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Development of Qualification Guidelines for Personal Computer-Based Aviation Training Devices

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16. Abstract

Recent advances in the capabilities of personal computers have resulted in an increase in the number of flight simulation programs made available as Personal Computer-Based Aviation Training Devices (PCATDs).The potential benefits of PCATDs have been recognized by researchers and software/hardware developers alike. The purpose of this report is twofold: 1) present a conceptual approach based upon human learning principles and available flight training data for use in the development and evaluation of PCATDs; and 2) provide a detailed technical plan for an initial effort to develop and test guidelines for assessing the use of PCATDs in a training curriculum of a flight school conducted in accordance with the regulations stated in FAR Part 141.

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BACKGROUND

PC-Based Training Devices

Recent advances in the capabilities of personal computers have resulted in an increase in the number of flight simulation programs made available as Personal Computer-Based Aviation Training Devices (PCATDs). These devices are relatively inexpensive, compared with flight training devices and simulators that more closely approximate the physical characteristics of an actual aircraft. Aviation training devices should be distinguished from formal flight training devices, as defined in FAA Order AC 120-45A. The primary difference between the two is that the PCATD is an integrated, ground-based training device that would be used solely for aviation training purposes, and not for airmen qualification or certification. The appropriate use of PCATDs by flight training schools and individuals would greatly benefit the delivery of flight training instruction and enhance training effectiveness and flight safety.

The regulatory mission of the FAA includes establishing a sound basis for qualifying equipment, airmen training and certification programs, including the use of instructional aids and devices. Traditional approaches to crediting flight training devices and simulators heavily weights the physical fidelity, or similarity of the device, to an actual aircraft. This approach results in the production of extremely expensive training equipment, particularly if motion simulation is included. Further, it has been shown that high physical fidelity is not necessary to achieve acceptable transfer levels for certain flight training tasks (Lintern, Roscoe, Koonce, & Segal, 1990; Ortiz, 1993; Phillips, Hulin, & Lamermayer, 1993). This finding provides a useful opportunity for utilizing relatively inexpensive PCATD technology with relatively low physical fidelity for training specific sets of flight tasks.

Another expectation based on traditional crediting approaches is that training time on PCATDs should be creditable with a number of flight hours considered equivalent to training time in an aircraft based on training transfer equations. However, transfer of training estimates for a particular PCATD tend to vary, depending on the particular task being learned and the learning characteristics of the individual using the device. This joint variability makes it inadvisable to attempt to credit experience in a PCATD with some number of aircraft flight hours. The best course would be to limit use of PCATDs to the role of training aids within an integrated ground/flight training environment. The potential contribution of a particular PCATD should be evaluated on a task-by-task basis, according to whether, based on a set of rules or guidelines, the device could be expected to produce some minimally acceptable level of positive transfer of training to an airplane on a specific task.

Potential Benefits of PCATDs

The potential benefits of PC-based aviation training devices have been recognized by researchers and software/hardware developers alike, as is attested to by a recent collection of papers on the use of PC-based systems for instrument flight training (Sadlowe, 1991). Evidence of their effectiveness is also growing (Hampton, Moroney, Kirton, Biers, Eisterhoutd, King, Wright, 1993). Before these benefits can be enjoyed, however, guidelines must be established regarding the characteristics that are recommended in a PCATD for it to be an effective training device.

The use of PCATDs should enhance safety because students could gain at least minimum proficiency before attempting most flying maneuvers. In addition, training time could be reduced, which should result in a reduction of costs for both students and flight schools. By reducing costs, the flight school should be able to attract additional students, thereby increasing its student load and potential business. Also, the ability of students to gain self-guided practice at some tasks and maneuvers should improve skill maintenance and pilot proficiency.

Purpose and Development Plan

The purpose of this report is twofold: 1) present a conceptual approach based upon human learning principles and available flight training data for use in the development and evaluation of PCATDs; and 2) provide a detailed technical plan for an initial effort to develop and test guidelines for assessing the use of PCATDs in a training curriculum of a flight school conducted in accordance with the regulations stated in FAR Part 141. The initial user-client is the FAA safety inspector from a local Flight Standards District Office (FSDO), who has the responsibility of approving Part 141 flight training curricula. In follow-on work, the feasibility of extending these guidelines to other ratings could be explored, as well as extending them to other potential client-user groups, such as Part 141 school curriculum developers, PCATD hardware and software developers, and eventually, to individual users desiring to select a PCATD for self-guided use.

Figure 1 provides a milestone chart of how development will proceed on a conceptual basis for PCATD qualification and of the actual qualification guidelines. Results of Step 1, Develop PCATD Qualification Concept, are provided below. Results of the remaining steps in guideline development will be provided in subsequent reports. An initial set of guidelines for the instrument rating curriculum, packaged for the FSDO inspector, is expected to be available by the end of Oct. 1, 1994. These guidelines can be expanded to include other certificates, rating areas and client-users after the guidelines have been subjected to scientific verification and user acceptance testing. The steps to be accomplished and their relationship to each other in the development of PCATD qualification guidelines are shown in Figure 2. The guidelines will be organized into a procedural form that will be called the PCATD Qualification Tool (PQT). Numbers in the figure identify the individual steps to be accomplished. As can be seen from the figure, there are eight primary steps involved in the approach.

DEVELOPMENT OF PCATD QUALIFICATION GUIDELINES

Step 1 - Develop PCATD Qualification Concept

The first step in the task plan involved developing a concept for incorporating PCATD technology into the ground and flight training environment (See Figure 1 for the time frame on this task). The goal was *not* to provide a method of *qualifying* PCATDs, but to allow for their appropriate and effective use within the flight training community. An important FAA responsibility is approving curricula to be used by Part 141 flight training schools. Previous attempts at generating qualification guidelines for PCATDs (e.g., Forster, 1991) have not recognized the possibility of task-specific guidelines. Given the existence of task-specific qualification guidelines, approval of a Part 141 curriculum utilizing training on a PCATD would involve not only looking at the PCATD itself, but also at the plan for its use within the curriculum. Basically, the PCATD should not be used for training tasks in which it is not capable of producing an acceptable level of training transfer. Review of the training curriculum by a FSDO inspector using PCATD qualification guidelines should ensure that protection. This task involved the review of applicable literature on flight training and simulation and on the development and capabilities of PC-based aviation training software and hardware. This background was important to subsequent development of the theoretical structure needed for the qualification concept.

