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Training Augmentation Device For The Air Force Satellite Control Network

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BACKGROUND

From the 1960s and into the early 1980s satellite operations and control were conducted by Air Force Systems Command (AFSC), now Air Force Materiel Command (AFMC), out of the Satellite Control Facility at Onizuka AFB, CA. AFSC was responsible for acquiring satellite command and control systems and conducting routine satellite operations. The daily operations, consisting of satellite health and status contacts and station keeping activities, were performed for AFSC by a Mission Control Team (MCT) staffed by civilian contractors who were responsible for providing their own technically "qualified" personnel as satellite operators. An MCT consists of five positions: mission planner, ground controller, planner analyst, orbit analyst, and ranger controller. Most of the training consisted of On-the-Job-Training (OJT) with junior personnel apprenticed to senior personnel until they could demonstrate job proficiency. With most of the satellite operators having 15 to 25 years of experience, there was minimal risk to the mission.

In the mid 1980s Air Force Space Command (AFSPACECOM) assumed operational responsibility for a newly established control node at Falcon AFB (FAFB) in CO. The satellites and ground system program offices (SPOs) are organized under AFSC's Space and Missile Systems Center (SMC) to function as a systems engineering and acquisition agency for AFSPACECOM. The collection of the satellite control nodes, ground tracking stations, computer processing equipment, and connecting communications links is referred to as the Air Force Satellite Control Network (AFSCN).

Unlike AFSC's practice of staffing their MCT with contractors, AFSPACECOM's concept of operations is based on Air Force officers serving as the MCT. Furthermore, AFSPACECOM has started transitioning satellite operations to Noncommissioned Officers (NCOs). For routine satellite operations, a single Air Force officer will serve as space operations crew commander and oversee the activities of several NCO satellite controllers. Because of the frequent turnover of military personnel, retaining trained crews for AFSPACECOM presents some unique challenges. Initial training and satellite controller position certification became critical issues to AFSPACECOM. The training pipeline for AFSPACECOM consists of 12 to 18 months of Formal Undergraduate Space Training (UST), 1-3 months Initial Qualification Training (IQT) on the satellite (e.g. Global Positioning System (GPS), Defense Support Program (DSP)) and its command and control system, and 30 to 45 days of control center specific training. After completion of training, a satellite operator would have only two years to at best two years and ten months left on station. Upon completion of their training the students would be qualified crew members ready to perform their duties in their Satellite Operations Center (formerly known as the Mission Control Complex (MCC) and Test Support Complex (TSC)).

GENESIS OF SATELLITE OPERATIONS CREW TRAINERS

In the early 1980s AFSC initiated development of satellite crew trainers to support Air Force satellite launch and on-orbit operations. Provisions were also made to interface with NASA to support Air Force/NASA shuttle launches and missions. Prior to this time, the standard training method for crew training was to conduct training exercise on their operational equipment using a "paper simulation" method. Team members were given paper scripts during a training exercise detailing scenarios to which they were to respond (some scripts would provide the operator with failed, telemetry values); the operator's appropriate response(s) would then be evaluated. The "paper simulation" method was laborious to develop and time consuming to conduct for training large groups of teams coordinating over multiple voice-nets and consoles in support of a launch exercise. Unlike the "paper simulation" method, crew trainers provide Air Force satellite control teams with a simulated satellite telemetry stream that could be processed and displayed on the crew's command and control system in a dynamic and interactive manner.

Telemetry Simulation System. The Inertial Upper Stage (IUS) Satellite Operations Center (SOC) at OAFB became the first program to benefit from the development of a crew trainer, the Telemetry Simulation System (TSS). The system was developed by the Unisys Corporation (now PARAMAX Systems Corporation), designed using 8086 technology, and required a significant amount of program unique software development. Although initially fielded in 1984 for the IUS program, several other satellite application models were developed over the succeeding five years. An upgrade to the TSS hosted on 80286 technology was installed at both AFSCN satellite control nodes, OAFB and FAFB.

The TSS was the first Air Force trainer developed for space operations, which supported integrated training between the various positions of the SOC crew, the communications segment, and the Resource Control Complex (RCC). The TSS had several shortcomings. Each satellite software model was mission unique with very little reusable software code between programs. Model development time was from two to three years. Only one satellite model could be running at a given time on the TSS. The cost for satellite model development was approximately $5M to $7M per satellite application, $1.2 M for the hardware platform, and $3M per installation due to the hardware architecture and Air Force facilities and security requirements. The TSS did not simulate Air Force ground tracking stations; this limitation made the trainer inadequate for two of the five members of the satellite control crew (an orbit analyst who relied on satellite tracking data and a ground controller who needed tracking station configuration status information). The TSS software was written in PLM and Intel assembler. The code was costly to maintain and was not readily portable to other hardware platforms. Increased training and fidelity requirements exceeded TSS hardware architecture capabilities.

