AD-A268 484

INSTITUTE FOR SIMULATION AND TRAINING

Contract Number N61339-89-C-0045
~~Data Item A004/A005~~
PMTRADE
DARPA
September 1, 1990

DTIC
ELECTE
AUG 23 1993
S E D

Data Analysis & Networking Design

iST

Institute for Simulation and Training
12424 Research Parkway, Suite 300
Orlando FL 32826

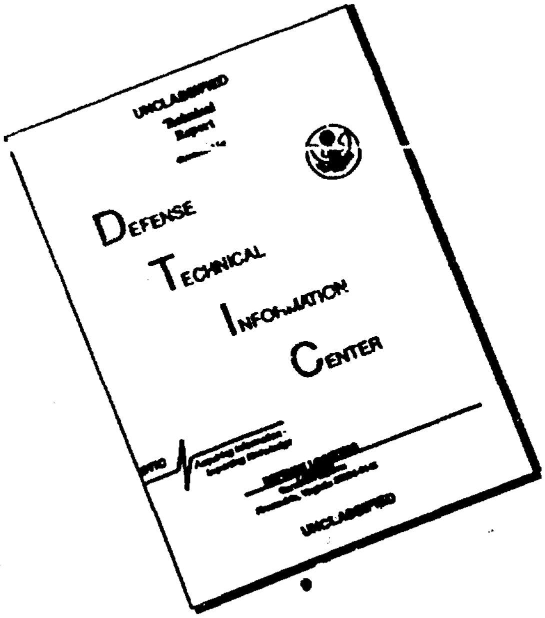
University of Central Florida
Division of Sponsored Research

93-19469

IST-TR-90-11

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

DTIC QUALITY INSPECTED 3

Accesion For
NTIS CRA&I
DTIC TAB
Unannounced
Justification
By
Distribution /
Availability Codes
Dist | Avail and / or Special
A-1

LOW COST AVIATION TECHNOLOGY TESTBED

Mr. Brian Goldiez
Mr. Jorge Cadiz

Statement A per Telecon
Raymond Green STRICOM/AMSTI-EC
Orlando, FL 32826-3276

NWW - 23 Aug 93

ABSTRACT

IST is developing a low cost Aviation Test Bed to investigate fidelity issues in low cost aviation and networking. This paper addresses the issue of determining a simulator's position or utility in the domain of networked simulation. In order to determine the simulator's utility in this domain, assessment and interfacing methods must be developed. IST is developing a new simulator performance assessment system and a general purpose design to network dissimilar simulators.

A three step approach of design, fabrication, and testing is being used to develop a simulator performance assessment system. The design phase includes requirements definitions, and design approaches. The fabrication phase includes integration of off-the-shelf equipment. The testing phase includes both system tests which validate the component design, and operational tests which gather and reduce simulator performance data. IST's approach to assessing simulator performance is novel in two ways: the approach uses parameter identification methods to establish a relationship between the aircraft, the simulation, and the piloted simulator; and it uses video tape to capture flight-relevant cues for parameter identification.

To network dissimilar simulators, IST has developed a prototype protocol translation system based on SIMNET technology. We have had limited success using the Generic Protocol Translator (GPT) to interface dissimilar simulators.

BACKGROUND

The Institute for Simulation and Training (IST) at the University of Central Florida is presently under contract to DARPA and the Army's Project Manager for Training Devices (PM TRADE) to develop a low cost Aviation Test Bed to investigate fidelity issues in low cost aviation and networking. The networking research involves developing methods to connect dissimilar simulators, developing bridging techniques to connect dissimilar networks, and developing network assessment tools. IST is also performing research into qualitative (i.e., man in the loop) and

quantitative (unmanned) performance characteristics of so-called "Selective Fidelity" flight simulators.
This research showed several interesting facts about Selective Fidelity flight training devices. First, flight testing of such devices to determine performance and handling qualities was not available in any consistent format. Secondly, procurement agencies did not appear to know what handling and performance qualities to specify in such devices. Thirdly, each device employed simulations of different aircraft systems to teach the same basic tasks. Finally, ancillary devices were often made available to augment the simulation.

INTRODUCTION

Traditionally, low cost approaches to flight simulation have entailed either comprehensive simulation of a limited number of aircraft functions, or a limited simulation of a large number of aircraft functions. As microprocessor technology has advanced, low cost approaches to simulation have been able to provide higher fidelity representations of the simulated environment. However, two phenomena have been observed. First, fidelity increases have not been made in a consistent manner. This has resulted in simulation devices which are a mix of high cost and low cost components which employ the notion of "Selective Fidelity." Selective fidelity provides different levels of realism in the various subsystems of a simulation. Selective fidelity is analogous to part task simulations. Unfortunately, this emphasis on low cost has resulted in high priority requirements being compromised for cost conservation. Consequently, cost effective simulations are being developed which do not meet user expectations and needs.

The second phenomena that has occurred is that the formal estimation of a particular selective fidelity device's utility occurs after the hardware and software have been developed. Traditionally, estimation of the simulation's utility occurs prior to development. Validation of its utility then occurs during development and operational tests of the simulator. Validation tests and evaluation must occur frequently to optimize the utility of the simulator design.

It is necessary that capabilities of simulators and training devices be quantified and validated as early as possible in order to maximize their utility. This process currently occurs in engineering simulations of many physical systems. Manned simulator validation, however, is different than physical model validation and is a reason why validation is not done early. In manned simulator validation, one may obtain perfect correlation between selected vehicle characteristics and the simulation model over restricted operating ranges. Correlation is achieved by matching performance curves between the physical model and the simulation. However, simplifications in the mathematical models, linearizing non-linear data, and quantization effects of digital computing cause inconsistencies to occur. These inconsistencies limit simulation fidelity to known levels. These limitations in fidelity can limit the validity of the simulation when a human operator is a part of the simulator. Since all of the cues in the actual aircraft cannot be represented in the simulator, some simulator cues must be exaggerated to get the simulator to "feel like the aircraft". The process of adjusting simulator cues to pilot perceptions is performed on a trial and error basis and often times invalidates the physical model.

OBJECTIVES

In order to solve the problem of validating simulator fidelity, IST is classifying the particular domains of networked simulations. Three activities are necessary to meet this objective. First, the domain of networking requirements for flight simulation must be defined. Second, the extent of a specific networked simulation's position in the domain must be determined (i.e., validation of utility). Third, specific technologies and evaluation methods to fill voids in utility must be developed. This paper addresses the second objective, the development of a method to assess validation of simulator utility.

