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OVERVIEW OF THE NASA AMES-DRYDEN INTEGRATED TEST FACILITY

Dale Mackall, David McBride, and Dorothea Cohen
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

ABSTRACT

The Integrated Test Facility (ITF), being built at the NASA Ames Research Center's Dryden Flight Research Facility (ADFRF), will provide new real-time test capabilities for emerging research aircraft. An overview of the ITF and the real-time systems being developed to operate this unique facility are outlined in this paper. The ITF will reduce flight-test risk by minimizing the difference between the flight- and ground-test environments. The ground-test environment is provided by combining real-time flight simulation with the actual aircraft. The generic capabilities of the ITF real-time systems, the real-time data recording, and the remotely augmented vehicle (RAV) monitoring system will be discussed. The benefits of applying simulation to aircraft-in-the-loop testing and RAV monitoring system capabilities to the X-29A flight research program will also be discussed.

INTRODUCTION

The Integrated Test Facility (ITF) will reduce flight-test risk by minimizing the difference between the flight- and ground-test environments for advanced research aircraft. These aircraft rely on embedded digital control systems and are characterized by the integration of flight control, propulsion, structures, and aerodynamics. Exhaustive ground testing of the embedded control systems is required to assure aircraft safety and the efficient use of flight-test missions. The ITF addresses the ground-test needs of aircraft with integrated systems through the application of advanced real-time capabilities.[1]

The Integrated Test Facility

A cutaway view of the ITF is shown in Figure 1. The facility contains test bay (hangar) space for six fighter-size or fewer larger size aircraft, and is divided into three separate areas. The engineering staff is located in the front section of the building, and office space is provided for visiting contractors. The aircraft technicians and maintenance staff are on the first floor of the central section. The flight simulation systems are located on the second floor of the center section of the building, near all six test bays. The location of the flight simulation systems to the test bays provides the short connection distances needed for closed-loop simulation with the flight vehicle.

Aircraft services, such as electrical power, hydraulic supplies, and cooling air are provided to support aircraft-in-the-loop simulations. All the aircraft services can be monitored in real time when performing tests with the aircraft (Figure 2).

The electrical power includes 277/480 volts (V) and 120/208 V, three phase, 60-Hz power; 120/208 V, three phase, 400-Hz power; and 28 volts direct current (Vdc) power.

The planned hydraulic systems for the six test bays will be independent, allowing different pressures and fluids to be used. The initial hydraulic system has three pumps providing 35 gallons per minute (gal/min) at 5000 pounds per square inch (lb/in^2) pressure. The flow per pump can be increased to 50 gal/min at a pressure of 3500 lb/in^2.

The planned aircraft cooling system is designed to provide each test bay with 4000 cubic feet per minute (ft^3/min) of air flow. Exit air temperature is 40° F, provided through two 14-in. supply ducts.

Generic Real-Time Capabilities of the ITF Test Systems

This section provides an overview of the ITF's real-time test systems. The simulation system is at the core of the real-time systems. It provides high fidelity modeling of the atmosphere, aircraft rigid body dynamics, and the flight control system (FCS). The section explains how simulation, real-time data recording, remotely augmented vehicle (RAV), and remotely augmented vehicle expert system (RAVES) are used to support testing aircraft with integrated systems.

It is important to note that all the ITF real-time systems, except for RAVES, can be controlled by an automated test system. This allows the test engineer to automatically run test cases from a high level mouse and menu interface.

Simulation

The NASA Ames-Dryden simulation facility will become an integral part of the ITF. This relocation will bring to the ITF 30 years of real-time simulation experience. Simulations are important engineering tools used through all phases of flight research[2] and perform various tests which include time response, frequency response, redundancy management, failure modes and effects testing, and pilot evaluation. Simulations are used to test a proposed modification in the ITF before it is installed on the aircraft.

To augment these diverse uses, the ITF will provide multiple simulation configurations for a given project with varying levels of aircraft hardware included. These simulations include simple batch versions, which use only the computer and a user terminal, as well as complex aircraft-in-the-loop versions. This diversity allows the project team to easily select the level of hardware needed to support a session's activities. This flexibility permits quick comparisons between software models and flight hardware.

High-fidelity modeling of the aircraft and its systems is of key importance in the ITF. This high-fidelity modeling provides aircraft hardware with a realistic flight environment while in ground test. The success of this modeling becomes increasingly important as aircraft systems become more interdependent.

The simulation interfaces give users fingertip control of the simulation. The simulations can be controlled by buttons and switches in the cockpit, or from a menu of display pages on a cathode ray tube (CRT), or the entire control mechanism can be run from the automated test system workstations. The user generates simulation command files to automate the process of running tests. This approach eliminates the need to know the simulation commands which would otherwise be entered through the simulation CRT display page.

Real-Time Data Recording

The ability to record all the data needed to verify the correct response to a test and to analyze anomalies is essential to any environment used to test complex interdependent digital systems. Such recording is perhaps the most demanding problem faced by the ITF. In the past, when a problem occurred the detailed data needed to resolve the problem were often not recorded. The test would then be rerun with the proper instrumentation, but the anomaly would not repeat. By recording all possible aircraft and simulation data during a run, the ability to resolve a problem without repeat runs is greatly increased.

The ITF real-time data recording system will record data from the simulation, the aircraft flight control analog interfaces and digital busses, the telemetry system, and the ITF services (hydraulics and electrical power). The data from these sources are supplied to the data recording system by way of an interprocessor communication link. This link connects the different computers at memory access speeds over long distances. The estimate of the quantity of data to be recorded is shown in Table 1. These data are time tagged to provide exact correlation of events which occur at different data sources.

Remotely Augmented Vehicles

The ITF provides RAV capabilities for ADFRF's research aircraft. The RAV laboratory provides ground-based computers interfaced to the aircraft in flight through telemetry and uplink radio links. These components allow the ground-based computers to provide closed-loop control of vehicles or to drive aircraft displays which aid the pilot. As with the simulation systems, ADFRF has a great deal of experience with RAV systems.

The ground-based computers are known as the control law computer and the pulse code modulation (PCM) computer and are FORTRAN programmable. The control law computer is used to augment the onboard control systems. The control law computer uses telemetry downlink data and software coded control laws to generate aircraft commands. The PCM computer shares memory with the control law computer and is the interface between the control law computer and the aircraft's telemetry stream. The PCM computer converts scaled integers used in the telemetry stream to engineering units used by the control law computer.

