DESIGN AND USE OF EFFECTIVE, HIGH-IMPACT, COMPUTER-BASED ACADEMIC COURSEWARE FOR PILOT TRAINING

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Abstract

It wasn't until simple-to-use multimedia software tools became available, and Personal Computers (PCs) gained a sufficient amount of computing power, that the viability of using PCs for producing and administering self-paced academic courseware sophisticated enough for training pilots became a reality. Such courseware developed for PCs prior to this time, was little more than the old 35mm slide presentation, only with audio narration instead of a stand-up instructor. Unfortunately, with the powerful multimedia PC tools available today, design and implementation of computer-based, self-administered pilot training courseware has not evolved much past a page-turning affair. As a result, the term CBT (Computer Based Training) has gained a bad reputation in the pilot training world rather than the high tech connotation its name implies.

Boeing entered the world of CBT pilot training courseware in 1989 for its commercial airplane pilot training requirements. They have since evolved the development process and courseware effectiveness, which culminated with pilot training CBT courseware for the 777. This courseware is so dynamic and interactive, that 777 pilot trainees are continually amazed at how the drudgery of the ground school portion (the academics) of learning a new airplane has been made into such an enjoyable, yet effective, learning experience.

The techniques learned in Boeing's Commercial Airplane Group are being incorporated into the F-22 academic courseware for both pilot training and the training of airplane maintainers. This paper shows the benefits of self-administered CBT academics for pilot training when the courseware is designed to the strengths of PCs and multimedia software. It also details the philosophy, rules, and techniques to use for making CBT an effective training tool, not only for academics, but also for testing. For testing, it describes how CBT is used to test a student's knowledge and understanding of a subject by using a real-life, interactive, operational format as opposed to a multiple choice, knowledge-only type format.

About the Author

Terral (Terry) L. Chamberlain is a 1971 Northrop Institute of Technology graduate with a B.S. Degree in Aerospace Engineering. His first of 25 years with Boeing was spent as a structural engineer in the 707/727/737 wing group. He was then selected as one of 20 young engineers to be the nucleus of Boeing's newly created Computer Aided Design group to help bring Boeing into the age of designing airplanes using computers.

In 1979, Terry's passion for flying led him to take advantage of an opportunity to transfer into Flight Crew Training, where he has spent the last 20 years, 18 in Commercial and 2 in Military. In Commercial Flight Training, he designed and produced pilot training courseware and taught in the simulators for all of Boeing's commercial airplane models. He's always been leading the charge to find new and innovative ways to improve academics for pilot training. He's helped evolve academics from classroom instructor standup, to student-paced slide tape, to CBT. He was the program lead for the development of 777 pilot training academic courseware because of his innovative ideas that, for the first time, matched an operational training philosophy to a presentation medium capable of administering that philosophy. Pilot training has a unique audience, and it was Terry's techniques that made the 777 pilot training courseware, "...the standard of the world by which all other pilot training courseware will be measured..." Terry presented a similar paper at two international commercial aviation conferences before leaving the commercial side of the house to help incorporate his techniques into F-22 pilot training academic courseware.

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INTRODUCTION

As airplane cockpits have advanced from simple wind-in-the-face enclosures with few or no gauges, to the pressurized multi-system cockpits of today, one necessary item in learning to fly any airplane has remained constant; ground school. With today's sophisticated airplane systems and cockpits, classroom academics are a necessity more than ever in order for anybody to climb into an airplane and get it safely off the ground and back on again, let alone use it to do the specific job its designers intended.

The most effective and economical use of today's expensive, real-as-life simulators and table top trainers can only be realized after a pilot learns the reason and use of each control, indication, and annunciation on/in those devices.

Unfortunately, ground school is the cruelest form of torture for any pilot. Pilots, as indicated by the very job they do, are a hands-on, kick-the-tires and light-the-fires type of people. These characteristics are very important when designing and building academic ground school courseware. The challenge is to design academic courseware that commands the attention and interest of the student at all times so that he can learn all that he is suppose to learn.

