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FLIGHT STUDY OF A VEHICLE OPERATIONAL STATUS AND MONITORING SYSTEM

By James E. Love, William J. Fox,
and Edward J. Wicklund

Flight Research Center
Edwards, Calif. 93523

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16. Abstract

An analog onboard monitoring system was installed on a YF-12 airplane as the first phase of a program to monitor the engine inlet and portions of the airplane's electrical and fuel management subsystems in flight.

The system provided data which were considered to form a suitable base for diagnostic test logic and decision criteria for the rest of the program. The data were also adequate for the purpose of maintaining the engine inlet and identifying malfunctions within it.

The investigation showed that the requirements of an onboard monitoring system should be considered during the original design of the system to be monitored.

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James E. Love
Flight Research Center

William J. Fox
Lockheed California Company

and

Edward J. Wicklund
Honeywell, Inc.

INTRODUCTION

Space shuttle mission schedules and economics require a short ground turnaround time. On the basis of present plans, no more than 10 days after the vehicle's return from a mission of up to 30 days' duration are available for ground verification (vehicle checkout and repair).

Ground verification of the complex subsystems that exist today is anything but an exact science. This is particularly true of vehicles that operate in space or at high altitudes. Many of the malfunctions that occur in flight are difficult or impossible to reproduce or simulate on the ground.

Onboard monitoring in real time is one way to improve mission reliability and safety and reduce ground verification time. Many theoretical studies and several laboratory investigations have dealt with this subject, but almost no flight data are available, particularly for the flight environment with which this paper is concerned.

To acquire such data a flight program in which an analog onboard monitoring system was installed on a YF-12 airplane was begun. The four separate but interrelated goals of this program were to:

(1) Determine the technical feasibility of onboard in-flight data monitoring, failure detection, and failure isolation.

(2) Develop a credible base of data with which to evaluate the operational value of an onboard monitoring system.

(3) Investigate the man/machine interface to determine the extent, form, and method of data presentation most acceptable and meaningful to operating and maintenance crewmen.

(4) Establish baseline data for comparisons between conventional ground checkout and onboard monitoring systems with respect to the operational comprehensiveness of

preflight testing.

The program has three phases, the first of which is discussed herein. The objectives of Phase I were to:

(1) Develop diagnostic test logic and decision criteria from flight data and establish the comprehensiveness of the possible decision criteria. The test logic and decision criteria are intended for use in succeeding phases of the program to verify the feasibility of failure detection and failure isolation by means of in-flight data monitoring.

(2) Provide in-flight data to the ground crews to assist the maintenance operation. This is in partial fulfillment of the second, third, and fourth program goals.

This report describes the hardware and results associated with Phase I of this program.

ONBOARD MONITORING SYSTEM

The onboard monitoring system used in Phase I was an airborne integrated maintenance analog data recording system. Figures 1(a) and 1(b) show the elements of the onboard monitoring system and the flow of data. Figure 1(a) represents the airborne systems, and figure 1(b) shows ground-based data reduction equipment. Analog sensors continuously monitored equipment performance.

After the system acquired a signal, usually through a transducer, the signal went to a remote unit (shown in figs. 2(a) to 2(c)) where it was conditioned and multiplexed. The signal was then sent to a 16-track magnetic tape recorder.

The recorder electronics assembly, the recorder itself, and the remote multiplex signal conditioner weighed 77.6 kilograms (171 pounds) and occupied 0.076 cubic meter (2.68 cubic feet) of volume. The system required 2.5 amperes at 28 volts. It had no unusual environmental requirements. Seventy-three parameters, which are listed in table 1, were monitored. The system was capable of recording up to 12 hours of continuous flight data.

After each flight the tape was removed and processed on the ground. The recovery equipment played back the tape and formatted the data on a new tape for processing by a general purpose computer.