Currently, hardware identical to the control law computer is paired with each simulation computer for verification and validation of the RAV ground-based software. The simulations are designed to interface to this computer in the same manner as the PCM computer. Timing relationships are preserved to model the flight system accurately. The relationship between the control law computer and the PCM computer in the RAV laboratory and in the simulation lab is shown in Figure 3.

The RAV activity is divided into three categories as described in the following and shown in Figure 4.

1. Remotely augmented vehicles (RAV) use the ground computer to augment the onboard control system. This capability can be used to test alternate control laws, insert sophisticated autopilots to fly precise research maneuvers, or to generate pulses or frequency sweeps for data analysis. The X-29A airplane is an example of a current research aircraft using RAV operation.

2. Remotely computed displays help guide the pilot in flying precise maneuvers. The control law computer uses downlinked data to calculate the fly-to signals sent to

the aircraft display. This capability is used extensively by the flight research projects.

3. Remotely piloted research vehicles (RPRV) are flown from a ground-based cockpit. The vehicle's control laws are coded in FORTRAN and executed in the control law computer. The RPRV that have been flown at the ADFRF range from the subscale highly maneuverable aircraft technology (HiMAT) vehicles to the joint Federal Aviation Administration/NASA controlled impact demonstration using a Boeing 720.[3]

The Remotely Augmented Vehicle Expert System

The RAVES was designed to enhance real-time monitoring of critical flight parameters in the RAV laboratory. The earlier RAV displays were enhanced to use color graphics and mouse capabilities. The color graphics and mouse capabilities allow quicker comprehension of in-flight problems.

The RAVES is based upon NASA Johnson Space Center's (JSC) real-time display system used in support of the space shuttle.[4] The benefits of using JSC's software are twofold. First, development costs are reduced by using existing software. Secondly, NASA ADFRF and NASA JSC share in any new developments to the software.

The RAVES workstation receives the data for display by way of a 16-bit parallel interface and a Loral advanced decommutation system (ADS)-100A. The ADS-100A can receive data from the raw PCM telemetry stream and the Mil-Std-1553 bus connected to the RAV computers, Figure 5, allowing the user to monitor the data from either or both sources. There is an RS-232 serial port connection between the workstation and the Loral ADS-100A for setting up the system.

A unique aspect of the RAVES is the implementation of both Masscomp® graphics primitives and Visual Intelligence Corporation's Data-Views® (DV) graphics displays running simultaneously under the same program. Incorporating two diverse graphics packages in the same program allows the programmer to tailor the graphics to the application. For example, the project specific main displays are developed with DV-Draw, an interactive drawing program which is included in DV, while the fault window, a simple text display requiring a fast update rate, is programmed in Masscomp® graphics primitives. Data-Views® allows engineers to design their own displays quickly[5] and does not require programming. New displays can be designed, implemented, and tested in as little as one hour. This is a vast improvement over previous methods, which could take as long as one week.

The four major windows in RAVES are status line, main display, fault message window, and expert system popup window. The status line shows which aircraft is being monitored and its flight number. The date is displayed with the day of the week, month, day, year, and Julian date. The current time is continuously updated. The main display is either a generic RAVES or a project specific display. The user chooses the main display from a menu of options. The fault message window displays a message whenever a failure occurs,[6] even if the current main display is not processing that parameter. These messages are continuously scrolled in the fault message window and are color-coded according to urgency. Sound (the bell) may also be added to a message.

The RAVES was designed to acclimate new engineers quickly to the RAV system and its terminology. This is done two ways (1) displays that have warnings written out in English terms and (2) the expert system popup window. The display which uses English terms has a corresponding display which uses acronyms and variable names from the source code. By using these two displays an engineer can become familiar with the acronyms while monitoring the RAV system. The expert system popup window can be chosen at start up and suggests what to do in a failure situation by explaining the cause of the failure. Troubleshooting instructions are provided in an easy step-by-step format.

Although currently being used only in the RAV laboratory, RAVES will soon be used as part of the ITF systems to monitor aircraft ground tests.

The Application of the ITF Real-Time Systems to Flight Projects

The following sections show how the ITF real-time systems have been applied to the X-29A program to meet the safety and operational requirements of the project. The first section discusses the X-29A ground testing performed by connecting the actual aircraft to the flight simulation. The second section describes the application of the RAVES capability to the monitoring of the X-29A RAV system.

X-29A ITF Requirements

Advanced flight research aircraft like the X-29A[7] require extensive end-to-end testing of their complex interdependent systems prior to flight. Figure 6 is a photograph of the X-29A test configuration. The purpose of the X-29A testing was to safely evaluate the functions of the aircraft systems in as near a flight configuration as possible.

®Masscomp is a registered trademark of Concurrent Corporation, Tinton Falls, NJ.

®Data-Views is a registered trademark of Visual Intelligence Corporation, Amherst, MA.

Five major test capabilities were required of the ITF systems by the X-29A program:

1. A five degree of freedom (DOF) real-time simulation which included as much of the aircraft systems as possible. (The sixth DOF (altitude) will be incorporated in the final ITF configuration.)

2. Capabilities to use automated test techniques to perform and document tests.

3. A failure modes and effects testing capability which used the actual flight vehicle systems.

4. A ground resonance and limit cycle testing capability to investigate structure/FCS interaction on the flight vehicle. The capabilities include the summation of pulses and sine sweeps with pitch, roll, and yaw rate signals and the capability to introduce pulses and sine sweeps of various amplitudes and time durations into the stick and pedal command channels.

5. Rapid reduction of data into a format for comparison with existing data and predicted results. Reduction of data and analysis of results in near real time.

X-29A Flight Control System and Test Configuration

Under normal flight conditions the X-29A flight control computers (FCC) output surface position commands to provide aerodynamic control and stability. Deflection of aircraft structure is a secondary effect of surface motion. The motion of the aircraft and response of the surfaces are fed back to the FCC and summed with pilot commands. The results of this summation are used in further surface commands. The interactions of all these components are of primary interest during ITF aircraft-in-the-loop testing.

