REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
26-07-2004

2. REPORT TYPE
Abstract

3. DATES COVERED *(From - To)*
Jul 2004 - Aug 2004

4. TITLE AND SUBTITLE
Modeling and Simulation Technologies: Reconfigurable Flight Simulators in Modeling Evaluation Technical Report

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Williams, Guy W.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Flight Test Center
412 TW/DRP (ACQ)
Building 1020
Edwards, California 93524

8. PERFORMING ORGANIZATION REPORT NUMBER
PR-04163

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Flight Test Center
Edwards AFB CA

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION / AVAILABILITY STATEMENT
A Approved for public release; distribution is unlimited.

20041008 231

13. SUPPLEMENTARY NOTES
CC: 012100 CA: Air Force Flight Test Center Edwards AFB

14. ABSTRACT
The Test and Evaluation Modeling and Simulation (TEMS) facility at the Air Force Flight Test Center (AFFTC) Edwards Air Force Base, California, provides developmental test and evaluation flight test programs with virtual, piloted real-time simulators. The TEMS facility has a requirement to support multiple aircraft programs with high fidelity cockpits and out-the-window visual systems within limited facility space and tight budget constraints. The AFFTC's Modeling, Simulation and Integration (MSI) program has developed low cost, reconfigurable, high-fidelity cockpits which provide the TEMS facility with an advanced, multi-configuration, man-in-the-loop (MITL) flight simulation capability representative of real-world conditions. The reconfigurable design allows TEMS to support multiple customers (i.e. aircraft programs) with the highest fidelity simulators without dedicating cockpits or facilities to any particular aircraft type. By maximizing the reuse of common components for the MSI program, SYMVIONICS has developed a reconfigurable simulator that is flexible, maintainable, mobile, and affordable. This paper describes the reconfigurable flight simulator designed for the AFFTC TEMS facility. Topics discussed include the TEMS requirements, limitations on space and funding and their impact on design decisions. The overall design of the reconfigurable cockpit is described along with how reuse and commonality help keep costs down, and how the reconfigurable cockpit allows the AFFTC to make more productive use of the TEMS facility. Lessons learned are also presented.

15. SUBJECT TERMS
Test and Evaluation Modeling and Simulation(TEMS) Modeling, Simulation and Integration(MSI)
Air Force Flight Test Center (AFFTC) man-in-the-loop (MITL)

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Unclassified Unlimited	13	Guy Williams
					19b. TELEPHONE NUMBER *(include area code)* 661-527-7009

Modeling and Simulation Technologies:

Reconfigurable Flight Simulators in Modeling and Simulation

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The Test and Evaluation Modeling and Simulation (TEMS) facility at the Air Force Flight Test Center (AFFTC) Edwards Air Force Base, California, provides developmental test and evaluation flight test programs with virtual, piloted real-time simulators. The TEMS facility has a requirement to support multiple aircraft programs with high fidelity cockpits and out-the-window visual systems within limited facility space and tight budget constraints. The AFFTC's Modeling, Simulation and Integration (MSI) program has developed low cost, reconfigurable, high-fidelity cockpits which provide the TEMS facility with an advanced, multi-configuration, man-in-the-loop (MITL) flight simulation capability representative of real-world conditions. The reconfigurable design allows TEMS to support multiple customers (i.e. aircraft programs) with the highest fidelity simulators without dedicating cockpits or facilities to any particular aircraft type. By maximizing the reuse of common components for the MSI program, SYMVIONICS has developed a reconfigurable simulator that is flexible, maintainable, mobile, and affordable. This paper describes the reconfigurable flight simulator designed for the AFFTC TEMS facility. Topics discussed include the TEMS requirements, limitations on space and funding and their impact on design decisions. The overall design of the reconfigurable cockpit is described along with how reuse and commonality help keep costs down, and how the reconfigurable cockpit allows the AFFTC to make more productive use of the TEMS facility. Lessons learned are also presented.

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I. Introduction

As the recognized leader in test and evaluation (T&E), the Air Force Flight Test Center (AFFTC) has played a major role in the development of every major aircraft in the Air Force (AF) inventory. It is a natural extension of the AFFTC's testing expertise to provide manned weapon system simulators in support of all phases of the acquisition process. The AFFTC has a rich history of using modeling and simulation to support T&E activities. The Test and Evaluation Modeling and Simulation (TEMS) facilty, in existence since the 1970s, provides real-time man-in-the-loop and non-real-time constructive simulations to support T&E. The Modeling, Simulation and Integration (MSI) program was formed in an effort to modernize the aging TEMS capabilities. SYMVIONICS was selected as the contractor tasked to develop a new, reconfigurable flight simulation system to take the AFFTC M&S capabilities into the 21st century. The MSI systems developed by SYMVIONICS represent a unique technological approach to M&S. The reconfigurable design saves money in development costs as well as operations and maintenance (O&M) costs. The reconfigurable design allows TEMS to support multiple customers (i.e. aircraft programs) with the highest fidelity simulators without dedicating cockpits or facilities to any one particular aircraft type. By maximizing the reuse of common components for the MSI program, SYMVIONICS has developed a reconfigurable simulator that is flexible, maintainable, mobile, and affordable.

