F-15E VIRTUAL REALITY INTERACTIVE COURSEWARE SIMULATION, ARMAMENT MAINTENANCE TRAINING SYSTEM

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ABSTRACT

Previously, the F-15E Weapons Block of the Aircraft Systems Apprentice (F-15) Mission Ready Technician course was taught in eight hours to students slated for F-15E bases. The delivery method used for F-15E Safe for Maintenance (SFM) task training was lecture and student handouts only. In accordance with Standard Instructional System Design, a hardware-training device is needed due to the hands on nature and safety aspects of this task. In the early 1990s, the Armaments Apprentice School programmed funding for a hardware trainer but the device was rejected due to a cost of approximately $4M. By this time, negative feedback from the using commands on F-15E weapons training was growing. The Schoolhouse spent $425,000 to develop a "virtual" F-15E aircraft equipped with both cockpit and aircraft wing weapon pylons to fill the need for hardware-like skills training. The new Virtual Reality Interactive Courseware (VR-ICW) was devised to increase training quality, and decrease cost by using the "reference" F-15C/D SFM task performed on the real aircraft coupled with the "virtual" F-15E SFM task to provide a seamless learning experience. In general, students of the F-15E VR-ICW course, based on 1st generation VR hardware, were pleased with course content and thought the course was well organized and easy to follow. However, a few students experienced varying forms of headache and nausea during their interaction in the virtual world. About 9% of the target population did not complete the course due to VR Sickness. The pointing device drew mixed reviews. Many responded they had trouble selecting some of the switches due to their location and very small targeting areas. Surveys indicated the majority of graduates believed VR-ICW positively impacted their job performance and the supervisors spent under four hours on aircraft training time. This is a saving of 22 hours, based on the provided estimate of 26 hours per student to reach the "go" proficiency level. Recommend augmenting other aircraft maintenance courses with VR-ICW technology.

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INTRODUCTION

Air Education and Training Command (AETC) conducted a study of the feasibility of virtual reality (VR) simulation for F-15E Safe for Maintenance (SFM) training at Sheppard AFB TX. Maintenance trainees and their follow-on supervisors from 1998-2000 participated in the analysis.

Previous Studies

VR training in DoD comes in two varieties: desktop and fully immersive. Desktop VR provides an interactive environment in which 3D images are projected onto a 2D computer screen (Cochrane, Matthews, Cameron, & McCartney, 1997; Pfautz, 1997). The problem is that certain types of training require "virtual presence," the sensation of being physically present within the simulated environment (Sheridan, 1992).

Depth perception and spacial orientation are particularly critical in such areas as subsea systems, remote handling, architectural design, and aeronautical engineering (Cochrane, et al, 1997). Fully immersive VR, with its head mounted display (HMD) and hand manipulation device, can provide this type of experience.

Although much more expensive and complex than desktop VR, the popularization of fully immersive VR by the commercial game industry has considerably accelerated performance and driven down prices (Blau, 1997; Bonnani, 1997; Foran, 1997). An HMD now costs as little as $800 (Bolas, 1997).

Within the Air Force, the kind of training for which virtual presence is critical also tends to be the training for which the actual equipment is currently required (Greene, 2001). Setting aside military hardware for instructional purposes, however, can be very expensive. The $50M F-15E is one example. Even at the 1996 price of $425,000 a fully immersive VR system for the F-15E would provide a substantial savings.

Background

When the Armaments Apprentice School at Sheppard Air Force Base (AFB) set up their original Mission Ready Airman (MRA) training program for the F-15C, a problem developed because ACC, PACAF and USAFE began fielding the F-15E Strike Eagle.

Due to the budget constraints and low throughput of the F-15E Weapons population, the acquisition of a $50M Strike Eagle training aircraft was not cost effective.

The Instructional System Design (ISD) facilitators proposed an alternative media that consisted of a $4M hardware-training device. This device was also not economically feasible. Even without an aircraft or hardware trainer, the Armaments Apprentice School was still required to train MRA for the using commands.