With regard to fidelity, this paper distinguishes between simulator performance and simulator utility. Simulator performance is the degree to which a simulator matches the characteristics of the design basis vehicle, and simulator utility is the degree to which the simulation is able to meet its intended use. The distinction is critical to real time, pilot in the loop, flight simulators because it allows one to separately analyze the technical and behavioral domains of the simulation. In order to determine the position or utility of a simulator in the domain of networked simulation, assessment and interfacing methods must be developed. IST is developing a simulator performance assessment system and a general purpose design to network dissimilar simulators.

SIMULATOR PERFORMANCE ASSESSMENT SYSTEM

A three step approach of design, fabrication, and testing is being used to develop a simulator performance assessment system. The design phase includes requirements definition in addition to the development and specification of design approaches. The fabrication phase includes integration of off-the-shelf equipment. The testing phase includes both system tests which validate the component design, and operational tests which gather and reduce simulator performance data. IST expects this three step process to be iterative as our approach matures.

Design

IST is developing a design to capture flight simulator performance and handling quality characteristics using parameter identification techniques. These characteristics can be compared to the design basis aircraft to determine simulator performance. Flight testing of aircraft for performance and handling qualities involves the detection of control inputs and capture of output information which contains physical variables. Data capture systems normally use gyroscopes and accelerometers to collect analog information. Flight test data is typically subject to considerable post processing to obtain useful data for several reasons. One is that data is usually collected in noisy environments, and noise corrupts data (noise can be due to vibration, turbulence, and RF interference). Another reason is that control conditions are also difficult to duplicate consistently. In order to assess simulator fidelity , IST developed a method to collect flight relevant parameters. Data reduction is performed as a post processing activity using parameter identification methods. Long range efforts will look at filling cue voids through hardware development (e.g., low cost control loading systems) and through math model enhancement (e.g. control law changes).

Selective fidelity simulators currently under development rely heavily on visual feedback to determine flight conditions and attitudes. Tactile and audio feedback are secondary cuing systems in such devices. Figure 1 shows this cuing relationship between the aircraft and the flight simulator. It is necessary to capture data which can be analyzed to determine the fidelity of the simulator when compared to the aircraft from a pilot in the loop perspective. Because of the temporal nature of the data, it is necessary to have a measure of time directly coupled with the data.

Cue replacement and modification is critical to the concept of "Selective Fidelity." However, cue replacement/modification concepts have not been applied consistently in flight simulation. As an analogy to help understand the cue replacement process, studies have been conducted in the past with respect to handicapped individuals and the augmentation of cues through hardware and software (Nickerson, 1978; Elliott, 1978). A simple example of cue replacement could be the use of hearing aids for the hearing impaired, or audible devices for proximity detection by the blind. The hearing aid augments or enhances a missing human sense. In a similar manner, our study investigates

DATA ANALYSIS/ACQUISITION SYSTEM THEORETICAL BASIS

- **Aircraft Cues Are:**
  - Visual
  - Tactile
  - Audio
  - Vestibular
- **Aircraft Flight Tests Use:**
  - Video Cameras (limited)
  - Force Gauges
  - Audio Recording
  - Accelerometers/Gyros
- **Selective Fidelity Simulator Cues Are:**
  - Visual
  - Tactile (limited)
  - Audio (limited)
- **Selective Fidelity Tests Use:**
  - Video Cameras
  - Force Gauges (limited)
  - Audio Recording
  - Analog/Digital Data

Figure 1

situations where a fully capable individual accustomed to experiencing a full range of flight cues is exposed to a simulator with degraded or missing cues. The problem is identifying those cues which are necessary for the operator to perform a specific function within the context of a larger goal.

In order to determine specific cue replacement parameters, it is necessary to determine the degree of fidelity (performance) offered by the specific simulation and the context within which the simulation is delivered (utility). The degree of fidelity must be compared to some quantified baseline to allow for comparisons of simulation approaches. IST's approach uses actual aircraft data as a base of comparison. In our approach, simulator flight testing is first conducted to compare simulator to aircraft performance. Next, a human is inserted in the simulation loop to study the effect of how the human perceives the performance of the simulator compared to the actual aircraft. Studies are conducted on isolated tasks (e.g., rolls at 1-G) as well as embedded tasks (e.g. rolls as a part of a tactical maneuver). Cooper-Harper ratings are used to relate simulation performance to simulation utility. Cooper-Harper variation with task complexity is also studied. This building block approach is firmly rooted in the performance of the actual vehicle, making analysis a straightforward matter. The simulator can also be a control device to suppress selective cues.

The current method used for determining simulator performance is to compare the simulator's aerodynamic and performance curves to a given design basis aircraft over a limited operating range. However, the relationship of simulator performance to simulator utility is not clear. This lack of clarity results in unpredictable utility when simulator performance is changed. A new approach, description following, is novel from two points of view. First, the approach uses parameter identification methods to establish a relationship between the aircraft, the simulation, and the piloted simulator. Secondly, the approach uses video tape to capture flight-relevant cues for parameter identification.

Parameter identification is currently used to glean parameters from aircraft flight tests that can be used for a simulation. IST is studying the feasibility of using similar parameter identification methods to glean simulator parameters which could then be compared to the actual aircraft. This would allow simulation validation without detailed knowledge of the specific implementing software and hardware. The parameter identification method will include unmanned and manned flight. This approach accounts for the pilot in the loop and quantifies the effect of specific cues that contribute to the acceptability of a simulation. Parameter identification methods will not only be a valid method to compare simulator performance to the actual aircraft, but will also be valid in IST/UCF's cue replacement analysis.

Since the most significant cues in selective fidelity flight simulators are visual in nature, IST believes that video tape is a valid method of capturing pertinent simulator performance and utility data. Tactile and audio cues also represent a potentially significant source of cues to pilots, so these cues will also be captured and correlated with visual information.

A suite of test equipment is being developed to capture flight simulator performance and handling qualities data. Ideally, such equipment should gather data without intruding into the simulator or affecting its operation. In addition, sampling rates should be such that critical data is not lost and time skewing is minimized. Figure 2 shows a diagram of IST/UCF's hardware design for flight simulator data collection. This system is similar in configuration to one used at the Naval Air Test Center (NATC) for human factors evaluations during flight test.

