YF-17 Ground Testing and Simulation

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The flight control test stand (FCTS) is one of the engineering tools used in the flight control system development of the Northrop YF-17 airplane. The FCTS is a functional simulator of the airplane involving mechanical, hydraulic, electrical, and electronic systems. The systems are the same as those used on the airplane. In its fundamental mode, the FCTS is used to qualify and life-test the flight control system. In its ancillary mode, it is used as a fixed-base simulator to investigate flight control system performance and as a test bed for control system modifications. This paper describes the FCTS and its use in the testing and qualification of the YF-17 flight control system. The application of the FCTS in the system development of the Control Augmentation System and, in particular, the failure management system is discussed. Examples are presented of the supporting role played by the FCTS during the flight test development of the YF-17 prototype airplane.

I. Introduction

TWO major engineering tools as shown in Fig. 1 are among those that have been employed by Northrop in the design and development of the YF-17 lightweight fighter airplane. The first is the large-amplitude flight simulator (LAFS), which was used from early in the preliminary design through completion of the design and development process. Its principal applications were in flight control law development, failure mode testing, and total systems investigations necessary to provide the aircraft with excellent flying qualities throughout the flight envelope.

The second tool is the flight control test stand (FCTS). The primary application of the FCTS was in the verification of the design performance of the flight control subsystems and the provision of qualification data on the numerous subsystems prior to the initial flight. In the iterative design process leading to the definition of the control system, the FCTS also performs significant complementary design and development roles indicated in Fig. 1. In the design role, the FCTS is used in the control augmentation system (CAS) signal flow optimization, and hydraulic system optimization. It is used to optimize failure monitoring and built-in test concepts. In the development role, the FCTS is used to investigate limit cycle tendencies in the mechanical and electrical control systems and to study the control system contribution to flying qualities.

This paper is concerned principally with the uses of the flight control test stand as a tool in the development of the control system for the Northrop YF-17 lightweight fighter airplane. First, the flight control test stand, the flight control system, and the airplane will be discussed from the flight control system designer's point of view. Following this, the use of the FCTS in the development and qualification of the hydraulic, electrical, and mechanical control systems will be discussed. Finally, some unique applications to which the FCTS was put during the YF-17 flight test program will be used to illustrate the versatility of the FCTS as a design and development tool.

Received Aug. 1, 1975: presented as Paper 75-986 at the AIAA 1975 Aircraft Systems and Technology Meeting, Los Angeles, Calif., Aug. 4-7, 1975; revision received Feb. 4, 1976.

Index categories: Aircraft Handling, Stability, and Control; Aircraft Testing (including Component Wind Tunnel Testing).

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II. Technical Discussion

YF-17 Flight Control Test Stand

The flight control test stand is shown in the photograph of Fig. 2. The flight control test stand is provided with mechanical, electrical, and hydraulic systems that are duplicates of the actual aircraft systems. The aerodynamic surfaces also are duplicated on the test stand. The test stand contains a fully instrumented cockpit. An aerodynamic control surface loading system and a pilot controls force simulation system are used to simulate control surface and system loading.

A hybrid (analog-digital) computational system is part of the test stand system and provides, through small perturbation equations of motion, the drives to cockpit displays and the ability to simulate aerodynamic forces for the control surfaces. It thus is possible to conduct pilot-in-the-loop simulation on the flight control test stand.

YF Flight Control System

The flight control system of the YF-17 is a hybrid electromechanical system in which the primary control is through the mechanical system. The mechanical control system is complemented on three axes by an electrical control augmentation system (CAS) in pitch, roll, and yaw. The maneuvering flap system, which involves the leading and trailing edge flaps, is a digital fly-by-wire system. Fig. 3 characterizes the control systems on the YF-17 from the flight control designer's viewpoint. Starting with the proper arrangement of the cockpit displays and controls, the primary control of the aircraft is achieved through the mechanical control mechanisms and the