Instead of using a real F-15E or training device, an eight-hour block of stand-up lecture with student handouts was implemented for instructors to build the needed skills using the existing F-15C and a stand mounted Conformable Fuel Tank (CFT).

Difficulty arose in teaching this hands-on objective due to vast differences between the F-15C and F-15E aircraft.

Within months, stacks of negative critiques from the field were received. Newly trained weapons apprentices assigned to F-15E Strike Eagle Units could not perform an aircraft SFM procedure without several hours of painstaking, individualized instruction conducted by the operational units. This produced a large negative impact on mission readiness due to non-certified airmen unable to perform core maintenance tasks.

In response to this problem, Armaments Apprentice School instructors developed the idea of using new, experimental "virtual reality" technology. The instructors' idea was to bring a "virtual" F-15E Strike Eagle to the Armaments Apprentice School.

In 1996 through collaboration with Air Force Research Lab (AFRL), F-15E SFM training was developed with a virtual F-15E Strike Eagle center stage on a virtual hanger floor (Figure 1).

Figure 1. VR View of the F-15E

The equipment selected was Silicon Graphics hardware that drove a first generation VR consisting of a Head Mounted Display (HMD) and a joystick in lieu of gloves (Figures 2, 3, 4).

The joystick is mirrored in the virtual world by a virtual joystick. The virtual joystick is a pointing device that glows red if it's too far from an item, then glows green when in range (Figure 5). Pulling the joystick's trigger tells the targeted "Switch" or "Button" to "Flip" or "Move" in the desired direction.

Figure 2. User with HMD and Joystick

Figure 3. The HMD

Figure 4. The Joystick

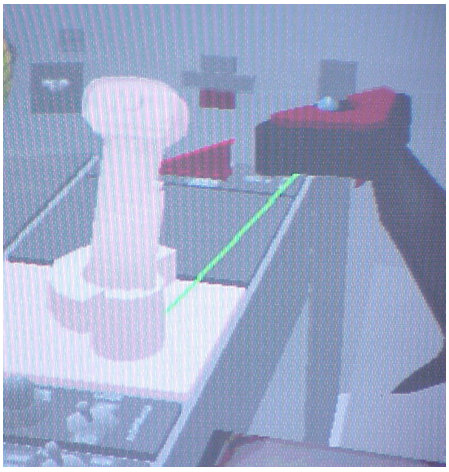


Figure 5. The Virtual Joystick

STUDY APPROACH

Baseline Data

Before VR, F-15E SFM training consisted of eight hours of lecture and PowerPoint slides. Unfortunately, no trend data from this period is available. The Graduate Assessment Survey (GAS) data was not usable due the lack of F-15A/B/C/D/E specific references. Nevertheless, curriculum developers from that time indicated receiving a very large volume of negative feedback.

Study Data

(1) Embedded Software gathered data on student performance during immersion in the F-15E VR-ICW. A report was printed after the student completed Aircraft SFM training.

In addition, three questionnaires evaluated the effectiveness, usability, interactivity, and quality of the F-15E VR-ICW. After course completion, graduates, OJT trainers, and immediate supervisors were queried to determine if they perceived any change in the graduate's job performance. The three questionnaires are:

(2) F-15E VR-ICW End of Course Instrument (Air Force Research Lab developed)
(3) Operational Unit Graduate Questionnaire (AETC Studies and Analysis [SAS] developed)
(4) The Operational Unit Supervisor Questionnaire (AETC SAS developed)

Note: There are three distinct sample populations. Data was collected from 32 AETC students using Embedded Software (1) and End of Course Instrument (2) from Feb-Oct 98. These were the first students to use the F-15E VR-ICW. The Operational Unit Graduate Questionnaire (3) population consisted of 55 graduates assigned to six operational bases (Elmendorf AFB, AK; RAF Lakenheath, UK; Mountain Home AFB, ID; Eglin AFB, FL; Seymour Johnson, SC; and Nellis AFB, NV). This data was collected from Apr-Dec 00. The Operational Unit Supervisor Questionnaire (4) population consisted of 20 personnel supervising the same technical school graduates surveyed with the Operational Unit Graduate questionnaire. This data was collected from Apr-Dec 00.