When a data sampling system is designed, one must determine if the system being sampled is discrete or continuous. In the case of data acquisition, feedback into the simulator is not important. This fact simplifies any mathematical analysis if the data acquisition is unobtrusive (i.e., does not influence the operation of the simulator). In the case of a simulator, the point where the sample is taken is critical to the determination

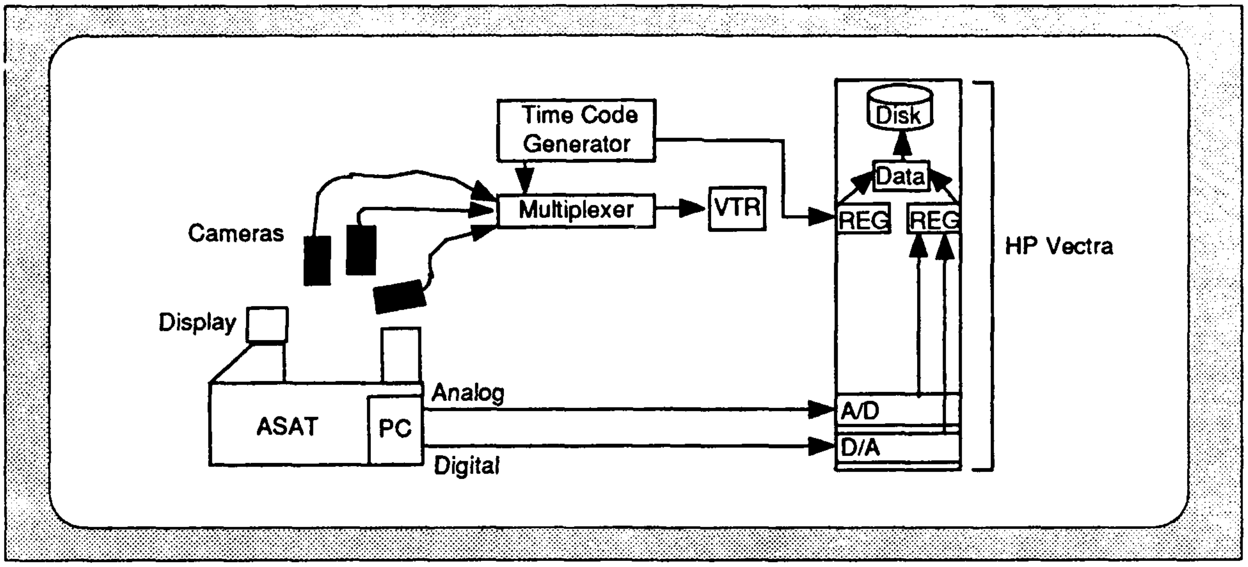


Figure 2

of continuous or discrete sampled systems. We have concluded that capturing information in an analog format is most appropriate because, for the most part, the data can be obtained from standard output devices.

Video tape is the initial format for most of the data to be captured. This approach avoids intrusion into the simulator and the problems associated with discrete sampling influences back to the baseline system. Problems associated with proprietary hardware and software are also avoided, along with the attendant test suite reconfiguration necessary for implementations which may be in hardware on one simulator and in software on another device.

Sampling rates are critical in flight test methods. IST/UCF has analyzed the requirements of simulators to ascertain the suitability of using video as a medium to record simulator flight tests. Nyquist's sampling theory dictates that the sampling frequency should be at a rate at least twice the natural frequency of system under study (Haykin, 1978). Typical values of the natural frequency for jet aircraft is 3Hz. (Roskam, 1972.)

The pacing factor in the IST/UCF system is both the video camera configuration and the use of a single video tape or master clock to synchronize multiple tapes. The video tape is limited to 60 Hz field rates for compatibility with commercially available NTSC television standards. Therefore, sampling rates cannot exceed 60 Hz in the IST/UCF design. The number of cameras becomes the divisor in determining the sampling rate for data collection.

The simple equation below shows this relationship.

$$\text{Sampling freq (ws)} = \frac{\text{video tape players x video tape rate (60 Hz)}}{\text{number of cameras}}$$

IST/UCF is using analog to digital converters and digital to digital converters to capture control information not amenable to video. In the F-16 simulator this information consists of control stick inputs (as the control stick is stationary and is responsive to pilot force inputs). In addition, several discrete controls on the HOTAS (Hands On Throttle And Stick) are necessary for both human factors and flight performance tests.

Collecting information from flight instruments is being conducted in a manner similar to that which humans use to receive the information. As stated earlier, the primary source of stimulus for the trainee in selective fidelity devices is visual. We believe that visual stimulus is being used to replace many vestibular cues common in most aircraft. For example, the cues experienced by the pilot during a simple roll are vestibular, tactile and visual. Most selective fidelity devices do not contain control loading systems which provide necessary tactile feedback or motion systems which provide vestibular cues. Therefore, the visual system of the human has the task of providing the stimulus to give the sensation of conducting, for example, a coordinated turn. This information is currently being collected and will be analyzed for both the fixed wing and rotary wing situation. IST/UCF believes that a low cost control loading system for tactile feedback coupled with a quality sound system for audio and limited vestibular cues will be necessary to increase the utility of many selective fidelity simulators.

Using the flight simulator as the test vehicle for parameter identification purposes is new. The use of parameter identification methods from the simulator results in two useful products. First, the manifestation of specific simulator performance parameters can be visualized as a system output. This fact is useful to study and validate design parameters such as update rate, integration routines, natural frequency and phase lag of the simulator. Second, parameter identification can be useful to study potential changes in simulator control laws, which we believe can have a large effect on simulator utility. Relationships between simulator control laws (based on differing degrees of acceptability using such methods as Cooper- Harper ratings), theoretical aircraft control laws, and actual aircraft control laws can then be studied to determine any mathematical linkage. Trends in different flight regimes can also be studied using the above methodology.

Parameter identification normally attempts matching time histories between the aircraft and simulator. The baseline data (normally aircraft flight test data) must normally be processed through some type of Kalman filter to remove random noise. Aliasing errors must also be removed. The case under study is easier because we are using processed flight test data. Simulation dynamic tests can also be controlled to eliminate or introduce noise and can be performed in a repeated manner. However, as with all parameter identification studies, the specific parameter matching should be decided upon prior to the study. IST/UCF believes that matching frequency response characteristics between the simulator and the aircraft is critical to pilot acceptance. In addition, performance characteristics, such as rate of climb, stall speeds, etc. are important to pilot acceptance. Frequency response characteristics must consider the closed loop aircraft response at the flight controls and visual system.

