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Abstract

The modern advanced avionics in new high-performance aircraft strains the capability of current technology to safely monitor these systems for flight test prior to their generalized use. New techniques are needed to improve the ability of systems engineers to understand and analyze complex systems in the limited time available during crucial periods of the flight test. The Dryden Flight Research Facility of NASA's Ames Research Center is involved in the design and implementation of an expert system to provide expertise and knowledge to aid the flight systems engineer. This paper discusses the need for new techniques in monitoring flight systems   the conceptual design of an expert-system status monitor. The status of the current project and its goals are described.

Nomenclature

AFTI	advanced fighter technology integration
DFCS	digital flight control system
FCC	fire control computer
FCS	flight control system
FSW	forward-swept wing
HiMAT	highly maneuverable aircraft technology
LVDT	linear variable differential transducer
RCVD	remotely controlled vehicle and display
SMS	stores management set
WATR	Western Aeronautical Test Range

Introduction

The increasing complexity of modern high-performance aircraft systems requires innovative techniques to allow the flight test community to safely and effectively test these systems prior to their generalized use. These complex systems are often crucial to flight safety and require teams of engineers in a ground control station for analysis and monitoring. These systems range from new and unusual aircraft, such as the X-29 forward-swept wing (FSW) aircraft, through advanced avionics and flight control systems (FCS), as in the advanced fighter technology integration (AFTI) F-16 aircraft, or advanced wing design and control,

as on the AFTI/F-111 or F-8 oblique wing aircraft (Fig. 1). Each of these advanced system concepts are intensively flight tested (incurring extensive costs and time expenditures) prior to their use in a production environment. Current techniques available to engineers involved in flight testing include monitoring aircraft analog parameters (on strip charts and CRT displays) and discrete information, such as system status and failure identification (on simple CRT displays or light boards). Engineers involved in monitoring test flights are required to have a complete knowledge of the system they are monitoring and an ability to identify critical events as they occur. In the brief time allowed during critical flight test events, in high-stress situations, it is difficult for any individual or group of individuals to always correctly identify and rectify, if necessary, problems that often occur on new advanced systems.

A major concern in advanced high-performance aircraft systems is the digital flight control system (DFCS). New high-performance aircraft are often substantially unstable and require augmentation from a full-time, full-authority FCS. The complexity of a control system required to control the unstable aircraft and improve mission performance dictates that the FCS be a digital computer. As DFCSs become essential, monitoring becomes more critical. Problems that occur in the DFCS can cause the loss of an aircraft, the abortion or cancellation of a flight, or forced modification of the flight test. Fast and informative displays of the status and health of the DFCS can save a flight, a mission, or the aircraft itself. Currently established flight test monitoring technology involves discrete data transmitted from the aircraft and displayed on CRTs or light panels with little, if any, interpretation.

Figure 2 illustrates the levels of flight monitoring automation involved in evaluating and correcting the status and health of DFCSs. Level 1 is early systems monitoring with primitive capabilities, which involved immense light panels displaying the discrete information with no interpretation or evaluation, as used in the early highly maneuverable aircraft technology (HiMAT) program. The systems engineer who monitored the flights was required to monitor over 100 lights, determine the status and health of the FCS, and recommend the correct action required to improve the crisis situation. Level 2 is the current level of flight monitoring in which some logical operations are performed on the discrete information downlinked from the aircraft; however, no interpretation is available, and the systems engineer must still determine the DFCS status and health from multiple discrete information displays on a CRT. Both the AFTI/F-16 and X-29 aircraft, with their complex DFCSs, are currently at this

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level of automation in systems monitoring. The systems engineer still must assemble all the information, determine the status and health of the DFCS, and recommend the best procedures to resolve discrepencies; these functions are all performed in a high-stress environment, in an extremely limited time frame, and with very little easily accessible information other than that remembered at the time. For safety, current DFCSs contain backup systems that relieve some pressure from the monitoring systems engineer.

