Fusion Interfaces for Tactical Environments: An Application of Virtual Reality Technology

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Abstract

The term Fusion Interface is defined as a class of interface which integrally incorporates both virtual and non-virtual concepts and devices across the visual, auditory and haptic sensory modalities. A fusion interface is a multi-sensory virtually-augmented synthetic environment. A new facility has been developed within the Human Engineering Division of the Armstrong Laboratory dedicated to exploratory development of fusion interface concepts. This new facility, the Fusion Interfaces for Tactical Environments facility, or FITE, is a specialized flight simulator enabling efficient concept development through rapid prototyping and direct experience of new fusion concepts. The FITE facility also supports evaluation of fusion concepts by operational fighter pilots in an air combat environment. The facility is utilized by a multi-disciplinary design team composed of human factors engineers, electronics engineers, computer scientists, experimental psychologists, and operational pilots. The FITE computational architecture is composed of 25 80486-based microcomputers operating in real-time. The micro-computers generate out-the-window visuals, in-cockpit and head-mounted visuals, localized auditory presentations, haptic displays on the stick and rudder pedals, as well as executing weapons models, aerodynamic models, and threat models.

1 Introduction

Future tactical aircraft will be operating in a much more demanding environment than they do today. The lethality of weapons systems continues to increase. The proliferation of advanced weapon technologies such as directed energy weapons, reduced target detectability, and increasing use of passive sensor methods will create increased air combat dynamics as well as requiring additional time critical decisions to be made by the pilots of future tactical aircraft. This will place the tactical aircraft pilot in a more difficult mission environment

than he currently experiences. To counter the increasingly complex tactical environment, advanced pilot-vehicle interface (PVI) techniques, which enable a more efficient use of the pilot's abilities, are required to be developed and employed, thus providing greater situation awareness, enhanced controllability of the overall weapon system, increased lethality, and increased survivability. These factors, in turn, combine to enhance weapon system effectiveness.

The cockpit is not the only environment in which advanced interfaces may increase the performance of a total system. The link, or interface, between man and intelligent machine, may be limiting the productivity and efficiency obtainable through automation and machine intelligence [3]. The challenges involved in linking humans and intelligent machines are increasing due to increased computational power, increased availability, increased machine-to-machine communication capability, increased functional capability through higher level languages, and increased memory capacity.

The PVI can be viewed as a type of human-machine interface, with the machine representing the advanced avionics system. This generalization highlights an opportunity, that being the opportunity to transition military-sector advanced PVI concepts and devices to the commercial-sector, as human-machine interface concepts and devices. This paper describes ongoing research and exploratory development of multi-sensory virtual interfaces, an advanced PVI technology within the Human Engineering Division of the Armstrong Laboratory.

2 Multi-sensory virtual interfaces

A melding, through the interface, between user and system can couple the inductive capability of the system with the enormous deductive power of the human user. Advanced multi-sensory interface concepts and technologies can aid this melding process by providing a flexible and adaptive interface medium.

Multi-sensory virtual-interfaces may enhance weapon system performance during tactical engagements by contemporaneously and coherently providing display of multiple-sensory channels of information to the fighter pilot and enabling novel control methodologies to be employed through the use of virtual devices. In the same way, multi-sensory virtual-interface concepts may provide enhancements in other human-machine links by capitalizing on the human's innate ability to integrate, assimilate, and fuse multiple sensory experiences simultaneously. Multi-sensory interfaces may better support the interactions necessary to fully realize and direct the capability of increasingly powerful avionics and weapon systems.

The application of advanced, multi-sensory interface concepts may best be accomplished using a combination of non-virtual (or conventional) and virtual control and display devices. The use of a combination of virtual and non-virtual devices can create a novel experience for the user, such as in high-

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fidelity embedded in-flight training, wide field-of-view multi-sensory imagery portrayal, or in cockpit portrayals adaptive to the tactical situation and the pilot's condition. This type of experience, in the general sense, has been termed in the current literature as virtual reality [10]. The perceptual space created by this experience has been termed the virtual environment and more recently, the synthetic environment.

3 Enabling Devices for Virtual Interfaces

Three sense modalities lend themselves for use as virtual interfaces within tactical environments. These are vision, audition, and touch. Touch may be more clearly defined, in this context, as haptic, involving both cutaneous and kinesthetic stimulation. Several technologies are currently being utilized to create virtual interfaces within these modalities. Some of these technologies are very mature while others are in their infancy.