Three methods of parameter identification are currently used; the Equation Error method, the Output Error method, and the Maximum Likelihood method (Duval, 1989). The Equation Error method is the easiest of the three to implement, but requires a measurement of all vehicle states and controls and gives biased parameter estimates in the presence of system noise. The Output Error method generates system states by integration of the equations of motion. In the Output Error methods, successive iterations are necessary to tune the time histories. The Maximum Likelihood method is the most general with respect to data needs, but requires extensive processing through some type of Kalman Filter. We believe that the Equation Error method can be used to extract parameters from the simulation because of the noise free simulation environment, the ability to control the initial vehicle state, and the ability to measure all controls and vehicle states.

Fabrication

The system under development at IST will consist of a three camera apparatus with the potential for an array of up to four camera inputs, each of which will be on line with its own video recorder. This is preferable over several multiplexing techniques which require only one VCR and a video multiplexer. While requiring somewhat less hardware, it was concluded that the synchronization of video multiplexing hardware would not be sufficient for our experimentation, since ultimate success lies in the frame-by-frame evaluation of the data.

The camera equipment consists of SONY DXC-325 Color Video cameras and SONY VO-9800 U-matic Videocassette recorders or their equivalents. The apparatus will be driven by means of an ADX synchro system which will drive the video recorders and synchronize on a frame-by-frame basis.

The accuracy of this video setup was found to be more acceptable than multiplexing. This synchro unit will also provide a digital clock which will emit a clock pulse at the same rate as each frame is recorded. From this, analog and digital signals from various simulator controls can be sampled by means of PC data acquisition hardware, specifically the MetraByte DAS-20 data acquisition board, and time stamped to correlate to the data retrieved from each frame of video. This process, which is to some degree intrusive, will be done on IST hardware for IST purposes, but will not necessarily be a requirement for remote applications.

Normal configuration on selective fidelity devices observed by IST will not exceed 3 cameras. One camera will be used for the Head Up Display (HUD), one camera for instruments, and one camera for stick and throttle. The system designed by IST/UCF can accommodate additional channels of video information by using a set of mirrors to divide data being received by a camera. Dividing video information on one camera is accompanied by a loss in resolution proportional to the camera aperture consumed by each image.

Capture of analog information is controllable at nominal frequencies of up to 4000 Hz for all analog signals. This is far in excess of the individual aircraft's natural frequency. Up to 16 single ended values may be sampled with conversion to digital consuming 12 micro seconds.

The problems associated with video capture revolve around parameter identification methods. Aircraft parameter identification methods are subject to noise from many sources. As such, when data is pulled from instruments, indicators, or HUDs, performance parameters may become corrupted in ways different from the actual aircraft. The primary corrupting factor is due to the simulation of the specific instrument. State variables are used as inputs to an instrument model. The specific instrument model then simulates the characteristics of the instrument. On the other hand, aircraft effects such as aeroelastic bending and vibration can corrupt data. Therefore, the relationship between the simulation and aircraft from an engineering point of view is not apparent. Parameter identification techniques are being developed at IST/UCF in order to study these relationships.

Testing

IST/UCF has performed two types of testing on its simulation validation system: one set of tests on the concept and one set of tests on the parameter identification methods. Concept tests used the concept of progressively building on a validated baseline. The baseline in the case of IST/UCF's work has been the F-16A aircraft.

IST/UCF has obtained flight test data from the F-16A courtesy of the US Air Force F-16 System Program Office. IST/UCF has two F-16 simulators known as the Avionics Situational Awareness Trainers (ASAT) which were manufactured by Perceptronics. These networkable devices were designed to train Beyond Visual Range (BVR) target acquisition and engagement. These devices generate packets of data on a local area network which allow the two devices to train two sets of F-16 aircrews. IST/UCF is developing software which can change the data packets to allow the output of any variable set which does not exceed the byte length allocated to unmodified ASAT. Using this software allows IST/UCF to output state variables or other pertinent data (e.g., stability derivatives) which are used as inputs to the HUD. In this manner, IST is able to verify ASAT performance on a basis similar to the actual F-16. Effects of instrument simulations, if any, can be isolated by comparing instrument indications to state variables. Spatial and temporal comparisons are made between the instrument indication and the simulation state variable. In addition, initial vehicle physical parameters, such as weight and inertias can be varied to a limited extent to match those of the test aircraft.

IST/UCF has also performed limited flight tests to begin the parameter identification process. Initial tests have been limited to roll performance tests. These tests are extremely useful because of the single axis nature of the maneuver. Performance tests include time to achieve a 30 degree, 90 degree, 180 degree, and 360 degree roll attitude at a stable mach number, altitude, and 1-g flight condition. Initial tests were performed using students as pilots. IST/UCF is in the process of obtaining a software program known as the Controls and Simulation Test Loop Environment (CASTLE) from the Naval Air Test Center. CASTLE can be used to provide repeatable system trim and forcing functions using an off line trim program.

Initial concept testing has been completed by IST/UCF. Several maneuvers were executed repeatedly for consistency purposes. There were several purposes for these concept tests. The first was to investigate any video synchronization problems between the HUD and the video camera. The second was to investigate physical restrictions in data gathering with respect to camera set-up, lighting, and special fixtures necessary. The third was to ascertain qualitatively if sufficient resolution and contrast were available to acquire meaningful data from a video camera. Video synchronization differences are apparent in the tests run at IST/UCF. A band is often visible in the video due to differences in the synchronization in the vertical retrace of the camera and source imagery. This effect is quite common and can be alleviated by using an external synchronization signal to control the image source and image collection devices. Close examination, though, reveals an apparent loss of contrast and not resolution. Therefore, if a high contrast ratio image source is used, video tape is acceptable to capture pertinent imagery from a synchronization, but not aesthetic, point of view.

Physical restrictions to gathering data were investigated. Physical restrictions included lighting, support fixtures, and camera configuration. Lighting has proved to be the physical item with the greatest degree of sensitivity. First, some aircraft instruments are sources of light (i.e., self illuminating), while other instruments require an external lighting source. In the case of IST/UCF's initial experiments, the HUD was a source of lighting, while a Liquid Crystal Diode (LCD) stop watch required external lighting to be visible to the camera. External lighting causes glare on a CRT face depending on the orientation and type of lighting source. Therefore, a focused light source was aimed at the stop watch to have sufficient lighting to view both images from a single unmodified aperture. Other physical constraints are caused by the physical configuration of the simulator. A standard camera tripod and commercial test fixtures can accommodate most configurations on selective fidelity devices. Figure 3 depicts this test set-up. Manned experiments may require additional video camera lenses to allow simultaneous data acquisition and piloted operation. Camera weight and size should be minimized to minimize visual obstructions due to the camera and support apparatus. Remote video taping is therefore desired and is being implemented by IST/UCF. Test results for simulated roll experiments are depicted in Figure 4.