II. TEMS Environment: The Problem of Space and Money

The traditional approach used to support the M&S needs of flight test programs has been to design and build a flight simulation capability for a specific aircraft. This includes a cockpit simulator with associated power supplies, an input/output (I/O) system, out-the-window (OTW) display system, computer resources, and a facility all dedicated for that particular aircraft flight test program. The dedicated simulator approach has the following characteristics:

a. Provides high-fidelity representation of specific test aircraft
b. Requires a facility dedicated to each specific program
c. 100% of the cost of the simulation capability must be covered by one flight test program, even if they do not use the simulator 100% of the time
d. Simulator and facility costs increase linearly with the addition of capability to support multiple flight test programs (total simulation cost = cost per simulator x number of programs supported)
e. The number of different flight test programs that can be supported are limited by available facility space and funding

Each of these characteristics is expanded upon in the following sections.

A. High Fidelity Simulators

It is important to the flight test program that the simulation cockpit represent the actual test aircraft with the highest possible fidelity. When the pilot sits in the simulator cockpit, the pilot-vehicle interface should have the exact look and feel of the real aircraft. This realism allows the pilot to concentrate on the details of his mission rather than the differences between the simulator cockpit and the real cockpit. Having a simulator that is dedicated to one specific aircraft type allows the simulation engineer to design and build an exact replication of the test aircraft, including sight lines and look down angles, cockpit instruments, displays, stick, throttle, rudder pedals, and seat.

B. Facility Availability

M&S requirements vary from program to program, and even within a program. Some programs will require use of a simulator for a few hours a day, 3 to 5 days a week. Other programs will require simulator use 8 hours a day, 5 days a week for 10 to 12 weeks and then not need it again for a few months. The requirement common to all programs, however, is when the simulator is needed it is needed now so it had better be available. Having a dedicated facility provides the optimum availability, but may not be the best use of facility resources.

C. Simulator Costs

Flight simulators with full 360-degree OTW visual systems such as an M2Dart or WASP, and the related computer systems and engineer work space, require at least a 2,100 square foot facility. Added requirements such as engineering data rooms and mission monitoring/debrief rooms can easily add another 1,200 to 1,500 square feet or more. Construction costs for Top Secret simulation facilities typically run around \$400 to \$500 per square foot, so start up costs for such a facility can cost anywhere from $840K to $1.8M. And that is just the cost of building the empty facility! Hardware and software costs add another $5M to $7M. The estimated total cost to bring up a dedicated simulation facility to full operational capability is around $6M to $9M. A conservative estimate of operation costs (including labor, utilities, maintenance, security, etc.) for such a facility would be approximately $500K annually. If the simulation facility is dedicated to a specific flight test program, either that program must pay for 100% of the cost of the facility (whether they are using it or not), or the flight test center must subsidize the facility costs out of overhead. This is a costly business model. A more cost effective way of doing business is necessary in an era of shrinking budgets.

D. Costs Per Cockpit/Flight Test Program

The costs mentioned above are for one dedicated simulator for a given program. If a program needs more than one simulator, the costs can dramatically increase. There may be some items that would not necessarily have to be duplicated (for instance engineering data room equipment), but for the most part costs are linear in the traditional dedicated simulator model. Likewise, if other flight test programs need M&S support, the costs for the new programs remain the same as the costs for the first program. There are no cost savings in non-recurring engineering and no savings in shared resources or facilities because the system is dedicated to a specific aircraft.

E. Number of Flight Test Programs Supported

Adequate facility space for the required number of cockpits, displays, and related computer systems for each program must be available to support multiple flight test programs. Facility costs and program related security requirements are a major factor in the O&M costs associated with M&S capabilities. A more efficient use of facility resources is needed to support M&S in the future.

III. Reconfigurable Cockpit Requirements

To provide the best possible M&S capability for flight test programs of the future, a system must be developed to address the issues raised in Section II. Namely, the new system must be cost effective, allowing for shared use of resources to achieve high facility utilization rates across all programs. At the same time, the new system must provide multiple, high-fidelity cockpits without having dedicated cockpits for each flight test program. To meet these requirements, the MSI program developed a reconfigurable flight simulator that provides high-fidelity simulations that are affordable to acquire and maintain.

A. Reconfigurability - Supporting Multiple Aircraft Types without having Multiple Cockpits

The solution to the dedicated simulator problem is to make a simulator that is reconfigurable. That is, design a simulator whose configuration can be changed from one aircraft configuration to another aircraft configuration easily and quickly. There is nothing new about the concept of a reconfigurable simulator. The M&S community has made attempts in the past to make reconfigurable simulators. Most attempts resulted in a software configurable cockpit with computer displays as the main instrument panel (virtual instruments). This approach allows the simulation engineers to change simulation aircraft types simply by loading different aircraft display software. This approach results in a highly configurable cockpit, but one that is of low to medium fidelity. The main instrument display may look similar to the real aircraft, but it does not have the exact look, and certainly not the same feel as the real aircraft. This lower than real fidelity may be adequate for some M&S requirements, but it does not meet the high-fidelity requirements of most training and mission level M&S requirements. Figure 1 shows the typical trade off between reconfigurability and fidelity. The higher the reconfigurability, the lower the fidelity.