The technology to totally emulate naturally occurring environments within a virtual environment does not exist at this time. However, devices enabling the creation of a limited virtual experience do exist [3]. Helmet mounted displays, helmet mounted head, hand, and eye line-of-sight trackers, three dimensional auditory displays, and tactile stimulation devices have been developed and evaluated by several academic, industrial, and military institutions in a non-integrated fashion or, context independently, since the mid 1960s [4], [5], [12], [14], [13], [11]. Perceptual research which may impact the design, development and application of virtual environment technology in the areas of vision, audition, and proprioception is continuing internationally.

3.1 Virtual Visual Devices

The virtual visual interface is composed of a visual image generator and a visual image portrayal system. The visual image generator can be a computer graphics system, an imaging camera, or other similar sensor. Of the three modalities, the technology for visual virtual interface application is the most mature. Computer graphics, sensor technology, and image portrayal mechanisms are important technologies for the creation of robust and high-fidelity virtual environments. Image portrayal technologies involved in the transformation of electronic-formatted imagery to a visual format include miniature cathode-ray tubes, liquid crystal displays, optics, interface electronics. Many of these technologies are being considered for incorporation, or are already integrated, into aircraft cockpits. These include HUDs, and helmet mounted displays (HMD), as well as three-dimensional panel mounted displays. Virtual visual controls include helmet mounted head position/attitude trackers and eye line-of-sight trackers. A discussion of helmet mounted display technologies can be found in a paper by Kocian [6].

3.2 Virtual Auditory Devices

Virtual auditory displays have been developed which utilize three-dimensional auditory localizers combined with audio image sources and stereo headsets. The three-dimensional auditory localizer samples the auditory image created by an audio image source such as an intercom or computer generated tone source, digitally filters the signal based on a head-related transfer function that is a function of sound location in azimuth, elevation, and range, and results in a stereo audio pair. The stereo pair is converted to an analog form and displayed over a stereo headset. A discussion of current technology and perceptual research issues concerning auditory localization is found in papers by McKinley [7], Wenzel [15] and Durlach [2].

3.3 Virtual Haptic Devices and Virtual Control

Haptic displays, which enable the portrayal of virtual cutaneous and kinesthetic information, and other virtual control methods, are less developed technologies then the visual and auditory technologies, but may be made available for use as currently ongoing research makes advances. These include tactile/haptic stimulation devices, hand and body flexure measurement devices, direct vestibular stimulators, direct retinal displays, and directly-coupled brain-actuated control. Control loaders, typically utilized in flight simulation to accurately model the stick feel of a particular aircraft, also fall into this category but are a mature technology. Some of these technologies are discussed by Rheingold [10], Meyer [8], and Monkman [9].

4 Fusion interfaces

The term Fusion Interface is utilized within this context as a class of interface which utilizes both virtual and non-virtual concepts and devices integrally across the visual, auditory and haptic modalities. A fusion interface is a multi-sensory virtually-augmented interface.

Although much is known about human perception and performance [1], the creation and evaluation of multi-sensory virtually-augmented interfaces presents a design problem in that it is difficult to design or evaluate these interface attributes without experiencing them within the application context. In many cases, what seems to be a valid display or control concept breaks down when it is experienced. For this reason, multi-sensory virtual-interface creation, integration, and evaluation can best be accomplished within a rapid prototyping environment capable of generating the virtually-augmented environment for the pilot. The Fusion Interfaces for Tactical Environments (FITE) laboratory, a facility within the Crew Systems Directorate of the Armstrong Laboratory, has this capability and is currently supporting the exploratory development of multi-sensory virtual-interface technologies for tactical cockpits by a multi-disciplinary

team composed of operational pilots, human factors engineers, electronics engineers, computer scientists, and experimental psychologists.

4.1 Development Process within the FITE

The products of the FITE laboratory are the multi-sensory virtual-interface concepts themselves, the evaluations of the interface concepts, and the identification of basic research topics to be pursued in more controlled experimental settings. The FITE laboratory operates in three main cycles. These cycles, and the resultant products, are depicted in Figure 1. The three cycles are the rapid prototyping loop, enabling the rapid creation and initial evaluation of concepts, the basic research loop, outputing basic research topics to other facilities and inputting results back into the interface design process, and the evaluation loop, which is the traditional simulation evaluation loop.

4.2 FITE Hardware Architecture

The central component of the FITE laboratory is a F-16 cockpit shell which is the focus of the multi- sensory virtual-interface concept development and evaluation. The other components of interest in the FITE are its computational structure, its virtual and non-virtual visual displays, its virtual auditory display, and its haptic display. A block diagram of the hardware architecture is show in Figure 2.