Figure 3

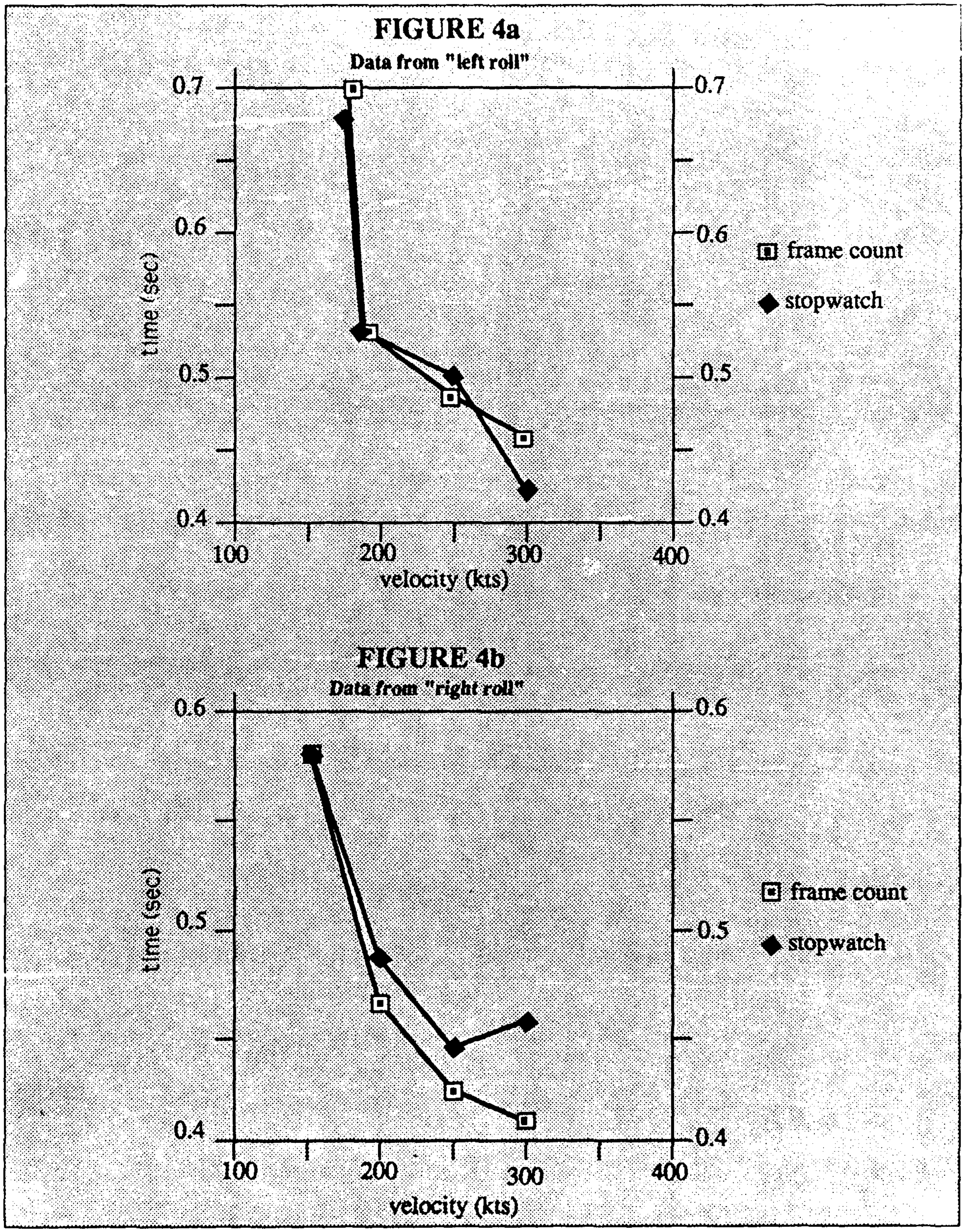


FIGURE 4a
Data from "left roll"
0.7
0.6
0.5
0.4
time (sec)
100
200
300
400
velocity (kts)
frame count
stopwatch
FIGURE 4b
Data from "right roll"
0.6
0.5
0.4
time (sec)
100
200
300
400
velocity (kts)
frame count
stopwatch

Figure 4

Additional testing will be performed in the future using a pilot in the loop, operational simulation validation hardware, and expanded flight tests to facilitate parameter identification studies. Tests will include both fixed and rotary wing aircraft and simulators.

NETWORKING

The simulators which we have been referring to are networked devices. It is necessary to develop techniques which allow a flexible arrangement of simulator assets so that experimentation can be performed. Until recently, the SIMNET units could not be networked with other simulators in our laboratories. IST/UCF has developed a prototype protocol translation system based on SIMNET technology, which is also being extended to other applications outside of SIMNET. This device can be used to allow a non-SIMNET training device to connect and interact with the SIMNET trainers.

Currently, networking techniques are being developed which will allow a variety of devices to interact in real time. A Generic Protocol Translator (GPT) is the key element of interfacing an individual device into a larger system of networked simulators because it allows two dissimilar devices to communicate with one another as if they were operating in the same environment. Without the Generic Protocol Translation device, the packets of one simulator would be ignored by any destination simulator which did not operate under the same protocol as the transmitting simulator. The translation task, which is to be performed by the GPT, is divided into two functions: (1) the user interface and (2) the protocol translator.

The user interface allows for an individual to access the GPT and describe the rules and formats of his simulator's protocol. The Generic Protocol Translator must be given certain control parameters and characteristics of the protocols between which it will be translating. These parameters and characteristics will be stored in the GPT's memory where the user may access this file later and edit as needed. Once the information is compiled for two systems, the GPT will compare the two formats and create algorithms for translating discrepancies which may exist between the protocols of the two systems.

