FLIGHT SAFETY FOUNDATION
HUMAN FACTORS &
AVIATION MEDICINE
Vol. 43 No. 4 For Everyone Concerned with the Safety of Flight July–August 1996

Standard Computer Hardware and Software Configured to Produce Useful Flight Simulator in Study

U.S. researchers developed a research simulator using personal computers and two commercially available flight-simulation software packages. A study found that such economical and readily assembled systems offer promise for use in pilot performance research and in training.

Robert L. Koenig
Aviation Writer

Flight simulation, which has traditionally been extremely expensive and complex, has become increasingly accessible in recent years through improvements in computer hardware and software. Now, even simulators using commercial (off-the-shelf) components promise to be useful for research and training, a new study reported.

The study, by the U.S. Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma, found that one such personal computer (PC)–based simulator "can be a useful and economical tool for examining experimental questions involving general aviation pilotage," despite some minor drawbacks. Although this study examined the uses of PCs and standard software for general aviation research, it has potential implications for air transport aviation in the future.

A system called the Basic General Aviation Research Simulator (BGARS) was designed to represent the cockpit environment of a popular, single-engine general aviation aircraft including instrumentation, controls and external visual cues. Although it can be used for training, BGARS also was developed to allow researchers to manipulate certain research variables and to extract performance data.

The CAMI report, *Use of Off-The-Shelf PC-Based Flight Simulators for Aviation Human Factors Research*, is the first of a series of studies planned in a CAMI general aviation human factors research program. The report concludes that BGARS is capable of producing "outcomes that are comparable to those obtained in other simulation devices and, in fact, aircraft."

The software sampling frequency might need to be increased for tasks beyond maintaining aircraft altitude and track, the report said. But for parameters of this study, CAMI research found that "the task environment simulated was sufficient to the degree that the behaviors/errors likely to be observed in the real world were also observable in the simulation ... ."

The report said that the modular, microprocessor-based BGARS was "comparatively inexpensive to integrate and maintain." And it suggested that fast-developing improvements in computer hardware and software "will further enhance the possibilities for research on visually guided behaviors beyond geographical orientation, pattern flying and visually guided approaches."

Aircraft trainers and simulators have been used since the early days of aviation, but early versions demonstrated only general flight techniques.

In 1929, Edwin Link assembled readily available components from nonaviation applications to create an aviation simulator. Link's device helped teach pilots how to fly, but its instrumentation was not specific to any aircraft type.

Since then, aviation researchers and technicians have developed increasingly complex and expensive devices to approximate the flight dynamics and typical environments for specific aircraft types. But computer technology has allowed the greatest advances in simulator quality.

Recent improvements in PC processor speed, video memory and memory speed and density "mean that flight simulations can now be run on personal computers at reasonable update rates and with out-the-window views that provide a moderate level of scenic detail," the report said.

Noting that "the potential for applications in both research and training is substantial," the report added that "the comparatively low cost of such systems may justify re-examination of many of the previously held beliefs concerning what the necessary criteria are for useful flight simulation."

> ***"The comparatively low cost of such systems may justify re-examination of many of the previously held beliefs concerning what the necessary criteria are for useful flight simulation."***

CAMI suggested that the increasing tendency to use relatively inexpensive simulations on PCs, rather than using expensive simulators, makes it important for researchers to investigate:

- How much flight-simulation fidelity is needed for the effective transfer of skills or for generalizing research data;
- How much of a complex flight task can be represented effectively in a simulation; and,
- The cost-effectiveness of various types of simulators.

The report said that "the economics of simulation have changed such that we can now get more simulation for less capital investment." In fact, some flight simulation programs now cost less than a one-hour rental of a single-engine aircraft.

"This requires us to ask the question: 'If we can get more simulation for the same investment, what is the "more" that we should ask for?'"

Simulators have become an increasingly important tool for behavioral research. For example, at the 1993 annual meeting of the Human Factors and Ergonomics Society, 27 presentations referenced flight simulation, mostly as a behavioral research tool.

In a paper published in 1967,[1] E.R. Jones listed what still remain sound reasons for training using simulators. Jones noted that simulations are sometimes preferable to actual flight training because simulators reduce the costs and hazards of training, and at the same time make training, especially for emergency situations, more easily available.

Although Jones was mainly considering the use of simulators in flight training, some of those conclusions also apply to research. "Both cost and hazard are issues that clearly favor the use of simulation for flight research," the report said.

