Flight Simulators

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Since thousands of U.S. and allied pilots learned to fly in the "blue box" instrument trainer during World War II, simulation has become increasingly sophisticated. Link has kept pace with advances in aerospace and supplies training systems for each new type of aircraft and also for space vehicles. The company's expertise extends into other areas, including industrial trainers, power plant simulators, naval and maritime training systems, and railroad simulators. The paper covers flight simulation and describes wide-body jet transport simulators that provide the capability and fidelity to train airline crew members in the execution of normal, abnormal, and emergency operating procedures. Military weapon system trainers are discussed, and details given of how they allow duplication of the flight environment of high-performance jet fighters, bombers, and helicopters with realistic reproduction of the radar, electronic countermeasures, and weapon delivery system. Research simulators are represented by the simulator for air-to-air combat, which has a unique large field-of-view visual system, and space simulators are included by reference to the shuttle mission simulator.

More than half a million pilots received part of their initial training during the Second World War in the original Link flight trainer. This device was a pneumatic-mechanical system in which the controls and instruments were similar to aircraft of that period. By present standards, these trainers would be considered primitive, but they nevertheless contributed to the instruction of pilots in the use of instruments and the fundamentals of aircraft control.

When a pilot sits in today's flight simulator, he or she is surrounded by an exact replica of the aircraft he or she is being trained to fly. The instruments and controls are driven by digital computers to respond in exactly the same way as would the actual aircraft. The same computers generate the aerodynamic and mechanical sounds associated with the particular aircraft as well as radio communications and also control hydraulically driven motion platforms to give the pilot the valuable sensory cues that are used to fly the actual aircraft. The scene through the cockpit window is also reproduced, and although this is not as realistic as the other inputs provided to the pilot, it has sufficient fidelity to enable many visual flight maneuvers to be trained.

A major attraction of flight simulators is that they allow all of the time allocated for training to be usefully employed. When an aircraft is used for training, a considerable amount of time may be wasted in waiting for take-off or approach clearance and, of course, in the real-world the training mission will be highly dependent on weather conditions. A number of other factors also make simulators attractive for both civil and military flight training.

EFFECTIVENESS OF FLIGHT SIMULATORS

Simulators may be applied to the following phases of training:

1. Initial training,
2. Advanced training and proficiency training,
3. Crew training tactical operations, and
4. Training in skills that cannot be practiced in the real world.

All of these points are important, but the last one is obviously of overwhelming significance for the military.

The operating advantages of flight simulators are as follows:

1. Safety,
2. Continuous availability,
3. High rate of use, and
4. Low operating costs.

A simulated aircraft may be flown in the most inclement weather conditions with serious equipment malfunction and may, indeed, crash without anybody being hurt. Compare this with the obvious real-world hazard that is present in training a crew to perform an engine-out approach in one of today's jumbo jets. The flight simulator is always available for training, is not dependent on the weather or density of traffic, and is often used 16 h/day, 365 days/year.

A factor that has assumed greater importance with the ever-increasing cost of aviation fuel is the low operating costs of the simulator compared with the cost of aircraft. The ratio of operating costs may be as high as 15:1, depending on the type of aircraft, and it has been estimated that the U.S. airline industry saves 204 million gal of fuel each year by its intensive use of flight simulators. The U.S. Air Force undergraduate pilot training instrument flight simulator program allowed a reduction of 40 h/pilot in the use of T-37 and T-38 aircraft, and in one year, this represents a saving of more than 23 million gal of jet fuel.

Apart from saving fuel, the military also saves ammunition through the use of weapon system trainers. These flight simulators have the capability of training in the operation of the aircraft weapon systems as well as operational flying. Since some of today's advanced weaponry costs in excess of $10 000/round, it is easy to understand why a crew only gets to fire one per year in the actual aircraft. In the simulator, they may practice to their heart's content at almost negligible cost.

