ORLY: A DIGITAL COMPUTER FLIGHT SIMULATOR

Dan Cohen and Edward Taft

Harvard University

1. *Introduction*

ORLY is an all-digital computer flight simulation system designed for both visual and instrument flight training. The system features real-time operation with a trainee and an instructor at the controls, and includes facilities for varying flying conditions and for recording the trainee's performance for later evaluation. In addition, the system is constructed in a modular fashion so as to easily permit experimentation with different flight models, instrument configurations, training techniques, and the like.

The implementation of the ORLY simulation system utilizes two general-purpose digital computers communicating via a computer network. The trainee's and instructor's controls and graphical displays are connected to a low-power local computer, while the bulk of the computations for both the dynamic simulation and the display generation are performed on a larger, time-shared computer facility that may be physically remote from the flight consoles.

The simulation is time-driven rather than event-driven so as to compensate for non-uniform service obtained both from the time-shared computer facility and from the network. An attempt is made to balance the tradeoff between minimizing delay and maximizing bandwidth on the network to achieve optimum performance. The result of this is that the user of the ORLY system sees smooth, uniform real-time operation despite such variations in service.

Besides its use as a flight trainer, ORLY has considerable educational value and serves as a convenient tool in the design and testing of new flight systems such as improved instrumentation and navigation aids.

2. *System Description*

The trainee's station consists of a computer-driven cathode ray tube display and a number of flight controls. The display includes a cockpit window in which a three-dimensional perspective projection of the simulated outside world is continuously generated. Also displayed are a full set of flight indicators and navigation instruments, presented as realistically as the available graphics equipment permits. These consist of power, airspeed, altitude, and rate-of-climb indicators, as well as a compass, an artificial horizon, and indicators for the instrument landing system (ILS) and various radio navigation aids.

The flight controls include a stick for controlling the airplane's attitude, a throttle, and a small number of dials and switches for controlling the navigation equipment and engaging or disengaging the autopilot.

Using the ORLY system, a trainee may practice a large variety of flight manuevers. These include both visual and instrument landing approaches, the latter assisted by a full-scale instrument panel. Radio navigation aids such as ILS, VOR, ADF, and DME may also be used by the trainee for approaches and to plan courses, practice holding patterns, and solve other navigation problems.

The instructor's console consists of a control panel and a computer-sensed stylus, with which the instructor may change many of the simulated flight conditions. Also displayed are a map of the vicinity of the airport, as well as a vertical cross-section of the glide path to the runway. Using these facilities, the instructor may graphically specify the initial position, altitude, and heading of the airplane. While the simulation is under way, he may at any time vary a number of conditions both internal and external to the cockpit. For example, the altitude of the cloud ceiling may be raised or lowered, the wind direction and speed may be changed, and varying amounts of random turbulence may be introduced. Additionally, instruments on the trainee's console may be selectively disabled to simulate their failure on a real airplane.

The ORLY system also includes a number of other training aids. At any moment, the simulation may be suspended so as to give the instructor and trainee an opportunity to discuss the situation or review the preceding flight sequence. The horizontal and vertical flight paths may be displayed on the instructor's console, or an entire flight sequence may be recorded and later played back. To give the trainee a sense of flying under pressure, the simulation may be performed at a rate faster than real time (in fact, for demonstration purposes, ORLY is generally run six times

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faster than real time, making the airplane very difficult to fly, and especially to land!) To gain practice landing at unfamiliar airports, one may erase the current world description, and draw in new airports and define navigation aids on the displayed map.

3. *Technical Description*

The implementation of the ORLY simulation system is highly modular. This is both to facilitate program maintenance and documentation and to allow convenient modification or replacement of different portions of the simulator.

One such module is concerned with computing the dynamic flight characteristics of the airplane, using as data the previously computed position and attitude, the current settings of the trainee's and instructor's controls, and the elapsed time since the previous computation. The results of this computation are passed to several other modules, which display the picture visible through the cockpit window, the states of all the instruments, and the updated airplane position on the instructor's horizontal and vertical approach maps. Still other modules perform functions such as initialization, recording and playback of flight sequences, and operation of the autopilot.

The ORLY program relies on a general-purpose support package that was developed for ORLY but has been used in several other applications. This package includes a set of graphical utility and display program generation routines running on the remote, time-shared computer facility along with ORLY itself; a program for managing, posting, and deleting display programs on the local processor; and routines for communication between the two systems over the computer network. This division of labor is such that all of the application-specific computing is performed on the more powerful, remote facility, as well as most of the necessary graphical computations. This leaves only the display hardware and flight control management and network communication to be performed on the local processor, which, being quite slow, is utilized almost to capacity by these tasks.

At Harvard, the local processor used is a PDP-1, a very slow computer whose design is nearly fifteen years old but which has connected to it a wide variety of equipment for performing high-speed interactive graphics. The remote processor is a PDP-10, a somewhat more modern and much faster time-shared computer system. The two machines communicate via the ARPA Network, a nationwide network of about 40 computers located principally at universities and computer research facilities. Though ORLY is usually run on the Harvard PDP-10, which is located in the same room as the local PDP-1, there are about 15 other PDP-10s on the ARPA Network on which ORLY may also be run without modification.

The performance obtained is dependent on the distance between the local and remote processors, the user load on the remote processor, and (to some extent) the amount of traffic on the network. When the remote processor is the Harvard PDP-10, which is only twenty feet away and typically has a relatively small user load, the update rate in the simulation is about five frames per second, which is adequate to maintain the appearance of smooth motion. When more distant and more heavily loaded PDP-10s are used (in Los Angeles, for example), the update rate drops to two per second or even less, resulting in somewhat jerky motion. This is usually still adequate for the instrument displays but not for the visual display. However, as we have already mentioned, the ORLY program is time compensated so as to maintain a constant rate of simulation despite such variations in service.

4. *Conclusions*

The ORLY flight simulation system has proven to be successful and worthwhile for several reasons. First, of course, it is useful for flight training. Though the system is not yet completely suitable for commercial use and the visual display is less than optimal (due to hardware limitations), ORLY is an excellent instrument flight trainer.

Equally as important is the fact that ORLY is well suited as a test bed for experimentation in such applications as new cockpit instrumentation systems, autopilot designs, collision avoidance systems and the like. Its modular construction and the fact that it is implemented on general-purpose digital computers makes it easy to modify for such experimentation.

Finally, ORLY demonstrates the advantages and feasibility of performing interactive computer graphics over a network, thereby making it possible to utilize very powerful computer resources that might not otherwise be available locally. Such resources may be more fully utilized (hence economically justified) when many, widely separated users have access to them. We feel that for all these reasons, the use of digital computers, graphics, and networks for flight simulation and other applications of interactive graphics should be more fully investigated and exploited.