

REQUIREMENTS AND DESIGN APPROACHES FOR FLIGHT TRAINING DEVICES

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ABSTRACT

In the commercial market arena, much attention has been given over the last 3 years to FAA Advisory Circular 120-45A - "The Qualification of Flight Training Devices". The primary focus of this attention has been on Level 4 through Level 6 devices, which replicate a specific aircraft cockpit and are designed to be included within training programs for specific aircraft. Manufacturers of these devices often capture software from a full flight simulator and package the device using common modules (IOS, computer, interfaces, etc.). These Level 3 devices are generally more applicable to flight training schools and the regional airlines. However, they are also well suited to the requirements of the various military services. They meet an ever-increasing demand for low-cost, generic training devices which are applicable to both the military and commercial organizations. This paper discusses the application and technology of the low-end training devices and how they may fill the gap between the very low-cost off-the-shelf solutions and fully-tailored specific training devices (i.e., Levels 4-6). The military applications of these devices will be emphasized to meet the demanding low cost procurements.

ABOUT THE AUTHOR

Graham Upton has worked in the simulation industry since 1975, when he moved from British Airways, where he was an Avionic Engineer, to Singer-Link Miles (U.K.) as a Systems Design Engineer. After working at various positions both in the U.K. and overseas, he joined the Commercial Simulation Operation of Singer-Link Division in Binghamton, NY, in 1984. He later transferred to the newly formed CAE-Link Corporation after the divestiture of the Singer-Link Miles and U.S. domestic commercial simulation operations in 1988. His current position involves responsibility for the commercial products within CAE-Link, with particular emphasis on Flight Training Devices.

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INTRODUCTION

The full flight simulator (FFS) has been the mainstay of the training industry for many years. We have all come to know and understand the capabilities and certification requirements for these devices.

Flight Training Devices (FTDs) are not really new; airlines and flight training schools have had training devices in place for many years that were part of their curriculum, but not necessarily certified. The recent release of the AQP (Advanced Qualification Program) and the AC120-45A by the FAA have allowed these devices to become part of a certified program.

Traditionally, on the military side of the house, training devices can be categorized into two main types:

- The PTT (Part Task Trainer) is built to train either a specific piece of equipment (avionics - INU or GPS, etc.) or a specific member of the flight crew (the NAV officer, weapons system officer or flight engineer). They are not generally required to train all the crew to a generic level.
- The CPT (Cockpit Procedures Trainer) is built to train non-flying type tasks and procedures but basically uses the entire crew. All systems (flight, nav, etc.) would usually work to a high level of fidelity but controls may not even be implemented to fly the trainer.

The intent of the FTD in the commercial arena was to bring the benefits of simulator training to the lower-budget operators, but it has now been perceived by the large operators to be cost effective. The AQP is designed to improve aircrew performance and to allow certificate holders (who are subject to the training re-

quirements of Parts 121 and 135) to develop innovative training programs that incorporate the most recent advances in training methods and techniques.

Flight Training Devices (FTD's) are categorized Level 1 through 7. Level 7 is the highest category of FTD. This device identically replicates a specific aircraft cockpit and meets all the requirements of a Level C (Phase II) Full Flight Simulator (FFS) except for the motion and visual systems. A Level 7 FTD is the only device which can be upgraded to FFS status (Level C) by adding motion and visual systems.

Levels 4 through 6 FTD's represent a specific type of aircraft. A Level 6 simulates the majority of functions of a FFS, but real aircraft parts are not required. Reasonable replicas are sufficient. Levels 4 and 5 do not require a closed cockpit and only one system (electrical, hydraulic or navigation, for example) need to be operational. The difference between the two is that Level 5 is flyable, with a response which represents the appropriate class of aircraft and is good enough to fly on instrument approach.

Levels 2 and 3 FTD's are generic devices. The Level 2 is designed to the same criteria as Level 5 and the Level 3 is equivalent to a Level 6. This paper primarily focuses on the Level 3 FTD type. The Level 1 FTD's have so far been undefined by the FAA and are reserved to encompass all other devices which have some training value but do not meet specific criteria to be categorized Level 2 to 7.

When the draft advisory circular for AC 120-45A appeared in 1989 and early 1990, little attention was given initially to the training devices in the Level 2 and Level 3 categories. These devices were simply categorized as being generic, representing only a class and category of airplane. However, although a Level 3 FTD is numerically below a Level 4 and 5 FTD, it is

in most cases more complex and complete than its higher-level companions.