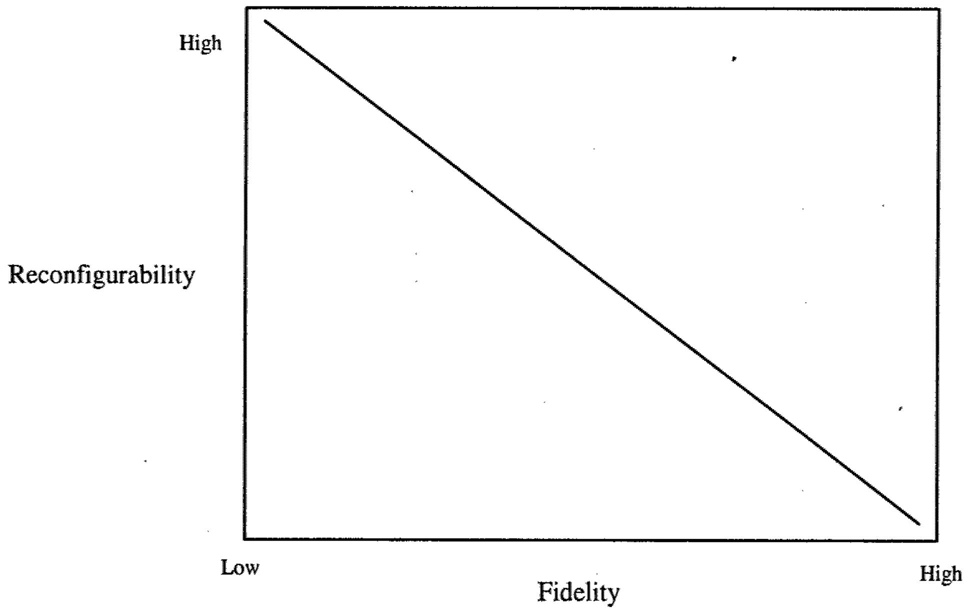


Figure 1. Reconfigurability vs. Fidelity

One of the requirements of the MSI program was to develop a reconfigurable flight simulator that was not only highly reconfigurable, but also maintained a high-fidelity pilot-vehicle interface. Conservation of the "tactile" feel of an actual aircraft cockpit was to be achieved.

B. High Fidelity without High Cost

Another challenge to the MSI program was to provide a high-fidelity simulation capability without the high cost of a dedicated simulator and facility. The facility, and 360-degree visual system, should be designed to support multiple customers. The biggest challenge would be creating a high-fidelity cockpit that could be used by multiple programs. The cost of high-fidelity simulator grade instruments, hands on throttle and stick (HOTAS) controls, and seat and pedals is the same whether they are in a dedicated cockpit or a reconfigurable cockpit. Therefore, cost savings can only be achieved by maximizing commonality while retaining high fidelity in a reconfigurable cockpit design.

IV. Reconfigurable Cockpit Design

The MSI design addresses all of the concerns and requirements expressed above. The heart of the MSI simulation system is the SYMVIONICS DeltaSym™ reconfigurable cockpit. Utilizing the DeltaSym™ cockpit, the MSI team developed a simulation system that is reconfigurable, high fidelity, and cost effective to build, use and maintain. This is accomplished by maximizing reuse of components that are common to all aircraft types and making the aircraft specific components the highest fidelity possible.

A. Maximizing Reuse of Common Components

The DeltaSym™ design maximizes the reuse of components that are common to all military single seat aircraft types. The MSI design team analyzed all of the components of flight simulators. These components were placed in one of two categories: those unique to a particular aircraft type and those common to all aircraft types. The design team then set out to design a reconfigurable cockpit that placed all of the components common to all aircraft types in the cockpit infrastructure. This infrastructure never changes and is therefore only purchased once, regardless of the number of aircraft types being supported. The aircraft unique components are installed in removable sections of the cockpit, such as the crew compartment. Features of the major DeltaSym™ components are discussed below.

1. Base Frame Assembly

The common infrastructure is called the base frame assembly. The base frame assembly consists of the following components:

a) Base Frame Structure
b) Aircraft Seat
c) Rudder Pedals & Control Loaders
d) Data I/O System
e) Data Acquisition System

Each of these components is described in more detail below.

a. Base Frame Structure

The cockpit modules and components are mounted on top of a welded steel base frame with electronic component bays underneath. Electronics Industrial Association (EIA) standard rails are mounted in all accessible spaces underneath the base frame to accommodate 19-inch electronic racks and components. Casters and leveling legs are mounted in each of the base frame corners to provide mobility and ease of leveling. The rear of the frame is designed to accept air ventilation from an external facility cooling system. An internal ground buss system is also included in the base frame assembly. Figure 2 shows the base frame structure.