One concern about using simulators is that they might result in unmotivated performance by trainees or research subjects. But good pilots' high level of motivation to succeed tends to reduce the likelihood of unmotivated performance, even in a simulator.

In analyzing simulators, researchers examined the fidelity (simulator accuracy in reproducing operational behavior) of flight procedures as well as the fidelity of the manual, psychomotor aspects of flight control. The report suggested that, for researchers, simulator fidelity in flight procedures may be more important than psychomotor fidelity, such as the force characteristics and gain of manual controls.

"Common sense can generally dictate many fidelity decisions, with some notable exceptions," the report said. "It should be clear that the study of navigation computer interfacing with the pilot, involving graphical interface and menu hierarchy design, will not likely require the fidelity of manual flight control input/output that one would need to execute manual control theory studies."

Although most past simulation efforts have sought high fidelity in all aspects, the report suggested that "the research community now stands to benefit from the development of lower-cost simulations that can reasonably represent selected flight tasks of interest."

The idea is to allow cost-effective research that produces valid results. Simpler simulation systems tend to be more reliable, and have lower maintenance costs, than high-fidelity systems. And using lower-cost, lower-fidelity simulators would also free higher-fidelity simulators for more focused research.

BGARS, developed in six months, using commercially available hardware and software, strives to represent a familiar single-engine general aviation aircraft while meeting the criteria of a research simulator.

BGARS is based on two commercially available flight-simulation programs:

- The FS-100 instrument flight trainer (for the Beech Bonanza or Beech Sundowner), which provides cockpit displays, control input processing and the collection of 16 performance variables; and,

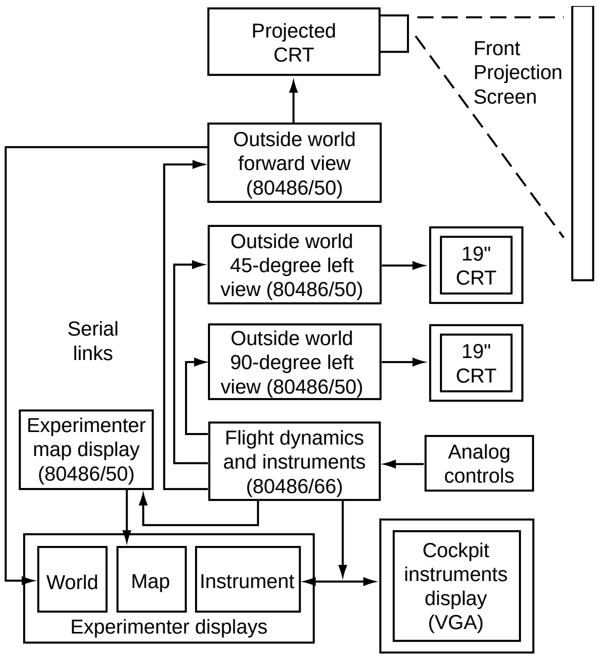
- The ATP “game-type” flight simulation, which is used to produce all outside views, depending on the processor/display combination. Having three outside views requires three separate processors running the same program, each selected to depict a different viewing vector.

BGARS features variable flight instrumentation, a map display and external world views representing forward, 45-degrees left and 90-degrees left. Developers included the left-hand external views to simulate visual meteorological conditions under visual flight rules and left-hand traffic patterns with visual reference. The system also provides high-fidelity analog control inputs (such as throttle and yoke, and controls for gear, flaps, trim and radio).

Although the initial configuration of BGARS used five computers (Figure 1), the report said that an acceptable simulation (e.g., forward view and instruments) can be produced using only two computers.

Because BGARS involved the simultaneous use of two previously self-contained simulation programs, researchers had to address challenges related to the geographic data base, communication between the two programs and specific research requirements. Those software issues included:

Simplified Schematic of Basic General Aviation Research Simulator (BGARS), Version 1



CRT = Cathode-ray tube VGA = Video graphics accelerator

Source: U.S. Federal Aviation Administration Civil Aeromedical Institute

Figure 1

Geographic location of airports. BGARS requires that the two processor/software packages in the system use identical geographic data bases. And the quality of the data base can affect simulation fidelity.

Most mass-market flight simulators, including ATP, use the readily available U.S. National Oceanic & Atmospheric Administration (NOAA) data base. FS-100 uses the Jeppesen Sanderson (JS) data base. A license is required to obtain the JS data base, which features frequently updated data.

