Computers can digitize a million picture elements per scene and update it sixty times a second.

The Simulator Revolution

BY JOHN RHEA

WHEN the Apollo astronauts first landed on the moon some twenty years ago, they were thoroughly prepared for that first step because they had rehearsed the mission hundreds of times in simulators back on earth.

Mission rehearsal was the key to the success of the Apollo program. Now it is becoming critical to success—and survival—in the increasingly demanding world of tactical warfare. Fortunately for the US Air Force, supporting technologies are keeping pace with the challenge.

Apollo astronauts trained rigorously for two years in a mission simulator that would be considered primitive by today's standards. They "landed" a replica of their lunar module, using actual flight controls, on a simulated area of the Sea of Tranquillity known as a model board. They viewed this subscale world out the window via closed-circuit television. As the astronauts manipulated their controls, the TV camera moved correspondingly to give them a realistic sense of motion.

Until the computer revolution hit the simulation business with gale force within the past decade, that's all mission-rehearsal simulators were: TV cameras, model boards, and replicas of flight vehicles. Now the outside world is being reproduced digitally in the bowels of computers and displayed to the trainees in a way that allows them to interact with a broad range of stress-inducing situations.

This new technology is called computer-generated imagery (CGI), and it is the foundation for new training methods with sufficient realism to prepare today's warriors for tomorrow's challenges.

A Broad Geographic Sweep

Unlike TV model boards, CGI simulators can provide trainees with pictures of large geographic areas (including the routes to and from targets as well as the targets themselves) in which all the threats are accurately located with the aid of timely intelligence data. The astronauts could be reasonably confident that there wouldn't be anybody on the moon shooting at them, but that would not be the case for Special Operations Forces on missions to such areas as the Middle East.

On an Evans & Sutherland ESIG-1000 computer image-generation system, a NASA space shuttle is shown undertaking a space mission.

Furthermore, in the increasingly threatening environment of electronic warfare, mission success will depend on sensor data from outside the narrow visual portion of the spectrum. These data can also be computer-generated during mission rehearsals. So can fog, smoke, and haze. Just as the new sensor suites are intended to give fighter aircraft all-weather, day/night capabilities, their supporting mission-rehearsal simulators must do likewise.

George H. Branch III, manager of military marketing at General Electric's Simulation and Control Systems Department in Daytona Beach, Fla., sees a trend toward greater reliance on nonvisual data in both training and actual missions. Ten years ago, the out-the-window view amounted to 100 percent of tactical-warfare simulation, he says. Today it's seventy-five percent and dropping. He sums up the situation succinctly: "There's more avionics to simulate."

These nonvisual data, which occupy much larger portions of the electromagnetic spectrum, include forward-looking infrared (FLIR) and narrow-field infrared, synthetic aperture radar, night-vision goggles, and low-light-level TV (LLLTV). This increased data flow requires sensor fusion techniques to funnel vital information to the pilot *[see "Sensors Across the Spectrum," November '87 issue]* in both the operational vehicles and the mission-rehearsal simulators.

On GE's Compu-Scene V (above), a simulated MH-53J helicopter flies over Nevada. The real thing is shown below. The MH-53J weapon system trainer, now being developed for the Special Operations Forces, uses specialized simulation computers that are much faster than the most powerful supercomputers of today.

Fifty Billion Instructions

That, in turn, increases the need for computer power to run today's state-of-the-art CGI simulators. For example, the MH-53J helicopter weapon system trainer, which GE is developing for the Air Force's Special Operations Forces, uses a combination of general- and special-purpose computers with processing speeds ranging from ten to fifty billion instructions per second, according to Mr. Branch. That is much faster than even the most powerful supercomputers of today, although the two classes of machines aren't quite comparable because of the specialized nature of simulation computing.

The data-storage requirements are equally demanding. To simulate a 300,000-square-mile area of the United States used for Air Force training exercises (essentially from Arkansas to Kentucky and parts of California), GE used four 300-million-byte disk storage devices. To simulate the 3.6 million square miles of the fifty states would require twelve times that amount. Of course, for mission rehearsals the areas to be simulated would be mostly in the Eastern Hemisphere, and the database for that is available from the Defense Mapping Agency and from what are known in the trade as "national technical means."

The visual fidelity of CGI simulators is good and getting better, to the point where further improvements may not be necessary. As a rough measure of the capability of the human eye, if the normal field of view is digitized, it amounts to about a million pixels (picture elements) of direct vision and roughly another million pixels of peripheral vision.

Today's CGI simulators update the scene sixty times a second to give the illusion of reality. The human eye cannot sense individual pictures at rates greater than twenty-four a minute; therefore, that is the rate used in motion pictures (although each frame is projected twice to eliminate the jerky motion of the early silent films).