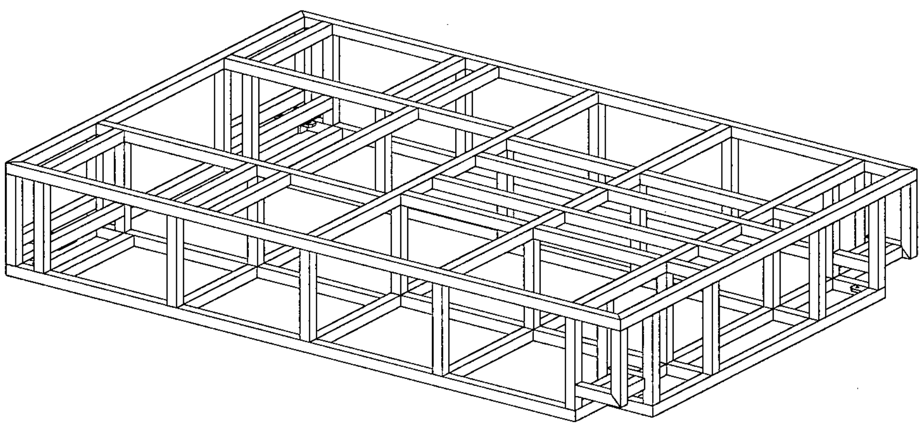


Figure 2. Base Frame Structure

b. Aircraft Seat

The aircraft seat is fully adjustable in the vertical and horizontal axis. It can also be tilted back as much as 25 degrees from vertical. This adjustability will accommodate all known US and foreign tactical fighter/attack aircraft. Figure 3 shows the aircraft seat mounted on the base frame structure, while Table 1 depicts the seat adjustment ranges.

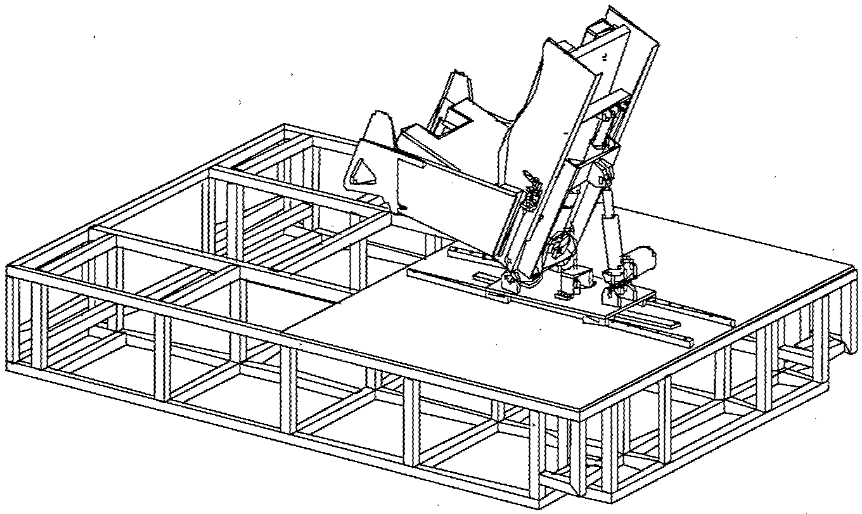


Figure 3. Aircraft Seat Mounted On Base Frame

Table 1. Seat Adjustability

Adjustment	Total Adjustment	Adjustment from Neutral
Seat Forward/Backward	25 inches	12.5 inches
Seat Up/Down	8 inches	4 inches
Seat Incline	25 degrees	15 degrees

c. Rudder Pedals

The rudder pedal subassembly is contained in a welded steel frame which attaches to linear rails on top of the base frame. The subassembly includes a control load module contained in the steel frame. The load module is programmable by a dedicated rack mounted PC located beneath the base frame and provides realistic force feedback to the pilot. The location of the pedals along the rails is adjustable, as is the height. In addition, the pedal control travel is also adjustable. The control loading system is a high-fidelity digital electric system. The control loading computer is a PC utilizing a Pentium™ processor running at 500 MHz with an inner loop iteration rate in excess of 3 KHz and with 16-bit analog resolution. The software model utilizes a coupled mass system that simulates feel springs, aerodynamic loads, trim, autopilot, boost actuators, cable stretch, and stops as required for the aircraft simulated. Figure 4 shows the rudder pedal subassembly, while Table 2 depicts the rudder pedal adjustability.