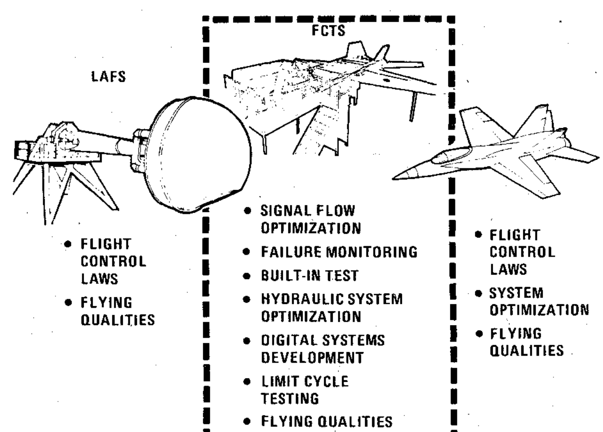

Fig. 1 Flight control design and development tools.

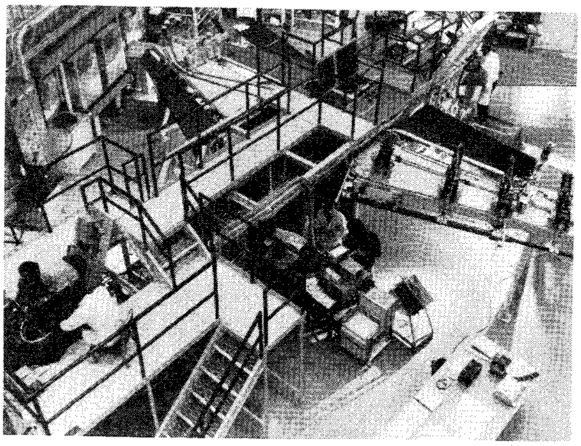

Fig. 2 YF-17 flight control test stand.

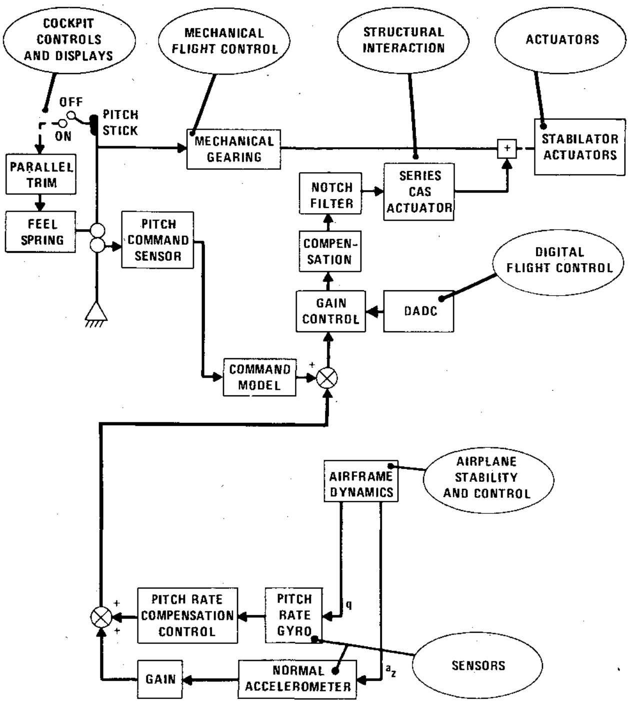

Fig. 3 Flight control system block diagram.

hydraulic actuators. Refinements to the control of the aircraft also are achieved from the cockpit through electrical controls.

Not shown in Fig. 3 are the multiple mechanical and electrical paths employed in the control system to minimize the impact of failures. In general, the control system on the YF-17 is a multiple-dual type of system. This type of system was used on the prototype to maximize the utility of the system as a technology development tool. An example of this utility was the conversion of the roll control system in the wing from a mechanical to an electrical system during the development cycle. Had a more production-oriented control system been used, the conversion to the electrical system would have required major rework of the secondary actuators to a multiple-valve system. Such a change could not have been achieved in the prototype program.

