FMC will assume

A - the reported winds at the origin airport.
B - the cruise wind direction and velocity entered on the Perf Init page prior to takeoff.
C - an average of the reported winds at the origin and destination airports.

26. (Refer to Figure 5.) What is the current position of the aircraft?

A - Over top of PESCA.
B - 34 NM short of WAGES.
C - 187 NM short of FIM.

27. (Refer to Figure 5.) What is the predicted altitude of the aircraft at SYMON?

A - 15,000 feet.
B - 15,000 feet or below.
C - Cannot be determined.

28. (Refer to Figure 6.) Suppose you are passing through 9,000 feet during your climb out and LNAV and VNAV are engaged. If no further input is made by the crew, the aircraft will

A - climb to FL330 and fly there indefinitely.
B - climb to FL330, maintain FL330 until reaching the planned top-of-descent point, then begin a descent.
C - climb to FL230 and level off.

29. (Refer to Figure 7.) Suppose you have just reached your top-of-descent point and are commencing your descent out of FL330. If the current time is 1655 Z, what is the descent rate in feet per minute planned by the aircraft if your descent restriction is BAYST at 10,000 feet?

A - 880 feet per minute.
B - 1,000 feet per minute.
C - 1,750 feet per minute.

30. When VNAV is used during a descent, what factors can cause the aircraft to deviate from the planned descent speed?

A - non-standard pressure.
B - unexpected winds and pressure.
C - calm winds.

31. (Refer to Figure 8.) Line 4R on the Hold page indicates

A - the FMC's estimate of how long the aircraft can safely remain in the holding pattern.
B - the crew's estimate of how long the aircraft can safely remain in the holding pattern.
C - the expect further clearance time minus the time at which the hold was entered.

32. After instructing the aircraft to exit a hold, the aircraft will

A - immediately depart the holding pattern and proceed to the next waypoint shown on the Route Legs page.
B - continue in the holding pattern until the hold fix is reached, and then continue with the route shown on the Route Legs page.
C - remain in the holding pattern until the expect further clearance time is reached.

33. If the crew makes an addition or modification to the programmed FMC flight route but does not push the Execute button on the front of the CDU

A - the FMC will continue to follow the existing programmed flight route.

B - the FMC will automatically execute the modifications after a period of 180 seconds (3 minutes).

C - the FMC will automatically execute the modifications if any other autoflight function is engaged.

34. If Heading Select is engaged and no further actions are taken by the crew, the aircraft will

A - maintain the present heading indefinitely.

B - maintain the present heading for 80 NM and then disconnect.

C - maintain the present altitude until the FMC route is recaptured.

35. The speed of the aircraft can be changed during a Level Change climb or descent

A - only by manually adjusting the thrust levers.

B - by dialing the new speed into the Speed window.

C - by dialing the new speed into the Speed window and then engaging Speed mode.

36. Level Change is useful for accomplishing

A - constant speed descents.

B - constant rate descents.

C - earth-referenced descents.

37. When a pitch or roll mode is "armed" it

A - will engage automatically as soon as its engagement conditions have been met.

B - is set to be engaged manually by the crew as soon as its engagement conditions are met.

C - will automatically engage as soon as the crew disengages the mode that is currently engaged.

38. Setting the proper takeoff thrust during the takeoff roll is accomplished by

A - the autothrottle

B - both the flight crew and autothrottle

C - the pilot flying

39. (Refer to Figure 9.) Which flight mode annunciator depicts an airplane engaged in Altitude Hold and Speed modes?

A - A
B - B
C - C

40. (Refer to Figure 9.) Which flight mode annunciator depicts an airplane engaged in a Level Change climb?

A - A
B - B
C - C

41. (Refer to Figure 9.) Which flight mode annunciator depicts an airplane engaged in a Level Change descent?

A - B
B - C
C - D

42. A late descent scenario is one in which your aircraft

A - has too little energy.
B - has too much energy.
C - has excess speed.

43. To prepare for a late descent, prior to receiving your descent clearance, which autoflight function is likely to be of most use?

A - Altitude Hold.
B - Level Change.
C - Speed.

44. Your ultimate priority when executing a late descent maneuver is to

A - recapturing the descent profile as early as possible in the descent.
B - minimizing your use of the speed brakes.
C - managing your descent speed.

45. An intermediate level-off during descnt is

A - more problematic than an intermediate level-off during climb.
B - less problematic than an intermediate level-off during climb.
C - about as problematic than an intermediate level-off during climb.

