NASA Technical Memorandum 101695

Simulation at Dryden Flight Research Facility From 1957 to 1982

John P. Smith, Lawrence J. Schilling, and Charles A. Wagner

February 1989

National Aeronautics and
Space Administration

NASA Technical Memorandum 101695

Simulation at Dryden Flight Research Facility From 1957 to 1982

John P. Smith, Lawrence J. Schilling, and Charles A. Wagner
Ames Research Center, Dryden Flight Research Facility, Edwards, California

1989

National Aeronautics and
Space Administration
Ames Research Center
Dryden Flight Research Facility
Edwards, California 93523-5000

ABSTRACT

The Dryden Flight Research Facility has been a leader in developing simulation as an integral part of flight test research. This paper reviews the history of that effort, starting in 1957 and continuing to the present time. The contributions of the major program activities conducted at Dryden during this 25-year period to the development of a simulation philosophy and capability is explained.

INTRODUCTION

The Dryden Flight Research Facility has utilized simulation for support of flight research since 1957. During the late 1950's simulation was considered supplementary, but hardly essential, to flight programs. Predictions developed from the simulator and its contributions to flight results were questioned not only by pilots (who would rather fly airplanes), but also by many engineers.

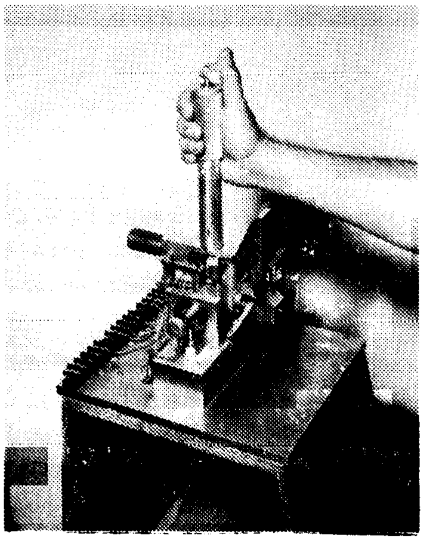
Simulation at Dryden has developed over the past 25 years into an integral and essential part of the flight research program. Today pilots, as well as engineers, demand that simulation be included in the flight program. When the manager of one joint NASA/DOD program first learned the cost of a simulator, he asked, "What did you do before simulators?" The project pilot replied, "We named a lot of streets after pilots!" This statement reflects the most important value of simulation as it is practiced at Dryden: flight safety.

This paper reviews the history of simulation at Dryden, including the evolution of a simulation philosophy and the development of the laboratory appropriate to the type of flight research conducted at Dryden. The Dryden mission, which is to conduct research in flight, not in simulators, has greatly affected both the simulation philosophy and the resulting laboratory.

BEFORE THE X-15 PERIOD

Before 1957 Dryden's experience with simulation was restricted to the use of other organizations' capabilities. The contribution of simulation to two programs that were conducted by members of the Dryden engineering staff during the period form 1955 to 1957 using a USAF simulator had a significant impact on the decision to acquire an in-house capability. In the first program a simulation using an analog computer led to an understanding of the roll coupling phenomenon, and during the second program simulation accurately predicted the X-2 lateral-directional control problem at Mach 3. The importance of these discoveries led Dryden to decide to acquire an analog computer capability. The X-2 experience in particular convinced the engineering staff that simulation had an important role to play in the future X-15 program.

In 1957 the resulting Dryden simulation laboratory consisted of one 48-amplifier analog computer and a cockpit simulator. The cockpit simulator consisted of an office chair, a simple spring-loaded control strick (Fig. 1), a 21-inch cathode ray tube (CRT) for pitch and roll angle presentation, and a maximum of three voltmeters with grease pencil markings to represent important cockpit instruments. This equipment was capable of solving the aircraft equations of motion for either five degrees of freedom (velocity and altitude constant), or three degrees of freedom (roll, yaw, and sideslip constant). Coefficients were required to be linear for the five-degree-of-freedom case, and they could vary only with Mach number for the three-degree-of-freedom solution. The principal uses of the simulator were experiment and system design and data reduction. Experiment design included studies to determine whether desired test conditions could be obtained, and it seldom involved the use of pilots. When a set of flight maneuvers was found which obtained the desired test conditions, a pilot would "fly" the simulator before the maneuver was incorporated into the flight plan. System design was limited to such tasks as evaluating the effectiveness of using velocity and attitude command (as compared to acceleration command) as reaction control system commands for the X-1B aircraft. The work in data reduction used the analog simulator as a tool to estimate aerodynamic coefficients based on flight data. The recorded flight control inputs were generated by a curve follower device and the programmed coefficients were adjusted until a reasonable match of the recorded flight maneuver was obtained.



