CID-720 AIRCRAFT

HIGH-ENVIRONMENT

FLIGHT INSTRUMENTATION SYSTEM

R. S. Calloway
NASA Langley Research Center
Hampton, Virginia

NASA/FAA Government/Industry CID Workshop
NASA Langley Research Center
April 10, 1985

This paper summarizes the presentation at the Government/Industry CID Workshop on April 10, 1985, at Langley Research Center. The paper is organized into three major sections:

I. Design and Development
II. Installation and Combined System Tests
III. Performance on CID

The HIGH-ENVIRONMENT FLIGHT INSTRUMENTATION SYSTEM was designed to acquire Langley's structural response data during the Full Scale Transport-Controlled Impact Demonstration Test.

There was only one opportunity for data acquisition. Thus a high reliability and crashworthy design approach was implemented. The approach featured multi-level redundancy and a vigorous quality assurance testing program. Complying with an accelerated schedule, the instrumentation system was developed, tested and shipped within 18 months to Dryden Flight Research Facility. The flight instrumentation system consists of two autonomous data systems, DAS #1 and #2, and an excellent checkout subsystem. Each data system is partitioned into four pallets. The system was designed to operate on manned and unmanned flights. There are 176 data channels per data system. These channels are sequentially sampled and encoded into 1 megabit/sec pulse code modulation (PCM) data signal. To increase the probability of success, a special PCM distribution subsystem was developed. This subsystem distributes the PCM signal to two transmitters, one delay memory, and eight recorder tracks. The data on four of these tracks was digitally delayed approximately 300 msec to maximize data acquisition during impact. Therefore each data system's data is redundantly recorded onboard and on the ground. There are two time code generators. Parallel time from each is encoded into both data systems. Serial time from each is redundantly recorded on both onboard recorders. Instrumentation power is independent of aircraft power and self-contained. Each data system's power subsystem consists of an external power supply for system checkout and dual flight batteries for the actual flights. The flight instrumentation described also includes many special interface subsystems, high reliability power control and distribution subsystems, accurate real-time monitoring capability and thermal protection covers. The high environment flight instrumentation system successfully acquired 343 out of 352 channels of structural response data during the controlled impact. The electronic subsystems survived a post-crash fire and are operational.

DESIGN APPROACH

Approximately four years ago, the Aircraft Instrumentation System Section was asked to make a cost estimate for a 1100 channel data system. After many discussions on the number of channels versus cost and delivery schedule, a compromise was established. This compromise was to design and deliver a 352 channel data system to Dryden in 18 months. Since there was only one opportunity to acquire data, a High Reliability and Crashworthy Design Approach was implemented. The approach includes the following features; multi-level redundancy, fault tolerant techniques, and environmental protection techniques.

- Compatible with crash environment
- High reliability
- Large channel capacity
- Development in 18 months

FIGURE 1

ACCELERATED SCHEDULE

Complying with an accelerated schedule, two data systems were developed, tested, and shipped to Dryden Flight Research Facility within 18 months. There was a vigorous quality assurance test program on the component and the system level. The quality assurance program included shock, vibration, and temperature testing. In addition, a third data system was built and tested to qualification levels in an actual airplane section.

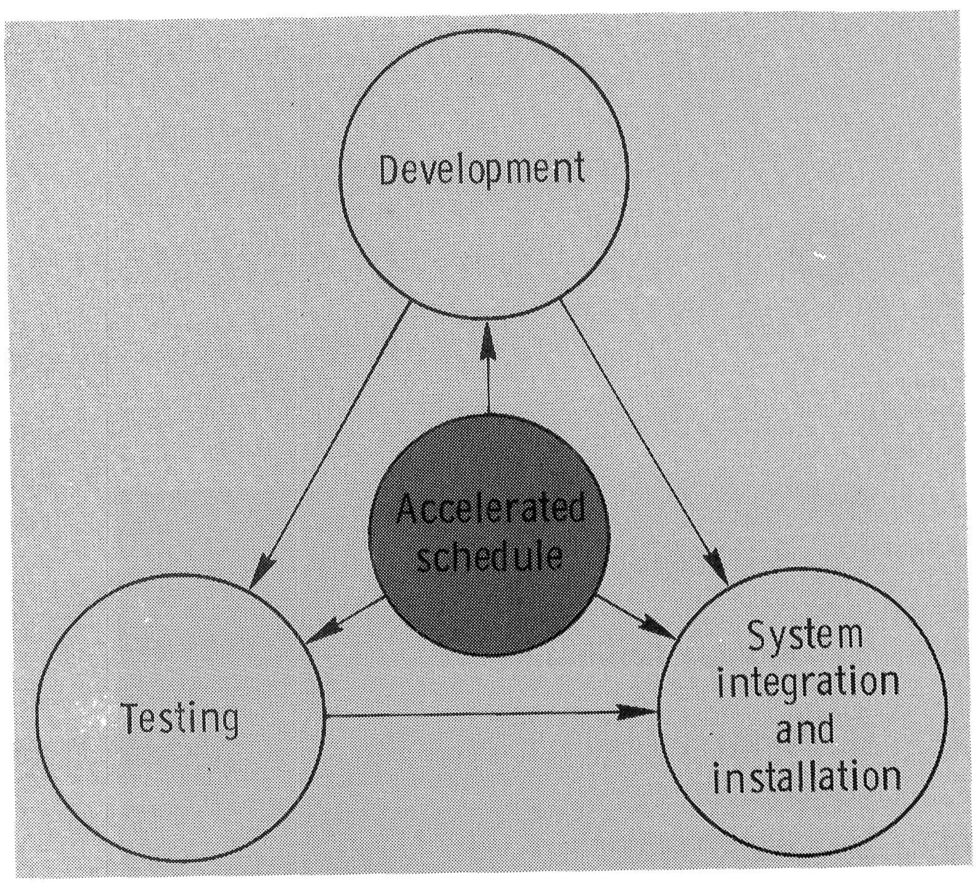


FIGURE 2

MEASUREMENT REQUIREMENTS

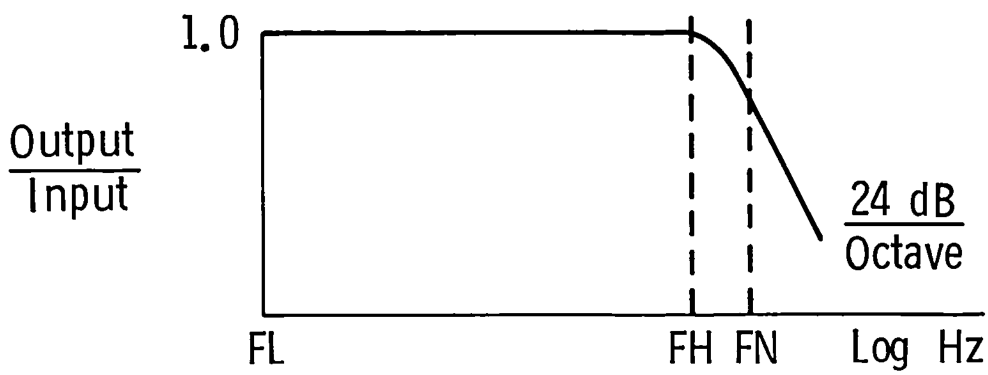
There were 352 data channels. In addition, there were 36 channels used to monitor the data system performance parameters.

- Data channels 352
  - Acceleration/shock . . 298
  - Tension (seat belt) . . 32
  - Structural strain . . . 22
- Monitor channels 36
- Total channels 388

FIGURE 3

FILTER FREQUENCY RESPONSE

There were three filter classes used: 36, 60, and 108. Each four-pole butterworth filter had the following amplitude tolerances: ±1/2 dB at .1 Hz, -1 to 1/2 dB at .6 cutoff frequency, and -4 to 1/2 dB at cutoff frequency.



	FL	FH	FN
Filter class			
36	0.1	36	60
60	0.1	60	100
108	0.1	108	180
Tolerance, dB			
High	1/2	1/2	1/2
Low	-1/2	-1	-4

FIGURE 4

MEASUREMENT FREQUENCY DISTRIBUTION

There were 243 100-Hz filters, 101 180-Hz filters, and 8 60-Hz filters.

Total filter channels: 352

Frequency	Quantity
• 180 Hz	101
• 100 Hz	243
• 60 Hz	8

FIGURE 5

INSTRUMENTATION BLOCK DIAGRAM

Due to the large channel requirement, the design was partitioned into two autonomous data systems. Each system records and transmits redundantly a PCM signal containing 176 unique data measurements. In addition, each system redundantly records the PCM and time code signals from the other system's outputs. Subsystems were selected on the basis of superior performance history at Langley and crashworthiness. Many subsystems were developed at Langley. Procured subsystems were modified to improve reliability as required.

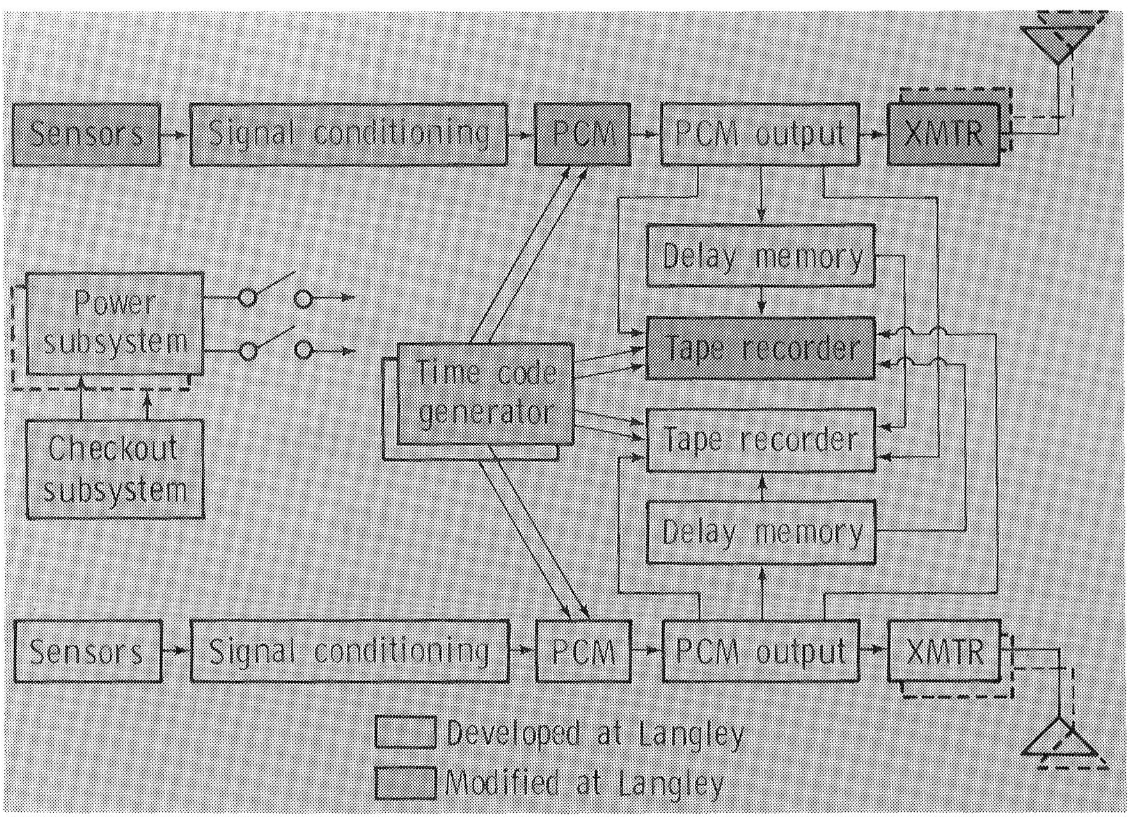


FIGURE 6

SIGNAL CONDITIONING

The Metraplex signal conditioning was selected for the following reasons:

- Successful acquisition of data in crash environments.
- Modular design featuring maximum in-the-field flexibility.
- Individual excitation regulation per channel.
- Solid state calibration technique eliminating relay switching problems during the impact sequence.

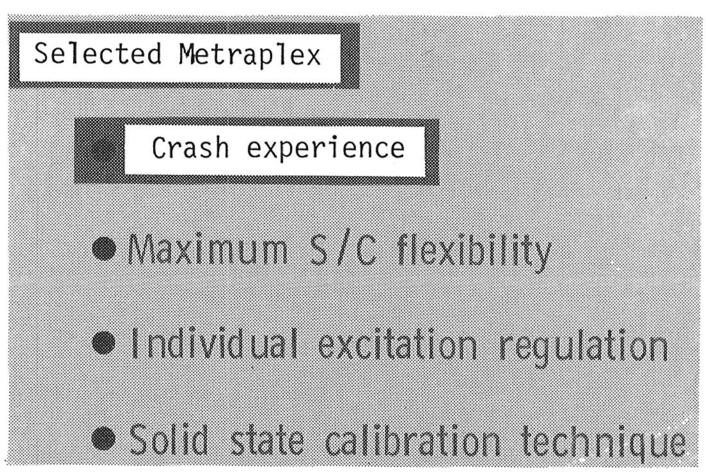


FIGURE 7

SIGNAL INTERFACE

An example of a typical sensor interface to the data system is shown. The 7264 accelerometer uses a half bridge design. To increase accuracy the completion resistors were installed at the sensor location. With a 10V excitation voltage supplied to the bridge a sensitivity of 2 mV/G is obtained.