“The two data bases are not congruent; indeed, we have found displacements orthogonal to runway centerlines ranging from 50 [feet] to 200 feet [15.25 meters to 61 meters],” the report said. “This can be most unnerving when one flies a ‘perfect’ instrument landing system approach and finds, on short final, that the aircraft is *not* aligned with the runway.”

To solve the problem, BGARS experts edited the ATP package to move the airports in the NOAA data base into alignment with those in the JS data base. In most examples, only minor adjustments were required.

Researchers also found “discrepancies between the representation of an airport in the instrument-package data base (and thus [the] moving-map display) and the depiction in the out-the-window scene.” Discrepancies appeared to occur more with secondary-destination airport representations. Therefore, researchers recommended “that one not choose airports as primary or secondary destinations (or even emergency fields) without fully assessing the [extent of the] agreement between the two data bases.”

Altitude. Differences in representations of field elevation posed a more difficult simulation problem.

The FS-100 software package assumed terrain elevation to be that of the nearest airport, but ATP used an interpolative approach to determine altitudes between major reference points. Also, there were “small differences” (50 feet to 100 feet [15.25 meters to 30.5 meters]) between altitudes shown in the two data bases, making some landing simulations unrealistic. To solve the problem, experts transmitted altitudes above ground level to the scene-generating software.

Heading. In early testing, the method by which heading — shown as the forward viewing vector — was communicated between software packages created anomalies. FS-100 transmitted the heading as a vector measured from true north, but ATP expected to receive the heading information measured from magnetic north. That, plus a difference in the internal representations of data between the two software packages, resulted in such phenomena as an extreme drift to the right while flying aligned with the runway centerline on approach to one simulated airport.

To solve the problem, researchers modified the processing of transmitted heading to correct the mismatch.

Collision with ground or objects. To enable the system to accurately detect ground collisions, the two software packages must use the same basic data on factors such as altitude. “Compatibility is critical,” the report said.

The experimental setup had only one-way data flow from the transmitting “host” computer (running FS-100) to passive “peripheral” computers (running ATP). But the report said that object collisions could, if desired, be simulated by having the forward-view-generating computer determine when an object in the visual scene had been struck and then send a signal back to the host.

Visual display. Researchers wanted to choose the highest-resolution imaging available for the out-the-window views. An early selection was FS-5 software in video graphics accelerator (VGA) mode, which did minimize distortion along the horizon line and linear boundaries. But FS-5’s visual texture was found to have a dark overall effect that made terrain features and runways difficult to see on the large projection monitor used for the forward vector. A modification was made that brightened the image, but at the cost of producing “washed-out,” pastel-like colors and reduced definition. The researchers found that ATP, with its simpler, uniformly filled-in on-screen objects, was better suited to the task.

The report found that BGARS “appears to have great utility for both research and training.”

Modifications required for research. Originally, BGARS had to be modified in two ways to make it suitable for research. Experts programmed the system to allow the researchers to manipulate certain independent variables and to record several dependent variables.

As an example of manipulating independent variables, two early research studies used different types of simulated instrumentation — conventional navigation displays (such as the directional gyro [DG] and very-high-frequency omnidirectional radio range [VOR] indicators) vs. integrated displays (such as the horizontal situation indicator [HSI]).

Meanwhile, researchers found that recording dependent variables was relatively simple because “most of the dependent variables of interest were already being recorded in the replay memory.”

Nevertheless, experts added a few changes to facilitate the recording of 16 dependent variables: a header record to identify data files; a sample number for each data “slice”; an event marker that the experimenter could insert using the keyboard; and lateral error, in feet, from the VOR/localizer course.

Flight task difficulty/aero models. Initially, BGARS used an aero model (the set of mathematical equations used for simulation) of only the Beech Bonanza A-36, which researchers found to be too sensitive to control inputs and “somewhat unstable longitudinally.” Researchers decided to add a simplex (single-engine, fixed-pitch prop, fixed-gear) aero model of the Beech Sundowner.

Because the Sundowner simulator’s flying characteristics were similar to those of the aircraft itself, “pilots without complex aircraft experience found it comparatively easy to fly.”