Generic Telemetry Simulator (GTSim). As the development on the TSS was reaching its apex in the middle 1980s, NASA through a contract with Singer Link (now CAE - Link) began developing the GTSim for the Centaur program. Following the Challenger accident, AFSC completed the development of the GTSim to provide the reusable, reconfigurable training platform to overcome the shortcomings of the TSS. An application for the Defense Satellite Communications Satellite (DSCS) was developed by General Electric under contract with the DSCS SPO and deployed in 1992.

The GTSim again proved the importance of computer simulation to mission success. However, the GTSim did not live up to expectations. Development cost for the satellite model were approximately $6 M ($1 M over initial projections because very little of the Centaur software could be reused). Installation cost due to unique GTSim hardware architecture, and Air Force facility and security requirements were in excess of $2.5 M. The software development time increased from one to nearly two years. Like the TSS, there was no ground tracking station model in the GTSim.

THE NEXT GENERATION

Satellite Control Simulation Study. In the latter part of the 1980s the Satellite Control and Data Handling SPO (SMC/CW) sponsored a study (Satellite Control Simulation Systems Study) exploring areas in which simulation and modeling technology could facilitate Air Force satellite control operations. The study concluded that several of the capabilities required for simulation and operations could share the same software modules if designed properly. For instance a satellite model and supporting orbit propagation models were needed to support mission team training, plan validation, and anomaly analysis aids. Software reuse, evolutionary acquisition procedures, extensive use of Commercial-Of-The-Shelf (COTS) hardware and software, and a common space vehicle application user interface were some of the study's recommendations. For satellite crew trainers the major recommendations were to maximize reuse of software simulation models, provide a standard trainer architecture for hosting various satellite models, employ rapid satellite modeling development tools to meet mission objectives, provide instructional control over telemetry values and training session, and support multiple contacts. This study set the course for the development of the next generation crew trainer.

Training Systems Working Group. A Training Systems Working Group (TSWG) was established within the Air Force Satellite Control community to specify trainer requirements and coordinate activities to promote the development of a standard Air Force satellite crew trainer. Its membership was drawn from HQ AFSPACECOM, both Air Force satellite control nodes including operators and training personnel, and the Air Force satellite ground system and satellite acquisition agencies. The TSWG supported the conclusions of the Satellite Control Simulation Systems Study and developed a comprehensive set of operational requirements reflected in an AFSPACECOM Statement of Operational Need (SON 012-88, Aug. 90).

Training Augmentation Device. The opportunity to meet AFSPACECOM's SON arose when the U.S. Navy and the Air Force jointly funded the Training Augmentation Device (TAD) to provide satellite crew training for Air Force SOC crew responsible for operating the Ultra High Frequency Follow-On (UHF F/O) satellite. The requirements for the TAD were specified in the 50th SpaceWing Technical Requirements Document (Feb. 91), and were translated into system requirements by SMC/CWD (Aug. 91). These requirements focused on providing a crew trainer that could simulate the UHF F/O satellite, certain satellite anomalies, and Air Force and Navy satellite tracking stations. PARAMAX Systems Corporation was selected to develop the TAD architecture based on their in-house prototyping efforts. PARAMAX subcontracted to Hughes Aircraft Company, the UHF F/O satellite contractor, to develop the satellite model for the TAD.

The development strategy for the TAD was based on an evolutionary development concept. While TAD requirements were fully flushed out by the user community in the initial stages, design and development would occur incrementally. A system design covering the overall software and hardware architecture was scheduled to provide the Air Force community insight into the TAD's architecture. Instead of a single massive software detailed design, a series of small detailed design meetings were held. The above "evolutionary development" approach was initiated to preclude rigidity in specifying a grand design that was likely to be plagued with innumerable changes when the actual design implementation occurred. Several critical program milestones were established that enabled the contractor to incrementally design and build the TAD architecture. This approach enabled the Air Force community to have significant insight and input into the TAD's architecture throughout its development cycle. Installation of TAD hardware at FAFB, completion of TAD's basic common software models and delivery of TAD's UHF satellite models were designated as major program milestones. TSWG team involvement was maintained throughout the course of the contract. TSWG members participated in the design of the TAD's operator interface and satellite component's building block paradigm. This insured user involvement in the TAD's design throughout its development.