BACKGROUND

It wasn't until Commercial-Off-The-Shelf (COTS) personal computers gained an appreciable amount of computing power, and multi-media software became available and easy to use on those computers, that effective interactive self-paced courseware could be designed and built for the pilot population.

The first attempt by Boeing at developing computer-based academic courseware for pilots was in 1989 for a 767 customer. The customer had recently converted its DC-10 pilot training program over to Computer Based Training (CBT) and was realizing a significant reduction in training time. In addition to learning quicker, pilots were retaining more than from the traditional slide/tape courseware. As a result, this customer wrote into its 767 purchase contract the requirement for pilot and maintenance training academic courseware to be interactive and computer- based.

Like most new products that expand the envelope of technology, that first 767 CBT was a bit ragged, way over budget, and over a year late. However, its teaching effectiveness was so much better than that of the slide/tape AVT (Audio Visual Tutorial) format, that Boeing adopted it as their standard for 767 pilot training academics. In addition, since the 767 and 757 are so similar, having common type ratings, the 767 CBT was "morphed" into 757 CBT.

CBT never came out of the box again at Boeing until the 777 came along. Boeing wanted the training technology to match that of the new airplane. In addition, the 757 and 767 CBT had proven their worth, not only in teaching effectiveness, but also in the reduction of days in each of the two curricula.

A lessons learned team was assembled consisting of members from the previous 767 CBT program and representatives from two 777 kick-off customers. A vision was defined based on the capability of then existing COTS PC hardware and multimedia software, both of which had advanced significantly since the 767 program.

The effectiveness of the 777 pilot training CBT can clearly be seen by comparing the flight crew course cycle times of the pilot training curricula for Boeing commercial jets (Figure 1).

In comparing the cycle times, or curriculum lengths, it is apparent that CBT alone has accounted for a larger reduction in pilot training time than any other single device or methodology. A reduction in training time itself is reason enough for CBT courseware, but effectiveness and overwhelming student acceptance make it the best learning tool that has come along since the introduction of full flight simulators.

