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Technology Leaps All Around Propel Advances in Simulators

by Ian W. Strachan

Ever since Edwin Link developed his “blue box” in 1928, it has been obvious that computer-based simulation is a powerful technology. Link originally had difficulty in selling his concept to the U.S. Army Air Corps, but a series of aircraft crashes during instrument and night flying forced the issue in the 1930s.

The Link Trainer was rescued from being merely a curiosity and fairground attraction, and its serious training potential was recognized. During World War II, virtually all allied pilots were trained in instrument flying in the “blue box,” and a few other simulators and training devices were produced for aircraft, gunnery and navigation systems. By the end of the 1950s, replica cockpits with analogue simulations had been developed for the more expensive aircraft, but were regarded as secondary to training on the real vehicle.

During the 1960s and 1970s, developments in simulation included the replacement of analogue systems by digital, better modeling of vehicle characteristics, more powerful computing, and viable visual and hydraulic motion systems. Indeed, what had been developed by the end of the 1970s was the first standard of what is known in civil aviation terminology as a full-flight simulator, or FFS.

Well into the 1970s, the aircraft itself continued to be used for hazardous training. The events of the 1930s, which led to the acceptance of the Link trainer, were repeated, in the form of a string of fatal accidents on crew training sorties, particularly involving engine-failures.

According to the Federal Aviation Administration (FAA), in the period 1962-72, eight aircraft and 41 lives were lost on crew training sorties being carried out under FAA regulation. These mishaps resulted in the deaths of six FAA flight inspectors and 13 people on the ground. One result was a directive from the U.S. National Transportation Safety Board (NTSB) to investigate safer ways of carrying out such training, and the solution was found through systematic application of modern simulation technology.

‘Zero Flight Time’

In the mid 1980s, advances in technology had progressed to the extent of allowing the FAA, the United Kingdom’s CAA and then the European JAA to adopt rules for the “Zero Flight Time” (ZFT) concept for recurrent training. This allows the use of high-quality flight simulators, instead of the aircraft for crew training sorties and also for conversion of already experienced pilots to similar types of aircraft to those on which they are already qualified.

The characteristics of such flight simulators are specified, tested and supervised by the appropriate regulatory authority. The FAA level D simulator now has become the norm for training in airliners of any size. Indeed, the concept has been so successful that there has been talk of a level E simulator, which could have enhanced fidelity. This could include not only visual and motion cueing, but also areas such as radio communication, radio background, and the ability to network with other flight simulators and with simulators for air traffic control.

On the military front, statistics on training and other accidents are more difficult to find, but they are estimated to exceed civilian figures many times over.

In the past, accidents on training sorties generally were accepted as an inevitable consequence of preparing for emergency situations. At times, more pilots and aircraft would be lost practicing engine failures than from real failures. In many ways, acceptance of training accidents in the military remains to this day. The culture is difficult to change, since the military is its own regulatory authority and has a more hazardous operational role than its civil counterpart.

It is, therefore, difficult to separate the training tasks concerned with basic operation of the vehicle itself from realistic training for operational applications of the vehicle and weapon systems.

A systems emergency can occur when involved in combat, caused by random parts failure, human error or battle damage. However, the increasing power of simulation has allowed military training devices to become much more than expensive procedures trainers. For large military aircraft, the civil level D standard is often rightly specified for the basic simulator build-standard, with additions for military tasks, such as low flying, air drop and air refuelling.

The balance between simulator and aircraft—in the case of fighter and attack aircraft training—is more difficult. Simulation technology often is used to free the aircraft for activities not possible in a simulator.

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The current Distributed Mission Training (DMT) concept advocated by the U.S. Air Force shows that the “simulation nettle” finally is being grasped. Young fighter pilots, brought up on video games, will expect no less. Amongst other improvements, high-resolution visual scenes now are used in mission rehearsal tasks, both on simple workstations and in full simulations. This applies both to pre-planned databases and also to rapidly-developed new ones.

The spin-off into simulation technology is significant. Back in 1996, in Albuquerque, Edward McCracken (then chairman of Silicon Graphics) said that high-resolution visual imagery was no longer being driven by Pentagon requirements, but by the games industry.