SYSTEM DESIGN OVERVIEW

The primary purpose of the TAD is to provide satellite operations crew readiness training for launch, early-orbit, and on-orbit operations in their SOC. The TAD dynamically simulates the external environment to the SOC including the ground tracking stations and the satellite. The TAD permits the SOC crew to verify new satellite command(s) or command sequences prior to their transmission to a satellite by comparing the satellite's simulated response to the predicted response. The TAD supports off-line analysis of satellite anomalies, work around procedure, development, and mission planning. TAD satellite subsystem models permit the insertion of anomalous states permitting the user to match the actual anomalous condition aboard the satellite. Satellite workaround procedures can then be developed by SOC crews and verified against the TAD prior to their transmission to the satellite.

System Design. The TAD's system design is based on the "open systems" architecture approach. The software can operate in a single environment (e.g., workstation) or take advantage of a symmetrical multiprocessor environment. This scalability permits the TAD to address simulation applications that support 1 to N simulated objects. Symmetrical multiprocessing using portable parallel processing application software was selected to meet Air Force crew trainer growth and performance requirements. Symmetrical multiprocessing under a UNIX operating system was selected to meet the TAD's performance requirements. The TAD provides classified (red) and unclassified (black) data separation. Due to limited available floor space within the SOC, the TAD must be located outside the SOC. The TAD is connected to the SOC via the facilities communication segment.

Hardware Design. Except for a Multibus I interface to support unique AFSCN interfaces, all of the TAD's hardware is composed of COTS equipment. The TAD is hosted on two interconnected Unisys U6085 minicomputers. One minicomputer runs the ground tracking station network models, while the other minicomputer runs the satellite models. The hardware is based on an open systems architecture which permits heterogeneous software, scalability of processors, dynamic processor loading and interoperability. TAD's software language, operating system, display software file systems, computer interfaces and databases have been ported to other UNIX operating systems (i.e., Sun, HP and IBM). The U6085 is a parallel processor with four dual 80486/25 MHz boards capable of 11 Million Instructions Per Second (MIPS). The U6085 provides upward scalability to a total of fifteen dual boards per U6085. Each U6085 contains over 1 Giga Byte (GB) removable hard drive for storing program unique applications and running in a classified mode.

