The H1E System Configuration Set Lays the Foundation for Decades to Come

Pamela Palmer
CrossTalk

Recoding 1.3 million lines of F/A-18 assembly language code to a more cost effective High Order Language (HOL) has made every piece of aviator functionality fast, modular, and inexpensive enough to ensure that aircraft capabilities can be expanded for years to come. The HOL is a significant leap forward in flexibility of computer code and test efficiency.

While it took 20 years to create the functionality in the Navy's current fleet of 950 F/A-18 aircraft, the Naval Air Systems Command (NAVAIR) government-industry team recently fielded the High Order Language Version 1 F/A-18E and F (HIE) System Configuration Set (SCS) that recoded 1.3 million lines of F/A-18 assembly language code to a more cost-effective High Order Language (HOL) in just five years. In addition, every warfighting function was verified in two years of intensive lab and flight-testing. Simultaneously, new hardware for the mission computers and displays was created, and is considered part of the SCS. The HOL is supporting aircraft production schedules of 400 F/A-18 E/F aircraft.

The project's goals were ambitious. Make every piece of aviator functionality fast, modular, and inexpensive enough to ensure that aircraft capabilities can be expanded for years to come. The challenge was to create new hardware and software to work in a real-time combat environment while meeting production line schedules. The risk involved simultaneously changing hardware and software to the U.S. Navy's primary aircraft. Finally, not letting costs escalate was a key requirement.

A Multitude of Innovations

The idea to convert the F/A-18's real-time processing from assembly language to the more efficient HOL originated with the manufacturer, Boeing Integrated Defense Systems. "Boeing recognized the direction we were heading, so they put their independent research and development (IRAD) dollars into getting it started," said Harlan Kooima, H1E project manager. "Then we took over the idea for completion."

The project's requirements were based on the detailed documents developed over 20 years that describe how the F/A-18 operates. "The basic requirement was to make the new software package look and function the same as the previously fielded system," said Kooima. "Any deviations were captured and stated in written documents. "A solid understanding of requirements was key to our success."

The software was redesigned from a top-down approach to an object-oriented design. In the legacy system, written in CMS2 assembly language, rehosted functions were recoded in C++. A significant investment was made to ensure the architecture supported on-demand, all-the-time requirements of a real-time system, while being modular and easily maintainable. "Today we have much better structured software that has good partitioning," said Kooima. "When we make changes in one area, it does not induce problems in another area. For example, if a change is made to a radar module, we have a high level of confidence that it won't affect the radios."

"There are also benefits transitioning to a layered software architecture," said Marty Montgomery, H1E software manager at Boeing Integrated Defense Systems. "In testing, we were able to adapt quickly to multiple versions of target hardware and low-level software with only a few problems."

This $160-million software and $210-million hardware project involved more than 100 major warfighting capabilities such as Heads-Up Display and Backup Mode, with more than 1,000 possible operator selections. According to Kooima, there were just 166 instances of differences in operator interfaces between the legacy system and the HOL conversion. These were understood and negotiated prior to implementation.

"Our goal was to be as close to the fielded legacy system as we could be," Kooima said. "Out of the million-plus features the operator uses on a mission, we kept the same basic commands he is used to. We didn't change his life."

Commercial off-the-shelf (COTS) products were leveraged to automate code generation. The development environment consisted of real-time models running on Silicon Graphics workstations and a debugger tool set running on a Sun server. The project team created a new capability making the entire mission computer Operational Flight Program (OFP) available on a user's desktop computer for user interface development, training, and debugging. The desktop environment (DTE) allowed developer tests to occur on a workstation versus a separate test facility. The DTE mitigated risks associated with parallel hardware/software development and was acquired for use on AV-8B. Also the innovation of an automatic display code generator shows promising use in flight simulations, test facilities, trainers, and technical publications.

"The portability of the commercially based flight software and its layered architecture makes it usable in simulators and in trainers," said Montgomery. "COTS tools have allowed us to prototype and advance our final display software, and that has helped reduce cycle time and errors. The DTE has the same type of capability in non-display software and has really impacted the quality of what we take to the target."

Kooima added that the COTS-based system is the enabler for future capability enhancements. "It allows us to grow and add more computing horsepower on demand, for example, to expand the F/A-18's use into an electronic attack role. We've made updating the aircraft's entire functionality more modular, economical, and faster."

The H1E SCS hardware was built from the ground up. The F/A-18 E/F Advanced Mission Computer (AMC) is a totally new development and a move to commercial-based architecture for the hardware, said Montgomery. The two AMCs contain six processor modules each, and are connected using a high-speed fiber channel. There were unique challenges for COTS, he said. From a software standpoint, the biggest challenge was for these intense, embedded software applications to have the built-in software test capability to perform debugging. COTS products have fewer capabilities than our custom hardware developments. So the DTE was built for this reason. "Due to the layered architecture, we could run the OFP on our desktops and use Microsoft Studio to mature the product before we went to the target hardware. This minimized the number of undetected bugs."