Other information that must be provided to the GPT is any timing considerations that are necessary for proper interfacing of two unlike devices. Timing information is provided by the user to the GPT during the User Interface session. The user must define whether his device operates in a synchronous or an asynchronous mode. If the device is a synchronous simulator, it will receive and transmit packets at a rate which is dependant on the simulator's design. When this simulator is interfaced with an asynchronous device, there is a chance that this device will not be able to provide enough packets to interface properly. In this case, the GPT will perform an extrapolation of the asynchronous simulator's characteristics and supply the synchronous simulator with the necessary packets. In the case of interfacing two synchronous simulators with different data rates, the GPT must supply the simulator with the greater data rate with necessary packet information.

The protocol translation portion of the GPT device will use the algorithms developed during the User Interface session to receive the packet from a source simulator and translate it into a format understandable by a destination simulator. At IST's Networking and Communications Technology Laboratory we have had limited success in using a protocol translator to interface dissimilar simulators . The interconnection of dissimilar simulators into a single environment was performed by IST as a proof-of-principle experiment to demonstrate the ability to network two simulators that operate under different communications protocols.

ASAT TO SIMNET PROTOCOL TRANSLATOR

Two platforms were used for this experiment. The first was the Avionics Situational Awareness Trainer (ASAT) from Perceptronics, Inc. The second platform was a SIMNET M1 tank simulator. To achieve networked communications between the two simulators, a protocol translator was placed as a node on the ETHERNET network (Figure 5 depicts the ASAT/SIMNET Network). The translator listens to the network traffic and copies any packets which are transmitted by the ASAT trainer. Every packet copied by the protocol translator is converted to the proper SIMNET format and transmitted onto the ETHERNET so that the SIMNET units can portray on their visuals a proper model of the ASAT. The conversion is accomplished within 30 ms. A complete description of the protocol translator's hardware and software is available in Cadiz (1990).

The protocol translator was developed on a 20 Mhz 80386 AT compatible PC. To connect it to the ETHERNET network, the translating PC was outfitted with a 3Com Etherlink II Network Adapter. The 3Com board was configured to operate in promiscuous mode so that it would monitor all packets transmitted onto the network. The translator would filter all unwanted packets, taking only the properly addressed packets into its memory for processing.

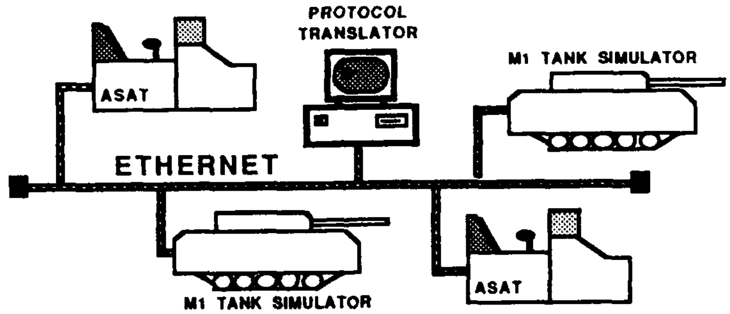


Figure 5

ASAT Protocol

Due to the ASAT's limited application, the ASAT Protocol is much simpler than the SIMNET protocol. Currently there are four different types of packets that the ASATs use to initialize and execute an exercise:

- Packet Type 0: used during initialization of an exercise to perform handshaking, determine the master system, and calculate the number of enemy targets and friendly vehicles

- Packet Type 1: activates the vehicles with their proper parameters (e.g., position, orientation, speed, weapons' capabilities)

- Packet Type 8: transmits a vehicle's location, orientation, status, etc. It also provides this information for any missiles that the vehicle may fire. Packet Type 8 has functions similar to SIMNET's Vehicle Appearance PDU.

- Packet Type 9: the vehicle appearance packet for all computerized targets.

By using these four packets, the ASAT simulation environment can support up to twelve vehicles (including computerized targets) in a single exercise.

SIMNET Protocol

The communications protocol used by the SIMNET network is the SIMNET Protocol Version 6.0 which is described in Pope (1989). The SIMNET protocol has three subprotocols: Data Collection Protocol, Association Protocol, and the Simulation Protocol. The only protocol of interest in the translator experiment was the Simulation Protocol. The Simulation Protocol provides the necessary tools for allowing a simulator to describe any of its actions that may affect other nodes participating in the same exercise. Several of the functions that are furnished by the simulation protocol are:

- Activation and Deactivation
- Vehicle Appearance Updates
- Vehicle Status
- Weapons' Effects and Interactions
- Detection and Reactions to Vehicle Collisions
- Service and Repairs to Vehicles

ASAT/SIMNET Interfacing Problems

In trying to network the ASAT and SIMNET simulators, several complications prevented their complete interfacing. One was that the SIMNET vehicles could not be initialized properly into the ASAT Environment. Proper activation of the SIMNET simulators would allow them to be "legal" players in the ASAT exercise. In the SIMNET environment, it is not critical for this function to be performed. If a vehicle is not activated properly, the other vehicles on the network will proceed to acknowledge the vehicle's existence in the exercise and allow it to interact with other players. However, the ASATs will not allow another vehicle to enter their exercise without proper initialization.

Upon activation, the ASAT trainers undergo a handshaking process. From this process each ASAT creates a list of all participants in the exercise. If a vehicle is not involved in this initialization procedure, it will not be a participant, and the rest of the simulators will ignore any packets received with the source address of that vehicle. The SIMNET's inabilities to perform the handshaking and to be placed on the players list made it impossible for the SIMNETs to be initialized into the ASAT exercise.

Other complications arose because the ASATs were designed to train pilots in air-to-air Beyond Visual Range targeting techniques, as opposed to SIMNET's ground level and low altitude training applications. One problem was that the ASATs do not support vehicles which have zero velocity. Because the SIMNET M1s are ground vehicles, they operate at low velocities and are static in many situations (zero velocity). These scenarios could not be duplicated in the ASAT environment without modifying the ASAT source code. The design requirements of the ASATs did not call for the existence of ground vehicles, therefore no dynamic models for vehicles such as tanks are provided in the ASAT environment. The models that are provided by the ASAT trainers are the F-16, Mig21, Mig29, and a generic missile.

Another problem was the ASAT addressing scheme: its protocol is not of a standard IEEE 802.3 format. The ASATs begin their packet with the source address immediately followed by data. In ETHERNET, the packet begins with the Source Address, Destination Address, and type field, followed by the packet data (see Figure 6).

