Software Wars

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The basic premise behind the F/A-18 aircraft design was that capability growth could be achieved through software upgrades rather than requiring frequent hardware changes to increase functionality. At least that was the vision back in the late 1970s when the concept for the F/A-18 aircraft was first developed. The F/A-18 platform's recent return to the Persian Gulf region has provided us with a rare opportunity to examine the extent to which we have been able to achieve capability growth through software upgrades, and to consider the lessons we have learned as a major military system.

The U.S. Navy's F/A-18 Hornet is a single- and two-seat, twin engine, multi-mission fighter/attack aircraft that can operate from either aircraft carriers or land bases [1]. The F/A-18 relies on two primary mission computers for navigational control and weapons employment. The original F/A-18 A/B model aircraft mission computers use 1970s software technology with 32 thousand (K) of memory in each computer. From the start, the F/A-18 Hornet was designed to perform both the fighter and attacker roles. To support these dual roles, multi-function *programmable* radar was created. Instead of being wired to do just one job, the radar would be software reprogrammable.

A programmable radar signal processor and data processor provide the flexibility to change missions and select radar mode based on pilot inputs. For example, the F/A-18 uses the same radar for air-to-air target acquisition and tracking, as well as air-to-ground Doppler beam sharpened target mapping. Another key element was breakthrough technology in human factors and the pilot-to-vehicle interface allowing an effective one-man operation.

A concern in designing a dual role aircraft was how to provide all the information the pilot needed to effectively perform the mission without overwhelming the pilot with information. An innovation incorporated into the Hornet for one-man operation is the combination of the heads-up display (HUD) and three *heads-down* displays. As the pilot looks through the HUD toward the sky, the land, or the sea, dynamic symbols are presented displaying everything the pilot needs to safely fly the plane and deliver weapons. The HUD displays symbols that are projected at infinity, eliminating the need for the pilot's eyes to refocus from long distance, or infinity, to the instrument panel, which reduces incidences of vertigo.

Twenty buttons used to manipulate information presented on the screen surround each heads-down display. By pushing one button, the pilot can see a *menu* of available choices. Then, by pushing additional buttons, a diagram of the weapons being carried is displayed. The pilot selects a weapon for use and enters a delivery program (e.g., number of weapons to be released, release interval, fusing options).

Two of the three heads-down displays are identical, allowing one display to back up the others in a malfunction. The third display can project a moving groundmap combined with additional situational awareness or navigational data. This map is programmed to follow aircraft movement showing aircraft position relative to specific ground features (e.g., roads, railroad tracks, cities).

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The HUD and three heads-down displays work in concert via their software programming. For example, air-to-air targets may be displayed from a *bird's eye* view on one of the heads-down displays, while the HUD displays a line-of-sight cue (from the pilot's viewpoint) outlining the highest priority target and current weapon selected. In all cases, critical information on the heads-down display screens also appears via the HUD, usually in a graphical format designed for rapid pilot comprehension.

The center instrument panel contains the up-front-control panel. The aircrew uses the 10-digit keypad panel to change radio frequencies or enter data such as target latitude/longitude. A pilot sometimes changes radio frequencies as many as 40 times an hour. After a little practice, this placement allows the pilot to change frequencies without looking.

During a dogfight maneuver, push-button selection may be difficult due to the number of G-forces being endured by the pilot. Therefore, all controls needed to manipulate the Hornet during stressful maneuvers are located on the engine throttles and the flight control stick. This convention is termed *hands-on throttle and stick*. This enables the pilot to select radar modes, weapons, and targets and control engine power, all with the touch of a finger. Designers of the F/A-18 knew a pilot's survival might depend on a swift response in dealing with attacks from a hostile fighter.

Deployment

The first real test of the F/A-18 A/B came in 1986 with air strikes against Libya. An F/A-18 aircraft attached to the U.S.S. Coral Sea launched high-speed anti-radiation missiles against Libyan air defense radars and missile sites, effectively silencing them during the attacks on Benghazi facilities [1]. After the attack, the F/A-18s were armed and ready to counter any air-to-air or air-to-ground threat the Libyans may have planned.

