

Flight Simulation

Simulators are increasingly employed to train pilots for complex tasks. Generating the accompanying visual scene continues to present a challenge to computer technology

by Ralph Norman Haber

Most pilots learn to fly today just as they have for 75 years—with their hands on the controls of a real plane in real flight. They may begin with an instructor sitting beside or behind them, but as soon as they can land safely most of the rest of the training is done solo. Consequently learning to fly has posed increasingly severe problems as the performance capacities of planes increase and as the multiple demands for the pilot's attention escalate.

Whereas a World War II fighter plane could barely exceed the 250-mile-per-hour speed of the race cars at the modern-day Indianapolis Motor Speedway, today's fighters routinely fly two to five times as fast. More important, their maneuverability at the higher speeds means that reaction times for responses have to be incredibly quick. Even at a lazy 600 knots a plane travels more than 1,000 feet per second—a mile every five seconds. Moving at such a speed in level flight at an altitude of 1,000 feet, the plane will collide with the ground in 20 seconds if the ground slopes upward at a 5 percent grade, a slope often difficult to detect from the air. The collision time drops proportionately with altitude and becomes only two seconds for flight at an altitude of 100 feet. Two seconds may still be enough time to avert disaster—except that the pilot may also be listening to a warning from a wingman, or looking behind for a possible attacker, or preparing to attack a target already in sight ahead. Even with only a few of these added tasks 20 seconds may not be enough time to avoid crashing.

How can pilots be trained for such complex tasks without killing them in the process? The preferred solution, introduced during World War II, is the flight simulator, in which the pilot can practice many flying tasks while sitting safely on the ground. He or she

can even practice responses to unlikely events, particularly those that might lead to disaster.

A commonly encountered relative of the aircraft flight simulator is the automobile driving simulator. In the automobile simulator the car windshield is replaced by a projection screen on which a roadway scene is displayed. A preprogrammed motion picture presents challenges to the driver, who must react to them. Other cars approach, for example, or the road turns or highway signs and signals appear. The driver's task is to control the car by operating its steering wheel, gas pedal and brake. This type of simulator has a major limitation: the handling of the controls by the driver does not produce a corresponding change in the scene displayed on the screen. Turning the wheel does not allow the driver to see or feel the car turn. Nearly all automobile simulators are of this "open loop" type.

In a "closed loop" system, in contrast, the use of controls does produce changes in the scene. To close the loop in a simulator the scene being presented must actually exist either as a physical model or as a program in a computer. When a physical model is used in a flight simulator, for instance, a moving camera photographs the model from the position in the model occupied by the aircraft and moves as the craft moves. In this way the pilot sees the part of the model over which the plane is traveling, so that if the pilot speeds up, the camera speeds up correspondingly, and if the plane turns, the camera turns too. When the air scene is constructed by a program in a computer, instead of using a physical mod-

el, the computer generates an image of that part of the scene directly in front of the plane. The scene changes in relation to the movement of the plane. Both procedures depend heavily on computers.

Flight simulators are now used to train people for each crew position in every type of fixed-wing aircraft, helicopter and spacecraft. I shall focus on pilot training in jet-fighter aircraft because it is here that simulation poses the greatest difficulty. The combined effects of high speed and low altitude make it a technological challenge to change the visual scene and the apparent motion of the simulator realistically in response to the pilot's actions.

The basis of a typical jet-fighter simulator is a real cockpit and seat without the rest of the plane. The cockpit is enclosed by a projection surface on which the visual scene is shown. To simulate the motion of the plane the cockpit is mounted on a platform that can be moved up and down and from side to side as well as tilted. As the pilot operates the controls of the aircraft both the visual-scene content and the sensation of aircraft motion change. The simulator can also reproduce the sensation of atmospheric turbulence.

The cockpit (surrounded by the image-producing devices and mounted on the motion-producing platform) is generally in a room by itself. A separate control room contains the associated computer, from which all aspects of the simulated flight are supervised, monitored and recorded. The simulator is usually monitored by an instructor pilot who is in communication with the pilot in the simulator. The instructor can enact the role of wingman, ground control or mission control, and

SIMULATED LANDING of an AV-8B Harrier II light attack aircraft on the deck of a carrier is demonstrated by a U.S. Marine Corps pilot. The training system, which is known as an Operational Flight Trainer, was developed by the McDonnell Aircraft Company.

he can also manipulate or interfere with the various tasks to be done by the pilot. The instructor can, for instance, move targets, fire surface-to-air missiles, make other planes appear and even attack, suddenly change the weather, cause the plane to malfunction, amend the student pilot's orders and in general produce realistic chaos.

How are such simulations created? The first step is to make a model of the terrain over which the flights are to take place. The content and detail of the model are determined by the training task. The earliest models were of airfields or aircraft carriers, because flight simulators were first employed primarily for practice in takeoff and landing. Other models are of tanker planes in an otherwise empty sky (to provide practice in air-to-air refueling) or of one or more fighter planes (to simulate air-to-air combat). Recent models have included larger stretches of ground over which low-level flight

can be simulated. Such terrain can also include targets to be observed or attacked, surface-to-air missiles to be evaded and, of course, natural features to be avoided.