A review of Agency regulatory needs and policies concerning PCATD utilization was performed to ensure that the approach taken was consistent with those issues. The information collected from those reviews was used to develop an initial concept for qualifying the manner in which PCATDs are incor

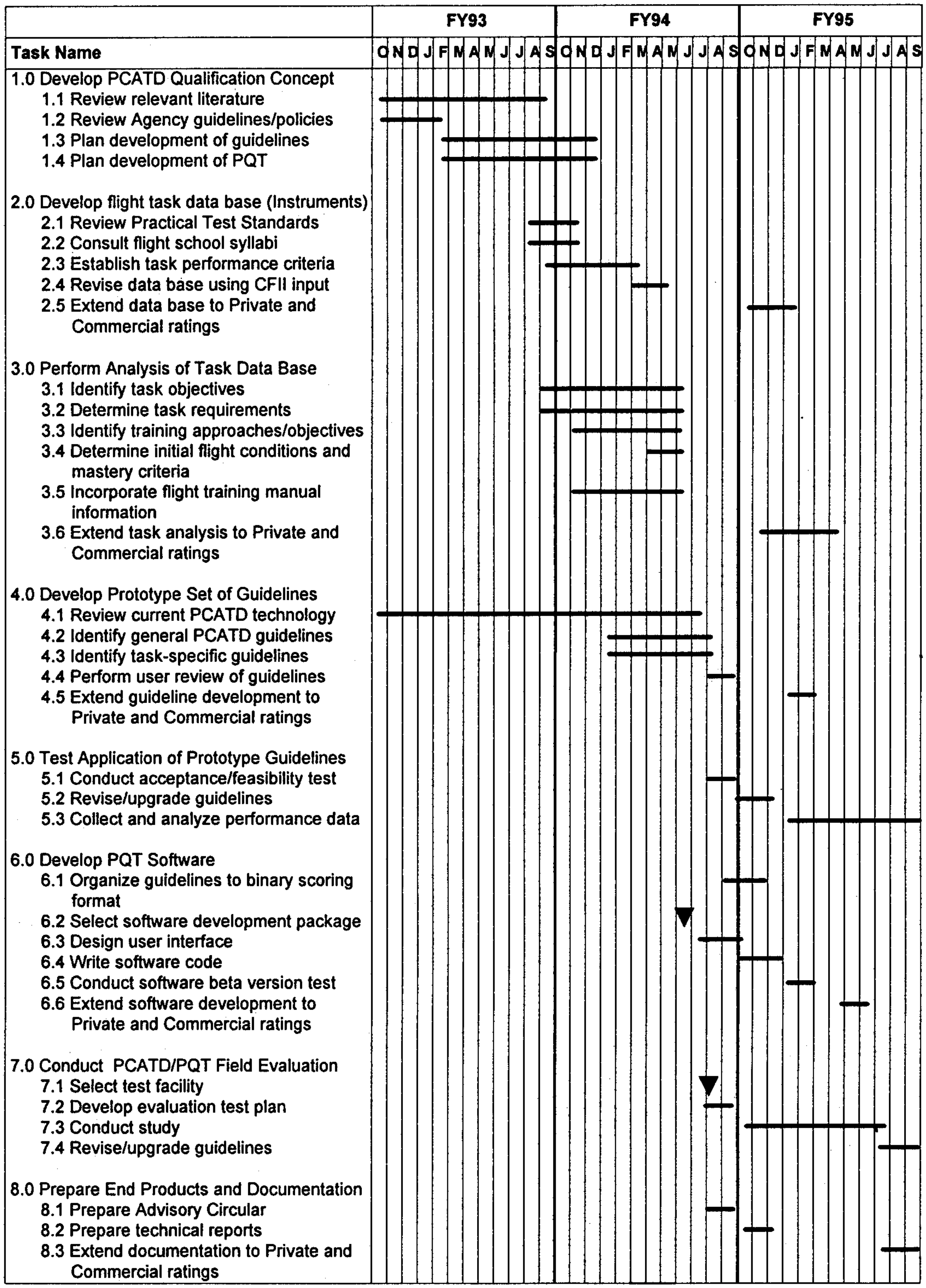

Figure 1. PCATD guideline development and evaluation schedule.

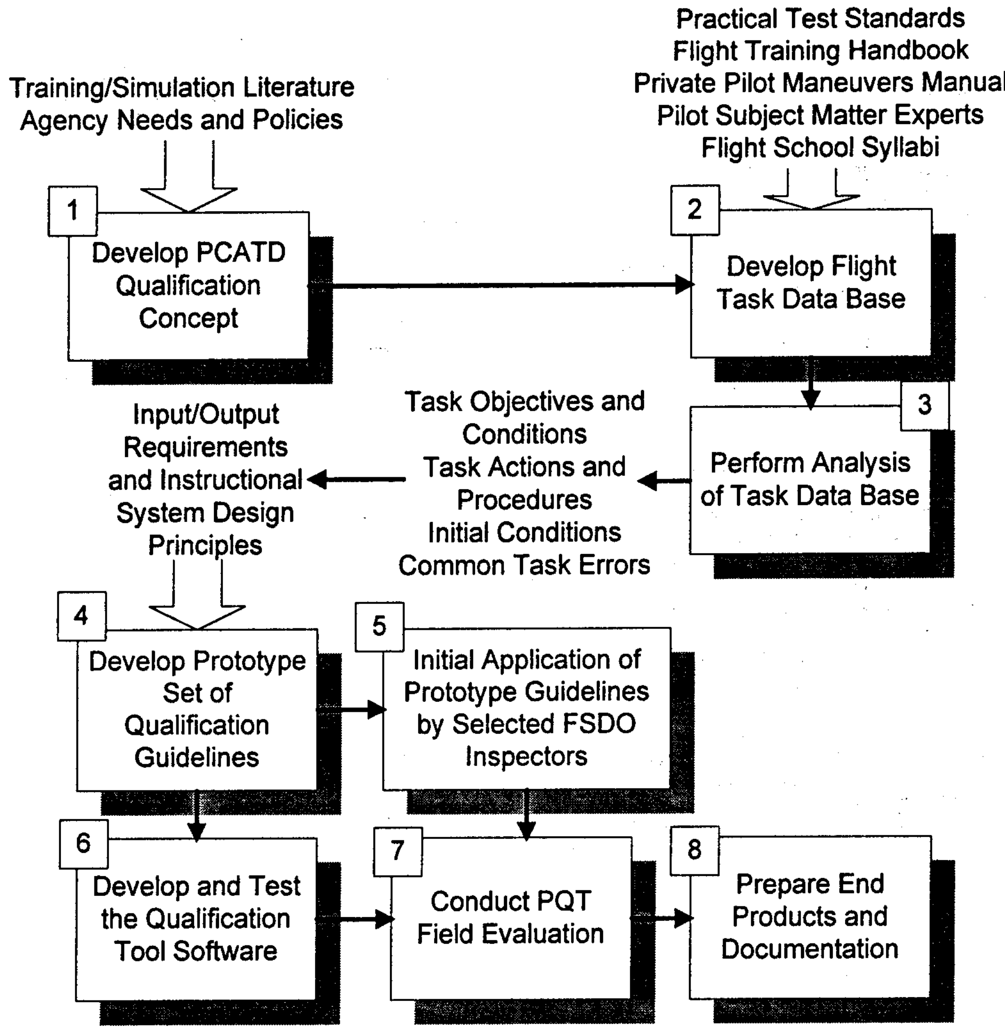

Figure 2. Development of PCATD qualification guidelines.

porated into ground and flight training curricula while minimizing Agency regulatory involvement and at the same time providing for broad utilization of PCATD current and future technology. Our concept involves the use of a set of qualification guidelines based on a detailed flight task data base with criterion-referenced levels of acceptable performance. These task-referenced guidelines would provide assurance of, but would not guarantee, at least some transfer of training from a particular PCATD to the training aircraft. This approach is based on the proposition that skill learning occurs in stages, and that a PCATD must possess the ability to support at least initial-stage learning of a particular task (or task set) if useful transfer is to occur.

This task-based approach is similar to that used for the Advanced Qualification Program (AQP) for qualification events and associated flight training equipment (AC 120-54, Appendix C). The resulting PCATD qualification guidelines will be incorporated into an analytic tool, which can be computerized and employed by a number of potential user groups in determining the individual or relative merits of specific PCATD designs.