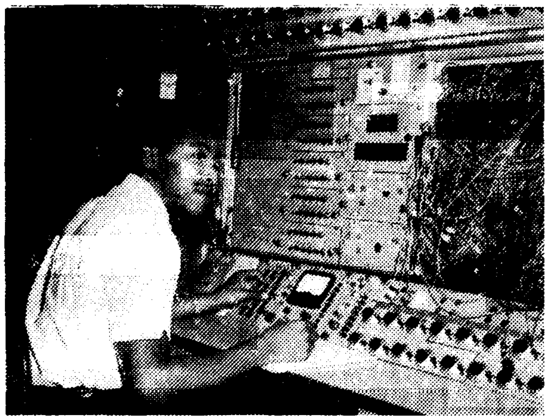
E 2633

Fig. 1 Early simulator control stick.

The Dryden simulation capability was expanded between 1957 and 1960: cockpits became more advanced and computer capability doubled. The cockpit displays included servo-driven attitude indicators and a simple center control stick with forces provided by a hydraulic system. Both the displays and the center stick systems suffered from noise problems. The center stick would sometimes go into a hardover condition, which was of concern to anyone sitting in the cockpit seat. The expanded computer allowed, for the first time, the simplified simulation of an aircraft in six degrees of freedom. This capability was used to support the X-1B flight program. This was the first serious attempt to integrate a simulation into a flight program at Dryden. Unfortunately, the aircraft developed major problems which terminated the program before the value of the simulator could be demonstrated.

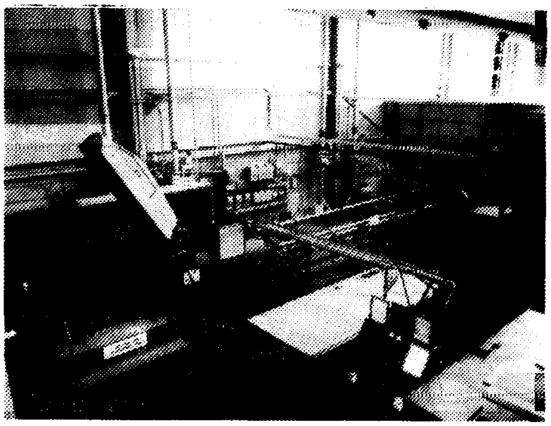
X-15 PERIOD

From 1960 to 1968 the principal activity at Dryden that involved simulation was the X-15 program. This program more than any other established the simulation philosophy at Dryden. The simulator consisted of several large analog computers that were mechanized to solve the equations of motion (Fig. 2) and a fixed base cockpit simulator and control system mockup (Fig. 3) which was developed by the builder of the X-15 aircraft. The control system mockup was used by the builder as a design tool for the definition of the X-15 control systems.



E 10298

Fig. 2 X-15 analog computers.



E 6910

Fig. 3 X-15 cockpit simulator and control system mockup.

During the flight program the simulator was used primarily for flight planning and pilot training. The flight planner made a great deal of use of the simulator to determine the flight plan that best enabled the pilot to reach a particular test condition. After a flight plan was formulated, the pilot practiced the planned flight repeatedly. This permitted him to evaluate the proposed mission from the piloting standpoint and to recommend any modifications he felt necessary.

Because of the high risk nature of this program, the simulation of the X-15's aerodynamic characteristics was continually re-evaluated and corrected as the program progressed. For the first flight the simulator was programmed with the aerodynamic characteristics predicted from wind-tunnel tests and theory. After each envelope expansion flight the flight results were compared with the simulator predictions, differences were resolved, and the simulator was updated. As a result simulator performance became accurate, which significantly improved flight safety and contributed to pilot acceptance.

The validation of the simulator aerodynamic coefficients and the extrapolation of the coefficients into areas where the vehicle had not yet flown were of particular value. This approach allowed a comprehensive analysis of vehicle handling qualities at an early date and provided a basis for evaluating and resolving potential flight problems. For example, the X-15 simulator predicted that a reentry from an extremely high altitude could not be performed successfully if the stability augmentation system (SAS) malfunctioned. Simulator studies predicted that the removal of the lower rudder would permit successful piloted reentry from very high altitudes even if the augmentation failed. This configuration was tested in flight, and the results confirmed the simulator prediction.

The cockpit simulator and control system mockup for the X-15 were more sophisticated than any other simulation that had been used at Dryden. The cockpit was an exact duplicate of that of the X-15 (Fig. 4). The control system mockup included all of the vehicle linkages and cables, actuators, servos, hydraulic lines, hydraulic reservoir, and simulated control surfaces. Electronic breadboards of the stability augmentation and automatic control (MH-96) systems were provided.


E 6589

Fig. 4 X-15 cockpit simulator.

