BENEFITS OF SIMULATED EFIS AND MFD HARDWARE FOR TRAINING APPLICATIONS

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Abstract

There are several drawbacks to the use of flightworthy avionics in training devices, especially in Part Task Trainers where initial cost is a primary consideration. This paper will present a comprehensive life cycle analysis of flightworthy versus simulated "glass cockpit" instrumentation in FULL FLIGHT simulation, MAINTENANCE training, COCKPIT PROCEDURES training and PART TASK training applications for devices performing equivalent functions.

Initial cost, maintainability, reliability and orientation of the user community will be addressed as part of the life cycle analysis. The pros and cons of breaking the link between aircraft maintenance and trainer maintenance will be presented. The context is of a single centralized development station for maintaining different instrument configurations in the aircrew and maintenance training systems of a varied fleet of operational aircraft. Currently these systems are unique, and relate to aircraft type and avionic specific components.

Overview

Existing aircraft simulations for use in the Department of Defense (DoD) use an approach which exactly duplicates the cockpit of the aerospace vehicle. Where necessary, or at the direction of the customer, these cockpit simulations have been achieved by stimulating actual aircraft hardware. Glass Cockpits have been slow to appear in DoD aircraft. The constraints, limitations and expense of these avionics systems has forced the simulated approach to remain focused only on a few programs. These programs usually deal with the test and prototype environment, or are in a research and development simulation laboratory.

Typically,maintenance training devices do not include the Electronic Flight Instrumentation System (EFIS) parts due to availability and expense. Therefore, the technicians assigned to maintain these aircraft learn on-the-job. Automatic and manual maintenance test stations are quite capable of isolating faults on aircraft equipment. However, these units are not good training devices due to their complexity and primary mission demand. Dedicated test stations for maintenance training can be useful, but the expense and lack of full use becomes an issue.

Aircraft Versus Trainer Utilization

Traditionally, simulator manufacturers used stimulated actual cockpit electronic flight instruments to offset the lack of simulation technology. This new technology would produce simulated instruments of the same fidelity at a reduced acquisition and implementation cost.

When an aircraft enters the active inventory ground support equipment is bought concurrent to the aircraft to keep the weapons systems ready for the designed missions. The supply level is based on the in-commission time of the aircraft parts. Also considered is the number and type of avionics, and their mean-time-between failures. An operational unit dedicates little of these resources specifically to training. Instead they rely on technical support from the original equipment manufacturer, or on receiving qualified technicians through the ATC pipeline.

Contractor technical representation is usually phased out after the first years of operation of the new aircraft. If no experience has been developed within the Air Force, or if no further contractor support is available, the combat ready status of the Wing may suffer. The contractor usually does not go with the aircraft if it is deployed to a hostile environment, yet highly skilled, fully trained personnel must be available to support mission activities.

While technicians have been successful at learning older electro-mechanical systems from the actual aircraft, the introduction of computers and their automated systems introduces different problems. This integration allows for centralized malfunction reports. It also gives a common point to connect all sensor and sub-system elements. Maintenance personnel can review an entire aircraft's configuration in minutes from a single point in the cockpit. Appropriate maintenance actions follow in a cost effective manner due to reduced troubleshooting and mis-diagnosis of symptoms. Avionics maintenance training equipment provides the technical force with hands-on training while not using the aircraft as a training medium.

Each command has a tradition of solving these training problems by themselves on a project by project basis. The level of success is mixed and the cost to implement numerous training programs on multiple systems is high.

Airworthy System Benefits

The benefits of the use of actual equipment in the training system are many. These are the same parts which will later be found in the equipment on the flight line, so an exact relationship is made as to "look and feel". Form, fit and function are maintained and a positive transfer of training exists.

The actual equipment requires an actual setting for its operation. Mission computers drive aircraft busses which have assorted sensors and display devices attached. Equipment which checks good on the test bench but does not operate properly in the aircraft may be attached to this system for further diagnostics. This practice however, can lead to failure in the training system. Repair dollars or technicians may not be available for the training system repair, so it and its training value suffers until repairs can be made.

The use of on-board mission computers in the trainers means that the aircraft software can operate in the ground training equipment. A new software release can be issued to the trainers to keep them current. This also makes the trainers very dependent on timely issue of changes software. Often the trainers support is through a different depot and supply channel. The funding of trainer modification can and often does lag well behind the aircraft. Effective training mandates that these events happen simultaneously.