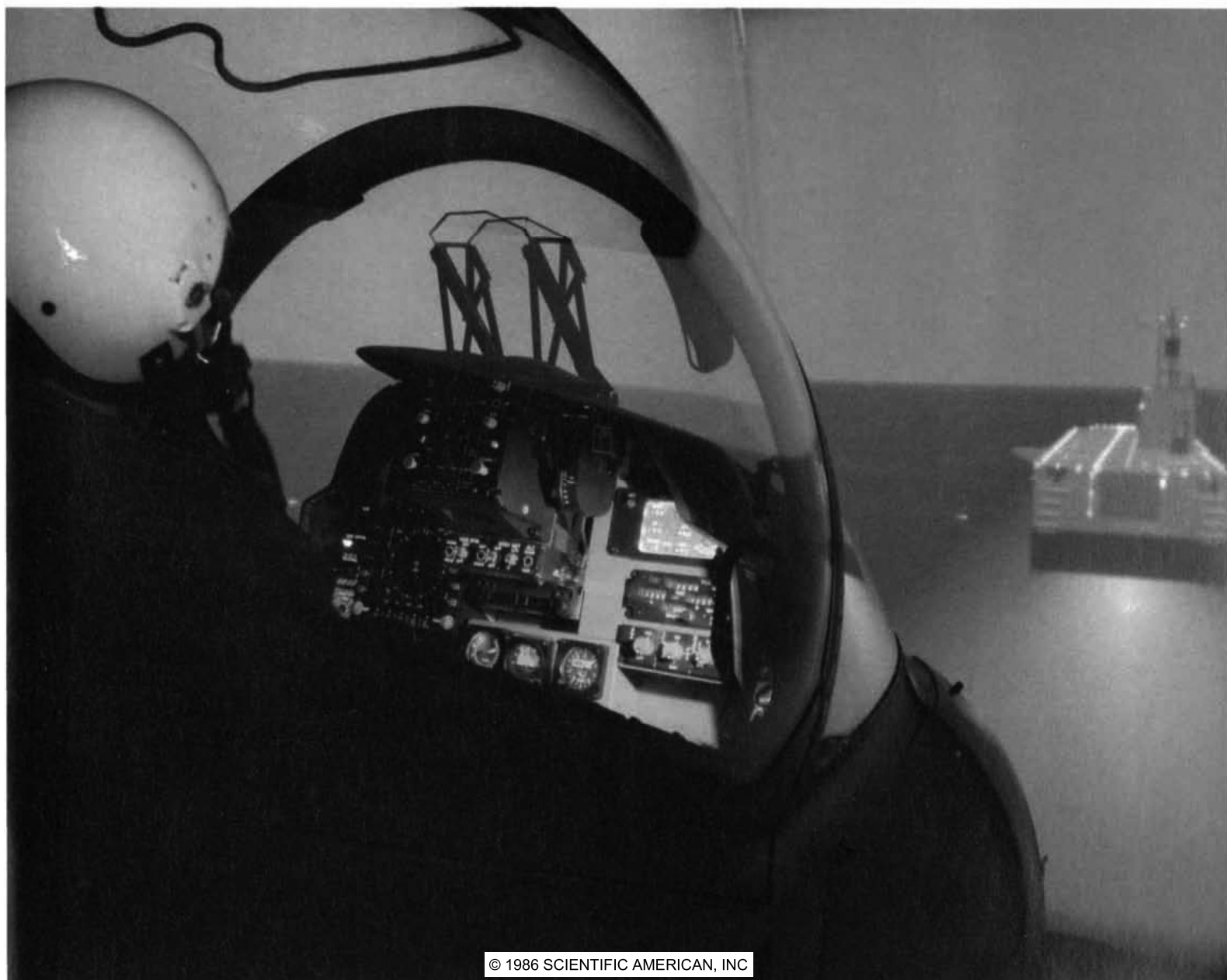
The model begins as a conceptual description, which is currently realized in one of two ways: as a physical board model over which a camera is "flown" or as a computer program capable of generating and displaying an image. In either case the image of the scene is displayed to the pilot on a projection or video screen.

A typical board model might be 30 by 60 feet, scaled to represent about six square miles of terrain. The flight controls operated by the pilot in the simulator cockpit are connected to high-speed motors that move a video camera over the board exactly as the plane is made to fly; the movement of the camera is in scale with the model.

The main advantage of the board model is the tremendous detail it can present—something no computer im-

agery system is ever likely to duplicate. The effectiveness of the board is limited by how close to the surface the camera lens can be flown. A pilot in a plane on a runway might be 10 feet off the ground, which corresponds to a distance of less than half an inch off a modeled runway constructed at a scale of 300 to 1; this is closer than the lens can be positioned without risk of damage. Moreover, at that small distance normal lenses do not have enough depth of field to simulate the sharp images a pilot would ordinarily see. Newer techniques using laser sensing scanners are being developed to solve both technical problems.

Board models are expensive to construct, cumbersome to alter and limited as to the size they can represent. They are also noninteractive: objects do not move or disintegrate in a puff of smoke when they are attacked. Because board models are small, they are also quickly memorized during repeated practice. They are therefore effec-



tive only for the simulation of repeated flying tasks near the ground (particularly landing), flight over difficult target areas or flight in which extensive surface detail is required, as it is in hovering practice for helicopters.

Computer-generated imagery is far more versatile, and a growing number of jet-fighter simulators use scenes generated by a computer. The first step is to develop a conceptual model similar to a physical board model, except that its size is limited only by the amount of memory and speed of the computer. The model defines the physical dimension of the terrain, its surface texture and character and any objects and artifacts that might be on its surface.