Level 3 requires a system that interprets the data, automatically provides this information to the monitoring systems engineer, and allows the systems engineer to access the knowledge on the operation of the DFCS. Further enhancing such a system (level 4) would permit the monitoring system to automatically recommend and justify corrective action. Level 5 evaluates the health and status of the DFCS and reconfigures the control system automatically to accommodate this evaluation. The body of this paper presents the design and development of a level 3 system that can be developed to level 4. An expert-system flight status monitor is being developed that will inform the systems engineers of the FCS problems and determine their cause; this expert will recommend corrective action and generate appropriate procedures for normal and emergency operation.

Motivation for Expert-System Flight Status Monitor

During flight testing of new and complex DFCSs, problems have occurred that the systems engineer has attempted to solve in real time, not always successfully. The resolution to the problems is often discovered after several days of studying the documentation, after which the engineers realize that they had known the solution but had not applied it to this situation. Another situation that often occurs is that a flight is aborted or a mission cancelled because of a detected problem; it may later be determined that the problem was negligible or not as severe as first thought, and the flight could have been shifted to another mission, accommodating the failure. At the Dryden Flight Research Facility of NASA's Ames Research Center both situations have occurred, costing both time and money. Three examples of situations that have occurred at Ames-Dryden are included to illustrate the need for an improved method of DFCS monitoring.

HiMAT Gear-Up Landing

The NASA HiMAT remotely piloted vehicle was a highly successful program with only a few in-flight problems, one of which is discussed here. The HiMAT was performing a normal mission when it lost one of two uplink recievers used to accept commands transmitted from the ground station. The HiMAT was flown remotely by a pilot in a ground cockpit, with commands transmitted to receivers on the aircraft and aircraft feedbacks transmitted to ground computers. A cockpit switch signaled the control system computer to deploy the gear, and the control system translated the command into a cycled signal understood by the HiMAT. The TF-104 chase crew member controlled a backup gear deployment switch that could be manually cycled, if necessary, to provide the correct signal to the

aircraft. After the loss of one of the uplink receivers on board the HiMAT, the cockpit gear switch was activated, but the gear did not deploy. The correct sequencing requirement was remembered and correctly performed, but the gear stayed up, and the vehicle was landed (safely) on its belly. The problem was investigated after the flight; the systems engineers ultimately realized that the loss of one uplink receiver changed the command persistence requirement for the gear-down sequencing. Knowledge of the sequencing and persistence requirement for cycling the gear switch was available, but it was not recalled during the critical period and was not included in the normal documentation.

AFTI/F-16 Multiple Mode Change

The AFTI/F-16 aircraft includes a complex avionics suite, including a stores management set (SMS) and fire control computer (FCC) along with a complex triplex DFCS, all of which communicate on an IEEE 1553 data bus, with the FCC acting as the primary bus controller and the SMS acting as backup bus controller. During the DFCS flight test phase, the AFTI/F-16 contained four standard modes, four decoupled modes, and multiple submodes. On an early flight the DFCS received multiple (over 300) uncommanded mode change requests, which it then acted upon; this resulted in the aircraft experiencing multiple mode changes in a short time period. When this problem was detected on the ground through the flashing of mode lights, a solution was sought. Approximately 5 min later the systems engineer had the pilot turn off the SMS, and the mode switching stopped. The four standard FCS modes and multiple submodes were all engaged through the SMS via the 1553 data bus with no protection built into the DFCS to prevent multiple mode switching in a short period of time. In the stressful environment of an early flight on an unusual and complex flight control system in an urgent situation, the systems engineer could not readily recall the critical knowledge and required more than 5 min to determine the appropriate action.

AFTI/F-16 Flight Control System Failure Indication

Each channel in the triplex DFCS of the AFTI/F-16 aircraft is capable of determining its own status and health, as well as that of the other channels, and then transmitting that information to both the pilot and the ground monitoring station. At the same time, failures on the DFCS are divided into several subcomponents and levels, making it difficult to determine the actual operating state of the system. The failures are displayed to the pilot and ground station in a numeric code that indicates each channel's diagnosis of the problem and the element that has failed. During an envelope-expansion flight, an onboard failure of the FCS caused each channel to establish a different failure state and to provide conflicting information to the pilot. The systems engineer had to decipher the fault codes generated by each channel for all components, determine the failure condition, and recommend a corrective action, all within minutes. The recommended action was to reset the FCS, hoping that the situation would improve without a complete understanding of the condition of the system. The

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reset caused further degradation of the system, forcing the actuator to select the backup hydraulic system. The aircraft remained controllable and landed safely due to the redundancy built into the DFCS. The systems engineers spent several hours after the flight determining what the fault codes meant, and several days elapsed before they understood the problem along with its cause (an internal software switch had induced different states into each of the three flight control channels, causing each channel to develop a different view of the aircraft and system state).