This rate, providing a further smoothness of motion, is essential in interactive mission simulations because conflicting visual cues can cause motion sickness among the trainees.

Thus the computational requirement for CGI is dictated by the need both to provide at least a million digitized picture elements per scene and to do it sixty times a second. That's where today's computers built out of very-large-scale integration (VLSI) components have taken over, muscling out TV model boards in the process. "The picture quality is there," says Mr. Branch. "No more pixels are needed."

Antithesis of "Simnet"

This approach of high fidelity, rel-

The Air Force did not introduce visual simulation in trainers until the recent F-16 upgrade program. The new F-16 simulator (above), a relatively low-cost system, is not a traditional full-mission simulator, but its field-of-view device can simulate takeoffs, landings, and some missions with convincing realism (below).

atively high costs, and limited interaction for simulators based on powerful stand-alone central computers can be thought of as the antithesis of the Defense Advanced Research Projects Agency's Simnet (simulator network) approach. Simnet uses low-cost distributed computers to produce maximum interaction among participants in training exercises, but at this point it is capable of only relatively crude graphics *[see "Planet Simnet," August '89 issue, p. 60]*. It is reasonable to expect that, in the future, these approaches could converge to create even more powerful simulators.

According to Michael R. Willmore, a staff scientist at Link Flight Simulation, Binghamton, N. Y., a division of Toronto-based CAE Industries, effective mission rehearsal depends on countering three kinds of uncertainty: situational uncertainty, probabilistic uncertainty, and operational uncertainty.

Situational uncertainty applies to the purely physical nature of a region where the conflict is to be modeled, essentially terrain and weather. Probabilistic uncertainty includes the capabilities of the weapons that all the participants bring to the battlefield: system performance, reliability, probabilities of hit and kill, even electronic signatures. Both of these are well within the realm of current simulation technology, Dr. Willmore maintains.

The outlook is not so bright for operational uncertainty. Dr. Willmore calls it the most difficult aspect of warfare to simulate or even account for in reality. It is the result of how cohesively the command structure is organized, how efficient the control processes are in directing force responses on the battlefield, and the connectivity strength of communications systems in passing essential information among the entire command control and communications (C^3) architecture.

"It is pointless to design a static threat simulation for mission rehearsal that can only record and play back one presupposed set of conclusions about the mission environment or what the conflict should look like during mission rehearsal," Dr. Willmore states. "Such 'tactical' simulations, created by writing scripts from a set choreography, cannot possibly respond to the dynamics generated by a single participant, let alone several others who may be operating together as a mission unit.

"Instead, mission rehearsal should serve as an adjunct to the final mission planning activity that occurs just prior to executing tactical missions in reality," he continues. "Participants explore the planned missions by asking themselves, 'What if we did this?' and 'What if the enemy does that?' and 'What if this happens?' and the entire litany of other questions designed to better prepare themselves for the uncertainty at hand."

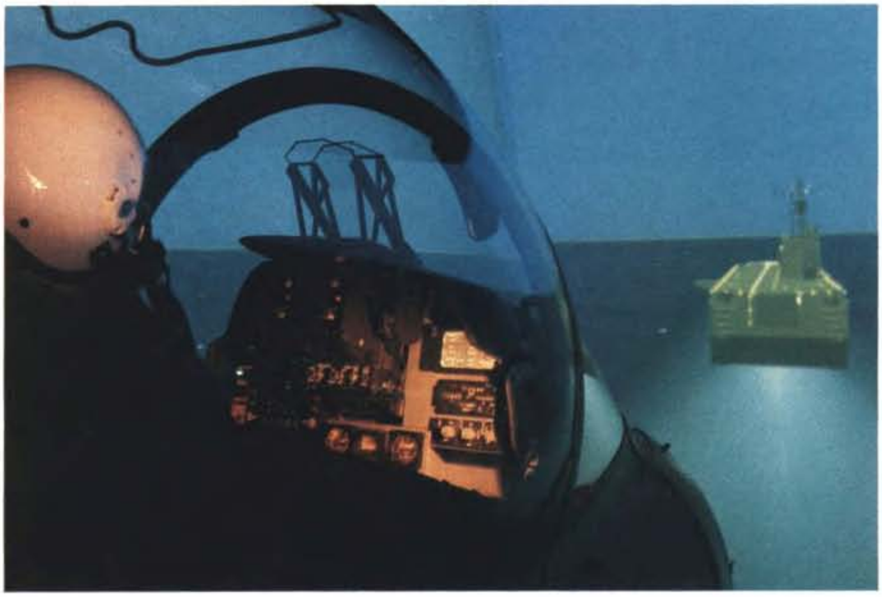
High Costs—For Now

Then there's the issue of costs. Simulators aren't cheap. GE's MH-53J system, for example, is projected to cost more than $30 million. But they are getting cheaper, at least on a cost-per-function basis. Through the use of VLSI components (and soon, it is hoped, transportable software), simulators are getting smaller, cheaper, and easier to support. Mr. Branch estimates this price decline at about ten percent a year, but he cautions that simulator prices are likely to remain steady because the military customers are likely to opt for increased performance instead of lowered system costs.