During this timeframe, the entire aircraft contained approximately one million lines of code. Early F/A-18s contributed in multiple areas, primarily the air defense role in the form of combat air patrol and suppression of enemy air defense. Like all later model F/A-18s, all necessary information to land on the aircraft carrier is available on the HUD. This eases the effort required by the aircrew to *get aboard* and land safely on the carrier.

Operation Desert Storm

In 1987, the next major variant of the Hornet (F/A-18 C/D) was released to the fleet. The early F/A-18 C/D models utilized 256K processing power in each of its primary computers, with later model C/D aircraft possessing 2,112K memory for each primary processor, and a total of six million lines of code in the aircraft.

To understand the significance of the F/A-18 C/D's dual role, lone operator, and system capabilities, it is useful to imagine what it is like for a pilot to bomb an enemy target. The following is Navy Lt. Nick Mongillo and Lt. Cmdr. Mark Fox's recollection of an event that occurred during Desert Storm.

> Fox and Mongillo had launched their first combat mission. Carrying four 2,000-pound bombs, two AIM-9 heat-seeking Sidewinder missiles, two AIM-7 Sparrow radar-guided missiles, and a centerline 330 gallon external fuel tank, the F/A-18s made their way toward the designated target approximately 550 miles from the carrier.
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> As they approached the target area, the pilots had their radar in air-to-ground mode when they suddenly received word of approaching enemy fighters. "The E-2 (early warning aircraft) gave us a call saying, 'Bandits on nose at 15,' which is a confirmed bad guy at 15 miles," recalled Fox. "We quickly went back to our radar search mode, got locks on them, confirmed they were bad and shot them both down."
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> Fox fired two shots to down the first MiG: a Sidewinder followed by a Sparrow. Both missiles hit the Iraqi jet, and the exploding MiG was clearly visible on the videotape that recorded the action through the HUD. "I fired a Sidewinder at what seemed to be a relatively long range, but it wound up working. I wasn't sure it was going to do that, so I fired a Sparrow to make sure," said Fox.
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> Mongillo's kill came only a few seconds after Fox's and was made at close range with a Sparrow. It was also clearly visible on the HUD videotape. Furthermore, the tapes show two retreating MiGs were within missile range when the Hornets disengaged to complete their bombing run. Both Hornets then dropped their bombs on target from an altitude of 18,850 feet. "The idea of a strike fighter is valid. I'm not going to make any grandiose claims, but I do believe we're the first guys to kill anybody while carrying 8,000 pounds of bombs," said Fox. [2]

Overall, more than 210 U.S. Navy, Marine Corps, and Canadian F/A-18 Hornets were engaged in Operation Desert Storm. More than 6,000 targets were hit by Hornet aircraft flying a variety of missions from fleet air defense to reconnaissance to suppression of enemy air defenses to neutralizing ground forces. The F/A-18 aircraft delivered 18 million pounds of ordnance, and clocked more than 30,000 flight hours while flying 11,000 sorties – an average of 1.2 sorties per day. Throughout Desert Storm, the aircraft averaged 90 percent readiness. Hornets completed 95 percent of scheduled sorties and missed none for maintenance reasons [3].

Desert Storm was the first major conflict to make use of *smart* software-enabled bombs like the Joint Standoff Weapon (JSOW). Smart weapons can be programmed before aircraft takeoff to execute a series of software-controlled navigational changes. These navigational changes minimize the risk of the weapon being disabled by enemy fire before reaching its assigned target. Maverick anti-tank missile and laser-guided bombs developed during the Vietnam War continue to be very effective against high-value targets.

The heart of the F/A-18 is the integration of software and hardware into a single system. During Desert Storm, F/A-18 software was viewed as the glue that held the hardware elements together. Because of this tightly integrated system, changes to the software in one or more of its computers can effect a major improvement in the aircraft's capabilities without requiring hardware or airframe modifications to the aircraft. For example, adding a new weapons system to the aircraft inventory rarely requires hardware modifications. Changing the software is much easier and faster than changing the hardware, shortening the time required to integrate the weapon on the aircraft.