46. Intercepting a radial requires

A - only the use of LNAV.
B - the use of LNAV and Heading Select.
C - the use of Heading Select and then VOR/LOC.

47. Delegating a task to a reliable automated system

A - often makes the human operator nervous about completing the task.
B - sometimes causes the human operator to lose touch with what is going on.
C - raises the human operator's level of awareness.

48. Which of the following is a difficulty that is commonly associated with monitoring an automated system?

A - Automated systems are usually unreliable and require a lot of attention from the flight crew.
B - It is difficult for most pilots to trust an automated system when performing a task that has traditionally been performed by a human pilot.
C - It is sometimes difficult to determine what the automated system is trying to do.

49. A common problem associated with the use of flight deck automation is

A - the problem of deciding who will operate the control display unit and mode control panel.
B - that communication can sometimes break down between crew members, and between the crew and the automated system.
C - poor reliability of flight deck automation.

50. Errors made using the flight management system tend to be

A - more easily detected.
B - more difficult to detect.
C - less severe.

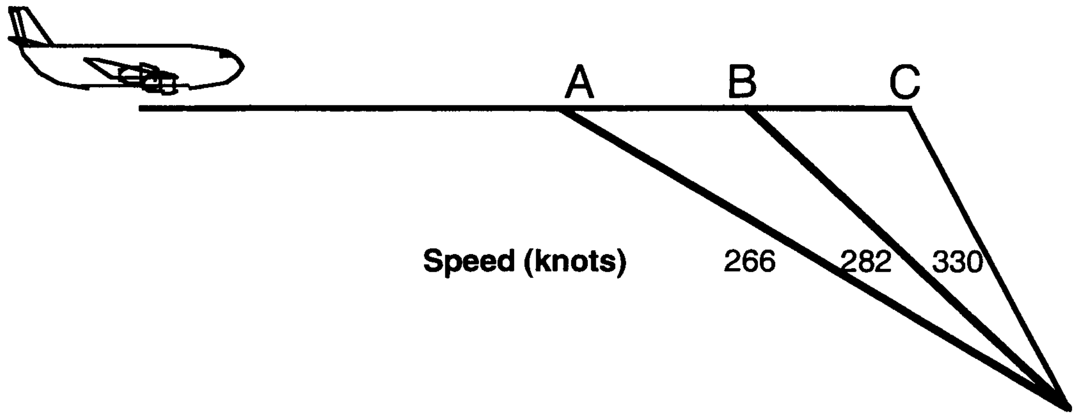

Figure 1

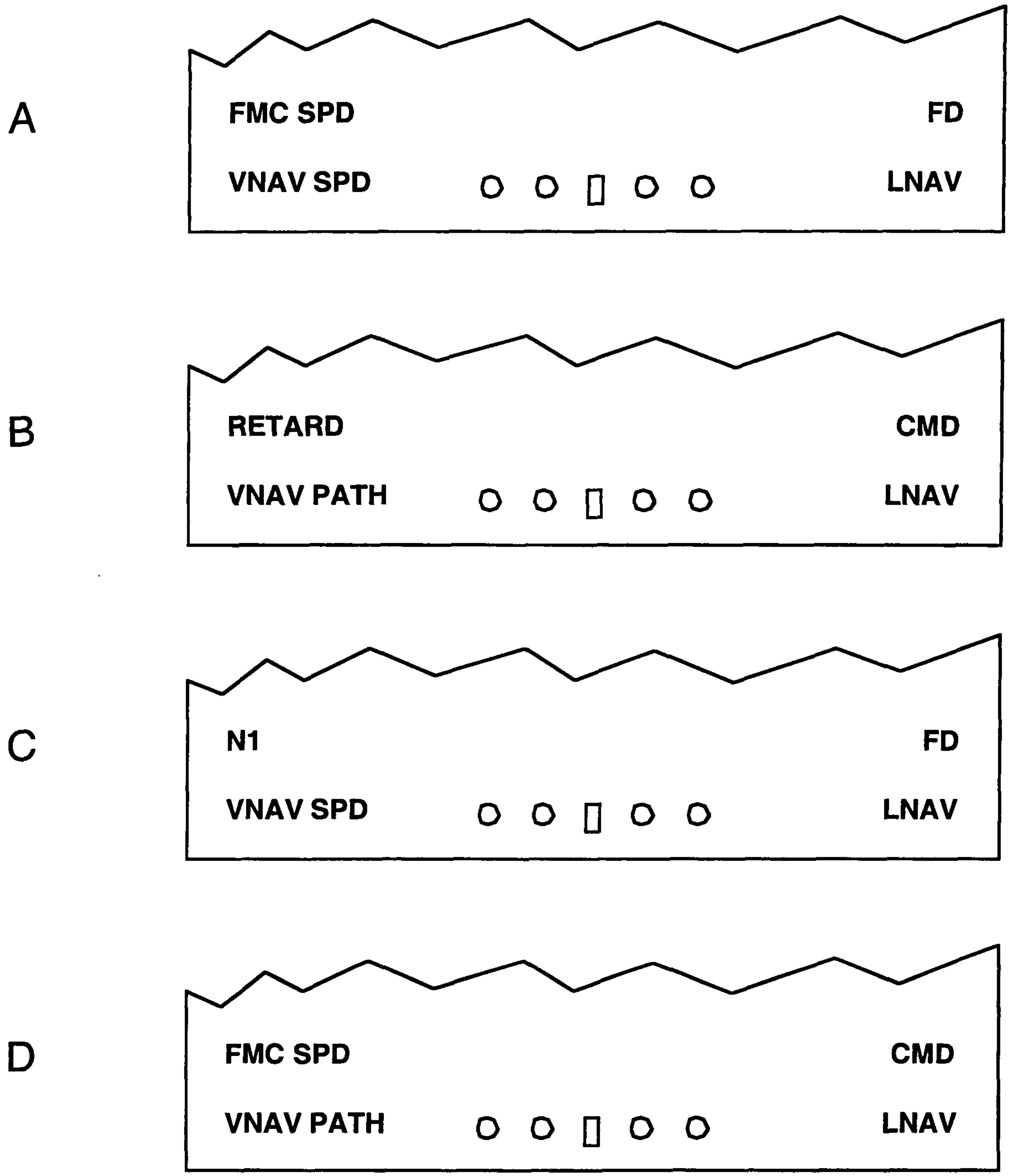
A
FMC SPD
FD
VNAV SPD
LNAV
B
RETARD
CMD
VNAV PATH
LNAV
C
N1
FD
VNAV SPD
LNAV
D
FMC SPD
CMD
VNAV PATH
LNAV

Figure 2

PROGRESS			1/4
FROM	ALT	ATA	
SFO04	2106	1615	
	DTG	ETA	FUEL
PORTE	2	1619	14.1
PESCA	15	1624	13.7
WAGES	34	1634	12.9
TO T/C			FUEL QTY
1637 Z / 51 NM			11.2
DME	IRS (L)	DME	
PYE 113.7		OSI	113.9