The three problems just described are only a sampling of problems that occur during the flight testing of new, advanced, complex systems. Even with the best design process, not all contingencies are covered. Information may be discovered too late in the design and test cycle to be incorporated immediately, and it must be carried as part of the system knowledge until it can be included in the design. The system complexity also requires a great deal of system knowledge simply to monitor the system within normal operations. At Ames-Dryden, an expert system is being developed to help solve these problems. An expert system would contain the knowledge (which the systems engineers so laboriously acquire) in an easily accessible form in the control room, which would reduce the time necessary to recall or rediscover the needed knowledge. The same expert system would also be able to recommend the appropriate corrective action to more quickly reduce the hazard by using its ability to draw on a larger data base than the systems engineer. The probable causes of the problem could be assessed by this expert system and relayed to both the systems engineer and the pilot for evaluation, which would again reduce the time required to develop a safe solution.

Description of the Expert System

A conceptual view of an expert-system flight status monitor is shown in Fig. 3. The system must be able to receive information on the status and health of the FCS from telemetry downlink data and translate this information into a usable format. Conventional programs have been developed that receive telemetered downlinked data and very rapidly translate them into digital words. This information could then be input to the expert system. The expert system must then determine whether any changes have occurred compared with the previous sample and, if so, evaluate the effect of these changes. The expert-system flight status monitor must update its knowledge base at a rate that is compatible with the aircraft downlinked data. A data-driven foreground loop will determine the state of the system and inform the user, in this case the systems engineer, of the changes and consequences. If a failure occurs, a warning or caution will be issued along with corrective or emergency procedures, if required. As a part of this evaluation, the expert system may be required to ask the user questions on the state of the aircraft. A background task will allow the user to query the monitor for information on FCS state or the rationale the monitor used to reach its conclusions. The expert system will interrupt

the background task when necessary to evaluate new data. If the state of the FCS has not changed between inputs, the expert system will not re-evaluate that state.

The knowledge base will contain both aircraft specific rules,

> If AC Power is Failed
> Then Analog Reversion Mode
> is Failed,

and metarules, the rules that the systems engineer uses to determine the correct action for a failure situation,

> If All Downlink Data is Failed
> Then There Was A Telemetry
> Spike.

The knowledge base will also contain rules to allow the expert system to determine the aircraft state and the required corrective action and to inform the systems engineer of its evaluation. The expert system will consist of rules to emulate the failure detection system of the FCS and compare the state it generates to that of the aircraft. If the monitor's conclusions disagree with the aircraft state, a warning will be issued and the user will be able to ask the expert system to resolve this conflict. The conflict resolution will be processed as part of the background task to allow the monitor to evaluate the aircraft information as it is generated. The ground-based expert system will also be able to communicate with the pilot by a remotely computed display driven from information generated by the expert system and telemetered to the aircraft via the NASA Ames-Dryden uplink system. The ability to transmit the expert-system knowledge to a pilot display using ground computers will allow pilot interaction without waiting for the development of flight-qualified systems and will allow the pilot to access much-needed information in critical situations without the delay of waiting for the information from the ground station. A technique will be developed to allow the pilot to respond to queries from the expert system for information needed to determine the status of the aircraft.

A major concern in the development of an expert-system flight status monitor is the capability of operating in real time, since the information is available to the expert system from the aircraft at speeds of 40 to 50 Hz and the amount of information to be processed can be from a few words to over 100 bits of information. The time available to analyze and develop recommendations when a problem occurs in the flight environment is very short because the aircraft can lose control within seconds; consequently any expert system developed to assist in monitoring must be able to respond in seconds. Therefore, the real-time issue is of great concern and is being explored. Different inference techniques for real-time operation are being investigated, along with the data, or rule, representations. The development of data structures that improve the real-time implementation and allow easy modi-

fication and adaptation to the knowledge base is essential for an operational system.