The proposed guidelines would be based on an analytical process by which the specific input/output requirements of a given training objective (task element) would be identified and compared to the specific hardware/software characteristics of a given PCATD in providing those necessary input/output requirements. An evaluation score would be provided based on task and task set assessments with respect to the acceptability of the candidate PCATD in fulfilling specific learning objectives. *The proposed guidelines would be used for qualifying a PCATD for training only, and not for proficiency assessment.*

PCATD qualification guidelines can be categorized according to whether they apply to the simulation fidelity of the training device or to managing the instructional environment (e.g., allowing the ability to pause the system during simulation of a maneuver). In addition, the guidelines can be categorized according to whether they relate to every task to be trained, or only to specific tasks or task sets. An example of a guideline that would apply across all tasks would be a requirement that the instrument layout of the training device correspond to that of a common training aircraft. This guideline would hold true regardless of the task being trained.

Basic Premises

Our conceptual approach for developing PCATD qualification guidelines centers around three premises. The first premise is that guideline development should be driven by a detailed analysis of the specific learning objectives to be accomplished using the device. If a device can support the learning that is expected to occur on a specified task element, then that is a sufficient criterion to qualify the device for the training of that task element. Another way of stating this concept is in terms of transfer of training. To be qualified for use as an aid in instructing on a particular task, a PCATD must provide some minimal level of transfer of training for that task.

The second premise is that the development of guidelines for a training device should also be driven by the objective of avoiding producing *invalid expectations* in the trainee when the task is transferred to the airplane; or, producing negative transfer of training.

The third premise is that guideline development should be driven by the need to take full advantage of the medium to be used for training; that is, the personal computer. PCs present unique opportunities for enhancing the learning environment for aviation training.

In summary, the three premises for developing PCATD qualification guidelines are 1) provide a minimal level of positive transfer of training from the PCATD to the airplane; 2) avoid negative transfer; i.e., establishing false expectations; and 3) take advantage of the training delivery medium, the computer. Each premise is described in more detail below.

Promoting Positive Transfer

Positive training transfer is not an all-or-nothing phenomenon. Every complex skill is composed of a number of component skills. These component skills can consist of a motor movement, perception, retrieval of information from memory, or processing information. When endeavoring to master a complex skill, it is important to note that skill acquisition, including the acquisition of complex psychomotor skills, occurs in discrete stages (Anderson, 1982, 1987; Fitts, 1962; Rasmussen, 1986). All of these researchers propose three stages of skill acquisition. These stages proceed from 1) the understanding of task objectives, task parameters, and any procedures involved, through 2) the establishment of correct patterns of behavior, and finally 3) to the point at which the task becomes largely automatic. Learning at later stages is dependent on learning at earlier stages.

Given the existence of skill acquisition stages, the next major concept, first expressed at least 40 years ago (Miller, 1954), is that the level of physical fidelity of a training device required at the initial stages of skill acquisition is less than that required at later stages. As the level of the skill progresses, so must the level of physical fidelity of the training device.

During the first stage of skill acquisition (Fitts' cognitive stage), the trainee learns the basic task objectives, the location of displays and controls, and the relationship between different controls and displays within the context of the task. Miller proposed that in the first stage, simple simulations (pictures, diagrams, mock-ups) could be used to allow learning to occur.

During the second stage of skill acquisition (Fitts' associative stage), the trainee learns to coordinate movements and anticipate actions in the same manner as the actual flight task. During this stage, the trainee learns the basic movements involved in the task and when, and under what circumstances, those movements are needed. For example, in learning to perform a takeoff, the trainee must learn to apply back pressure on the stick to rotate the aircraft when airspeed reaches a certain point and to depress right rudder to counteract the left-turning tendency of the aircraft and maintain directional control during takeoff. The trainee does not need to know exactly how much back pressure to put on the stick or how far to push on the rudder — yet. That level of skill will come during the third, and final stage of skill acquisition.

The final stage (Fitts' autonomous stage), involves refining the skills to the point where they become relatively automatic. Precise motor movements are refined until the trainee does not have to expend effort in controlling those movements. What is ultimately required is a refinement of the motor skills to fit the response characteristics of the aircraft. This level of finesse is likely to be developed only in the aircraft, or a flight simulator or flight training device with high physical fidelity.

The PCATD, to be useful for the training of a task, should be designed to support the learning of that task through the first two stages of skill acquisition. If it can do so, sufficient positive transfer of training for that task can be expected to occur to support the use of the device for that task.

The relationship between incremental transfer, cost, and physical fidelity is shown in Figure 3, according to a rationale provided by Roscoe (1980). Also illustrated is the relationship between stage of learning and transition from PCATD use as a ground training aid to its use as a flight training device. A basic reality of training device design, shown in Figure 3, is that as physical fidelity increases to higher levels of skill training, so must the cost of the device.

These curves suggest that a steady gain in incremental transfer can be expected for nominal investments in physical fidelity, up to the point at which training enters Stage III (autonomous stage) and where use of the PCATD begins to transition from that of a ground training aid to that of a flight training device (see bottom two variables in Figure 3). At that point, increases in physical fidelity necessary to reach higher levels of skill training result in decreasing increments in training transfer, until such point that increasing investments in physical fidelity result in essentially no appreciable gain in incremental learning transfer.

The shaded portion in Figure 3 depicts the area in which incremental transfer is greatest relative to the costs incurred; i.e., the area of maximum payoff in training effectiveness for investment in PCATD physical fidelity. Beyond that point, increasingly smaller increments in learning cost increasingly more in design investment.

The challenge to the PCATD developer is embodied in technological innovation in hardware and software design, manufacturing techniques, and in the integration of principles of computer-based instruction (CBI). If, through technological innovation, costs could be decreased and learning effectiveness

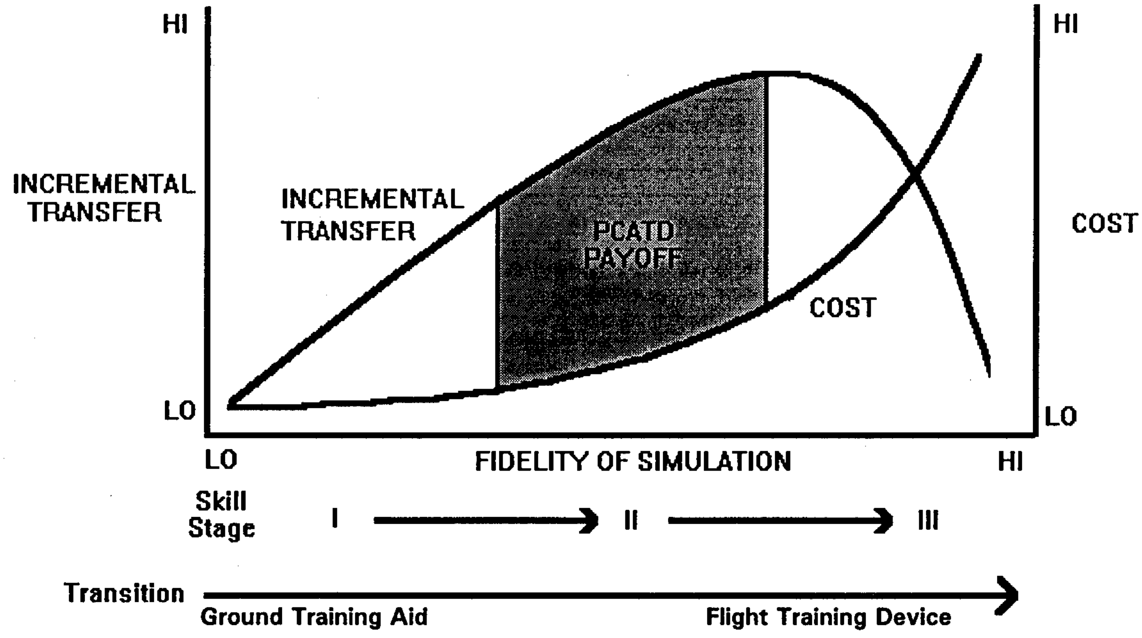

Figure 3. Tradeoff between physical fidelity, cost, and transfer of training effectiveness.

increased, then the point at which the two curves cross can be moved to the right, representing improved training cost-effectiveness. The end result would be that higher levels of skill training could be performed on the PCATD, including some flight training maneuvers at a cost considerably less than that of the airplane.