SIGNAL CONDITIONING

The signals listed in table 1 were conditioned in the remote unit (fig. 1(a)). The signal conditioning converted each signal to a 0 to 2 Vdc voltage level. These signals were then multiplexed and sent to one of 13 voltage-controlled oscillators in the electronics assembly. The oscillators converted the conditioned signal to a proportional frequency-modulated (FM) signal of 266.6 hertz to 433.3 hertz. The FM multiplexed signal was then recorded on one of the 13 data tracks of the magnetic tape in the recorder assembly. Voiced communications were recorded on the fourteenth track.

The other two tracks on the 16-track tape were reference tracks. One track recorded clock reference pulses, which enabled the ground processing equipment to demultiplex the signals. The other track recorded a fixed-frequency reference so that the data reproducing and digitizing equipment (fig. 1(b)) could compensate for errors introduced by temperature variations and tape motion.

The data reproducing and digitizing equipment was used to decommutate the recorded data, digitize them, and record them digitally in time sequence. The equipment also had the amplifying and smoothing circuitry necessary to drive up to 50 channels of strip chart recordings.

DATA FORMAT

The data reproducing and digitizing equipment reproduced data in two forms: analog signal outputs that could be directly recorded on strip charts of up to 50 channels at a time, and digital magnetic tape which contained time-sequenced data in a digital format that could be read with a general purpose digital computer.

Data were reproduced and used in three forms. Time history strip charts were available the first or second day after the flight for a quick look at anomalies and simple fault analysis. (A typical fault analysis that used the strip charts is described in a following section.) One or 2 days later a digital printout of each parameter was available from information that had been processed in a general purpose computer. Data in this form are more difficult to analyze. However, the measurement of anomalies in any particular time span is more precise. For the more difficult problems, cross plots of two channels of flight data were displayed on an X-Y plotter. Cross plots were also valuable for identifying meaningful performance decision criteria for online monitoring systems in later phases of the program.

SELECTION OF SUBSYSTEMS TO BE MONITORED

One of the critical decisions in this project was the selection of the subsystems to be monitored. The task of monitoring each subsystem was beyond the scope of this project in terms of both cost and need.

The engine inlet and portions of the electrical and fuel management subsystems were chosen for monitoring because (1) they are complete and relatively independent systems where cause, effect, and maintenance actions can be easily measured and classified; (2) the test point access is relatively simple, and the number of test points required for diagnostic purposes is relatively small compared to a subsystem such as the inertial navigation system; (3) the failure rates of these systems are potentially high, and many of the failures are of the type that cannot be reproduced on the ground; and (4) the test signals pertinent to these subsystems (hydraulic pressures, mechanical movement, digital signals, analog signals, air data signals) encompass almost all the test signals that exist in airborne vehicles.

RESULTS

Data from 16 flights were collated, compiled, and verified for reasonableness. The data are representative of the entire flight envelope of the monitored subsystems. Preliminary data analysis did not disclose any obvious areas of uncertainty or unexplainable phenomena, so the data were judged to be suitable for the development of preliminary diagnostic test logic and decision criteria for the second phase of the program. The data were subsequently used to develop the in-flight test logic for Phases II and III, particularly for the selection of logic levels and constraints.

The onboard monitoring system was also used to provide data to ground crews for flight-to-flight aircraft maintenance. Twenty-three malfunctions were identified with the monitoring system during the 16 flights, four of which could not have been detected in normal ground checks. Eleven malfunctions were detected which could have caused a future flight to have been aborted if they had not been identified and corrected.

DISCUSSION

The YF-12 airplane was selected as the flight-test vehicle for the onboard monitoring system because it normally flew every 7 to 12 days at the NASA Flight Research Center and therefore simulated the shuttle schedule and environment more closely than any other available vehicle.

The test points in the engine inlet system, which was the most important subsystem monitored, were oriented toward ground tests. As the program developed, this seriously limited the acquisition of the data required for in-flight analysis. The problem was partially solved later in the program by reworking the inlet computer to bring out more meaningful intermediate test points; this gave the experimenters a better idea of the internal functioning of the subsystem.

This problem illustrates the fact that in-flight systems monitoring and diagnosis is different enough from ground testing to require the monitoring of different parameters. The choice of parameters should be made during the subsystem design phase, when it is relatively easy to provide access to them.