Figure 3

PROGRESS 1/3

FROM	ALT	ATA	
PESCA		1624	
116°	DTG	ETA	FUEL
WAGES	34	1634	12.9
126°			
AVE	117	1653	11.7
148°			
FIM	94	1703	9.4

TO T/D FUEL QTY

1650 z / 32 NM 9.6

DME IRS (L) DME

PYE 113.7 OSI 113.9

Figure 4

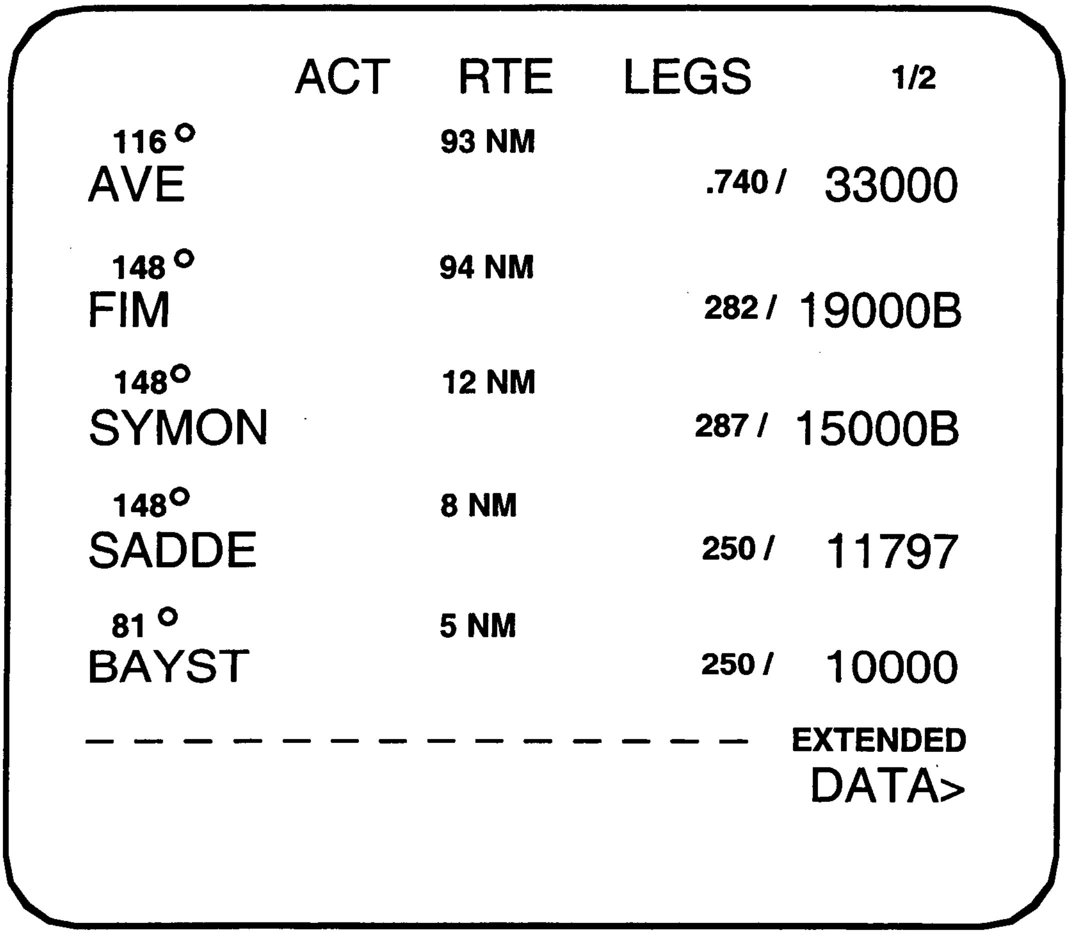
ACT RTE LEGS 1/2
116°
93 NM
AVE
.740 / 33000
148°
94 NM
FIM
282 / 19000B
148°
12 NM
SYMON
287 / 15000B
148°
8 NM
SADDE
250 / 11797
81°
5 NM
BAYST
250 / 10000
EXTENDED
DATA>