The airplane would most likely be needed ultimately for checking and for certification but, with less time and replications, overall training costs could be expected to be less. As a result, flight training would become more affordable, allowing an increased number of students to pursue instrument training, with the attendant payoff in enhanced aviation safety. Additionally, with greater affordability, an increased number of students would be attracted to ab initio flight training programs with the much sought for boost in the economic health of general aviation.

Avoiding Negative Transfer

To support the first two stages of skill acquisition, a training device would not have to simulate the exact look and feel of the aircraft. By concentrating on the first two stages of skill acquisition, the level of physical fidelity required in the training device is much less than would be required for the third stage of skill acquisition. The movement of controls has to match only the general characteristics of aircraft controls (i.e., moving the stick forward pitches the nose down, moving the stick to the left causes banking to the left, etc.). Likewise, flight dynamics, display characteristics, and out-the-window scenery need only be realistic enough to support the learning of the cognitive/procedural aspects of the task.

Exceptions to this statement occur when the training device promotes the establishment of invalid expectations about actual flight skills and procedures or promotes the formation of bad habits. The idea of an "expectation" is related to that of a mental model (Johnson-Laird, 1983), in that it is a trainee's mental representation of a real-world activity (flying).

Rasmussen (1988) referred to the first level of skill acquisition as knowledge- or *model-* based behavior because trainee actions in a given situation were dependent on their mental model of the system.

Use of a training device establishes certain expectations about the actual task. These expectations would not be task specific, but would apply to the overall task of flying the aircraft. These expectations can be either valid or invalid. An example of establishing an invalid expectation would occur through the use of a mouse as a substitute for the aircraft yoke. Normal aircraft yokes automatically return toward a neutral position during flight when control pressures are released. A mouse control, however, has no neutral position and, therefore, might promote the expectation that the yoke must be guided back to a neutral position.

Taking Advantage of the Learning Media

In addition to promoting positive transfer and avoiding negative transfer, a third goal in the development of qualification guidelines for PCATDs is to make the best possible use of the medium on which training will occur. Computer-based training systems provide the opportunity to deliver training to a student in a reasonably organized fashion, free from the biases and limitations of human instructors. Caro, for instance, suggests that the content of flight training "...often is based upon tradition and upon instructors' judgments and unique experiences rather than upon detailed, systematic analyses of piloting tasks." (Caro, 1988 p. 248). The use of a computer-based training system would ensure that all aspects of a particular flight task were covered in the training.

The use of low-fidelity training devices is valid for transition through the first two stages of skill acquisition, as long as care is taken in the design of those devices to guard against the establishment of invalid expectations. However, *even if the level of physical fidelity is appropriate for a given level of skill acquisition, learning will not occur unless some general principles of instructional design are followed.*

Research on instructional design (for instance, see Patrick, 1992) suggests that for any kind of training to be successful, there are four requirements that must be met: 1) the trainee must have a clear notion of the objectives of the training (for our purposes, these objectives should be stated at the level of individual flight tasks); 2) for a given set of training objectives, the trainee must know the procedures and actions required for achieving the objectives; 3) the range of conditions under which the performance occurs must be learned; and, 4) specific feedback must be presented to the trainee regarding task performance.

For a PCATD to be useful for training a particular task, it should have the following characteristics: 1) sufficient physical fidelity to accommodate training through the first two levels of skill acquisition for that task; 2) avoidance of physical design characteristics that lead to the establishment of invalid expectations regarding actual flying; and 3) general instructional design principles noted above in the control of a training session.

Use in Training

Initial approval of PCATDs will be restricted to Part 141 flight training schools. Figure 4 illustrates how the curriculum approval process would occur. Box 1 denotes that the curriculum approval process would be initiated by application of a flight training facility aspiring for approval as a Part 141 training school.

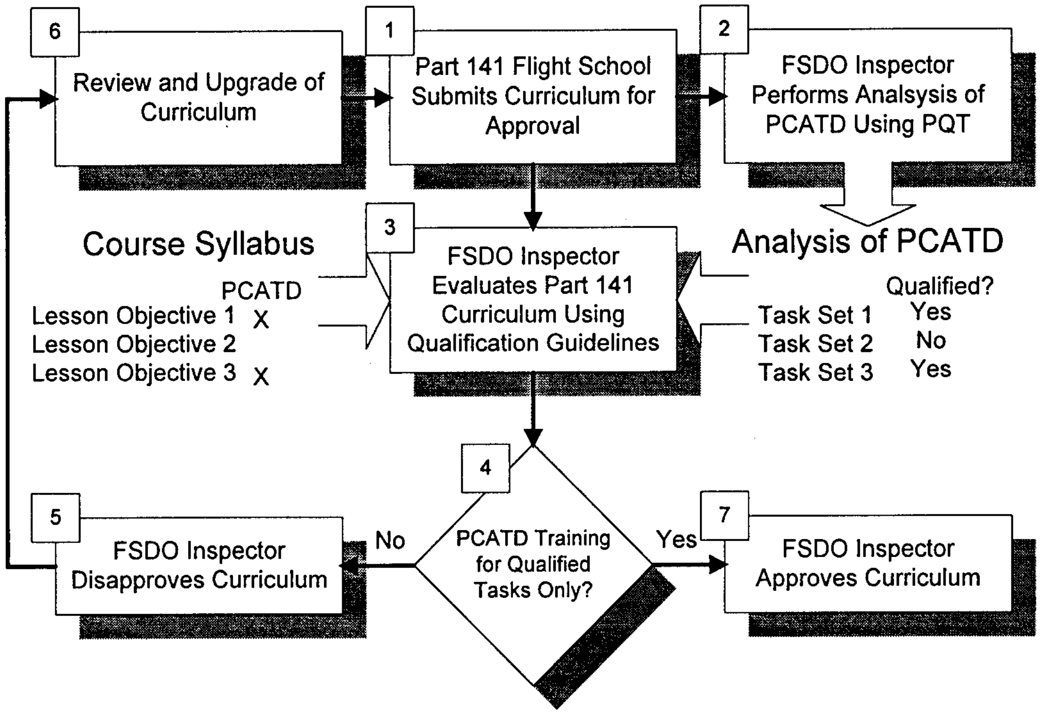

Figure 4. Approval of a Part 141 curriculum using the PCATD qualification guidelines.