The ultimate goal in the development of an expert-system flight status monitor is to demonstrate the capability of a real-time expert monitor providing "intelligent" interpretation of system status information and to apply this monitor in the control room environment, the Western Aeronautical Test Range (WATR). The system will initially be designed as a stand-alone system capable of evaluating simulation or flight tapes. Then the system will be incorporated into the simulation environment for testing and evaluation, installed in the control room, and later, extended to the aircraft to allow the pilot direct interface with some subset of the monitor. A small subset of a DFCS is currently being used to develop the knowledge representation and inference mechanisms for a demonstration system, but the knowledge base will be expanded to incorporate the full FCS as the expert system develops. The system will continue to expand, from a full description of the FCS to other systems on board the aircraft, until the expert-system flight status monitor cannot operate in real time. At this point, new computer hardware or software techniques will hopefully be available to allow the system to expand and operate in real time.

Development Approach

To address the development of an expert-system flight status monitor, Ames-Dryden systems engineers are developing an experimental system while an experienced contractor is developing an operational system in cooperation with Ames-Dryden engineers. The in-house effort concentrates on developing experience in expert systems while a knowledge base is developed for the operational system. Various knowledge representations and new techniques will be investigated prior to operational implementation. The contractor's parallel effort is directed toward developing an operational system using the aircraft-specific knowledge derived from in-house development, developing a working real-time system, and sharing proficiency in expert systems.

The first developmental go in the real-time system is an operational demonstration system capable of processing simulation or flight data; such a system will improve the speed of processing failure information after a flight and will interact with the user to determine the FCS state. This system (to be developed by the contractor in association with Ames-Dryden engineers) will be an interactive, non-real-time system that will demonstrate the rule base and inference structure to be used on the real-time system. After the successful completion of the non-real-time expert-system flight status monitor, a real-time system based on the previously developed structure will be implemented and interfaced with a real-time hardware-in-the-loop simulation of the aircraft. The simulation will provide real-time FCS data via a data bus interfaced with the expert-system flight status monitor. The simulation will be used to test the system in a real-time environment and to provide necessary verification and valida-

tion of the expert system prior to its implementation in the control room (Fig. 4). After verification and validation, the system will be interfaced to the downlinked data from the aircraft systems, through either the control room (WATR) or the remotely controlled vehicle and display (RCVD) simulation facility. Once an operational system has been developed, the knowledge base will be expanded until either the limit of the expert system is reached or the aircraft systems have been completely defined. After an expert-system flight status monitor has been successfully demonstrated in the control room, the system will be extended to allow interfacing with the pilot through the Ames-Dryden uplink system. A remotely controlled display, driven by the remotely computed display system, will be developed to interface the expert system with the pilot.

Status of Expert-System Flight Status Monitor

In-house development of the expert-system flight status monitor has been underway since November 1984, and a working non-real-time system has been demonstrated on a multiuser VAX 11/750 in Common LISP. The knowledge base currently includes only the input sensors for the aircraft and their respective status and mode indications (Fig. 5). Input sensors include roll rate, pitch rate, yaw rate, pitch stick command, roll stick command, yaw pedal command, actuator position feedbacks, normal accelerometer, lateral accelerometer, air data, and power interfaces. The FCS used for the demonstration (Fig. 6) is a triplex configuration with both input and output voting. It features a triplex independent backup system that is dissimilar to the primary system and digital channels capable of independently switch from the primary to the backup system. The actuators used also contain a voting plane, but they were not included in the current expert-system flight status monitor. The hierarchy, or relationship of each element to the others (Fig. 5), is included in the expert system at a level at which only the direct interrelationship is included, with no interpretation given. This allows the monitor itself to develop the tree-like interrelationships, thereby eliminating the human error of missing an interface or inputting an incorrect interface.