4.2.1 Computational Structure

The computational structure consists of a distributed collection of 80486-33 MHz computers configured with 4 Mbytes of memory and a single high-density floppy drive. This computer configuration provides real - time performance inexpensively. The computers interface in real-time through an off-the-shelf 128 Byte shared-memory unit manufactured by Bit-3. The computer communications through the shared-memory is transparent to the software executing within the computers enabling software protocols to be eliminated. Software development is performed on two 80486-33 MHz machines configured with hard-drives and off-the- shelf compilers and linkers. Software development and run-time execution is performed under the DOS operating system. High-C and Absoft FORTRAN are the software languages used and are linked with the Phar- Lap DOS extender enabling utilization of extended memory.

All of the visual displays are generated using Irisvision boards, which are an off-the-shelf two-board graphics card set fabricated by Silicon Graphics and Pelucid. The Irisvision boards are physically located inside the 80486-33 MHz systems. The graphics systems provide several video formats ranging from standard television formats (NTSC or PAL) to 1280 by 1024 pixels, non-interlaced, at 60 Hz. The FITE facility has standardized on a 1024 by 768 pixel format,

interlaced, at 30 Hz . Independent of video format, the Irisvision graphics systems provide double-buffering, anti-aliasing, 24-bit z-buffering, Gouraud shading. 90,000 triangles/second, and over 14,000 shaded triangles/second. This capability supports symbology-only, imagery- only, and symbology-over-imagery graphical depictions. Data acquisition, digital-to-analog, and analog-to- digital conversion is performed by off-the-shelf data acquisition cards, manufactured by Computer Boards Inc, which are incorporated into the 80486-33 MHz computers.

The tactical environment, including aerodynamic modeling, weapons modeling, avionics modeling, as well as digital and manned threat modeling, are computed on distributed 80486-33 MHz systems. The processors within the FITE cycle in real-time at integer multiples of the visual imagery update rate of 30 Hz due to synchronization considerations. While most of the processors operate at 30 Hz, , the manned threat stations, the out-the-window scene generation, and the complex aerodynamic models operate at 15 Hz.

4.2.2 FITE Visual Displays

The FITE laboratory incorporates several non-virtual and virtual visual displays. The front panel of the F-16 cockpit shell is filled with 6 off-the-shelf color LCDs forming a composite large area head-down display. The head-down display is virtually-augmented with a see-through HMD, the Tactical All-Aspect Helmet Mounted Display (TAAHMD). The TAAHMD provides an instantaneous monocular 20° field-of-view wherever the pilot aims his head. The TAAHMD is used not only for displaying information, but also for aiming weapons and pointing avionics. A head-tracker is incorporated into the TAAHMD and allows displays to be stabilized to the outside world, to other aircraft, or to the cockpit, allowing augmentation of head-down displays. Out-the-window visuals are portrayed using 6 off-the-shelf monochrome-white projectors focused onto flat screens forming a cube around the F-16 cockpit shell. The cube is approximately 3.7m on each edge and the out-the-window projections cover an area slightly greater then the frontal hemisphere relative to the pilot. A single monochrome-green projector is used to portray HUD imagery. Each of the LCDs, the projectors, and the HMD is driven by a graphics card-set incorporated into a computer system for a total of 14 systems utilized for visual display.

Three Kaiser Sim-Eye HMDs, which are binocular, monochrome, and incorporate a 60° by 40° field of view, are integrated into flight stations which support other participants during real-time simulation. These helmet mounted displays are used to portray the out-the-window scene as well as a totally virtual visual cockpit for the other participants.

4.2.3 FITE Audio Displays

Audio signals from tone generators, intercoms, and speech synthesizers are driven through an auditory localizer which provides spatially-linked auditory displays. Tone generation and speech synthesis are performed by Sound Blaster Pro cards, manufactured by Creative Labs Inc. The auditory localizer, a Convolvotron, is also off-the-shelf and is manufactured by Crystal River Engineering. The auditory localizer can input four audio signals and localize in azimuth, elevation, and range. Because the azimuth, elevation, and range provided to the localizer is computed within the flight simulation, various localization algorithms can be employed, ranging from radar warning receiver tones emanating from the aircraft producing the radar energy, to using localization to enhance non-position derived information, such as tail aspect angle of an attacking aircraft. The intercom allows voice communications between individuals within the flight environment with individual stations being localized in real-time.