Some of the problems of actual equipment in the ground training equipment is already noted. Other issues which surface must be included. The MIL-SPEC requirement for flight certificated equipment is understood. These parts are subjected to extreme environmental and operational conditions and they must meet these rigorous standards. The expense of these standards should only be brought to the aircraft parts for this is their sole reason for existence.

Disadvantages of Airworthy System Approach

The airworthy aircraft equipment installed in the ground based training equipment introduces a host of complications. The actual aircraft instruments were designed to operate for 2-3 missions per day, 5 days per week. This could mean 10-25 hours of operation per week. Between each aircraft flight, technicians test avionics systems to be sure that the weapons system is functioning properly. The flight simulator's design is to operate 16-20 hours per day, 7 days per week.

A study, conducted at Cannon AFB, NM. for the F-111D, tried to quantify aircraft versus simulator equipment hours. The aircraft equipment used in the simulator were receiving six times the cycles of the same equipment in the aircraft. The failure rates in the simulator reflect this ratio. Re-supply of functioning parts did not effect the study because working equipment was in local bench stock. This also showed that occasionally flight line aircraft equipment is used to support mission critical simulation schedules. The Not-Combat-Ready (NCR) status of mission aircraft due to avionics cannibalization is a difficult decision for the Directors of Operations. This decision is often discussed in heated tones with the Directors of Maintenance.

If actual aircraft parts are specified for the training devices several unfortunate ramifications occur. The airplane builder is trying to produce aircraft at a schedule which may now change by delivery of flight avionics to the ground based training equipment. Given a choice, this builder will route these slots to aircraft and sacrifice the trainers' delivery.

With additional parts in inventory, additional labor and equipment must be dedicated to the repair of these items. Each time a trainer part arrives at the test station, its repair delays maintenance of mission critical equipment.

Lead time for initial and replacement avionics equipment may not fit into the scheduled ready-for-training dates of these trainers. It is doubtful that any simulator manufacturer could accept an additional one year delay for cockpit displays due to aircraft production priority.

Using prototype or the first of the production flight hardware can bring the trainer to an unacceptable in-commission rate. This is primarily due to the associated mean-time-between-failure rate of this new equipment.

I remember one time at three o'clock in the morning while trying to ready a flight simulation for the first mission of the day. A malfunction in the attack radar pointed to the scan converter as the source of the problem. Unit after unit was brought to the simulator while trying to find one that would function. I still can see six units around my feet while thinking that "here is 3 million dollars worth of equipment and none of it works ..., there has got to be a better way." Each piece tested good on the avionics test stations. The simulator environment was just slightly different enough to limit the use of units which would function there. If red tagged dedicated simulator equipment is selected as a way to avoid this problem, why not integrate simulated avionics from the start?

Next Generation System

Just this year the DoD has, or will, let contracts for aircraft training systems which will include EFIS. These include training systems for the C-17, V-22 and P-7. The complexity of the missions for each aircraft requires that the configured instrumentation system be very complex. Complex equals expensive in every case. The aerospace ground training equipment need not experience these expenses.

The V-22 program could have each Operational Flight Trainers (OFT) and Maintenance Training Devices (MTD) burdened with $1.2 million in flight qualified EFIS equipment. The contractor must still integrate this equipment into the training device and deliver it to the Government. While this approach guarantees the 'look and feel' of the aircraft, its utility range suffers. The bounds are to the maintenance part task or flight mission part task of the specific training scenario. Often the EFIS mission is in a very limited area (such as system malfunction annunciators). The primary mission of its attached EFIS system may be a maintenance trainer for the landing gear or flight control system.

Aircraft qualified mission essential parts do not belong in the OFTs or MTDs. Their effectiveness will show itself in fulfilling the aircraft primary mission. Simulated equipment should substitute actual equipment for this vehicle's MTDs and OFTs. A savings of 75% over the cost of actual aircraft parts will show itself with the proper application of simulated EFIS. The integration now becomes a pure traditional simulation task. Limitations of the flight hardware disappear and all the power and flexibility of the implementation algorithm is in effect.

Lessons from Commercial Aviation

While this is a government forum, lessons learned in the commercial realm are meaningful in the use of simulated training equipment. One West Coast based airline found themselves nearing delivery of a new aircraft. The delivery of the ground training devices would not be in time to avoid flying non-revenue aircraft for training. Their training specialists gathered alternatives and presented them to management.