Figure 5

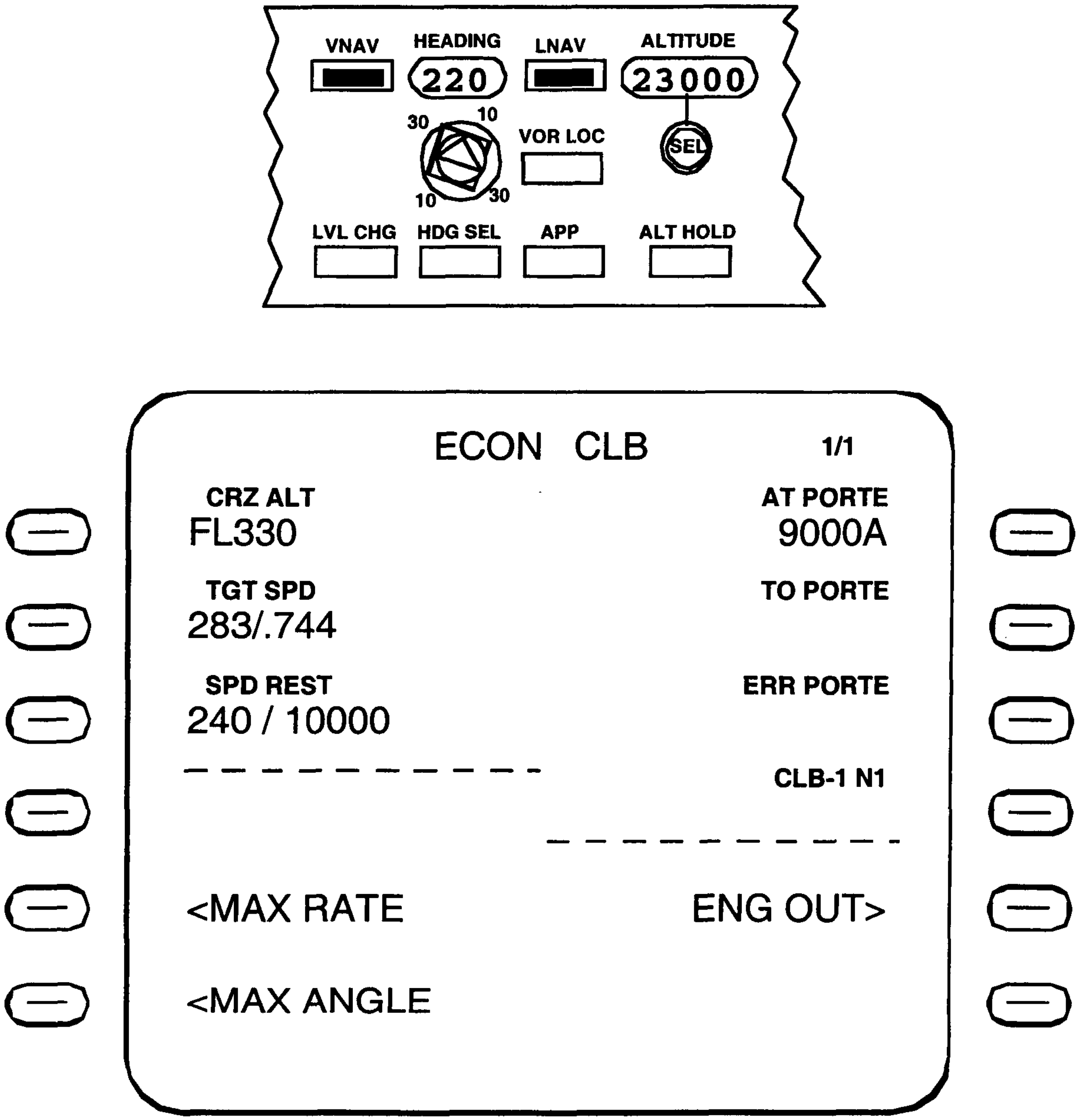
VNAV
HEADING
220
LNAV
ALTITUDE
23000
30
10
10
30
VOR LOC
SEL
LVL CHG
HDG SEL
APP
ALT HOLD
ECON CLB
1/1
CRZ ALT
FL330
AT PORTE
9000A
TGT SPD
283/.744
TO PORTE
SPD REST
240 / 10000
ERR PORTE
CLB-1 N1
<MAX RATE
ENG OUT>
<MAX ANGLE

Figure 6

PROGRESS 1/3

FROM	ALT	ATA	
WAGES		1644	
116°	DTG	ETA	FUEL
AVE	63	1702	9.5
148°			
FIM	94	1712	9.4
148°			
BAYST	37	1718	9.1
TO T/D			FUEL QTY
1655 z / 0 NM			9.6
DME	IRS (L)	DME	
PYE 113.7		OSI 113.9	

