Tomahawk Cruise Missile Control:
Providing the Right Tools to the Warfighter

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With fast-changing targets, unconventional enemies, and shadowy, pop-up targets of opportunity, our warfighters require the very best software solutions that take advantage of newest-generation cruise missile capabilities. The Tactical Tomahawk Weapon Control System gives the United States' and the United Kingdom's naval warfighters the right tools to carry out today's demanding strike missions.

The evening news program cuts to a videotape of a lone warship operating off a coastline far from home … the night sky is pierced by the brilliant flash of a cruise missile emerging from the warship's flush-mounted deck launcher, climbing, banking, and quickly disappearing over the horizon. A few miles away, the seascape is altered by another cruise missile emerging from the depths, sent on its way from a stealthy nuclear-powered submarine lurking beneath the waves. The attack is on, and Tomahawk cruise missiles are the first punch in the opening salvo.

Recent world events show that the United States and its coalition partners are being called upon to use *smart* weapons in both the prosecution of conflicts with other nations, and increasingly, in the global war on terrorism. Smart weapons in general and cruise missiles in particular are often the first surgical instruments of military power projection, focusing destruction only where intended while limiting the danger to our warfighters.

Improving the Tools

The Tactical Tomahawk Weapon Control System (TTWCS) is the next-generation system for planning and controlling Tomahawk cruise missile flight. The TTWCS development is part of the U.S. Navy's Tactical Tomahawk Weapon System Upgrade to improve the flexibility and responsiveness of Tomahawk cruise missiles, add new capabilities, and upgrade existing fleet systems.

The TTWCS' efforts include the full array of system development, including requirements definition, system engineering, system architecture and design, software development, software integration, hardware engineering, hardware manufacturing, hardware and software integration, system testing, logistics, training, and system installation. The TTWCS program will support U.S. surface ships and fast-attack submarines, and is planned for newly converted U.S. guided missile submarines and U.K. fast-attack submarines.

Tools in the Warfighter's Hands

The TTWCS was formally approved for initial operating capability in December 2003 to work with existing Tomahawk missiles in the nation's inventory. The TTWCS initial operating capability for the newest Block IV Tactical Tomahawk missile was achieved in mid-2004. The U.S.

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Navy began fleet installation of the TTWCS system in early 2004 and could provide up to one hundred new weapon control systems by 2008.

The Right Team

The TTWCS program consists of a multidisciplinary team (systems engineers, software developers, system testers, hardware engineers, and logistics and training specialists) composed of the acquisition agent, Naval Air Systems Command for Cruise Missile Weapon Control Systems, Patuxent River, MD; the Naval Surface Warfare Center Division, Dahlgren, VA; the Naval Undersea Warfare Center Division, Newport, R.I.; and the prime contractor, Lockheed Martin Tactical Control Systems, Valley Forge, PA.

Tomahawk Command and Control Legacy

The U.S. Navy's Cruise Missile Program has been effectively evolving for almost 30 years. The original Tomahawk Weapon Control System effort started in the late 1970s, and the follow-on Advanced Tomahawk Weapon Control System (ATWCS) program lasted from June 1993 to December 1998.

The ATWCS was a large-scale hardware and software integration and software development program to replace the Tomahawk cruise missile shipboard operational hardware and software system. The ATWCS team designed, developed, and integrated software products from commercial corporations and U.S. Navy laboratories into a cohesive, multi-security level weapons control system; conducted system level tests of the integrated products; prototyped future requirements; and successfully implemented the ATWCS on U.S. Navy surface ships and submarines.

Lockheed Martin won a competitive program to provide the third-generation cruise missile weapon control system, the TTWCS, in May 1999.

Benefits to the Warfighter
Shortening the Timeline

The TTWCS system will reduce the warfighter's Tomahawk timeline by bringing the missile mission planning function aboard the firing unit. Previously, this planning function was done solely at shore-based or dedicated afloat cruise missile support centers, taking much more time to replan and provide new or revised missions to the ship.

The system's Launch Platform Mission Planning component is a new capability that reduces weapon system reaction times by speeding up the tactical mission planning process. Another new capability is the ability to redirect missiles to new targets while in flight, available with the newest Block IV Tomahawk. These newest capabilities are particularly important today, with fast-changing targets,

unconventional enemies, and shadowy, pop-up targets of opportunity.