Experience gained during this program demonstrated the need to maintain an accurate representation of the aircraft cockpit for the programs conducted at Dryden. On one occasion, the instrument in the airplane was different from that in the simulator. In the simulator the pilot learned to check the panel for the position of the needle, instead of taking an actual reading, and since the position of the needle meant different things in the simulator and in flight, the desired test conditions were not obtained in flight. On another occasion the ballistic control system (BCS) on/off switch and the auxiliary power unit (APU) on/off switch were interchanged between the simulator and the airplane. It was normal procedure for the pilot to turn the BCS off after reentry. This was, of course, practiced on the simulator, as were all of the flight events. On one flight, the pilot caught himself reaching for the APU switch when he intended to shut down the BCS, an error that could have had serious consequences.

The control system mockup was initially intended to be a design tool for the SAS and MH-96 systems. X-15 numbers 1 and 2 were equipped with the SAS, and X-15 number 3 was equipped with the MH-96. The mockup was effective for its intended purpose. In addition, the mockup became a valuable facility for troubleshooting flight hardware problems. It was found to be a simple task to remove the flight control system boxes and interface them with the simulator. In this way the flight conditions where the problem occurred could be duplicated on the ground.

An event on a flight of the number 3 aircraft illustrates the use of the simulator in troubleshooting and correcting a flight problem. During reentry from high altitude, the pilot experienced an oscillation of the horizontal tail. This was detected as a low frequency rumble which rapidly increased in volume. The pilot switched the MH-96 system from the adaptive to the fixed gain mode, and the rumble went away. Analysis of the flight data indicated that a structural mode of the horizontal tail had been excited. To examine the cause of the problem, strain gages were installed on the mockup's simulated control surfaces. The strain gage outputs were combined with the computer-generated gyro signals and tied back into the MH-96. Simulator tests showed that the MH-96 had a gain peak at 13 Hz, which was close to the natural frequency of the horizontal tail. Once the horizontal tail was excited, the vibration was transmitted through the aircraft structure to the gyro package and then to the control system, which further excited the horizontal tail. The full potential of the problem was demonstrated when, during one of the simulator tests, the starboard simulated control surface separated from the mockup. The solution to the problem was the development of a 13 Hz notch filter, which was designed and verified using the simulator.

The simulator was found to be an excellent tool for preparing the pilot and mission control personnel for flight emergencies. Once this capability was recognized, it became normal practice for the pilot and engineering staff to war game those things that, if they went wrong in flight, might jeopardize the vehicle or the mission objectives. The simulator was modified to include a malfunction generator, which made it easier to simulate emergencies. The generator allowed the simulation of major and minor malfunctions. An example of a major malfuncion which occurred during a flight early in the program with the XLR-11 engine illustrates the value of this capability. It was determined on the simulator that a premature shutdown of the engine at a particular point in the flight profile made it difficult for the vehicle to return to a landing site. If this malfunction occurred, the pilot had 2 seconds to initiate the proper maneuver. This emergency, which was practiced on the simulator, did occur in flight. The pilot initiated the proper maneuver, and the vehicle was recovered without incident. Minor malfunctions (those that jeopardized mission objectives) were also practiced. The use of the simulator so sharpened the pilots' abilities to cope with minor malfunctions, such as loss of cockpit indicators, that they became confident that they could complete an altitude mission with only the angle of attack indicator, altimeter, and cockpit timer.

The X-15 program also demonstrated that gound-based systems to simulate high *g* loads on the pilot during exit and reentry, cockpit motion cues, and high quality visual presentation of the outside world are not required at Dryden. This is consistent with the Dryden mission to conduct research in flight, not in a simulator. The experience and the engineering background of the pilots who participate in Dryden programs allow them to extrapolate the simulator experience to the flight environment without the help of these cues. Where physiological cues are necessary, in-flight or ground simulators at other sites are utilized.

By the end of the X-15 program simulation was established as an integral part of the flight program. The capabilities and events described in the preceding paragraphs contributed significantly to this. Other factors that were important in getting the pilots into the simulator were the limited amount of flight time available in the rocket engine vehicle and the highly competitive nature of the pilots. The following example illustrates the impact of these factors. Two pilots had the primary responsibility for making the high speed flights necessary to obtain heating information. This was a particularly difficult control task because of the high dynamic pressure, and it required a high level of pilot proficiency. One of the pilots spent as much time as he could get practicing the planned flights on the simulator. The other pilot only flew the simulator if he could not find anything else to do. The pilot who practiced extensively established a high percentage of data return, while the other pilot established a low percentage. This persuaded the poorer performing pilot to accept the simulator. He was the last pilot to accept simulation as an integral part of the flight program. After he was converted, it became normal for a pilot to spend 100 to 200 times as much clock time in the simulator as in actual flight.