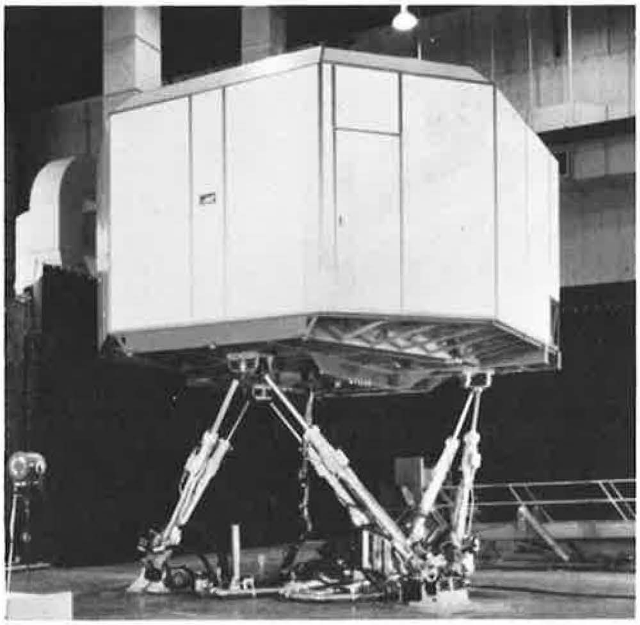
The training advantages of simulators are as follows:

1. Absolute control of the training environment,
2. Standardization of training, and
3. Automated training practice in otherwise impractical tasks.

Control of the training environment means that the instructor is able to select exactly the weather conditions that are appropriate to a particular phase of training. Through the control console, cloud base, cloud top, visibility, temperature gradient, and so on are set up. The instructor determines whether it is day, night, or dusk and the visual scene responds accordingly. The instructor has the same control over the simulated airfield lighting as does the air traffic controller in the real-world situation, and so he or she can select the runway to be lit, lighting intensity, and so on.

Parameters related to the simulated aircraft are also under instructor control, and he or she decides on the weight of the aircraft, fuel load, and center of gravity. As the simulated flight proceeds and fuel is consumed, the weight, inertia, and center of gravity of the aircraft vary accordingly, and the pilot needs to retrim the controls to maintain stability.

Figure 1. Aircraft simulator.



For each aircraft system, whether it be electronic, electrical, or hydraulic, a mathematical model exists in the digital computer. The simulation runs at real-time update rates and every control input produces a corresponding output, perceived by the flight crew through instrumentation and indicators, the feel of the primary flight controls, through the motion system, or as a change in the visual scene through the cockpit window. Because he or she has total control of the simulated aircraft, the instructor may introduce faults and emergency conditions at will.

Consider, for example, the training of a flight crew to cope with the loss of an engine just as the aircraft rotates to assume a positive climb rate and lift off the runway. Apart from the safety aspects of performing this maneuver in the actual aircraft, in order to simulate an engine failure, the instructor must close the throttle for the appropriate engine--not shut down the engine as this would be too dangerous (suppose it was a two-engined aircraft)--and the instructor or another instructor pilot sits in the right-hand seat in case the student pilot cannot cope with the emergency. The realism of the situation is thus reduced to a large extent. Furthermore, the large engines used on jet transports such as the DC-10 develop about 10 000 lb of thrust at flight-idle and about the same amount of drag if they are shut down and windmill. Representation of an asymmetric engine configuration in the actual aircraft is therefore unrealistic and effective training can only be performed in the simulator.

A time-saving aspect of simulators is their ability to transition instantly through time and space, and this means that it is not necessary to waste time on the routine, unproductive segments of a training flight. For both the military and civilian training community, this represents a dramatic reduction in training time. An hour in the simulator is equivalent to more than an hour in the actual aircraft.

With total control of the training environment, standardization of training may be achieved. Every pilot, flight engineer, and weapons systems officer experiences exactly those flight situations that are considered to have the maximum training effectiveness. Standardization of training is further enhanced by taking full advantage of the capability of the digital computer and automating the training process. If it is required that, in a training scenario, an enemy aircraft should manifest itself through the simulated aircraft's sensor systems and in the visual scene at a particular point in the mission, then it is not necessary for the instructor to push buttons or whatever. As a preprogrammed event, the controlling software will introduce the threat aircraft and cause it to behave in a predetermined manner.