During testing, the simulation computer reads aircraft surface positions, calculates the rigid body aerodynamic response, and provides various signals required by the aircraft, Figure 7. These signals are transmitted to the simulation interface device (SID) where they are summed, converted, scaled, and distributed to the X-29A aircraft. Vehicle surface positions are also routed through the SID, then back to the simulation computer. Other simulation input signals are routed by way of a Mil-Std-1553 bus from the extended aircraft interrogation and display system (XAIDS) which was used to monitor real-time system performance.[8]

X-29A ITF Test

Three types of tests were performed using the ITF capabilities to verify the FCS characteristics of the X-29A aircraft:

1. Open loop: rigid body, open loop, frequency response tests–aircraft sensors out of the loop.

2. Closed loop: rigid body, closed loop, frequency response test including limit cycle tests–aircraft sensors out of the loop.

3. Ground resonance: flexible body, closed loop, active flight control system tests–aircraft sensors in the loop.

This series of end-to-end ground tests was required to provide the program team with adequate confidence to proceed with the first flight of X-29A ship 2.

Open-Loop Tests

These tests measured the open-loop frequency response characteristics of the sensor to control surface paths (with the simulation providing test stimulus by way of sensor inputs to the FCS) as shown in Figure 8.

For each test the aircraft was supported on jacks. The aircraft sensor inputs to the FCS were replaced by simulated sensors interfaced through the SID. In each case the feedback path of interest was opened and the forcing function, a sine sweep, was inserted in place of the feedback. The results of each test were compared to predictions obtained by running the same test on the X-29A hardware-in-the-loop simulation.

Closed-Loop Tests

The closed-loop tests are intended to verify the FCS/rigid-body stability by deriving equivalent open-loop gain and phase margins. The gain and phase margins are derived from frequency response and limit cycle tests with the FCS as shown in Figure 9. This configuration requires that the simulation computer close the aerodynamic loop around the aircraft.

For each test the aircraft was supported on jacks. The aircraft sensors were replaced by simulated sensors interfaced through the SID. The forcing function was a doublet, a step, or a sine sweep.

Limit cycle tests were performed by increasing/decreasing feedback gains in the simulation computer and measuring frequency response in three axes. For each test the aircraft was supported on jacks. The aircraft sensor signals were replaced by simulated signals interfaced through the SID. The forcing function was a sine sweep. The feedback gains corresponding to each of the simulated sensors were changed and a frequency response was generated to compare results before and after the change.

Ground Resonance Tests

These tests are closed-loop, surface stimulated resonance tests. The tests are intended to verify that undesirable structure/FCS interactions do not exist. The set up is shown in Figure 10. If a problem relative to structural/FCS interaction were to occur in flight, the effect could be a possible destabilization of the control system caused by high rate demands on the actuators.

For each test the aircraft was sitting on the landing gear and all panels except the external hydraulics access panel were installed. Future ITF capabilities will provide "soft support" for these types of tests. A soft support will provide a free floating platform for the aircraft to rest on during the test, removing unwanted gear dynamics.

Results of Using X-29A ITF Test Capabilities

The X-29A program experienced considerable time savings by using the ITF test capabilities. Compared to previous testing with the X-29A using different test facilities and tools, approximately two-thirds of the actual test time (3 weeks of testing reduced to 1 week) and 50 percent of the preparation time was saved. Total effort for the program was reduced approximately eight man months. This testing allowed the X-29A program team to proceed to the flight stage with confidence, knowing that the flight control system was working as designed.

Monitoring of the X-29A Remotely Augmented Vehicle System

The RAV system, when engaged, has direct control of the X-29A aircraft control surfaces. Monitoring of RAV operations is essential to ensure both flight safety and mission success. The RAVES capability meets this need with a variety of graphic displays.

The RAVES is a visually oriented monitoring system which allows users to respond quickly to failures. The RAVES generic capabilities are used for self-diagnosis, parameter monitoring, and for event logging. Logging is the ability to time tag significant events for easy post-flight processing. Six X-29A project specific displays are available in the main display window, they are:

1. Status—a color coded alphanumeric display of control law and PCM parameters using project specific acronyms.

2. Alternate status—an alphanumeric display that provides all the information of the status display in more common engineering terms. For example, ARMODE on the status display is written out as **analog reversion** on this display. See Figure 11.

3. Dataflow—a high-level graphic block diagram display of the RAV system components and data paths. See Figure 12.

4. Aircraft fault detection—a graphic representation of the onboard RAV mode disengagement logic.

5. Fail—an alphanumeric display of ground and aircraft failure parameters.

6. Expert—a popup window that gives information on what caused a failure or situation and advice on how to resolve it.

There are three major areas in which RAVES is beneficial to the X-29A program: ease of new display implementation, quick user response to failures, and rapid understanding of RAV terminology by engineers.

Initial use of the RAVES during X-29A flight tests has demonstrated a real-time monitoring system which will have applications to other flight test programs and be a viable tool in the ITF.

ITF PROJECT STATUS

Test Systems Status

The development of the ITF computerized test systems discussed in this paper is nearly complete. The simulation capability has long been a part of ADFRF's engineering tools and has been interfaced to the X-29A and other aircraft. Our ability to monitor RAV performance has been greatly enhanced with the RAVES. The final testing has begun on the real-time data recording capability and the interprocessor communication devices which link the ITF computers and their data at memory access speeds.

Building Status

The ITF building at the time of this writing is 60 percent complete. The construction should be complete and the test systems moved to the building by mid-1991. At that time the full capabilities and benefits of the ITF developments can be applied to all our flight research aircraft.

CONCLUDING REMARKS

The Integrated Test Facility, with its new capabilities, will provide a ground-test facility crucial to the next generation of flight research aircraft. Routinely interfacing the aircraft with the ITF systems will reduce the risk of flight test by creating the flight environment on the ground. Real-time data recording and monitoring with the RAVES will greatly enhance ground- and flight-test efficiency.

The ITF capabilities allowed the second X-29A aircraft to enter its initial flight test phase safely and significantly reduced the time required for the aircraft to achieve its first flight.

The ITF brings to the flight test community the capabilities needed to maintain our leading role in aeronautics and provide safe, efficient flight testing.