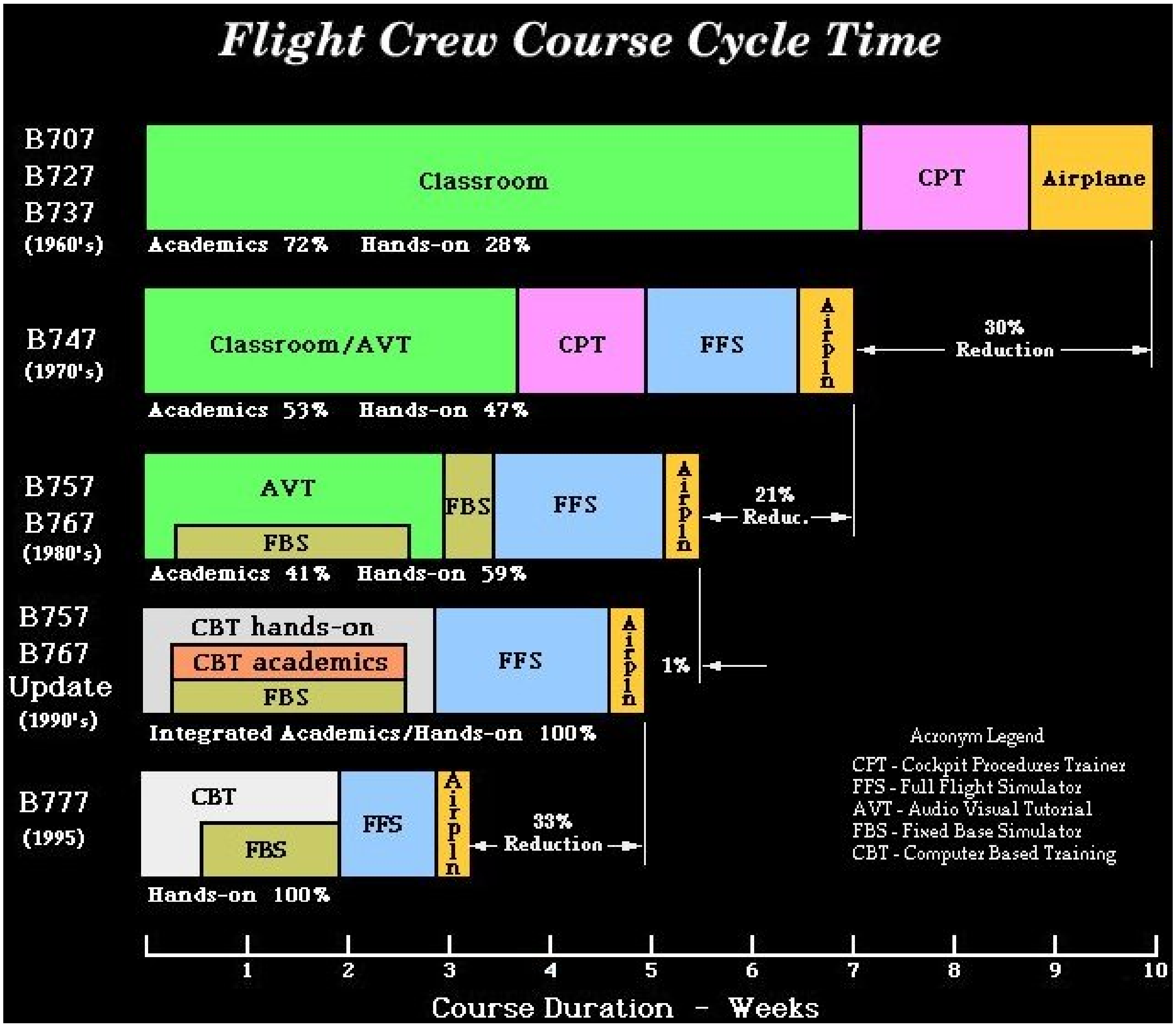

Figure 1 - Flight Crew Course Cycle Times

THE PROBLEM

The problem with nearly all CBT pilot training courseware in the industry today is that they use the latest state-of-the-art technology to administer lessons designed with 50 year old instructional methodologies. Instead of taking advantage of the strengths of PC tools and capabilities to incorporate dynamic animated graphics, and to provide meaningful operational interactions to the student, most pilot training CBT have remained nothing more than page-turning slide shows

delivered on PC computers. As a result, CBT has gained a bad reputation in the pilot training world as being nothing new, just more expensive. This bad reputation became painfully apparent when developers from the 777 CBT program moved to the F-22 program.

The F-22 Training Systems Specification designated CBT as one of the media for delivering academic courseware to the student. The Air Force realized that the commercial world of pilot training methodology was ahead of the military world, and thus also specified that the CBT courseware was to be designed and developed using, "...best commercial practices." However, even with this mandate, a great deal of effort was required to overcome CBT's bad reputation when trying to convince the future users of the courseware that CBT was indeed a better mousetrap. As with all products, the greatest technology and best raw materials are useless unless the design is correct.

THE SOLUTION

Since production of F-22 pilot training courseware is barely one year old, many of the examples cited in the remainder of this paper are from the successful 777 program. Examples from F-22 academic lessons are used when availability and security clearances permit.

To develop effective, engaging (high impact) courseware, three things must be considered, the capability of training technology, the target audience for whom the courseware is written, and most importantly, the design of the courseware.

Training Technology

Determining the capabilities of technology is simple. The challenge lies in <u>not</u> incorporating those technological capabilities that don't add value to the product. Technology for technology's sake is merely frustration to a student trying to learn.