The Airplane

The Northrop YF-17 is a low-wing-loading, high-thrust-to-weight-ratio, two-engine, lightweight-fighter prototype airplane, as shown in Fig. 4. Of significance are the control surfaces. The maneuvering leading and trailing edge flaps are used to improve stability, control, and performance characteristics. Differential horizontal tail is used to provide

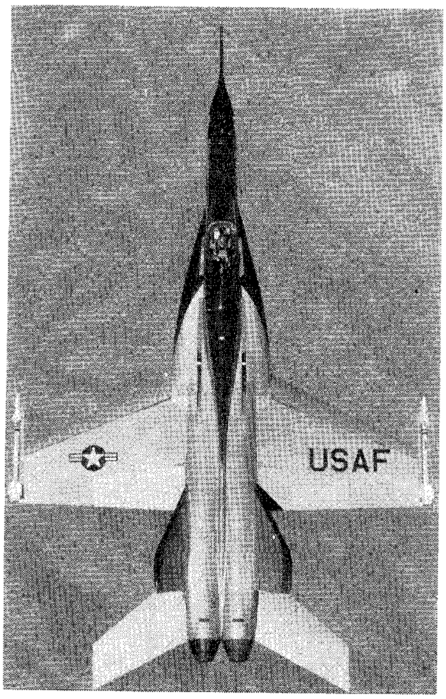

Fig. 4 YF-17 lightweight fighter airplane.

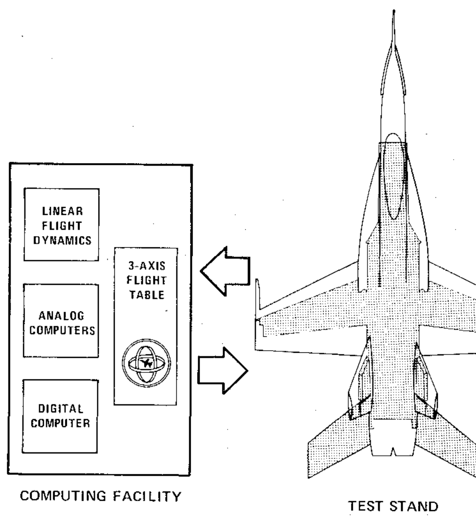

Fig. 5 Test stand as a fixed-base simulator.

longitudinal control and complement lateral control. Ailerons are used to provide roll control, and the rudders provide directional control. Some secondary systems such as diverter bleed doors, which control inlet ramp boundary layer, and landing gear release systems are not apparent in the figure but are simulated on the FCTS.

Flight Control Test Stand Applications

The airplane, the flight control system and the flight control test stand have been discussed in general terms. In this section, the application of the FCTS in the design and development of the airplane control system will be discussed. Since the flight control test stand is to be used in flight justification testing, in life-cycle testing of the flight control system, and in the hydraulic systems, it must be available some four to six months before the initial flight. In the case of the YF-17, the FCTS was essentially complete four months prior to its initial flight.

Fig. 5 shows schematically the arrangement of test equipment in the flight control test area. The stand itself has all of