4.2.4 FITE Haptic Displays

A McFadden hydraulic control-loader provides real-time-modifiable stick and rudder feel to the cockpit as well as providing flight control inputs from the pilot to the simulation. In real-time, several characteristics of the stick and rudder pedals can be manipulated, such as position, force reflection, friction, damping, dead-band, velocity limits. Break points for non-linear position-based characteristics can also be manipulated. This capability provides the ability to modify stick feel as a function of any combination of variables within the flight simulation. The resultant algorithms could modify stick feel as a function of aircraft energy state or even tactical situation.
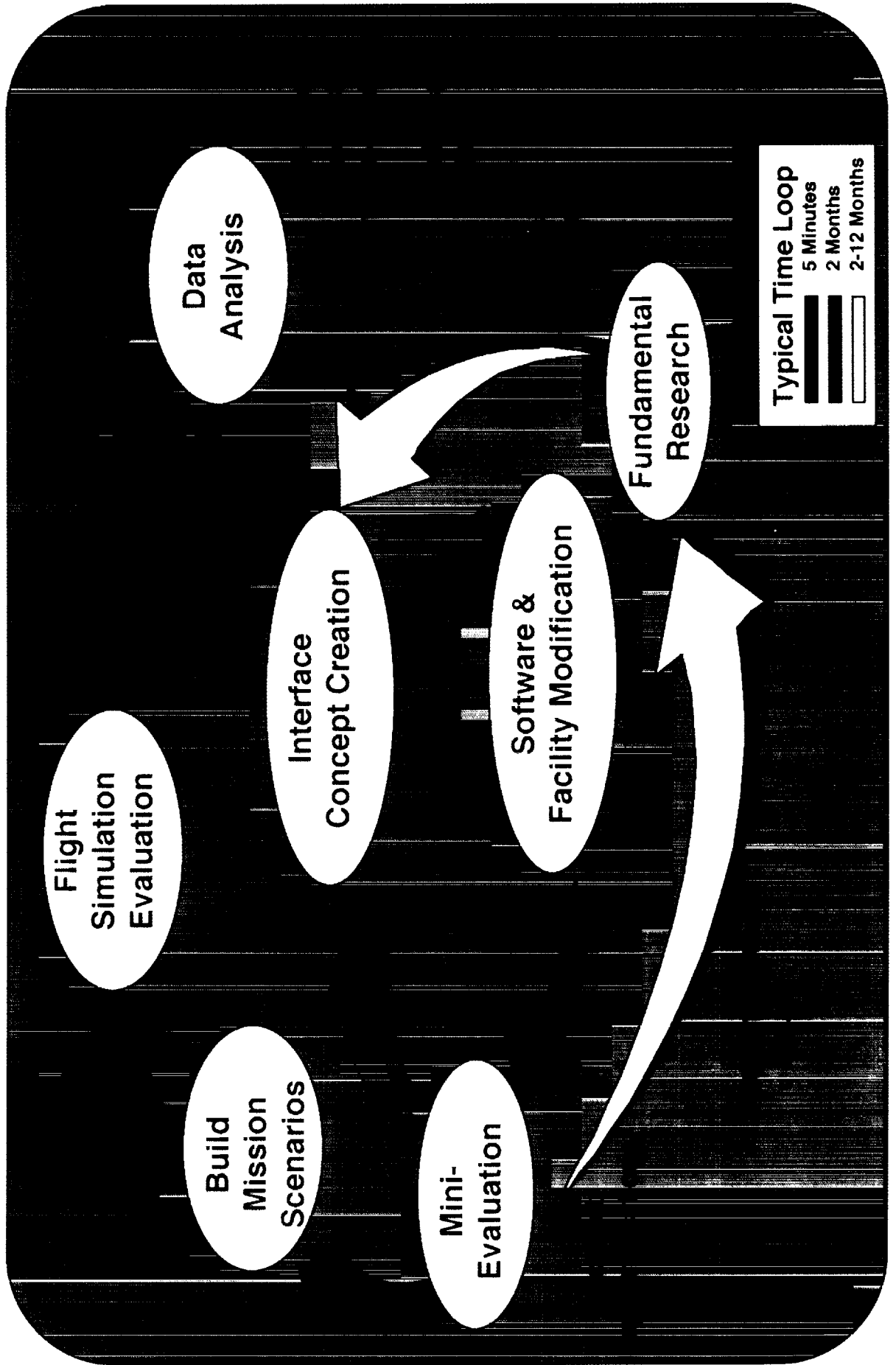
5 Summary

The human is a complex and adaptive receiver whose perceptual performance within a virtual environment is tied to the quality of the visual, auditory, and haptic stimulus generated within the multi-sensory virtual-interface. Many questions remain unanswered regarding virtual techniques, which, when answered, may increase the potential usefulness of virtual interfaces. In-context rapid prototyping is required to support creation and evaluation of multi-sensory virtual-interface concepts. Facilities can be developed utilizing off-the- shelf technology which provide high-fidelity flight simulation capability for in-context development of multi- sensory virtual-interfaces concepts for tactical aircraft. The Armstrong Laboratory has developed the FITE laboratory as part of an exploratory development program investigating multi-sensory virtual interfaces for tactical aircraft and is currently utilizing the facility to develop the initial multi-sensory virtually-augmented cockpit for air-to-air combat.