For the commercial market, the AC 120-45A circular helped categorize what used to be loosely set trainer types known as CPT, PTTs, system trainers, etc. In the military there are no documents or circulars which define particular levels of training devices. Later in this paper, I will attempt to make some comparisons between the commercial categories and their application with the military requirements and how they might best be met.

In the military establishments, the FAA and the customer are one whereas in the commercial arena, they are separate organizations. This difference affects the validation process and the methods of simulator certification.

Level 3 Definition

To most of us, FTD definitions are now very familiar, but to those not acquainted with the commercial policies, the following summaries from FAA AC 120-45A are highlighted. The minimum flight training device requirements for Level 3 qualification are:

- A cockpit in which actuations of controls and switches replicate those in the airplane.
 - A Level 3 device must be representative of a single collection of airplanes, and must have navigation controls, displays, and instrumentations as set out in FAR 91.33 for IFR operation.
- Lighting environment for panels and instruments must be sufficient for operation being conducted.
- Circuit breakers should function accurately and be properly located when they are involved in operating procedures or malfunctions requiring or involving flight crew response.
- Simulated effects of aerodynamic changes for various combinations of drag and thrust normally encountered in flight, including the effect of change in airplane attitude, gross weight, center of gravity, thrust, drag, altitude, temperature, and configuration.
- Digital or analog computing of sufficient capacity to conduct complete operation of device, including its evaluation and testing.
- All relevant instrument indications involved in the simulation of the applicable airplane entirely automatic in response to control input.
- Navigation equipment corresponding to that installed in the replicated airplane, with operation within the tolerances prescribed for the actual airborne equipment.
- Communication equipment (interphone, air/ground, and oxygen mask/microphone system) corresponding to that installed in the replicated aircraft.
- Crewmember seats should replicate the seats installed in the respective airplane for size, forward, aft, and vertical adjustment capability, and relative location.
- In addition to the flight crewmember stations, it must have suitable seating arrangements for an Instructor/Check Airman and FAA Inspector. These seats must provide an adequate view of crewmember's panel(s) and need not be a replica of an aircraft seat, but be as simple as an office chair placed in an appropriate position.
- Installed systems must simulate the applicable airplane system operation, both on the ground and in flight. Systems must be operative to the extent that applicable normal, abnormal, and emergency operating procedures included in the operator's or other user's training programs can be accomplished.
- Instructor controls that permit activation of normal, abnormal, and emergency conditions, as may be appropriate. Once activated, proper system operation must result from system management by the crew and not require input from the instructor controls.
- Control forces and control travel which correspond to that of the replicated airplane, or collection of airplanes. Control forces should react in the same manner as in the airplane, or collection of airplanes, under the same flight conditions.
- Significant cockpit sounds which result from pilot action corresponding to those of the airplane.
- Timely permanent update of flight training device hardware and programming subsequent to airplane modification.

Requirement for Level 3 Device

Why is there a requirement for a Level 3 device? During the early stages of a pilot's training curriculum, flight training schools have realized the emphasis necessary on ab initio training. Increased demand and rapid turnover have created an urgent need for new training programs. The growing shortage of qualified pilots worldwide has far-reaching implications for flight safety and economics.

The Cockpit Procedures Trainer (CPT) in the military varies from one customer to another a great deal. Some are very close to Operational Flight Trainers (OFTs), without motion while others limit training to separate systems. In general, the CPTs are more specific type than generic.

The FAA has a heavy emphasis on take-off/landing and emergency procedures (engine failure, for example), whereas the military concentration is more on mission-specific tasks (tactics, maneuvers, etc.).

Tolerances between the FAA and military are also inconsistent. Because of these and other factors, a perfect comparison between the requirements of the commercial and military cannot be made.

Market analysis has discovered that a Level 3 training device meets the requirements for flight training schools; airline training, and military organizations for multi-crew, multi-type training. Students can log in excess of 100 hours in these devices prior to transferring to specific simulator type training. Cockpit familiarization, ab initio flying, navigation, instrument flight procedures, and basic systems.

Priced competitively, Level 3 devices will represent a sizeable part of the FTD market in the 1990's. Flight training schools, regional airlines, and military establishments, as well as the larger commercial carriers, all see the need for these lower-end yet complete cockpits as part of their training programs.