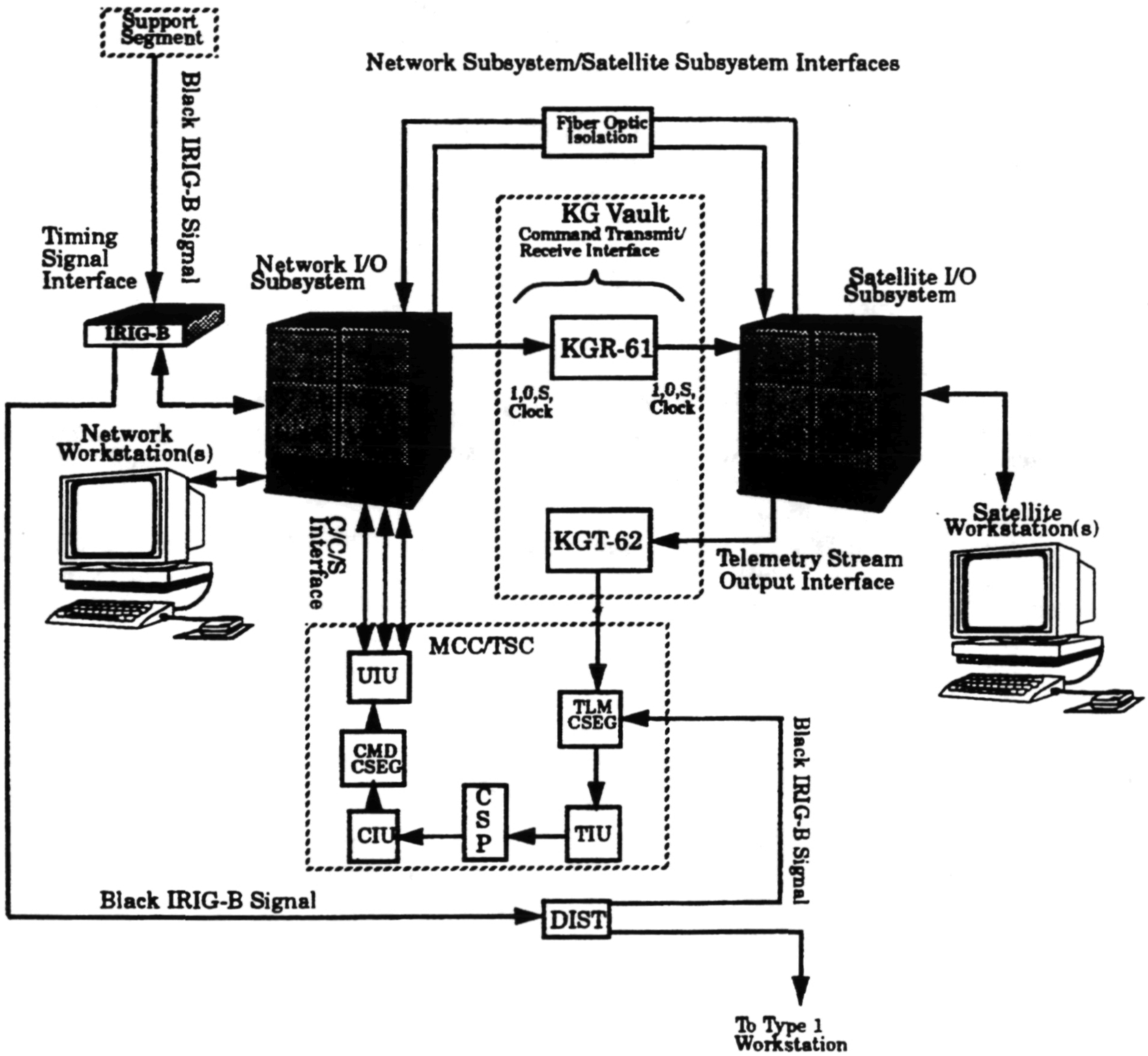

Figure 1. UTAD Hardware Design.

Connected to each U6085 minicomputer (satellite and network) is an Operator Interface Station (OIS) consisting of an IBM RS 6000/520 workstation that provides the human interface. This workstation allows real time monitoring of selected data points, injecting anomalies, manipulating simulation models, and changing simulation speed. Each workstation contains over 1 GB removable hard disk which contains any program specific data, training scripts or classified data. Display of selected satellite telemetry and student interactions is via IBM GT4X 24-bit graphics card. A high speed printer is connected to each RS 6000 to print training data as necessary. Connectivity between the U6085s, Multibus I and the RS 6000s is via fiber optics or TCP/IP Ethernet LAN.

The TAD's Multibus I interface is used to connect to the SOC's AFSCN custom data interfaces. The Multibus I is composed of commercially available Single Board Computer (SBC) printed circuit boards. A custom board that generates TAD satellite telemetry attaches through a standard connector to a commercial Multibus SBC printed circuit board. It supports a variety of telemetry formats and telemetry data rates up to 2.5 Mbps. The telemetry generator is the only custom piece of hardware in the TAD's architecture. Data rates are programmable and encoding schemes are selectable. Telemetry commutation is performed on the host programmable SBC board. A Loral NASA Command Formatter (NCF) board resides on the Multibus I and serves as the command ternary receive port for SOC satellite commands into the TAD. Six different telemetry boards can be connected to the Multibus I, which could be driven by six separate simulations at the same time, thus supporting six different SOC training crews.

Software Design. The software design was predicated on the use of the Ada programming language and whenever feasible the use of COTS software to reduce development cost. Use of Ada programming language as the main software language was mandatory per DOD policy and Air Force policy. Use of other languages in the TAD are limited to special functions or routines such as existing I/O driver software, revised satellite models, interfaces to UNIX or COTS software, and fourth generation language (4GL) with Structured Query Language (SQL) database code. Two different operating systems support the TAD: U6085 Unisys System V Operating System, and the IBM RS 6000 AIX Operating System. Both systems support a security rating of C2 and provide discretionary access control, user identification, passwords, and audit trails. The TAD workstation employs X-Windows X.11 standard to establish its windowing environment. The user can open several display windows on his work station and monitor the status of several on-going activities. X-Windows standardize the manner in which a user can open or close display windows permitting increased operator productivity. The workstation's human interface is developed using the Dataviews tool from Visual Intelligence, Inc. Dataviews supports X-Windows.

Database development is supported by the Progress tool from Progress, Inc. The 4GL that is provided by Progress inherently supports concurrency control, recovery, import/export of data. The Progress 4GL Structured Query Language (SQL) standard is also used to build user data displays and report requests.

TAD local area network uses a standard IEEE 802.3 Ethernet protocol supporting the Network File System (NFS) and Remote Procedure Call (RPC) open standards sponsored by Sun Microsystems, Inc.

On-line documentation access to the TAD's user manual and another documentation is supported by the desk top publishing tool Framemaker, which uses quick look-up hypertext links provided by Frame Technology Inc.

Telemetry commutation software using PLM software developed for the TSS was adapted into the TAD architecture along with the NASA Command Formatter software. Figure 2 identifies the various commercial languages by percentage of total lines of code (573.5 KSLOCs) used in the TAD.