Figure 7

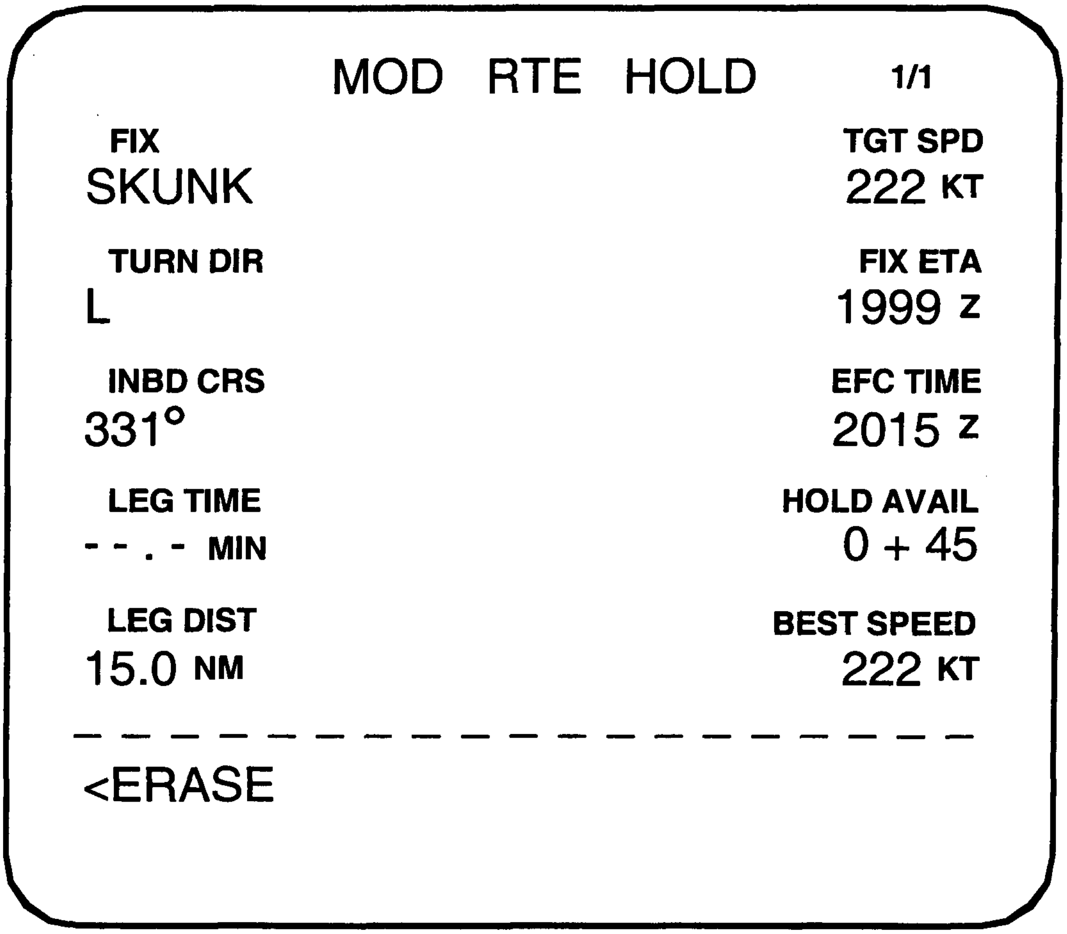
MOD RTE HOLD 1/1
FIX
SKUNK
TGT SPD
222 KT
TURN DIR
L
FIX ETA
1999 Z
INBD CRS
331°
EFC TIME
2015 Z
LEG TIME
- - . - MIN
HOLD AVAIL
0 + 45
LEG DIST