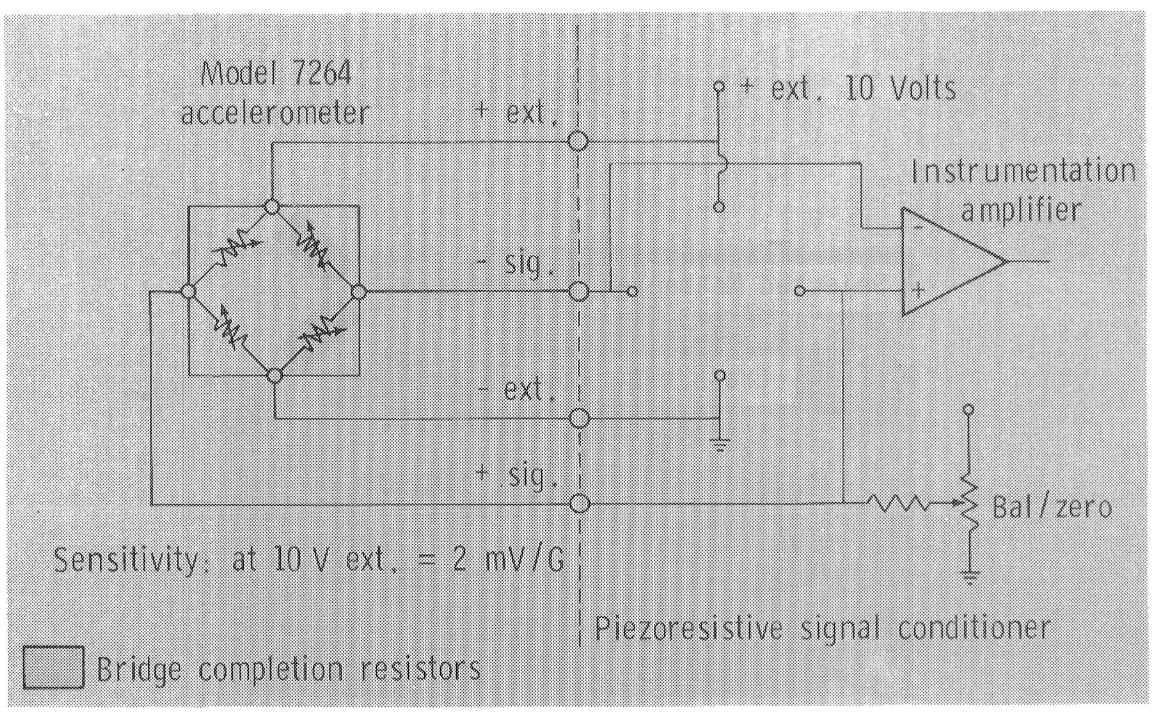


FIGURE 8

SIGNAL CONDITIONER

There are two signal conditioners shown in this figure. All components used on the project were inspected by Fred Austin, Quality Assurance Officer. His inspections included the following areas; parts and material, crashworthiness, and workmanship. To improve reliability the signal conditioners were modified at the vendor's facility and at Langley upon delivery. A combined list of improvements follows:

- Higher Quality Integrated Circuits
- Improved Filter Specifications with Test Documents
- Mil Spec Connectors
- Self-locking Helicoils
- Extended Base Plate for Mounting Purposes
- Heavy Gage Front Plate for Improved Crashworthiness

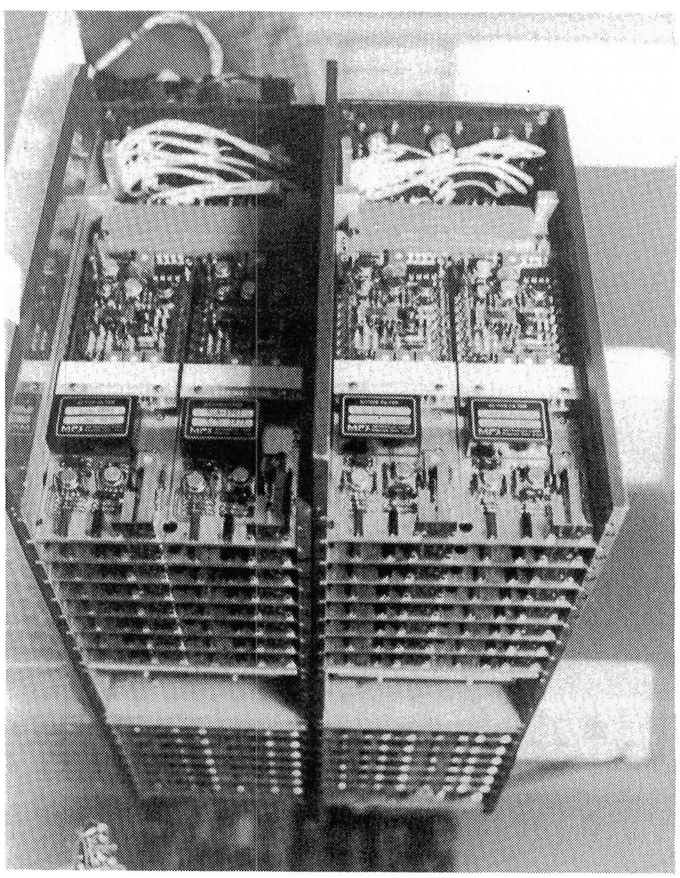


FIGURE 9

DIGITAL SUBSYSTEM

The teledyne PCM multiplexer was selected. This PCM's maximum operating rate was 1.5 megabit. Therefore the unit could easily operate at the desired 1 megabit rate. The unit met crashworthy criteria and has a excellent performance history at Langley Research Center and Dryden Flight Research Facility. The teledyne PCM multiplexor excelled in an independent survey by JSC/Lockheed and was the clear choice for this program.

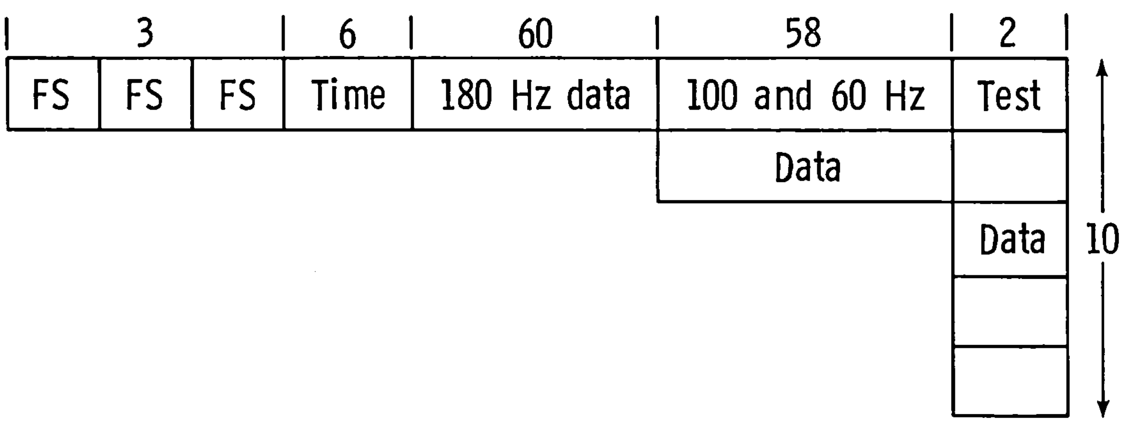
Selected Teledyne PCM

- 1 megabit data rate
- Met environment requirements
- JSC/Lockheed study
- Familiar to Dryden/Langley

FIGURE 10

PCM FORMAT

Each PCM subsystem had a 129 word mainframe. Each word contained 8 bits. The subsystem sampled at 125K words/sec or 1 megabit/sec and had an equivalent sampling index of approximately 5 or greater for all channels. With the 4 pole butterworth filters, the maximum possible aliasing error was 2% RMS.



PCM setup

Bit rate	1 megabit	Sampling index	
Bits/word	8	180 Hz data	5.38
Words/frame	129	100 Hz data	4.85
Words/sec	125 K	60 Hz data	8.08

2% RMS alias error (max) with 4 pole Butterworth filters

FIGURE 11

PCM DISTRIBUTION

The PCM distribution electronics were developed to increase the probability of successful data acquisition in a crash environment. Some of the main features are listed:

- Multi-level redundancy: There were 4 outputs per data system, each containing digital data representing the 176 data channels.
- Capability to drive long cable lines: The outputs of each data system are redundantly recorded on the other data system's on-board recorder.
- There are 2 on-board transmitters/data system.
- Fault tolerant techniques were used to prevent catastrophic failure.

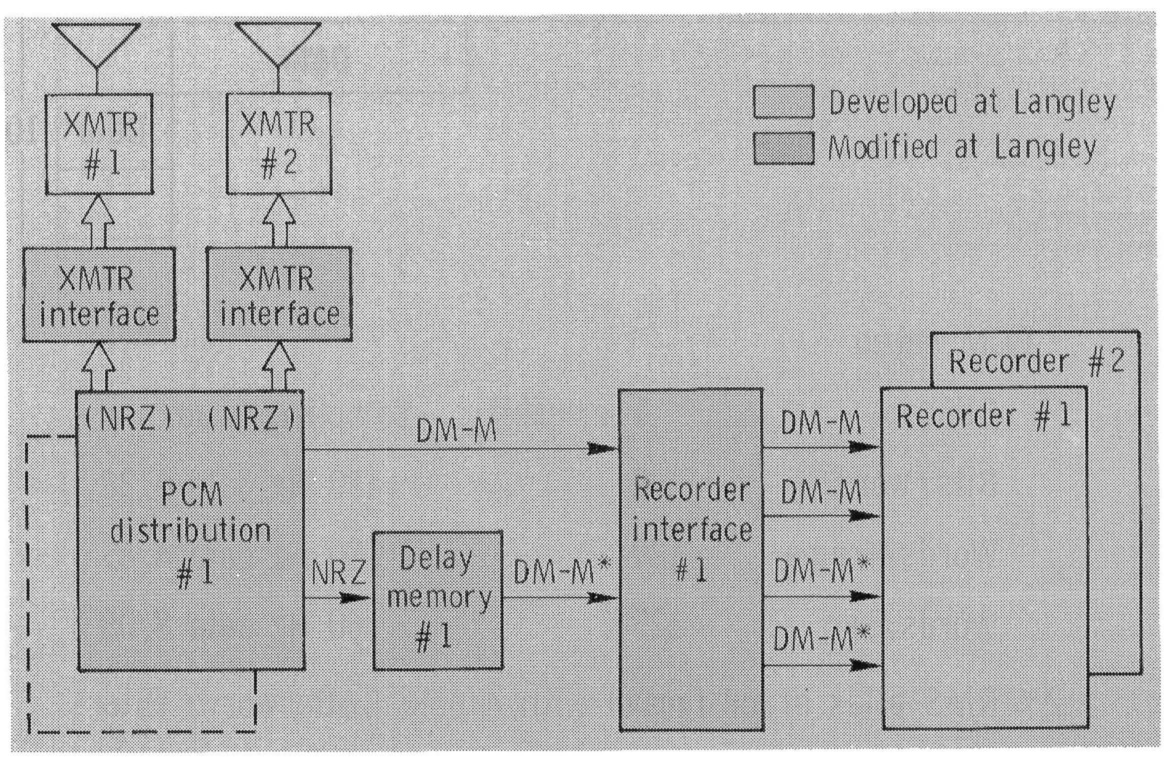


FIGURE 12

TIME CODE SUBSYSTEM

To ensure time correlation, there were two time code generators, one per data system. The outputs per time code generator were recorded on both on-board tape recorders and encoded, in the parallel format, into both PCM data signals. To correlate time on the on-board film, each time code generator modulated one of two LEDS located in each on-board camera.

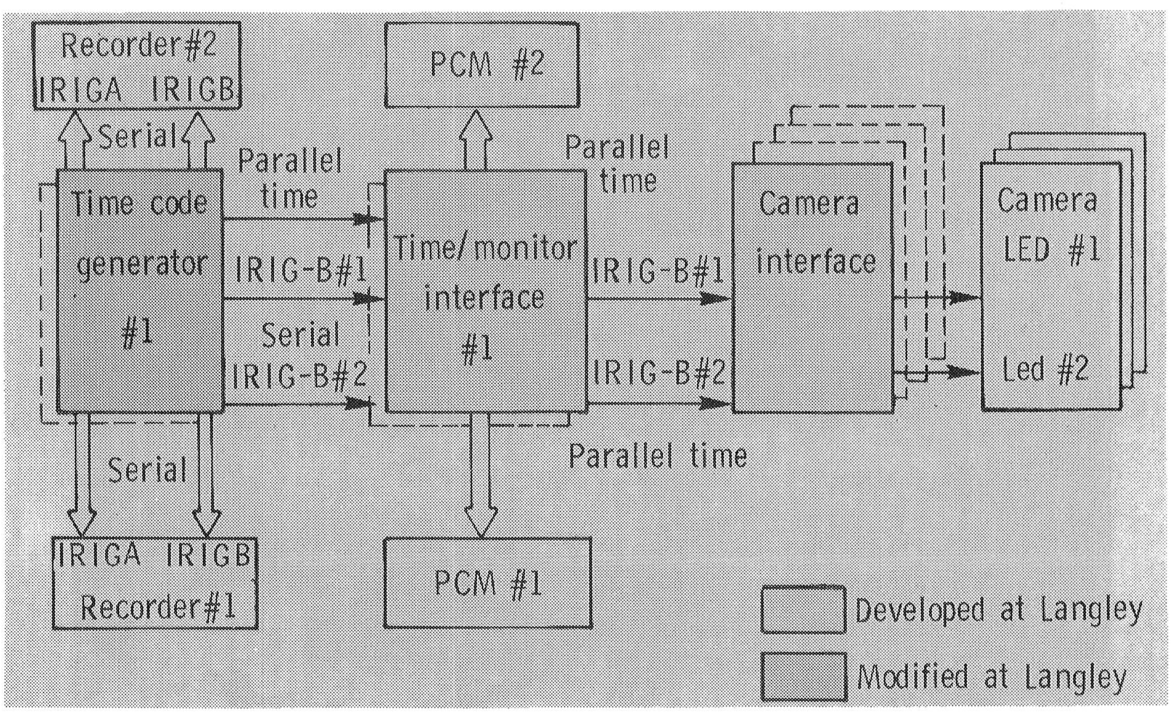


FIGURE 13

DAS MAIN PALLET

Each data system is partitioned into four pallets. The main pallet is shown below. Located on the top shelf are the digital subsystem with special shock isolation, the delay memory subsystem, the time code subsystem and the power control and distribution subsystem. There are six signal conditioning units located on the other three shelves. The layout features maximum accessibility for in-the-field operation and maintenance. The external power supply is shown in the right lower corner.

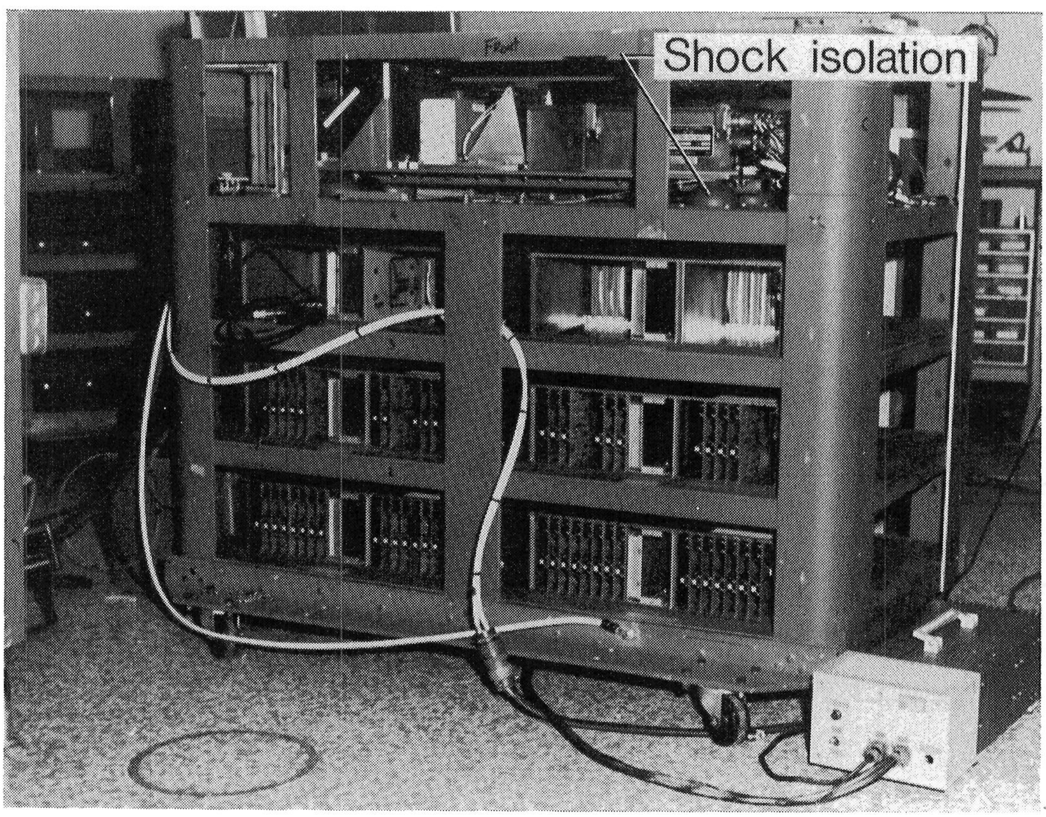


FIGURE 14

ON-BOARD RECORDING SUBSYSTEM

The Bell and Howell Mars 1000 recorder was selected for the following reasons:

- Met 1 megabit data rate requirement.
- Extensive experience with unit on aircraft programs at Langley.
- Successful data acquisition in crash environments.