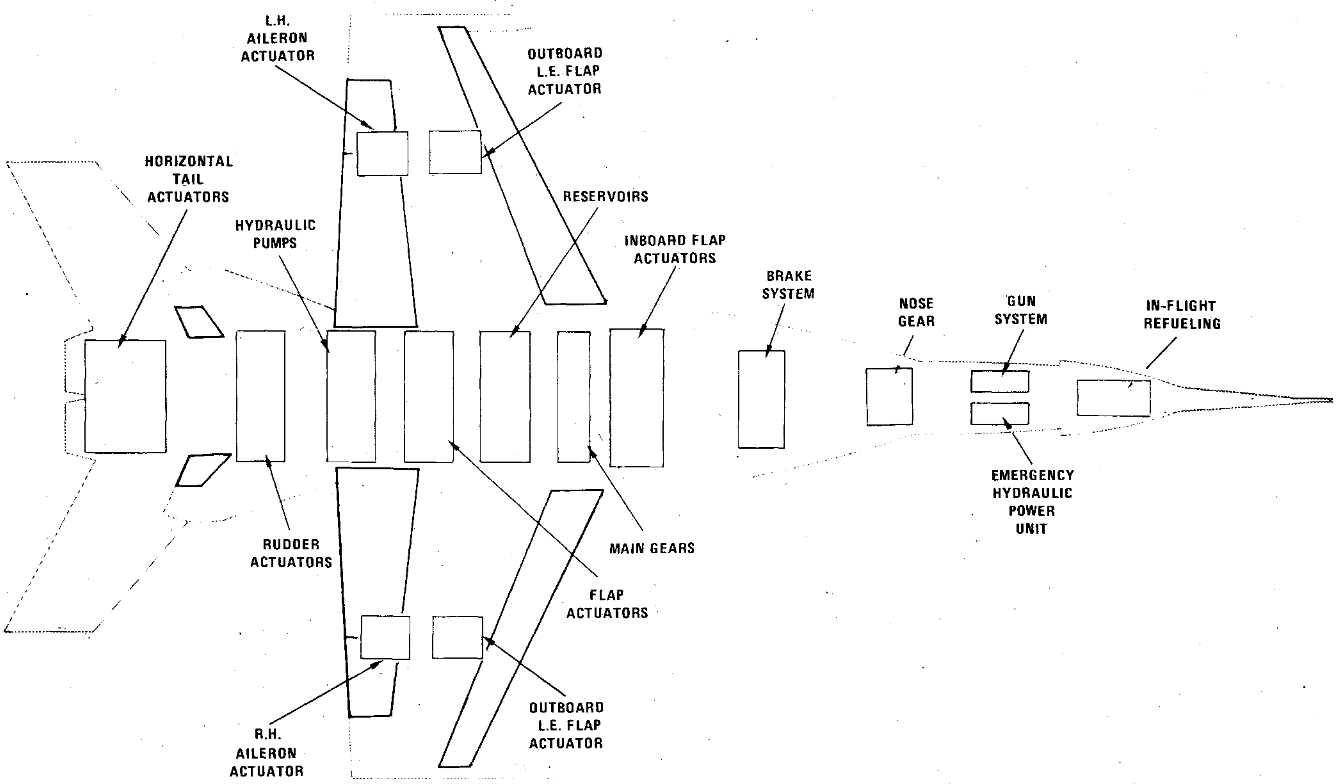

Fig. 6 Flight control test stand hydraulic system.

the pertinent systems installed. Test equipment is assembled so that the systems under test can be simulated and the reaction recorded and evaluated. Digital and analog computers are used to simulate flight conditions and flight loads. Digital memory simulators are used for digital flight control and CAS built-in test investigations. Data acquisition is fully automated to improve testing operations.

Initially, the installation test work orders (ITWO) were performed followed by the design test work order (DTWO). The ITWO is used to verify that the systems have been installed as required by the designer's drawings. The design test work order is used to evaluate the system and to assemble data on its performance.

Hydraulic System Testing and Qualifications

The hydraulic system testing on the test stand was performed to meet the requirements of MIL-H-5440. The purpose of the hydraulic systems test on the test stand was to obtain confidence in the operation of the system, to develop maintenance procedures, and to have the test stand available for flight test support and failure testing should this be required during the flight test program. The test stand hydraulic system (Fig. 6) was identical to the actual aircraft hydraulic system, including all sensors used during flight test. The mounting of the components to the test stand frame simulated the actual airframe mounting.

The initial tests performed were verification of the proposed flushing procedures and reservoir filling procedure. This was followed by operation of the individual subsystems with emphasis on checking for smooth, full-range operation and checks for subsystem peculiarities. Besides the flight control system components, the test stand also contains the parts required for simulating landing gear, wheel brake, emergency wheel brake and accumulator, emergency hydraulic power unit, and gun operation. Systems operation was possible from the aircraft hydraulic pumps or an external hydraulic mule.

The test stand hydraulic system was operated under all simulated phases of flight ranging from takeoff, landing, gear transition, maneuvering flight with simulated gun firing, to two engine-out operation where hydraulic power was supplied by the emergency hydraulic power unit. Among the significant goals achieved were verification of the pressure regulation under varying load conditions and verification of satisfactory pump response under varying system demands. The structural soundness of the lines, filters, and fittings was verified by varying hydraulic pressure and flow conditions and searching for any resonance within the hydraulic system.