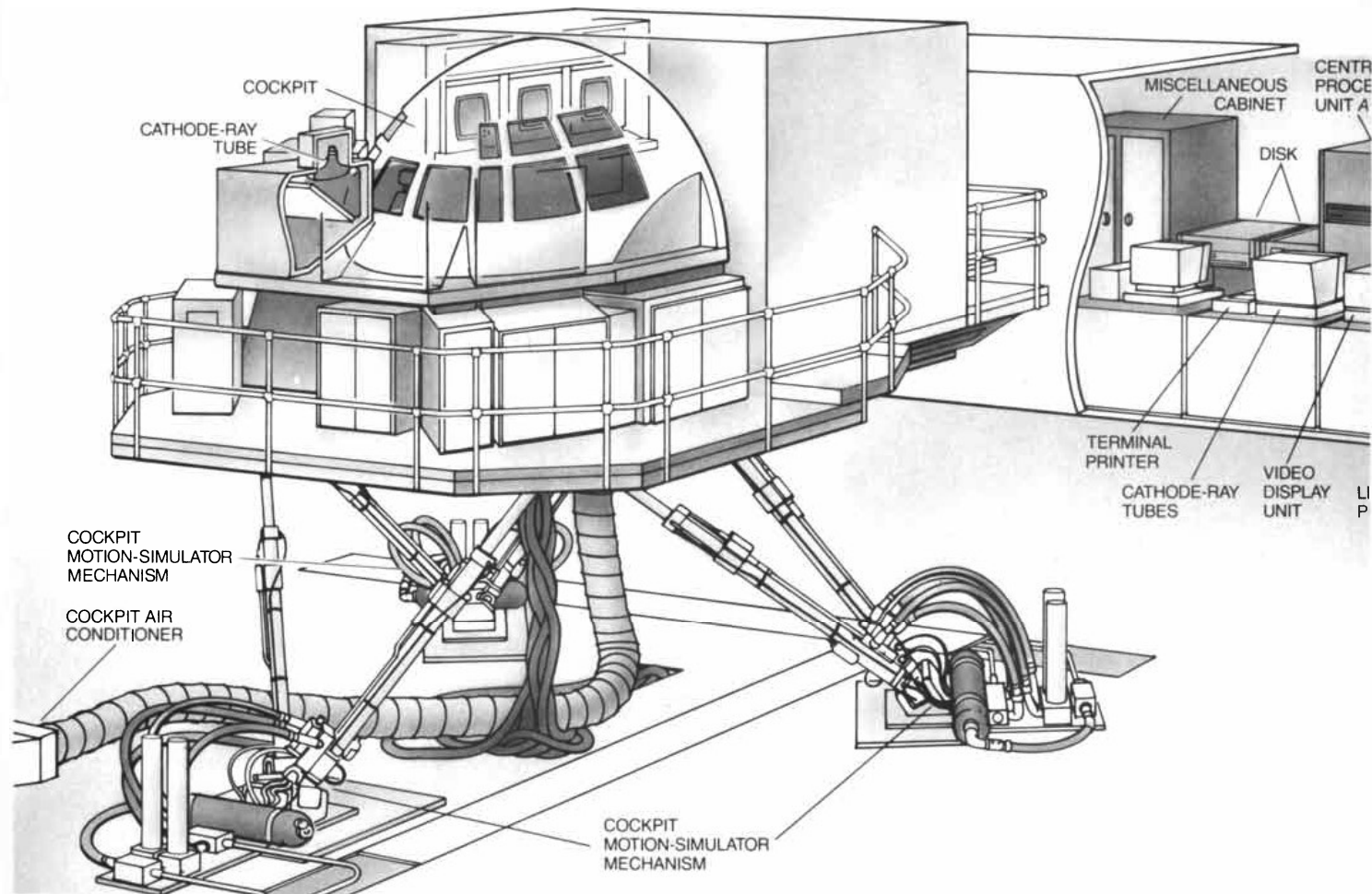
Once a model is programmed and stored in the computer's memory it is manipulated so that particular parts of it—corresponding to the pilot's view from the cockpit at a given instant—are displayed. This requires the program to compute the location of each part of the model with respect to the position of the plane. The vast major-

ity of the scene is invisible at any one time, including what is behind the plane, what is too far ahead to be visible or what is hidden behind more prominent features in the line of sight.

For terrain features that are visible the program computes the projection appropriate to the angle of regard of the pilot. A pilot flying across a square cornfield planted on level ground, for example, does not see a square image. When it is approached from a distance, the field seen straight ahead is greatly foreshortened, with the far edge shorter than the near one and the two sides converging to a vanishing point at the horizon. When the plane gets closer to the field, the sides of the field elongate in relation to the near and far edges, and the shape becomes less trapezoidal as the sides become more parallel. The field would be projected as a square only if the plane were directly over it and all four sides were simultaneously visible, and that is possible only if the plane is diving at the center of the field. The geometric transformations of a surface as a function of viewpoint are well known, but

different computer-generated imagery systems follow different procedures to achieve them.

The main advantage of computer-generated imagery systems so far has been the unlimited size of the terrain they can generate and display. Whereas board models represent only a few miles of ground, computer-generated imagery can encompass the entire vault of the sky, spanning thousands of square miles of every possible kind of terrain, from deserts to mountains. Although in theory a program can be written at any level of detail, in practice the greater the detail is in the surface texture (leaves on trees, markings on buildings, roads or runways, rocks on mountain slopes), the longer it takes the computer to generate any specific instance of the model. Since the program has to generate the model in real time as the plane flies over it, the level of detail is limited by the computer's size and speed and by its "refresh" and "update" rates. This is particularly critical when the plane is flying close to the ground. Even though computer-generated imagery



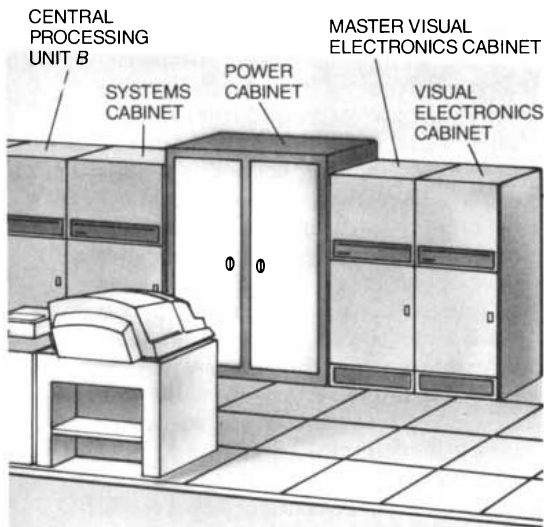
FLIGHT SIMULATOR consists of a cockpit (left) and a control room (right). The cockpit is enclosed by a projection surface (shown as a series of cathode-ray tubes) on which the visual scene is displayed. To simulate motion the cockpit is mounted on a platform that can be moved up and down and from side to side as well as

tilted. As the pilot operates the controls of the aircraft both the visual-scene content and the sensation of aircraft motion change. The control room contains the associated computer, from which all aspects of the simulated flight are supervised, monitored and recorded. The simulator is usually monitored by an instructor pilot

systems could in principle generate a scene with as much detail as that of a board model, none of them is currently capable of doing so in real time, particularly the real time demanded by rapid flight at low altitude.