Box 2 shows that the FSDO inspector would first perform an analysis of the PCATD being used in the curriculum using the PQT. Box 3 illustrates that the FSDO inspector would then use the qualification guidelines to evaluate a Part 141 curriculum. The incorporation of PCATDs into a flight school curriculum requires a method for qualifying PCATDs for use on specific lesson objectives using criterion-referenced tasks and task sets. FAR Part 141.53 requires FAA approval of training courses, or amendments to training courses, through the local FSDO. Part 141.55 specifies the information that must be submitted to the FAA for this purpose. A FSDO inspector, whose task it is to approve a Part 141 curriculum, must ensure that the PCATD to be used in the curriculum will be used to train only those lesson objectives (tasks) for which it has been approved.

Box 4 shows that the FSDO inspector, after comparing the course curriculum to the results of the evaluation of the PCATD, will decide if the PCATD is being used to train only those tasks that it is qualified to train. If it is not, the inspector will disapprove the curriculum with an explanation of how the PCATD is being inappropriately applied (Box 5). The school can then review and upgrade the curriculum and begin the approval process again (Box 6). If the training device is being used properly within the curriculum, the FSDO inspector will approve the curriculum, and the process is complete (Box 7).

Step 2 - Develop Flight Task Data Base

Step 2, which is currently underway, involves organizing the flight task data base according to certificate or rating and will be an expanded version of those found in the Practical Test Standards (e.g., FAA-S-8081-4A). Information for this task comes from two main sources. The Practical Test Standards provide a listing of the flight tasks, along with minimum performance criteria for each task. Syllabi from selected Part 141 flight schools will be used to supplement the flight task lists. The resulting data base will be confirmed and extended using certified flight instructors for instrument flying (CFIIs) as subject matter experts. A listing of an expanded version of flight tasks taken from the Instrument Rating Practical Test Standards (FAA-S-8081-4A) and other sources is given in Appendix A.

Step 3 - Analyze Flight Task Data Base

Step 3 will involve conducting a task analysis to identify the training device characteristics required for completing each task. Figure 2 places the task analysis within the overall context of the approach. The first step in the task analysis will be to break down the tasks to the task element level. It is expected that mastery of some task elements on the PCATD will transfer reasonably well to the aircraft, while others will not. In addition, it is expected that some of the task elements correspond to learning that takes place in the initial stages of skill acquisition, while other task elements correspond to learning that takes place in later stages of skill acquisition. A PCATD will be judged useful for the training of a particular task if (1) adequate transfer can be expected for all early stage task elements, and (2) later stage task elements can be performed without the PCATD introducing invalid expectations to the trainee.

What determines whether the learning of a task element will or will not transfer adequately to the aircraft are the inputs and outputs presented by the PCATD to support performance of the task element. The identification of the required inputs and outputs will be made through an analysis of the task objectives and criteria, task nomenclature, controls, displays, environmental information used in the task, and movements and procedures required to complete each task. It is expected that task elements of a more cognitive nature will require less physical fidelity than those of a more psychomotor nature. This is due to the ability to represent certain tasks symbolically.

Caro (1988) refers to this symbolic representation as *mediation*. Caro defines a mediator as a word, phrase, thought, or action that helps a trainee associate meaning with a particular stimulus and that can substitute in training for an action that is overt in the aircraft. For example, if a student is required to perform the task element of tuning a radio to a specific frequency during the performance of a task, this action can be accomplished in several ways during training that will all transfer adequately to the aircraft. Turning a knob, pushing buttons, or clicking on a mouse can all substitute for the actions required to tune the radio.

The major portion of the data for this step will come from pilot SMEs. Interviews will be conducted with instructors from flight schools. Data will be collected about each flight task regarding how the task is trained in the aircraft. These data will include items such as the initial conditions of the task and task objectives. "Initial conditions" refers to the state of the aircraft (relative location, airspeed, heading, altitude, etc.) at the time the task is said to have begun. Data regarding the most common types of errors that students make when performing a particular task will also be collected. The task analysis will be supplemented with data from commercially published private pilot maneuvers guides, the Instrument Flying Handbook (AC 61-27C), a review of current flight training programs, and relevant research literature.

Tasks will be organized according to certificate or rating and will be an expanded version of those found in the Practical Test Standards. Initially, the tasks will be limited to those involved in obtaining an instrument rating.

Step 4 - Develop Prototype Set of Qualification Guidelines

Step 4 will involve translating all of the data into a prototype set of qualification guidelines that can be compared to candidate training device specifications. To aid in the specification of guidelines, a baseline set of qualification guidelines will be developed to try and encompass a majority of the requirements needed for a useful training device. Appendix B contains the set of baseline qualification guidelines to be used during the task analysis. Using this baseline set of guidelines, each flight task will be examined in order to decide whether any further guidelines are required to perform training for that task. Identification of further guidelines will be made on the basis of the learning objectives for that task, input and output requirements for the task, and any other training considerations that need to be addressed such as task-specific feedback that is unique to the task.

The guidelines will be organized into four categories: 1) controls, 2) displays, 3) flight dynamics, and 3) instructional management. The first three categories deal with the simulation of flight and the aircraft cockpit. Instructional management characteristics of the device manage the nature of, and kind of training, that can be accomplished using the device. Individual approaches to task instruction, such as part-task versus whole-task training, would be left up to the discretion of the PCATD developers.

Development of the guidelines for each task will proceed on the basis of ensuring that the device can support the performance of the task to the levels stated in the task learning objectives. For example, if the flight task requires that the aircraft maintain altitude within 100 feet, airspeed within 10 knots, and heading within 10 degrees, then the degree of precision and resolution of the aircraft displays and out-the-window scene and the level of response of the controls should be such that those task objectives can be met.

In addition, if the task requires a particular movement from the trainee, such as applying back pressure on the stick during the performance of a steep turn, then the device should support such a requirement. Because the goal is only to support transition through the first two stages of skill acquisition, the exact forces required in an aircraft do not have to be simulated, only the general movements involved. The purpose of the PCATD is to introduce basic objectives, general location of displays and controls, the relationship between different controls and displays within the context of the task, and to allow the trainee to learn to coordinate movements and anticipate actions in the same manner as in the actual flight task. Appendix C provides the results of an analysis of an example instrument flight task, along with task-specific guidelines for that task beyond the baseline set of guidelines provided in Appendix B.

Step 5 - Test Application of Prototype Guidelines

This will involve an initial test of the usefulness and acceptability of the guidelines by providing them to a selected set of FSDO inspectors for use in evaluating sample Part 141 flight school curricula. Feedback from these user feasibility tests will be used to make revisions and additions to the guidelines. In addition, initial validation of the guidelines could be accomplished through the collection of performance data from each Part 141 school employing a PCATD in its curriculum. The performance data would be collected and sent to a centralized location to be analyzed. Such data possibly could be used in lieu of a formalized empirical validation of the guidelines, should such an approach prove to be cost prohibitive.

Step 6 - Develop PQT Computer Software

After the qualification guidelines have been developed, reviewed, and feasibility tested, the next step in the process would be to incorporate the guidelines into a computer program that will automate the evaluation process. The computerized PQT will structure the collection of information about a particular PCATD and then generate a list of qualified flight tasks that can be trained using the device.

Use of the tool would involve answering a series of binary questions regarding various features and characteristics about a particular PCATD. After the device evaluator provides responses to each of the questions, the system will automatically compare those responses to the qualification guidelines for each flight task. If there is a match between required and actual responses for a given task, the computerized PQT will indicate that the device can be qualified for training on the task. A list of all qualified tasks, grouped by certificate or rating, will then be generated. In addition, the program will be able to generate a list of guidelines a device lacks. If a manufacturer wanted to produce a device qualified for all of the tasks involved in achieving a specific pilot certification, the program would be able to generate a list of upgrades for the device to qualify it for training on those tasks.