LIFTING BODY PERIOD

The lifting body program, which overlapped the X-15 program and lasted through the early 1970's, required the next major simulation activity. The program involved a series of vehicles, starting with a lightweight glider and concluding with three rocket airplanes. Although the program did not bring about any major changes in the use of simulation or the simulation philosophy developed during the X-15 program, it did result in the refinement of some of the approaches developed for the X-15, and it brought to the surface the need to make major changes in the simulation laboratory. It also marked the first exclusive use at Dryden of a simulator to design a flight control system.

Because of the nature of the lifting body design, the amount of flight time available to acquire data and to maintain pilot proficiency was even more limited than during the X-15 program. For example, each 3- to 4-minute HL-10 glide flight yielded about 2 minutes of data time; each powered flight yielded about 5 minutes. In the first 37 flights only 3 hours, 25 minutes of total flight time and 2 hours, 20 minutes of data time were available. As a result, each flight had to be planned to utilize every available second. The extensive use of the simulator for flight planning enabled the performance, stability, control, hinge moments, and handling qualities of the HL-10 to be well documented from Mach 1.8 to landing over a 25° angle-of-attack range with this limited amount of data. The use of the simulator for pilot proficiency was very important in this program because of the very limited flight time. During the first 5 years of the program, the average number of flights per pilot per year was two.

One of the most difficult phases of the flight of a lifting body was the landing. This task required the initiation of the landing flare within a narrow time interval. Since these low-lift-to-drag-ratio vehicles were unpowered during landing, initiation of the flare too early would result in a potential stall before landing, whereas being late in the flare would result in a hard landing. This situation was examined on the simulator using a simple visual display device, and it resulted in the installation of a small solid propellant rocket as an emergency device for landing. The primary simulator for lifting body landings was an F-104 configured to approximate the lift-to-drag ratio of the lifting body in the landing configuration. The use of a flight vehicle to simulate the difficult landing task proved to be a very effective tool.

During the lifting body program it became clear that major changes in the simulation laboratory were needed. The X-15 utilized a dedicated simulator. The analog computer was programmed in 1960, and except for updates to the aerodynamic coefficients, it remained essentially unchanged during the life of the program. There was more than one lifting body, and because of economic considerations not every vehicle could have its own dedicated analog computer. Therefore the analog computer had to be reprogrammed for each vehicle.

The computer simulations, which required a six-degree-of-freedom solution with nonlinear aerodynamic coefficients, were complex to set up, and it was diffiucult to verify correct operation. The time required to convert the simulation from one configuration to another was 1 week with overtime. This required that the flight program be conducted in such a way as to minimize the number of simulator changes. Since the majority of the time was needed to set up analog function generators and verify their performance, it was decided to acquire a digital computing system for function generation. Although a small digital computer was acquired during the X-15 program, this was the requirement that initiated the conversion of the simulation laboratory to the existing all-digital facility.

During the lifting body program, it was observed that the pilot felt that events occurred ore quickly in flight than on the simulator. Experiments showed that running the simulator at 1.5 times real time represented a realistic representation of the flight environment to the pilot. Other programs have shown that this fast time factor appears to accurately represent the time frame of experimental flight.

The lifting body test period also resulted in the investigation of potential aerodynamic uncertainties for purposes of planning the first flight of each new vehicle. The errors in the aerodynamic coefficients that were thought possible on the basis of experience were evaluated and mechanized on the simulator. This technique was very successful in predicting the range of control problems that might occur in flight. The mechanization and investigation of these uncertainties are now a standard feature of Dryden flight programs.

AFTER THE LIFTING BODY

After the lifting body program the simulation environment at Dryden changed significantly. The programs involved not experimental aircraft, but rather modified conventional aircraft. These programs did not require the extensive simulation necessary to evaluate a new vehicle's full mission capability, but rather a simpler simulation aimed at particular test conditions. This resulted in increasing numbers of simulations, shorter program lifetimes, and decreasing lead times (the time available for developing the simulations). Although these simulations did not require full mission capability, they did have to be high fidelity.

This period also marked the start of the digital flight control system programs. The first program supported was the F-8 digital fly-by-wire. The standard F-8 mechanical system was removed and surplus Apollo guidance system components and a lunar module guidance computer were installed. An "iron bird" was assembled and interfaced with the simulation computers. The iron bird was a modified F-8 with the digital flight systems installed. This was the first time that non-analog aircraft systems were either simulated or interfaced at Dryden.

The need to support an increased variety and number of simulations, simulate and interface with digital rather than analog flight systems, and the reduced lead time to develop a simulation led to the conversion to an all-digital facility and the development of modular reusable cockpits and specialized interface equipment. It became apparent that few programs could justify or afford a dedicated cockpit simulator, and that the simulation facility would have to be standardized to deal with a number of programs effectively.