The technology used to develop the type of courseware we're discussing is all commercial off-the-shelf, and primarily consists of the following:

- 233 MHz PC with 1GB hard drive, 92 MB RAM, 16 bit sound card, and 1024 x 768 capable 32 bit color display card
- Windows NT (or 95)
- Authorware 4 by Macromedia
- Paint Shop Pro 4/5 by Jasc Software
- Photoshop 5 by Adobe
- 3D Studio MAX by Kinetix
- Wavefront by Silicon Graphics

Authorware was chosen as the primary authoring tool because of its immense capability and simple, easy to use icon-authoring format that does not require a computer science degree to use. The remaining software are graphics programs that allow the creation of photorealistic graphics and three dimensional motion animations.

While Wavefront is a fairly expensive and sophisticated graphics software, it became a logical software tool to help "mine the gold" from engineering's 3D computer definition of the airplanes (F-22 and 777). Using the 3D geometry directly from engineering guaranteed not only accuracy of the graphic, but also the most up-to-date version of the airplane configuration. Since Silicon Graphics (SGI) computers were required to access engineering's 3D geometric definitions, it was logical to use the same SGI platform to manipulate and render the geometry (using Wavefront) into the photorealistic images required for the Authorware lessons.

In addition, on the F-22 program, Wavefront (and its replacement Maya) has the capability to produce sophisticated 3D graphics and dynamic 3D animations, which can significantly enhance the teaching of airplane maneuvers lessons.

The Target Audience

Academic courseware customized to a specific audience type is much more effective in its teaching abilities than courseware designed for a general audience. Even though pilots, commercial or military, have varied backgrounds and college degrees in every vocation imaginable, the one constant is that they all fly airplanes. As a result, from a training standpoint, learning to fly a new airplane, be it a heavy transport or a maneuverable fighter, is the same (although some pilots might argue that point).

Given a license to deviate from some well established instructional methodologies, the 777 Lessons Learned Team was able to define an effective instructional strategy to accommodate the learning style of pilots. In addition, presentation rules, standards, and guidelines were redefined to accommodate the dynamic presentation medium of computers.

In the 777 program, the defined instructional strategy by which all academic lessons were built was known as, "The Strategy". However, in the F-22 program, "The Strategy" did not accommodate everything that needed to be taught to a fighter pilot. Therefore, two additional strategies were defined.

Definition of the two additional instructional strategies was based on the nature of the subject matter that needed to be taught. For F-22, the three strategies are known as:

- Systems
- Maneuvers
- Employment

The systems strategy is merely a copy of the 777 strategy. It was labeled, "Systems" by the F-22 team because the strategy taught composition and operation of airplane systems (most heavy jet commercial flying is accomplished by manipulating the auto-pilot and other related aircraft systems).

The "Maneuvers" strategy, as its name implies, is a strategy designed to use 3 dimensional animated graphics to teach the mechanics of flying specific flight paths for specific situations, a primary role of fighter aircraft.

The "Employment" strategy is used to teach identification and interpretation of situations from resources available to the pilot (including cockpit displays, AWACS, etc.), and the appropriate resolution(s) of the situation to the benefit of the mission.

Lesson Design

Since the purpose of this paper is to describe an academic lesson design philosophy for teaching existing pilots the basic operation of a new/different airplane and all its systems (i.e. how to operate the airplane to get it safely off the ground and back on again, plus address any systems emergency/malfunctions should any occur during that time), only the "Systems" strategy will be discussed here. Strategies that describe teaching philosophies for teaching the specific use of an airplane for its designed purpose (e.g. to shoot down other airplanes, aerial reconnaissance, etc.) are subjects for future papers.

Due to the nature of the dynamic presentation medium, new presentation techniques and screen design standards were defined. Before discussing the "Systems" instructional strategy, a short discussion on these new but simple techniques and standards is in order, because of the way they significantly enhance the presentation of an instructional subject using this medium. The important ones are:

- When developing graphics of airplane parts (panels, components, etc.), the graphics must look real. With the graphic software and talented artists available, there is no reason why a graphic should not look real. By bringing the cockpit to the desktop, it's easier for the student to assimilate when he enters the real thing.
- When teaching specific controls/indicators on a panel, always show the entire panel, even if the other controls on the panel have no bearing on the subject being taught. This allows the student to become intimately familiar with the cockpit panels, the relative location of the panels in the cockpit, and the relative location of all the controls and indicators on those panels before ever seeing the real thing.
- Force student eye contact on the part of the screen graphic that the narrator is addressing. This can be accomplished by using highlights (such as arrows or boxes), motion (such as a symbol moving across a display), and other such techniques.
- Keep instructional screen text to a minimum. If a student is reading instructional text on the screen, then he's not listening to the narrator or looking at the part of the graphic the narrator is talking about. The cliché of a picture is worth a thousand words holds true.
- There shall be no gratuitous touches (interactions just because the technology is available). Students should interact with the lesson for only three reasons:
  - To operate a switch or control that closely mimics the same action he would perform in the cockpit.
  - To navigate through the lesson, e.g. pause the lesson, move backwards, advance forward, etc.
  - To select an answer during testing.
- Use any graphic or technique available to bring uninteresting (but necessary) theory, tables, graphs, and other such subject matter to life. Pictorially relate such dry information to the operation of the aircraft. Remember, the target audience is a hands-on type person.
- Use of cartoons and humor (not jokes) is OK. However, cartoons and humor must be meaningful and effective in conveying a teaching point.

Use of cartoons and humor in pilot training courseware has always been a controversial issue. However, cartoons can be used very effectively when simplifying the functionality of complex systems where the actual system components are not relevant to the target audience.

Use of humor can also be effective for breaking up a monotonous part of instruction, or reinforcing a teaching point. Figure 2 is an example of acceptable use of a cartoon and humor in describing 9 abreast seating in 777 tourist class.

Figure 2 - Use of Humor & Cartoons

There are other techniques and standards, but these basic seven are considered the most important, and if incorporated into any multimedia lesson will increase the effectiveness of that lesson by a huge factor.

Systems Instructional Strategy

An effective CBT lesson is composed of three sections; instruction, practice/review, and testing. With the interactive capability of CBT, an operationally structured practice section allows a student to evaluate himself to see if the objectives taught in the instruction section were learned. The practice section is immediately followed by a performance-based test.

Based on the results of the Boeing 767 and 777 pilot training programs (reference Figure 1), "best commercial practices" has shown that a self paced CBT lesson containing these three sections is the most effective in pilot training academic courseware. However, due to the poor reputation of CBT, as described above, and some Air Force traditional requirements, the F-22's CBT approach to pilot training is slightly different. Use of the effective multimedia presentation techniques described above, however, remain the same in both programs.

The F-22 program uses self paced CBT as the introduction to a subject, a sort-of electronic workbook containing instruction only. An instructor led CBT, building upon the information learned in the self paced module, completes the information on the subject. Each lesson (consisting of the self paced module and instructor led module) is generally followed by a 1/2 to 1 hour session in a cockpit training device. Multiple choice tests are electronically administered after completing a block of instruction, which generally consists of 2 to 6 lessons.

Instruction Section

What a pilot needs to be taught is a controversial issue debated every time a new airplane is built. Fortunately for pilots today, pilot training academics has evolved over the decades from lengthy, detailed, technical courses on how the airplane is built (nutsy boltsy maintenance type), to need-to-know type courses (just the facts ma'am) of today.

As a result, the instruction section of a systems lesson begins with a conceptual description of what the system does, how it works, and its major components. Remembering that the target audience is pilots, not maintenance personnel, the description is kept at a high level, often using cartoon graphics to represent the components.

A building block approach is used. A component is not added to the graphic until it's time to talk about it. If schematics are used, they are kept extremely simple. Motion is added to the graphic to indicate flow, or operation of a component

This overview of the system is required to next relate the controls and indicators in the cockpit to the components of the system that they monitor and operate. A basic understanding of the system is also required so that the pilot understands what's happening when something goes wrong during an emergency/abnormal situation.

Next, the system controls and indicators are introduced. Controls and indicators used only during normal operations are discussed first. A pilot must first understand normal operation of a system before learning how to cope with a system that isn't working correctly.

