A COMBAT SYSTEM INTEGRATION LAB FOR ENGINEERING LIFE CYCLE SUPPORT

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ABSTRACT

BAE Systems Combat Simulation and Integration Labs (CSIL) are a culmination of more than 14 years of operational experience at our SIL facility in Santa Clara. The SIL provides primary integration and test functions over the entire life cycle of a combat vehicle's development. The backbone of the SIL operation is the Simulation-Emulation-Stimulation (SES) process. The SES process has successfully supported BAE Systems US Combat Systems (USCS) SIL activities for many government vehicle development programs. The process enables SIL activities in vehicle design review, 3D virtual prototyping, human factor engineering, and system & subsystem integration and test. This paper describes how CSIL applies the models, software, and hardware components in a hardware-in-the-loop environment to support USCS combat vehicle development in the system integration lab.

INTRODUCTION

BAE Systems is a global defense and aerospace company delivering a full range of products and services for air, land and naval forces, as well as advanced electronics, information technology solutions and customer support services.

Figure 1: BAE Systems Vehicle Programs

Within BAE Systems' Land and Armaments (L&A) operating group, the US Combat Systems (USCS) business unit develops and manufactures major ground combat systems, including tracked and wheeled vehicles for the government as well as the forces of allied nations. Figure 1 shows the major combat vehicles developed by USCS.

The development of ground-based combat vehicles is a complex process, requiring the coordinated effort of multiple engineering disciplines that include vehicle electronics and tactical software integration at the component, subsystem, and system levels, combat mission profile validation, human factor engineering (HFE), vehicle design, as well as modeling and simulation (M&S), to perform integrated design analysis and to perform system integration, test, and validation.

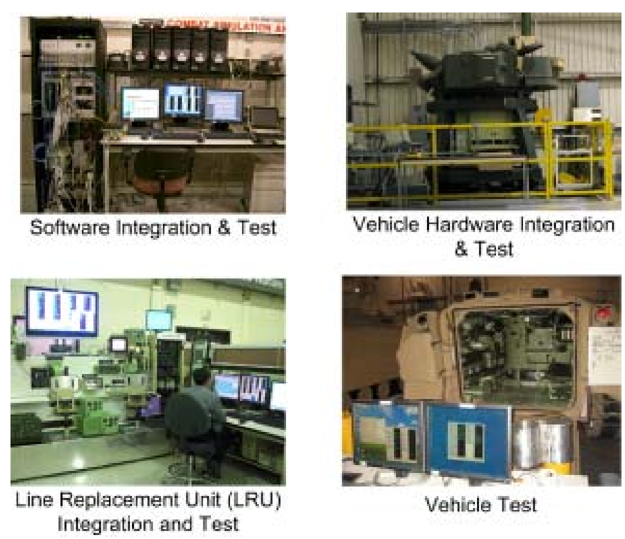

Figure 2: SIL Applications

A Combat Simulation and Integration Labs (CSIL) has been established to support the full engineering development life cycle: requirements generation, concept prototyping, engineering development, initial interface and subsystem integration, war-fighter/man-machine-interface assessment, system integration and lab testing, as well as vehicle evaluation. The lab applications, as shown in Fig. 2, have provided significant risk reduction in both the development schedule and cost.

SIMULATION-EMULATION-STIMULATION PROCESS FOR SYSTEM INTEGRATION

The Simulation-Emulation-Stimulation (SES)[1] process, as shown in Fig.3, was developed for system integration, specifically for vehicle electronics and software conceptual testing[2], as well as component, subsystem, and system level integration and test. The Simulation phase of the SES process consists of an initial architecture and interface design conception and verification using only simulation models of the vehicle systems. The Emulation phase of the process utilizes models (or hardware) that execute on subsystem emulators, which represent the actual vehicle hardware interfaces and which mimic specific critical behavior. The Stimulation phase of the process seamlessly replaces emulators with actual vehicle hardware to provide hardware-in-the-loop integration and testing.