The first attempt at a standardized computer program was called ICARUS. The name was chosen to caution the engineer about the use of this approach. ICARUS was a generalized digital simulation program. The program included the six-degree-of-freedom equations of motion with the capability of a number of undefined control terms and aerodynamic coefficients. The program defined the number of coefficients that could be a funciton of one, two, or three variables. The engineer was required to specify the aerodynamic data to be used within the constraints of ICARUS. The engineer could elect to use the linear control system provided by ICARUS or program some other transfer function.

ICARUS was a highly successful first step in the development of a standard software system. The initial uses of the system demonstrated that a simple six-degree-of-freedom simulation program could be assembled and checked out within 1 week. This approach has been extended in recent years to a more advanced software library system using high level software languages. The major factors in establishing a simulation at Dryden are the definition of the aerodynamic models, the programming of the control system, and (in the case of systems aircraft) the interface or simulation of those systems. The use of generalized software systems using high level languages has enabled Dryden to support today's workload, which is several times greater than it was in 1970, with half the number of simulation engineers.

Current simulation philosophy at Dryden stresses convenient user interfaces. Complete control of the simulation from the cockpit station is provided through control boxes and a remote CRT. The CRT provides displays which have been tailored to a project's requirements to provide all data of interest. These displays are dynamically refreshed at high rate during operation. The control boxes provide many functions at the push of a button and are also tailored to project needs. Standard functions include autotrim, initial condition control, initial condition capture, and mode and gain control interfaces for the aircraft control system. If the initial condition capture feature has been selected, the vehicle's state vector is stored upon request, allowing the simulation to return to the stored condition whenever desired. The tools combine to improve user productivity and reduce support requirements. Simulation sessions can be and are productively conducted by one individual in many cases.

With the development of digital computer simulation programs, it became possible to restore a simulation easily. Whereas it took 1 week to restore a lifting body on an analog computer, a program of similar complexity could be restored on a digital computer in a few minutes. Where the analog computer might give a range of results for given inputs, the digital computer would produce consistent results every time, if loaded correctly. The limiting factor on changing a simulation then became the simulator cockpit.

In 1970, Dryden's simulation laboratory set a goal of being able to completely reconfigure a cockpit simulator in 30 minutes. This required the development of a general purpose cockpit shell and wiring system (Fig. 5) that could accept a wide range of cockpit side panels, controls, and instrument panels. The resulting cockpit shell (Figs. 6 and 7) can be used for a wide range of simulation programs. The biggest problem in meeting a 30-minute reconfiguration requirement was the cockpit control system. Up to that time, most simulations at Dryden used spring-loaded force systems, while such simulations as the X-15 and F-8 digital fly-by-wire used hydraulic systems. The answer was found in the dc torque motor-driven electric stick. This system (Fig. 8), which was invented by two Dryden engineers and is programmed by a specially designed analog computer, enabled the reconfiguration requirements to be met. The electric stick proves a wide range of capabilities (Table 1).

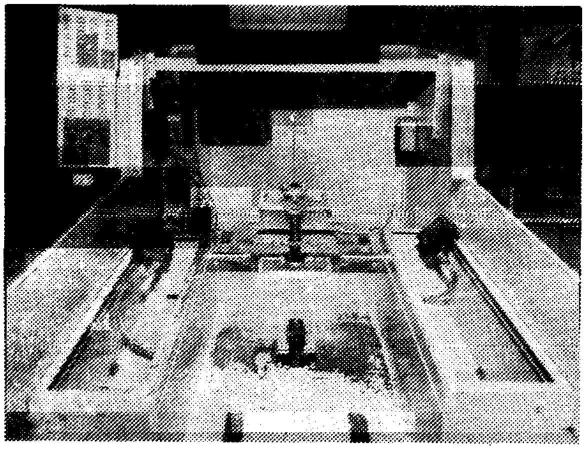

E 39025

Fig. 5 Simulator cockpit shell.

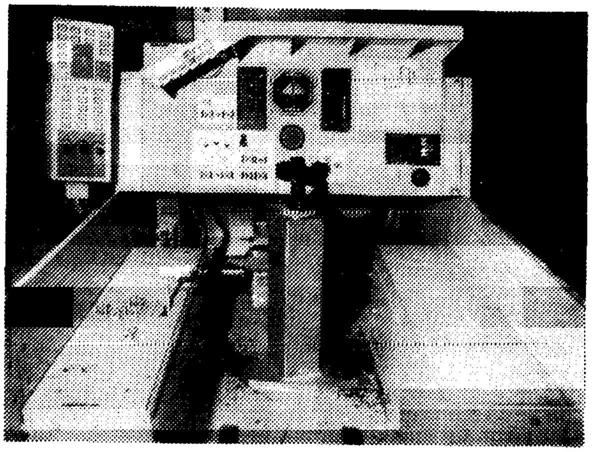

E 39024

Fig. 6 Cockpit configuration A.