Update rates and throughput. Originally, the BGARS installation used processors based on the 80486 microchip for the flight instruments/aero model package (66 megahertz) and the out-the-window views (33 megahertz). The instrument panel update rates were 12 hertz to 16 hertz, but the exterior (out-the-window) views, which involved more graphics, tended to operate more slowly, in the six hertz to 10 hertz range. “This update rate was not objectionable for most operations, and only became noticeable in steep-banked turns,” the report said.

After the study, researchers upgraded the computer system to 100-megahertz Pentium processors with the programming communication interface (PCI) bus for all computers except for the map display, which used an 80486 processor running at 66 megahertz. That upgrading “significantly increased throughput,” with all instrument and out-the-window view-update rates “at or above 16 hertz.”

The report found that BGARS “appears to have great utility for both research and training.”[2]

Advantages include the low cost of computer hardware, the relatively low cost of the software (compared with a fully customized system), the simplicity of the communications protocol and the modular hardware and software, which allows upgrading any component or expanding simulation capabilities by adding components.

“The low cost and ease of assembly/integration allow multiple ‘standardized’ systems to be distributed for cooperative interlaboratory studies,” the report said.

Nevertheless, those advantages of low cost and simplicity were obtained by sacrificing some flexibility that is useful for research.

For example, using commercial software and not having access to the source code “poses a potential problem for investigators who wish to manipulate variables not directly accessible through the program.”

The researchers reported “reasonable success” in working with the software developers to make the modifications necessary for research, but they were unable to make timely modifications in some areas. Some delays were caused by problems with scheduling development time; in other situations, the desired changes would have had a major impact on the software structure.

One solution that researchers pursued was to add processors on the system's serial distribution to provide additional features, such as air traffic control (ATC) and automated voice inputs. Doing so allowed researchers to maintain control of the auxiliary functions and to modify and develop the software code as needed for research. In addition, the approach allowed development of auxiliary instrument displays.

"Additional modifications are being made to the software that will provide access to more data variables in real time as well as to some discrete failure modes, multiplying the options available to the experimenter," the report said.

To validate the utility of BGARS, researchers compared experimental outcomes for a specific aviation problem to the results of parallel aircraft-based and simulator-based research.

The experiment involved comparing two ways of presenting course-deviation information for VOR navigation: first, using separate VOR and DG indicators; and second, using an HSI, which combines the functions of the VOR and DG indicators.

The validation experiment also compared results from situations in which pilots used instrument formats with short-term memory aids ("bugs") to the results obtained when pilots used formats without such aids.

Researchers anticipated that HSIs with bugs would make it easier for pilots to integrate data, and they wanted to find out how much difference the advanced instrument formats would make, to determine whether it would be cost-effective to install HSIs with bugs in general aviation aircraft.

Researchers wanted the simulations to have enough "task fidelity to motivate generalizable behavior"; to be able to collect enough continuous real-time performance data; and to stimulate, through realistic task and workload representation, the types of procedural errors that occur on real flights.

During the initial study's three phases, more than 36 pilots flew the simulation. Twelve were experienced pilots, mainly instructors with more than 500 hours of flight time; the rest were private pilots with less than 200 hours of flight time. Each pilot flew the simulator for two two-hour sessions. The first session was to familiarize them with the system, and the second was to collect data.

The experimental data showed that pilots using HSI demonstrated "better acquisition and tracking performance," a result that was consistent with previous studies of such navigational displays.

Researchers observed two categories of procedural errors made by pilots, in a pattern largely consistent with previous research. The observed categories and numbers of errors (Table 1) were:

- Navigation/orientation errors, including the inappropriate setting of the omni bearing selector, flying through radials without taking corrective action and turning the wrong direction for an intercept; and,
- Memory errors, including failure to recall the assigned heading, altitude or radial.

"These findings were largely as anticipated, demonstrating more errors with the VOR/DG combination and without bugs than with the HSI and bugs," the report found.

"This suggests that the simulation system can be useful for examining problems of this nature where procedural compliance and navigational decision making are involved, and information is being derived from a dynamic instrument representation."

Table 1
Procedural Errors of 11 Subjects Using PC-based Flight Simulator

	VOR/DG		HSI	
Error	**No Bugs**	**Bugs**	**No Bugs**	**Bugs**
Navigation/orientation	17	12	6	8
Memory	5	4	5	1
Total	22	16	11	9

VOR = Very-high-frequency omnidirectional radio range
DG = Directional gyro
HSI = Horizontal situation indicator

Source: U.S. Federal Aviation Administration Civil Aeromedical Institute

Responding to posttest questionnaires, most pilots described the Beech Bonanza A-36 simulation as more sensitive to control inputs, and more difficult to fly, than the aircraft itself. They also found the Sundowner simulation to be sensitive, although not as touchy as the Bonanza. In general, however, those assessments tended to correlate with the flying style (the amount of control inputs) of the pilot.