Ease

The new TTWCS program took on the task of providing the next-generation cruise missile weapon control system to handle the newest technological improvements to the Tomahawk missile, while keeping the system user-friendly enough to be maintained by young shipboard operators not far removed from high school graduation. Simply put, the TTWCS adds much more capability to control the Tomahawk missile(s), direct, redirect, mission plan, and replan, while at the same time keeping the system interfaces easy to use for the officers and sailors onboard.

Space

Space on ships and submarines is in great demand by equipment to power and protect the ship, by weapon systems, and by people. The TTWCS successfully reduced the command-and-control equipment footprint onboard from seven racks of computer equipment to three, all while adding vital new capabilities.

Software's Vital Role in the TTWCS

Multiple Platforms

The TTWCS is being installed or is planning to be installed on U.S. Navy surface ships (destroyers and cruisers), U.S. Navy converted guided missile submarines, and fast-attack submarines (Los Angeles class/Virginia class/U.K.'s Trafalgar and Astute class). On U.S. fast-attack submarines, the TTWCS runs on the Combat Control System common hardware. The TTWCS surface-ship environment consists of multiple, redundant, single-board computers, running UNIX and Windows operating systems. The fully redundant, VME-based hardware architecture is housed in two TTWCS equipment cabinets. The software is executed by operators at four tactical display consoles on surface ships and from one to four consoles on submarines. The TTWCS interfaces with several shipboard systems, including the inertial navigation system, weapon vertical launch system, the global command-and-control system – maritime, and communications networks.

The Right Software

The TTWCS is a major software-based reengineering upgrade to implement even

greater warfighter capability over previous Tomahawk missile control generations. The program's software development is certified at the Software Engineering Institute's Capability Maturity Model® (CMM®) Integration (CMMI®) Level 5. The software development incorporates a variety of components that spans new development, reused software from the predecessor ATWCS program, and government and commercial products.

The TTWCS software consists of six computer-software configuration items with approximately 500,000 lines of new and modified development code and 500,000 lines of reused code. The delivered software is C, C++, Java, and Ada, and is developed to be compatible with the Defense Information Infrastructure Common Operating Environment (DII COE). The DII COE is a Department of Defense-wide common operating environment that enables common standards

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and implementation tools for military tactical situational awareness and system interoperability. Prior to DII COE, each new military system requiring situational awareness and interoperability developed individual solutions.

The TTWCS program reached a DII COE Level 7 (8 is highest possible), signifying virtually no duplication of DII COE functions within the system application. The TTWCS demonstrated the benefits of the DII COE reuse concept through reduction in development and life-cycle costs. The DII COE software is incorporated into the TTWCS infrastructure layer, which minimizes redundant code and maximizes consistency for system services and evolution to newer computing platforms. Software development is accomplished using object-oriented methodolo-

gies and Common Object Request Broker Architecture for interfaces among software components.

The Right Development Environment

The TTWCS software development environment consisted of a network of Hewlett Packard (HP) workstations (B-180Ls and C-110s) and servers (K-360 and K-580 mid-class), all running HP UNIX. Engineers used desktop PCs to access the development network via XOnNet. Tools used include Popkins' System Architect (system/software architecture design); Telelogic's COOL:Jex (detailed software design); Telelogic's DOORS (requirements traceability); IBM's ClearCase (configuration management); IBM's ClearQuest (problem reporting/resolution database); HP's SoftBench (C/C++ compiling and debug); ADA Core Technology's GNAT (Ada compiler and coding); and Aonix' Teleuse and Builder Xcessory (human-computer interface display generation).

The Right Development Model

The TTWCS benefits from an incremental software development model that offers improved quality, reduced cost, and better adherence to schedule over spiral or waterfall development. Each increment adds functionality and is taken through a full development and test cycle. In software increment one, legacy software from ATWCS was integrated with TTWCS hardware. During increment two, the TTWCS infrastructure (Operating Environment and Common Services Middleware Layer) was implemented and matured. Software increments three through six added new functionality to the heritage weapon control system. The final increment contained the full TTWCS functionality and was formally tested under rigorous supervision.

Incremental software development allows for risk reduction through incremental system integration. Each successive increment is developed at reduced technical risk due to a solid functional and performance foundation established in the preceding increment.

Software Metrics

The TTWCS contract was awarded to Lockheed Martin in May 1999. The U.S. Navy and Lockheed Martin jointly determined that the TTWCS would be a focus program for implementing CMM Level 5 processes and supporting tools. In

December 2000, the TTWCS was scored at CMM for Software Level 5. In June 2002, Lockheed Martin Management & Data Systems (now Lockheed Martin Integrated Systems & Solutions) became one of the first companies in the world to achieve CMMI Level 5.