To display the visual scene, whether it is produced by a board model or by a computer-generated imagery system, most simulators rely on a device known as a raster-scan cathode-ray tube, which is similar to a conventional television tube. A simple system appropriate for an airplane with only a narrow field of view to the front requires only a single cathode-ray-tube screen positioned straight ahead in the pilot's line of sight. Most fighter aircraft have a wide field of view, however. In order to create a visual scene for them a number of separate screens are positioned in front of, above, to the sides of and even to the rear of the pilot's head.

A raster-scan cathode-ray tube produces an image through the rapid illumination of discrete points, called pixels, arranged along scan lines. Home

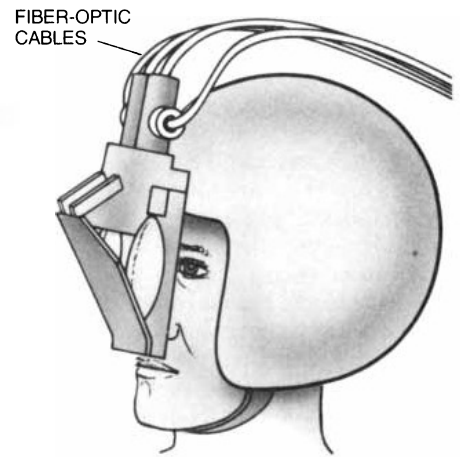


who is in communication with the pilot in the simulator. The illustration is based on the C-130H flight-training simulator, which is under development at the Link Flight Simulation Division of the Singer Company.

television sets in the U.S. have a standard number of 480 horizontal scan lines, regardless of the physical size of the tube's display area. There are 640 separate pixel positions located on each scan line, and each position can be illuminated by an electron gun whose beam moves along the line. To reduce the flickering effect of the sequential illumination of the points, the pixels on the odd-numbered rows are illuminated first, starting at the lower left-hand corner of the tube, going across each of the 240 odd rows and sequentially moving up the screen. Then the process is repeated for the 240 even rows. It takes a sixtieth of a second to do the odd rows and another sixtieth of a second to do the even rows. All the pixels needed to define the scene being displayed are illuminated 30 times per second, which defines the quantity known as the refresh rate for the cathode-ray tube.

For flight simulators the number of scan lines varies from 300 to 1,024 and the number of pixels per scan line varies from 512 to 1,024. Both variations affect the resolution of the tube: the fineness of detail that can be displayed and that can be distinguished by the viewer. For a cathode-ray tube, resolution is determined by the distance between the pixels in relation to the viewing distance. If the number of scan lines and the number of pixels per scan line are held constant, the resolution of a cathode-ray tube decreases as the screen size is enlarged in relation to the distance from which it is viewed. In other words, when a cathode-ray tube has to cover only a small visual angle, its resolution capabilities can be quite high, so that fine detail can be displayed and perceived. If, however, a cathode-ray tube has to cover a wide visual angle, resolution is reduced. To avoid reduced resolution, multiple independent tubes are mounted side by side in the simulator. The F-16 jet-fighter simulator currently uses seven 36-inch tubes, which provide a field of view measuring 300 degrees horizontally and 150 degrees vertically.

The brightness of a scene displayed on a cathode-ray tube is determined both by the light output of the cathode-ray tube itself and by the nature of any optical elements placed between the surface of the tube and the pilot. When a real scene is viewed from a fighter, its details are effectively at optical infinity. Collimating lenses are therefore placed between the tube and the pilot, so that the light rays coming from the tube are made parallel, as if they were reflected from distant objects. The scene generated on each surface of a cathode-ray tube is imaged on a diffusing screen window. Com-



PROJECTION SURFACE can also be incorporated in the pilot's helmet. The displayed image is transmitted from a projector behind the pilot through a pair of fiber-optic bundles. The system has only just been developed; several experimental prototypes are now in the early stages of testing.

pared with a normal room illumination of about 50 candelas per square meter the cathode-ray tubes in the F-16 system would generate about 100 candelas (if the tubes could be viewed directly). The collimating lenses and diffusing screen windows absorb so much light, however, that the maximum light reaching the pilot's eyes is only about one candela—closer to the light level of twilight than to that of high noon. Because the pilot is able to adapt to such a light level easily, there is little difficulty in seeing all the details of the scene. Unfortunately the low light level puts a limit on the contrasts in light possible—a limit that makes it difficult to display objects close to the lower threshold of vision.

Although cathode-ray tubes provide the visual simulation for most of the flight trainers in use today, there are two other display procedures. In one of them the scene is projected onto a panoramic motion-picture screen in front of the pilot. A system of this kind achieves slightly better resolution and brightness than a cathode-ray-tube display but otherwise has similar characteristics.

In the other display procedure the projection surface is incorporated into the pilot's helmet. This system has only just been developed, with several designs still in the testing stage. The displayed image either can come from a pair of miniature cathode-ray tubes also attached to the helmet or can be transmitted from a projector behind the pilot through a pair of fiber-optic bundles. When it is perfected, the helmet-mounted display should prove to be a highly cost-effective visual simulator because it is so small. Although

both the computer and the projection equipment are similar to those needed for other types of simulators, no external screen is required or any battery of mammoth cathode-ray tubes: everything fits in the pilot's helmet.