The most common manifestation of a malfunction or an anomaly in the engine/inlet system is an aerodynamic disturbance. Aerodynamic disturbance is a purposely general term which covers such anomalies as engine compressor stalls and improper inlet shock wave location. Only considerable analysis reveals the cause of the disturbance, so the term is used until analysis is complete.

Five examples of the use of the onboard monitoring system are described below.

(1) The flight plan called for an increase to a rather high angle of attack and then a pushover to more normal flight conditions during an acceleration at a reasonably high

Mach number and altitude. Aerodynamic disturbances occurred in both engines. Analysis by the onboard monitoring system indicated that compressor stalls had occurred because of the high angle of attack. The pilot decreased the angle of attack and went through standard procedures for restoring the engine to normal operating conditions. Ground checks verified that no malfunction had occurred.

(2) An aerodynamic disturbance also occurred during an acceleration as the airplane made a turn. The onboard monitoring system indicated that the inlet spike had not moved to the proper position for the maneuver. Replacing the manual spike control corrected the problem.

(3) After another flight, data from the onboard monitoring system indicated that the pumps in one of the fuel tanks had cycled on and off several times when there were reliable indications that the tank was empty. On the basis of these data, the scavenge pump was replaced. Laboratory tests verified that the pump failed intermittently. There is no way to test the operation of the scavenge pump in this airplane on the ground except in the laboratory.

(4) The onboard monitoring system indicated that one of the two fuel boost pumps did not operate during a particular flight. Investigation revealed that the pump float switch had failed in the open position. This condition could have caused an engine flameout if a high fuel demand had been made on the left engine.

(5) Figure 3 shows an anomaly in the right spike position trace. This anomaly indicated a malfunction because under normal conditions there would have been a corresponding anomaly in the left spike position trace. The malfunction could have been an actual spike movement or an intermittent transducer signal. Since the inlet did not unstart, and the forward bypass door did not react, as it would have if there had been a quick spike movement, there appears to have been a malfunction or an interruption in the circuit. There was no comment by the pilot on the malfunction.

These examples represent a savings in manpower and demonstrate the versatility of the onboard monitoring system. In the first incident, the system showed that the disturbance was caused by a maneuver rather than by a malfunction, saving hours of unnecessary troubleshooting. In the second example, the system made it easier to pinpoint the location of the malfunction. The pump failure in the third incident could be detected only during flight. The boost pump failure in the fourth example might have gone undetected for several flights, a situation which could have become serious under certain circumstances.

The advantage of fault analysis using the strip charts is demonstrated by the fifth incident. The number of times the onboard monitoring system identified problems which could only be detected in flight is a fair indication that the information it made available to the ground crews was adequate to meet their maintenance requirements.

The preliminary data analysis reported here did not disclose any obvious areas of uncertainty or unexplainable phenomena. Only these data were used to develop the inflight test logic, including the selection of logic levels and constraints in Phases II and III.

The primary objective of Phase I of this program was to provide baseline data to be used for developing diagnostic test logic and decision criteria for Phase II, and this objective was met.

CONCLUDING REMARKS

An analog onboard monitoring system was installed on a YF-12 airplane to monitor the engine inlet and portions of the electrical and fuel management subsystems.

The data provided by the system constituted a suitable base for diagnostic test logic and decision criteria for the remaining two phases of the program.

The data were adequate for the purpose of maintaining the engine inlet and identifying malfunctions in it. Data requirements for onboard monitoring and diagnostic analysis differ from those for ground-based maintenance to such an extent that the parameters to be analyzed must be selected during the design phase of the subsystem to be monitored.