ETHERNET Header	Destination Address	Source Address	Type	Data
	Bytes 1-6	Bytes 7-12	Bytes 13-14	Bytes 15-xxx
ASAT Header	does not exist	Source Address	does not exist	Data
		Bytes 1-6		Bytes 7-xxx

Figure 6

After considering these problems, we focused the experiment on translating ASAT vehicle appearance updates to SIMNET Vehicle Appearance Protocol Data Units (VA PDUs). By translating the ASAT vehicle appearance updates into SIMNET VA PDUs, we could furnish all entities of the SIMNET simulation exercise with information related to the location, velocity, orientation, and appearance of the ASAT F-16.

SIMNET Vehicle Appearance PDU Template

The ASAT to SIMNET Protocol Translator creates a template of the SIMNET VA PDU for each ASAT packet that is to be translated. The packet structure for the SIMNET VA PDU template is shown in Figure 7a. This template is supplemented by translated ASAT data to create a complete VA PDU for the ASAT. The fields which are supplied by the ASAT packet are:

- Source Address
- Vehicle Location
- Vehicle Speed
- Rotation (derived from ASAT roll, pitch, and yaw angles)

The PDU created by incorporating this information with the SIMNET VA PDU template provides any SIMNET node with sufficient information to depict the ASAT vehicle in the SIMNET simulation.

ASAT Packet Type 8 (appearance packet)

The ASAT Packet Type 8 is used for transmitting the ASAT vehicle's appearance. This protocol translator will use a Packet Type 8 to extract the information necessary to create the VA PDU template. The structure of ASAT Packet Type 8 is shown in Figure 7b. Once this packet is received into the translator, the information from the highlighted fields is extracted and manipulated to correspond with the SIMNET format, and then placed into a SIMNET VA PDU template.

Translator Performance Tests

There are several considerations when translating a simulator's packets through a protocol translator. Two factors which are of importance are the amount of increase in traffic on the network, and the transmission delay due to processing the ASAT packets.

The increase in network traffic must be considered a factor in networks which have a limited bandwidth. The increase in traffic is proportional to the number of simulators which are dissimilar to the standard network. In our experiment, we had one ASAT simulator which was connecting into the SIMNET network. The increase in traffic was given by the simple formula:

Increased traffic [one-way translation] = $N_{pt}(R_a)$

Increase in traffic [two-way translation] = $N_{pt}(R_s + R_a)$

where N_{pt} is the number of protocol translators on the network, and R_a and R_s are the rates of transmission for the ASATs and the SIMNETs, respectively. In our experiment we had a single protocol translator performing a one-way translation. We are assuming that one translator will translate the traffic of a single ASAT simulator. The increase in traffic is equal to adding another ASAT module onto the network. This means that on the average the increase will be:

(1 translator)(113 bytes/pkt)(12 pkts/sec)=10.8 Kbits/sec

This increase in traffic is merely 0.15% of the usable network bandwidth. However, it must be kept in consideration that the ASATs are selective fidelity simulators and do not have as rapid an update rate as most flight simulators. With a network of high fidelity simulators, a protocol translator that does not duplicate received packets may be more appropriate.