Because it is capable of much greater resolution and brightness, the helmet-mounted display system offers substantial theoretical advantage over other systems. Furthermore, it allows separate visual input into each eye. Research suggests that binocular disparity is useful in processing depth, and that information about depth from relative motion is also processed binocularly, yet no current simulator provides the pilot with this information.

Display and computer-generated imagery systems are not overly taxed when they are used to simulate training tasks such as air-to-air refueling, formation flying or air-to-air combat, since in each such task only one or two planes need be displayed against an otherwise empty sky. Problems in displaying details do occur, however, in the simulation of all aspects of low-level flight, including target detection, air-to-ground attack, visual and radar avoidance by flying close to the ground, and close-in support and reconnaissance.

The problems in displaying scenery for low-level flight arise for two independent reasons: more detail is needed so that the pilot can correctly perceive altitude and maneuvering room (this

demands more resolution) and the detail has to be changed faster given the rapid movement of the viewpoint from moment to moment (this demands faster update rates). The need for detail arises because the ground cannot simply be a matrix of uniform checkerboards; empty checkerboards specify little about the undulations of the ground. Without substantial added surface details and objects a pilot has great difficulty telling altitude or judging whether ridges can be cleared or obstacles avoided. If the task is one of hugging the ground as closely as possible in order to avoid detection, then richness of surface texture and detail becomes overwhelmingly important.

Three solutions have been pursued to provide enough detail for low-level flight. Since most computer systems create features by drawing straight lines or curved edges, one solution has been to demand more edges in real time. This demand is gradually being met. Off-the-shelf systems now have 10 times as many available edges as they did just five years ago, and the industry expects another tenfold increase in the next five years.

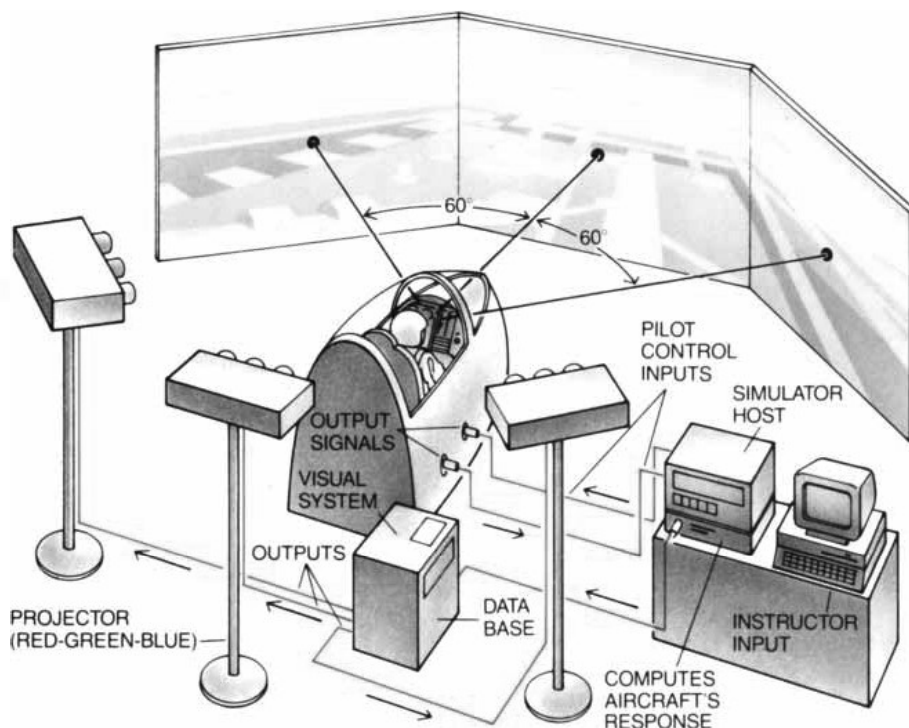
The second solution has been to add an extra high-resolution channel to the display system, one that can be moved around depending on the direction of the pilot's gaze. An eye- or a head-position sensor detects the direction of gaze at every moment. Either electronically or mechanically, the area of the scene directly in line with the direction

of gaze is displayed with a resolution much finer than that of the rest of the screen. This can be done if, instead of using each cathode-ray tube to cover a 90-degree-square area, the high-resolution channel is fed to a cathode-ray tube that covers a 30-degree-square area—a tripling of resolution. The overlapped area is blanked out of the background channels so that only one image is seen, but the display straight ahead is much sharper.

The third solution depends on deciding which kinds of detail are really necessary, and then on displaying just those. In the long run this approach will be more effective, but the research is just being done, so that only a few answers are available. One general finding appears to be that the different sources of information vary in value depending on the perceptual task facing the pilot. When the plane is flying low and fast, for example, edges used to define surface texture are less important than edges used to define changes in relative position. In other words, the information about relative motion of ground features may be more important than information about ground texture itself.

Low-level flight also strains computer-generated imagery systems because all the edges in the scene must be replotted at a very rapid rate. The refresh rate of a raster-scan cathode-ray tube is 60 times per second: the tube completely rewrites the contents of the scene every 16 milliseconds. Since the scene itself is changing, the computer must update the display to reflect the new positions of every object in the scene as perceived by the pilot. With the need for rapid change, as when the pilot flies low and fast, the available update rates for the entire scene are simply inadequate. Larger and faster computers will help to solve this problem, but more inventive display systems are needed as well.

In actual flight the pilot can see the movement of the plane across the terrain and can feel the changes in gravitational forces on him associated with turns, climbs, dives and atmospheric turbulence. These perceptions arise from visual motion information that comes to the eyes and gravitational-force changes that come to the vestibular organs in the inner ear. Most motion can be perceived by vision alone, so that the inclusion of gravitational information in a simulator is technically not necessary. Since such information is always available to pilots in real flight, however, many flight simulators include a motion platform whose movement stimulates the vestibular organs.