Selected Bell and Howell: Mars 1000

- 1 megabit data rate
- Extensive aircraft experience
- Shuttle booster crash experience

FIGURE 15

ON-BOARD RECORDING SUBSYSTEM

The recording subsystem electronics were developed to increase the probability of successful data acquisition in a crash environment. In conjunction with the PCM distribution electronics, this special circuitry provided the following features:

- Multi-level redundancy; there were 4 recorder tracks per data system dedicated to each data system's PCM signal.
- There were 2 recorder tracks per data system dedicated to each data system's serial IRIG time output.
- There was an on-board delay memory per data system. The data on four tracks per recorder was digitially delayed approximately 300 msec to maximize data acquistion during impact.
- Accurate real-time monitoring capability was developed to ensure on-board data acquisition.

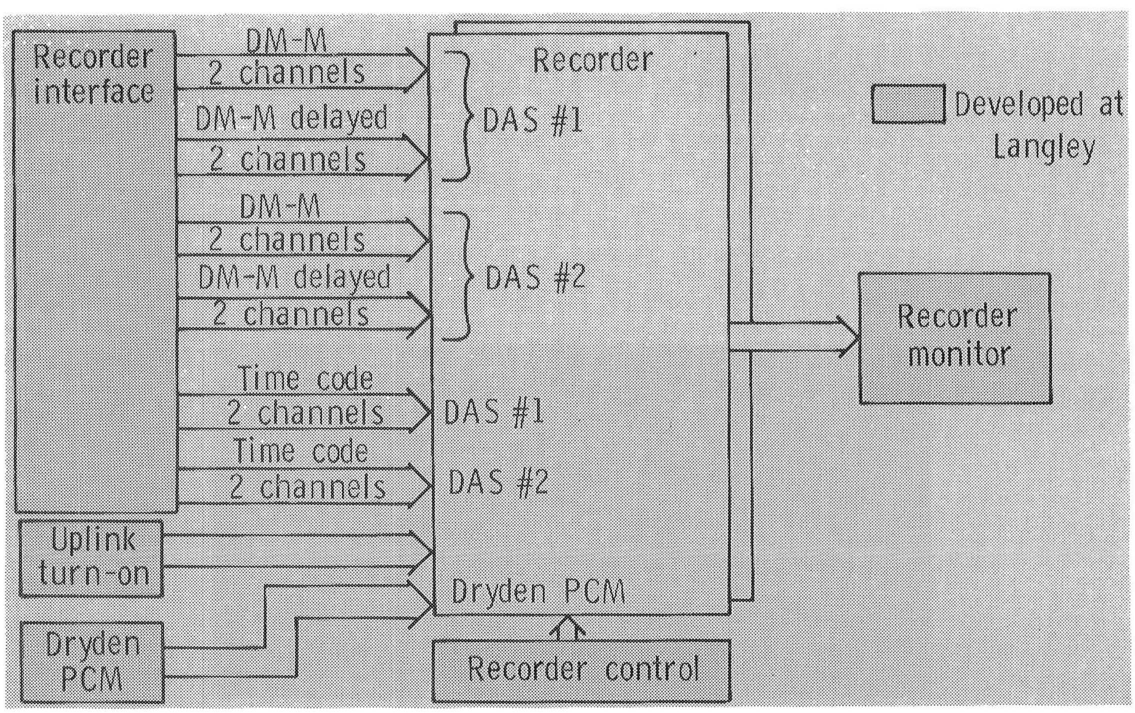


FIGURE 16

RECORDER SUBSYSTEM

Some additional features of the interface electronics were:

- Recorder interface expands 2 PCM signals into 8 signals for redundant recording.
- Recorder monitor; a 10 KHz signal is recorded and monitored via the playback head real-time using phase-lock loop techniques.
- Special shock and vibration isolation techniques were developed to increase probability of successful data acquisition.

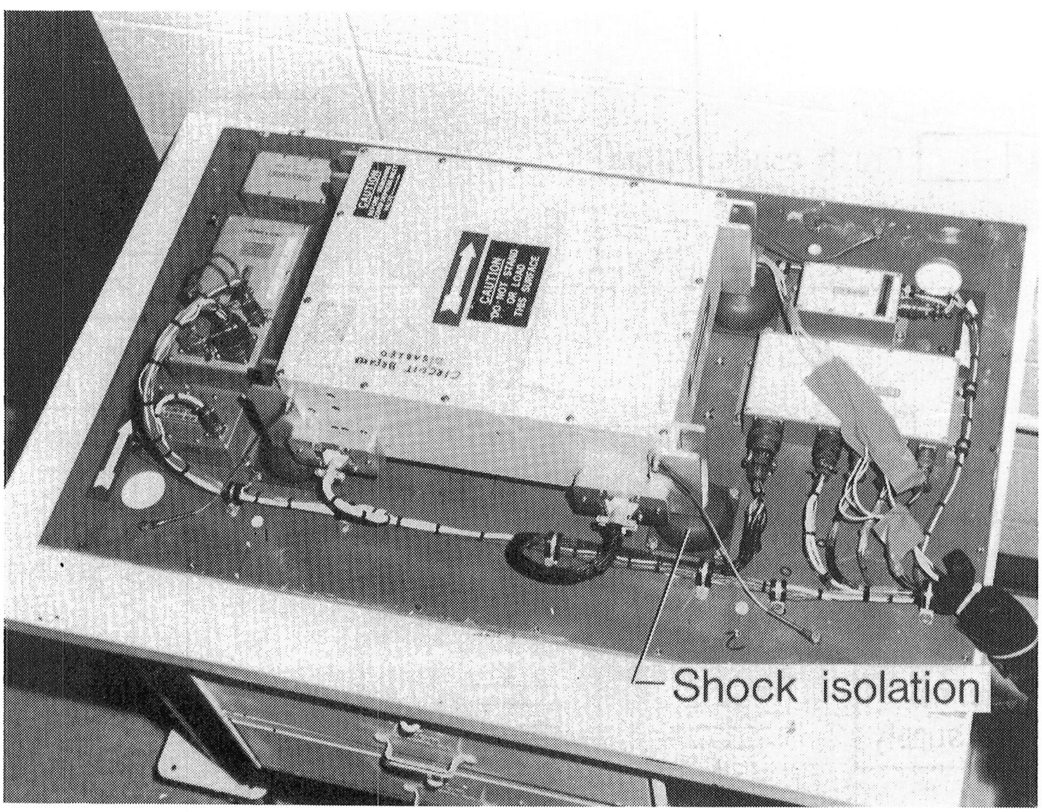


FIGURE 17

POWER SUBSYSTEM

Instrumentation power was independent of aircraft power and self-contained. Each data system's power subsystem consists of an external power supply for system checkout and dual flight batteries for the actual flights. A relay control subsystem was developed to transfer power from the external power supply or the internal batteries to the data system.

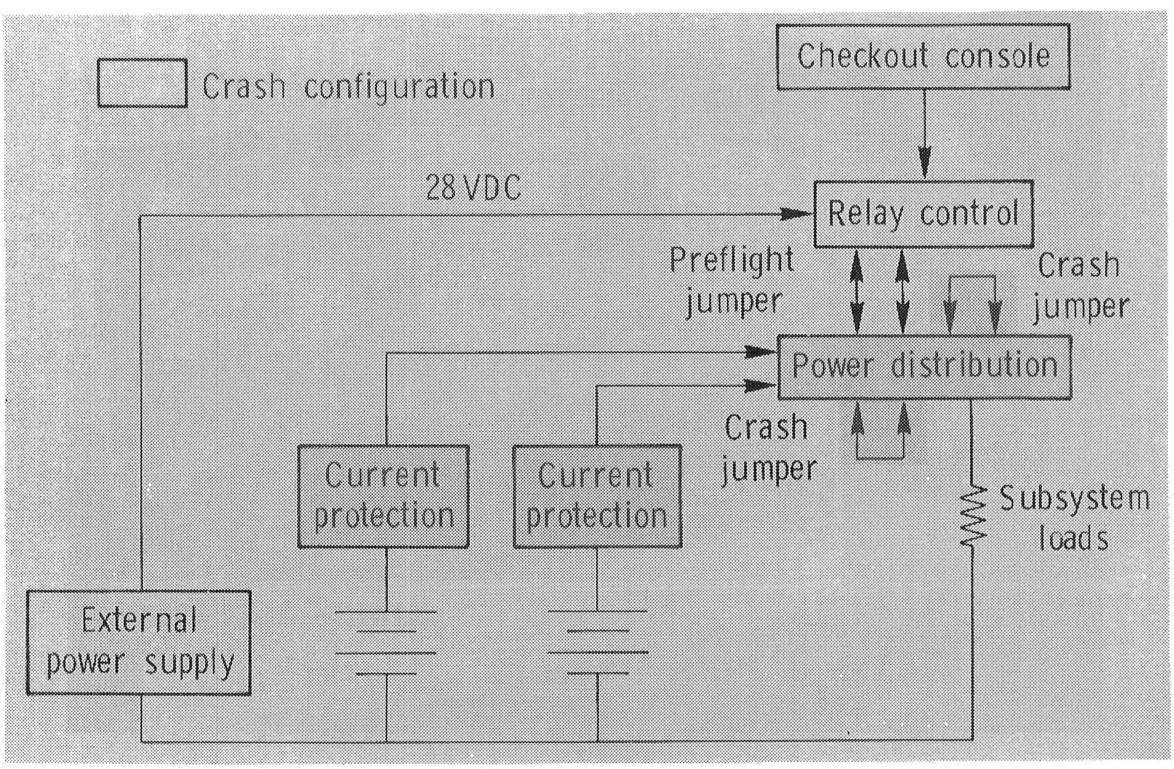


FIGURE 18

BATTERY AND DIODE BOX

A special 23 cell nicad battery was developed for this project. Unique stress release connector links were designed to increase crashworthiness. A redundant parallel fuse technique was used to increased reliability. Series diodes were used to prevent the flight batteries from reverse charging each other.

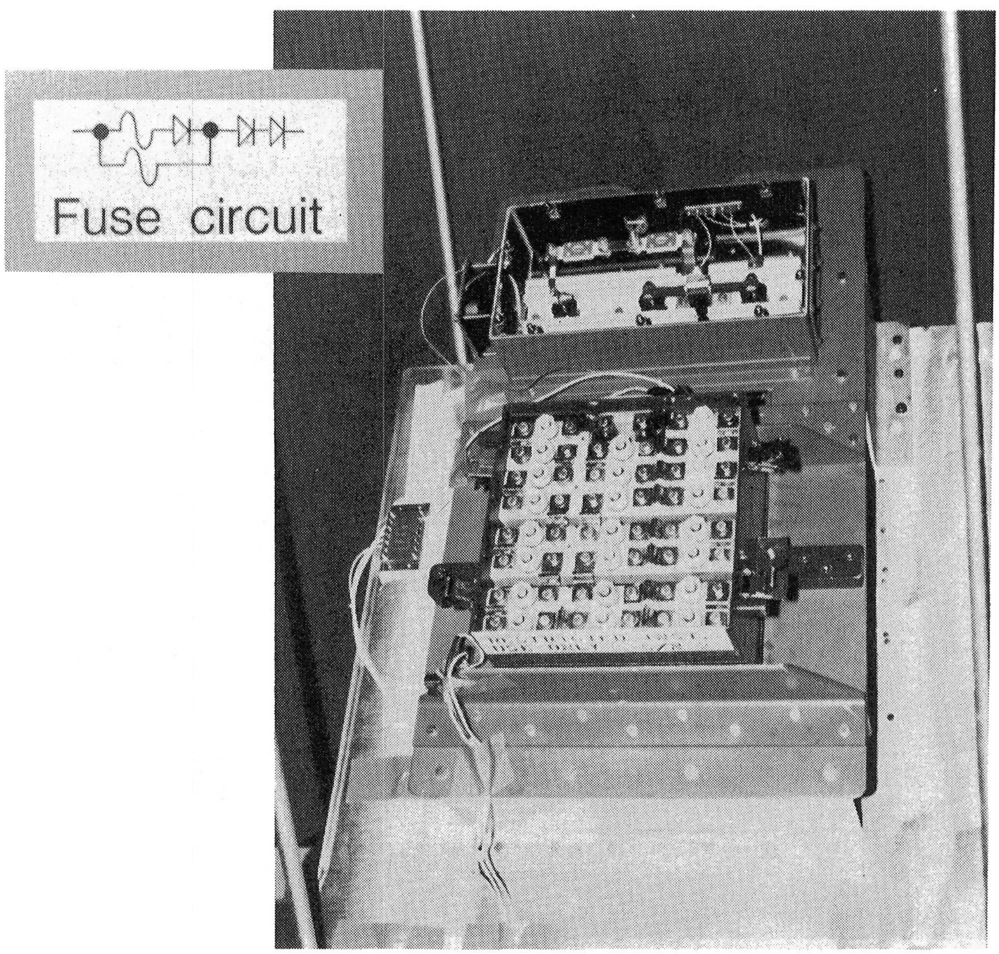


FIGURE 19

POWER DISTRIBUTION BOX

A central power distribution subsystem was developed to ensure reliable power delivery to each subsystem. The design features crashworthy techniques in the construction and the selection of electrical and mechanical components. A redundant parallel fuse technique was implemented. This technique used a unique high "G" fuse in each branch circuit. There was a screening program for each fuse that included electrical tests and X-Ray analysis.