A basic hardware infrastructure is, however, necessary to provide the ability to take advantage of the F/A-18's reprogrammability. A standard language for communicating between processors allows new weapons to be added to the inventory without requiring a hardware change to the aircraft. Just as faster processor upgrades are necessary to support expansion of software applications, the F/A-18 transitioned to faster processors so that *smart* weapons can exchange more complex data in less time.

Operation Iraqi Freedom

As good as F/A-18 operations were in Desert Storm, there was plenty of room for improvement. As of May 1999, Hornet pilots had accumulated more than 3.7 million flight hours and, in the process, established new records daily in safety, reliability, maintainability, and mission performance [1].

Primarily due to multiple software updates, the aircraft in Operation Iraqi Freedom have significantly more combat capability. The most dramatic is the introduction of a family of new global positioning system (GPS)-guided munitions. The Joint Direct Attack Munition (JDAM) and JSOW allow autonomous and highly accurate weapons delivery in all types of weather. GPS-guided weapons improve the lethality of the F/A-18 weapon system over the laser-guided and ballistic weapons used in Desert Storm, which required clear air to be effective.

Additionally, there was a host of other weapon improvements. Some improvements were made within the weapons' software and others within the F/A-18's processors to enhance data exchange between the weapon and aircraft.

The F/A-18 aircraft's source lines of code now exceed 8.3 million versus less than one million in 1987. In Desert Storm, a specific mode within a given subsystem did not share data with other modes or, put another way, the data within a given function was separate. For example, the radar would lose the data from multiple air-to-air tracks generated in track-while-scan mode when commanded to switch to single-target-track.

Since Desert Storm, software updates have been developed and fielded to retain data from the previous mode when switching from one mode to another. The significance of exchanging data between subsystems was identified and software upgrades incorporated to establish connectivity between the various subsystems. For example, software was used to exchange information between the radar and the weapon control computer. By Operation Iraqi Freedom, we had taken a quantum leap forward sharing data between air, sea, and ground forces. Now one source can take a picture of the target, share that data with an F/A-18 loaded with the desired ordnance, and pass on the coordinates and other information for rapid, precise targeting.

Today, the same core set of weapons used in Desert Storm is now capable of being redirected to a different target during flight. The efficiency and effectiveness of the weapons were increased through minor upgrades to software. Our ability expanded from delivering multiple weapons on a single target to delivering multiple weapons on multiple targets.

Navigation was dramatically improved with the introduction of GPS and digital moving maps in the F/A-18s. These additions improved situational awareness and sustained higher accuracy than the older inertial platform used in Desert Storm.

Operation Iraqi Freedom shifted the focus of combat. Our situational awareness expanded from focusing on a single F/A-18 mission and its intended targets to all forces (ground, air, weapon) coming together to achieve a single mission in a coordinated manner. Coordination at this level required rapid and accurate identification of forces.

The ability to quickly determine friendly from hostile contact was inherent to performing assigned tasks. Timely information exchange among the Navy, Air Force, Marines, Army, and coalition forces using common, easily understandable formats is the core element in our most recent deployment. First deployment of systems like the Digital Communication Set and Multifunctional Information Distribution System onboard the F/A-18 brought the battleforce commander the ability to flex the plan based on current information regarding target location, status, and lethality.

Future Growth

By 1991, it was becoming clear that avionics cooling, electrical, and space constraints would begin to limit future growth of the F/A-18 C/D. The multi-mission F/A-18 E/F *Super Hornet* strike fighter is an upgrade of the combat-proven F/A-18 C/D.

From an interoperable, total ownership cost viewpoint, the biggest advance is achievement of a 90 percent commonality of avionics between the C/D and E/F models. However, the F/A-18 E/F cockpit features a touch-sensitive, upfront control display; a larger, liquid-crystal multipurpose color display; and a new engine fuel display. The F/A-18 E/F aircraft are 4.2 feet longer than earlier Hornets, have a 25 percent larger wing area, and carry 33 percent more internal fuel that will effectively increase mission range by 41 percent and endurance by 50 percent.