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NOMENCLATURE

ADFRF	Ames-Dryden Flight Research Facility
ADS	advanced decommutation system
CRT	cathode ray tube
DOF	degrees of freedom
DV	Data-Views® product of Visual Intelligence Corp.
F	degrees Fahrenheit
FCC	flight control computers
FCS	flight control system
gal/min	gallons per minute
HiMAT	highly maneuverable aircraft technology
Hz	hertz
ITF	Integrated Test Facility
JSC	Johnson Space Center
lb/in^2	pounds per square inch
Mil-Std	Military Standard
NASA	National Aeronautics and Space Administration
PCM	pulse code modulation
RAV	remotely augmented vehicle
RAVES	remotely augmented vehicle expert system
RPRV	remotely piloted research vehicle
SID	simulation interface device
Vdc	volts direct current
XAIDS	extended aircraft interrogation and display system

TABLE 1– DATA SOURCE AND ESTIMATED QUANTITY FOR RECORDING

Source	Number of parameters	Rate, Hz	Total samples/sec
Simulation	50	100	5,000
Aircraft			
flight control	300	100	30,000
digital busses	1500	100	150,000
Telemetry	100	100	10,000
ITF services	20	10	200
Total			195,200

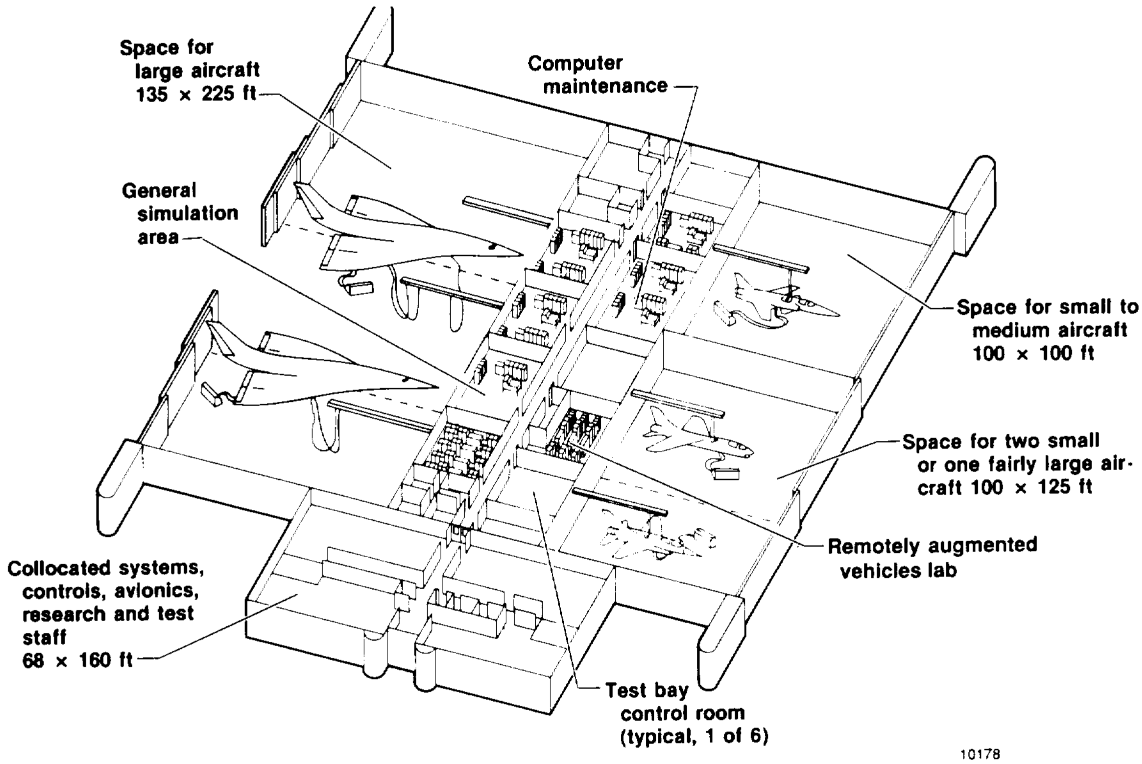

Figure 1. Overview of the integrated test facility.

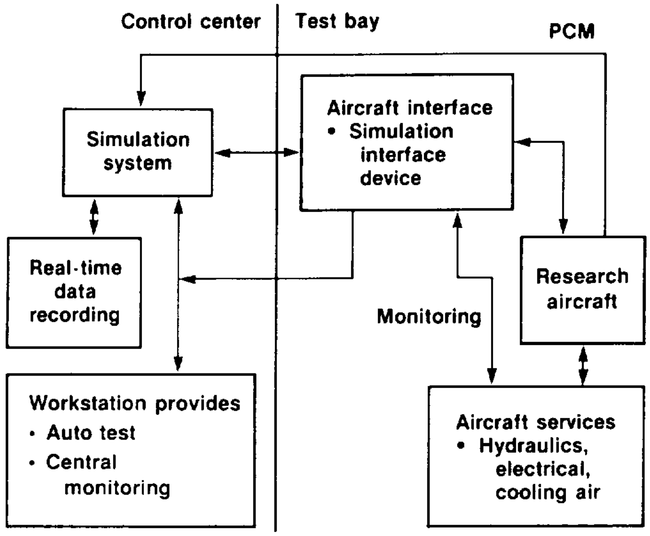

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Figure 2. Overview of ITF test systems.