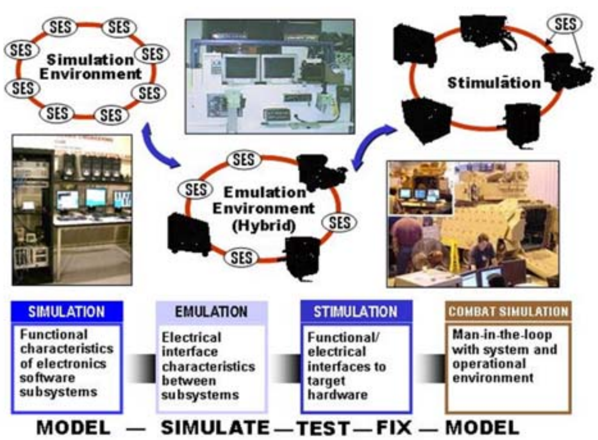

Figure 3: SES Process

Within the Simulation phase, models are developed using industry standard simulation tools such as [MATRIXx][3] and [Mathworks][4]. Because actual vehicle hardware is likely unavailable at such an early stage in the vehicle development process, physical behavior and functional characteristics of the electronics & software are simulated to support both the concept screening and the development of an integration environment for testing functional interfaces. This facilitates the progression of early concept integration and interface requirement specification (IRS) development tasks without the need for fully developed software or hardware being available.

During the Emulation phase, models are wrapped with more matured hardware design to execute on real-time platforms (emulators), which mimic vehicle interface messages, via actual hardware protocols, such as MIL-STD-1553, Control Area Network (CAN) and direct analogy & discrete I/Os. Actual connectors, protocols, and tactical messages are employed to enable early prototype integration and verification. Hardware interfaces, tactical message timing, logical behavior, and fault handling and response design are performed using emulators, before the hardware prototypes are built. Using emulators and tactical software, system design and integration issues are captured and resolved without the burden of an expensive hardware prototype.

Finally, during the Stimulation phase, emulators are replaced with available vehicle hardware, especially the Line Replacement Units (LRUs), to enable the validation of vehicle hardware behavior, interfaces and requirements. Certain emulators are converted into fault injectors to support test cases in system qualification tests.

In addition, vehicle-troubleshooting tasks can be accomplished in the lab environment with greater ease then on an actual vehicle. With the majority of hardware issues captured and resolved, the transition to the vehicle platform can be accomplished smoothly and in a timely manner.

APPLICATION CASE 1: 3D VIRTUAL PROTOTYPING

To mitigate development risks and increase product concept prototyping efficiency, USCS has developed a 3D stereo virtual environment, as shown in Fig. 4, to effectively collaborate and communicate new product concepts in a 360 degree immersive graphical environment. The environment employs a motion-tracking system to support evaluating the spatial arrangement of a design and to assess visibility limitations from different viewpoints. The 3D virtual environment[5] has been applied to virtual vehicle design, operational scenario simulation, and vehicle performance simulation, as shown in Fig. 5.

- Virtual Vehicle Design

  Prior to the manufacturing of any mockups or hardware prototypes, which can be costly and time consuming, engineers and customers can virtually walk through and view life-size designs soon after their conception. This virtual vehicle design capability enables engineers to collaboratively review space utilization and enables the development organization to display conceptual designs to prospective customers.

- Operational Scenario Simulation

Operational scenario simulations consist of realistic battlefield situations to demonstrate a future product's potential operational capabilities. Following the subsystem-level CAD analysis and the system and platform-level physics-based analysis, the virtual vehicles can be simulated within a system of systems environment in order to demonstrate how this future product or enhancement will be used in a realistic mission scenario.

- Vehicle Performance Simulation

The 3D virtual environment has integrated Modeling and Simulation capabilities such as mobility and dynamics simulations, thermal analysis, and electromagnetic (EM) simulations with high-fidelity CAD models to enhance the collaboration of product design knowledge and to enhance the communication of vehicle performance to customers.