Perhaps traditionalists in the simulation industry did not believe him at the time, but recent releases from companies such as Sega illustrate the point. And because companies operating in the simulation market also sell in the games area, there is direct spin-off in system features, architecture and price.

At that time, Anita Jones (then the Defense Department’s director of research and engineering), announced that a number of simulation standardization protocols would become mandatory for the award of Pentagon contracts from 1999 onwards. Standards such as DIS/HLA, US MIL-STD 1820/1821 are now part of all U.S. military simulator requirements. They also are used by many other countries in specifying their simulators and training aids.

Applications of Technology

Simulation technology applies equally to ground and sea vehicles, weapon systems of all types, offensive and defensive, missiles and guns, electronic warfare, maintenance training, medical training, war gaming at all levels, laser-based tactical engagement systems (TES), sonar and acoustics, and so forth.

Illustrations of the technology and capability now available can be seen in various projects. One significant project is the Air Traffic Control (ATC) simulator at NASA Ames, on the southern end of San Francisco Bay in Silicon Valley. The system is called Future Flight Central (FFC). The ATC tower simulation has a full-size replica visual control room with no less than 12 visual windows and full 360-degree cover.

In addition, local and area radar cover is simulated in a full-size, replica control room below the visual tower simulator. This is the most capable ATC simulator in the world, according to NASA. It is used for testing different scenarios and for optimizing ATC procedures, rules and layouts. Once tested, these then can be applied to real-world situations. It has been operational for several months.

The second example of state-of-the-art technology is the National Advanced Driving Simulator (NADS) of the U.S. Transportation Department’s National

Driving Simulator (NADS) of the U.S. Transportation Department´s National Highway Traffic Safety Administration. NADS is about to become operational at a specially prepared site on the University of Iowa campus. It uses one of a set of full-size, real, instrumented vehicles that can be mounted in a flattened visual projection dome, with a high-resolution 360-degree visual scene. The dome is on a large six-jack (hexapod) motion platform.

The entire platform and dome stand on rails, which in turn are mounted on a lateral transit system. The result is that the hexapod can be moved 64 feet along the rails, and the rails can be moved a further 64 feet sideways.

The reason for this unique arrangement is to obtain larger sustained accelerations than would have been possible with the hexapod alone. This is useful in studying crash and emergency situations, particularly side impacts

This system has substantially increased performance over the EADS (formerly Daimler) vehicle simulator that has been operating in Berlin for several years and was last updated in 1995. The Berlin simulator also has a dome and a large hexapod motion platform that can move an extra 5.6 meters along a rail, propelled by a hydraulic ram.

Visual systems with full 360-degree cover also have been used in a number of ship bridge simulators. The replica bridge may be mounted on a motion platform, and a number of these devices are networked with simulators for other ship functions such as machinery, operations rooms and weapons. These simulators are expensive, but so are the ship systems that are being trained, as are the penalties for failing to train. Other ship systems that can be simulated include the operations rooms, propulsion, power and other machinery, sonar, and specialities such as mine warfare and electronic warfare. Submarine operations, including sensors and weapons, can be simulated in the same way as those for surface vessels.

Most activities on land can be simulated as well—ranging from vehicles of all sorts up to the main battle tank, anti-aircraft and anti-armor weapons, direct and indirect fire, small arms, and weapon effects. These can be linked using coded lasers to replace live rounds, in the so-called tactical engagement simulation (TES) systems. Such systems can replicate many different vehicles and weapons, and can be used for field exercises. On the civilian front, growth areas include driver training and simulation training in the medical field.

Simulator Costs

A typical FAA/JAA level D flight simulator costs about $15 million. This may be considered expensive, but has to be compared with the costs of using real aircraft for training. A presentation at a conference of the Flight Simulation Group of the Royal Aeronautical Society, in London, indicated that for a Boeing 747, the cost ratio was in excess of 1:40 in favor of the level D simulator. For a military fighter, the range was between 1:15 and 1:20 in favor of a similar standard of simulation, depending on the nature of the aircraft and the simulator.