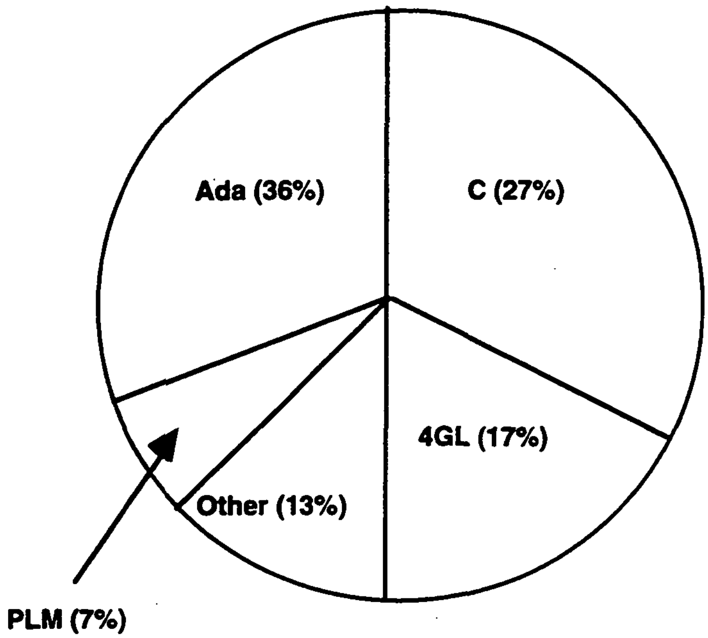

Figure 2. TAD Software Programming Languages.

Software Architecture. The software is divided into two primary Computer Software Configuration Items (CSCI). The TAD's Common User Software (CUS) CSCI includes all those functions which are common among satellites, while a separate Mission Unique Software (MUS) CSCI is required for each satellite application model, only if a high fidelity capability is required. The CUS models support rapid scripting of TAD simulation models, scenario generation and operates with the various COTS software to provide data to the TAD operator workstations along with executing satellite and space environment models during simulation run time to support telemetry generation and dynamic responses to crew initiated commands. Figure 3 identifies the TAD's Architecture.

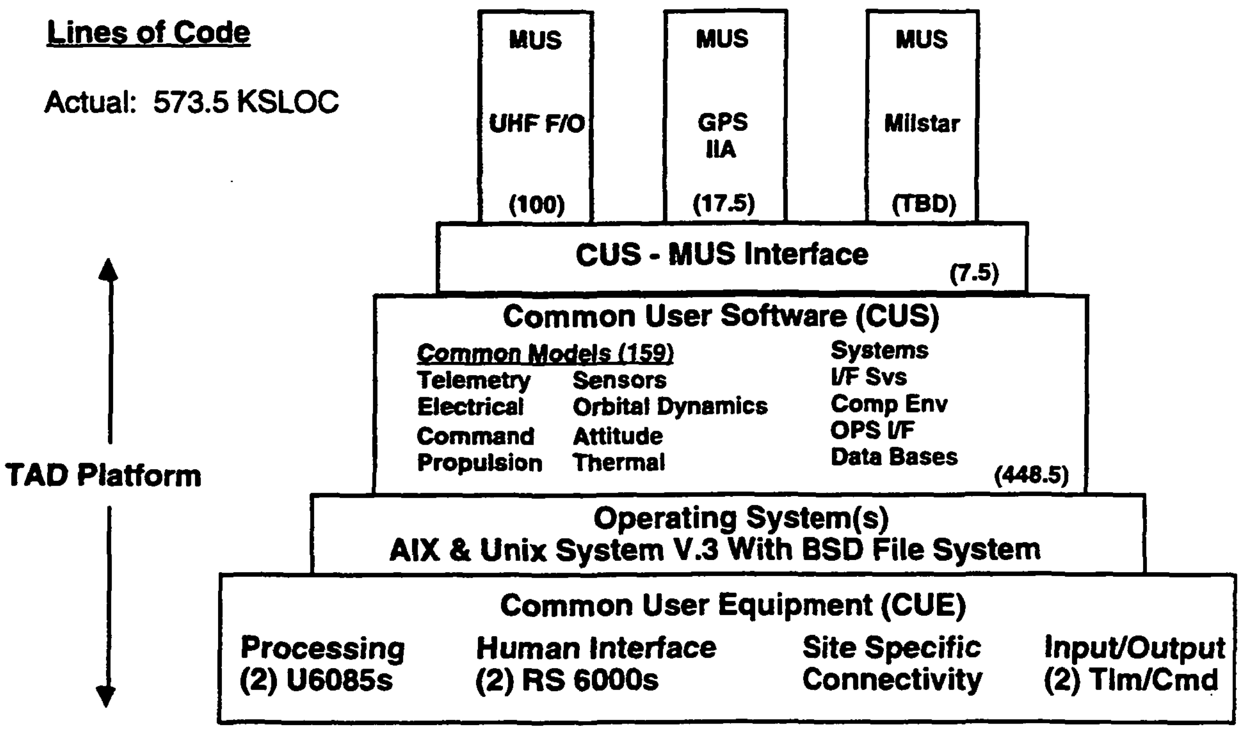

Figure 3. TAD Architecture.