Figure 4: **3D Virtual Prototyping Environment**

Figure 5: Vehicle Virtual Prototyping Applications

Overall, the 3D virtual prototyping environment enhances the product development efficiency, cross-functional synergy, and the ability to create more customer-centric products.

APPLICATION CASE 2: CREW STATION DESIGN EVALUATION

The reconfigurable Crew Station simulator provides man-in-the-loop simulation capability to support the simulation-based design process. A rapidly reconfigurable crew station simulator, designed to support Warfighter-Machine Interface (WMI) functions, has been utilized in supporting combat vehicle programs. The Crew Station Simulator provides rapid engineering prototyping capability for Human Factor Engineering (HFE) evaluation, high-fidelity engineering performance analysis, and man-in-the-loop testing of virtual subsystems for ground applications.

To support a rapidly reconfigurable simulator, a distributed simulation environment was established with a cluster of 20+ computers, touch screens, simulated (or actual) control panels, and hand station devices. In order to provide quickly reconfigurable computer generated graphical user interfaces (GUI) to support various crew missions (i.e. driving, gunnery, commanding), a computer controlled 16x16 video matrix switcher is utilized to route the desired GUI and simulated sensor video to the crew displays in support of the Human Factor Engineering (HFE) assessment. To reduce the development burden of the actual hardware interface, all communications messages are simulated via Ethernet protocol, as shown in Figures 6 and 7.

The man/hardware-in-the-loop crew station simulator is used to support hardware design and concept assessment, such as display hardware and hand stations, WMI switchology analysis, and crew operational efficiency & effectiveness during various mission profiles.

To support the required rapid configuration changes for the HFE assessment of various hardware design concepts, the simulator framework must satisfy the following requirements:

- Efficient reconfigurability of the graphical displays – necessitates object oriented software design and video matrix switching capability.
- High-fidelity models [6] to provide positive correlation of the assessments – requires physics-based models integrated into simulation system.
- Easy & quick changeover of hardware devices – requires hot swap (or at least plug and play) capability in the design.

To effectively perform a hand station hardware design assessment, the quick changeover requirement continues to be the most challenging issue in the framework design. Without a unified hardware communication protocol, vendors provide hand stations and prototypes, which use different interface protocols, ranging from generic analogy/discrete, RS232, USB, MIL 1553, and CAN BUS.

Figure 6: Man-In-The-Loop Simulator

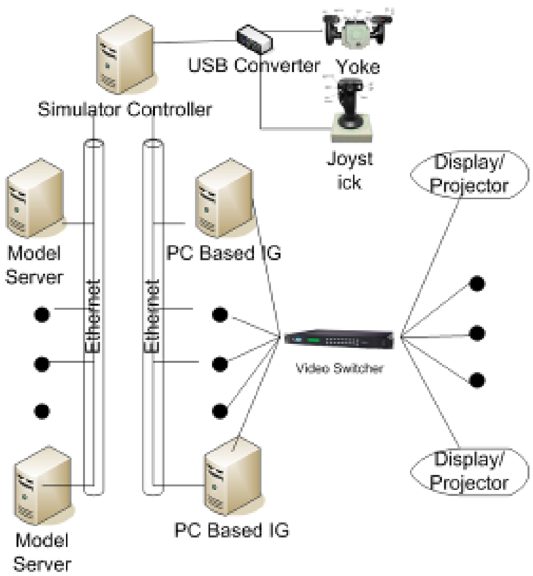

Figure 7: Man/Hardware In-the-Loop Simulation Framework

With more than 20 computers used for the simulation, changing a hand station can potentially be a time consuming process, especially if it requires restarting the system to accommodate a different protocol. To ensure an effective HFE assessment, hot swapping hand stations becomes a necessary function of the system. To meet the hot-swap and minimum reset time (in minutes) requirements, all hand stations used in the simulation environment are stripped of their network cards and revert back to a generic analog/discrete interface containing a built-in hardware ID. A USB converter has been developed to allow this hot-swap to be performed while the simulation is in a pause state, as shown in Figs 8 and 9.