A dedicated piece of aircraft equipment could be bought for some money, let's say $300K. This would act as a stand-alone training device. It would allow one aircrew member at a time to manipulate its controls and receive the required training. As it was an aircraft system, timely delivery was in doubt due to the late buy request and the schedule of the aircraft program.

A computer based training (CBT) course and a network of six terminals could be bought. This would enable instructor led or individual training on all the differences of the aircraft. This could also act as a platform to grow additional training courses. The FAA required only demonstration of familiarization of new system operation. This system would fit the training requirement and allow six times the number of students as the dedicated equipment. All of this for about the same implementation cost.

A simulated systems trainer could be obtained which combined the touch-and-feel of the actual equipment with the utility of the CBT system. Multiple lessons stored in the trainer memory enabled interface to many scenarios, and manipulation of all new aircraft controls in a controlled setting.

This airline actually decided on a combination of the last two discussed approaches. First they had the

CBT system commissioned to solve the short term training problem. The regulatory agency (FAA) was included in each decision which hastened the employment of this system. Early student feedback showed that this system worked well in getting familiar with the new and different systems and as a procedures trainer. Tactile feedback and psycho-motor response suffered in having all equipment portrayed on CRT screens.

This feedback led to the use of a training system which included simulations of selected panels and systems. These are connected to intelligent units for real-time application training. This system even allows different control panels be attached as the training schedule changes. The same base training system is used for multiple aircraft. What a novel idea!

In the dedicated system, if a part is removed for maintenance, all training activity ceases until repairs occur. If you consider the generic training system, the student moves to the next available carrel. If all training stations are in use, only one student is affected by a malfunction. Re-supply is not dependent on aircraft parts for the simulated system. Most items are available through a second source and much less expensive than its aircraft equivalent.

As noted earlier in the F-111D study, failure rates which may be acceptable for operational aircraft may not apply to the ground based training equipment for that same airframe. Flight and mission simulators are in operation continuously. Time not used for aircrew or maintenance training is dedicated to its own maintenance (typically being readied for the next training day). Scheduled training sessions demand near 100% in-commission rates.

Simulated instruments and avionics displays are designed for thousands of continuous working hours. It is normal to see mean-time-between-failure rates in the ten thousand hour range. One of these simulated systems may operate continuously for years before the first notable failure. Even then the mission aircraft are not influenced by this failure, as dedicated spares are also simulated parts repaired through separate channels.

Support Equipment

In units where aircraft are deployed there is a concentration of flight and maintenance training equipment specific to the flightline aircraft. If a simulated approach is taken in the avionics portion of these devices a single piece of Aerospace Ground Equipment (AGE) can be used to maintain all like devices.

The specifics of drawing images on displays is discussed below. This type of system could be used in all of the applications for display devices applicable to any aircraft. In a perfect world this works well and our world is less than perfect. However, future systems specifications may include some of this capability so as to bring the benefits to the units.

The Centralized Development Station

Most aircraft have centralized Development, Engineering and Prototyping Sites (DEPS). Here modifications are installed and tested. Time Compliance Technical Orders are prepared and issued by their Depot for distribution to operational Wings. The maintenance of displays and flight Operational Flight Programs is performed and this too is prepared for distribution. A prototyping system for the simulated displays could be located at these sites. It would be used to update the simulated displays of all types of trainers from this central location. Some of the applications include the mission computers as part of the simulation. This system could also test the interaction of the new pages under the direction of the actual flight software.

A development station co-located with the simulators and maintenance trainers would allow local technicians to support concurrence at the direction of the DEPS. Also, maintenance of the display devices could be performed off-line using this capability. This would reduce down time due to travel of defective units to and from depot locations.

This will now give the ground trainers a separate low cost system to use for maintenance. The flightline AGE can deploy with the operational units without effecting the status of the training equipment. Maintenance technical support is justified as the concentration of like equipment will keep this staff occupied on a full time basis.

Simulation System and Its Benefits

The mastery of image generation techniques and the correct application of computer and graphic technology allows industry to offer a better solution. Real-time multi-channel high resolution graphic generation in a cost effective package is now available. These were not available even two years ago. The real-time image generation of that sophistication exists in *the past only in a few multi-million dollar units.*

An acceptable system must cost well less than the actual equipment, and reduce the interface and maintenance requirements over those of the stimulated equipment. The system must faithfully represent any display in both a maintenance training device and a flight simulator.

Treated in the training system much like a visual system, simulated EFIS offers the maximum effectiveness for the lowest integration price. This system disconnects itself from aircraft equipment and its inherently high failure rates. This offers the user very high mean-time-between-failures with an average repair time of 15 minutes.