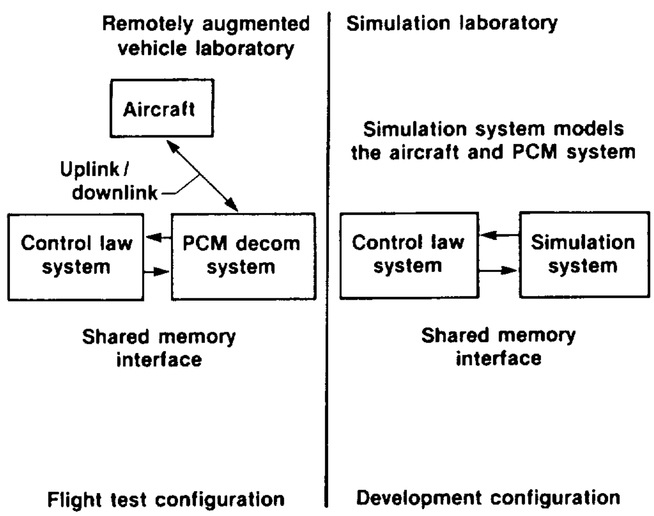

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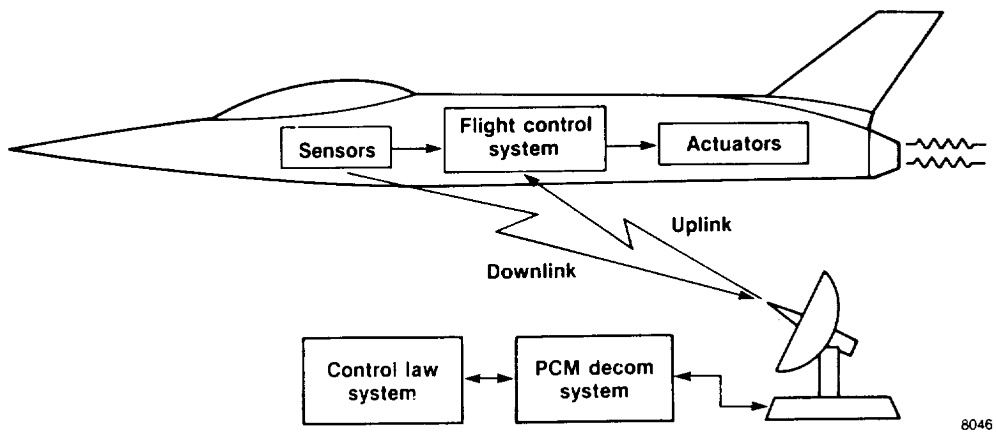
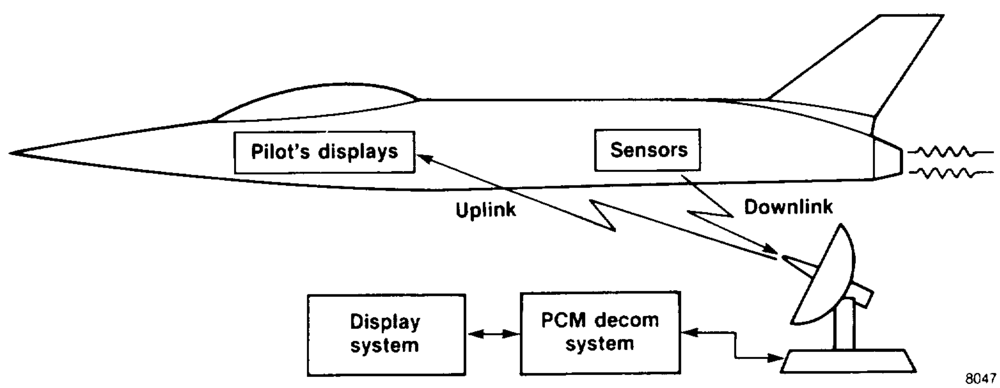
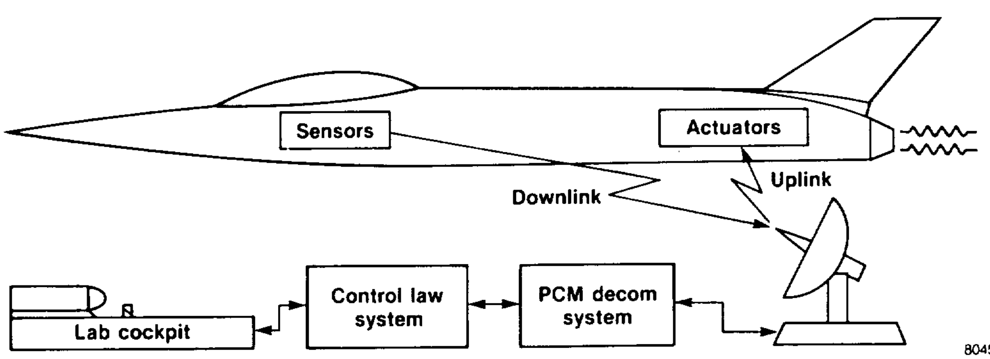
Figure 3. Control law system configuration for flight and development.



(a) Remotely augmented vehicles.



(b) Remotely computed displays.



(c) Remotely piloted vehicles.

Figure 4. The three remotely augmented vehicle configurations.

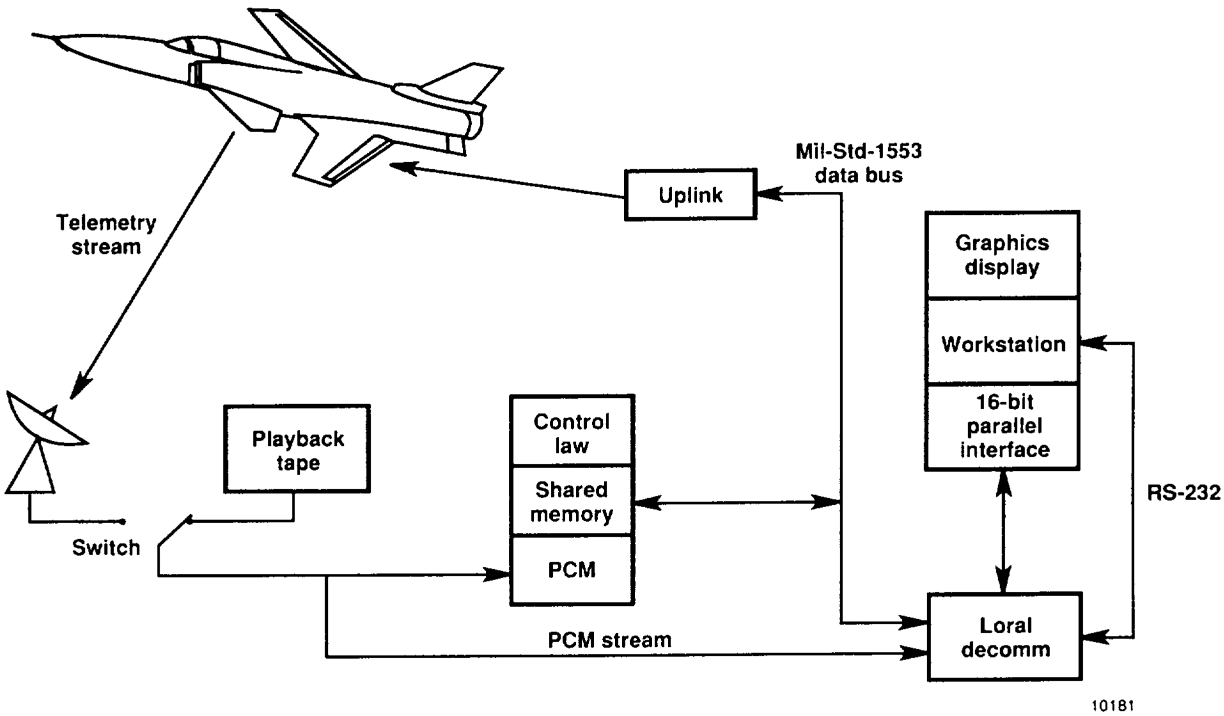


Figure 5. The RAVES hardware configuration.

