KEEPING Trident *EVER READY*

Since 2002, Draper has been the prime contractor on a 10-year effort to extend the service life of the Trident II (D5) missile's MK6 inertial guidance system through the year 2042—25 years beyond its original design life.

The existing MK6 system, built in the 1980s, is highly reliable and accurate, but its custom processors, end-of-life memory technologies, and outdated tool sets make it impractical to maintain through 2042. The goal of the MK6 Life Extension (MK6LE) development effort is to continue the superior performance levels of the existing system, while implementing a variety of modifications to improve maintainability and provide flexibility to support new missions and upgrades.

With the Critical Design Review (CDR) scheduled for September of 2007, many challenges still remain in MK6LE; however, the initial application of the IDEAS (Innovation, Design Engineering, Analysis & Simulation) methodology in the program to date has significantly improved the likelihood of realizing a highly reliable system that meets the cost, maintainability, testability, extendibility, and performance goals established by the Navy. Since the MK6LE is an upgrade program, the Innovation phase of IDEAS was constrained significantly and focused on support of conceptual system architectures and algorithm exploration. During this concept exploration, we produced the foundational Analysis and Simulation elements that will be leveraged through the embedded design and mission implementation phases of the program. This extensive, "high-fidelity" modeling and simulation infrastructure will be heavily utilized throughout the design engineering process, from testing the algorithms and prototype designs to final system validation.

Innovation: Concept Exploration Phase

The challenges of the MK6LE are unique because the resulting design must incorporate next-generation technology while also replicating the system interfaces, physical characteristics, and performance of the existing MK6 system. Many of the existing components, particularly the case and mechanical gimbals, are being reused and the new components must be maintainable, highly reliable, and cost effective over the remaining 30+ years of the system life. In addition, the system must operate in a harsh radiation environment, which severely limits the choices of processor and memory technologies that can be utilized, potentially restricting software functionality. The advances in digital electronics and components capability since the original design in the 1980s allowed us to enhance both modularity and flexibility by implementing certain functions in software that were previously done in hardware. During the innovation phase, we identified potential processor candidates and

Artist rendering of Trident Submarine (all images in this article courtesy of U.S. Navy).

made initial judgments regarding which capabilities should be hardware or software-based. We determined that development costs could be reduced by examining the system for common functionality requirements in order to create common reusable components. Finally, we identified candidates for commercial-off-the-shelf (COTS) parts that would address both cost and maintenance concerns.

Design Engineering

For the preliminary design engineering phases of the program, our multidisciplined, multiorganization team has leveraged Draper's innovative all-digital analysis and simulation capabilities and design frameworks for proposing and assessing several possible alternative MK6 LE architectures and evaluating these conceptual designs. This high-fidelity simulation capability already has provided an excellent environment for analysis of fault-tolerance techniques and has helped the team accurately identify potential COTS parts for the system, enabled us to determine the appropriate shift of functionality to software, and ultimately provided a high level of confidence in the feasibility of the conceptual system, hardware, and software architectures as we move forward.

Analysis & Simulation – Total Life-Cycle Support in High Fidelity

Draper has been developing an infrastructure for supporting the simulation and analysis of the MK6LE throughout its life cycle. This includes preliminary design of the guidance system, detailed design of the software and hardware, verification and validation of software, and eventual fleet support after the system is deployed.

Determining software requirements is a key component of preliminary design engineering steps. Our method for validating the preliminary design of the system consists of using simulations constructed from a model repository to develop and verify the design as requirements flow down to the subsystem level. Analysts can use these "functional" models of the virtual system in a simulation environment (known as VSSim) to verify the design and establish and baseline system design for all future analyses.

For embedded software development, the simulation infrastructure needs to provide the embedded software teams with models of the target processor and the necessary development environment. We selected the Simics[1] ™ processor Instruction Set Simulator (ISS), which models the hardware-software interface provided by the selected processor, and expanded it to add models of the MK6LE digital electronics. This capability allows developers to compile and execute code on an accurate model of the target environment. We have further integrated this ISS technology with models based on prototyping the guidance instrument hardware and the missile flight environment, allowing developers to fly their software virtually in an all-digital

Trident II missile

[1] SIMICS is a trademark of Virtutech.

simulation rather than the traditional hardware-in-the-loop (HWiL) simulation. This environment provides a non-real-time, reproducible, scalable software development environment without the cost, lead time, and facilities required for an HWiL environment. Draper also is developing the capability to host the true digital designs of the systems' application-specific integrated circuits (ASICs) in the simulation environment by synthesizing and compiling the actual ASIC designs into a hardware accelerator. This technology can host the entire digital design of the system down to the gate-level logic and execute the design with system-clock-level timing resolution at reasonable execution speeds.

As embedded software development transitions into system verification and validation, the environments mature as well by providing higher fidelity models of the instrument hardware and flight environment and either ISSs or actual digital models. These virtual systems can host the embedded software, execute missions, inject faults into the system, and collect the necessary data to either verify that the software is correct or identify defects in a reproducible environment. After MK6LE is deployed, the virtual environments will remain on-line for fleet support.

IDEAS Will Aid Integration

As system development continues, multidisciplined teams composed of system, electrical, embedded software, control, thermal, mechanical, radiation, ASIC design, testing, and reliability engineers will work together to provide innovative solutions to the technical challenges of the program. Draper's solid foundation of Analysis and Simulation will help reduce system design costs and improve reliability. Ultimately, as MK6LE progresses, the IDEAS methodology will be critical in the process of evolving all components of this complex system into a truly integrated embedded solution.

Draper IDEAS™ for Embedded Software *(cont. from page 3)*

the application; we develop the software in increments and we integrate and test the components to create the required real-time embedded solution.

Analysis & Simulation

The foundation of our framework is an analysis and simulation capability that is integrated throughout the two design engineering spirals. Every step of the way, we review, refine, and correct the analysis and simulation tools to increase their fidelity as the design matures.

During concept exploration and the front end of the embedded design spiral, we use analytic models, covariance simulations, waveform analyses, and other high-level tools to characterize all aspects of the system performance trades. Preliminary versions of the algorithms that ultimately will capture our solution are used at this stage.

As we make design decisions, we prototype the design in the target computer language and test the code in components using Draper's high-end software simulations to assess software reliability and evaluate task timing. These highly detailed instruction and cycle-accurate processor simulations support a full range of development activities from conceptual modeling through validation of flight-quality embedded software.

Finally, these software simulations are coupled with Draper's hardware-in-the-loop, dynamic system simulation capability to provide an integrated environment to evaluate the embedded system performance in its target embedded environment before final test in the field.

This methodology, coupled with the unique skills and capabilities of our diverse staff, contributes to Draper's continuing track record of producing embedded software solutions for complex and unique technical challenges.