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Multi-Sensory Development Process
A Near-Term Vision

Data Analysis

Fundamental Research

Interface Concept Creation

Software & Facility Modification

Flight Simulation Evaluation

Build Mission Scenarios
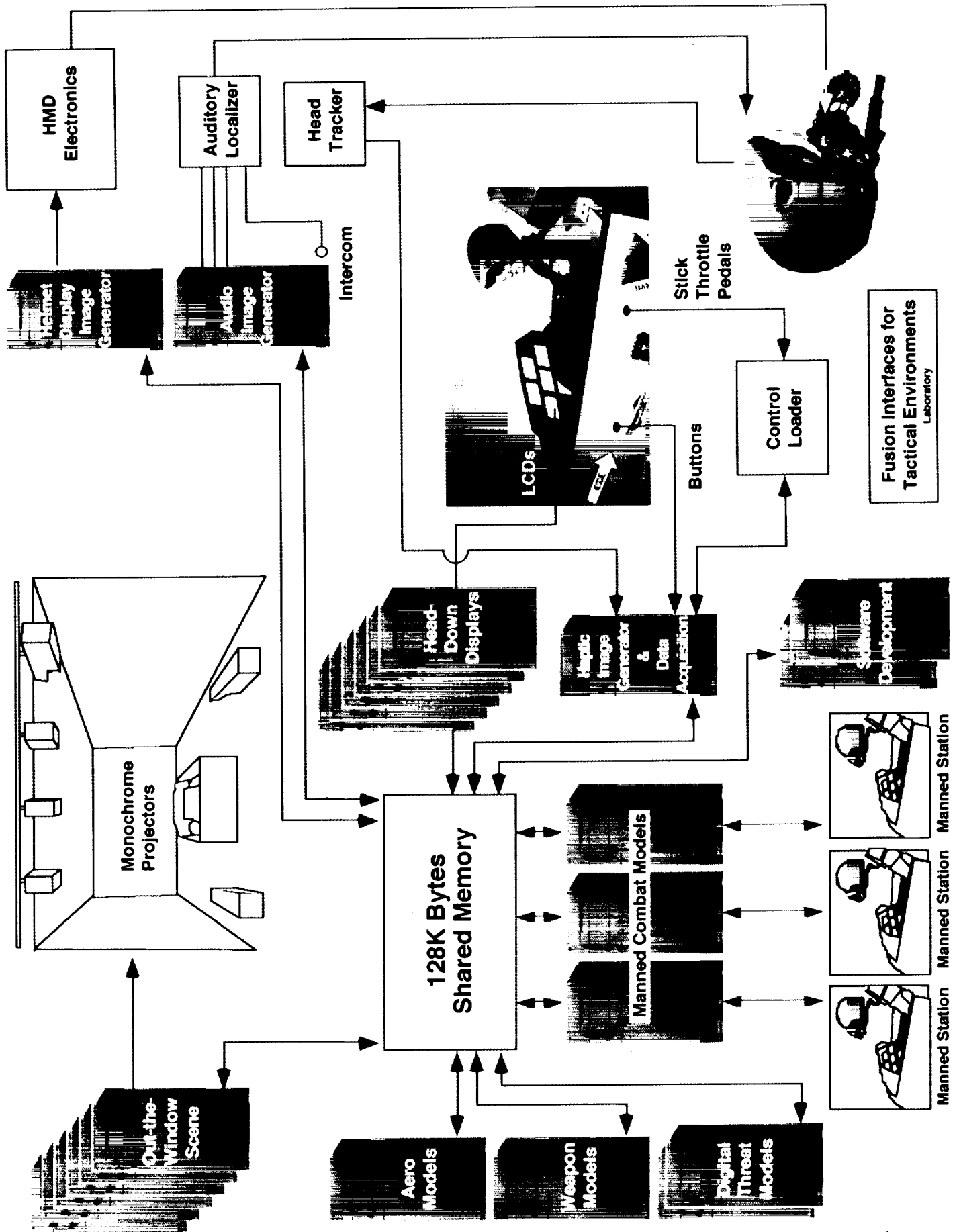
Mini-Evaluation

Typical Time Loop
5 Minutes
2 Months
2-12 Months

Figure 2 - FITE Laboratory Architecture