The purpose of automated training is twofold. It relieves the instructor of the task of managing the simulator and allows concentration on monitoring and commenting on the trainee's performance. It also improves training effectiveness by fully utilizing the simulator's capability and making every instructor as proficient as the one that designed the automated training scenario. Automatic training features also allow systematic performance evaluation, scoring, and data collection.

In peacetime, the prime task for the military is one of training to ensure combat readiness. Many tasks are impractical to train in the real world. For example, an incursion into a potential enemy's airspace and an attack on a critical target might be difficult to arrange in the real world. The use of similar territory within our own political boundaries does provide invaluable training, but total simulation is the ultimate solution.

Airline Flight Simulators

In the past 10 years, Link has built more than 100 training simulators for the world's major airlines. The list of aircraft simulated includes the early mainstays of the airlines jet fleet (707 and DC-8) through the latest wide-bodies (747, DC-10, L-1011, and A-300). Link is already under contract to deliver simulators for the new Boeing series of aircraft (767 and 757), and it is becoming common practice for an airline to take delivery of the simulator ahead of or concurrent with the delivery of the first of their new fleet.

Figures 1 and 2 show views of simulators mounted on six-axis motion systems. We see that the aircraft cockpit is completely enclosed in its own room to facilitate air conditioning and equipment cooling. Unlike earlier simulators, virtually all electronic equipment is arranged around the exterior of the cockpit and is carried on the motion platform. The new packaging concept leads to higher reliability and ease of maintenance.

Figure 3 shows the interior of a cockpit complete with instructor's station. The most common type of visual system used by the airlines is one that provides a highly realistic representation of the dusk and night environment.

B-52 Weapon System Trainer

The B-52 weapon system trainer, currently in production, is depicted in Figure 4 and includes defensive and offensive weapon stations as well as the flight deck. Three instructor's consoles are used and the complete system is used to simulate an entire real-world mission--from take-off to touchdown--with interactive operation between the cockpit, the offensive weapons, and defensive avionics stations. By using computer image generation techniques, inflight refueling may be practiced. Figure 5 shows the beginning of such an exercise and a KC-135 tanker visible through the forward windshield. Also apparent in this photograph are displays associated with the electro-optical viewing system (EVS) that

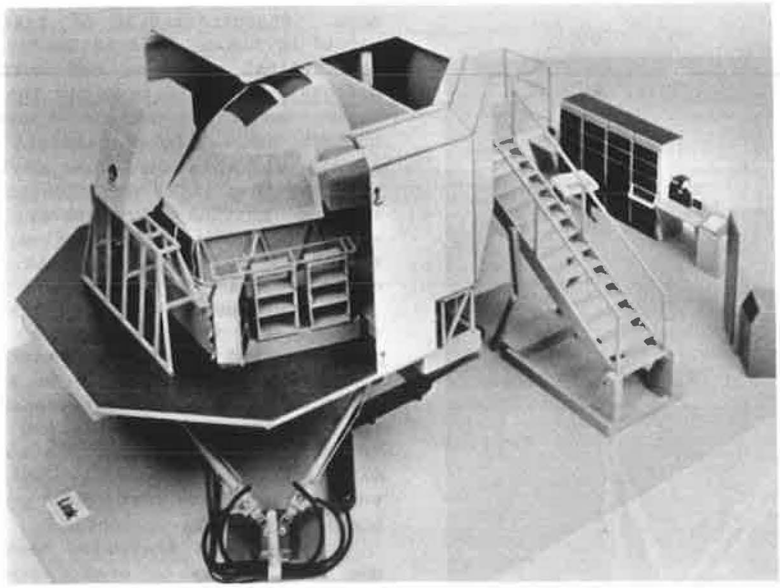


Figure 2. Cutaway view of simulator.