PROJECTION SCREENS offer yet another alternative to cathode-ray tubes as a means of displaying simulated visual scenes. The control room of a flight simulator need not be large; in some instances, such as the one depicted here, even a small microcomputer is sufficient.

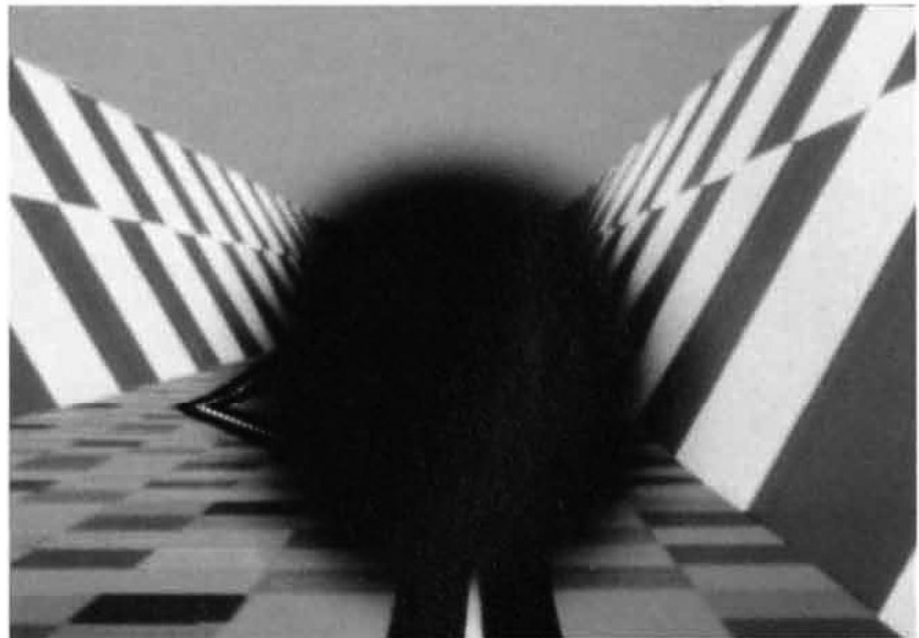
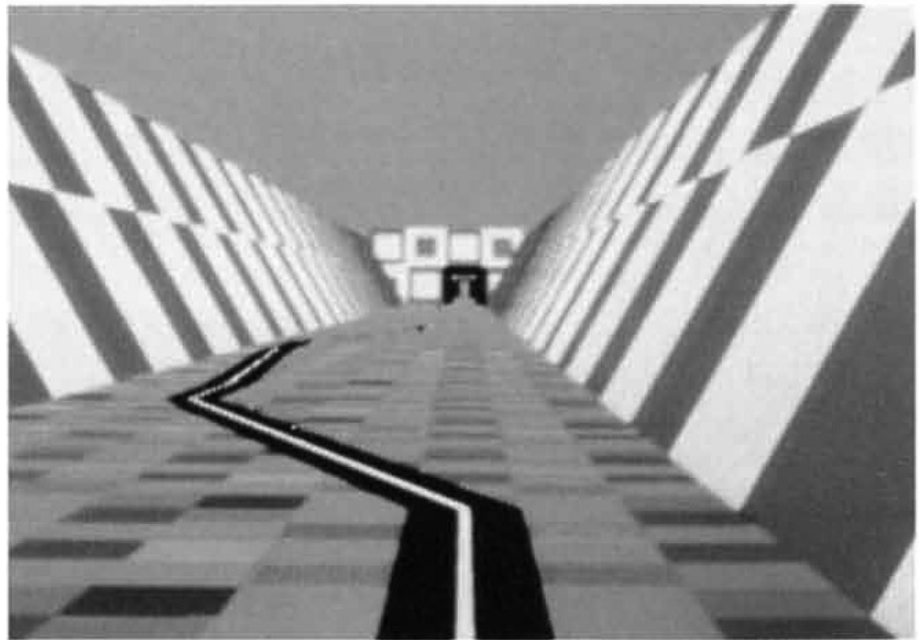
When the body is moving at a constant speed, only changes in the relative positions and sizes of objects as detected by the visual system provide information about that movement. The vestibular organs can detect only acceleration and deceleration, which are changes in the rate of motion. The changes can be in a transverse orientation, such as those felt in a car or an airplane when it speeds up or slows down. A well-tuned sports car in a jackrabbit start can produce an additional g (a unit of force equivalent to the force of gravity) of transverse force, equivalent to a momentary doubling of the driver's weight during the start. A 727 jetliner creates about 1.5 additional g 's on takeoff.

In addition to the transverse forces, changes in motion along a vertical dimension can also be felt, as in the starting or stopping of an elevator. Whenever a plane begins to climb or to bank into an inside turn, gravitational forces push the body down in the seat (positive g 's), whereas beginning a dive lifts the body out of the seat (negative g 's). In a fighter plane turning provides the strongest change in motion information. Just as the weight of a bucket at the end of a rope increases as it is swung around faster, so the plane and its pilot become heavier as the plane makes tighter turns at higher speeds.

Such changes are also expressed in terms of g forces. A roller coaster can produce up to about $+4 g$'s of lift during its sharpest turn; an F-16 jet fighter can exert more than $+11 g$'s of lift on the pilot (and plane) during a steeply banked level turn. This is equivalent to increasing the pilot's weight from, say, 200 pounds to 2,200 pounds during the turn; a four-pound helmet suddenly weighs more than 40 pounds. Although $+11 g$ turns are made only rarely, turns producing from $+6$ to $+9 g$'s are made routinely.