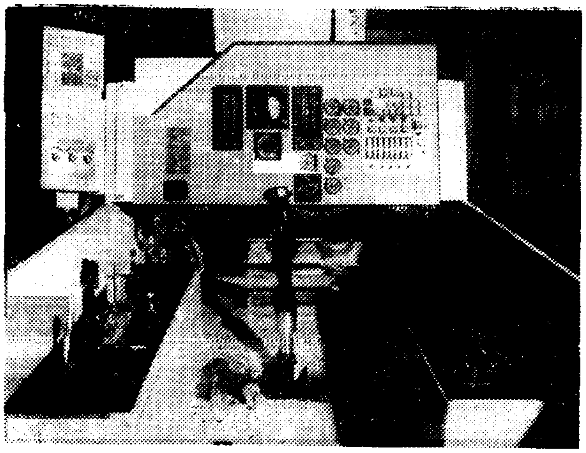

E 39026

Fig. 7 Cockpit configuration B.

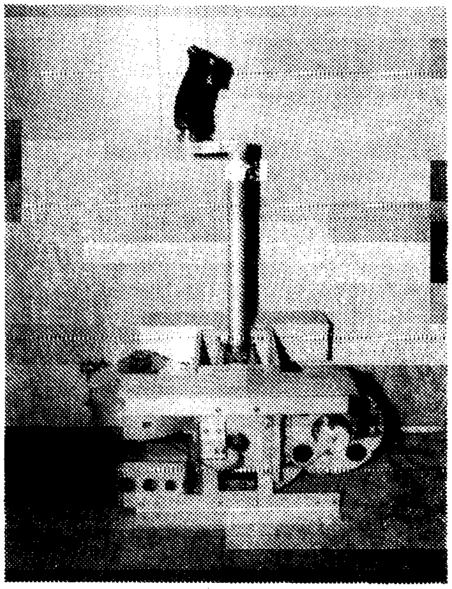

E39022

Fig. 8 Electric stick.

TABLE 1. ELECTRIC STICK CHARACTERISTICS

	Pitch stick	Roll stick	Rudder pedals
Maximum force, lb	60	52	153
Total travel range, in.	16	13.4	9.6
Absolute maximum force gradient, lb/in.	80	50	560
Maximum velocity, in/sec	64	75	26
Maximum programmable gradient, lb/in.	10.6	11.8	67
Maximum programmable breakout, lb	16.9	14.5	42
Maximum programmable friction, lb	11	9.8	28

Size of stick assembly, excluding stick shaft, in.	27.5 × 19 × 15 high
Size of rudder pedal assembly, in.	19 × 25 × 13.3 high
Weight of stick assembly, lb	150
Weight of rudder pedal assembly, lb	97
Electrical power consumption, idle, KVA	0.66
Electrical power consumption, maximum, KVA	2.64

Programmable variables in each axis:

- Travel limits (hard stops), independent in each direction
- Trim travel limits, independent in each direction
- Linear force gradient
- Damping
- Breakout force
- Trim rate
- Friction
- Mass
- Initial trim position

The trim function can be switched from paralled trim, where the stick moves with the trim position, to series trim, where the stick is stationary.

The reconfiguration time has been reduced to less than 20 minutes. Through the use of three general purpose cockpit stations, the facility supports virtually uninterrupted simulation 10 or more hours per day, with sessions usually lasting 2 hours.

The modular cockpit and electric stick have been strongly endorsed by pilots who have used simulators at Dryden. When Dryden developed its remotely piloted research vehicle (RPRV) laboratory, the pilots requested that the simulation cockpit systems be utilized. Pilots who have come in contact with the Dryden capability have been impressed. The chief pilot of a major airframe contractor, who was not known to be a simulation proponent, flew a Dryden simulation of one of his company's airplanes as part of a joint NASA/DOD program. Later, when he was going to conduct a test program at his facility on that airplane, he flew 3000 miles to get time on the Dryden simulator.

REMOTELY PILOTED RESEARCH VEHICLE AND SYSTEMS AIRCRAFT PERIOD

The current period at Dryden involves significant simulation requirements for remotely piloted research vehicles and systems aircraft. This period draws upon the technology developed over the 25 years that simulation has been used at Dryden. Simulation today performs the full range of functions that have been described in this paper. A significant additional requirement of simulation in this period is the development, validation, and verification of flight software. As a result, the percentage of piloted simulations in many programs has decreased. Typical of programs with heavy systems requirements is the highly maneuverable aircraft technology (HiMAT) program. Before the first flight, 2200 hours were spent in simulation activity, of which only 125 hours were piloted. On the other end of the spectrum, an effort to develop remotely computed displays involves pilot participation almost 100 percent of the time.