In particular, the various military reserve organizations could benefit from the commercial approaches applied to their low-end requirements. Military budgets for training equipment will continue to be tightened over the next decade and as a result, these generic type training devices will play an ever-increasing role in satisfying this market. Furthermore, the international military market requirements could also be met to sustain basic/concurrency training during periods of intense activity. The Level 3 FTD has a particu-

lar attraction for currency training during periods of extended deployment (i.e., Desert Shield). The mobility of such a device if housed in a trailer or container and ruggedized if necessary can provide training in any environment.

Requirements for the Future

New aircraft types introduced over the last 2 years are becoming more common. Cockpit designs and displays are becoming similar and layouts are less varied across manufacturers.

Rapidly expanding technology will allow the Computer Based Trainer (CBT) to be fully integrated with an FTD to provide a family of training devices at the lower end of the market.

Developing the Design Approach

To meet the demands of industry, it is necessary to develop a state-of-the-art approach for the Level 3 requirements.

To reduce the final cost to the customer and yet retain all the functionality and fidelity requires a modular building block approach using many off-the-shelf components and standard packaging to fit a variety of applications. Additionally, although not an FAA 120-45A requirement, many customers have indicated a desire to have either a low-cost motion or visual system (or even both). These subsystems can be easily added and interfaced, again using familiar, off-the-shelf components.

The Building Blocks

The Computer System - As a computer system for the low-end flight training devices, the Motorola VME monoboard computer or a similar computer is ideal.

This system offers a very powerful, yet cost-effective solution to the computing requirements. It also offers expansion capability to allow for modifications and updates in the future.

The 32-bit microcomputers are implemented as a distributed processing architecture providing an environment capable of supporting high-performance, real-time simulation (see Figure 1).

The simulation software is ideally written in FORTRAN and can be writer-compiled and assembled on line. A UNIX operating system is used as a development platform.

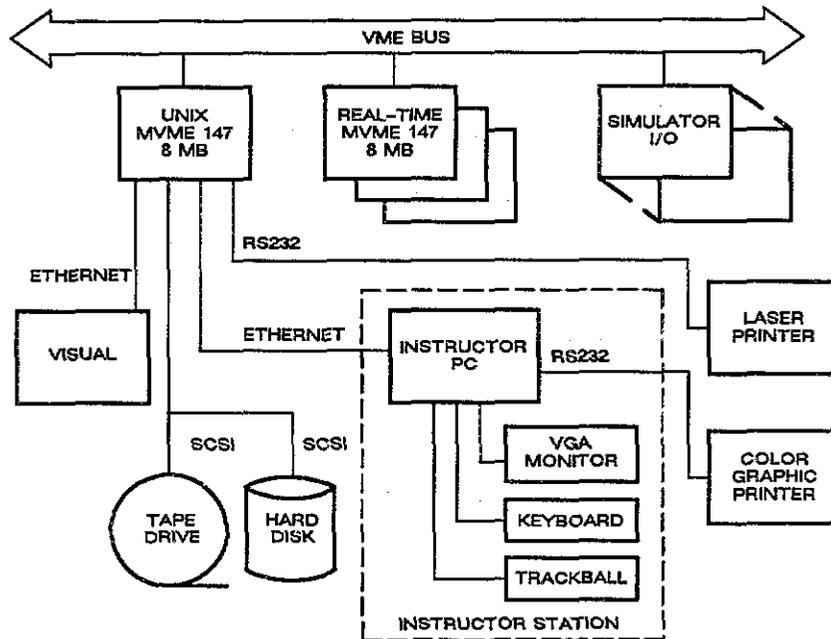


Figure 1 Computer System Configuration

The Interface System – The interface system (I/O) on a low-end flight training device must be simple and reliable. The system must offer high accuracy, modular design, and ease of expansion. The I/O system should be memory-mapped to the microprocessor, i.e., the microprocessor should address the I/O channels in the same fashion as it addresses its local memory.

Current I/O cards are double Eurocard size and are mounted in a card rack using DIN connectors.

Special interface cards can accommodate the various buses and unique interface requirements of various aircraft designs.

On-line and off-line diagnostics must be provided for ease of maintenance.