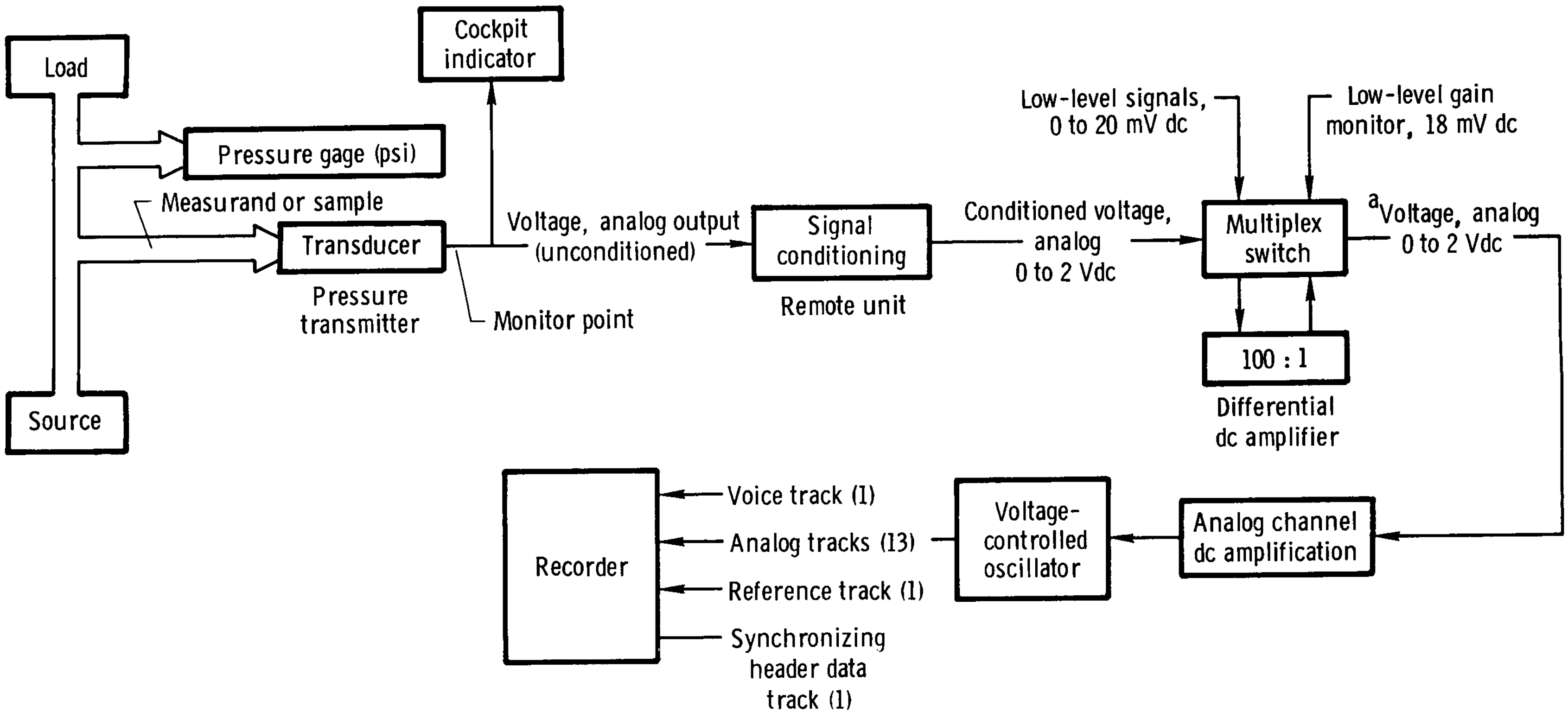
Flight Research Center
National Aeronautics and Space Administration
Edwards, Calif., September 21, 1973

TABLE 1.- PARAMETERS MONITORED BY ONBOARD MONITORING SYSTEM

Knots equivalent airspeed
Mach number
Altitude
Vertical acceleration
Yaw angle, left engine
Angle of attack, right engine
Total free air temperature
Pulse-code-modulation (PCM) system switch position
Scissor switch
Bus tie voltage
dc bus voltage
Tank 1, 2, 3, 4, 5, and 6 pilot control
Tank 6 -
- Return fuel temperature
- Return fuel flow

Fuel pumps -
- 1-1 and 1-2
- 1-3 and 1-4
- 2-1 and 2-2
- 3-1 and 3-2
- 4-1 and 4-2
- 5-1 and 5-2
- 6-1 and 6-2
- 6-3 and 6-4