The complexity of today's systems aircraft, some of which are also RPRV's, is so great that attempting to develop them without a simulator would be futile. The HiMAT project at Dryden has been one of the major users of this type of simulation. This program used a hierarchy of simulations, ranging from an all-computer synthesis of the vehicle systems to providing the interface with the flight vehicle (Fig. 9). For systems aircraft, simulation is the principal tool in the design, development, validation, verification, flight certification and troubleshooting for the systems.

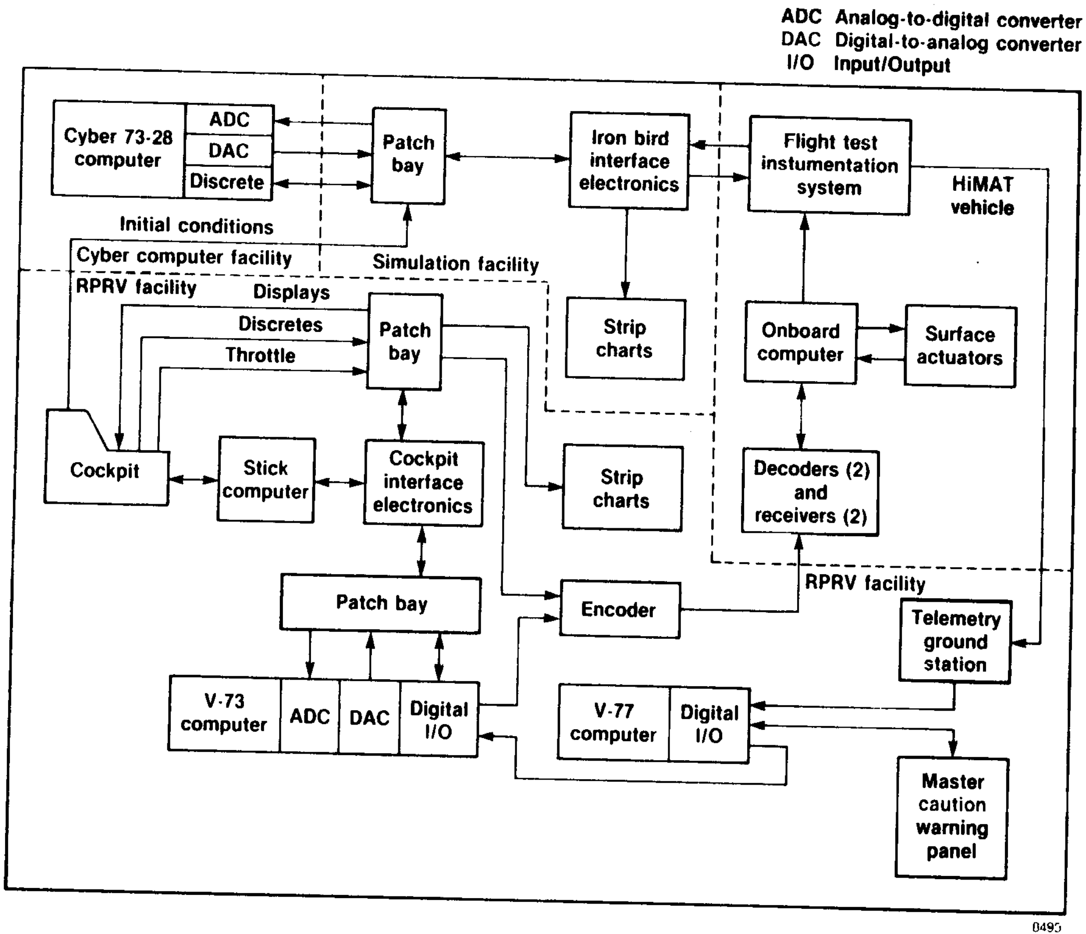


Fig. 9 HiMAT heirarchy of simulation.

Software development, validation, and verification requirements for RPRV's have resulted in the use of identical control law computers for both simulation and flight. Special interface equipment has been developed which makes the simulation control law computers perform as if they were interfacing with flight systems rather than with simulation computers and simulated flight hardware. In this way, the flight code is exercised the same in simulation as it is in flight. As a result, the certification of the flight software can take place predominantly in the simulation laboratory. Before an RPRV flight, a copy of the control law computer code is transferred from the simulation laboratory to the flight system control law computer.

The interchangeability of software between the simulation and flight systems, which was developed to satisfy the software development, validation, and verification requirement, is a key capability for today's programs. The development of cockpit display algorithms is another example of the application of this capability. Display algorithms are developed on the simulator to assist the pilot in obtaining a desired test condition. The software interchangeability allows the direct transfer of these algorithms to the flight system. The use of simulator-developed display algorithms has allowed Dryden to duplicate flight test conditions to the accuracy of a mechanical fixture in a wind tunnel.