Temperature testing was done with all hydraulic systems being cycled. Satisfactory performance is defined as the absence of hot spots within the system and total system temperature, below 275°F which is allowed by MIL-H-5440. The hydraulic system test stand activity also included checkout of an "air-elimination" system for possible incorporation into the aircraft. The system worked well on the test stand but was not required in the aircraft.

Mechanical System Testing and Qualification

The mechanical control system testing on the stand was performed to confirm that the system met requirements of MIL-9490C and in-house design criteria. The goals were similar to those of the hydraulic system testing. In addition to information on the kinematic performance of the mechanical elements, information was obtained on stick and pedal force characteristics and system performance in the presence of failed components. Frequency responses with and without surface loading were obtained on all axes.

Electrical Control System Testing and Qualifications

The electrical power distribution system on the test stand (Fig. 7) was a duplicate of that on the aircraft. The prime purpose of the electrical power distribution system tests was to verify that there were no undesired interactions between different power circuits. Secondary considerations were related to power loading on the individual circuits and buses, the arrangements of the power return leads, and sources of excessive heat generation.

The CAS computer interface, which was more complex than the electrical power system, had a high potential for damaging the CAS computer. The YF-17 CAS computer,

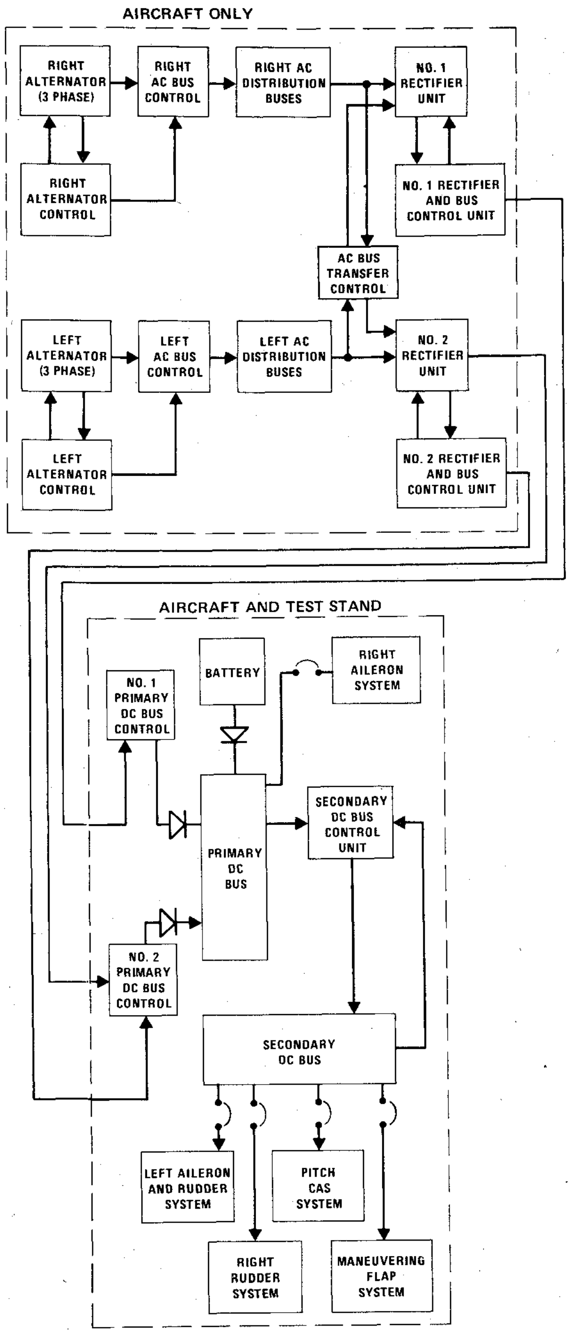

Fig. 7 Electrical power distribution diagram.