In order to provide creditable engineering analysis studies, high-fidelity, real-time vehicle models, such as multibody vehicle dynamics and hybrid electrical propulsion systems are integrated into the crew station simulation environment to reflect the laws of physics. A realistic, simulated vehicle system supports operational performance evaluations over a virtual proving ground, such as Churchville Proving Grounds, for the engineering performance evaluation.

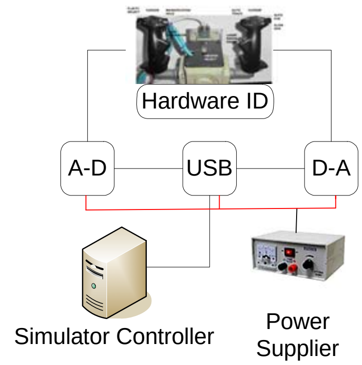

Figure 8: Hand Station USB Converter

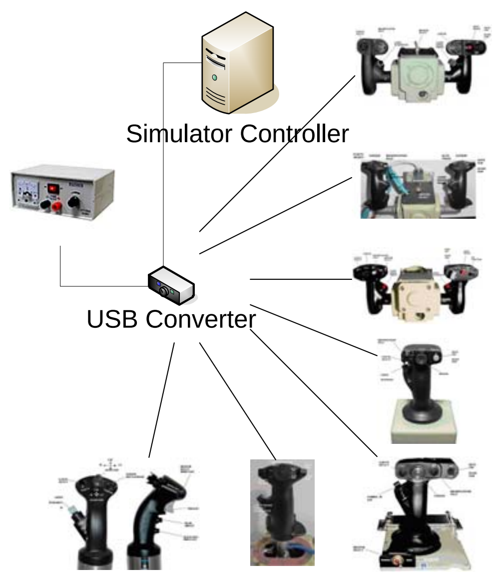

Figure 9: Unified Hardware Interface via USB Conversion

The engineering evaluation concept has been extended to include a prototyping propulsion system in a dynamometer lab. The integrated lab setting provides repeatable testing of inputs & results via realistic (actual) load scenarios when the war fighter drives the "actual" propulsion system through the "virtual" proving ground, without the risk of damaging system hardware or endangering personnel.

The crew station simulator provides a hands-on operational environment for vehicle engineering studies via a reconfigurable environment. Aspects of the environment can be either simulated or substituted with real hardware-in-the-loop to support both current and future rapid prototyping and performance evaluations.

APPLICATION CASE 3: ELECTRONICS INTEGRATION OF MIL-STD- 1553 FRAMEWORK

Effectively managing and resolving integration hurdles is critical to modern combat vehicle development, especially the integration of complex electronic components and subsystems. An electorics SIL has been developed to mitigate the integration risk in a lab environemnt, by creating an entire vehicle system based on simulation models, electronic devices, and hardware interfaces in order to perform system integration on a testbench. This vehicle testbed allows engineers to troubleshoot faults, validate electronic component design, and test at a component, subsystem, or platform level in a controlable lab setting.

An integration and test environemnt supports the MIL 1553 based Vetronic integration of sensors and components. The heart of the testbed is a Simulation-Emulation-Stimulation (SES) framework that runs on a real-time targets with 1553 interfaces to interact with actual vehicle Line Replacement Units (LRUs) and emulated 1553 devices. Figure 10 shows the general architecture of the integration and test environment. A test manager controls the test sequencing and stimulation of the corresponding 1553 messages for selected test cases.