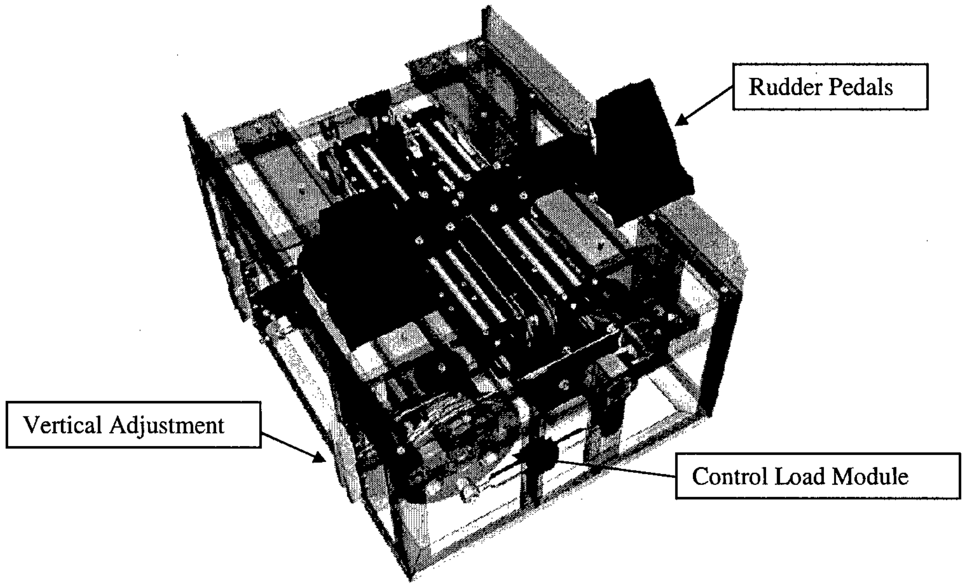


Figure 4. Rudder Pedal Assembly

Table 2. Rudder Pedal Adjustability

Adjustment	Total Adjustment	Adjustment from Neutral
Seat Forward/Backward	25 inches	12.5 inches
Seat Up/Down	8 inches	4 inches
Seat Incline	25 degrees	15 degrees from Neutral
Rudder Pedal Forward/Backward	14 inches	7 inches from Neutral
Rudder Pedal Travel Adjustment	6 inches	3 inches from Neutral

d. Data Input/Output System

The DeltaSym™ data input/output system is referred to as the Virtual I/O (VI/O) system. The VI/O provides the link between the cockpit and the simulation software. All input to, and output from, cockpit instrumentation and controls is processed by the VI/O system. The VI/O is comprised of two subsystems: the data acquisition subsystem and the VI/O software. The data acquisition subsystem consists of a set of chassis containing National Instruments data acquisition (DAQ) boards, which are capable of processing both digital and analog information from the cockpit. The VI/O software runs on a PC, which interfaces with the data acquisition subsystem to process all cockpit input and output. The VI/O software creates an aircraft parameter file for use by the simulation host software based upon the cockpit I/O.

e. Data Acquisition Subsystem

The data acquisition subsystem is comprised of a set of chassis containing DAQ boards. The chassis are linked together and connected to the VI/O PC by Ethernet. Figure 5 shows the data acquisition chassis.

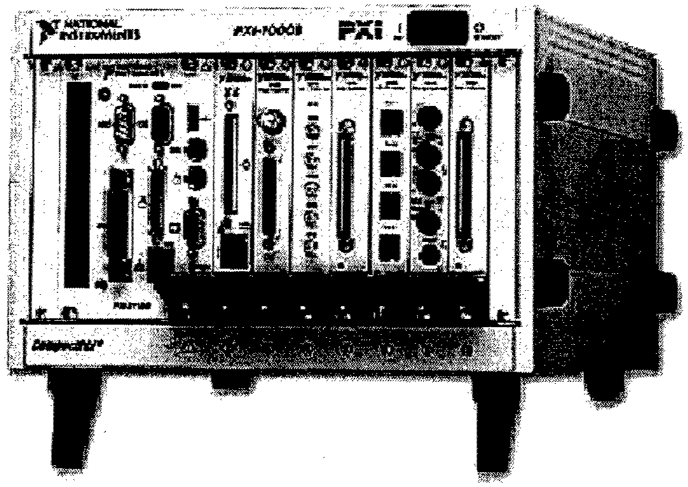


Figure 5. Data Acquisition Chassis

Four chassis, each containing eight boards, comprise the data acquisition subsystem. Each of the four chassis contain six DAQ boards and two linking boards to interconnect the chassis. The 24 DAQ boards provide 576 digital channels (which can be either input or output), 64 analog input channels and 80 analog output channels. This channel count assures that the I/O system can handle the data count for virtually any of the single seat fighters in the US inventory. For example, an aircraft with a heavy I/O requirement (current worst case) needs 407 digital input, 121 digital output, 45 analog input and 65 analog output. Table 3 indicates the DeltaSym™ standard I/O configuration as compared to the current worst case aircraft requirement.

Table 3. DeltaSym™ I/O Channels vs. Heavy I/O Requirement

	Digital In	**Digital Out**	**Analog In**	**Analog Out**
DeltaSym™	576		64	80
Heavy I/O Requirements	407	121	45	65

The chassis are installed in EIA bays in the cockpit base frame and connect directly with cockpit devices mounted in the side and front consoles.

2. *Virtual I/O Software*

The VI/O software is a key component of reconfigurability. It is the traffic cop that handles all data passed between the simulation host and the cockpit hardware. The VI/O software runs on a PC, in a Windows XP environment, and is linked to the data acquisition subsystem via Ethernet. The VI/O software acquires cockpit status information from the data acquisition subsystem and sends that data on to the simulation host software via Ethernet. The VI/O software obtains flight status information from the simulation host software and provides the digital and analog information for the cockpit instruments and displays via the data acquisition subsystem.