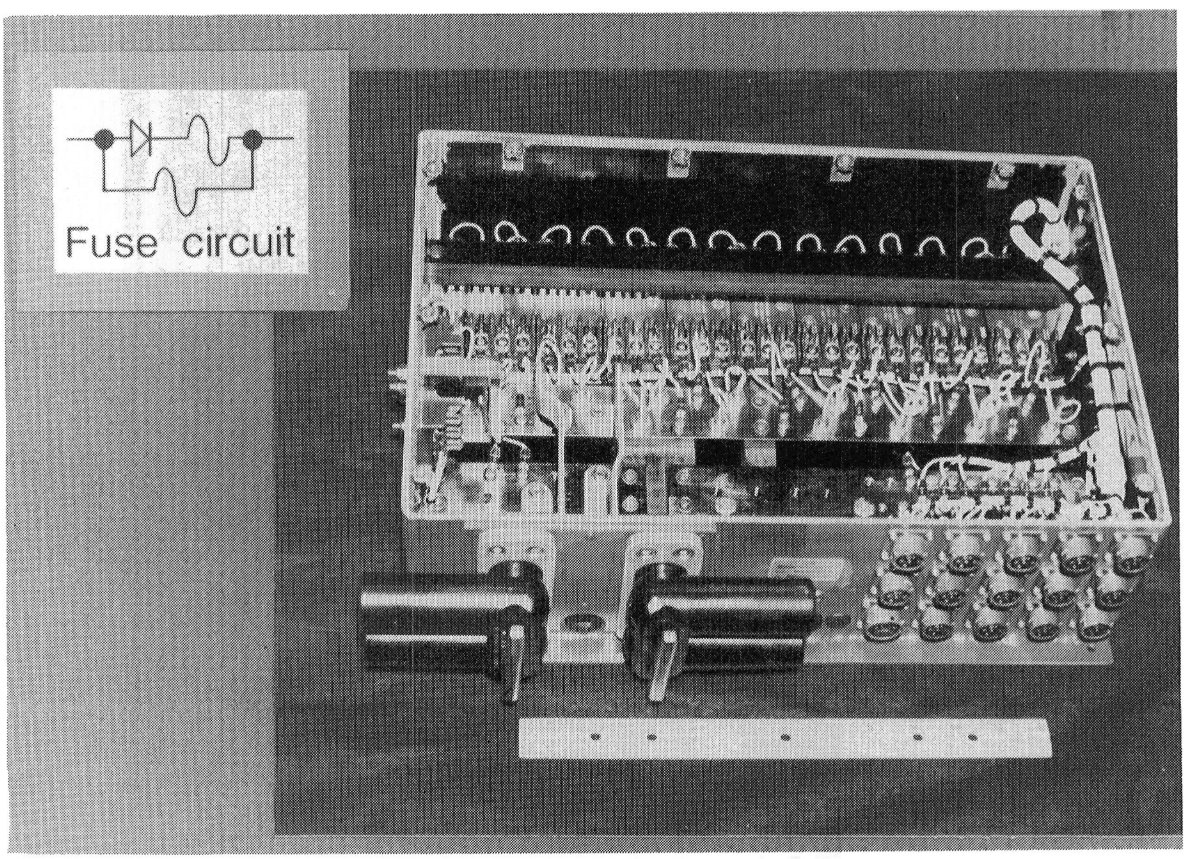


FIGURE 20

RELAY CONTROL BOX

The relay control subsystem controls power via the checkout console. High quality, high "G" components were used to perform this important function.

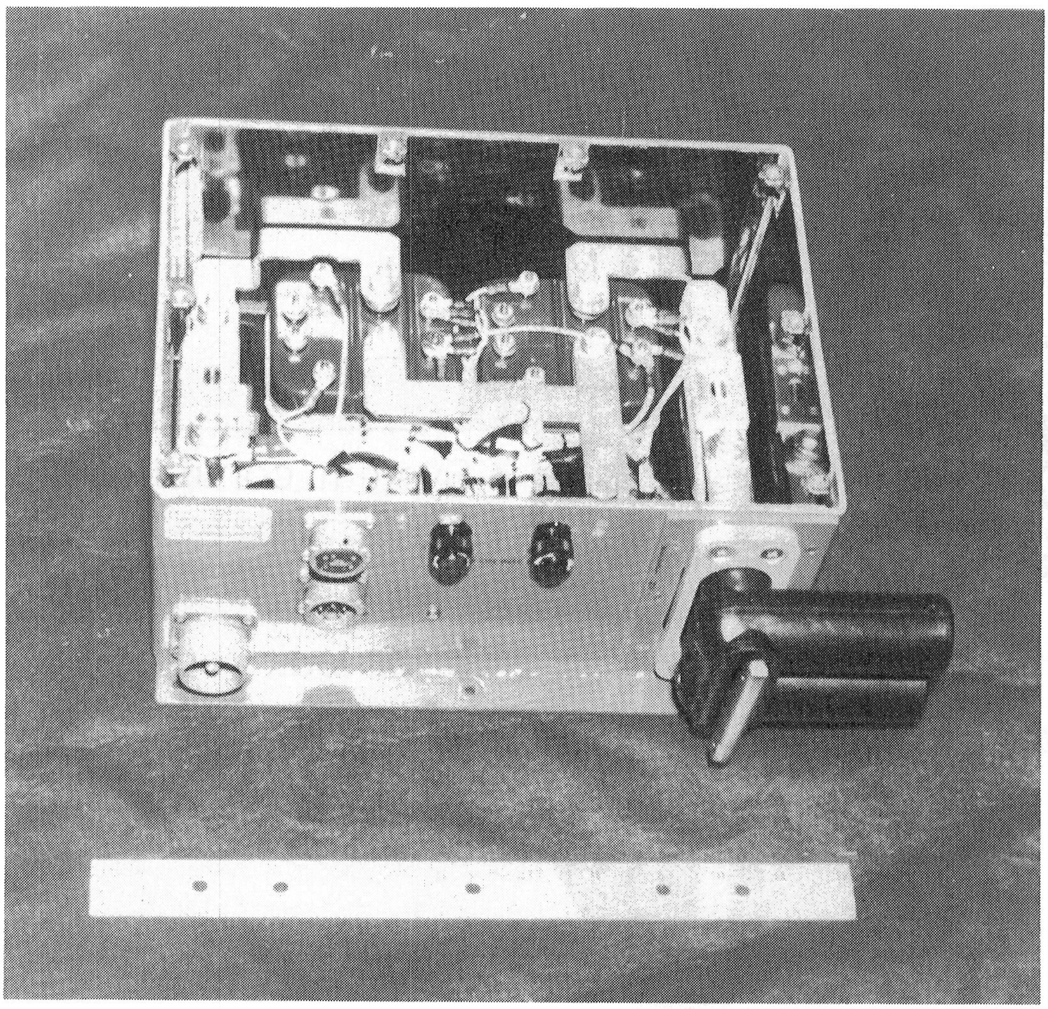


FIGURE 21

CHECKOUT SUBSYSTEM

An excellent checkout subsystem was developed to quickly assess the health of the data systems real-time. The checkout subsystem functions as a real-time monitor with quick-look capability. A checkout console/data system was used to control the data systems.

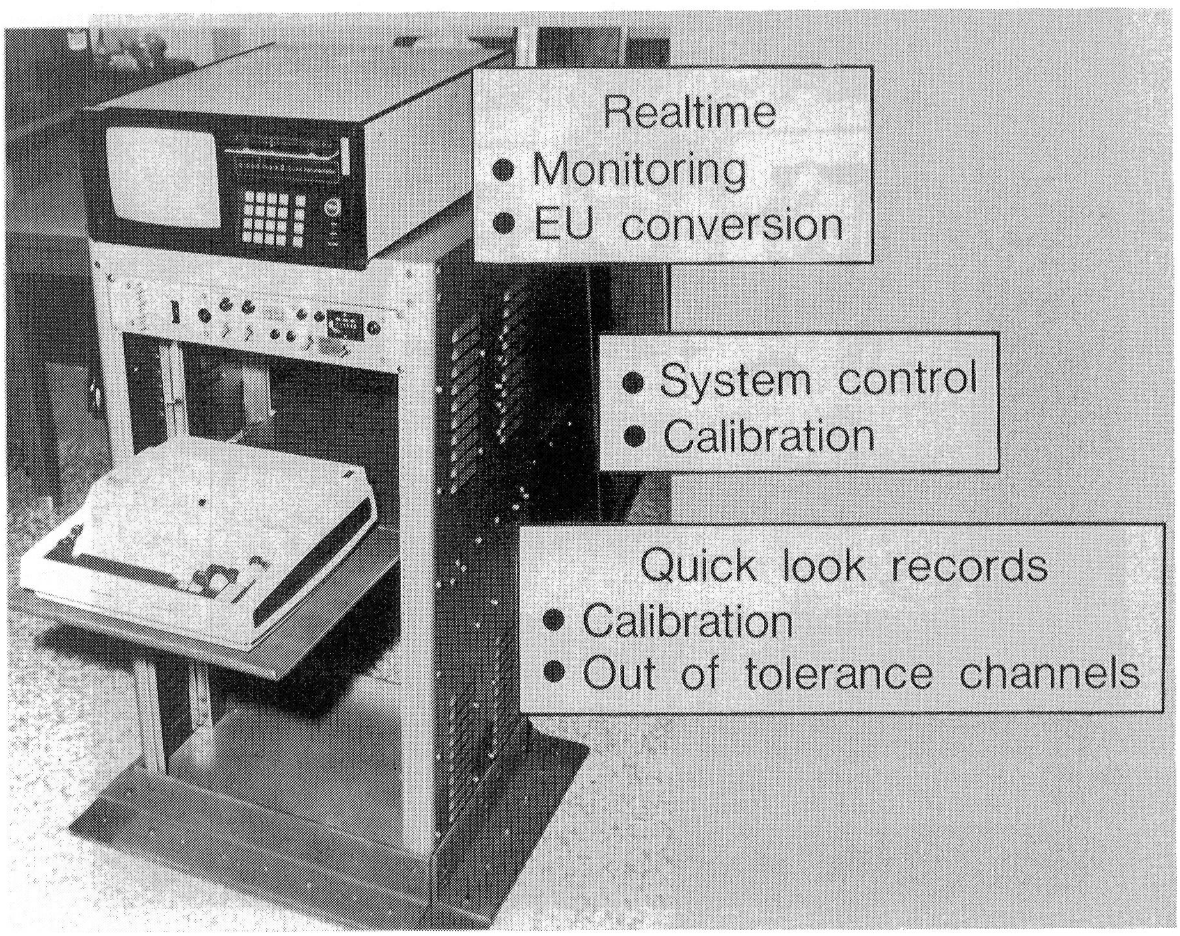


FIGURE 22

INITIAL DOWNLINK TELEMETRY SYSTEM

The initial telemetry configuration used a frequency diversity technique. This technique featured real-time selection of the best telemetry signal from the two transmitted signals per data system for on-the-ground recording.

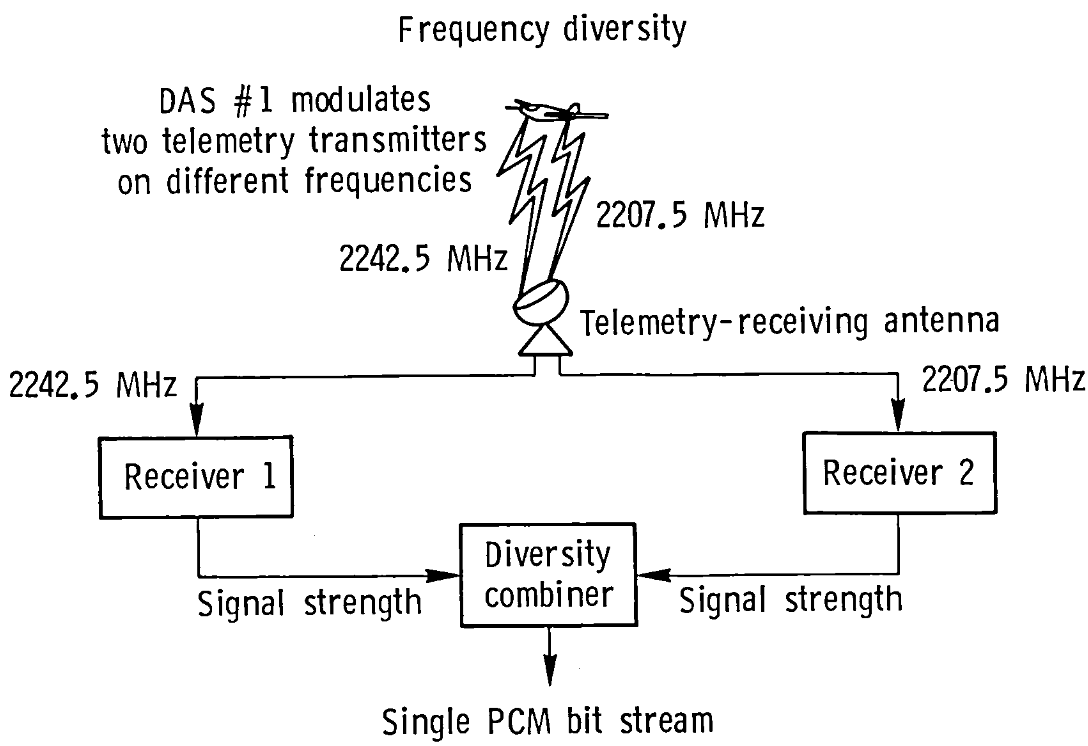


FIGURE 23

TELEMETRY PROBLEMS

The frequency diversity technique increased redundancy, but there were other problems. The most serious was the telemetry dropouts above the CID site. Another telemetry problem was the erroneous turn-on of the on-board recorders and photo instrumentation. The second problem was solved by installing diodes across the relay coils as required on other systems located in the aircraft. In addition a 1 second delay circuit was added to the uplink electronics system to eliminate erroneous turn-on by short duration spurious signals.