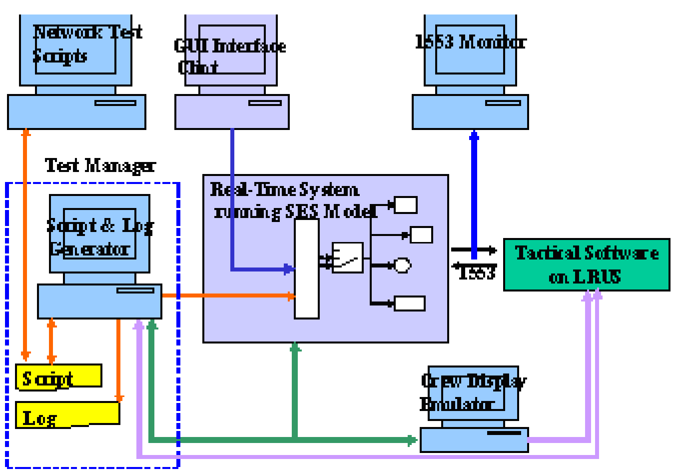

Figure 10: Electronics Integration and Test Environment

The key architectural concept is based on the objective of performing the integration and test under "actual" vehicle software and network environments to identify potential design faults and interface mismatches early in the engineering cycle. Figure 11 shows the general architecture of the test framework. The main backbone is its 1553 network with the main processing unit serving as the Bus Controller (BC), while all other LRUs are Remote Terminals (RTs). Besides the 1553, both analog and discrete signals are employed to pass time-critical messages as well as the support of existing (legacy) non-digitized devices. An Ethernet back-door has been added to the framework to also allow the real-time server and BC to be interfaced to other computers and Ethernet-enabled Devices.

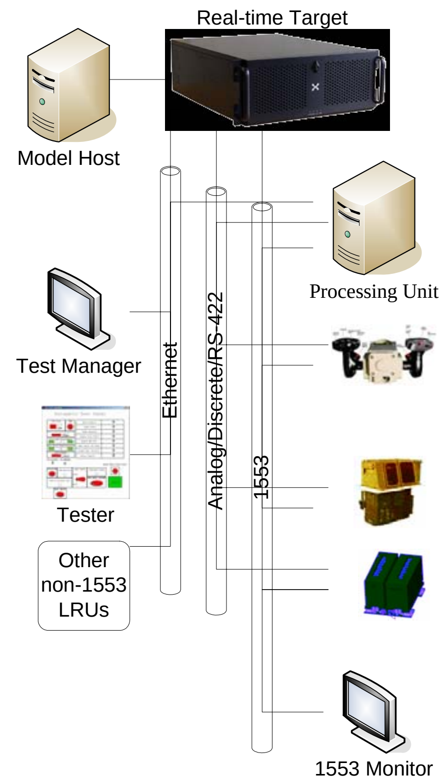

Figure 11: MIL 1553 Based Hardware LRU Integration and Test Environment

Although the environment is primarily based on a 1553 protocol, challenges arise from new recently developed devices that communicate via Ethernet or the Control Area Network (CAN) bus interface. Such a mixed protocol situation creates the need for bridging messages between protocols. Because the integration environment is used primarily to evaluate and to test interface implementations, the unified USB protocol implementation in the Crew Station environment cannot be used here. A new test framework is under development to handle the mixed 1553, Ethernet, and CAN environment.

As shown in Fig. 12, the concept of a vehicle electronics or "Vetronics" integration testbed has been sucessfully built upon an integral framework of the complex electronics devices, simulated electronics models, configurable power supply, real-time environment, and tactical software. This environment combines with the visibility of communication messages and signals from electronic components. The Vetronics integration environment has enhanced product quality, maintainability, reliability, and safety through a controlled and repeatable testing environemnt.