The VI/O software also has the capability to display, on the PC monitor, strip charts and summary data for any of the aircraft parameters and cockpit status information. This display provides system operators or observers with insight into cockpit and simulator status while the system is running. The VI/O is a great development tool as well. Software developers can test their simulation software without having the cockpit connected, in that the VI/O simulates the cockpit hardware. Figure 6 shows an example of the monitor display.

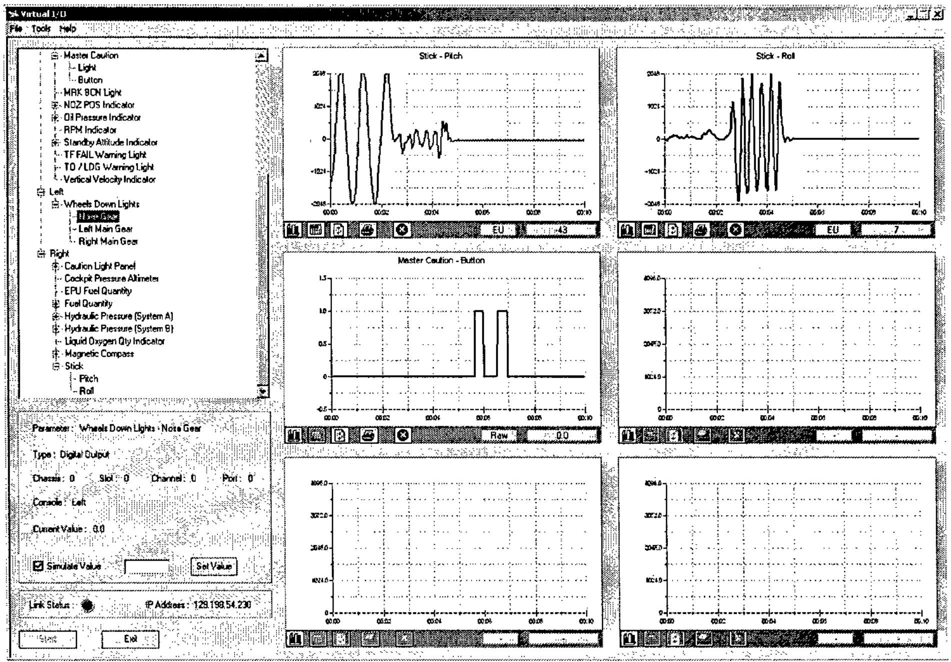


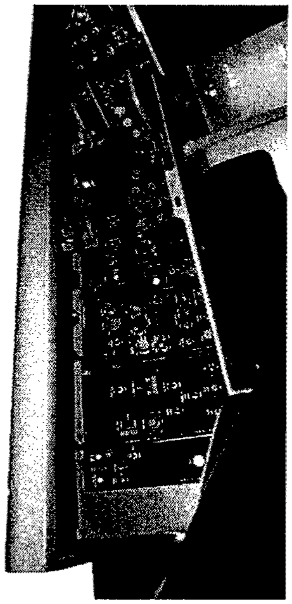
Figure 6. Sample VI/O Display

B. High-Fidelity Aircraft Specific Components

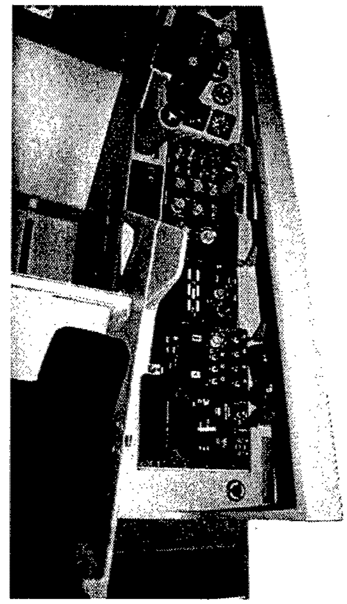
The components that are specific to a particular aircraft type are contained in the aircraft console sets. The consoles represent the crew compartment of the cockpit. A console set for a given aircraft is comprised of left and right side consoles and a center console, sometimes referred to as the main instrument or front console. The consoles are designed to have the exact shape of the real aircraft, inside and out. They contain high-fidelity, simulator grade instruments that have the exact look and feel of the real aircraft instruments. When a pilot sits in the simulator cockpit, it looks exactly like the real aircraft relative to instrument location, look and feel, sight lines, and look down angles.

1. Side Instrument Consoles

Left and right side consoles are designed to house the cockpit components (switches, knobs, instruments, controls, and displays). Components are mounted within ¼ inch of the position in the actual aircraft cockpit. Some components are mounted in dzus rails, while others are mounted directly to the consoles, just as they are in the real aircraft. The consoles are designed to support simulator grade or actual flight components. Input/output connections and distribution boxes, including electrical power, are contained in each console, with main data and power lines run to the equipment bays in the base frame. Each side panel attaches to the cockpit base frame using locating pins and latches. The locating pins assure exact placement of the consoles for every configuration. Figure 7 shows an example of the left and right side consoles for a high-fidelity cockpit.



Left Console



Right Console

Figure 7. High-Fidelity Side Consoles

2. *Center Console*

The center console is populated with the instruments and controls consistent with the simulated aircraft. As with the side consoles, data and power distribution is self contained with main cables running to the equipment bays in the base frame. Figure 8 shows an F-16 high-fidelity simulator center console.