First, a software development package will be selected. Next, the user interface will be designed and the qualification tool will be coded using the revised guideline listing generated during Step 4.

After the guidelines have been incorporated into the PQT, a beta version of PQT software will be developed. The software will be used to qualify a selected sample of PCATD hardware and software designs for training tasks from selected certificates and ratings. The ease of using the software will be evaluated and recommended changes will be made.

Step 7 - Conduct PCATD and PQT Field Evaluation

Two questions will be addressed in the field evaluation study. The first question involves determining the training transfer effectiveness of a representative set of PCATDs for a specified set of tasks. This study will require use of a control group who receive training only in an airplane. The second question will concern the ability of the PQT to discriminate tasks both within a given PCATD, based on expected transfer effectiveness, and between competing PCATDs. In the first instance, the objective would be to establish the ability to qualify a PCATD for training a specific set of tasks for a particular certificate or rating. The second instance concerns using the PQT to evaluate the relative predicted training effectiveness of two (or more) competing PCATDs. Subjects will be trained on both qualified and non-qualified tasks to address those questions.

This step will involve the support of a flight training facility with an ongoing flight training program having a sufficient number of trainees to supply the number of subjects required for the study, and with adequate facility and aircraft resources. The number of candidate PCATDs selected for study will depend on the number of subjects available and available funding. The initial effort on this task will be to develop a detailed test and validation plan such that the scope of the study, with respect to hypotheses tested, can be optimized against available facility and funding resources. Results of the study will indicate (1) the training effectiveness of personal computer-based aviation training devices; and (2) whether the PQT is a dependable aid in qualifying PCATDs for incorporation into Part 141 flight school operations. Results will also be used to upgrade and refine the PQT to improve its ability to serve that particular use, as well as other potential uses.

Step 8 - Prepare End Products and Documentation

In addition to a computerized evaluation process that would be distributed on a floppy disk, the guidelines will be organized into a listing that can be disseminated in the form of an FAA advisory circular. Users of PCATDs could then select a device on the basis of whether it can meet their training needs. Results of the field evaluation will be summarized in a technical report.

FOLLOW-ON DEVELOPMENT

The screening guidelines represented in the PQT developed initially for the FSDO safety inspector could be packaged for use by other potential user groups. Broad use of the guidelines would serve to consistently upgrade the quality of PC simulation by raising the standards of developers and the expectations of users. Also, follow-on development of the PQT concept should include other certificates and ratings to provide for the broadest possible use of PCATD technology. This would stimulate pilot training at all levels by helping to reduce the cost of flight training and increase the number of potential students seeking pilot certificates, added ratings, and proficiency training.

Flight schools aspiring to qualify for Part 141 approval would be benefited by using the PQT as an aid in selecting a PCATD to incorporate into their flight school curriculum. This step would greatly increase the likelihood of obtaining FAA approval, without having to replace highly limited PCATDs or to revise their curriculum to obtain approval.

PCATD developers constitute a prime user of the PQT guidelines, which would be ideal for planning product upgrades and expanding software developments to increase their product's responsiveness to market expectations and improve their competitive positions. Individuals seeking a PCATD for use in self-guided flight training would find the PQT an excellent aid in selecting a device that could be expected to pay off in terms of reduced costs of flight training. Also, a PCATD that meets PQT guidelines would be more likely to be consistent with a Part 141 training syllabus, should the individual choose that route for training.

As indicated in the milestone chart in Figure 1, follow-on development for the PQT is scheduled for late FY'94 and continued in FY'95. This follow-on work will involve the inclusion of additional certificates and ratings in the guidelines and packaging for other potential users. Figure 5 illustrates this expanded use of the qualification guidelines. In addition to the instrument rating, the guidelines could be expanded to include the private and commercial certificate. The packaging of the guidelines can also be expanded so that they can be used by Part 141 Schools, the PCATD development community, and individuals desiring to engage in self-guided flight instruction. In addition to these expanded uses of the guidelines, Figure 5 illustrates how performance data could be collected from each Part 141 school employing a PCATD in its curriculum that could be used to lend additional support to the validity of the guidelines. The performance data would be collected and sent to a centralized location to be analyzed and studied. The data could be used in lieu of a formalized empirical validation of the guidelines, should such an approach prove cost prohibitive.

EXPECTED BENEFITS

The approach recommended here has a number of benefits for both the FAA, PCATD developers, and the pilot training community:

FAA

- Provides specific guidelines to local FSDO inspectors for approving a PCATD for use within a Part 141 flight school curriculum
- Avoids the untenable position of trying to develop an hours-based crediting system for PCATDs, contingent on an expected level of transfer of training
- Allows market forces to be involved in determining which training devices are the best and/or most useful
- Provides detailed guidance to the PCATD development community as to specific design characteristics required to achieve task qualification
- Provides for the aircraft to be used as the validating instrument for demonstrating the usefulness of any particular PCATD
- Limits the need for new government regulations

PCATD Developers

- Provides useful guidelines for the development of robust training systems
- Does not stifle creativity by placing costly hardware constraints on the systems
- Allows systems to be engineered for different levels of training (different certificates and ratings or individual tasks and task sets)
- Provides definitive design guidance to PCATD developers on how to achieve more marketable and effective PCATD products