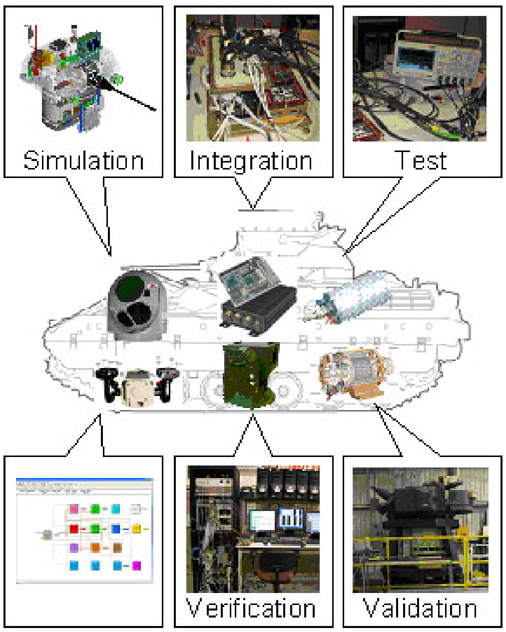

Figure 12: Electronics Integration Lab

APPLICATION CASE 4: AN INITIAL CASE STUDY OF MIXED PROTOCOL SYSTEM INTEGRATION

Integration and system performance issues arise from mixed network protocols such as differing frequencies across CAN bus and Ethernet. This example discusses the evaluation results of an early phase case study. The study focuses on solving fundamental architectural problems that includes the communication of data, signals and messaging between devices on networks of different protocols. Particularly, it addresses the need for a simple and reliable bridge between two commonly found networks in modern military vehicles: Control Area Network (CAN) and Gigabit Ethernet (GbE).

Two fundamental issues required attention in order to make the architecture meet the integration requirements. The first issue is developing a multi-rate sampling architecture in a multi-rate environment. The second issue is the indeterminate timing of message packet arrival schedule, due to the nature of the Ethernet.

The asymmetric messages across Ethernet and CAN bus are handled by a protocol bridge with carefully selected sampling rates, sampling and hold algorithm used in conjunction with extrapolation. With limited test cases, a conceptual protocol bridge has been developed to support initial integration and testing of the latest system architecture.

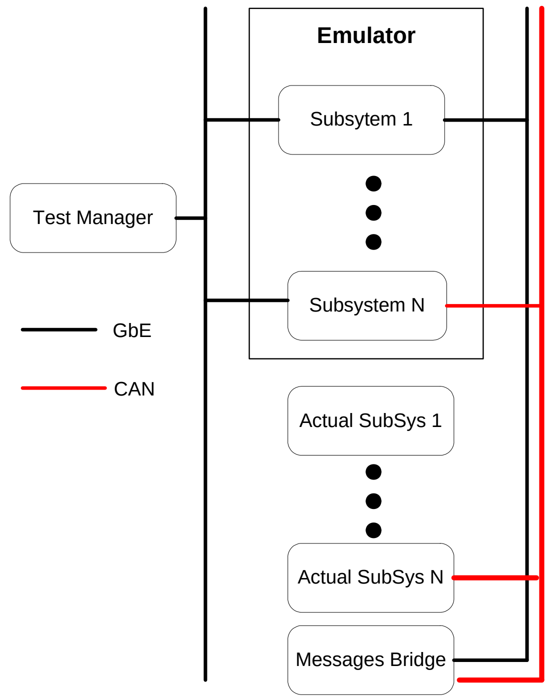

Figure 13: A Mixed GbE and CAN Architecture

This prototype, which works well in a simplified test environment, is based on rational multi-rate assumptions and utilizes software buffers. The timing issues of a complex distributed system may cause the prototype design to become unreliable when the timing has wide ranging and/or unpredictable periods, due to the late arrival of, or even missing, packets. We expect that more analysis is needed on multi-thread implementation, the mixture of real-time and non-real-time OS, higher order extrapolation and dead-reckoning implementation.

SUMMARY

By performing early simulation, emulation, integration, and testing of components, subsystems, and platform-level assemblies, the SIL's modeling and simulation-based infrastructure streamlines the engineering integration, rapid prototyping, and testing of new or upgraded vehicle systems.

As a result, it accelerates the product development lifecycle. System interface incompatibilities are eliminated, timing of electronic messages are identified, and tactical software goes through rigorous qualification testing prior to being released to the end-user. Overall, the utilization of a modeling and simulation-based system integration lab enhances product quality, maintainability, reliability, and safety by being able to verify, prior to actual hardware prototyping, hardware and software compatibility containing ever increasingly complex functionality and communication interfaces.

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[3] [MATRIXx] Registered trademark of National Instruments, Inc.

[4] [Mathworks] Matlab and Simulink are registered trademarks of The Mathworks, Inc.

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