Improved knowledge representation is currently under development to allow for a more effective system. A knowledge acquisition tool has been developed to allow easy user interaction and improved aircraft rule acquisition. The operational demonstration system (jointly developed by Ames-Dryden and the contractor) is to be completed by early fall 1985 (Fig. 7). With the demonstration of the feasibility of this system, development of the real-time system will begin by mid-1986, and an operational real-time expert-system flight status monitor will then be interfaced with the aircraft telemetry downlink data and evaluated by the systems engineers. The interface of the expert system to the aircraft crew station is not scheduled until 1987, and knowledge base development is expected to continue uninterrupted.

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Concluding Remarks

The application of expert systems to flight test monitoring is particularly appropriate. The monitoring task is manpower and information intensive and is fairly well understood. The capabilities of a system to monitor data down-linked from the flight test aircraft and to generate information on the state and health of the system for the monitoring engineers will provide increased safety during flight testing of new systems. The expert system will provide the systems engineers with ready access to the large amount of information required to describe a complex aircraft system; access to this information in an easily understood form will enhance engineering capabilities in understanding and developing future complex systems. The potential power of such a system, originating from the beginning of a development program, is enormous. As both the expert system and the aircraft system are developed, discrepancies can be resolved prior to the actual testing of the aircraft system. The expert system can be main-

tained at the same rate as the aircraft system, providing easy, user-friendly knowledge storage. The expert system can be integrated with the simulation prior to flight testing; anomalies that occur in the simulation can be better understood in real time without wasting hours of simulation time. As new information about the aircraft system is discovered, the expert system can be updated to contain the most complete knowledge available.

A demonstration system has been developed that, although not operating in real time, shows great promise for the use of expert systems in the flight test environment. The development of an expert system has been helpful in defining the operation of the FCS. Even though the knowledge base is limited, the development of the demonstration system generated new engineering knowledge that contributes to the effectiveness of the engineers and to program safety. The central location of the knowledge base is another useful byproduct of this development.
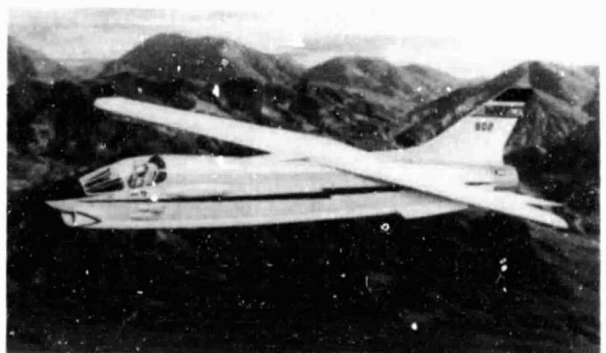

X-29A FSW advanced aircraft design

AFTI/F-16 advanced avionics and flight control system

AFTI/F-111 advanced wing control

F-8 oblique-wing research aircraft advanced wing control

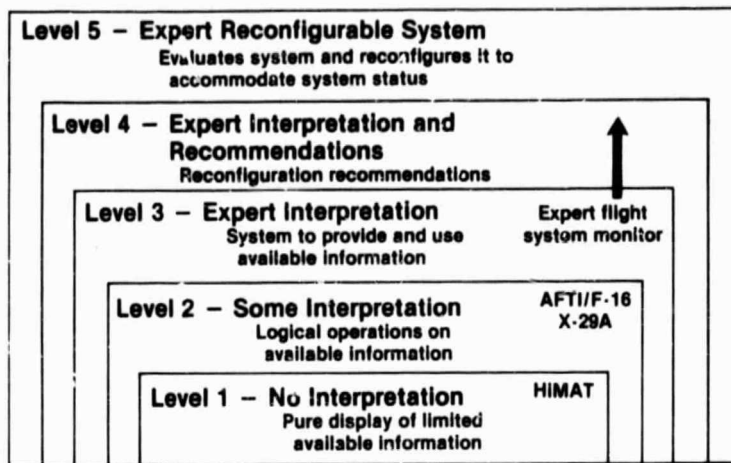Fig. 1 Typical Ames-Dryden aircraft with advanced control systems.

Level 5 – Expert Reconfigurable System
Evaluates system and reconfigures it to
accommodate system status

Level 4 – Expert Interpretation and
Recommendations
Reconfiguration recommendations

Level 3 – Expert Interpretation
System to provide and use
available information

Expert flight
system monitor

Level 2 – Some Interpretation
Logical operations on
available information

AFTI/F-16
X-29A

Level 1 – No Interpretation
Pure display of limited
available information

HIMAT

Fig. 2 Levels of flight monitoring automation.