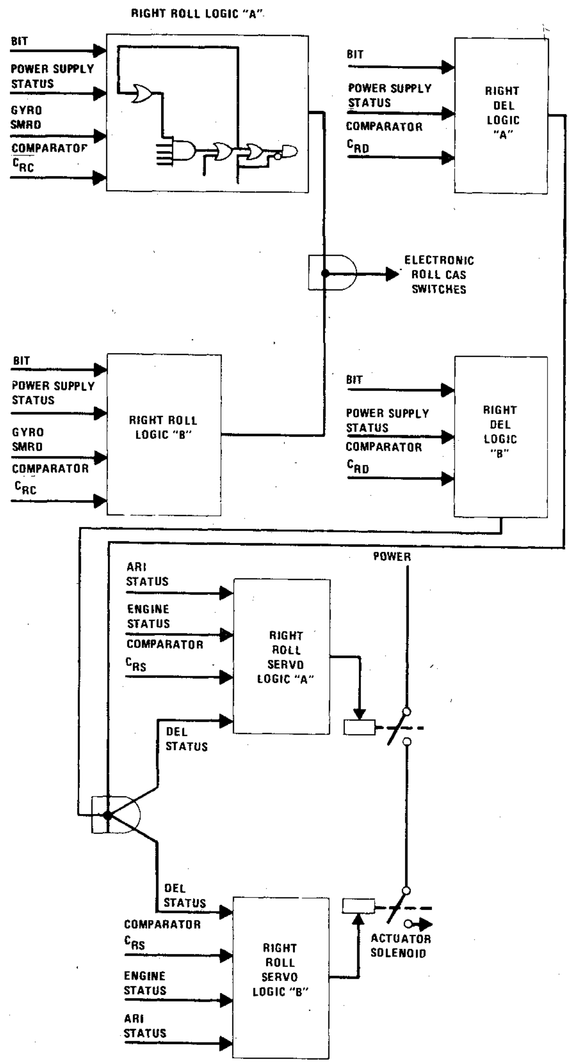

Fig. 8 Switching logic diagram.

which had over 400 input/output wires, could possibly contain wiring interface drawing errors. Furthermore, performing a wiring check on the 400 wires of the CAS computer and the 400 terminations on the other end could possibly lead to additional errors. In this case, an initial installation test work order was used to assure the safety of the CAS computer when power was turned on for the first time. To insure that the design parameters had been met, a design test work order procedure was used. The initial draft of these procedures is generally incomplete, and their use on the test stand is not only to assure test stand completeness, but also to verify that the procedures are correct functionally and satisfy their intended use. A significant part of the DTWO involved determination of the frequency response of the electrical control system, minimum increments of control, and establishing a correlation between the actual hardware performance and the mathematical models used in the system analyses.

System Development

A significant feature of the flight control systems with large complements of electronics is the performance of the mode switching and failure management system. The FCTS was used extensively to verify and improve the mode switching and failure management systems on the YF-17 before its initial flight. The mode switching functions, such as engage/disengage, gear up/down, and flap up/auto/down, were verified and checked for proper operation. A special interface fixture was employed which allowed each wire between the test stand and CAS computer to be interrupted on a patch board. Two adjacent connections on the patch board contained the wire to the test stand and the corresponding wire to the CAS computer. By interrupting selected connections and substituting test signals, the failure detection system's performance could be evaluated under open-loop conditions. The conditions simulated ground operation, taxi, takeoff run, and landing rollout of the aircraft. Determination of the signal levels that would cause system dropouts and the time delay associated with the failure detection for ground operation was accomplished. Fig. 8 is typical of a portion of the failure monitoring circuit within the electrical control system. Discrete status indicators from numerous monitors are used to control the signal flow within the control system.

It was the goal in using the FCTS in the development of the failure management system to minimize the nuisance disconnects consistent with the identification of actual failures. The method used to verify that there would be no nuisance discon-

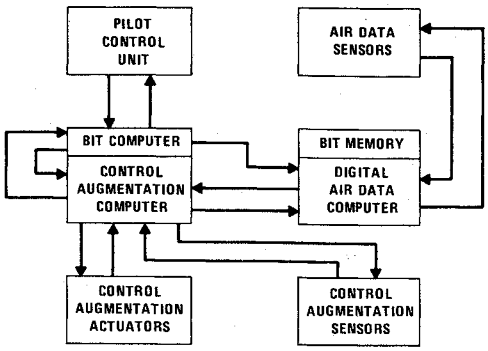

Fig. 9 Built-in test (BIT) system diagram.