Control panels are located from a photorealistic cockpit graphic and, as described earlier, are always displayed in their entirety. Each control is addressed in the order it would be used for a normal flight. When pilots learn a new airplane, they always think in terms of the steps they must perform to get the airplane airborne. Thus, keeping the presentation order in a phase of flight sequence helps simplify learning for this target audience.

Controls are introduced in an operational format, as if sitting in the cockpit with the student and the cockpit being the only tool available with which to teach. The control is first pointed out to the student, the student is then asked to operate the control, and finally the consequences of operating the control are pointed out and described. Sometimes a bit of discovery learning is used when the student is asked to operate a control without first being told where it's located on the panel.

Feedback from an incorrect touch is provided immediately by a highlight around the correct control that the student should have selected. The lesson does not progress until the student makes the correct selection. The objective here is to not let the student stray down the wrong path, possibly learning the wrong behavior.

Knowledge items, such as specific numbers like engine EGT (Exhaust Gas Temp.) start limits, are introduced at the time and in the context the student needs to know them. Presenting knowledge items in this manner tells the student when and why he needs to remember them. It is important to tell a student why some abstract fact or number needs to be remembered so that he has a reason to remember it (e.g. "If the 520 degree centigrade EGT limit is exceeded during engine start, major maintenance will be required on the engine.").

After the controls and indicators associated with normal operation of the airplane have been covered, those associated with emergency/abnormal conditions are addressed in a similar manner. Each abnormal condition is introduced by the annunciation, and aural alert if appropriate, that is used in the cockpit to alert the pilot to the condition. If the alert is one that needs to be reset, such as those associated with a master warning/caution system, the student is first made to reset that system. Even though student feedback from the 777 program indicated this resetting was a nuisance after the first two or three lessons, it conditioned the student to immediately accomplish the reset when in a cockpit environment, something that frequently was not accomplished during 757/767 simulator sessions.

Once the reset has been accomplished, instruction is provided on the cause of the alert, and the controls and indicators used to address the situation. The controls and indicators are covered in the same manner as the normal ones, except the order they're addressed is the order in which they are used while performing the associated emergency/abnormal checklist. Even though the checklist is being taught in a close to subliminal manner, the word checklist is never mentioned, referred to, or shown as a graphic. The purpose of CBT is to teach the operation, function, and reason for the system controls. Checklist usage is taught in the simulators, after academics, especially in this age of electronic checklists.

All abnormal conditions that alert the flight crew by way of some cockpit annunciation or indication are addressed, even if no action is required. If it's an alert, the student, at minimum, needs to know the probable cause.

Abnormals are covered in the order of most critical, (e.g. immediate action emergencies such as fire), to least critical, (e.g. a status advisory where no crew action is necessary).

At the discretion of the lesson developer, imbedded testing or review can be inserted at strategic locations within the instruction section to reinforce a student's comprehension of a complex teaching point.

Practice/Review Section

The primary purpose of a practice/review section is to integrate skills and knowledge learned from the instruction section. This section also provides the student confidence that he learned what he was supposed to, or point out specific areas he may need to view again in the instruction section.

It is important to note that due to the high automation of today's airplanes, sometimes a practice/review section ends up being just a review section, as some airplane systems that traditionally had controls no longer do.

The practice section consists of skills and knowledge from the instruction section grouped together in reasonably sized cohesive exercises. The exercises are designed to stand alone and are easily repeatable should a student desire. The exercises are presented in a phase of flight sequence, again because that is the way a pilot operates his airplane. Each exercise can be its own operational scenario, or, in conjunction with the other exercises of the section, part of a larger scenario. Whichever method is used, the scenarios are operational in format and reflect real life. If an annunciation or condition cannot happen in real life, it does not belong in the lesson.

The exercises are skill based as much as possible, although in today's cockpit environment of automatic resolution with no action by the pilot, that is sometimes difficult to do. Even though the student does not have the tactile feel of a switch or knob, the CBT medium does allow the student to operate the switches. If he can perform the operation on the CBT screen, he usually can perform it in the cockpit with little or no assistance.

