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F-22, Joint Strike Fighter Trainers Redefine 'Point-and-Click' Warfare

by John Stanton

When it comes to tactical flight simulators and trainers, two of the U.S. Defense Department's multibillion-dollar fighter aircraft programs mark a drastic departure from many of the conventional ways of doing business.

The Air Force F-22 Raptor and the multi-service Joint Strike Fighter (JSF) have introduced novel approaches to building training capabilities for current and future pilots, industry experts said. Not only are these new systems more technologically advanced, but they also benefit from management techniques that emphasize, for example, close industry-government cooperation.

The F-22 is built by Lockheed Martin Aeronautical Systems, in Marietta, Ga. The Boeing Company, in Seattle, is a major subcontractor on the program. Both companies, however, are pitched against each other in a competition for the JSF. The selection of the winner is scheduled for 2001.

The approaches followed by these two programs in developing flight training technology combine high-tech gadgetry with new ways of managing weapon systems, according to officials from the two firms and independent experts interviewed for this story.

"I've never seen a program [F-22] quite like it before," said Dan Farinella, program manager at L3 Communications, Link Simulation and Training, in Arlington, Texas. The company is building the training system for the F-22. "We have an unprecedented relationship with Boeing, Lockheed Martin and the government. They've taken their lessons learned ... to implement rigor into the program."

Dixie Mayes, Boeing JSF training manager, indicated that Boeing has more leeway in developing training devices than under previous tactical fighter programs. "We're more involved. The government said, 'You understand your system better than we do, so go ahead and develop it.'"

Lockheed Martin's Mark Hodge, director of Air Force advanced programs in Washington and instructor of the F-22 training device in Arlington, Va., indicated that "the government isn't taking a throw-the-design-over-the-fence approach. [Instead], they're supportive and involved." Hodge, a former Navy F-14 combat pilot, enthusiastically displayed an information-processing unit with roughly 16 separate slots holding removable CD-like devices.

"Back in 1983, the F-14 computer had about 64 megabytes of RAM [memory] and about 100 megahertz of power. Imagine being stuck with that today, and trying to find a manufacturer who would build a replacement processor for that," Hodge said. "In contrast, the F-22's central information processing unit has been designed so that when the newest technology comes out, we can pull out the card with the old processor and upgrade to the new one. While that may seem to be an obvious solution, you can't imagine from an acquisition perspective how many years it took to get here."

Lessons Learned

The F-22 and JSF simulation and training programs also incorporate lessons learned from the entertainment industry—in the areas of image fidelity and distributed simulations. In 1997, a National Academy of Science report, titled "Modeling and Simulation: Linking Entertainment and Defense," encouraged communication between the two seemingly disparate industries. "Modeling and simulation have become increasingly important to both the entertainment industry and the Defense Department. In the entertainment industry, technology lies at the heart of video games, theme park attractions and entertainment centers, and special effects for film production," said the report. "For the Defense Department, modeling and simulation provide a low-cost means of conducting joint training exercises, evaluating new doctrine and tactics, and studying the effectiveness of new weapons systems. Both industries are aggressively pursuing distributed simulation systems. ... These common interests suggest that they may be able to more efficiently achieve their individual goals by working together to advance the technology base for modeling and simulation."

Experts said it is important that military planners keep the channel open to the entertainment industry, if for no other reason than they have to consider the demographics of the pilots and aircraft maintainers they will be training during the next 50 years. For example, the pilot of 2010 is the 12 year old of 2000, who is "flying" and playing the F-22 and JSF video games now on a desktop computer. "We've had experienced combat pilots from all over the world fly this F-22 cockpit demonstrator, but the best pilot I've had in here was a 12-year-old girl," said Hodge. It's an issue that needs close attention, he added.

Roger Smith, chief software scientist at BTG Inc., in Orlando, Fla., agreed. “You’ve got to remember that these training devices and simulators are being designed just as we are beginning to use new methodologies in software such as reusable code and developing the distributed training environment,” said Smith. “The kids are playing advanced video games now, and I think that when they step into the JSF and F-22 training devices and simulators in 2010 or 2015, they will be disappointed.”

Dennis McBride, director of the Institute for Simulation and Training, in Orlando, and a former naval flight officer, reminds that pilot psychology is an important consideration in programs such as F-22 and JSF. The role of cognitive science in military aviation should not be underestimated, McBride pointed out. Psychologists participate in the aircraft design teams, he said, and new ground is being broken in cognitive science—which is having a direct impact on military aviation.

“Cognitive science is part of the bigger picture of psychological science. We are really making some breakthroughs in methodology particularly in the field of evolutionary psychology, which is shaking the foundations of psychological science and affecting the simulation and training environment.”