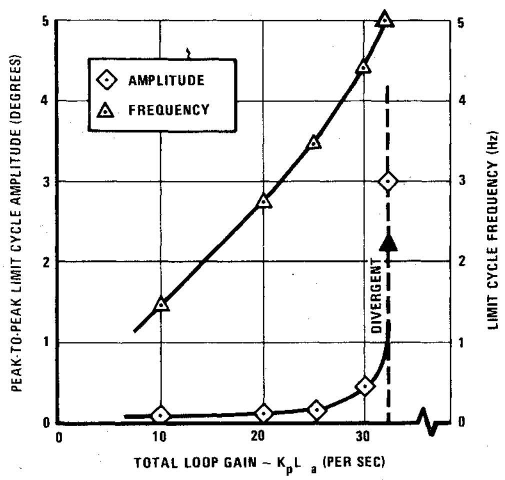

Fig. 10 Ground limit cycle characteristics in roll.

nects was to demonstrate that under twice normal airframe rates and accelerations the system would function normally. The failure detection tests consisted of switching from normal to failed operation with the aircraft in simulated flight. The failure detection time and initial transients were measured and compared with the design criteria. The data also were used to establish the mathematical models used in subsequent system failure simulations on the large-amplitude flight simulator. The failure management system was evaluated extensively in the LAFS prior to the initial flight to confirm that the flying qualities were acceptable during and after the occurrence of a failure.

Another impact of the growing use of electronics in flight control systems is the necessity for built-in test (BIT). The YF-17 CAS employed BIT, as shown in Fig. 9. The FCTS was used extensively to confirm the operation of the BIT when interfaced with the flight control system hardware. Any inconsistency in the timing between the BIT processor in the CAS and the central processor in the digital air data computer was identified and resolved on the FCTS.

Flight Test Support

One of the more effective uses of the FCTS was in the support of flight test. The YF-17 prototype was on an accelerated flight schedule. Therefore, flight control optimization and preparation were accomplished on the FCTS and then implemented on the airplane. An example of this is the preparation for limit cycle and ground resonance testing performed prior to the initial flight. The structural dynamics of the airplane were simulated on the FCTS, and the limit cycle characteristics (Fig. 10) and ground resonance test procedures were optimized. Although limit cycle data obtained in this manner were applicable directly to the airplane, only the procedure used in the ground resonance testing was significant. This arises because the limit cycle characteristics are not influenced by the airplane structural characteristics, as are those of the ground resonance.

As the flight test progressed, several other situations arose wherein flight time for control optimization was minimized by use of the FCTS. In one instance, the model used in the longitudinal control system required changing. This became apparent as a result of flight studies using a variable stability airplane. It appeared, as a results of these studies, that the landing flying qualities were compromised by the use of a second-order model in the forward loop of the pitch CAS. The selection of the model had been influenced strongly by air combat performance requirements. The test stand was used in a fixed-base simulator mode to complement the studies made using the large-amplitude flight simulator to determine the correct model for landing. In another instance, the maneuvering flap inner loop dynamics required changing to optimize the contribution that the flaps made to the maneuvering performance of the airplane. The FCTS was used as a fixed-base simulator to achieve inner loop optimization with minimum impact on the flight test program.

Research and Development

Northrop currently is investigating the application of digital computer technology to flight control systems for fighter aircraft using the FCTS in conjunction with the LAFS. In this way, it is possible to evaluate the advantages and disadvantages of digital control systems as effectively as in a flight test program.

III. Conclusion

This paper has related Northrop's experience in the use of the flight controls test stand in the design and development of the YF-17 flight control system. The following conclusions are reached:

1) The FCTS is an essential tool in the successful design and development of electromechanical control systems.

2) The FCTS must be functional four to six months before the initial flight to justify its use in the development process.

3) The FCTS has numerous applications, a major one being a research and development tool for advanced flight control system studies.