Indeed, it is now inconceivable that system failures should be trained on the aircraft, due to the risks involved. And in training scenarios such as electronic warfare in a complex multi-threat environment, modern simulation offers the only way of realistic training, short of real operations. The more expensive the equipment is to purchase and to maintain, the more cost-effective training by simulation is likely to be.

At the other end of the complexity and price scale is the large range of PC-based simulators and training devices. These vary from computer-based training (CBT) systems, to simulators and part-task trainers that use a PC or an array of PCs instead of a mainframe or an intermediate-level computer. Such devices can be applied to land, sea or air vehicles, and weapons and systems of all sorts. They can be cost-effective for the level of training offered, which is likely to be part of the total task, hence the term “part-task trainer.” However, the computer is but one of the systems and components which make up a simulator or training aid.

Image generation (IG) cards incorporated into a PC are now producing similar, if not better, imagery than some systems of the 1980s that used to cost $1 million per channel. In addition, images in the wider visual spectrum can now be simulated relatively cheaply. This includes infrared (both near and far), intensifier imagery, and radar of all wavelengths.

More advanced IGs are now capable of reproducing textures, shading, shadows, time-of-day effects, reflections, glints, moving and photo-based textures, visibility variation, cloud modeling, weapon effects, sea-state and water surface modeling, and high-resolution real-world scenes derived from satellites, ground and air photos, and maps.

Large and complex mechanical components of simulators have come down in price during the past 10 years. For instance, competition has brought down the cost of motion platforms. Such platforms are not in short supply and are available in all shapes, sizes and cost.

As well as those employing hydraulic jacks, electric platforms are now available in all sizes. Most of these operate through screw jacks, but platforms also are available with electromagnetic pistons and a minimum of moving parts. According to Jane’s Simulation and Training Systems, out of 140 types of motion platforms available worldwide, 74 have the full six-degrees of freedom and 61 are electric. Transport delays (latencies) have improved significantly over the platforms of the 1970s and early 1980s, which had delays as high as 300 milliseconds. This often hampered proper integration with visual cues. Latencies, even of large hydraulic platforms, are down to 100 milliseconds or so, and some manufacturers claim less than 25 milliseconds for small electric platforms with light payloads.

Further, the integration of platform motion with other cues, such as visual, is now understood and is achieved with high fidelity. The body motion sensors, now understood and is achieved with high fidelity. The body-motion sensors, such as the inner-ear semicircular canals, are basically acceleration transducers. They also have thresholds at low magnitudes below which they do not signal the brain. This is why pilots cannot “blind fly” for anything but short periods without the benefit of gyro instruments. It is also why the principle of “acceleration-onset cueing” that is used in simulator motion platforms, is able to match the way the body sensors work in the real world.

There is some argument about so-called “unusual position” training, but it has been noted that the Boeing 737 roll upsets have been reproduced in a good quality simulator with motion. And the early Space Shuttle’s longitudinal, pilot-induced oscillation was tuned out by using a simulator with motion—when a simulator without motion failed even to find the oscillation in the first place. Good cues of real motion are therefore available, except for high continuous Gs. A number of simulation techniques can be used to back up motion platform movement for the basic low-G cues. These include the use of special motion-seats, helmet loading, anti-G suits with a simulator-specific pressure schedule, and visual effects of high G such as loss of color vision, gray-out and black-out.

Visual Display Systems

Wide-angle systems continue to be improved. The FAA requirement for a 60-degree vertical field-of-view for helicopter simulators was achieved by SEOS Corporation in 1998, and several manufacturers are now producing such displays. Systems using direct screen projection, domes, partial domes, and other wide-angle displays are available.

Head-mounted displays are now available that are cheap, lightweight, and have a good quality of visual imagery. With the advent of commercial high-definition TV display standards, VGA and even SVGA display systems soon will be superseded.

Other simulator components include replica controls and panels, to avoid using expensive real parts from the vehicle or system being simulated. Also instrumented gloves and touch-sensitive devices, small 3-D tracking devices, sound and audio simulation, electronic warfare and other systems properly stitched in to the main simulation and training scene.