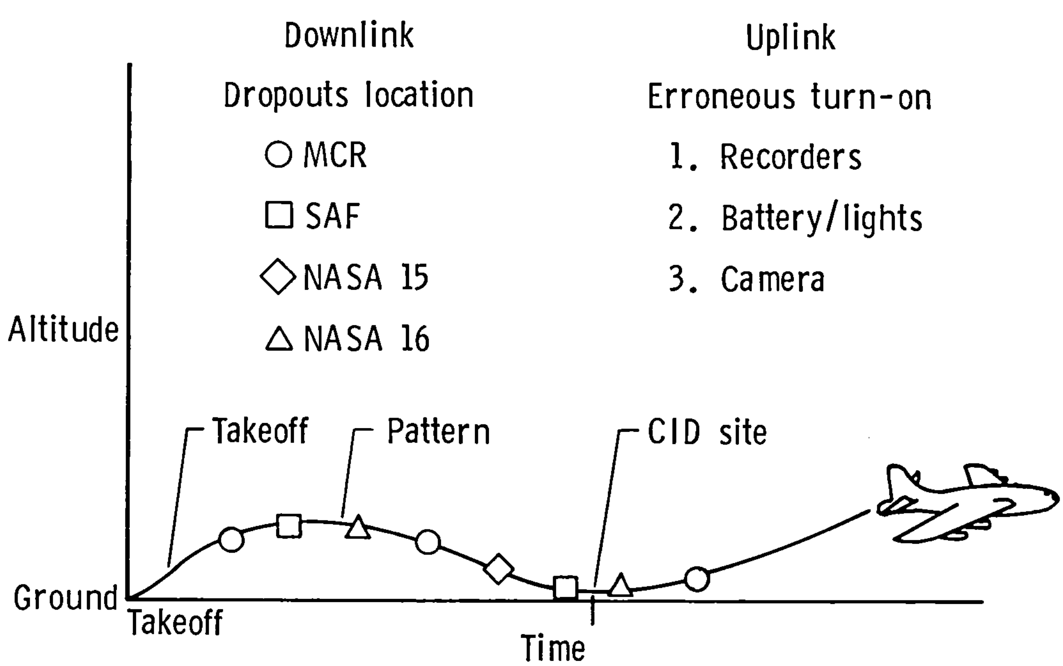


FIGURE 24

TELEMETRY REQUIREMENTS

The final telemetry configuration used a polarization diversity system. To maintain the desired redundancy two remote vans were utilized. One transmitter per data system was selected and these signals were received using the polarization technique at the ground station. The other transmitter per data system was selected and these signals were recorded by NASA 15 and NASA 16, the two mobile vans, respectively. The vans were stationed on opposite sides of the CID runway to optimize data acquisition. Two independent subsystems were activated simultaneously at 150 feet to turn on the on-board recorders and photo instrumentation. The primary activation subsystem was the uplink electronics and the secondary activation subsystem was the terminate electronics.

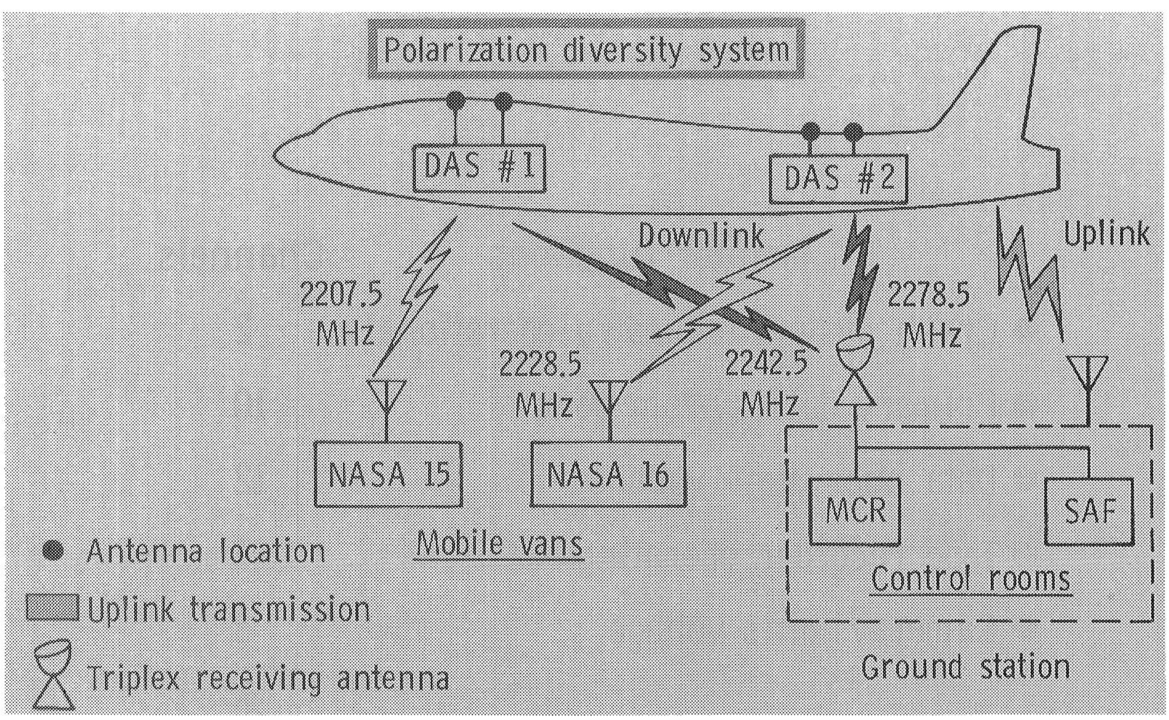


FIGURE 25

DOWNLINK REQUIREMENTS

There were 36 channels dedicated to monitoring the health of the data systems real-time in the ground station. These channels monitored subsystem voltages and currents.

TM monitor functions	Channels
• Crash system telemetry operational	2
• Primary data system power	10
• Data subsystem voltage	12
• Tape recorder operating	4
• Camera/lights voltage	8
	36

FIGURE 26

CONTROL ROOMS

There was capability to monitor data system #2 in the Spectrum Analysis Facility and data system #1 in the Main Control Room. The selected subsystem parameters and data channels were monitored real-time to establish mission readiness. There was a communication net available for communications between the control rooms and the remote vans.

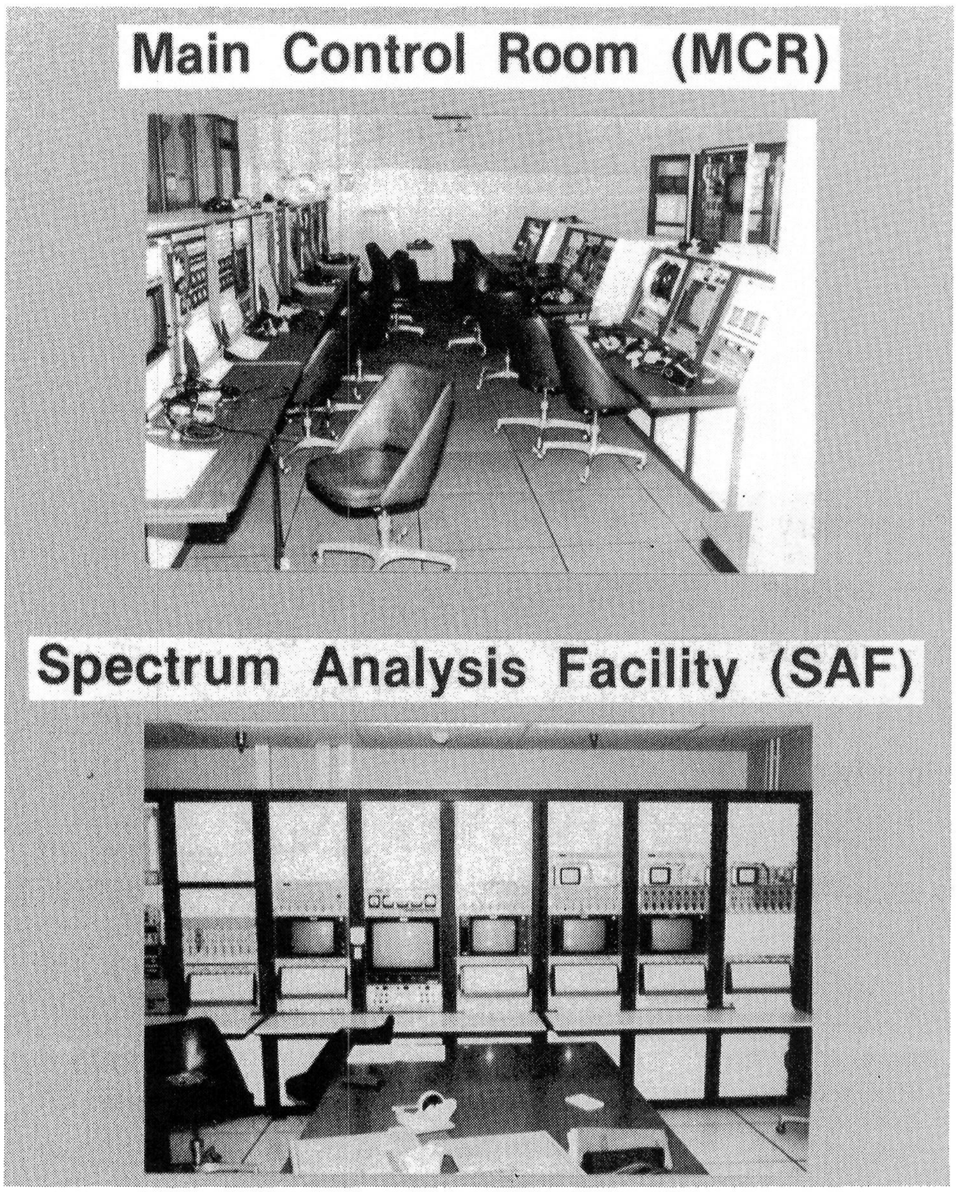


FIGURE 27

DATA SYSTEM INSTALLATION

The flight instrumentation system consisted of two autonomous data systems, DAS #1 and DAS #2, and an excellent checkout subsystem. DAS #1 was installed in the front of airplane. DAS #2 and the checkout subsystem were installed in the aft section of the airplane.

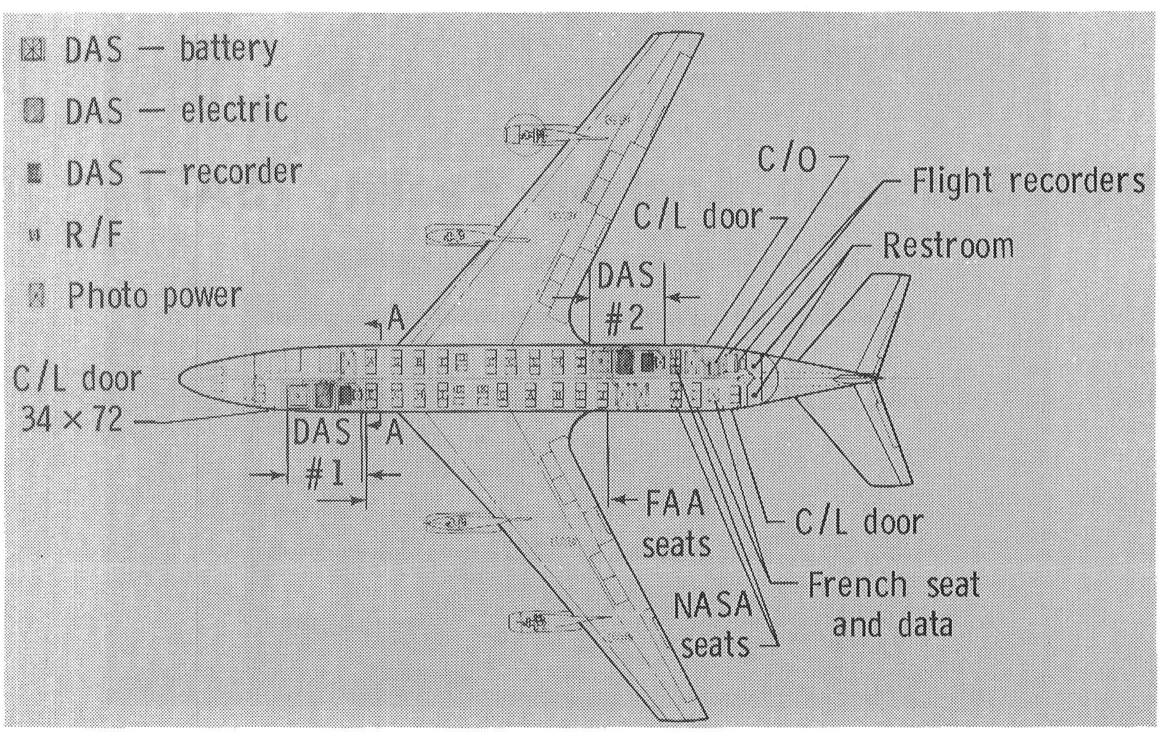


FIGURE 28

SENSOR INSTALLATIONS

Sensors were installed under the floors, in the wings, on the dummies, in the ceiling and at many other locations in the fuselage.

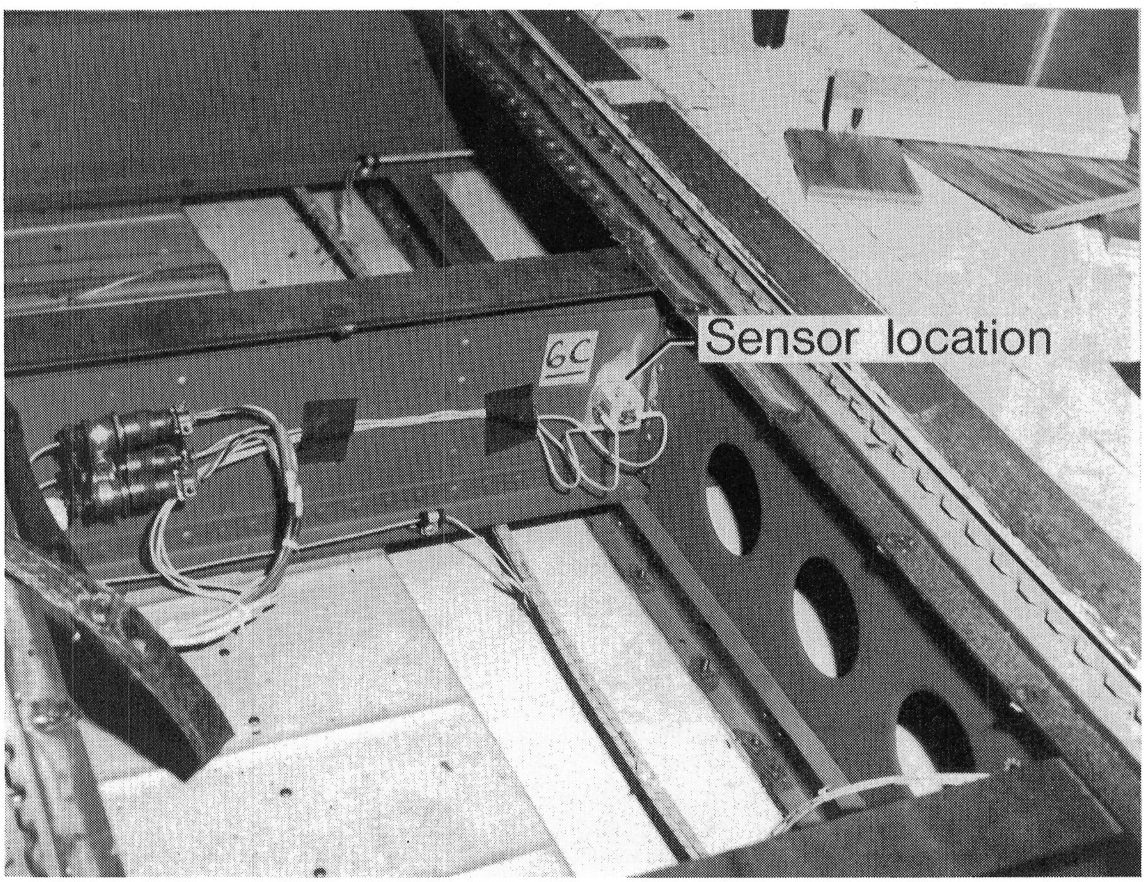


FIGURE 29

DAS #2 INSTALLATION

Each data system was partitioned into four pallets. The four pallets of DAS #2 and two of the four photo pallets are shown. There were over 800 crimp connectors installed. Solder connectors were installed on all inter-pallet cables. Special protective covers were installed to protect inter-pallet connecting cables. Thermal protective covers were developed for all the pallets.