A rule of thumb in the industry is that the customer will pay about ninety percent of the unit cost of the aircraft for its simulator. In the case of the Air Force's Advanced Tactical Fighter (ATF), which has a projected $35 million program unit cost, that means a likely ceiling price of close to $32 million for the simulator.

Development of the simulators for ATF, as well as those for the X-30 National Aerospace Plane, the aircrew training system for the Special Operations Forces, and the upgrade of the F-16 simulators, are all managed now out of the System Program Office for Training Devices (still referred to as SIM/SPO) under Col. Wayne Lobbestael at Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

This is a departure from past Air Force practice, in which the simulator efforts had been under the SPO managing the weapon system development. The Army and Navy have centralized their simulator development and procurement under the Program Manager for Training Devices (PM-TRADE) and the Naval Training Systems Center, respectively, both located in Orlando, Fla. Centralizing the simulator effort removes it by at least one step from the budgetary pressures that normally afflict weapons development programs—a distinct advantage.



At the Marine Corps Air Station, Cherry Point, N. C., a Marine Corps pilot in a McDonnell Douglas Operational Flight Trainer lands an AV-8B Harrier II light attack aircraft on a deck of a simulated carrier. The trainer's digital recording system adds realistic sound as part of the mission simulation.

Navy, USAF Take Different Paths

Because of the differing natures of their tactical air missions, the Air Force and Navy have taken different approaches to flight simulation. Since Navy fighters customarily operate off the decks of aircraft carriers, the Navy early on recognized the benefits of simulation to reduce the number of risky carrier operations. A classic example is an engine flameout during a carrier landing, something no pilot wants to practice in a real aircraft.

The Air Force has not felt such a need for flight simulators and did not introduce visual simulation until the recent F-16 upgrade program recently won by Evans & Sutherland of Salt Lake City, Utah. Dave Eccles, manager of strategic planning at E&S, describes the new F-16 simulators as relatively small field-of-view devices capable of simulating takeoffs and landings and some missions—but not traditional full-mission simulators. These are also relatively low-cost, estimated at about $1.5 million apiece.

But Mr. Eccles sees other forces at work that may win further customer acceptance of flight simulators. His company recently received a contract to supply at least six low-level flight trainers for the West German Tornado fighter, and this may be a bellwether for future procurements. Just as one of the purposes of DARPA's Simnet is to prevent tanks from tearing up farmland and causing intolerable traffic jams in West Germany, simulators for tactical aircraft in the NATO environment can be a force for better relations among NATO allies.

Looking beyond these current applications of flight simulators, Mr. Branch of GE traces the impact of size reduction made possible by new electronic components. GE's original Compu-Scene II system, introduced in 1980, consisted of twenty-six cabinets, each standing about six feet high and weighing 900 pounds. Compu-Scene V, introduced at this year's Paris Air Show, dropped that to six cabinets, and Mr. Branch says the next goal is to get an entire simulator into a single cabinet.

At 900 pounds per cabinet, the simulator could easily be installed on board an aircraft the size of a USAF C-5 transport to permit embedded training during normal flight operations. Another order of magnitude reduction, down to ninety pounds, would put that capability within reach of the ATF.

The Totally Enclosed Aircraft

Given the increasing importance of nonvisual sensor data, future derivatives of today's flight simulators might entirely replace the out-the-window view. Submarine commanders have been doing this for years. They rarely peer through periscope eyepieces anymore; the sensor data are funneled to them through a variety of mast-mounted devices and displayed in the submarine control center on television screens. This enables submarines to reduce their visibility to enemy forces.

In the case of high-performance fighters, it might be more efficient for the pilot to be in a supine position monitoring the sensor data over CCTV during periods of high G-forces. This approach could eliminate the traditional cockpit entirely, which would be valuable in reducing the aircraft's radar cross section. Pilots are already overly task-loaded with through-the-window data, and the use of sensor fusion could eliminate extraneous information. The value of sealing off the aircraft in a nuclear environment is obvious.

Taken together, these potential capabilities of CGI give this technology the edge for a variety of future applications. TV model boards put Americans on the moon and performed many other valuable functions, but today their importance has shrunk to what Mr. Eccles of E&S calls the equivalent of HO-scale railroad models. ■

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