15.0 NM
BEST SPEED
222 KT
<ERASE

Figure 8

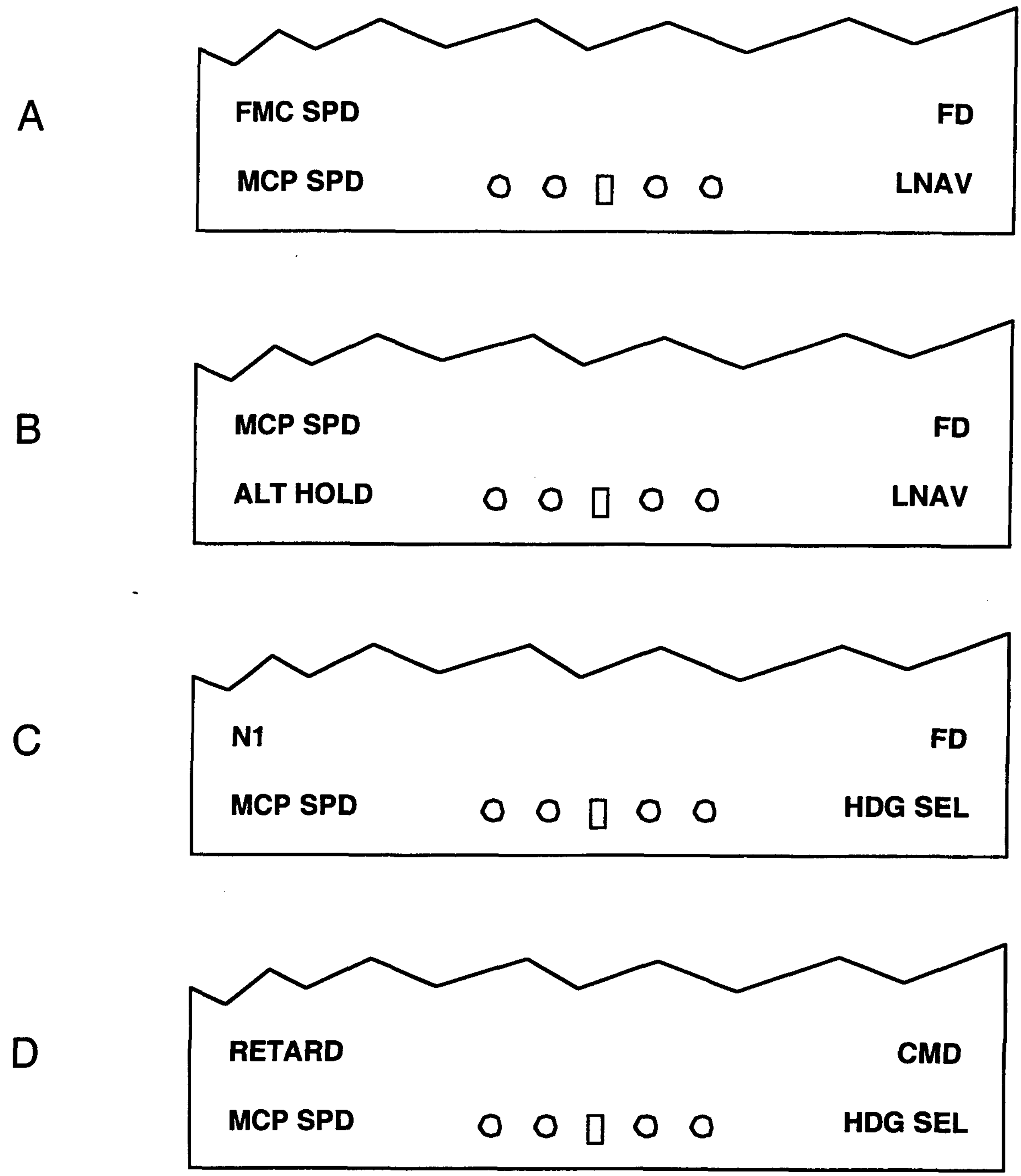
A
FMC SPD
FD
MCP SPD
LNAV
B
MCP SPD
FD
ALT HOLD
LNAV
C
N1
FD
MCP SPD
HDG SEL
D
RETARD
CMD
MCP SPD
HDG SEL