The more sophisticated an advanced aircraft cockpit becomes, the easier it is to simulate the instrumentation and working environment. Digital computers and CRTs replace analog instruments and dedicated circuits. Most of the cockpit functions are software implementations accomplished in the simulated environment.

Simulated Electronic Flight Instrumentation System (EFIS)

MicroPOLY 1 was developed by Rediffusion Simulation Incorporated (RSI) in 1987 as a graphics engine. It has its basis in a personal computer (PC) environment. The latest in a series of improvements has produced the MicroPOLY 1A system. The MicroPOLY 1A uses existing technology for the creation of EFIS page symbology.

Interfacing a simulated multi-function display (MFD) with a graphics generation unit requires none of the complex hardware of an actual aircraft MFD. Further, this equipment need not be flight certificated hardware, reducing the implementation and maintenance costs. The host simulator equations collate pertinent data and send these data to the image generation equipment (IGE) via IEEE 802.3 Ethernet. The IGE provides a video output which consists of all the display data. This output symbology appears on the simulated MFDs in the crew compartment. Discrete switches and lights within the MFDs provide key legend data activated by operator input. Any display bezel lighting is within the MFDs and handled internally.

When installed in a maintenance trainer or flight simulator, the IGE communicates in real-time with the simulation host. This provides updates for the functioning of the simulated display processors and flight deck EFIS. With these parts assembled, the remaining integration activity is simplified. What remains is the correct packaging of the display instruments, and generation of specific display pages. A Control Display Unit (CDU) can be a part of this suite of EFIS. The CDU is a text display which usually contains a monochrome monitor. The display presents a realistic representation of an aircraft CDU. Separate from the CDU but part of its function is the keyboard unit. This is a standard keyboard which looks and feels like the aircraft equipment. A host of different types of input and display devices can be a part of this system. A combination of different aircraft displays may be made in the same application area. The system is as flexible as the mission requirements.

The Display Process

The actual animation of displayable objects is a special part of the real-time state machine executive program. A Logic Integrator and a Lexical Analyzer reduce the Virtual Avionics Prototyping System (VAPS) Metafile output into a cognizant entity. One last manual process links simulation host block variables to the moving objects. Operator identified variable types pass as data and translate as part of the equation to the correct format for IGE use.

This now compressed data base stays in the Image Generation Unit (IGU) memory to await processing as a page in the real-time system. A typical page consumes 10-12 kilobytes of memory when in a state ready for display. With an IGU system configured with 4 megabytes of RAM the display processor has access to 250 pages. All page data transfers are performed at the speed of memory upon the command of the host block or from direct system intervention. This method makes sure that latency due to page input is minimum.

The Image Generator Control Unit (IGCU) houses all linkage equipment and any adapters required to communicate with other computers. Typically this communication is IEEE-802.3 Ethernet to the simulation host, and IEEE-488 to levels of the IGE. This IGE also interfaces to the MIL-STD-1553B bus. All aircraft bus traffic is available to the IGE in precise form when the mission computer is part of the simulation. Real-time host data arrives at this point and merges with the mission computer data list. Control layer management and caution and warning flags are added as required to change the several basic display types for each MFD. These flags and the EFIS control data pass to the IGU for display processing. This methodology follows conventions set up for mission computer communications and ease the interface requirements to an actual simulation host.

Data is moved to dedicated memory locations for use by the IGU in real-time (30 Hz). A return transfer sends data back to the simulation host and mission computers over their separate communications paths and at their separate rates. All of the simulated EFIS equipment is housed in a few levels of standard 19" equipment racks. Due to the application in ground training environment, a commercial type approach offers the best value while maintaining high operational standards. The modular approach also offers inexpensive and easy upgrades to the existing products. If a more powerful computer is required in the future, merely remove the existing module from its PC bus slot and replace it with the new unit.

Maintenance is handled in a similar manner. Faulty modules are found through automatic diagnostic or conventional troubleshooting and are replaced with spares from stock. As these modules are available from more than one commercial source, continued supply and low replacement cost is assured.

Page Authoring System

This system brings with it a new and unique technology to create custom and generic pages for the MicroPOLY 1A image generator. A Silicon Graphics 4D-20 development environment houses the VAPS. VAPS enables the page creator to design and create pages in hours instead of days using alternate methods to perform the same functions. Once page objects exist they become part of a graphics library used in any future application.