First Simulations

One of the first simulations of war, a game called Wei-Hai, was developed in roughly 3000 B.C. by the Chinese. Pre-battle preparation is as important now as it was 5,000 years ago. “Military simulations have arrived at their current state of sophistication and application through a long history of experimentation and evolution,” Smith said. The modern era of war games began in 1664, with the development of Koenigspiel by Germany’s Christopher Weikhmann. Additional developments followed through the 17th and 18th centuries with War Chess and Kriegsspiels, developed by Baron von Reisswitz in 1811. He used contoured terrain and porcelain soldiers.

According to Kevin Moore, a flight simulation historian based in Hove, England, an instrument-flying training simulator was developed by Link Simulation and Training in the early 1930s. As the importance of instrument training became more appreciated, the U.S. Army Air Corps began to purchase Link trainers. These simulators were able to rotate 360 degrees—which allowed a magnetic compass to be installed, while the various instruments were operated either mechanically or pneumatically. But computers drastically changed the nature of simulations.

The U.S. Navy initiated a research program at the University of Pennsylvania in 1950 to explore digital simulations. The general-purpose computers of the time, however, could not be used directly for real-time flight simulation, because of poor arithmetic and input-output capabilities. To address that problem, the Universal Digital Operational Flight Trainer (UDOFT) was developed by Sylvania Corporation, and completed in 1960. The UDOFT developed by Sylvania Corporation, and completed in 1960. The UDOFT project had demonstrated the feasibility of digital simulation and was mainly concerned with the solution of aircraft dynamic equations.

In the early 1960s, Link Simulation and Training developed a special-purpose digital computer, the Link Mark I, designed for real-time simulation. This machine had three parallel processors for arithmetic, function generation, and radio station selection. The first computerized image-generation systems for simulations were produced by the General Electric Company for the space program. Early versions of these systems produced a patterned ground plane image, while later systems were able to generate images of three-dimensional objects.

Fast forward to the year 2000.

“We’ve come a long way in terms of hardware, in terms of image presentation, in terms of networking it all together. All of these areas have improved by two, maybe three orders of magnitude,” said Smith. Indeed, both Boeing and Lockheed Martin have developed innovative software and hardware, along with communications protocols that allow pilots to “fly” with and share, in real-time, critical information over a geographically dispersed networked environment, almost like a LAN-in-the-sky (local area network).

Another challenge is to make new aircraft interact with legacy systems. Lockheed Martin’s JSF simulation architecture (JSA) ties legacy models together using the high level architecture (HLA) communication protocol mandated by the Defense Department. HLA allows simulation devices to communicate and share data over a network. In September 2000, Lockheed Martin successfully tested JSA in an air-to-ground training scenario—combining human-in-the-loop and war-gaming simulation models. Ten different legacy systems were linked into one distributed simulation.

Earlier this year, Boeing successfully linked its JSF full-mission simulator with U.S. Air Force Air Combat Command simulators, for real-time cooperative training missions. The training scenarios, with JSF and F-15 pilots flying together in the same threat environment, demonstrated how aircrews at different locations, with different types of aircraft, can practice JSF-representative missions together, Boeing officials said. The company linked a JSF full-mission simulator developed in Seattle, with flight simulation facilities in St. Louis, and the Boeing-operated Mission Training Center at Eglin Air Force Base, Fla.

The JSF is equipped with what is known as embedded training capabilities. While the pilot is airborne, he/she can engage the computer in a training mission while experiencing all the physical forces of flight. This was tested by Lockheed Martin and its partner, Fokker Space, this past summer. According to Anne Marie Schipper, embedded training program manager at the Dutch National Aerospace Lab, “Imposing a virtual world on the pilot in flight requires the addition of software to ensure flight safety, where the simulation is turned off automatically if hazardous situations occur. An embedded training session can be started only when all safety criteria are satisfied."

During the test, Royal Netherlands Air Force F-16 pilots detected and engaged simulated targets using air-to-air missiles. Embedded training is gaining attention in military aviation circles because it would help reduce the need for training ranges, officials said.

"The concept lessens dependence on training ranges by enabling mission simulations to be conducted in any suitable airspace," said Carolyn Hodge, a Lockheed Martin spokeswoman. "Future helmet-mounted display versions may include within-visual-range functionality, permitting a pilot to train for a low altitude land-attack mission while actually flying high over the sea, far from populated areas."

"What we're trying is really new," said Roger Smith. He was referring to the practice of reusing software code or using the same software that controls the airplane and the training simulator. "In the past, no one had formatted a simulator or an aircraft using the same code base. ... We can now test fly the code in the air and on the ground so that it becomes robust. The code gets stressed on the throttle, not just the keyboard."