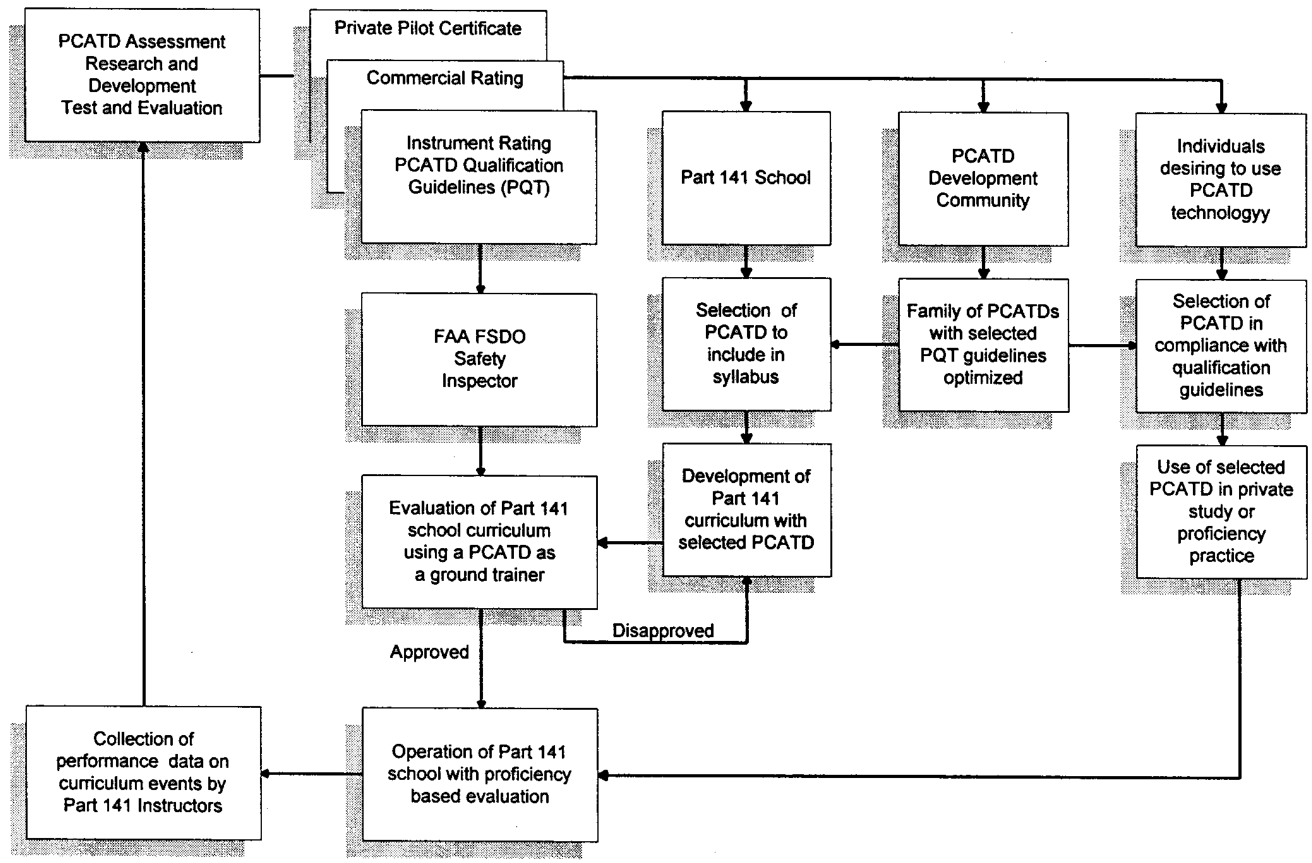

Figure 5. Expanded Use of PCATD Qualificatioin Guidelines

Training Community

- Provides for formal integration of PCATDs into the flight training process
- Allows more selective, tailored use of PCATDs in both flight schools and by individual trainees
- Provides individuals and flight schools with an objective basis for choosing among PCATD options
- Retains the CFI as an integral part of the training process
- Accounts for individual differences between trainees by providing a way for slower learning trainees to increase their training time (at home) without greatly increasing costs for them
- Organizes guidelines according to the particular certificate or rating sought, allowing a more focused use of the PCATD

One final advantage is that this approach will provide the incentive to develop ground and flight training programs that are more integrated. Currently marketed ground training and flight simulation programs employ two distinct approaches. The ground training approach involves teaching flight-relevant knowledge (e.g., procedures, weather, flight planning, airport lighting). The flight simulation approach allows the practice of flight skills (e.g., takeoffs, landings, turns). The knowledge approach involves more traditional computer-assisted instructional methods of providing specific feedback, repetition learning, and review of those areas where the student needs help. The flight skills approach, on the other hand, has left most of the instructional management up to the student. An integration of these approaches would result in a more effective system for training in both the skills and knowledge necessary for flying an aircraft. The guidelines that would be developed in this project would encourage such an integration and lead to more effective training systems.

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APPENDIX A.

EXPANDED FLIGHT TASK LISTING FOR AIRCRAFT INSTRUMENT RATING.

1.0 Ground Phase
- 1.1 Obtaining weather information
- 1.2 Cross-country flight planning
- 1.3 Aircraft systems related to IFR operations
- 1.4 Aircraft flight instruments and navigation equipment
- 1.5 Instrument cockpit check

2.0 Flight by Reference to Instruments
- 2.1 Straight-and-level flight
- 2.2 Change of airspeed
- 2.3 Constant airspeed climbs to altitude
- 2.4 Constant rate climbs to altitude
- 2.5 Constant airspeed descents to altitude
- 2.6 Constant rate descents to altitude
- 2.7 Precision descent
- 2.8 Non-precision descent
- 2.9 Level turns
- 2.10 Standard rate turns
- 2.11 Short turns
- 2.12 Climbing turns
- 2.13 Descending turns
- 2.14 Steep turns

3.0 Abnormal and Emergency Procedures
- 3.1 Unusual attitudes
- 3.2 Timed turns
- 3.3 Compass turns
- 3.4 Partial panel maneuvers
- 3.5 Loss of communications
- 3.6 Instrument failure
- 3.7 Systems failure
- 3.8 Turbulence
- 3.9 Engine failure
- 3.10 Lost procedures

4.0 Radio Navigation Procedures
- 4.1 VOR Navigation
- 4.2 NDB Navigation
- 4.3 Localizer & ILS Navigation
- 4.4 VOR/DME
- 4.5 VOR holding pattern
- 4.6 NDB holding pattern
- 4.7 Localizer holding pattern
- 4.8 DME holding pattern
- 4.9 Intersection holding pattern

5.0 Instrument Approaches
- 5.1 VOR/VORTAC instrument approach procedure
- 5.2 NDB instrument approach procedure
- 5.3 ILS/MLS instrument approach procedure
- 5.4 ILS back course approach procedure
- 5.5 RNAV approach procedure
- 5.6 Missed approach procedure

6.0 Communications Procedures
- 6.1 Air Traffic Control Clearance
- 6.2 Departure clearances
- 6.3 Enroute clearances
- 6.4 Arrival clearances

7.0 Cross-country Procedures
- 7.1 Departure procedures
- 7.2 Enroute procedures
- 7.3 Arrival procedures

APPENDIX B.

BASELINE QUALIFICATION GUIDELINES

This appendix includes the baseline PCATD qualification guidelines. The guidelines, given below, specify general device characteristics that any PC-based simulation device should possess regardless of the type of training to be done. These guidelines are divided into four categories: (1) controls, (2) displays, (3) flight dynamics, and (4) instructional management.

Controls.

Controls used in the PC-based simulation device can be of two types, both physical and virtual. Both types of controls should be recognizable as to their function and how they can be manipulated solely from their appearance. This requirement eliminates the use of a keyboard to control the simulated aircraft (although a keyboard may still be used in controlling aspects of the simulation such as setting initial aircraft state, location, wind, etc.). A virtual control is defined here as a realistic graphical representation of a control, displayed on the computer screen, that can be unambiguously manipulated through the use of a computer input device. An example of a virtual control is a realistic-looking flaps switch that is displayed on the computer screen and manipulated through any computer cursor-control device, such as a mouse, or more directly with touch-screen technology. The cursor is positioned on the flaps switch and "pressed" by an appropriate action with the input device. A virtual control provides a sense of direct manipulation of a control without requiring the presence of external hardware.

1. A physical, self-centering, displacement yoke or control stick that allows continuous adjustment to rate of change of pitch and bank.
2. Physical, self-centering rudder pedals that allow continuous adjustment to rate of change of yaw.
3. A physical throttle control that allows continuous movement from idle to full power settings.
4. Physical or virtual controls for flaps, pitch trim, communication and navigation radios, VOR, ADF, and a clock or timer. It is not necessary that the pitch trim control relieve control pressure as it does in an actual aircraft. However, the pitch trim control might allow the simulated aircraft to be stabilized at any particular pitch attitude with the yoke or control stick in the neutral position.
5. Time from control input to recognizable system response (transport delay) should be 300 milliseconds or less

Displays.