The Instructor's Console – The flight simulation industry has developed very complex instructor's consoles over the last 5 years. These have in part been driven by the customer, but also by the rapidly expanding technology in the computer and graphics industry. Traditionally, the instructor console was an extension of the main computer system, with graphics controllers, high-resolution screens, and a variety of input devices. More recently, the instructor console has consisted of a stand-alone computer system, interfaced to the main computer with a high-speed bus.

This is even more applicable to the low-end trainer market, where the instructor's inputs are simplified and require fewer modes of operation.

One solution for the low-end market is to use the personal computer with user-friendly commands and easily programmable software. The computer can be interfaced with the simulation computer by means of an Ethernet network. Very little training is required for the instructor to operate this device and input can be via a mouse, a trackball, a touchscreen, or a keyboard.

The instructor's console also provides an editor to allow the instructor to edit the navigational database, the predefined initial conditions, and maps.

The System Software – Traditionally, developing the software systems of any flight simulator has always been one of the highest cost elements of the device.

Engineering hours far exceed the manufacturing and production hours both in quantity and cost per hour. Although a follow-on simulator (that is, a simulator of the same type of aircraft that has been previously designed) can have significant savings in engineering costs, many customers have unique requirements and substantial savings can only be realized when the same customer orders a true follow-on device. Using a generic software package greatly reduces the cost of the training devices.

This can be achieved by developing a high-fidelity aero/engines software package that is suitable for a wide range of airplanes to meet the FAA Level 3 requirements or its military equivalents. These models are based on a selection of data from a variety of aircraft, mechanized to a high standard of accuracy. Special attention has been paid to the cross-coupling coefficients as well as to all of the data representing the aircraft idiosyncrasies. The detailed math model, hosted by the simulator's main microcomputer, will enable the simulated aircraft to respond realistically to all pilot controls, including control column, pedals, power lever(s) and controls for trim, propeller, flaps, and landing gear. The flight computations include aerodynamic, atmospheric, and ground effects. The simulation uses quaternions to permit full, continuous pitch, roll, and yaw rotations (see Figure 2).

More often the flight system accessories and navigation software has to be tailored to match the specific equipment on the aircraft and a true 100% generic device is not always possible. This increases the cost of this type of device beyond that of off-the-shelf

training devices that are offered by low-end companies. But a compromise is often reached to provide some aircraft uniqueness and keep non-recurring costs to a minimum.

Executive Software - The executive portion of the software often represents the most complex and least understood part of the total software package. Specialist engineers assigned to the development of these programs are usually in great demand and act as gurus during the design and testing phases of the simulator build schedule.

Executive software used for the low-end training device can be simplified and includes two main sections: real-time software and off-line software tools (non-real-time) (see Figure 3). Real-time software is the backbone of the real-time load. Off-line software such as UNIX may be used for developing applications software used under real-time software.

Real-time computer systems software is any software that is executed as part of the initialization process or during the real-time operation of the