To produce the same sensations on the pilot's vestibular system the entire cockpit of the simulator must be moved physically to imitate the changes in speed or altitude of the aircraft. The National Aeronautics and Space Administration has built centri-

GREATER DETAIL in the visual scene of a flight simulator can be provided by adding an extra high-resolution channel to the display system. An eye- or a head-position sensor detects the direction of the pilot's gaze at every moment. The area of the scene directly in the line of sight is blanked out of the background channels (*middle*) and displayed with greater detail by means of the high-resolution channel (*bottom*). Only one image is projected; the amount of visual detail is greatest in the forward direction.



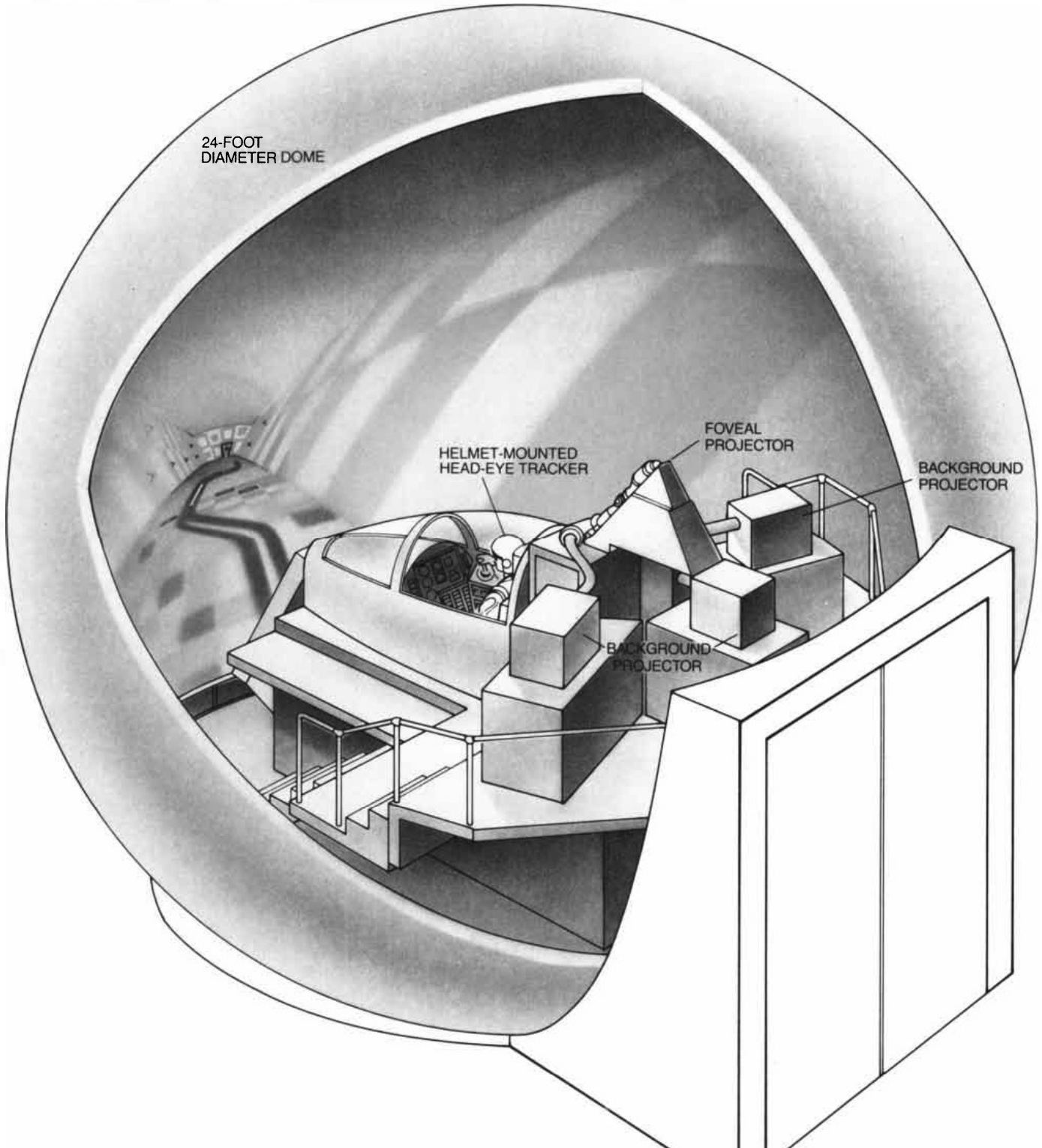
fuges to simulate the forces, which can exceed $+10 g$'s, that an astronaut experiences during the lift-off and return of a rocket. It is theoretically possible to mount an entire fighter cockpit in such a centrifuge, but that would be astronomically expensive and is probably not necessary.

Instead the cockpit is mounted on a

platform that is moved about by a set of hydraulic pistons. The distance of travel is rarely more than two feet in any direction, and the simulated forces are limited to $1.8 g$'s, enough to provide only "onset" cues to the beginning of a change in motion. The system certainly provides more motion information than no system at all, but there is

little evidence that it improves flying performance in the simulator. In training for instrument flying (necessary in fog or clouds), however, even the minimal motion cues provided by the motion platform are compelling.

A relatively inexpensive and ingenious method of simulating positive g forces is the inflatable g suit. A g



DOME-PROJECTION SIMULATOR under construction at Link will provide a continuous image over a field of view measuring 270 degrees horizontally by 138 degrees vertically. Known as **ESPRIT** (for eye-slaved projected raster inset), the system will endow the

visual area in the trainee's line of sight with greater detail than is received by the remainder of the visual area (see illustration on preceding page). The background projectors will display the peripheral images; the foveal projector will display the area in the line of sight.