Figure 9

Appendix C

Cockpit Automation: Script of Tasks and Questions Used During the Check Flight

Departure Clearance:

NASA 35 Heavy, cleared to the Los Angeles airport via the Porte Three departure, Avenal transition, Avenal, Sadde Six Arrival, Avenal Transition, ILS 24R. Maintain FL230, expect FL330 10 minutes after departure. Departure frequency will be 135.1 Squawk 3651.

- Check navigation database __________
- Access Route page __________
- Enter KSFO __________
- Enter KLAX __________
- Access Dep/Arr page __________
- Scroll __________
- Select PORTE3 __________
- Select AVE transition __________
- Select runway __________
- Access Dep/Arr page __________
- Select KLAX arrivals __________
- Scroll to STAR __________
- Select STAR __________
- Select transition __________
- Select approach __________
- Exec __________
- Check EVERY crossing restriction __________
- Step through route in Plan mode __________
- Eliminate all discos and redundancies __________
- Access Perf Init page __________
- Enter Cruise altitude __________
- Enter crossing restrictions __________
- Takeoff Page: make BIG (10/800 Flap/Accel Ht, 800 Accel Ht, 5 Thr Red, activate speeds)

____

- *What crossing restrictions do we have to meet?* __________
- *Show me two places I can see my predicted top-of-climb point.* __________
- *What will our climb speed be?* __________

Clearances:

NASA 35 Heavy, climb and maintain FL230, winds calm, cleared for takeoff, runway 1R.

(Passing through 500 feet) NASA 35 Heavy, contact departure.

- *What autoflight modes are engaged?* __________

(While on 200-degree heading) NASA 35 Heavy, fly heading 180, intercept the Point Reyes 135 radial, resume PORTE3 departure.

- Dial heading __________
- Engage heading select __________
- Arm LNAV __________

- *What roll mode is engaged?* __________
- *What is the next waypoint we will cross?* __________
- *What speed target are we pursuing?* __________
- *How are we achieving that speed target?* __________
- *Where are we with respect to the planned route?* __________
- *What is the next crossing restriction?* __________

(Leaving 8,000 feet) NASA 35 Heavy, contact Oakland Center, 125.45.

NASA 35 Heavy, proceed direct Avenal.