The upshot is lower software programming costs and improved safety, said Smith. "The same bug you find in the simulator, you'll find in the aircraft."

"We're running roughly 1.8 million lines of code in the F-22, " said Alan Blackstock, F-22 training devices manager at Boeing. "We can reuse at least half of that, which greatly reduces program costs."

Attention to Maintenance

Arguably, one of the most significant developments in the F-22 and the JSF programs has been the attention paid to the aircraft maintainers and logistics support crews. "We were determined not to treat maintainers as second-class citizens," said Mayes. "We put them into the same environment as the pilot, with the same virtual reality, the same simulator and the same software. Our maintainers are in the loop."

Jo-Anne Puglisi, Lockheed Martin's JSF training program manager agreed. "The pilot and maintainer are on equal footing. We have the exact same ground rules for the maintainers and the pilots, and we use the same basic training process."

Boeing employs subject-matter experts on both the maintenance and piloting sides of the equation, said company officials. Maintainers are drawn from pools of individuals who have repaired, retrofitted or outfitted just about every type of military aircraft. These experts often are former fighter pilots, such as Lockheed Martin's Mark Hodge and Bill Harrell—both of whom are instructors at the Lockheed Martin F-22 and JSF flight demonstration center in Arlington, Va.—and Craig Bernhard, an instructor at the Boeing JSF fighter demonstration center, also in Arlington.

“You look at what maintainers did in Desert Storm in terms of sortie generation rates. We need people who can operate at that pace,” said Boeing’s Farinella. “When we use a landing gear trainer, for example, we teach them how to remove and replace any section of the landing gear at a moment’s notice. The intent is to put these guys on the flight line. Our maintenance trainer has high fidelity. ... We keep it simple and we teach them to diagnose the problem, get the solution and get the plane in the air.”

Farinella pointed out that the maintainer’s task will be made easier by the adoption of so-called autonomic logistics systems, which will provide the maintainer with advance notice of the need for repair. In short, the machine will assist the human. Boeing used technology from the training portion of the F-22 and its own commercial jet 777 to create the JSF joint distributed information system (JDIS) which, according to Chick Ramey of Boeing, will be an information conduit between pilots, maintainers and other JSF personnel.

A network of computers and sensors on board the aircraft will trigger an automatic response to a pending maintenance need. If a part failure occurs or is predicted to occur, the JDIS will initiate a series of actions to get the replacement parts on time. Human interaction is minimized, as data flows from the aircraft through the maintenance infrastructure and ultimately to the suppliers. The goal is to get parts anywhere in the United States in 24 hours and to any place on the planet in 48 hours, said Ramey. A similar system already runs on the Boeing 777.

The importance of logistics support also was emphasized by Hodge, of Lockheed Martin. “Consider this: the F-15C requires 18 C-141B’s [large cargo planes] and 399 support people. The F-22 requires 8 C-141B’s and 258 support personnel. Spare parts needed to support the F-22 were reduced by almost 56 percent. The numbers speak for themselves.”

Intelligent Computers

A recent visit to the declassified F-22 and JSF training device facilities, in Arlington, confirmed that these simulators are not like any others previously built. The intelligence of the computers that control these aircraft is generations ahead of what exists on board military aircraft today. Targets are acquired by sophisticated sensors located all around the aircraft, data is fed into computers and the computer advises the “tactician” which enemy aircraft should get killed first. It’s point-and-click warfare with brightly colored iconography, consisting of small red triangles and circles.

To kill a target, said Craig Bernhard, a former F-15 aviator, “the pilot drags a circle and places it over a triangle—which represents a surface-to-air missile or aircraft—or puts the ball in the hoop, locks the setting and presses a red button—the pickle—on the joystick and the target is destroyed moments later.”

later.

A similar process takes place in the F-22 simulator. “It’s like jousting with someone, except that you have a really long pole and the bad guys have a number-two pencil,” said Hodge. “They can’t see you.”

At Boeing’s JSF demonstration facility, the pilot talks to the machine, using voice recognition technology, to command the aircraft’s computers. “The pilot can instruct the aircraft on any task using a voice command short of actually firing the weapon, “ said Bernhard. The pilot’s helmet provides all the basic heads-up display with a twist: when looking down through the helmet visor, the pilot doesn’t see the floor of the aircraft but rather a real-time image of the terrain below and, wherever he looks, the air space surrounding him.

Like in the movie, “The Matrix,” the pilot’s brain literally is plugged into the software and hardware of the machine. “That’s data fusion at work,” said Bernhard. “The software allows the pilot to be a tactician, rather than a sensor monitor. It gives the pilot situational awareness and makes him more lethal and survivable. ... And you can load that software on a laptop, travel and keep yourself familiar with the basics.”