Important knowledge items and display/indicator interpretations are integrated with the controls operations. Knowledge questions are asked at points in an exercise where the knowledge is required to correctly or safely perform the skill (e.g. "Notice that ignition has occurred and the engines are spooling up. What is the EGT limit that should not be exceeded during the start?").

In student feedback from the 767/757 programs, the most recurring student comment was the frustration of being forced to perform an operation the CBT's way when another way was possible and would accomplish the same end result. As a result of that feedback, if there is more than one way to accomplish an operation, the student is allowed to perform the operation in all possible ways (e.g. in the F-22 the altimeter can be set 3 different ways). If there is a preferred method, the less desirable way is acknowledged if a student attempts to use it, but the student is made to perform the operation by way of the preferred method. The reason for the preferred method is also provided.

Unlike the instruction section, feedback from an incorrect touch in this section is corrected in two steps. If the first touch is not correct, a small hint is provided to help jog the student's memory. If the hint did not help, feedback for the second incorrect touch is like the instruction section, a highlight around the correct control. By providing the student two chances, a small amount of credit and flexibility is given to him to think on his own and apply what he should have learned.

Testing Section

For the first time in pilot training, a medium is available to provide meaningful academic testing. With CBT, performance based questions can now be administered. Even though testing is administered at a different time in the F-22 curriculum than in the 777 curriculum, performance based tests can be used in both programs with the same good results.

The primary purpose of testing is to check if a student has accrued operational knowledge of the subject matter of the lesson. Questions that test skill based objectives can show a student's comprehension of a subject much better than the traditional multiple choice, knowledge-only type tests. Multiple choice questions still have their place however, in the testing of pure knowledge objectives. Though now those knowledge objectives can be tested in operational context.

It is impossible to test all skill objectives in academics. Some skill objectives, due to the nature of the skill, can only be tested in simulators or the actual airplane, such as takeoffs and landings. Of the remaining skill objectives, those selected for testing are based on the capability of CBT to closely replicate the real life cockpit skill, such as loading the inertial reference systems. Questions testing knowledge objectives are integrated into skill-related questions in the context the knowledge is needed.

Generally, 5 to 12 questions per lesson is sufficient to check whether or not an appropriate amount of subject matter was absorbed by the student. For reasons stated earlier, it may not be possible to develop that many skill based questions. But, with multimedia tools, dynamic graphics for all questions can now be used to closely replicate the exact thing a pilot sees and experiences in his cockpit.

All questions are stand alone so that they can be presented in a random order. They represent real life situations and conditions, both normal and abnormal, testing what is seen and done in the cockpit.

While the 777 program chose to grade each question before allowing the student to progress to the next question, the F-22 program preferred not to have any of the questions graded until all questions had been answered. This posed a limitation on the complexity of F-22 performance based questions.

By grading a question immediately, an answer to a complex, multi-step question can be graded wrong at the instant a student performs one of the steps incorrectly. Also, immediate feedback can be provided to the student showing the correct answer, and the reason that answer is correct.

If a question cannot be graded until all questions are answered, a student may never be able to answer the question completely should he make a mistake in one of the early steps. A near full simulation of the system would be required for that type of functionality, which is not feasible at this time. Also, immediate feedback to the student is not possible, a desirable functionality reflected in 777 student critiques.

CONCLUSIONS

As shown earlier, courseware designed to these simple strategies and techniques pay huge dividends, not only in the reduction of training time in course curricula, but also in the learning and retention of the subject matter by the students. Students become totally engrossed in the self-paced lessons and seldom, if ever, experience boredom or inattention.

In addition, self-paced courseware standardizes the presentation and insures the student is presented all the subject information he is supposed to receive. It also eliminates the superfluous information quite often interjected by a stand-up instructor. If designed correctly to an instructional strategy that speaks in the language of the target audience, <u>every</u> lesson will emulate the best, most interesting (sometimes entertaining) instructor and completely eliminate boring, dusty-dry, monotone instruction.