STUDY RESULTS

In the VR environment, students can practice SFM procedures in the classroom with a spatially correct aircraft. This provides students with a seamless learning experience as they progress from learning how to navigate in the VR environment through the remaining 20 lessons, covering F-15E forward and aft crew stations, and ending with exterior safety devices. The view (Figure 1) from the quarter-sized lens of the eye-piece is not very high in resolution or overly rich in fine details, but its power to place students up front and personal with the F-15E is extremely compelling. At times, students duck to avoid bumping into "virtual" wing tips.

(1) Embedded Software

Tracking progress of the 32 students in the F-15E VR-ICW, consisted of scoring the number of times students used the switches correctly and the number of safety violations students committed. After the last training module was completed, the instructor printed out a report with the student's final scores. Data from the following task areas was used to gauge student performance -

FWD Cockpit Left Hand (LH) Console Switch Drill
FWD Cockpit Main Console Switch Drill
FWD Cockpit Right Hand (RH) Console Switch Drill

AFT Cockpit LH Console Switch Drill
AFT Cockpit Main Console Switch Drill
AFT Cockpit RH Console Switch Drill

F-15E Weapons Station Drill
F-15E Safety Devices Drill
F-15E SFM Drill

Figure 6 depicts the view of the forward cockpit switches afforded to students with the HMD.

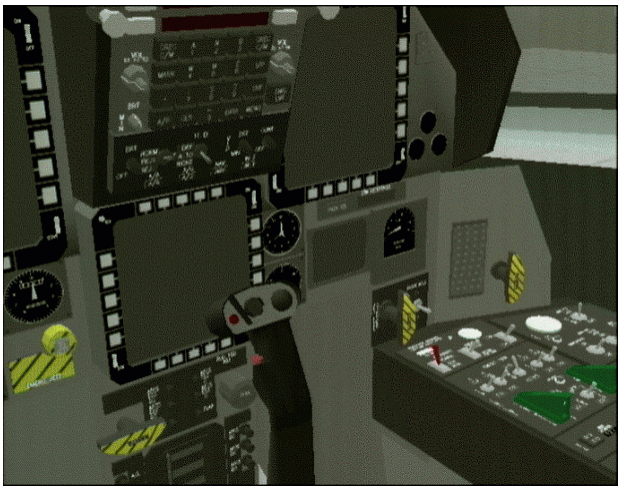


Figure 6. HMD View of Forward Cockpit

The rating scale for student performance (Table 1) is based on percent of students who received a passing grade (70%) or better.

Table 1. Student Performance

Low Difficulty >= 90% passed	**Main Console Switch Drill (FWD Cockpit)**
	RH Console Switch Drill (FWD Cockpit)
	LH Console Switch Drill (AFT Cockpit)
	Main Console Switch Drill (AFT Cockpit)
	RH Console Switch Drill (AFT Cockpit)
	F-15E Weapons Station Drill (Weapon Station)
	F-15E Safety Devices Drill (Safety Devices)
Medium Difficulty 81-89% passed	**LH Console Switch Drill (FWD Cockpit)**
	Safe for Maintenance Drill (SFM)
High Difficulty <=80% passed	**(none)**

Students performed quite well. Seven of nine performance areas rated "low difficulty." None rated high. These results do not include students who dropped out before testing.

(2) End Of Course Instrument

When the students completed the F-15E VR-ICW, they were given a VR-ICW End OF Course Instrument to capture what they observed while using the system. Thirty-two completed End of Course Instruments were received.

The End of Course Instrument had 18 open-ended questions on student understanding of the training objective and satisfaction with VR equipment.

The rating scale (Table 2) for the End of Course Instrument is based on percent of students giving a favorable answer to the item in question.

Testers measured student favorability across three broad categories: Training Objective (TO), Training Equipment (TE), and Virtual Reality Environment (VRE).