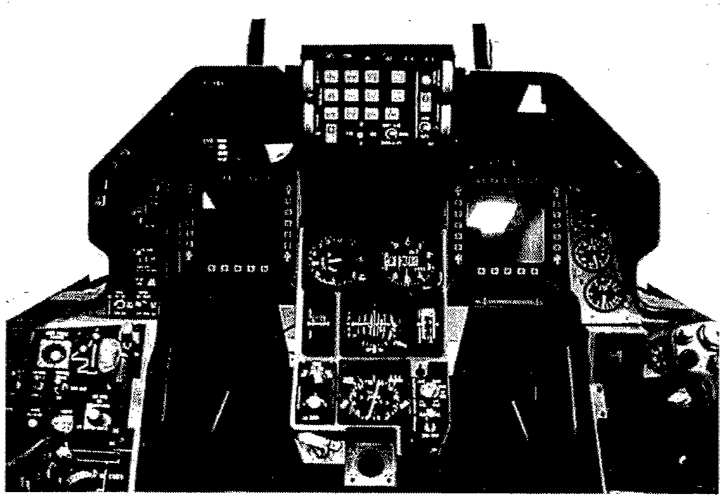


Figure 8. F-16 Simulator Center Console

V. Facility Design

A major factor in the cost of a simulation facility is having a dedicated facility for each aircraft type. The MSI approach is a facility designed to support multiple aircraft flight test programs by using the DeltaSym™ reconfigurable cockpit. Figure 9 shows the MSI simulation facility layout.

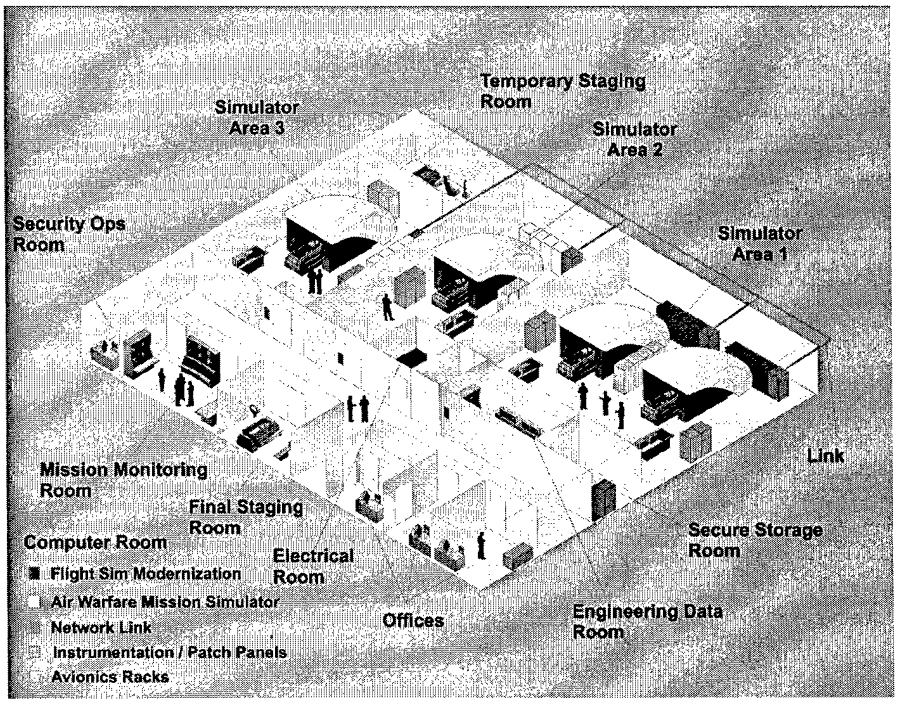


Figure 9. MSI Facility Notional Layout

The simulation facility is designed to support four simulators. The facility is divided into three areas. The first area contains two simulators, and the other two areas contain one simulator each. Each simulator has a mini-dome visual system, image generator computer system, simulation host computer system, DeltaSym™ reconfigurable cockpit, VI/O system, sound/comm system, and network infrastructure. The mini dome provides a 360-degree horizontal field of view and approximately 220-degree vertical field of view. A rail system is mounted on the floor inside the dome. This rail system allows the DeltaSym™ cockpit to be rolled into the dome and locked in the precise location every time, ensuring proper alignment of the eyepoint and protecting against damage to the front screen. To provide the highest possible fidelity, a mini dome front screen is provided for each cockpit type. The front screen is cut out to match the shape of the specific aircraft front console. This allows the visual system to provide the correct lookdown angle for each aircraft type. Each simulator area is self contained and capable of supporting programs up to the Top Secret/Special Access Required classification level.

VI. How the MSI Approach Allows the AFFTC to Make More Productive use of the TEMS Facility

The approach taken by the MSI program has the following advantages over the traditional approach to M&S:

- Supports multiple programs
- Supports multiple projects within a program
- Reduces O&M costs
- Increases return on investment
- Requires less operating and storage space
- Allows quick turn-around for design of new aircraft configurations
- Greater flexibility in supporting various levels of M&S

A. Supports Multiple Programs

With the MSI approach, the number of different aircraft programs that can be supported in the facility is limited only by the number of different console sets available. The facility design allows support for up to three different classified aircraft programs simultaneously. Four programs can be supported if two of them are unclassified. The unclassified programs would share Area 1.