CBT of this nature can be expensive to develop, although not as expensive as one might think if the development teams and processes are set up properly. Also, expensive becomes a relative term when considering the effectiveness of the courseware, the number of pilots the courseware will train, and the total cost of training a pilot to operate a multi-million dollar airplane.

Development of the seventy-six 777 CBT pilot training lessons was accomplished at an average of fewer than 350 man-hours per lesson. One lesson took over 900 hours to develop due to the nature and complexity of the system. However, a couple of other lessons took fewer than 50 hours each.

Figure 3 shows a breakdown of the hours spent in the 777 development process. What figure 3 does not show is the number of hours expended for task analysis and creation of the lesson objectives. However, even with those hours added, the chart shows that effective CBT courseware can be developed in a cost effective manner.

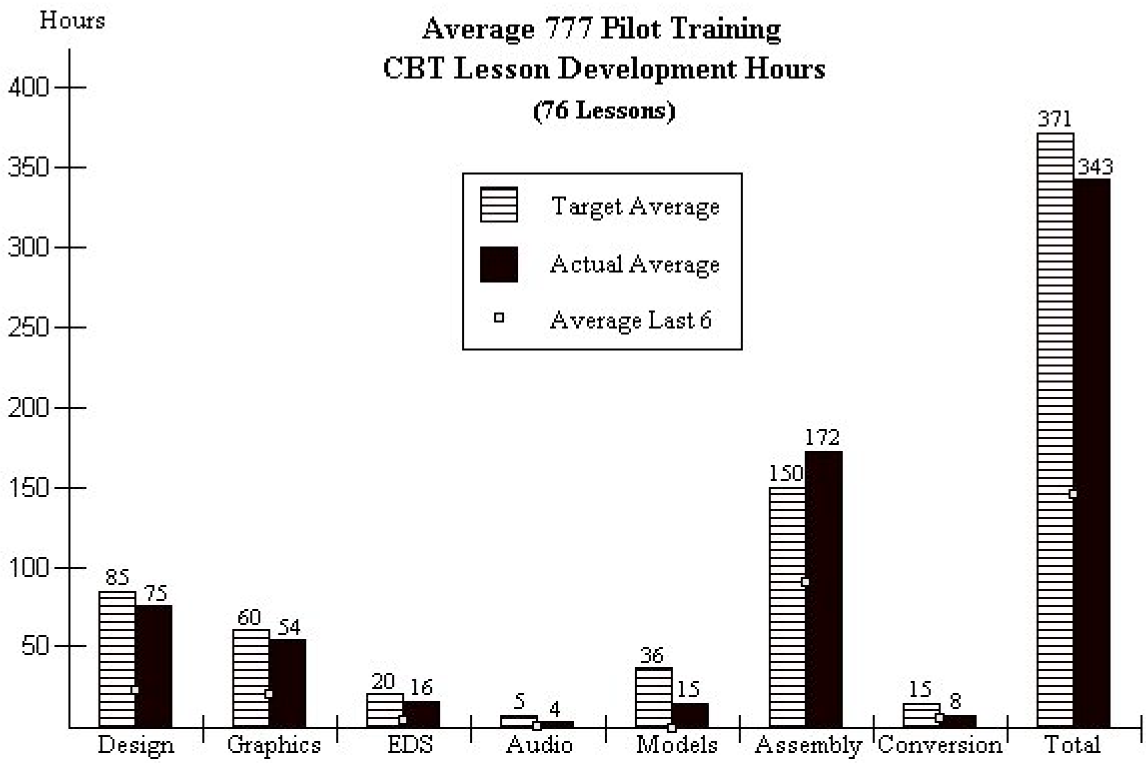

Figure 3 - 777 CBT Development Hours

With today's technology, effective, engaging, computer-based courseware is possible, and at a reasonably economic price if developed to a carefully thought-out process. However, like the high tech airplanes this courseware is built for, good CBT is the result of a good design, not the technology used to produce it.