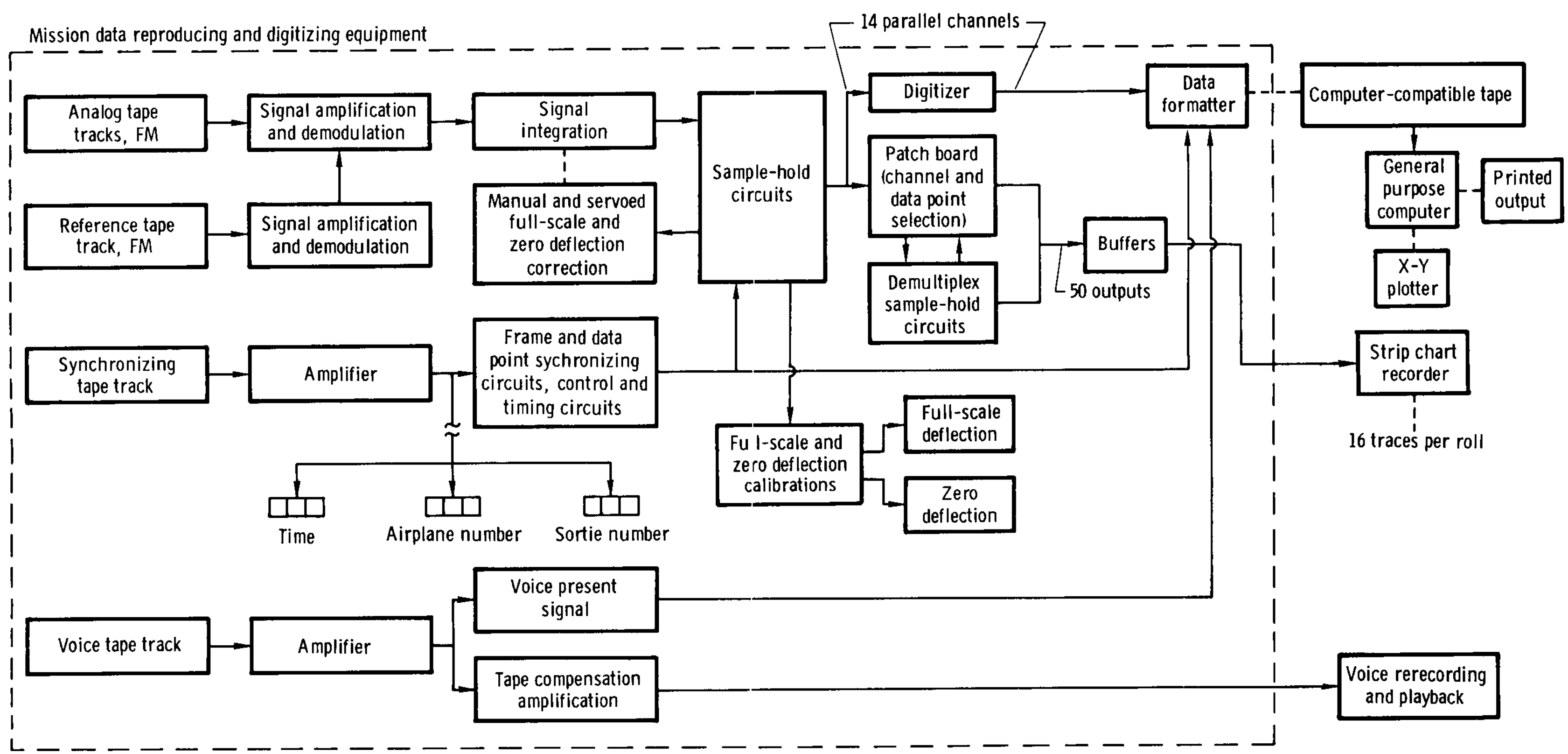
Left and right engines -
- Forward bypass door position
- Aft bypass door position
- Spike position
- Exhaust nozzle position
- Throttle position
- Engine bleed valve position
- Revolutions per minute
- Mass fuel flow
- Mass fuel flow, reserve
- Engine exhaust gas temperature
- Engine exhaust gas temperature auto/manual switch
- Inlet control
- Electrical phase voltage, generators A, B, and C
- Electrical phase frequency, generator C
- Generator logic malfunction
- Generator control panel, 24 Vdc, -24 Vdc, 12 Vdc
- Generator switch position
- Compressor inlet pressure
- Constant speed drive charge pressure
- Duct pressure ratio
- Duct pressure ratio error



[a]Individual parameters may be monitored here (0 to 2 Vdc) with demultiplexer unit.