Created objects fit into logical groups with other typed objects. These objects carry traits with them which describe specific behavior in the real-time environment of the IGE. These traits can reveal themselves as moving or static images on the display system. The IGE becomes a generic platform which is used to control how the desired page is displayed. For example, the now displayed page may be an aircraft attitude indicator with all the flight director indicators and scales. These objects all move in concert with the simulation host without requiring the host to control each object.

VAPS creates objects, and other integrated software utilities enables the user to link each object with a real-time host variable. Multiple objects can exist, each with its own real- time traits. For example, take a course deviation indicator moving across the face of a compass while the simulated aircraft is performing a turn. The pointer of the CDI is a moving object nested into the compass object. It has its own origin and its own moving traits. The moving bar of the CDI also has its own moving traits through its own space, nested into the other objects. All the time the main compass is moving about its center of rotation (usually the CRT center). The communication of rotation commands is at a rate determined by the simulation host via the host data block.

These combined software utilities are a key element in the prototyping and institution of the displayed pages in real-time. These utility enables a relatively inexperienced user to develop pages in a controlled environment. These pages can represent any object or text desired in any position on the page.

Disadvantages of Simulated System

New aircraft programs have problems of display page maintenance not normally found on older equipment. As these can change at all,implies that they will. The look of a non-EFIS instrument remains constant. However, the operating of the driver systems, and hence the presentation to the aircrew does indeed change. An EFIS is no different.

As each item of the presented display is a combination of software and display electronic elements, maintenance is a software management task. This paper discusses a simulation of an EFIS which uses software tools to alter the look and logical operation of each display page. A simulation approach for display electronics requires a system like this from a longer term maintenance approach.

Page Maintenance Life-Cycle-Costs

A simulator or maintenance trainer program must then contend with software configuration management for the years of the program. All simulated approaches impact the desire for concurrence in the display area. Software must change any time the display differs in presentation of information. This system offers a better method with which to effect these changes.

The mission computer often does not calculate all of the display information. Any off-loaded tasks parsed to the display system must change each time there is a revision to the display parameters. The software tools and the correct integration of them into the simulation environment reduces this modification effort. To arrive at a comparison consider the data in Table 1.

Further assume that average software engineering rates are $75.00 per hour. The code changing approach will cost $405,000.00 over a 5 year period just for the maintenance of pages. This is $6750.00 in program funds per month for concurrence maintenance. Typically a graphics illustrator will use these software tools to maintain pages. The cost of that labor is $45.00 per hour, but we shall continue to use the higher number as a comparison. Using the automated system will cost $54,000.00 for the 5 year cycle, or $900.00 per month.

The requirement of the these special purpose software tools may seem a detriment. However, it may actually be a strength in another view. The simulator is the perfect place to prototype and test the functioning of modified display pages. These changes can be made in minutes and tested in a safe and logical manner with none of the burdens of typical flight test bugs. Fully tested software and page displays can then go forward to flight test certification. This brings an additional savings realized in the reduced flight and maintenance of the test aircraft.

Other disadvantages to the use of simulated equipment are centered on acquisition of initial products, and the spares required to maintain the deployed system.

These can be moved to the prime contractor as part of the statement-of-work of the training equipment specification. The cost advantages outweigh the complications of logistics.

Table 1: Cost Comparison.*

	VAPS	CODE
	180 changes 4 hrs/change	180 changes 24 hrs/change
Sub-total:	720 hours	4320 hours
Documentation:	Self Documenting Metafiles	1080 @ 25% of labor cost
TOTAL:	720 hours	5400 hours

*Assume three display changes per month for the first five years.

CONCLUSION

I have surfaced most of the issues involved in the simulation versus stimulation argument. As there is never a safe and sure way to approach all tasks, that fits into the budget, tough decisions will have to occasionally be made. Stimulated is safe but VERY expensive in time and money. Simulated is lower cost and a safer integration but data and concurrency will always be issues. A wise man once wrote three words on a blackboard, and I will always remember them,

GOOD QUICK
CHEAP

The problem is that you must only pick two.

This system would not be necessary if only aircraft equipment is ever used in the simulators or maintenance trainers. As discussed the cost and schedule risk for the actual aircraft capability may be unmanageable. Try not to think of simulation of cockpit displays and mission computers as a trade-off to keep schedules on track. Instead a confidence in simulation technology moves conversation to include it as a viable path to high fidelity training systems. These new and exciting training systems will be populated with low cost, easy to maintain, easy to upgrade avionics simulations.