The implementation of Level 5 processes on the TTWCS has resulted in productivity improvements, defect reductions, and cost savings for the U.S. government. CMMI Level 5 has provided measurable improvements in software development: a 30 percent increase in software productivity, a 20 percent drop in development costs, and a 15 percent drop in detect/find/fix software cost.

- **Productivity.** Based on historical metrics for similar developments, using CMM Level 5 processes resulted in a reduction of over 15,000 development hours.
- **Quality.** In-process quality activities enabled early problem detection during design and code/unit test, resulting in a 30 percent reduction in defects during integration and verification.
- **Integrated Program Environment (IPE) and Integrated Development Environment (IDE).** The IPE enabled everyone on the program, regardless of location, to participate in daily decision making. The IDE enabled collaborative development among 500+ users across the United States.
- **DII COE Compliance.** The delivered software achieves DII COE Level 7 compliance for newly developed software and Level 5 for reused software. The DII COE software is incorporated into the TTWCS infrastructure layer, which minimizes redundant code and maximizes consistency for system services.
- **Global Command-and-Control System – Maritime Interoperability.** The Weapon Control System (WCS) Common Services minimizes redundant code and maximizes consistency for all system services by using services developed and maintained by the U.S. Navy.

Getting the Process Right

The TTWCS benefits from high quality, defect prevention, improved productivity, and reduced risk inherent in achieving the industry's highest level of software process maturity. The program also complies with ISO 9001 objectives. The TTWCS Product Assurance Plan spans the entire program life cycle and ensures adherence to mandatory processes; development of compliant software, hardware, and documentation; and application of quantitative management (metrics) techniques. The plan applies to all locations where program activities occur. The plan's proactive product assurance methodology encompasses the following:

- Preventive action and continuous process improvement.
- In-process inspections and process and product compliance audits at all sites.
- Root-cause analysis to identify areas for improvement, increased product quality, and reduced risk.
- Metric collection and analysis to identify areas for process improvement early in development and throughout the entire life cycle.

The Right Test Environment
Team Approach

The TTWCS test-approach leveraged facilities and personnel located at government and contractor facilities. This approach allowed the team to evaluate and test the Tomahawk Weapon System from multiple perspectives, ensuring a robust test program that reduced redundancy and validated the system's capability to meet the warfighter's needs. Finding problems early and getting timely fleet feedback in the development cycle reduced follow-on development costs.

At-Sea Testing

To support at-sea testing of the weapon control system as part of the larger weapon system, the TTWCS team validated the performance of all software builds produced by the WCS software development team prior to the installation aboard the test ship, U.S.S. Stethem, an Arleigh Burke class-guided missile destroyer. The team established a configuration that permitted the U.S.S. Stethem to simulate communication with multiple Tactical Tomahawk missiles, thus enabling the completion of the technical evaluation shipboard event.

The configuration allowed testing of high numbers of missile launches and in-flight communications, utilizing non-expended assets that offer repeatability, sustainability, and high accuracy at an established one-time cost for procurement and low operational cost. The test ship was able to perform missile redirection of multiple missiles simultaneously and request health and status information from the missiles during flight. The missile simulation responded with both scheduled and unscheduled health and status event messages as directed by the communications plan, resulting in a successful test event.

Summary: Providing What Matters

The TTWCS program's success to date in providing the warfighter with the very best Tomahawk cruise missile control capabilities is a direct result of the dedicated team that stands behind this vital warfighter system. Through a combination of strong warfighter guidance and contractor performance, adoption of industry best practices, and the exercise of innovative technical solutions, the TTWCS team has provided even more timely capabilities for the warfighter. Ships and submarines will have cruise missile capabilities that exceed even the successful capabilities seen recently in Kosovo, Afghanistan, and Iraq. In a hostile world where a surgical strike can be needed in a moment's notice, the TTWCS team has provided the capability that gives our warfighters exceptional flexibility, versatility, and timeliness to address threats to our nation.◆

About the Author

Marcus Urioste leads business development and internal research and development programs for Lockheed Martin's Tactical Control Systems in Valley Forge, PA. His recent experience includes business development in advanced technology, and in international business development for Lockheed Martin Global Telecommunications. He previously served with distinction as a nuclear-trained submarine officer in the U.S. Navy on two fast-attack submarines, and as a tactics instructor at Naval Submarine School. He has been published previously in the U.S. Naval Institute's "Proceedings." Urioste is a Phi Beta Kappa graduate in mathematics of Tulane University, where he received his Navy commission via the Naval Reserve Officers Training Corps program.

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