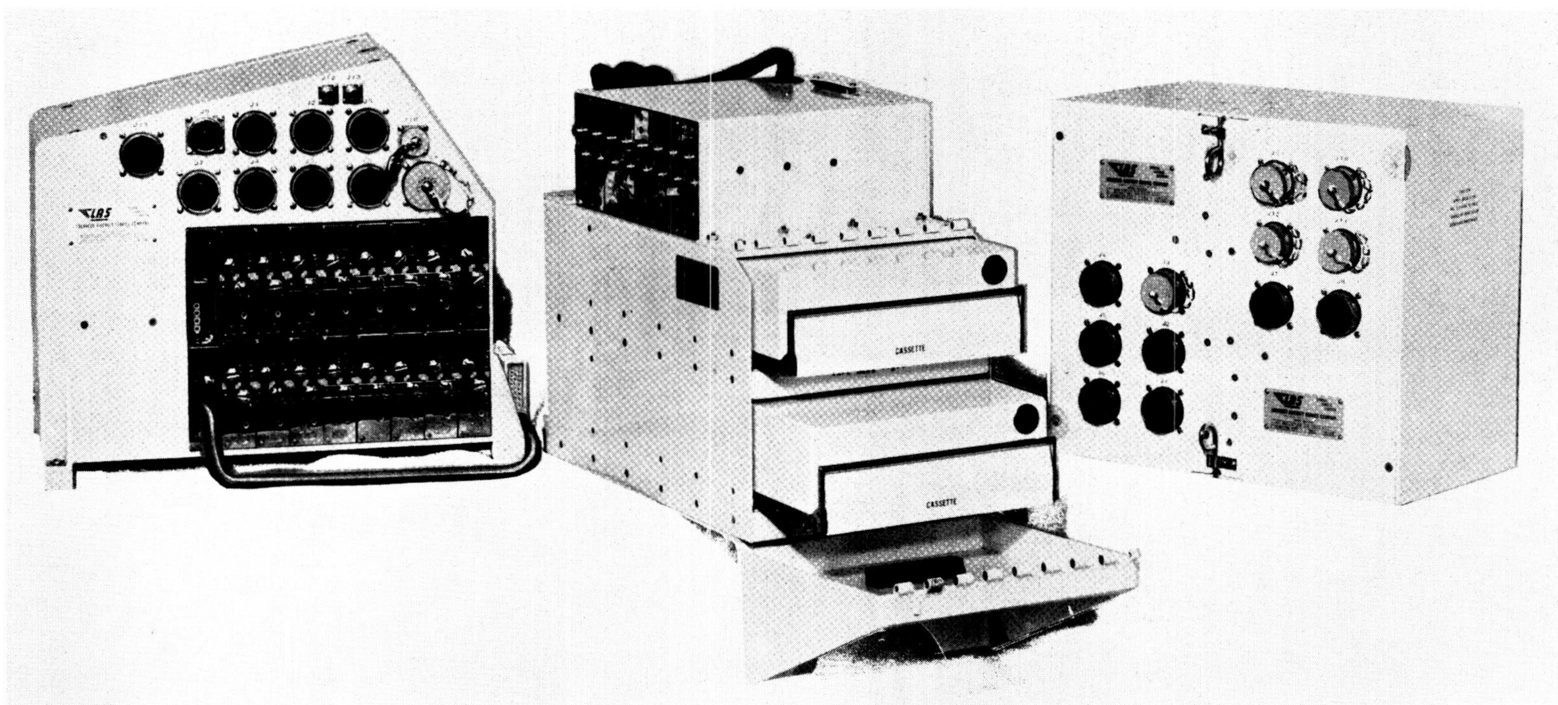
(a) Airborne systems.