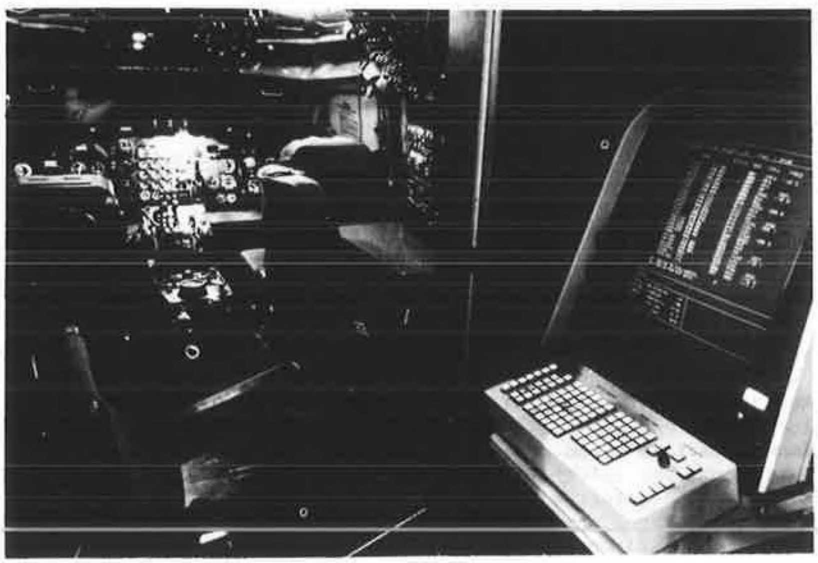


Figure 3. Cockpit interior.

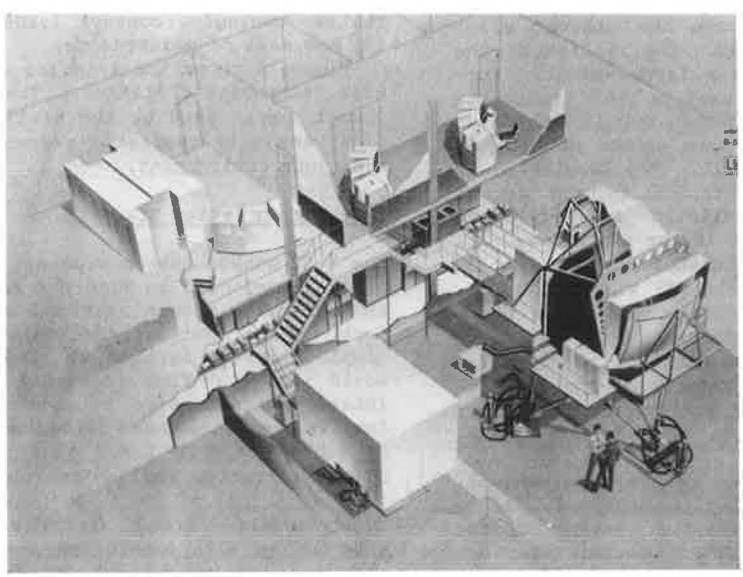


Figure 4. B-52 weapon system trainer.

Figure 5. Interior of B-52 simulator cockpit.