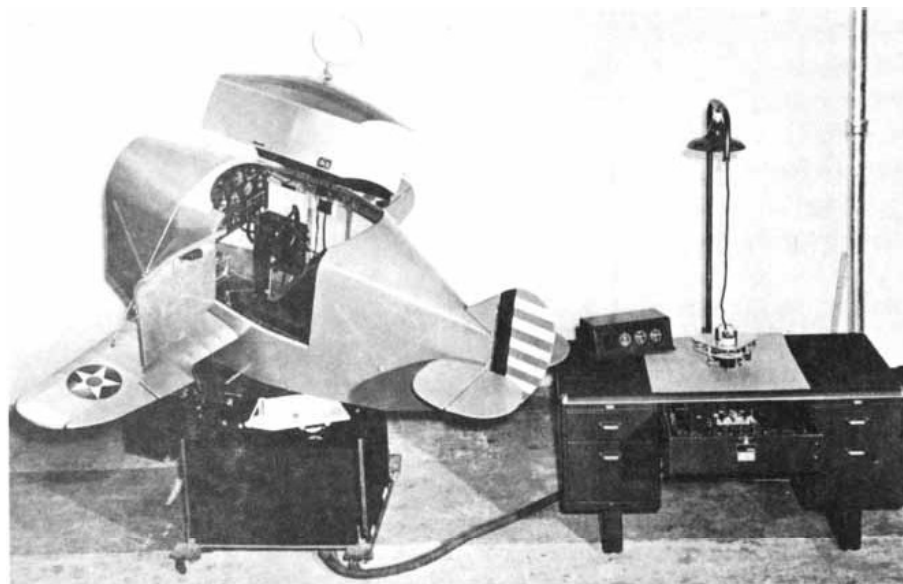
suit covers the abdomen and legs and acts much like a blood-pressure cuff around the lower parts of the body whenever positive g forces are experienced. This both increases blood pressure and retards the flow of blood away from the upper parts of the body, particularly the head. Even in a simulator without any motion platform, if the plane's motion would normally subject the pilot to positive g forces, the g suit inflates, providing a cuing sensation of a turn or a climb.

Flight simulators can obviously be justified in savings in fuel and maintenance for aircraft. Whereas it costs about \$5,000 per hour in fuel and maintenance to fly an F-16 jet fighter in training, it costs less than a tenth of that per hour to fly the F-16 simulator. More important, it costs nothing to crash the simulator, and all risk is removed that the plane and the pilot might be lost in an accident.

The strongest argument for simulators involves neither cost nor safety, however. Rather, simulators provide the opportunity to ensure training effectiveness in ways that are not possible in real aircraft in actual flight. Simulators can, for example, provide practice for responses to highly unlikely and potentially disastrous events. When a DC-10 lost an engine during takeoff in 1979, its crew had no experience with the sudden changes in stability and lift resulting from the uneven loss of power and damage to the wing. Although it is not realistic to practice such an event in a real DC-10, it is easy to simulate the effects of such changes on the aerodynamics of the DC-10 and let pilots learn to handle the emergency. In the simulator a wide variety of emergencies, failures and accidents can be experienced and countermeasures perfected.

The rate of learning can also be improved with simulated flying. Research has shown that some flying tasks are mastered more quickly and brought to a higher level of skill if the subcomponents of the task are practiced separately or in an order different from the natural one. It has been shown, for instance, that pilots learn to land better if they first practice the final approach without having to fly the earlier stages of the approach.

Simulated training also allows much greater concentration of trials. In air-to-air combat an hour's flying time may allow only three or four engagements, even though each one lasts for only a minute. In the simulator 20 to 30 such engagements can take place in an hour. As another example, in actual landing practice 95 percent of the time is spent circling and taxiing. All



EARLIEST FLIGHT SIMULATOR, the Link trainer, was used during World War II. Demands by air forces have been the chief incentive for the development of simulators.

of this can be eliminated in the simulator, so that 20 times as many landings can be made per hour of flight time in the simulator.

Some flight-training simulators are equipped with "freeze and replay" capabilities. If the instructor sees the pilot making an error, the position of the plane can be frozen and the error can be discussed and analyzed before flight is resumed. After the flight ends the entire sequence can be repeated with the computer piloting the plane just as the pilot had done previously.

The simulated scene can also add information that is not in the real scene to aid the pilot in developing flying skills or distance perception. In low-level flight, for example, pilots often have trouble at first in judging the height of objects or ground contours. To help them, artificial cues to height can be added until the pilot develops an internal scale. Then the cues can be gradually deleted from later practice.

The experiences of the major air forces in World War II, in Korea, in the Middle East and in Vietnam suggest another potential purpose for simulated training. Losses in combat are concentrated almost exclusively among pilots with five or fewer combat missions; if the fifth mission is survived, the probability of surviving the remaining ones is more than 95 percent, regardless of how many additional missions are flown. These figures suggest that if all pilots could be given the equivalent of their five combat missions before they face the enemy, losses could be minimized drastically, perhaps altering the outcome of the engagement or war.

Flight simulators could also facili-

tate comparisons of different training programs—comparisons that would otherwise be costly, risky and difficult to make. The advantages and disadvantages of each program could be examined in the course of training in the simulator. It would become possible to determine which components of existing training programs are effective and which are not and to test new ideas and procedures. This is particularly advantageous when the procedure under examination is only one part of a long training sequence.

A final justification for simulators goes beyond flight training altogether. Simulators of the kind described here are the best existing devices with which to carry out basic research on many aspects of visual perception. Is stereoscopic vision useful at 100 feet? How much information does a moving person get from peripheral vision? Can peripheral information be processed automatically without interfering with the need to focus on targets that lie straight ahead?

Experimental psychologists have asked these questions before, but up to now most research has relied on either impoverished laboratory presentation of stimuli or stationary displays and stationary observers. Flight simulation allows far better control over the presentation of moving stimuli while allowing for movement through or over the scene. It is obvious that answers to these questions can help to improve the design of simulators. More important, however, they can significantly advance understanding of how even earthbound human beings perceive their environment.