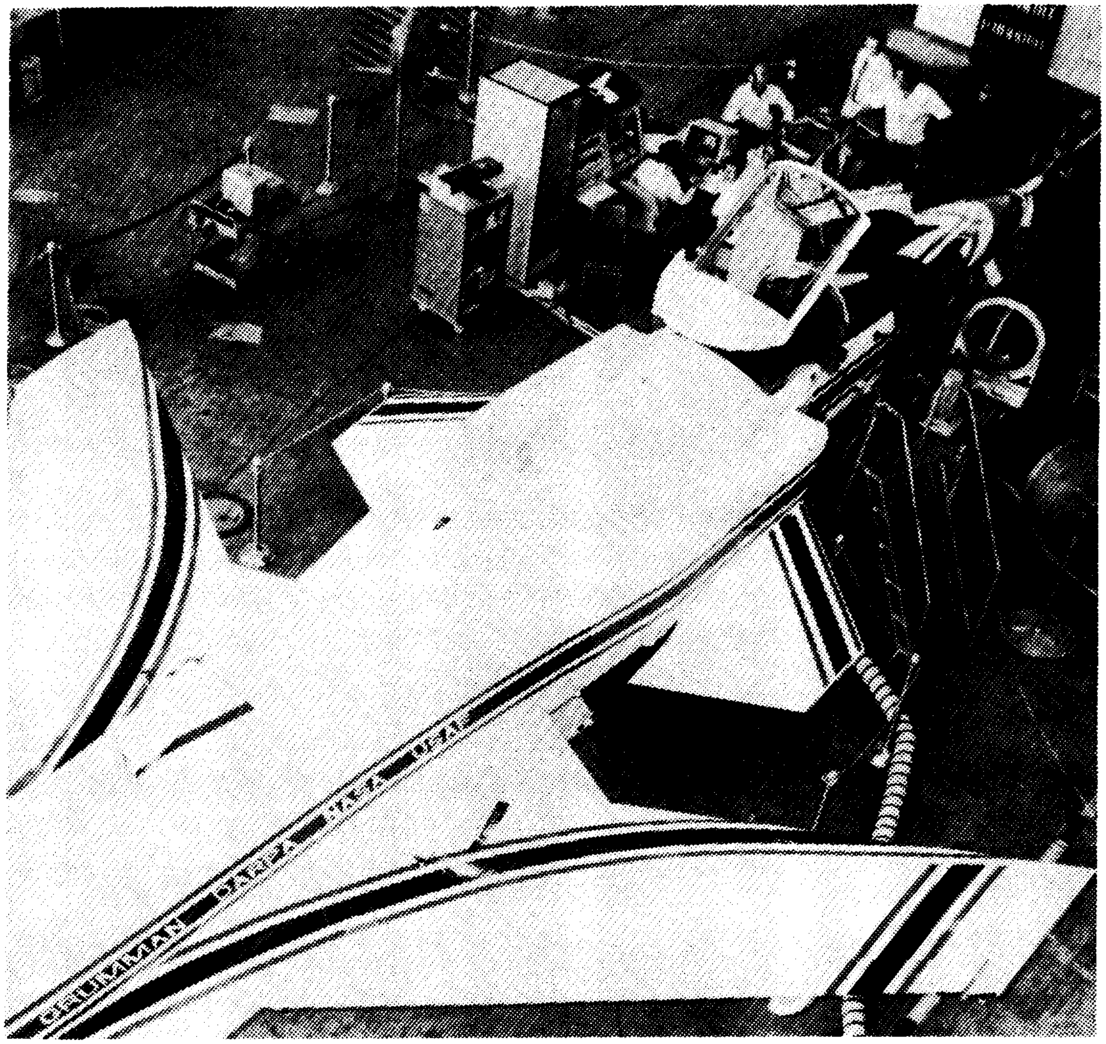


Figure 6. X-29A ITF test configuration.