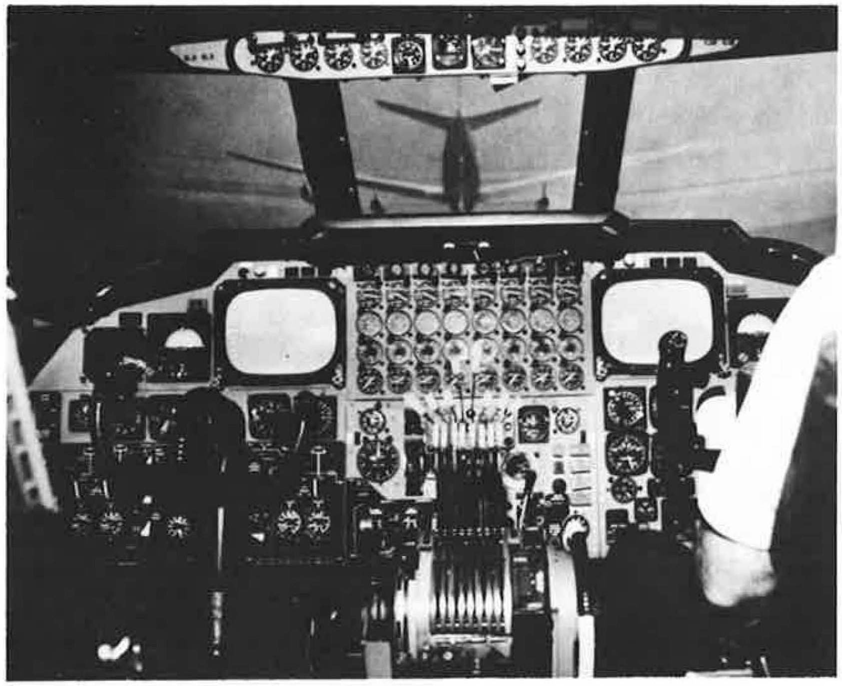
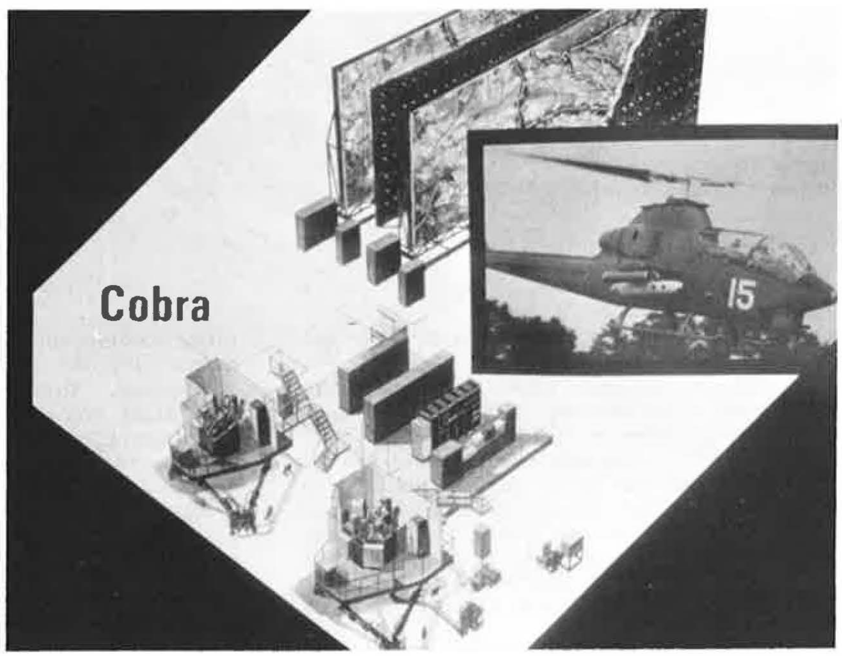


Figure 6. Cobra helicopter weapon trainer.



uses low-light television, forward-looking infrared, and radar information. All of these image systems are fully simulated and correlated with the out-of-the-window scene.

Maximum utilization of the complex is obtained through the ability of the three individual stations to operate in a combined or independent mode. The mode of operation may be changed during an exercise, thus one of the stations may freeze in time and space to review a particular situation while the other two stations continue the exercise without interruption.

Cobra Helicopter Weapon Trainer

The Cobra attack helicopter is a two-place gunship capable of carrying a variety of weapons. Crew members share the operational tasks and the gunner acts as copilot; the pilot is also able to fire weapons.

Figure 6 depicts the arrangement that was chosen for this trainer. The two cockpits are mounted on separate motion platforms--one duplicates the pilot's station; the other, the gunner's. Visual scenes are generated by using model terrain boards and closed-circuit television techniques and, like the B-52 mentioned earlier, the whole system may function in an integrated or independent mode.