- Access Dir/Intc page __________
- Select waypoint __________
- Exec __________

(Leaving FL200) NASA 35 Heavy, contact Oakland Center, 133.7

- *What speed target are we pursuing?* __________

(Force intermediate level-off by delaying altitude clearance)

NASA 35 Heavy, climb and maintain FL330.

- Dial altitude __________
- Engage VNAV __________

(After level-off)

- *What speed target are we pursuing?* __________
- *How are we acheiving that speed target?* __________
- *What are the aircraft's elevators being used to accomplish?* __________
- *When will we get to the top-of-descent point?* __________

(Approaching AVE) NASA 35 Heavy, contact LA Center, 135.3.

NASA 35 Heavy, reduce speed to .80 Mach.

- Access Cruise page __________
- Enter new speed __________
- Exec __________

NASA 35 Heavy, resume normal speed, contact LA Center.

- Access Cruise page __________
- Enter new speed __________
- Exec __________

NASA 35 Heavy, hold at DERBB, FL330, right turns, 20 mile legs, expect further clearance at HH:MM.

- Access Hold page __________
- Select hold waypoint __________
- Plug into 6L __________

- Enter turns __________
- Enter legs __________
- Enter EFC __________
- Exec __________

- *When will we reach the hold fix?* __________
- *How much fuel will we have left?* __________

NASA 35 Heavy, cancel hold at DERBB, resume normal speed, cleared for the Sadde Six Arrival.

- Eliminate Hold __________
- Exec __________

(At Avenal) NASA 35 Heavy, descend, pilot's discretion, FL240.

- Dial down altitude __________

- *If we didn't touch anything, what would the airplane do?* __________
- *How far until the top-of-descent point?* __________

(Before DERBB) NASA 35, descend now, FL240.

- Access Descent page __________
- Select Des Now __________
- Exec __________

- *What is our speed target?* __________
- *Where are we with respect to the planned descent path?* __________
- *If we didn't touch anything, what would the airplane do?* __________

NASA 35 Heavy, contact LA Center, 135.5.

NASA 35 Heavy, contact SoCal Approach 124.3.

NASA 35 Heavy, descend and maintain 17,000.

- Dial altitude __________

NASA 35 Heavy, cross BAYST at 10,000 and 250 knots.

(At BAYST) NASA 35 Heavy, descend and maintain 7,000, reduce speed to 200 knots, depart SMO heading 070.

- Dial altitude __________
- Engage FLCH __________
- Dial speed __________
- Dial heading __________
- Engage heading select __________

(At SMO) NASA 35 Heavy, descend and maintain 5,000, contact SoCal Approach, 124.5

- Dial altitude __________
- Engage FLCH if necessary __________

(At SMO 9 NM fix) NASA 35 Heavy, descend and maintain 4,000, reduce speed 180 knots.

- Dial altitude __________
- Engage FLCH if necessary __________
- Dial speed __________

(At SMO 15 NM fix) NASA 35 Heavy, fly heading 160, descend and maintain 3,000.

- Dial heading __________
- Dial altitude __________
- Engage FLCH if necessary __________

NASA 35 Heavy, fly heading 220, maintain 3,000 until established, cleared ILS runway 24R.

- Dial heading __________
- Dial altitude __________
- Engage FLCH if necessary __________

• Arm Approach function __________

(Upon readback of approach clearance) NASA 35 Heavy, contact the tower on 133.9.

• Dial speed down to 149 knots on final approach __________

(At ROMEN) NASA 35 Heavy, winds calm, cleared to land, runway 24R.

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13. ABSTRACT *(Maximum 200 words)*

This study explores the idea of teaching fundamental cockpit automation concepts and skills to aspiring professional pilots in a classroom setting, without the use of sophisticated aircraft or equipment simulators. Pilot participants from a local professional pilot academy completed eighteen hours of classroom instruction that placed a strong emphasis on understanding the underlying principles of cockpit automation systems and their use in a multi-crew cockpit. The instructional materials consisted solely of a single textbook. Pilots received no hands-on instruction or practice during their training. At the conclusion of the classroom instruction, pilots completed a written examination testing their mastery of what had been taught during the classroom meetings. Following the written exam, each pilot was given a check flight in a full-mission Level D simulator of a Boeing 747-400 aircraft. Pilots were given the opportunity to fly one practice leg, and were then tested on all concepts and skills covered in the class during a second leg. The results of the written exam and simulator checks strongly suggest that instruction delivered in a traditional classroom setting can lead to high levels of preparation without the need for expensive airplane or equipment simulators.

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