Researchers were encouraged that most pilots regarded the experimental scenarios as more challenging than their usual flying, and that pilots also reported that the simulation reasonably represented flight tasks in the ATC environment. In addition, the pilots appeared to be as involved in the simulation as they would have been in an actual flight.

Researchers sampled and stored flight data (longitude, latitude, magnetic variation, altitude, airspeed, heading and other variables) at 0.5-hertz frequencies.

Data suggested that "performance variables that can be sampled at lower frequencies (two hertz or less) and that represent outcome states (i.e., location of the aircraft in three dimensions relative to desired altitude and ground track) can be effectively monitored with the system, and provide adequate measures of aircraft system performance for navigation and altitude maintenance tasks."

BGARS' capacity for recording measurements has limitations, mainly related to data-storage space. But researchers concluded that the system "could be suitable for control-theory studies of manual flight control where the expected frequency of control reversal activity is not likely to exceed the measurement capabilities of the system during most normal realms of flight."

Meanwhile, researchers are revising the software to allow flight data to be transmitted to another computer system, which would ease the storage-space limitations and allow longer recordable flights.

At the time the CAMI report was written, BGARS had been operated for more than 880 hours, during 18 months, with only two failures that required stopping data collection. Both failures were related to the microprocessors. Researchers also noticed one transient failure of the projection system and a malfunction in an audio-system amplifier, neither of which interfered with data collection.

"Maintenance of the system can generally be performed on site by individuals with a knowledge of personal computer systems," the report said. In addition, researchers found that the system, which requires only about one minute to go from power off to full operational status, is relatively uncomplicated.

"The system is very easy to use, as all programs run automatically following initial system boot using batch files, and all operator-software interfaces are straightforward and easy to understand."♦

Editorial Note: This article was adapted from *Use of Off-The-Shelf PC-Based Flight Simulators for Aviation Human Factors Research*, Report no. DOT/FAA/AM-96/15, April 1996, by Dennis B. Beringer, Ph.D., of the FAA Civil Aeromedical Institute. The 12-page report includes a table, figures, references and an appendix with a schematic diagram of a six-processor version of BGARS.

References

1. Jones, E.R. "Simulation Applied to Education." McDonnell Co., April 1967.

2. For further information about the validity of PC-based simulators for training, see Taylor, H.L.; Lintern, G.; et al. "The Transfer of Training Effectiveness of Personal Computer-based Aviation Training Devices." In *Proceedings of the Eighth International Symposium on Aviation Psychology*. Columbus, Ohio, U.S., 1995: 1210–1215.

About the Author

Robert L. Koenig is a Berlin, Germany-based correspondent who specializes in transportation and science issues. He has written on aviation for Science *magazine and the* Journal of Commerce. *Before his move to Germany, he was a Washington, D.C., newspaper correspondent for the* St. Louis Post-Dispatch, *for which he covered transportation issues. He won the National Press Club's top award for Washington correspondents in 1994. Koenig has master's degrees from the University of Missouri School of Journalism and from Tulane University in New Orleans, Louisiana.*

HUMAN FACTORS & AVIATION MEDICINE
Copyright © 1996 FLIGHT SAFETY FOUNDATION INC. ISSN 1057-5545

Suggestions and opinions expressed in FSF publications belong to the author(s) and are not necessarily endorsed by Flight Safety Foundation. Content is not intended to take the place of information in company policy handbooks and equipment manuals, or to supersede government regulations.

Staff: Roger Rozelle, director of publications; Girard Steichen, assistant director of publications; Rick Darby, senior editor; C. Claire Smith, editorial consultant; Karen K. Ehrlich, production coordinator; and Kathryn L. Ramage, librarian, Jerry Lederer Aviation Safety Library.

Subscriptions: US$60 (U.S.-Canada-Mexico), US$65 Air Mail (all other countries), six issues yearly. • Include old and new addresses when requesting address change. • Flight Safety Foundation, 601 Madison Street, Suite 300, Alexandria, VA 22314 U.S. • Telephone: (703) 739-6700 • Fax: (703) 739-6708