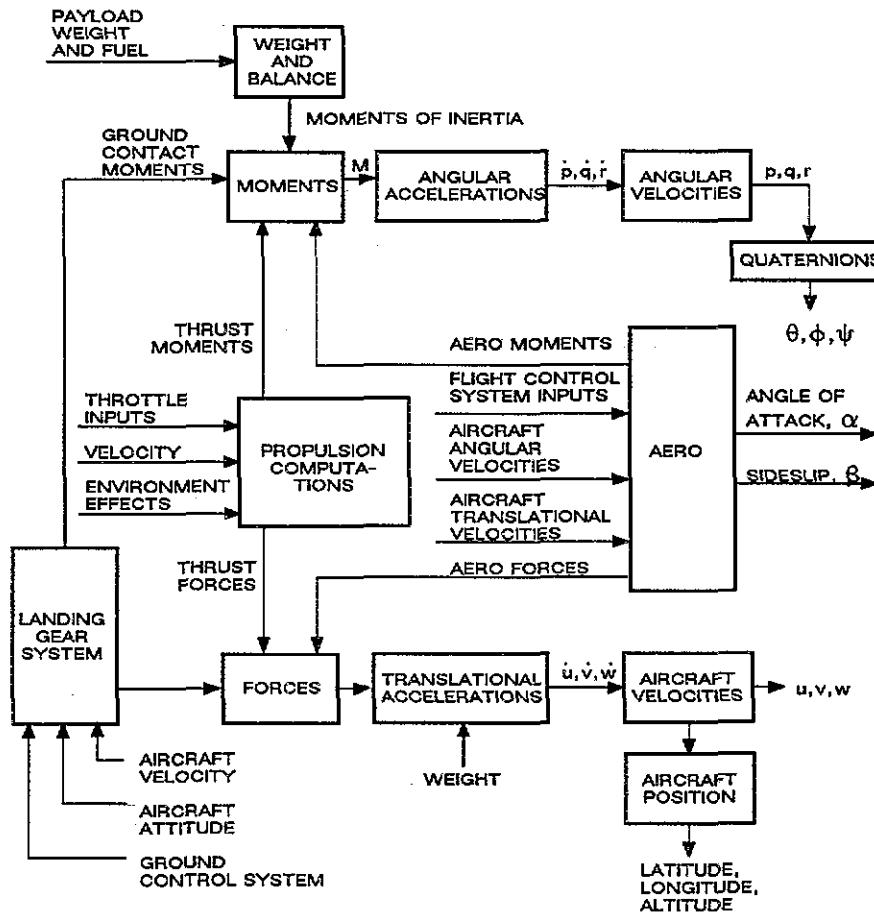


Figure 2 Flight and Aerodynamic Simulation

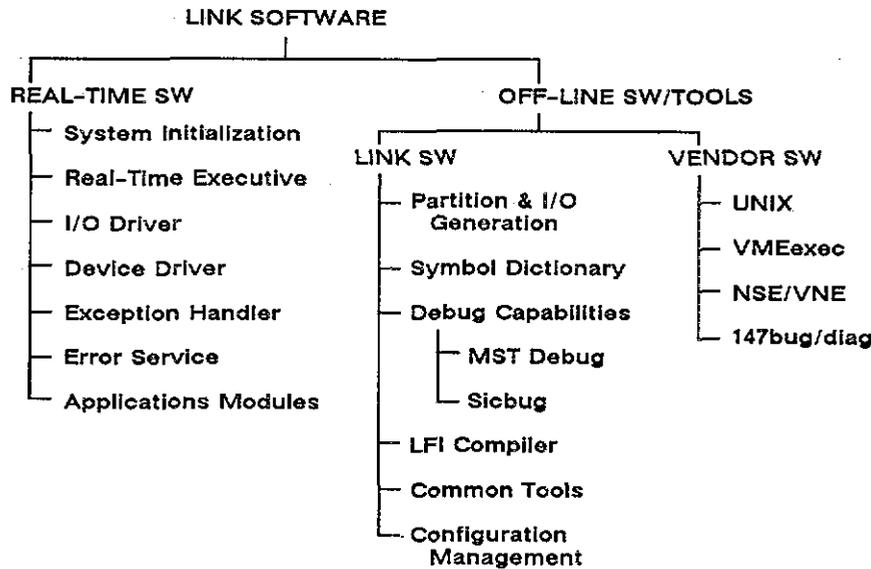


Figure 3 Software Components

simulator. After system initialization the load performs its own software initialization functions, such as exception vector initialization, and then enters the real-time execution loop. The heart of the real-time loop is the real-time executive, which schedules application software modules in a cyclic environment.

The off-line software can make use of the UNIX operating system, Motorola software packages and support tools, and application development tools.

A very user-friendly debug system, coupled with many off-the-shelf tools which are familiar to a wide range of computer operators (not just in the simulator field), is required to complement this overall system to keep it modular, simple, and easy to work on.

The Control Loading System - The control loading requirement for the Level 3 device states that "control forces and control travel which correspond to that of the replicated airplane or collection of airplanes should react in the same manner as in the airplane or collection of airplanes under the same flight conditions." This statement does not mandate that an Electric/Hydraulic digital or similar control loading system be installed in a Level 3 device or if certification can be obtained with spring controls only.

It is the opinion of some that certification can be obtained using a good spring control loading system, a far cheaper alternative in both procurement and maintenance costs than a dynamic system. However, the Level 3 requirement, coupled with the fact that the correct dynamic feel of the primary controls as perceived by the pilot is very important for any device,

almost mandates the use of a dynamic control loading system in Level 3 products.

One current control loading system uses a microprocessor-based digital hydrostatic system to provide full simulation of both static and dynamic forces. It is provided on three axes: the control wheel, stick, and rudder pedals. High-fidelity modeling and a very high degree of flexibility allow common hardware to be used in all the axes (see Figure 4).