Since the JSF has three variants—one for the Air Force, one for the Navy and one for the Marine Corps—there are different requirements on each platform. Harrell, of Lockheed Martin, took this reporter on a ride in the vertical take-off and landing training device that the Marine Corps will use. The computer does the work. The pilot merely drags and drops or pushes—icon on to icon—to hover, move forward or shoot. With the exception of manually engaging a “clutch” to place the engine in the proper position, some pedal pushing (functions which may be computerized in the future), and moving the joystick ever so slightly, it all resembles a video arcade game. “It’s an antiseptic environment in here,” said Hodge, “and you’ve got to constantly remind yourself that these machines are designed for a serious purpose.”

Psychologists have a lot to say about aircraft design and who qualifies as a tactician and gets plugged into a multi-million dollar aircraft such as the F-22 or JSF. It costs roughly $1.5 million to train a pilot, said McBride. Rigorous tests—both physical and psychological—are used to determine who has the best “raw material” for controlling a high performance aircraft. But those tests may need to be reviewed, as disciplines such as evolutionary psychology begin to alter the concepts of how the human psyche is affected by combat stress.

According to Leda Cosmides and John Tooby, of the Center for Evolutionary Psychology at the University of California, Santa Barbara, evolutionary psychology relies on “principles from evolutionary biology,” which are applied to research on the structure of the human mind. It is not an area of study, but rather a way of thinking about psychology that can be applied to any topic. This approach to psychology says the mind is a set of information-processing machines that were designed by natural selection to solve adaptive problems faced by our hunter-gatherer ancestors. This way of thinking about the brain, mind, and behavior is changing how scientists approach old topics and open up to new ones.

Meld evolutionary psychology with computer science and war-fighting, and the result is new doctrine and training. “What we’re doing now, and the Navy is leading the way, is making tradeoffs on the type of person that can be a pilot. 20/20 vision may not be necessary. ... If the candidate has 20/40 vision but scores higher than the 20/20 candidate on perceptual tests, then there may need to be a tradeoff,” said McBride. “We’re making a lot of guesses and not thinking. For example, it’s well known that the human visual system can see a target at 3.5 nautical miles. Yet that piece of information was not programmed into many simulators.”

Indeed, the National Academy of Sciences advised the Defense Department to take a step back from technology and attempt to increase the realism of its simulation and training programs by more accurately modeling individual and human behavior. “Achieving realism requires that models of human behavior employed in the simulation be based on psychological, organizational and sociological theory,” said a study by the academy.

Smith agreed. “We need to discover and create techniques for representing the behavior of human leaders, followers and groups that give them the ability to appear live or real to the humans interacting with them.”

“Do you know that the services have only one simulation based on actual combat data?” said Smith. “During Desert Storm, there was a tank battle known as the Battle of 73 Easting, during which U.S. forces engaged an Iraqi tank division. Data collectors were sent to the field and they talked with the combatants.”

Smith pointed out that despite all the advances in simulation and training, accurate data and new algorithms come at a premium. “The simulation community needs a set of behavior libraries that can be linked into a simulation in the same way we link in statistical distributions,” said Smith. That day will come, he said, as the next generation of weapons will be built with computers that will accurately record events taking place in the battlefield and allow simulation and training practitioners to build their libraries.

Basic Research

The National Academy of Sciences also recommended that government funding be increased for education and basic research and development in the simulation and training field. In Smith’s view, it’s unsettling that there are only a few universities in the United States that offer graduate programs in simulation and training. Those include the University of Central Florida, Old Dominion University, in Virginia, and the Naval Post Graduate School, in California. “There need to be more,” said Smith.

As the competition heats up between the two contractors vying for the JSF award, some believe that the simulation and training capabilities will be a factor in the selection process. “Our competitor on JSF has just not done anything like the distributed training that we have, they’ve just never done it before,” said Mayes, of Boeing.

According to Lockheed Martin’s Puglisi, “What we believe to be innovative is our systems approach to the training process. We combine virtual aspects such as the simulator, the software and the live components such as pilots and maintainers and bring the domains together. ... We’re developing tools that can train people and prevent accidents. There’s a tremendous amount of [thinking about] the best solutions for the customer.

“We have to step outside the box and do things in a totally different way,” she said.

“We too have taken a systems approach to the JSF,” said Mayes of Boeing. “Machine, pilot, and management are the three areas we are linking together. We are leveraging heavily off of lessons learned with the F-22, the 777, the C-17 [strategic cargo plane]. We don’t want JSF to be a stovepipe from any perspective.”