<u>Common User Software</u>. The TAD CUS employs Ada tasking model constraints which permit the spawning of multiple Ada tasks, each representing a simulation unit (e.g., satellite and tracking stations). When a parallel processor environment is present with a parallel Ada run time system, the simulation units takes advantage of the additional processors. The TAD's common user software (CUS) consists of a collection of reusable or common models such as satellite commanding, orbit line of sight, telemetry, orbit dynamics, satellite attitude, satellite sensors, actuators, orbit line-of-sight, propulsion electrical power, telemetry, tracking and control, and Connectivity models. Figure 4 identifies the TAD's Computer Software Components. A control system based block programming paradigm is also provided which permits training personnel to rapidly develop medium complexity satellite simulations.

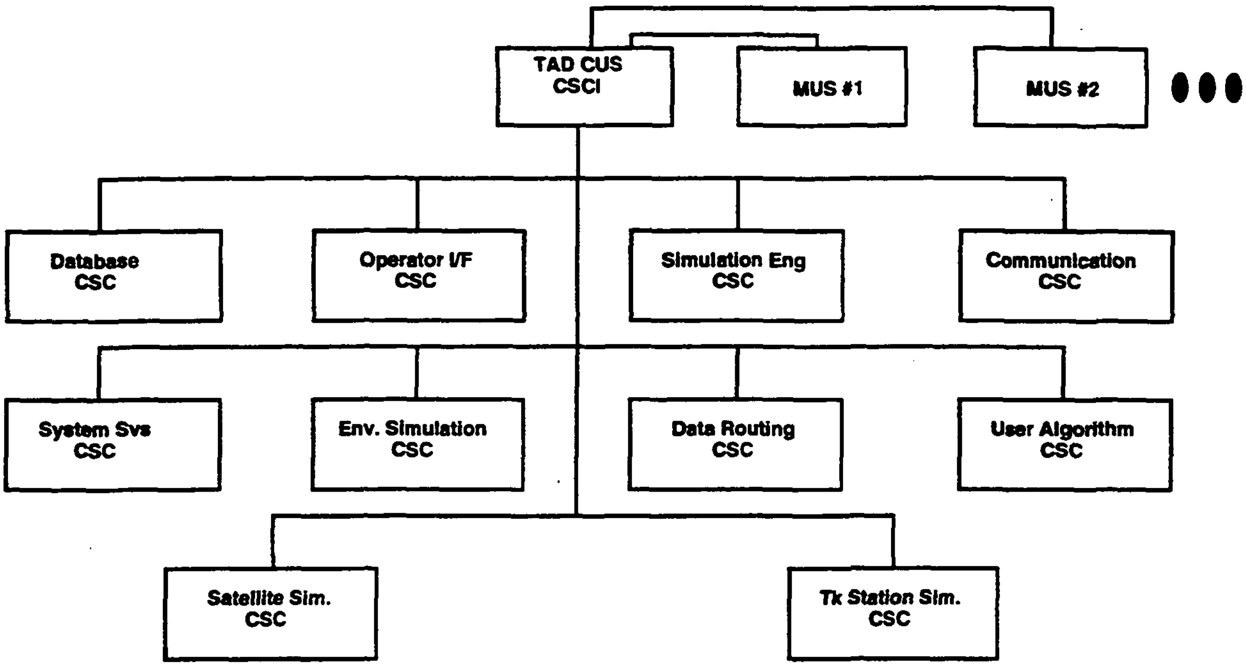

Figure 4. TAD Computer Software Components (CSCs).

The TAD CUS provides the software environment in which all TAD simulation activities take place. A broad suite of simulation tools is provided by the CUS such as scripting, logging, script generation from logs, SOC interface, simulation control, fast/slow forward time control, common satellite and sub component models, simulation state save/restart, multiple simulated time/spatial universes, multiple simulated objects, and evaluation utilities and reports. In addition to these features, the TAD CUS provides reconfigurable common math/logic models whose behavior is defined through database parameters. The CUS also provides a block programming capability that supports modeling of subsystems which have a high degree of variability that cannot effectively be handled by the common models.