As an alternative to the hydraulic system, an all-electric control loading system recently has been developed. This is the emerging state-of-the-art technology for control force simulation, particularly in the low-cost arena. Advances in the motor and controller design, coupled with low-cost, high-speed microprocessors, make electric control loading practical for a wide range of simulator types. Electrically powered control loaders have particular appeal for these types of devices, which, when motion is not part of the system, do not require a hydraulic supply and associated cooling.

The major components of this system are an IBM-compatible personal computer with a high-speed digital signal processor (DSP) together with analog I/O circuit boards. An Ethernet I/O board can be used to interface with the host computer. A diagram of this system, which provides a digital inner and outer loop high-fidelity servo control system, is shown in Fig 5.

Structure and Mechanical Components - Although Level 3 devices are essentially generic in construction, a standard cockpit frame and shell is not always the best solution and proposal response. As an

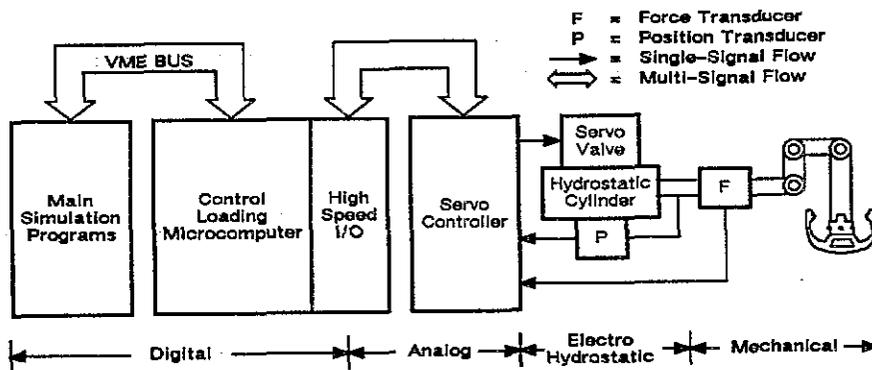


Figure 4 Functional Flow of a Digital Control Loading System

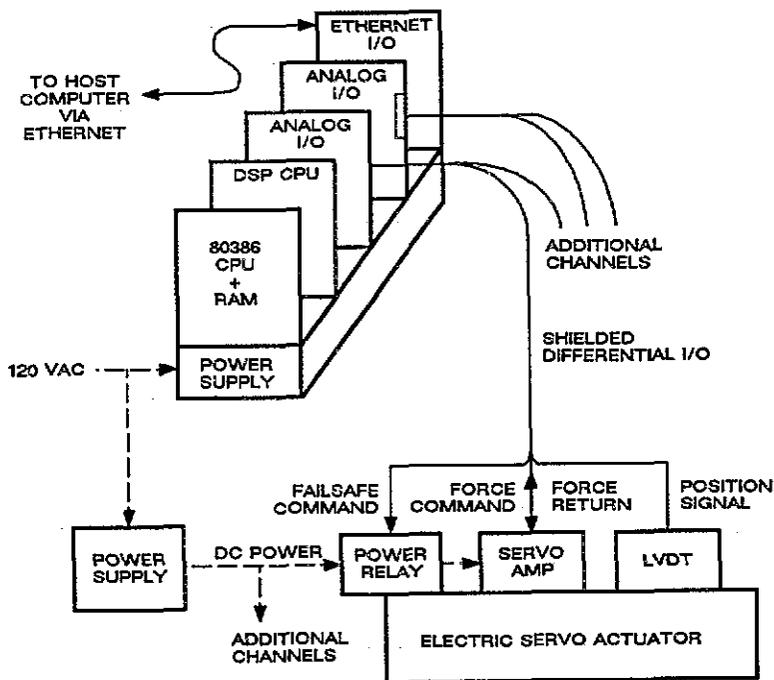


Figure 5 Electric Control Loading System

alternative a used or refurbished cockpit, or a buyer-furnished (BFE) cockpit provides the best and the lowest-cost solution for a Level 3 product. This solution is, of course, only possible if the quantity to be supplied is small, usually one or two. A real cockpit provides the added realism that is not always possible in a manufactured solution. Many aircraft parts can also be utilized to add additional realism and fidelity and reduce overall costs. To purchase new aircraft parts for these devices is not usually a good solution because the costs are very high and the lead times are too long in comparison with the overall FTD schedule.