The Super Hornet incorporates two additional weapon stations. This allows for increased payload flexibility by mixing and matching air-to-air and/or air-to-ground ordnance. The aircraft can carry the complete complement of *smart* weapons, including the newest joint weapons such as JDAM and JSOW.

Enabling Technologies and Processes

When the F/A-18 concept was first developed, software was an art rather than the science it is today. The engineering discipline has matured and expanded to include a systems view and commonly accepted process principles as contained in the Capability Maturity Model®. Predictable product delivery containing promised high-quality functionality within cost is the foundation of process improvement models.

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The F/A-18 was the Navy's first tactical jet aircraft to incorporate a digital, multiplex bus architecture for the entire system's avionics suite. The benefit of this design feature is that the F/A-18 has been relatively easy to upgrade on a regular, affordable basis. The software architecture provides the basis for making more frequent updates to system capabilities [4].

Achieving an integrated system solution demands communication and coordination between the end user, requirements personnel, system and software designers, and test personnel, which has manifested itself in adoption of Integrated Product Teams to move from concept through development to product support. Today's expectations are for a flexible system solution that meets demands of any current combat situation while continuously formulating options for the future. Current expectations assume a solid foundation of individual software components working seamlessly together to provide needed capabilities, not unlike the way we expect our laptop to perform needed functions at any time, every time.

The advent of new high-order programming languages brings many benefits to the software development arena. The complexity of needs that can be addressed through software algorithms and processing is huge compared to just 10 years ago. The new Super Hornets utilize the more modular, object-oriented design features that did not exist when the original F/A-18s were rolling off the production line. Basically, what took the Navy 20 years to create as functionality for the F/A-18 aircraft was converted to the more cost-effective High Order Language (HOL) in five years with every warfighting function verified in two years. This recoding of functionality involved some 1.3 million lines of code. The effort involved delivery of more than 100 major warfighting capabilities (e.g., HUD, backup mode), containing well over 1,000 possible operator selections. The F/A-18 Advanced Weapons Lab was recognized with the 2003 U.S. Government's Top 5 Quality Software Projects award for the HOL conversion.

Commercial off-the-shelf (COTS) products are major enablers in converting to HOL. Our COTS-based system is the enabler for future capability enhancements to the F/A-18 production line. It enables the F/A-18 platform to grow and adds more computing horsepower on demand, for example, to expand the F/A-18's use from its current fighter/attack role into an electronic attack (EA) role currently provided by the Navy's EA-6B aircraft. The combination of COTS and HOL has made updating the aircraft's entire functionality more modular, economical, and faster.

The tools available to develop software have undertaken unimaginable leaps to support integrated teaming across geographically diverse locations. Even the tools used to generate software code have become more sophisticated and visual, making the effort required to design and perform low-level testing more cost efficient. The F/A-18 program uses commercial tool suites for software development. Examples include the desktop environment that allows developer testing to occur on a workstation versus a separate test facility. Another innovation was an automatic display code generator that shows promising use in flight simulations, test facilities, trainers, and technical publications.

Long before Operation Iraqi Freedom, the tide had turned from just looking at what software processing could be achieved within a single mode, a single box, or even a single F/A-18. The battlegroup is turning into a single-striking unit making it difficult to look back and focus on highlighting the software aspect of this amazing

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evolution. We now realize our perception in the 1980s was that software was the end of the journey. The reality is that software is the enabler that ties individual units of a battlegroup into a single striking entity.

The F/A-18 program understands – and eagerly steps forward to engage in – the possibilities of net-centric warfare. The full potential of force multiplication relying on software is still to come; our most recent combat test with F/A-18 confirms the validity of our mission and software strategy.◆

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WEB SITES

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DACS and DSC Web Site

www.dacs.dtic.mil

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