FUTURE DIRECTIONS

Several significant changes are planned in the Dryden simulation laboratory. A new generation of digital computers will be acquired that can execute a frame of simulation software in less than 10 ms. The software will be written a high level language, such as FORTRAN. This improved capability will permit accurate simulations of high-frequency aircraft phenomena. It will also further increase the productivity of simulation engineers by reducing or eliminating the few programming tasks that must be done in assembly language.

Other planned changes include the conversion of all signal distribution systems from analog to digital. This change will provide three major advantages. First, signal quality will improve significantly, particularly where signals must travel great distances. Second, far fewer cables will be required to connect a simulation cockpit or an airplane to a simulation computer. Third, much of the work required to reconfigure a cockpit from one aircraft to another will be automated. The existing 20 minute time requirement will be reduced to less than 10 minutes. Human errors in making electrical adjustments will be virtually eliminated. The only remaining tasks will be physically installing the correct instrument and side console panels and loading the computer program.

The analog computer that controls the cockpit stick and rudder pedals will be completely redesigned. Some of the planned enhancements include incorporating programmable nonlinear force functions within the computer. All setups will be done automatically under simulation computer control. Stick characteristics will be controllable in real time by the simulation computer, enabling accurate simulation of force feel characteristics that vary with flight conditions.

These planned changes in Dryden's simulation laboratory represent the next step in an ongoing effort. This effort has several goals. Personnel productivity will continue to be increased. The laboratory will continue to become more flexible. As aircraft systems become more complex, the laboratory will maintain the capability to model, test, and verify those systems. We expect that simulation will continue to be one of the most significant tools in our flight test inventory.

Systems aircraft will be the major driver for the future simulation capability at Dryden. Simulation will not only be an integral part of the flight program but will also be a critical element of the flight system. In the successful programs of the future, simulation will provide the bridge, and safety net, from the concept to the flight system and vehicle.

BIBLIOGRAPHY

Deets, Dwain A.; and Szalai, Kenneth J.: Design and Flight Experience With A Digital Fly-By-Wire Control System in an F-8 Airplane. Advances in Control Systems, AGARD-CP-137, May 1974.

Holleman, Euclid C.; and Stillwell, Wendell H.: Simulator Investigation of Command Reaction Controls. NACA RM H58D22, 1958.

Holleman, Euclid C.; and Wilson, Warren S.: Flight-Simulator Requirements for High-Performance Aircraft Based on X-15 Experience. Paper No. 63-AHGT-81, ASME, 1963.

Layton, Garrison P., Jr.; and Thompson, Milton O.: Lifting Body Flight-Test Techniques. Flight Test Techniques, AGARD-CP-85, Feb. 1972, pp. 10-1–10-9.

Musick, R.O.; and Wagner, C.A.: A Flight Simulator Control System Using Electric Torque Motors. AIAA Paper 75-105, Jan. 1975.

Myers, Albert: Simulation Use in the Development and Validation of HiMAT Flight Software. Advances in Guidance and Control Systems Using Digital Techniques, AGARD-CP-272, Aug. 1979.

Stillwell, Wendell H.; and Drake, Hubert M.: Simulator Studies of Jet Reaction Controls for Use at High Altitude. NACA RM H58G18a, 1958.

Videan, Edward N.; Banner, Richard D.; and Smith, John P.: The Application of Analog and Digital Computer Techniques in the X-15 Flight Research Program. International Symposium on Analogue and Digital Techniques Applied to Aeronautics: Proceedings, J. Hoffman, ed., Presses Academiques Europeennes, 1964.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA TM-101695	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Simulation at Dryden Flight Research Facility From 1957 to 1982		5. Report Date February 1989
		6. Performing Organization Code
7. Author(s) John P. Smith, Lawrence J. Schilling, and Charles A. Wagner		8. Performing Organization Report No. H-1530
		10. Work Unit No. RTOP 505-68-27
9. Performing Organization Name and Address NASA Ames Research Center Dryden Flight Research Facility P.O. Box 273, Edwards, CA 93523-5000		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

This report was presented as a paper titled *Simulation at the Dryden Flight Research Facility* at SES/SFTE Simulation — Aircraft Test and Evaluation Symposium, Naval Air Test Center, Patuxent River, Maryland, March 16–17, 1982.

16. Abstract

The Dryden Flight Research Facility has been a leader in developing simulation as an integral part of flight test research. This paper reviews the history of that effort, starting in 1957 and continuing to the present time. The contributions of the major program activities conducted at Dryden during this 25-year period to the development of a simulation philosophy and capability is explained.

17. Key Words (Suggested by Author(s)) Aircraft flight readiness Piloted simulation Simulation computers	18. Distribution Statement Unclassified — Unlimited Subject category 05

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 13	22. Price A02

NASA FORM 1626 OCT 86

***For sale by the National Technical Information Service, Springfield, VA 22161-2171.**