To deal with supplier changes to COTS products, Kooima said, "We have a set configuration baseline. The hardware supplier can make changes to the baseline as long as the functional equivalent is still there. For example, an integrated circuit can change as long as the supplier ensures it is the functional equivalent when it is done.

In another major hardware enhancement, processing for the displays was put inside the computer versus inside the display head as it was on the legacy system. The Engenuity Technologies, Inc. Virtual Application tool makes cockpit display generation more like desktop displays and is based on commercial standard, OpenGL. As a result, this hardware allowed the team to use commercial tools to write more than 40 percent of the software at a much-enhanced productivity rate. It saved a lot of time and money.

Quality and Test Measures

In testament to the quality in the project, Boeing matured from a Software Engineering Institute Capability Maturity Model® (CMM®) Level 2 to a Level 5 using H1E SCS as part of its assessment. While there were trade offs in reaching Level 5 while completing the project, Kooima said he still believes doing it was a benefit. "Since we were developing totally new software from scratch along with new hardware, we didn't have to make changes to baseline processes and tools with the CMM."

The H1E SCS demanded more coordination than previous programs, said Kooima. It involved two program executive officers, two different N-78 sponsors, a major aircraft delivery program, and two fleet squadrons. Each delivery consisted of up to 1.4 gigabytes of data and executables. The test effort was huge in scope. "We weren't focused on the deltas from a previous baseline. We had to look at the entire F/A-18 system with fresh eyes and efficiently test everything from the bottom up." The total integration test effort for the H1E SCS was 3,000 hours and 500 flights.

Testing really was a build up approach, said Kooima. The lowest testing level was done on software engineers' desktops. From there it migrated to the software test facility that would run the software on real mission computer hardware. Then it went to the F/A-18 Advanced Weapons Laboratory (AWL) where it underwent full system integration testing on real, integrated avionics systems, aircraft ground- and flight-testing. "The entire focus on finding and resolving errors early was extremely successful."

While it is still controversial, Montgomery said that a real concerted effort was made to get into functional capability testing as quickly as possible; the DTE made this possible. "We did not do low level unit tests; instead we went straight into functional desktop testing. We saw the benefits."

Boeing identified three quantitative goals to ensure software quality: cost of less than 1.5 labor hours per line of code, delivery of less than 0.5 defects per thousand lines of code, and maintaining cost performance indices and schedule performance indices of greater than 0.95.

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Montgomery said these goals were reviewed weekly and were successfully met throughout development.

The team relied on the AWL's proven processes for measuring system maturity before determining a product is mature and ready for operational testing. Kooima said that other valuable F/A-18 processes were its risk identification and mitigation processes, as well as a rigorous process for assessing the risks and costs associated with changing requirements. The AWL's process for managing changing requirements calls for agreement by a NAVAIR Level 1 lead before the change is accepted into the project.

Kooima said that the H1E SCS's comprehensive metrics approach provided insight into product, project, and process quality throughout development. A summary of H1E plans versus actual metrics follows and has been independently verified.

- **Requirements Control.** Full functionality to the initial plan was delivered. Requirements scope was expanded to provide additional functionality.
- **Source Lines of Code.** This effort was primarily a conversion of 1.3 million lines of assembly code to HOL; however, it also included 3.8 percent growth in new, sponsor-requested warfighting capabilities and systems.
- **Schedule.** Product delivery occurred in the month promised.
- **Software Engineering Productivity.** Productivity for software engineering of legacy F/A-18 systems is 3.5 hours per line of code. The H1E SCS achieved a rate of 1.27 hours per line of hand-generated code.
- **Defect Density.** The number of escaped defects is .007 per thousand lines of source code for the first 90 days of operational use.
- **Test Activities.** Test activities (hours, type, anomalies) were tracked to ensure complete coverage of requirements.
- **Staffing.** Began the program with a staff of 40 C++ programmers. At its peak, which corresponded with the dot-com demand for experienced programmers, the H1E SCS utilized 180 software developers.

The Benefits Continue

In an added reuse bonus, the AV-8B program is picking up the H1E SCS software processes for use during the later phases of its own HOL conversion. Both programs create similar types of weapons and subsystems, said Kooima. They were going through a similar upgrade program and Boeing was the prime contractor. Boeing again recognized the business opportunity and moved forward with the reuse using IRAD money.

The H1E SCS lays the foundation for the E/F aircraft of the future, said Kooima. Using the HOL language is a significant leap forward in flexibility of computer code and test efficiency. It is the foundation on which new big-ticket, acquisition systems like Active Electronic Scanned Array can be built and fielded in less time. It provides growth for expanding the aircraft's utilization to support the Navy's need for a replacement to the EA-6B. Indeed, the H1E SCS lays the foundation for the Navy's aircraft advancements for decades to come.◆