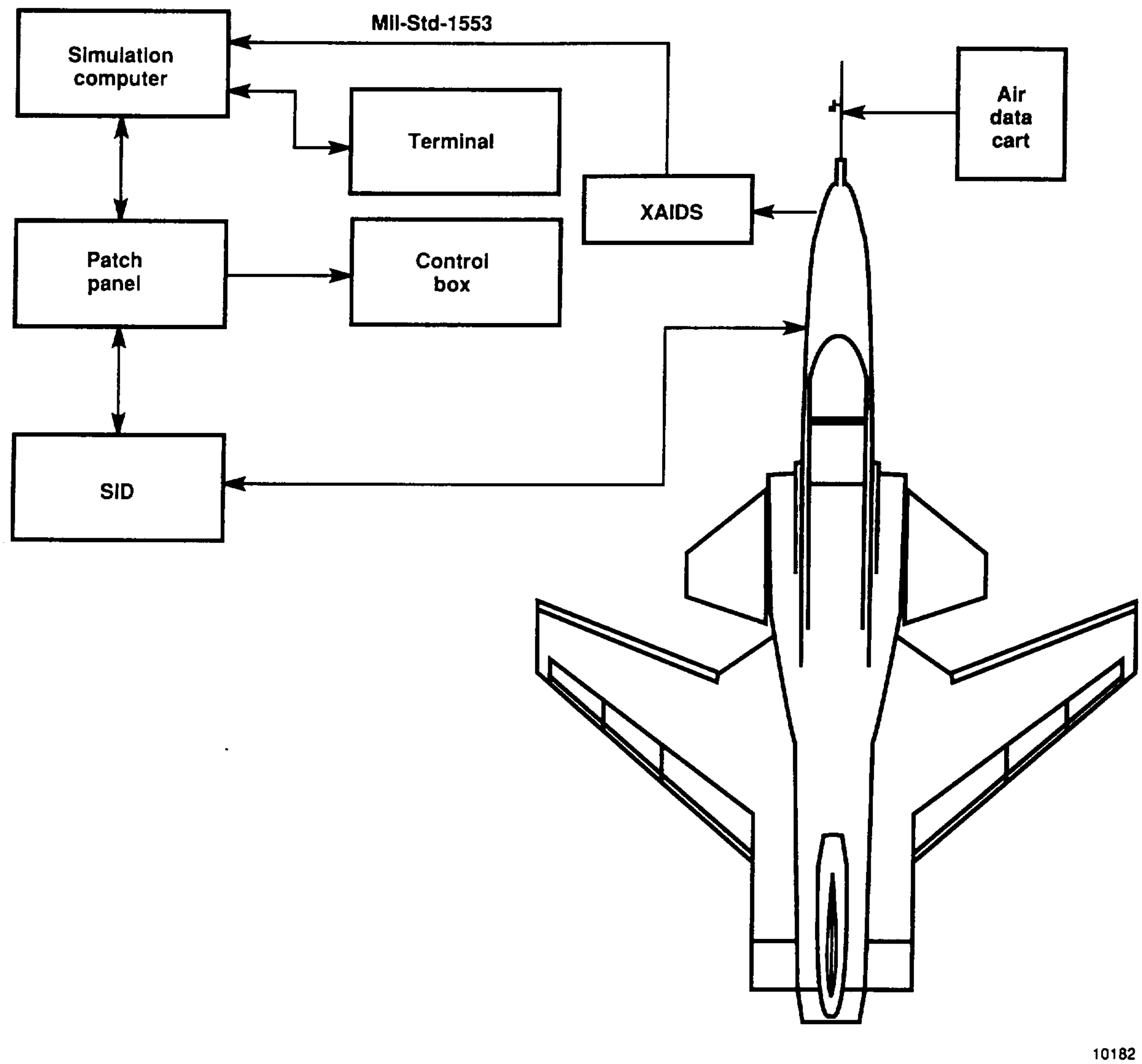


Figure 7. The ITF X-29A aircraft-in-the-loop simulation block diagram.

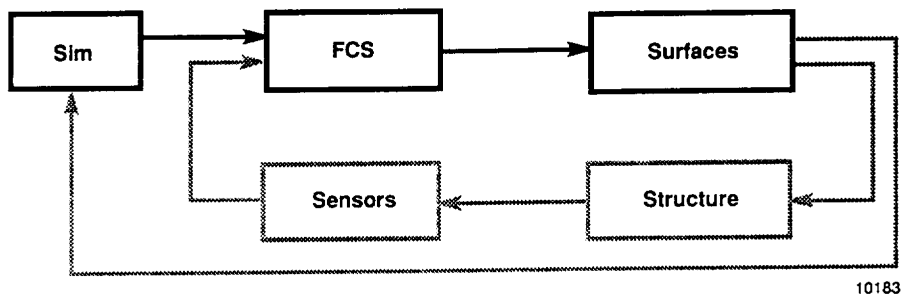


Figure 8. Open-loop test configuration.

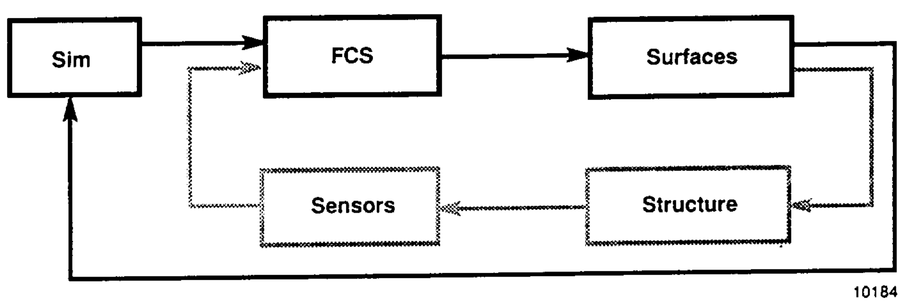


Figure 9. Closed-loop test configuration.

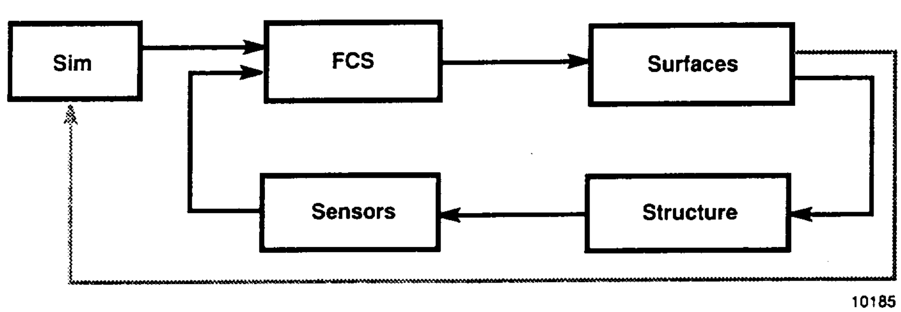


Figure 10. Ground resonance test configuration.