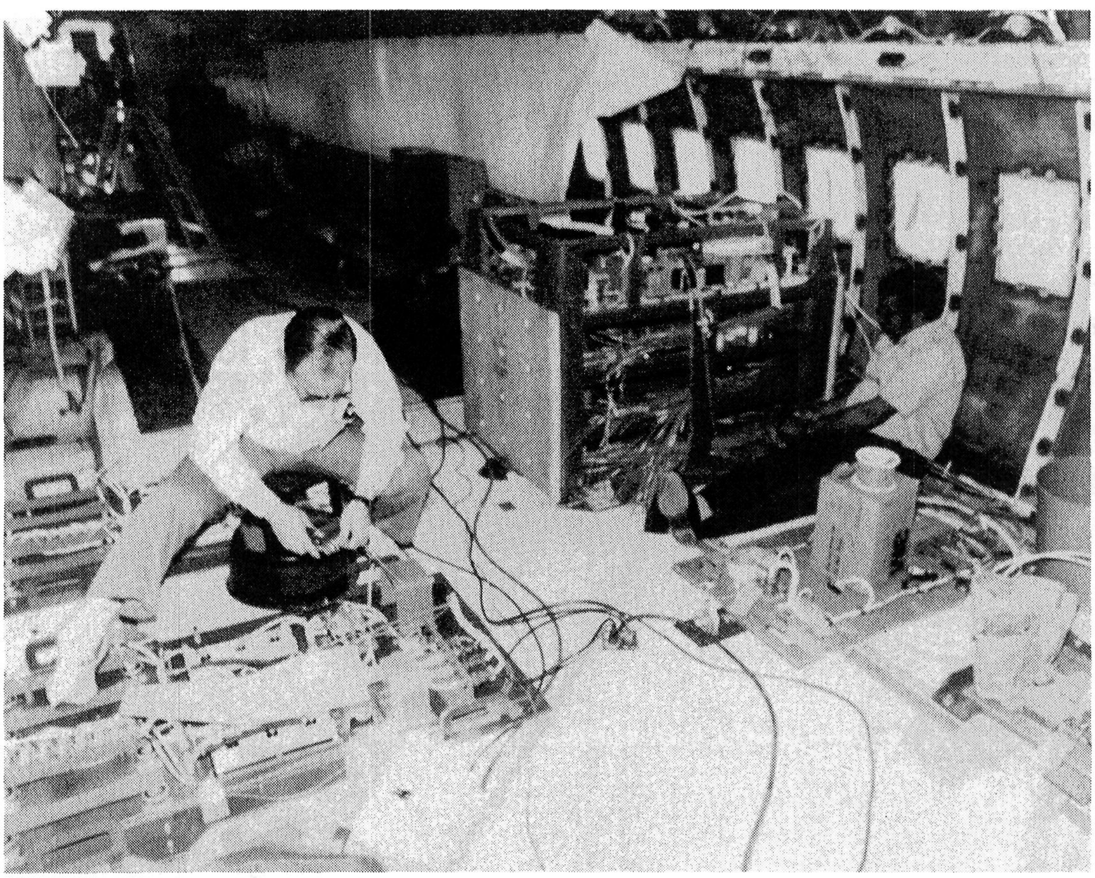


FIGURE 30

DAS #1 INSTALLATION

This photograph shows DAS #1 installation in the front section of the aircraft.

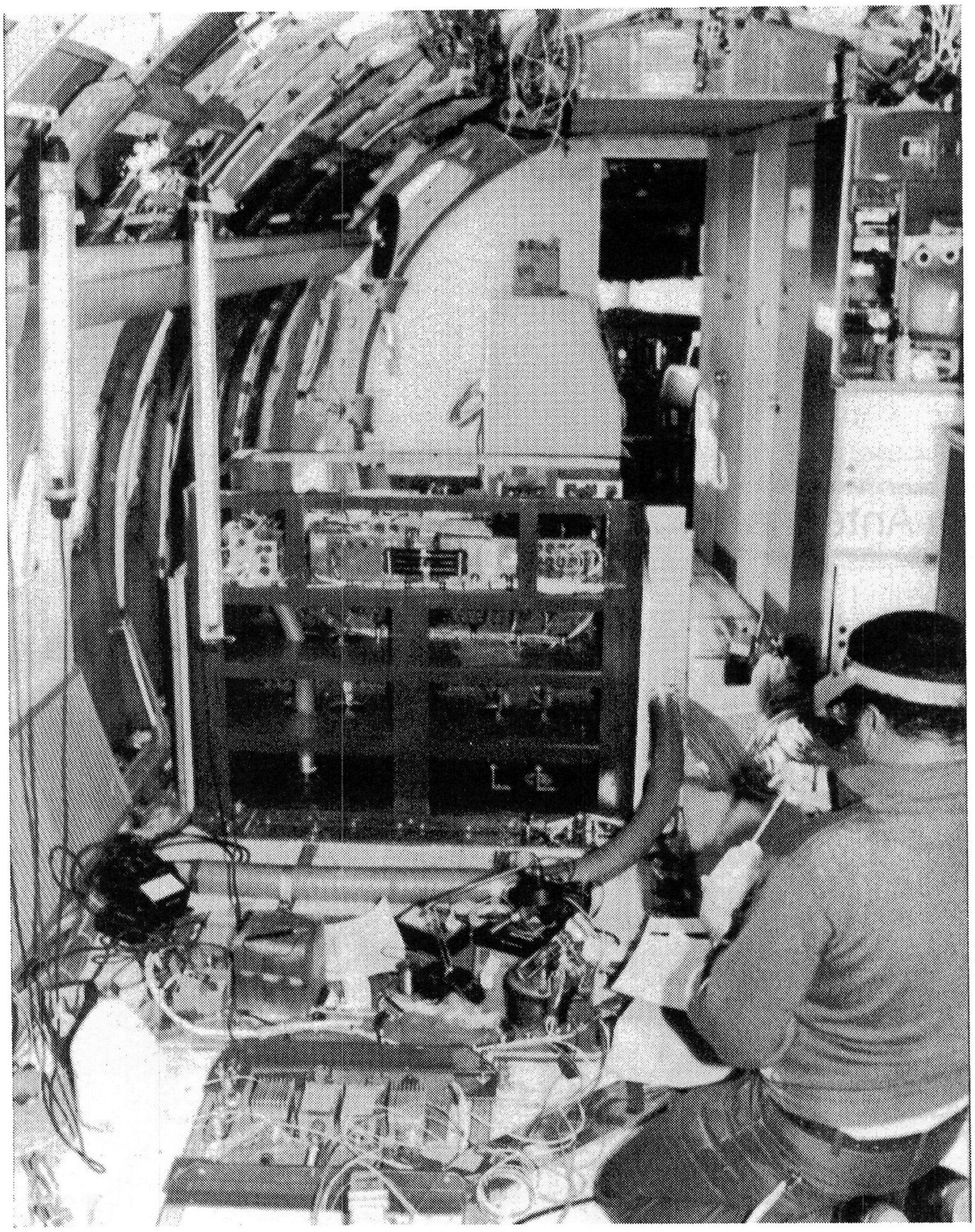


FIGURE 31

ELECTRONIC SUBSYSTEM CRASH SURVIVAL

The system's four antennas were installed in the ceiling. The telemetry signals were lost during the fire. Prior to fire, the ground recorders in the control rooms and the recorders in the remote vans successfully recorded the data during the impact sequence.

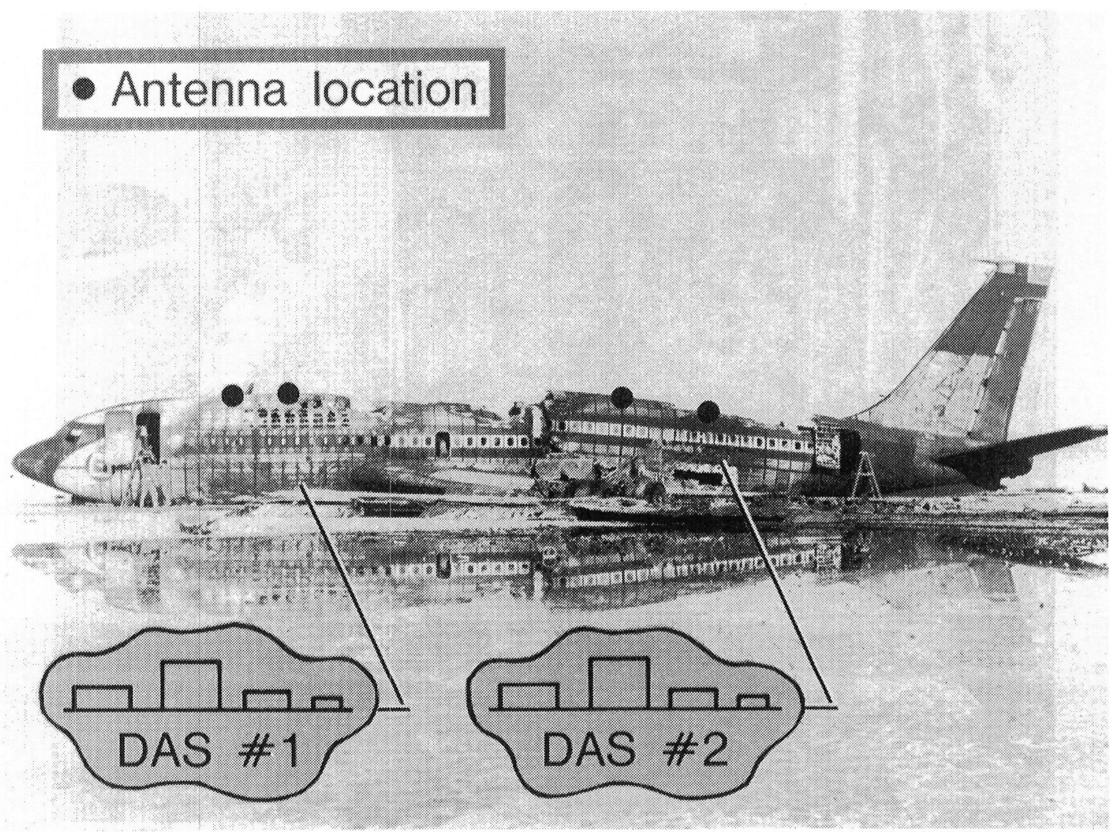


FIGURE 32

DAS #1 AFTER

All pallets were protected with thermal covers. The battery pallet is shown at the bottom of this figure. The batteries were removed from the aircraft. There was contamination on the pallet surfaces. The battery cases were externally blemished and there was a little discoloration inside the battery covers. The other pallets partially dropped below the floor level.

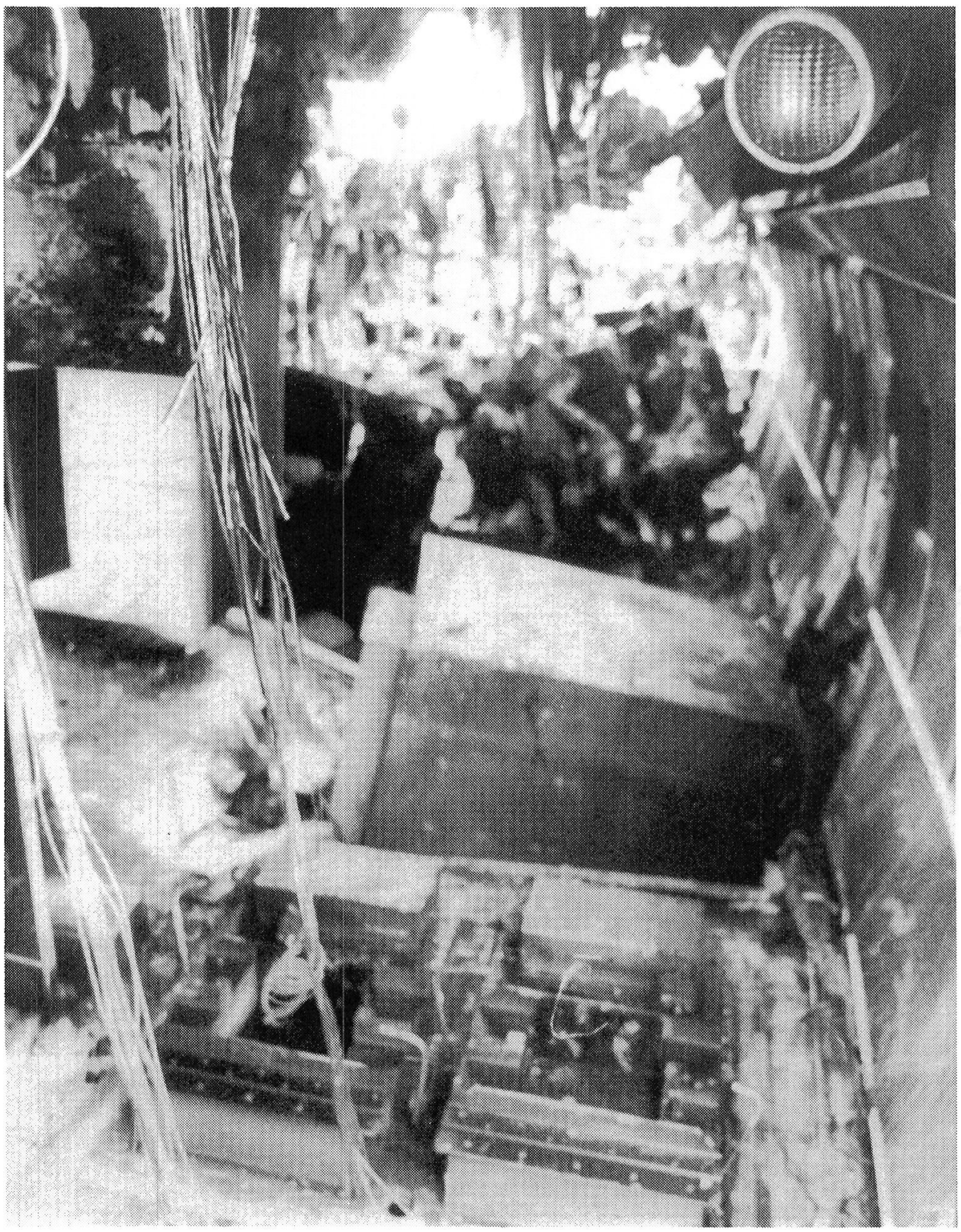


FIGURE 33

DAS MAIN PALLET

This figure shows a typical DAS main pallet before the fire.