6. Displays represented should include an altimeter, heading indicator, airspeed indicator, vertical speed indicator, turn and bank coordinator, attitude indicator, tachometer, flaps setting, pitch trim indication, communication and navigation radios, VOR (with ILS indicator), with an aural, morse code identification feature, ADF, with an aural, morse code identification feature, clock or timer, and a magnetic compass.
7. Relative layout of the primary displays must correspond to the standard "T" configuration with (a) airspeed, (b) attitude and (c) altimeter forming the "cap" with (d) the heading indicator, located in the "stem" below the attitude indicator.
8. Relative size, shape, and information content of displays should resemble those found commonly in a single-engine, fixed-pitch propeller, basic training aircraft with a fixed gear.

9. Display update should be 10Hz or faster.
10. The smallest display changes should be discriminable from pilot's normal operating position and correspond to the following information:

Airspeed indicator	Change of 1kt. or less in airspeed
Attitude indicator	Change of 2° or less pitch or bank
Altimeter	Change of 10ft. or less in altitude
Turn and bank	Change of 1/4 standard rate turn or less
Heading indicator	Change of 1° or less in heading
VSI	Change of 20 ft. per min. or less in altitude
Tachometer	Change of 25 RPM or less in engine power output
VOR/ILS	Change of 1/2 dot or less in bearing deviation
ADF	Change of 1° or less in bearing
Clock or timer	Change of 1 second or less

11. Displays should reflect dynamic behavior of an actual aircraft display (e.g., VSI reading of -500fpm is reflected by a corresponding movement in altimeter, an increase in throttle is reflected by an immediate increase in RPM indicator, etc.).

Flight Dynamics.

12. Flight dynamics of the simulated aircraft should be consistent with a single-engine, fixed gear, basic training aircraft with a fixed-pitch propeller.
13. Aircraft performance parameters (maximum speed, cruise speed, stall speed, maximum climb rate) should be consistent with a single-engine, fixed gear, basic training aircraft with a fixed-pitch propeller.
14. Aircraft vertical lift component should change as a function of bank, consistent with a single-engine, fixed gear, basic training aircraft with a fixed-pitch propeller.
15. Changes in flap setting should be accompanied by appropriate changes in flight dynamics.

Instructional Management.

16. User should be able to pause the system at any point for the purpose of receiving instruction regarding the task.
17. For the purpose of beginning a training session with the aircraft already in the air and ready for the performance of a particular maneuver, the user should be able to manipulate the following system parameters independently of the simulation:
    - Geographic aircraft location (location within the available digitized space)
    - Aircraft heading
    - Aircraft airspeed
    - Aircraft altitude
    - Engine RPM

18. The system should be capable of recording both a horizontal and vertical track of aircraft position during the performance of a task for later playback and review.

APPENDIX C.

EXAMPLE TASK ANALYSIS

Certificate: Instrument Rating
Task Set: 5.0 Instrument Approaches
Task: 5.1 VOR/VORTAC instrument approach procedure

Learning Objectives

5.1.1 Initial approach segment
- 5.1.1.1 Take out appropriate approach plate
- 5.1.1.2 Find primary and secondary VORs (if present) on approach plate
- 5.1.1.3 Set primary VOR frequency on NAV1 and ident
- 5.1.1.4 Set secondary VOR frequency on NAV2 and ident
- 5.1.1.5 Select final approach heading on OBS1
- 5.1.1.6 Select heading from secondary VOR on OBS2 for identification of FAF
- 5.1.1.7 From approach plate, note missed approach procedure and MDA
- 5.1.1.8 Maintain straight-and-level flight
- 5.1.1.9 Reset heading indicator to magnetic compass reading
- 5.1.1.1 Turn to headings under direction of ATC. Typical ATC instruction is as follows "Turn left heading 210°, maintain 3800 until established on final approach course, cleared for VOR 17L approach at Will Rogers."
- 5.1.1.11 Readback ATC instructions
- 5.1.1.12 Monitor course direction indicator (CDI) to primary VOR
- 5.1.1.13 As CDI centers, turn to final approach heading and track radial inbound

5.1.2 Intermediate approach segment
- 5.1.2.1 Continue to track radial inbound
- 5.1.2.2 Reduce speed 10% to 20% while descending to appropriate segment altitude indicated on approach plate at approximately 500 FPM
- 5.1.2.3 Begin level off at appropriate point prior to reaching desired altitude
- 5.1.2.4 Maintain straight-and-level flight until you reach final approach fix

5.1.3 Final approach segment
- 5.1.3.1 Communicate to tower that FAF has been passed, for example, "Cessna 918, passing Kongg".
- 5.1.3.2 Start timer (in order to identify missed approach point, unless DME equipment is available or FAF is positioned at the runway).
- 5.1.3.3 Begin descent to appropriate segment altitude at 500-700fpm.
- 5.1.3.4 Select bearing on OBS2 for identification of next intersection (if applicable)
- 5.1.3.5 Select first stage flaps (depending on aircraft, not in a Cessna 172)
- 5.1.3.6 Continue to track radial inbound
- 5.1.3.7 Monitor secondary CDI to identify final intersection passage
- 5.1.3.8 Level off until past final intersection
- 5.1.3.9 Begin descent to MDA at 500-700fpm

5.1.3.10 Level off at MDA

5.1.3.11 At missed approach point make decision to perform a missed approach or to land.

Input/Output Requirements

Input Requirements:

Pitch attitude
Bank attitude
Yaw attitude
Rate of change of pitch
Rate of change of bank
Rate of change of yaw
Altitude
Heading
Airspeed
Power setting
VOR station frequency and bearing
NDB station frequency and bearing
Instrument approach procedure plates
Time elapsed from specific points
Radio communications from ATC

Output Requirements:

Rate of change of pitch
Rate of change of bank
Rate of change of yaw
Engine power output
VOR station frequency
NDB station frequency
Course deviation indicator setting
Timer or clock setting
Radio communications to ATC

Training Considerations

The user should be able to begin the task with the aircraft positioned in the air, at a reasonable altitude for maneuvering, in straight-and-level flight, at cruising speed, at a position 5 minutes prior to beginning the intermediate approach segment to allow time to secure approach chart, set up navigational frequencies, reset heading indicator to magnetic compass, and review approach procedure. The system should provide feedback regarding the maintenance of heading within 10°, airspeed within 10 knots, bank within 5°, altitude within 100 feet, CDI within a full-scale deflection prior to the final approach segment and a three-quarter-scale deflection during final approach, and ADF bearing within 10°. During final approach, the system should provide feedback regarding maintaining altitude within 100 feet, but not below the minimum descent altitude until reaching the missed approach point. Amount of crosswind should be varied from none to at least 10 kts. ATC communications can be provided by the instructor. Although the example used two VORs, this task can be accomplished using one VOR and one ADF. Finally, it is required that at least some of the approaches practiced are local to the training area, which requires that the PCATD have a local navigational data base.

Device Qualification Guidelines

Baseline qualification guidelines

Controls:
Physical communications radio microphone

Displays:
none

Flight Dynamics:
The presence and amount of wind are reflected in the handling and performance qualities of the simulated aircraft and are consistent with a single-engine, fixed gear, basic training aircraft with a fixed-pitch propellor

Instructional Management:
Feedback is presented by the system regarding maintaining the CDI within a specified level of deflection.
Feedback is presented by the system regarding maintaining the ADF bearing within a specified level of deviation
Feedback is presented by the system regarding maintaining altitude within 100 feet, but not below the minimum descent altitude
Instructor can control the amount of wind encountered during the performance of the task both before the session begins and during the session.
PCATD has a navigational area data base that is local to the training facility

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