Only two of the items measured achieved a "highly favorable" rating. Five items, on the other hand, had a "slightly favorable" rating. All five fall under the "Virtual Reality Environment" category. In part these five low ratings may be due to the 1996, first generation VR environment, running on 195 MHz UNIX machines. The technology has improved considerably since the time of the study.

Table 2. End of Course Instrument

Highly Favorable >=90% favor	**Understand Objective (TO)**
	VR-ICW Computer Voice (VRE)
Moderately Favorable 81-89% favor	**Equipment Availability (TE)**
	Training Aid Support (TE)
	Training Objective/ Equipment Relationship (TE)
Slightly Favorable <=80% favor	**Material Support (TO)**
	No Heavy VR Sickness (VRE)
	VR-ICW Realism (VRE)
	Recommend VR (VRE)
	VR-ICW Lesson Length (VRE)
	No HMD/Joystick Difficulty (VRE)

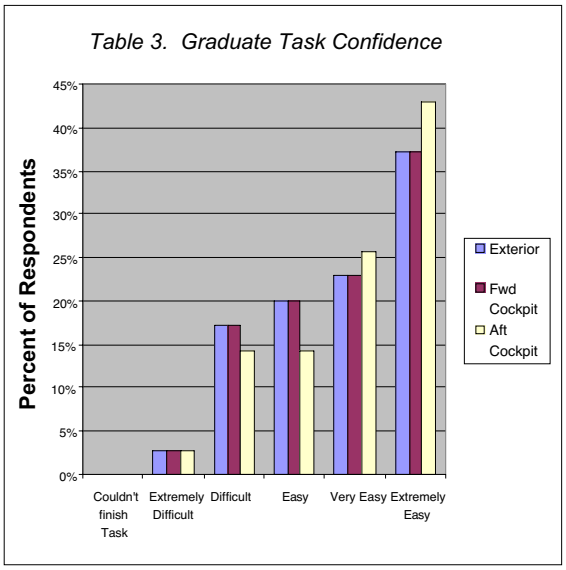
(3) Operational Unit Graduate Questionnaire

AETC SAS collected 55 usable responses from students in ACC, PACAF, and USAFE to the Operational Unit Graduate Questionnaire.

The Operational Unit Graduate Questionnaire consisted of 15 close-ended questions. For each question, respondents chose the response closest to their impression from a five-point scale. Questions gauged graduate confidence in performance of the VR tasks and how much they thought VR helped.
Students reported performing SFM tasks in all three areas - exterior, forward cockpit, and aft cockpit - over 1155 times or 21 times a year per graduate. Students need to perform SFM tasks very soon after graduation.

Graduate task confidence
Students were asked to rate their confidence level (Table 3) on a five point scale from 1 (extremely difficult) to 5 (extremely easy).

Table 3. Graduate Task Confidence



The majority of students rated SFM in all three aircraft areas as easy or extremely easy to accomplish. Average task confidence ratings on a five point scale are: exterior cockpit SFM – 3.74, forward cockpit SFM – 3.74, aft cockpit SFM – 3.92. In addition, the majority of the students were familiar with at least some parts of all three aircraft SFM tasks after their training on the F-15E VR-ICW.

Most students graduating from the block of instruction felt they were ready to start work right away and had few qualms about performing the F-15E SFM tasks on the live aircraft. For them, the advantage of VR-ICW over two-dimensional still images was its ability to provide lessons with complete spatial context. In other words, no need for hundreds of 2D still images that the trainee must process into approximations of the actual three-dimensional world.

Instead of "Switch 29b is located…" the trainee could "see" the item's location in its 3D and operational context.