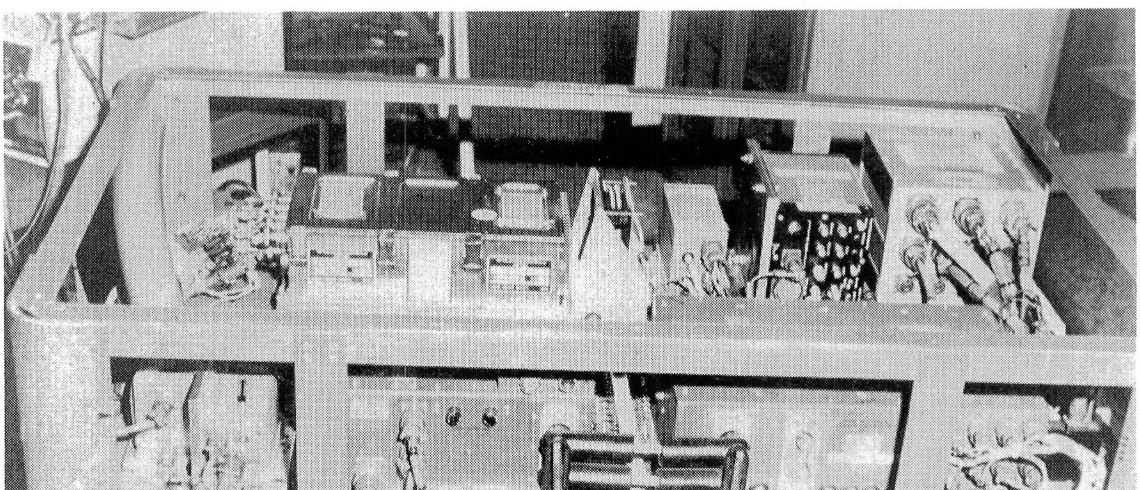


FIGURE 34

MAIN PALLET DAS #1

This figure shows DAS #1 at Langley after the fire. There was chemical residue contamination throughout the pallets' external surfaces. The residue entered all pallets via the airconditioning ducts. Further inspection revealed no signs of internal damage of any to the subsystems.

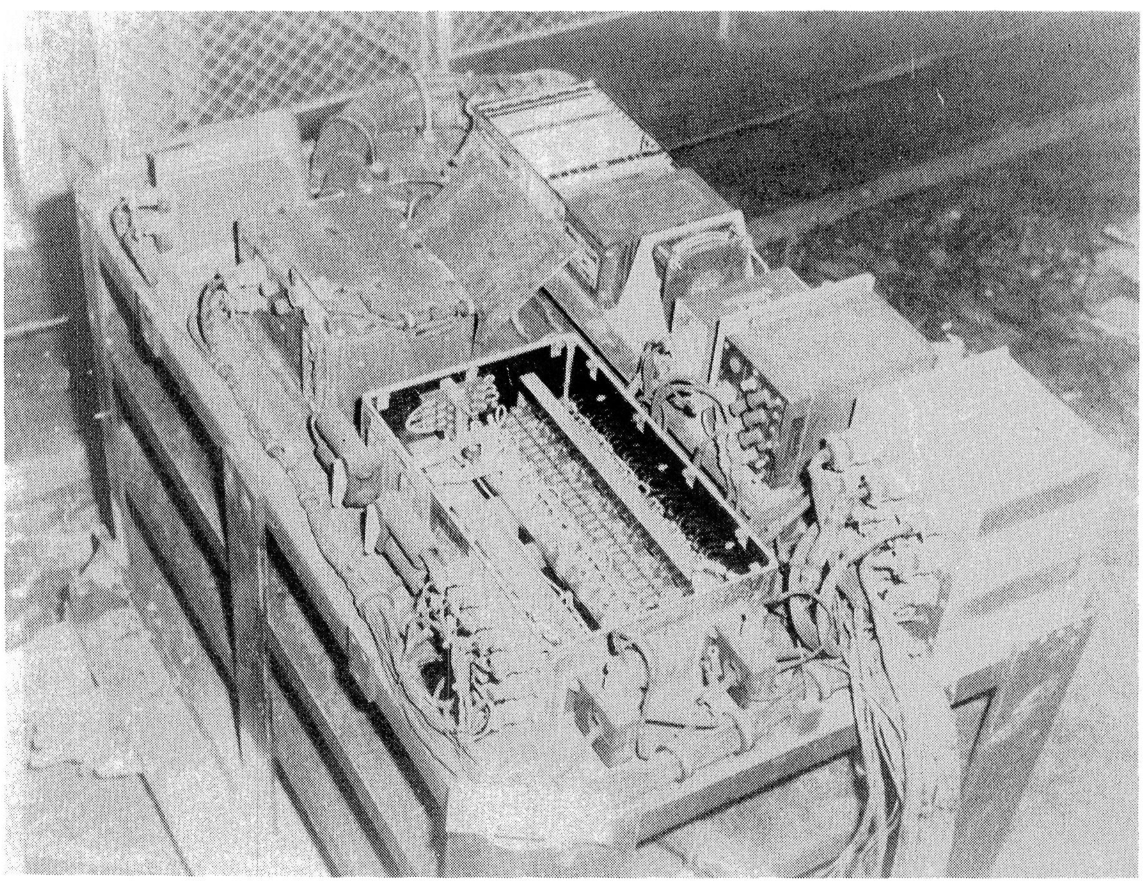


FIGURE 35

BATTERY PALLET

This figure shows a typical DAS battery pallet before the fire.

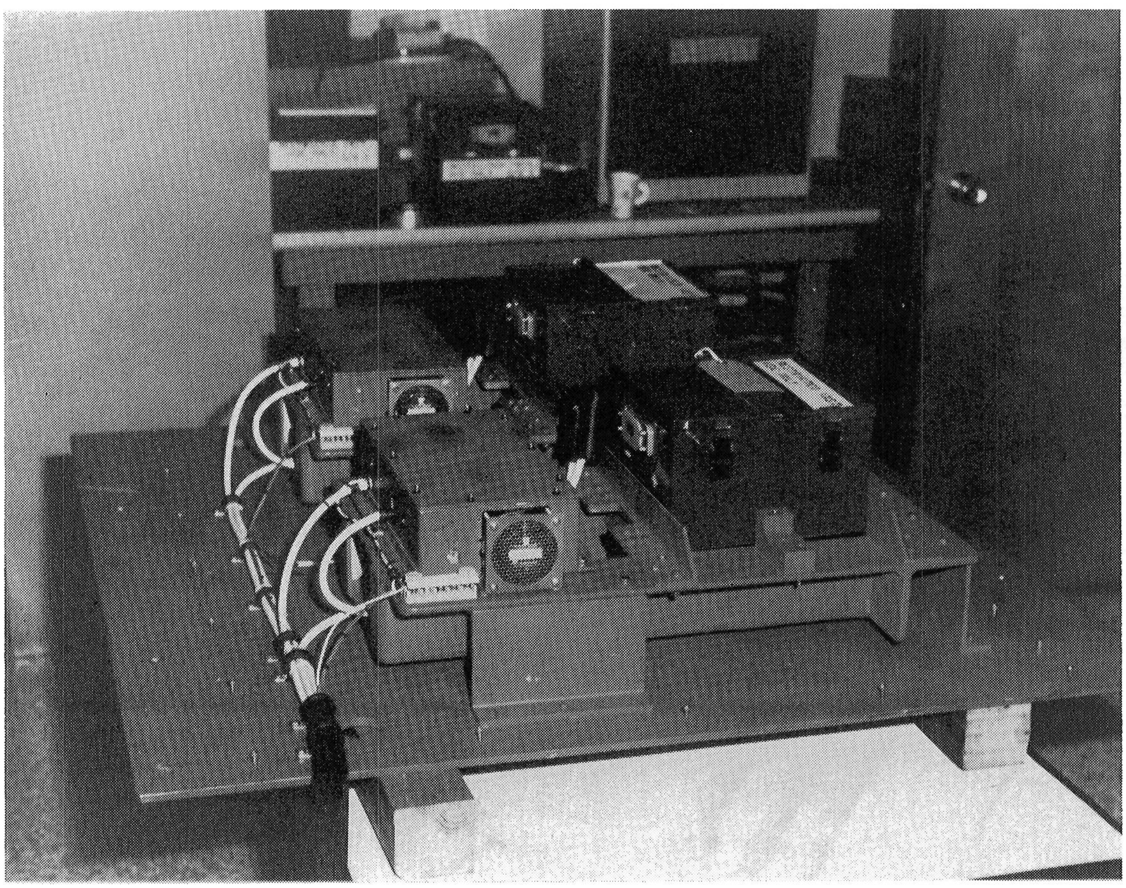


FIGURE 36

BATTERY PALLET (DAS #1)

This figure shows DAS #1's battery pallet after the fire.

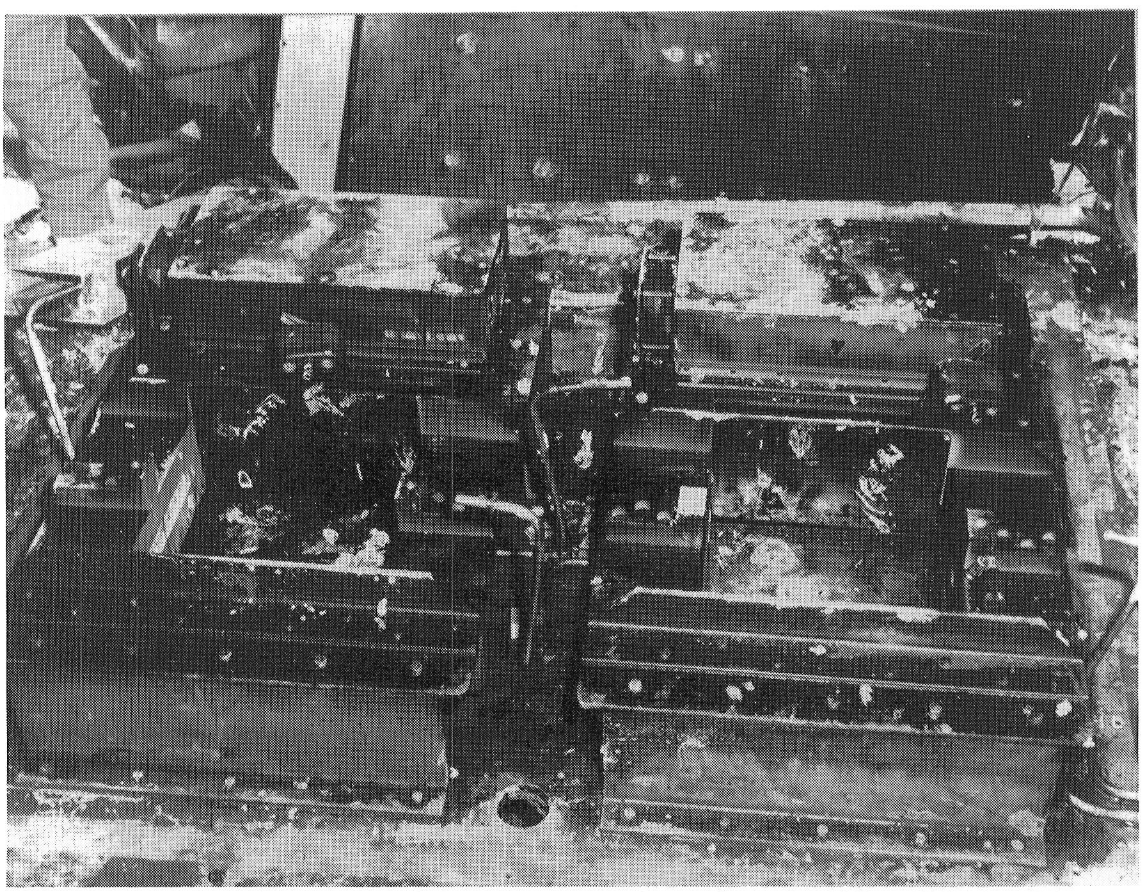


Figure 37

TRANSMITTER PALLET

This figure shows DAS #2's transmitter pallet before the fire.

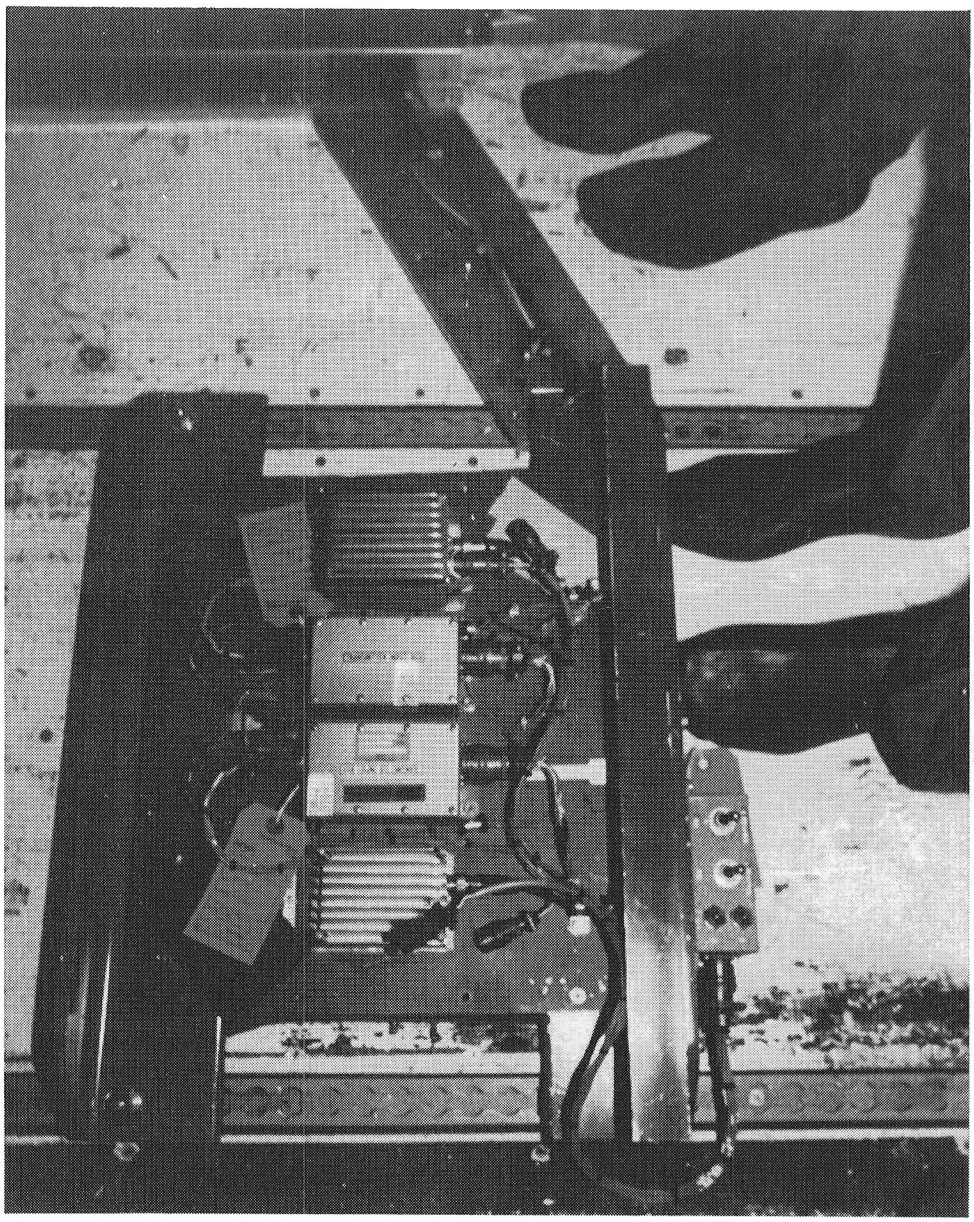


FIGURE 38

TRANSMITTER SUBSYSTEM (AFTER)

This figure shows DAS #2 transmitter pallet after the fire.