Where a used or BFE cockpit is not available a generic cockpit has been designed and manufactured. This is known as the Basic Trainer Unit (BTU). This lightweight metal construction can serve as a cockpit solution for FTD Levels 2 through 5. This BTU is constructed to accommodate a variety of aircraft types and sizes. It allows the generic Level 2/3 devices, as well as the specific Level 4 and 5 FTD's to be detailed from its basic form. The Level 3 and Level 6 enclosures are added at the rear of the device. Aircraft parts for this and other cockpit solutions can also be manufactured, but one has to consider the cost of design and tooling as well as the availability and cost of

the aircraft parts and data prior to undertaking this method.

Visual System – Why discuss visual systems on a Level 3 device? FAA AC 120-45A says quite clearly that visual is not required. It is apparent from numerous customer inputs that a visual system is more than just a nice thing to have on this type of device. More than 80% of inquiries for FTDs have included a visual system.

A Star Graphicon 2000 STX system provides a relatively low-cost solution without compromising the requirements. Some customers with even tighter budgets demand a low-cost Star system, the 1700S, or a high-end workstation solution such as the Silicon Graphics 4D25 or Indigo. One has to be careful of the workstation approach as real-time performance is somewhat degraded. The Ivex visual system also interfaces well and provides an excellent alternative.

Motion System – Why discuss motion systems on a Level 3 device? FAA AC 120-45A says motion is not required. Although not requested as much as visual systems, about 60% of customer requests include a motion requirement. A small 3-DOF system adds to the device a complexity that makes its purchase very tempting. Is it required? No. Is it needed? Probably not. But for a relatively low cost, a small 3-DOF can be added to satisfy the customer. We have found the Doron system to be easily interfaced both mechanically to our standard platform base and electronically to our computer and I/O system. This off-the-shelf motion system has proved to be the most cost-effective solution both to purchase and maintain (they are also used for entertainment systems) for FTD customers who insist they must purchase a motion system.

Design Data

You may say that data is not required for a Level 3 device – it's generic. Well, you're exactly right. This may be one of the reasons a customer chooses to purchase a Level 3 device. In the commercial marketplace, as simulator/trainer manufacturers, we continue to receive very high quotes for data packages, even for Level 4 through Level 6 devices. Customers cannot afford to pay these prices. In the military world, this is not such a problem as the customer usually provides the data. But this is not free, and it can dramatically affect the final cost.

The Level 3 device avoids this problem. There is no obligation to purchase or provide data, or obtain a license to use data, as a specific aircraft is not being simulated.

So where does the original data come from? We have found that the majority of aircraft manufacturers have aircraft flight manuals, operations manuals, and maintenance manuals that can be purchased at very reasonable cost. Often these can be obtained prior to contract award, at the proposal stage. The ideal Level 3 may not require any new data, but realistically a selection of typical data sets from an aircraft in the same category is always useful.

Conclusions

Training requirements were analyzed before and during the specification stage and state-of-the-art solutions for the computer system, the instructor station, the control loading system, and the motion and visual systems were applied throughout the program. Tools were developed to write efficient software to match the hardware configuration.

Focusing on the military applications of these Level 3 type training devices, the following types of current military equipment can be addressed:

- Weapon System Trainers (WSTs)
- Operational Flight Trainers (OFTs)
- Mission Trainer (MT)
- Part Task Trainer (PTT)
- Instrument Flight Trainer (IFT)
- Cockpit Procedures Trainers (CPTs)
- Computer Based Trainers (CBTs)

A generic standard is used by the major commands (MAJCOM) for the evaluation of aircrew training equipment. This standard establishes the requirements for test programs, test planning, test procedures, test criteria and other evaluation factors. This standard is used in the source data requirements analysis to determine the requirements for the level of accuracy needed in both the design and verification of source data to be developed by the training equipment manufacturers.

Each of the above training definitions could have many of their training requirements met by a generic Level 3 type device. Off-the-shelf solutions as detailed in this paper can be considered to meet many of the above training requirements.

A direct comparison between the various FAA levels and the above military categories is difficult to make so each requirement must be analyzed on an individual basis and the most cost-effective solution be applied. Moreover, joint service requirements and multi-role, multi-player requirements must also be considered when selecting the cost-effective solution.