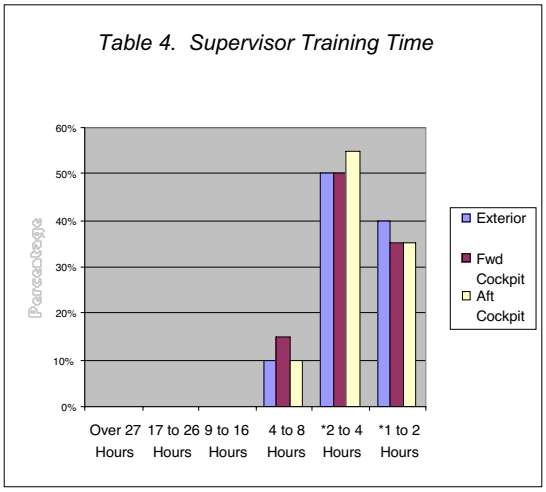
(4) Operational Unit Supervisor Questionnaire

AETC SAS collected 20 usable responses from supervisors in ACC, PACAF, and USAFE to the Operational Unit Supervisor Questionnaire.

The Operational Unit Supervisor Questionnaire contained 15 close-ended questions. For each question, respondents chose from a five-point scale of options. Questions gauged the supervisor's impression of the amount of job training required and amount of time needed to get a subordinate to the "go" proficiency level. They also gauged how well graduates met supervisor expectations.

Table 4 shows supervisor responses to the question - how long did it take to task certify a graduate in F-15E SFM procedures.

Table 4. Supervisor Training Time



The majority of supervisors spent under four hours training their troops to the "go" level of proficiency. This compares to the estimated 26 hours instructors report it used to take them before VR.

When asked to what extent graduates "met expectations," almost half of the supervisors said graduates surpassed expectations. Only 5% indicated trainees failed expectations.

DISCUSSION

Student objections to VR trace to two issues in particular – VR sickness and difficulty with the joystick.

The current system has produced three failures due to VR sickness. The numbers are quite low, but this is still a concern. Frame rates of fewer than 25 per second can cause the rendered scenes to slur into place inducing nausea in a small number of students. The F-15E VR-ICW frame rate ranged from 25 to 32.

Based on what has been learned, the VR sickness problem will not go away easily. A start will be to upgrade the hardware to a newer system with faster frame rates and lighter display. Here are three additional suggestions to help minimize the effects of VR sickness:

1. Pre-screen the students within the first two weeks of school and have them report to the clinic for a possible Dramamine prescription or other medication.
2. During immersion, some students move their heads too fast (greater than 120 degrees per second). The current system will not keep up. To help students minimize the effects of this mistake, they should try closing their eyes for 5 seconds to allow the view inside the HMD to stabilize.

A number of students indicated varying degrees of frustration using the joystick to interact with the VR world, several voicing on paper the desire for a VR glove to replace it. On the other hand, the joystick has proven rather trouble free and durable in use. The joystick forces the students to actively find the specific item called out in the technical manual. Joystick versus glove, therefore, remains an open question.

SUMMARY

The system in use today has not changed since 1996 due to budgetary and other constraints. Nevertheless, this system coupled with "reference" aircraft maintenance skills from the F-15C has proven to be quite successful in assisting the Armaments Apprentice School provide MRAs to the using commands.

Results from the End of Course Instrument indicate that most students understood the training objective and believed the training materials and equipment support the learning events. Objections focused on discomfort with the headset and joystick, and on VR sickness.

Graduate Questionnaire results show most students embarked on their new duties within weeks of arrival on station, felt confident in their ability to perform the task, and felt VR-ICW had contributed significantly to their performance.

The Supervisor Questionnaire reveals how *little time* was spent on actual aircraft training. Prior to VR-ICW, the estimate was 26 hours per student to reach the go level of proficiency. Afterwards, supervisors indicated they spent less than four hours to achieve the same result. This is a saving of 22 hours per graduate.

Supervisor performance assessments were overwhelmingly positive, with a sizable group rating their MRAs surpassing expectation.

No longer on the "bleeding edge," VR-ICW is ready today. For several major weapons platforms, such as the F-22, F-117, B-1, B-2, and Joint Strike Fighter, it would be prohibitively expensive to spare even a single aircraft for SFM training. The results of this F-15E experiment support the introduction of fully immersive VR as a cost effective supplement to other weapons system maintenance courses in DoD.

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