B. Supports Multiple Projects within a Program

Some flight test programs have multiple M&S projects, which are run at different classification levels. Personnel on one project may not be briefed into other projects, so they must be kept separate. In this case, each project is treated like it is a different program. Three projects of different classification can be supported in the MSI facility.

C. Reduces O&M Costs

Because the facility is not dedicated to one flight test program, the O&M costs can be shared across multiple programs. Fewer facilities and less equipment to maintain results in lower O&M costs. One staff member can operate and maintain the entire facility, cutting down on labor costs.

D. Increases Return On Investment

If a new aircraft program needs to use the facility, the only cost involved is the cost of a console set, a front screen, and the simulation software. The rest of the infrastructure is already in place and paid for. There are no facility construction costs and no capital investments for visual systems or computer systems. This allows more program funds to be used for actual simulation time rather than infrastructure development, resulting in a higher return on investment.

E. Requires Less Operating and Storage Space

Dedicated facilities require simulation lab space for every flight test program supported. If ten programs are supported, each needing 2,000 square feet, then the operating space required to support them is 20,000 square feet. With the MSI reconfigurable shared facility approach, the operating space is fixed regardless of the number of programs supported. A similar approach to a shared facility is one in which dedicated cockpits are rolled in and out of shared facilities. However, this approach requires storage space for full cockpits, not to mention the added cost of common components. With the MSI approach, storage space is only needed for console sets not in use, saving approximately 1/3 to 1/2 the storage space needed for full cockpits.

F. Allows Quick Turn-Around for Design of New Aircraft Configurations

With the traditional approach of dedicated facilities, when a new aircraft programs comes along needing M&S capabilities there is a long lead time required to build and prepare a new facility to meet the requirements. This lead time can be 3 to 5 years in some cases. With the MSI approach, new programs can be supported as quickly as new console sets can be developed and simulation software can be integrated. Console development typically takes 6 to 12 months, depending on availability of simulator grade instruments.

G. Greater Flexibility in Supporting Various Levels of M&S

The MSI DeltaSym™ approach allows great flexibility in supporting a wide variety of M&S requirements. High-fidelity aircraft-specific console sets meet the requirements for such things as mission level testing and emergency procedures training. The medium-fidelity "glass cockpit" console set meets the requirements of projects that do not need the more expensive, high-fidelity consoles, such as some performance and flying qualities tests.

VII. Lessons Learned

In the process of building the MSI simulation facility and the DeltaSym™ cockpit, there were a few key lessons learned, which are described below.

A. Rudder Pedal Design

The rudder pedal design has evolved over time. The MSI program did not start with a highly reconfigurable, self contained assembly with an internal digital control loader as is presently used. The first approach was to simulate control pedal resistance with springs. To change the pedal resistance for various aircraft types, different springs were installed. This approach did not work out very well. Getting springs to accurately match the breakout forces and tension of the real aircraft was difficult. Springs also have a way of changing characteristics over time. Making fine adjustments was also not possible with springs. The digital control loader system now used allows full programmability of breakout forces, travel, and resistance. Fine tuning the system is accomplished very easily by changing parameters on a computer screen.

B. Base Frame Design

One of the challenges in the base frame design was to keep the eye point low enough, yet still provide enough rack space in the base frame for all of the required I/O and power distribution equipment. Another complication was having casters that allowed for easily moving the cockpit from room to room without adding too much to the height. The final design was determined to provide the maximum amount of rack space within the given constraints. The base frame is 96 inches long by 66 inches wide by 15.38 inches high. This provides us with eight 19-inch equipment racks, which provide approximately 8U (DEFINE U) of rack height.

C. Future Improvements

While the current design is excellent and working out great, there is one improvement that would make reconfiguring the cockpits even easier. Currently, there are five to seven cables that run between each console and the base frame. Plugging some of these cables in can be a challenge in the confined space of the consoles. In the future, it is planned to add quick connect mechanisms, so that all data and power cables are automatically connected when the console is placed on the base frame.

VIII. Summary

The MSI systems developed by SYMVIONICS represent a unique technological approach to M&S. The DeltaSym™ reconfigurable design saves money in development costs as well as O&M costs. The approach taken by the MSI program has the following advantages over the traditional dedicated simulator approach to M&S:

- Supports multiple programs
- Supports multiple projects within a program
- Reduces O&M costs
- Increases return on investment
- Requires less operating and storage space
- Allows quick turn-around for design of new aircraft configurations
- Greater flexibility in supporting various levels of M&S

The DeltaSym™ reconfigurable design allows the AFFTC to support multiple customers (i.e. aircraft programs) with the highest fidelity simulators without dedicating cockpits or facilities to any one particular aircraft type. By maximizing the reuse of common components for the MSI program, SYMVIONICS has developed a high-fidelity reconfigurable simulator that is flexible, maintainable, mobile, and affordable.