Simulator for Air-to-Air Combat

The simulator for air-to-air combat (SAAC) was de-

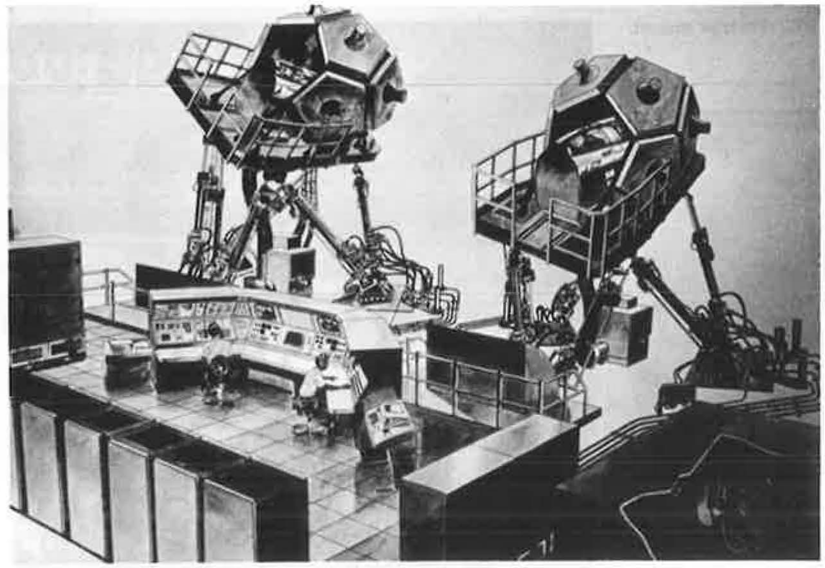


Figure 7. Simulator for air-to-air combat.

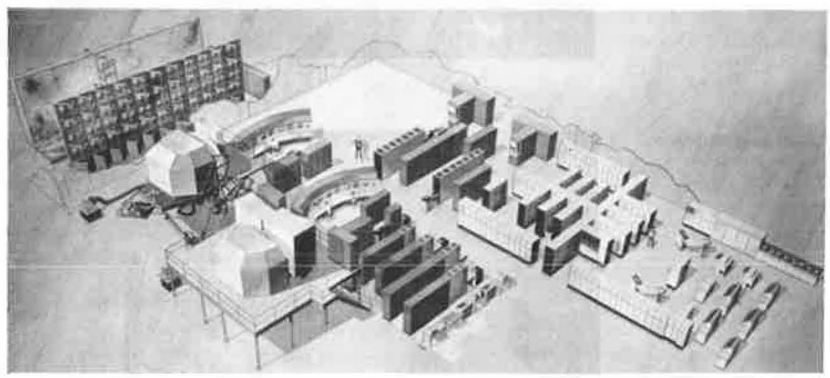


Figure 8. Shuttle mission simulator.

signed and built for the U.S. Air Force by Link and is depicted in Figure 7. SAAC includes two F-4 cockputs mounted on six-axes motion systems. The visual system uses eight pentagonal cathode ray tube (CRT) windows and provides a field of view equal to that of the aircraft. Computer image generation is used to display a terrain image and a view of the second aircraft. A pilot in one cockpit may thus engage in aerial combat with a pilot in the other cockpit and the device is used as a research tool for development of combat techniques and also for evaluation of fighter aircraft and tactical weapons design.

In this simulator the gravity forces experienced by fighter pilots during high-rate maneuvers are simulated by using so-called g-seats and g-suits. Both these devices operate by applying computer-controlled pressures to the surface of the pilot's body. In this manner, the sensations experienced by the pilot during sustained accelerations are reproduced. The g-suit operates in a similar way to the actual g-suit worn by fighter pilots and, in addition, blackout conditions are represented by dimming the cockpit lights and visual scene. In the g-seat the pilot feels pressure caused by air forced into the seat pan, backrest, and thigh panels, in addition to pressure from a controlled lap belt.

Shuttle Mission Simulator

Figure 8 is an overview of the shuttle mission simulator complex currently in operation at the National Aeronautics and Space Administration (NASA) in Houston, Texas. This system is intended to train crews and flight controllers in all of the phases of the space shuttle mission. This includes launch, orbital insertion, orbital operations, and reentry and landing. Both a fixed base and a crew station with a motion system are included in this complex and the visual imagery is available both from a model board system and a computer image generation system. The latter system is capable of supplying imagery through all of the space shuttle flight regimes, including views of the cargo bay with the doors open. Manipulation of payloads into orbit may thus be trained.

SUMMARY

Modern flight simulators have proven to be cost-effective devices and are currently being used to train pilots of commercial and military aircraft as well as astronauts. For the military in particular, many training tasks undertaken in the simulator cannot be performed in the real world.

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