Figure 1. Diagram of onboard monitoring system showing the flow of data.



(b) Ground data reduction equipment.

Figure 1. Concluded.



(a) Recorder electronics assembly. (b) Magnetic tape recorder. (c) Remote multiplex signal conditioner.

Figure 2. Onboard monitoring system components.

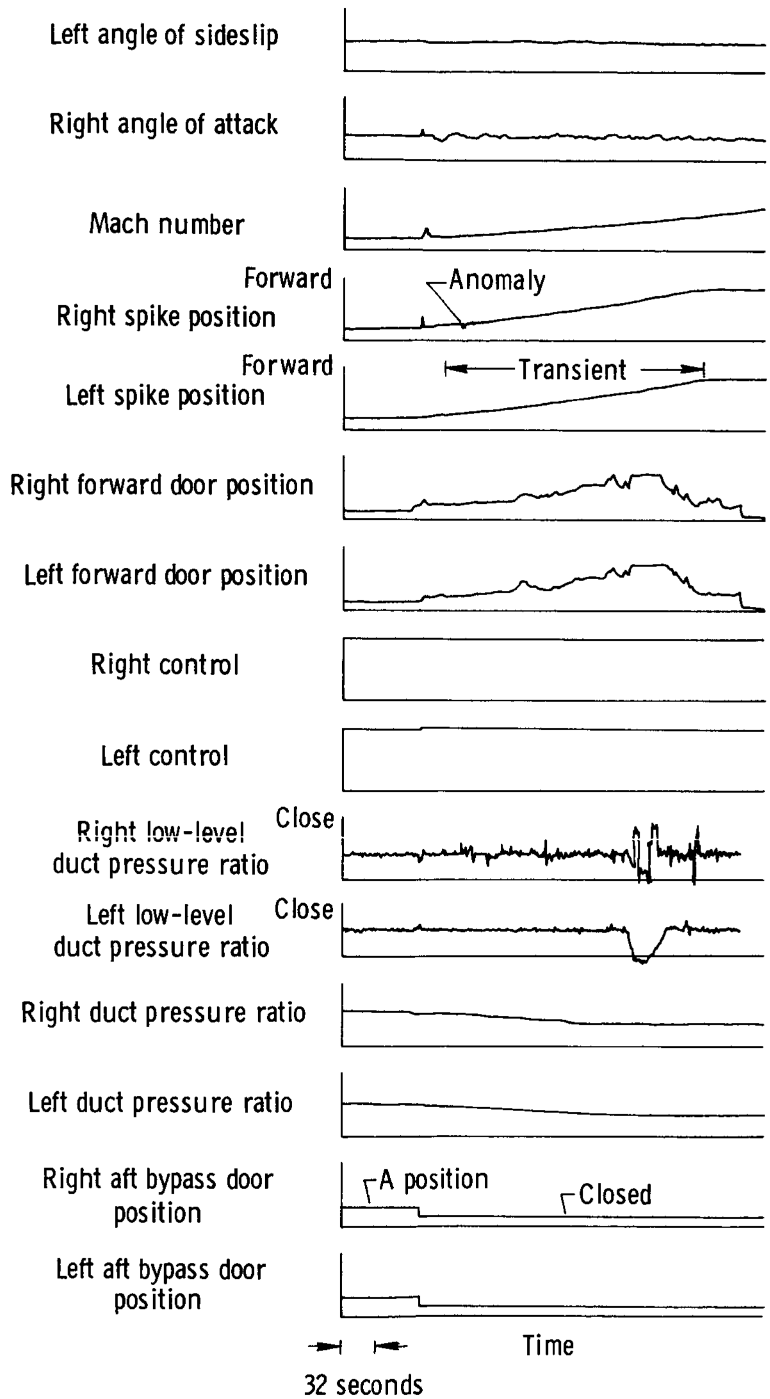


Figure 3. Strip chart data showing anomaly in right spike position trace.