Fig. 3 Overview of expert-system flight status monitor.
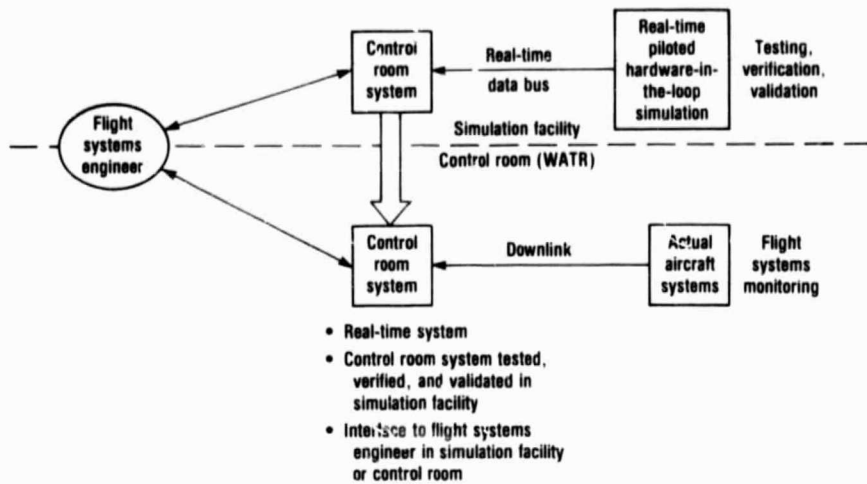
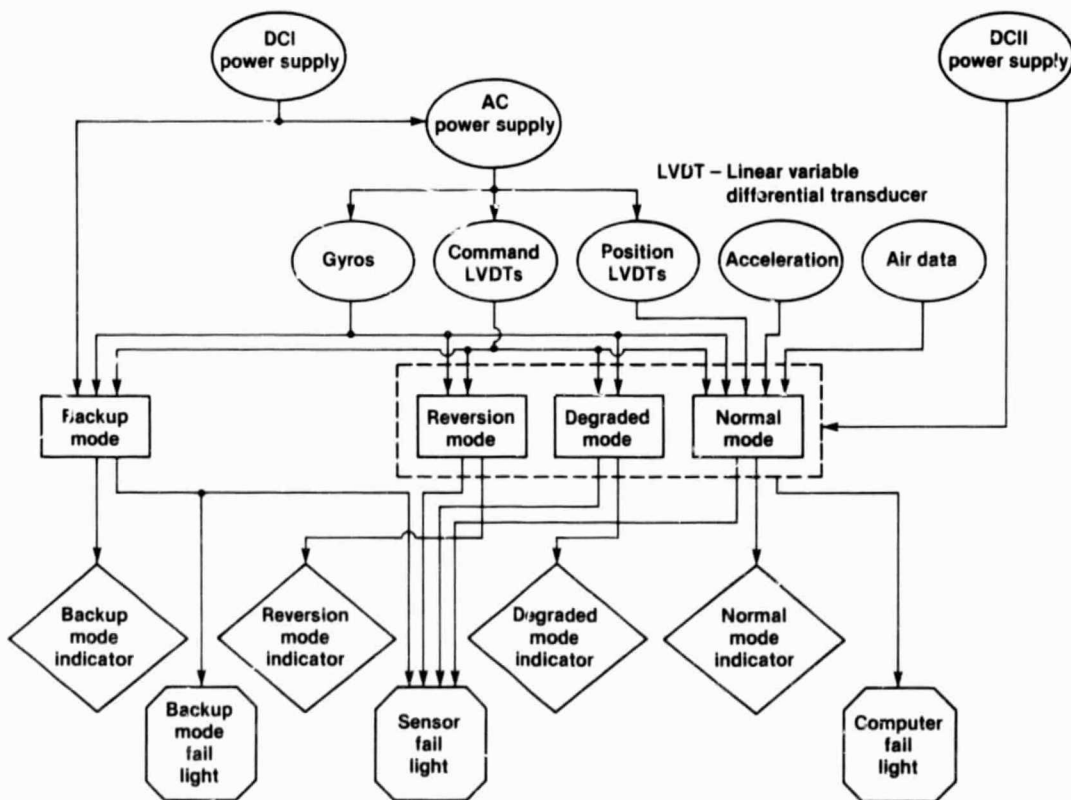*Fig. 4 Control room system.*