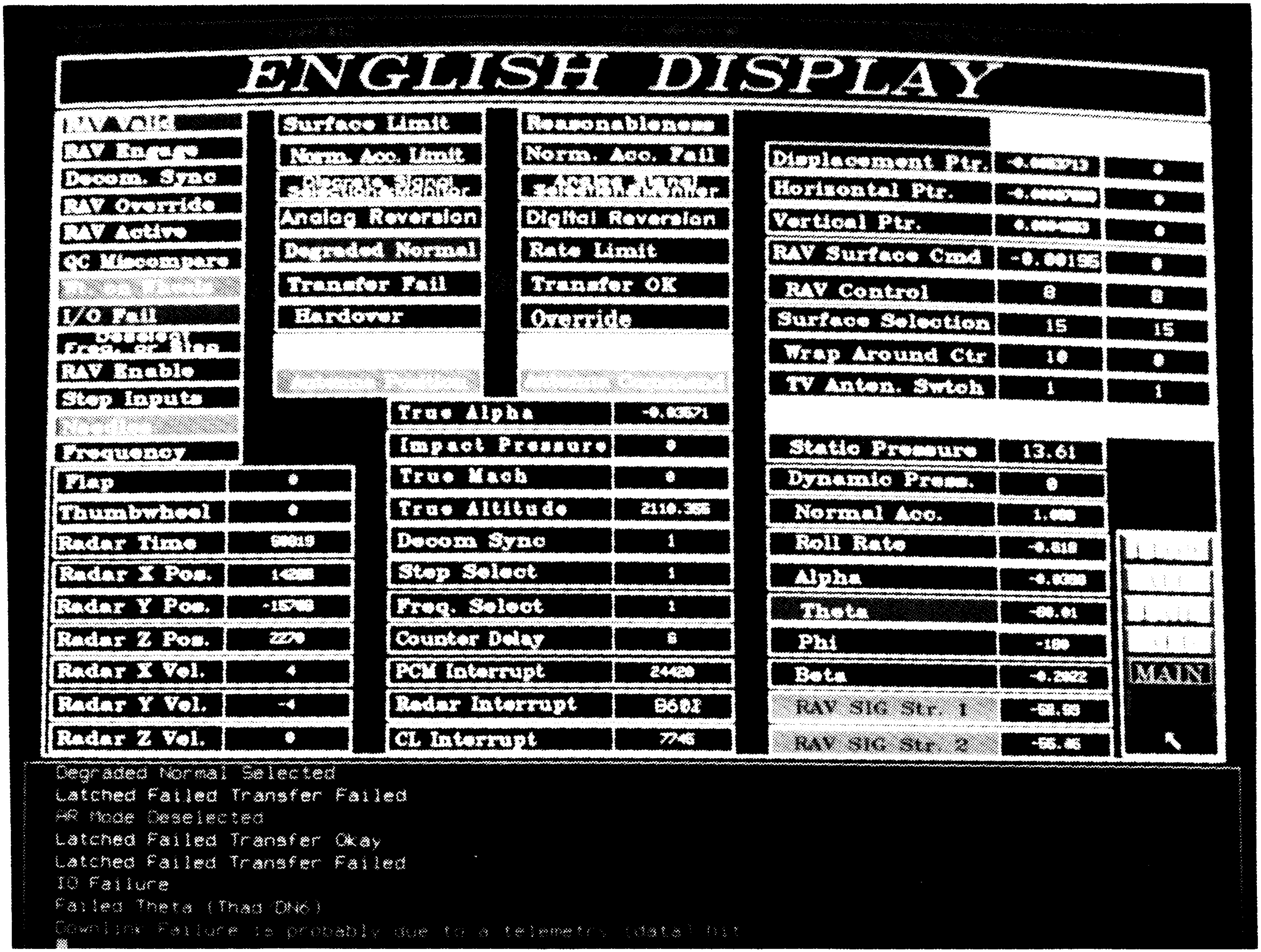


Figure 11. Example of alternate status display.

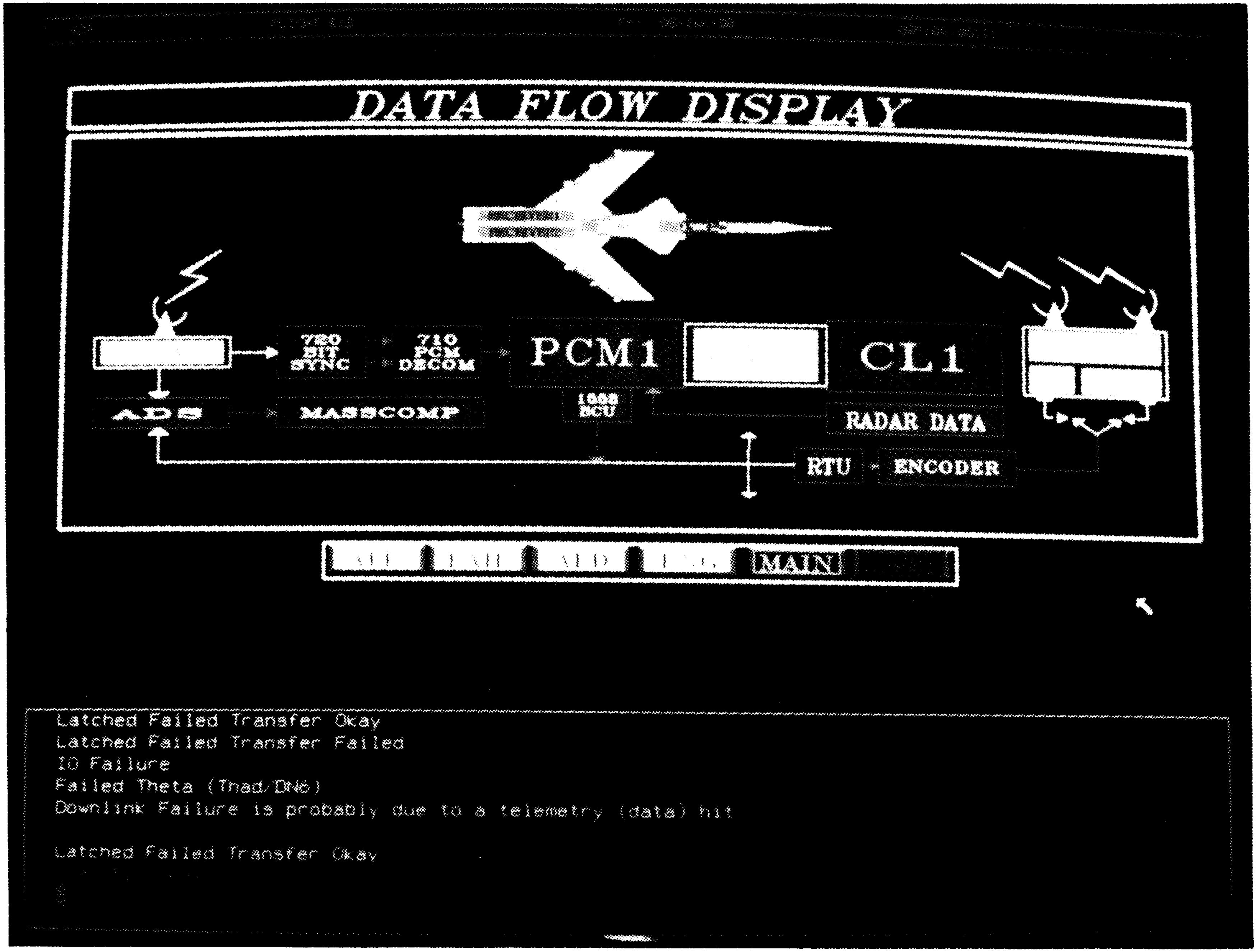


Figure 12. Example of dataflow display.