Database. The TAD database CSC provides the means by which an operator can enter new data, change existing data, or delete data from the MUS database. The MUS database is the data source for tailoring the behavior of the simulation environment and the objects which are within the environment. These functions are accomplished by Database application code, database load, and the Progress Database development tool modules.

The Database module provides database management, environment definition, satellite definition, tracking station definition, and software discrepancy report/definition. The database manager provides templates from which the operator may create new databases which are automatically cataloged. These templates may be created for a family of satellites which are similar which are then tailored for specific mission requirements. The software discrepancy report/definition function provides on-line identification of hardware or software problems.

The Database Load module provides a means of uploading actual SOC databases used in the operational command and control system directly into the TAD databases.

The Progress Database development tool, a COTS 4GL client/server product, is used to develop and maintain TAD CUS database application code.

Operator Interface. The operator interface CSC handles all of the processing required to present information to and receive directions from the trainer during execution of a training session. These functions are accomplished by the Human Interface, Display Processing, Scripting, and DataViews Tool modules.

The Human Interface module creates a main operations control window which is used by the trainer to initiate a training session. Each Operator Instructor Station (OIS) hosts exactly one Human Interface process which maintains separate control for each environment and simulated unit that is controlled by that OIS. The Human Interface takes advantage of a graphical user interface features such as windowing, mouse-and-menu control, and color graphics.

The Display Processing module is used by the Human Interface module to provide processing of 2-D graphics displays. The Scripting module processes any scripts that have been defined for the training session. The DataViews Tool module supports the custom development and maintenance of 2-D graphics displays.

Simulation Engine. The simulation Engine CSC provides the run-time control functions on the compute engine (i.e., U6085 minicomputer) which are accomplished by Simulation Engine Control and Ada Task Control modules. The Simulation Engine Control module initiates the processes that execute on the minicomputer, establishes communication with the OIS, and starts the processes that provide communication with the AFSCN interface software components.

The Ada Task Control module provides control over several module such as the Environment Simulation, the Satellite Simulation, and the Tracking Station. It is started by the Simulation Engine Control module when a simulated space/time environment is requested.

Communications. The communications CSC provides the communications interface services between all the hardware and software components, regardless of whether they are on the U6085 minicomputer or the RS 6000 workstation. These functions are accomplished by Ada Communications, Multibus I Communications, and Intersubsystem Communications modules.

The Ada Communications module provides communications between Ada tasks running on the U6085 and UNIX processes residing on the RS 6000. The Multibus I Communications module provides communication between the TAD system and the Air Force communications switch interface to the SOC. The Intersubsystem Communications module provides communication between the U6085 satellite and network subsystems.

System Services. The system services CSC provides communications, data routing and software utility support for TAD software components. These components include system control processes, human interface and display handling processes, Multibus I input/output processes, user defined algorithms, space/time environment models, and satellite and network subsystem models. These functions are accomplished by Time Control, Physical Environment, and Environment Communications modules. The Time Control module provides the OIS control over the TAD's run time environment, such as fast/slow forward, freeze, state save, start/stop. The Physical Environment module provides control of the simulation of the necessary physical characteristics of space surrounding the earth (e.g., sun, moon and planets). The Environment Communication module provides control over communication between objects in the same or different space/time environments.

Environment Simulation. The environment simulation CSC provides the simulation of space/time environment in which the satellite and ground tracking stations operate. The simulation of an environment includes: modeling of the passage of time from a specified starting point and the modeling of the necessary physical characteristics of space surrounding the earth.

Data Routing. The data routing CSC provides the transparent exchange of data between TAD components. Each simulated unit possess a data pool which has been generated by the Simulation module (Environment, Satellite, or Tracking Station) for that unit. Data in an objects data pool can be accessed by any of the TAD's components. It is this loosely coupled nature of the system that provides the flexibility to turn on/turn off individual models and update values in a data pool from alternate means (databases, look-up tables, external sources).

User-Defined Algorithm (UDA). The user-defined algorithm CSC provides the mechanism for the trainer to manipulate data during the execution of a training session. UDAs may be used to generate telemetry measurands, manipulate data for display purposes, or generate specific simulation data. UDAs may interact with other algorithms and TAD models via the data pools.