Fig. 5 Digital flight control interrelationships.
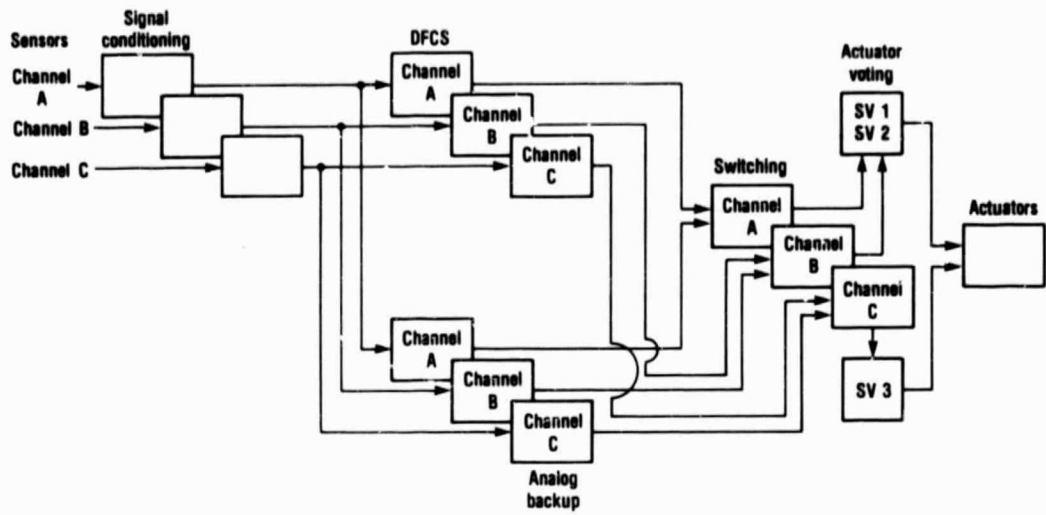
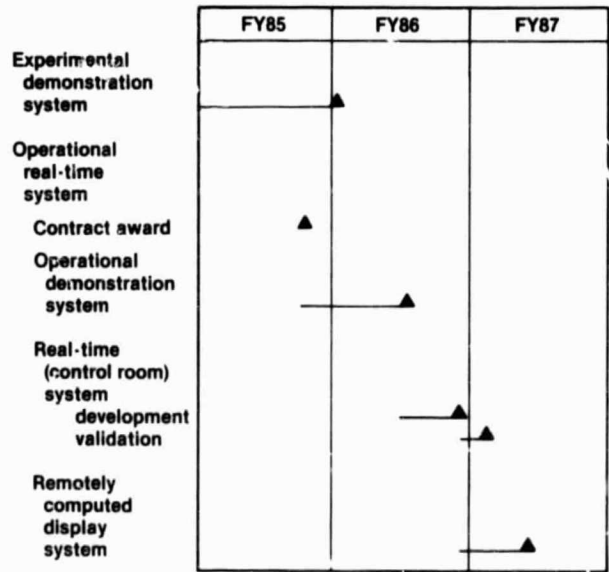*Fig. 6 Overview of digital flight control system.*

Fig. 7 Schedule for expert-system flight status monitor.

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16. Abstract

The modern advanced avionics in new high-performance aircraft strains the capability of current technology to safely monitor these systems for flight test prior to their generalized use. New techniques are needed to improve the ability of systems engineers to understand and analyze complex systems in the limited time available during crucial periods of the flight test. The Dryden Flight Research Facility of NASA's Ames Research Center is involved in the design and implementation of an expert system to provide expertise and knowledge to aid the flight systems engineer. This paper discusses the need for new techniques in monitoring flight systems and the conceptual design of an expert-system flight status monitor. The status of the current project and its goals are described.

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