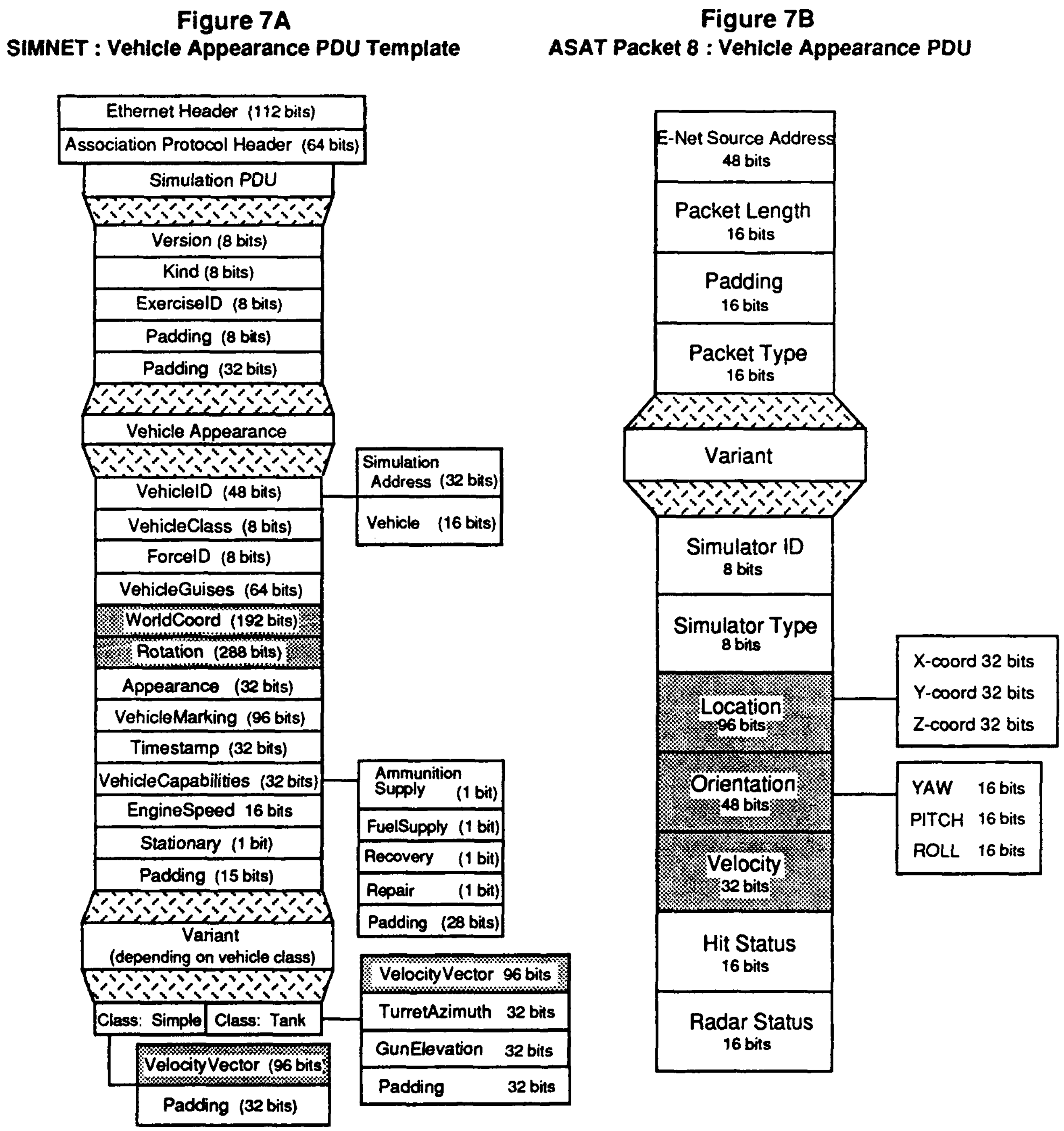


Figure 7A
SIMNET : Vehicle Appearance PDU Template
Ethernet Header (112 bits)
Association Protocol Header (64 bits)
Simulation PDU
Version (8 bits)
Kind (8 bits)
ExerciseID (8 bits)
Padding (8 bits)
Padding (32 bits)
Vehicle Appearance
VehicleID (48 bits)
Simulation Address (32 bits)
Vehicle (16 bits)
VehicleClass (8 bits)
ForceID (8 bits)
VehicleGuises (64 bits)
WorldCoord (192 bits)
Rotation (288 bits)
Appearance (32 bits)
VehicleMarking (96 bits)
Timestamp (32 bits)
VehicleCapabilities (32 bits)
Ammunition Supply (1 bit)
FuelSupply (1 bit)
Recovery (1 bit)
Repair (1 bit)
Padding (28 bits)
EngineSpeed 16 bits
Stationary (1 bit)
Padding (15 bits)
Variant (depending on vehicle class)
Class: Simple
Class: Tank
VelocityVector 96 bits
TurretAzimuth 32 bits
GunElevation 32 bits
Padding 32 bits
VelocityVector (96 bits)
Padding (32 bits)
Figure 7B
ASAT Packet 8 : Vehicle Appearance PDU
E-Net Source Address 48 bits
Packet Length 16 bits
Padding 16 bits
Packet Type 16 bits
Variant
Simulator ID 8 bits
Simulator Type 8 bits
Location 96 bits
X-coord 32 bits
Y-coord 32 bits
Z-coord 32 bits
Orientation 48 bits
YAW 16 bits
PITCH 16 bits
ROLL 16 bits
Velocity 32 bits
Hit Status 16 bits
Radar Status 16 bits

Figure 7

Transmission delays are a critical factor in the implementation of a protocol translator because in a distributed simulation environment, the systems can ill afford an extra delay produced by a protocol translator. With this in mind, we have conducted timing tests on the translator. These tests have produced statistics about the total translation delay introduced by the ASAT/SIMNET translator. The translation of the ASAT packet from the format shown in figure 7b to the format shown in 7a caused an average network delay of 29 ms. This included time of packet processing at the board level.

NETWORKING APPROACHES FOR RECORDING SIMULATOR FLIGHT DATA

Our experiences with simulation device protocol translation has led us to discover several approaches for recording of vehicular data. The concept is to connect a device onto the simulation network to timestamp and store the appropriate packets into some type of memory. Our first approach was to utilize an HP 4972A LAN Analyzer for obtaining data. The LAN Analyzer performed in an acceptable fashion, however, with the current Analyzer's hardware configuration, it is impossible to access the collected information with another computer. This made processing of the data an overly tedious task.

The second approach was to create a timestamping program on a PC that will allow the PC to record and timestamp the packets received during a period of transmission. This allowed us to access and process the packets received. The timestamping program was successful in receiving and recording the packets received through the ETHERNET. The Timestamping Program operates by accessing a 3Com ETHERNET Adaptor to perform its receiving and timestamping tasks. This approach allows the packets to be stored in a format which is easily tailored to the user's needs. Although this technique was successful, it had faults which prevented its use.

The primary problem with the Timestamping Program was an inter-arrival time of greater than 27.5 ms that produced an error which was too great for this application. It was discovered while verifying its accuracy. To verify the program's accuracy, it was run concurrently with the HP 4972A LAN Analyzer. The data collected by the PC was compared with the LAN Analyzer data. This comparison showed that when an interval between timestamps of greater than 27.5 ms occurred, an error of up to 30 ms was introduced. This error was a result of a one bit shifting which occurred in the return value of the hardware counter used in conjunction with the MS-DOS clock to obtain a high resolution timestamp. Thus, the fidelity of the Timestamp Program was limited to an inter-arrival time of 27.5 ms (or lower) between packets.

The third approach is to use an external time source. Timing information would be obtained from a time code generator and attached to the packet as it is stored into memory. This timestamped information can be easily retrieved for analysis. This approach was our eventual solution. The time code generator that will be used in this approach is currently being procured by IST.

CONCLUSION

Preliminary indications and tests show video tape as a suitable means to capture flight simulator data. The data set can then be used as a means to determine changes in flight test data required to yield a pilot- acceptable simulation. It is hoped that a consistent set of change parameters can be discovered and used across flight simulators to increase the utility of the simulator, and to decrease the amount of pilot tailoring necessary for simulator acceptance. These latter topics are the subject of future studies at IST.

It is also fully expected that hardware and software voids that could increase simulator performance and utility will be discovered. Currently IST feels that hardware gaps exist in visuals, networking, and control loading systems. Software voids exist in reusable software which is executable in real time, and math modeling of many avionics systems. Visual systems and networking are currently the only known areas noted above receiving attention and funding in the research community. It is expected that when these and other voids are identified, that research and development efforts will proceed to fill those voids.

ACKNOWLEDGEMENTS

This work is supported by the U.S. Army Program Manager Training Devices (PM TRADE) and the Defense Advanced Research Projects Agency (DARPA) under Aviation Trainer Technology, N61339-89-C-0045. The authors would like to thank student assistants: Brad Giedd, Jeffrey Lim, Boris Nguyen, Mike Ruckstuhl, and Mike Smith, for their help in software development, obtaining and analyzing network data, and preparing this report.

REFERENCES

Cadiz, J., *et. al*. (1990). *ASAT to SIMNET protocol translator hardware and software description.* IST Technical Report Number IST-TR-90-10.

Duval, R.W., et. al. (1989). Flight simulation model validation procedure a systematic approach. *Vertica, 13*, 3, p. 311-326.

Elliott, Lois L. (1978). Development of communication aids for the deaf. *Human Factors, 20*, 3, p. 295-306.

Haykin, S. (1978). *Communication Systems.* New York: Wiley.

Nickerson, Raymond S. (1978). Human factors and the handicapped. *Human Factors, 20*, 3, p. 259-272.

Pope, Arthur, (1989). *The SIMNET network and protocols.* BBN Report Number 7102.

Roskam, Jan (1972). *Flight dynamics of rigid and elastic airplanes*. Lawrence, KS: University of Kansas.