Satellite Simulation. The satellite simulation CSC provides satellite simulations capable of receiving space vehicle commands from a SOC and producing dynamic telemetry output which reflects ongoing evolution of the simulation environment and the simulated satellite's response to the received commands. The simulation of a satellite includes the modeling of the health and status of various subsystems. Satellite modeling employs common math/logic models that obtain satellite-specific characteristics from parameters specified in databases. The TAD common satellite subsystem models include: Orbital Dynamics, Attitude, Sensors, Actuators, Propulsion, Electrical Power Subsystem, Commanding, Telemetry Processing, Eclipse, Telemetry and Commanding Control and Status (TCCS), and a Common Spacecraft Processor Model. These models communicate primarily through Data Routing.

Tracking Station Simulation. The tracking station simulation CSC provides for the simulation of both Air Force and Navy satellite tracking stations. These simulations respond to configuration and control directives from the SOC and return realistic tracking and status information. This module also provides modeling of core equipment and antenna subsystems of the tracking stations. Like the satellite simulation module, this module employs common math/logic models that define tracking station-specific characteristics from parameters (tracking station coordinates such as longitude, latitude, altitude and obscura data) specified in databases. The TAD common tracking station models include: Tracking and Antenna, Command Generation, Tracking Station Control and Status (TSCS), and Tracking Station Equipment.

Mission Unique Software. The TAD's Mission Unique Software (MUS) constitutes the specific satellite application model (e.g., GPS or UHF F/O). For instance GPS Block IIA software running on the TSS at FAFB and totaling 45 KSLOCs of FORTRAN 77 is being transcribed into Ada for use on the TAD. It is scheduled to be completed by the Spring of 1994. The total estimate Ada lines is 17.5 KSLOCs. The reason for the significant reduction in lines of code is partially due to the nature of Ada being a high order language, but mainly due to the ability of TAD's common models to supplant significant portions of the original FORTRAN code. In the case of the UHF F/O satellite model developed by Hughes Aircraft Company, a custom C code to Ada software interface was developed. This interface permits the Hughes model (previously developed) to run in the TAD's software environment. The Hughes UHF F/O MUS model consists 100 KSLOCs of C code and is a modification of a previously developed satellite simulation for the Hughes HS601 satellite family.

PROGRAM STATUS

The TAD development is currently completing development. The TAD hardware and an initial software capability was installed in the summer of 1992 at FAFB. A successful demonstration of generating a telemetry wavetrain and of receiving SOC commands was completed in February 1993. The Hughes UHF F/O satellite model was ported over to the TAD and successfully run with the CUS in a simulation mode at PARAMAX's development facility in March 1993. The installation of the basic TAD CUS and UHF F/O MUS is scheduled for the summer of 1993 with an enhanced version of the CUS with the block programming capability scheduled for delivery in early 1994.

Installation of a TAD at OAFB is underway with completion scheduled for the end of 1993. The GPS Block IIA software rewrite has started and is expected to be completed by the spring of 1994. The MILSTAR satellite SPO is in the planning stages of developing a MILSTAR MUS to support training in their SOC at FAFB. The GPS Joint Program Office (JPO) is considering acquiring a TAD to support training at its satellite Master Control Station at FAFB along with developing an MUS for its new GPS Block IIR satellite.

An additional use of the TAD is as a test driver in the AFSCN Data Systems test program. A development laboratory TAD has been installed at IBM's satellite ground control software maintenance facility to support software maintenance and test activities. It is expected to be operational by the summer of 1993.

FUTURE DIRECTIONS

An advantage of the TAD is its portability across hardware platforms. Current technological advances make it feasible to port TAD software onto high performance graphic workstations (parallel architecture) and place them into the SOC at a significant cost savings over the present hardware architecture. This alternative is being investigated. With the TAD being ported to a workstation and located inside the SOC, its facility installation and security cost could be significantly reduced.

The TAD has been adopted as the standard AFSPACECOM crew trainer. Additionally, it has been identified as the simulation element for the Air Force's next generation satellite command and control architecture, the Advanced Satellite Control (ASC). The ASC stipulates a distributed architecture with heavy reliance on open architecture and commercial standards interconnected via high capacity high speed fiber optic data links.

Bibliography

1. The Aerospace Corporation, TOR-0089(4485-01)-1, Satellite Control Simulation System (SCSS) Summary, February 1990.

2. AFSPACECOM Statement of Operational Need 012-88, Satellite Control Simulation System (SCSS), August 1990.

3. AFSPACECOM UHF Follow-On Training Augmentation Device Technical Requirements Document, 8 February 1991.

4. System Specification for the Ultra High Frequency Follow-On Training Augmentation Device (UTAD), UNISYS, SS-CUE-000349, 2 August 1991.

5. Software Requirements Specification for the Common User Software for the Training Augmentation Device (TAD), CG-000360, 20 January 1992.

6. Prime Item Development Specification for the Training Augmentation Device (TAD), CP-CUE-000358, DRAFT, 30 September 1991.