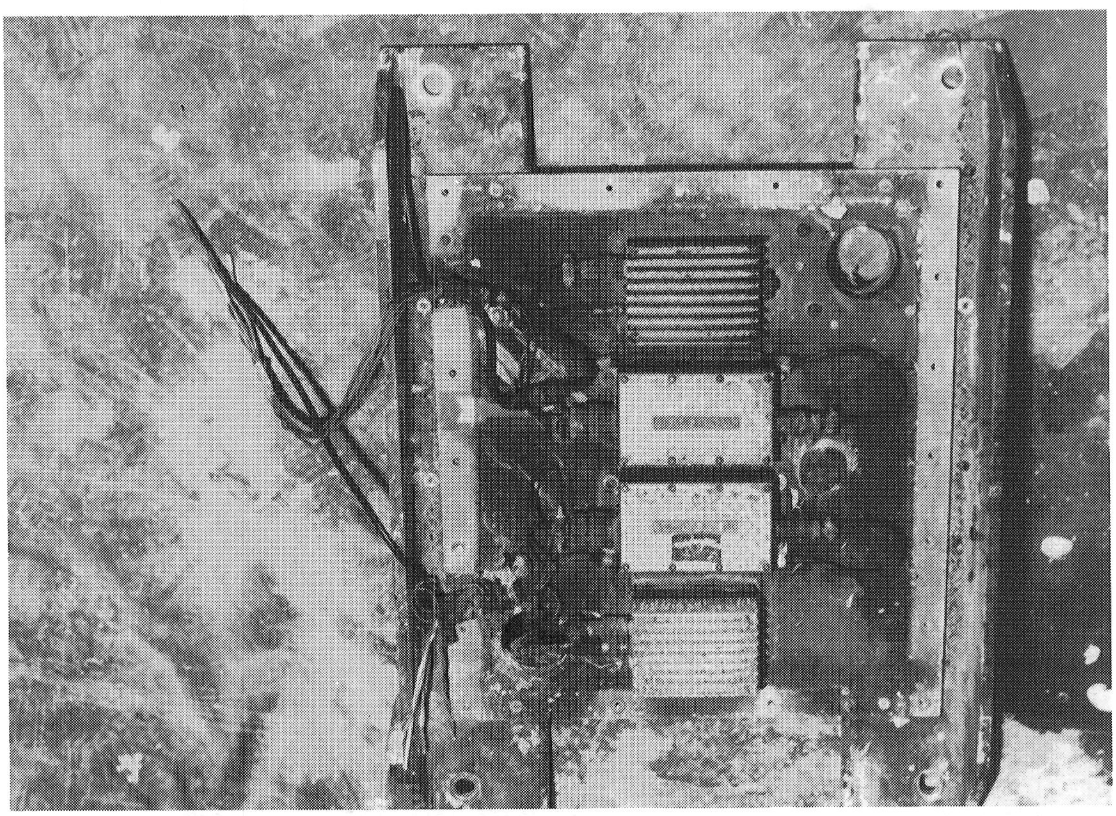


FIGURE 39

RECORDER SUBSYSTEM

This figure shows a typical recorder pallet after the fire and typical recorder before the fire.

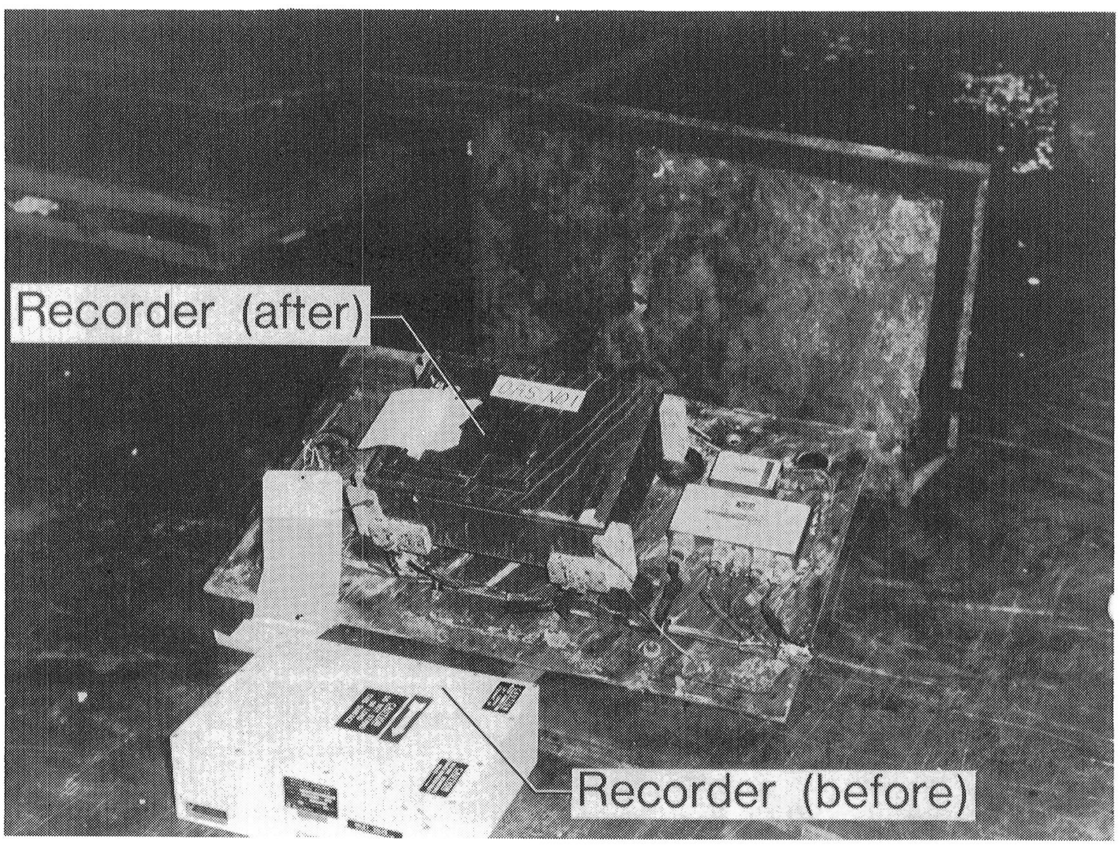


FIGURE 40

RECORDER SUBSYSTEM AND DATA TAPE (AFTER)

Both recorder pallets were externally contaminated by the chemical residues. Both recorders were started with 9 minutes of tape remaining per reel and faithfully recorded crash data until the end of tape! There were no signs of damage to either recorder internally.

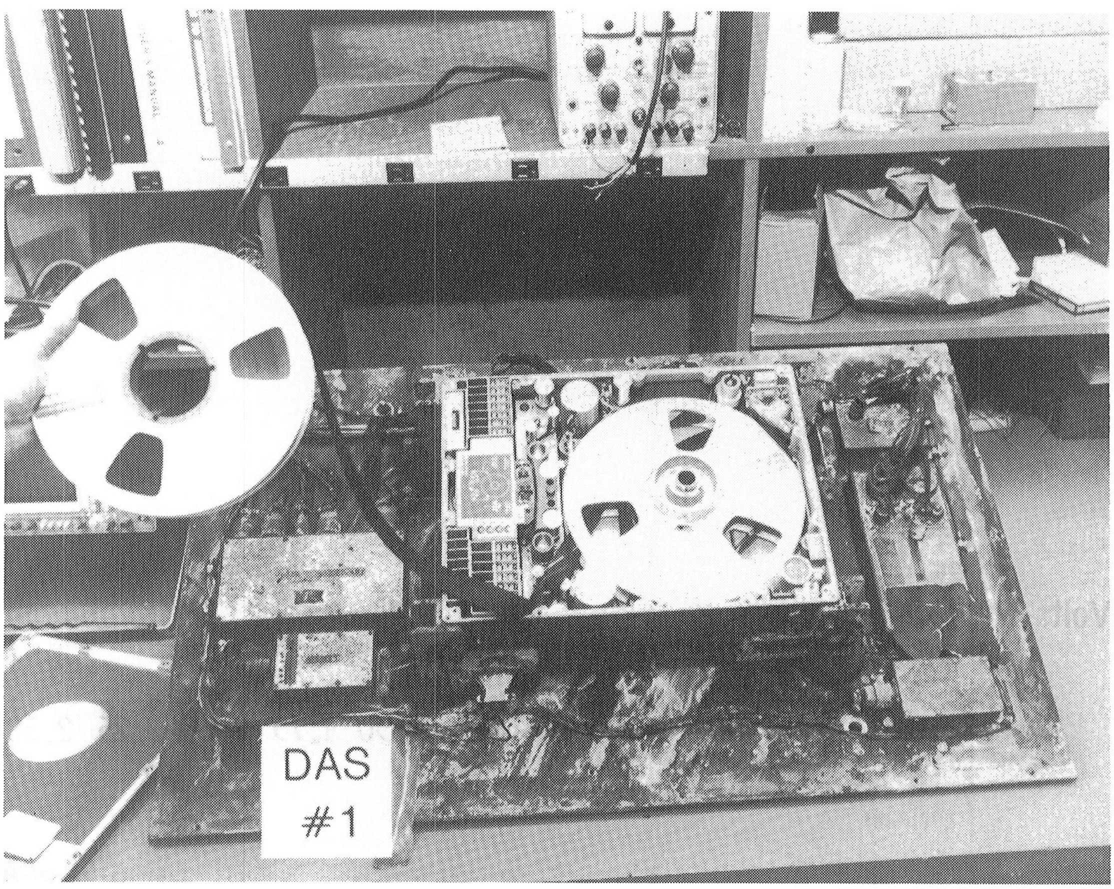


FIGURE 41

BUS VOLTAGE

The selected DAS parameters were monitored before the controlled impact and the reduced data is currently being analyzed. The battery bus voltages operated within specifications during the reduced data period. There was only one anomaly noted. Approximately two seconds after the left wing impact, there were two 40 msec spikes on the +5 volt secondary bus in signal conditioner #4. The minimum voltage during these spikes was 2.12 volts. Since this voltage was only used on the calibration card, no discernible interference on the data channels was detected.

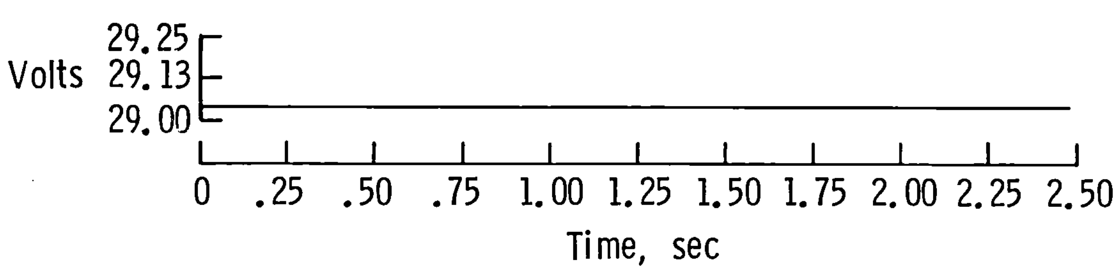


FIGURE 42

CAMERA PALLET #3 VOLTAGE (DAS #1)

There were four channels per data system dedicated to monitoring the photo pallets batteries. A typical signal is shown.

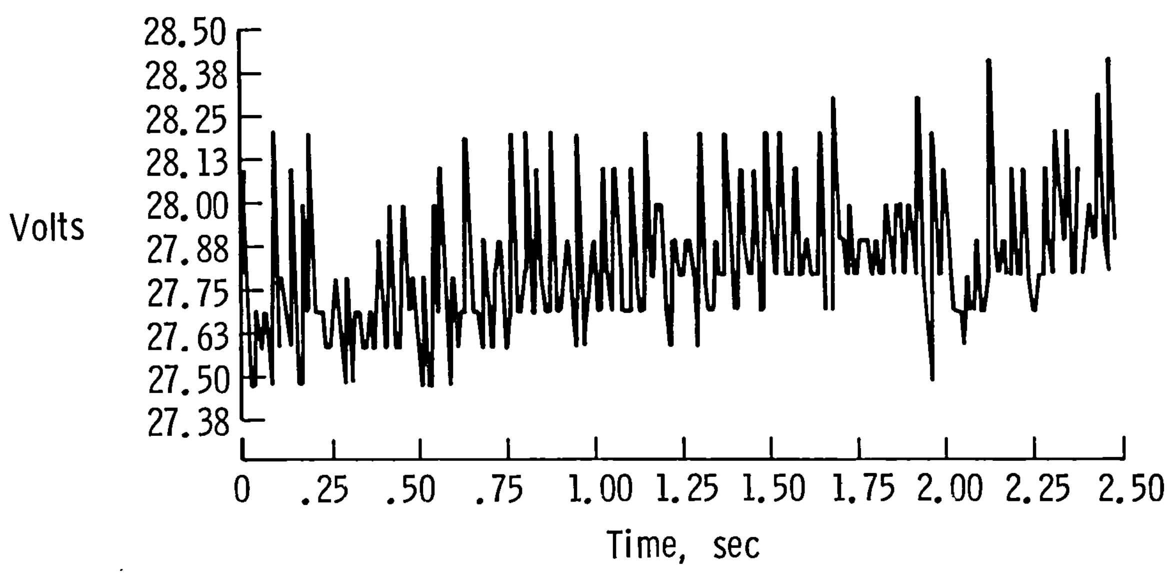


FIGURE 43

PROGRAM SCOPE

The following resources were required to develop and ship two large data systems in 18 months.

- 1.6 million dollars up front money
- Accelerated procurement priorities
- Accelerated delivery
- A dedicated work force to handle the enormous parallel efforts required
- High program priority at Langley, Dryden, and FAA

- Funding ~ 1.6 million
- Accelerated procurement and delivery
- Parallel effort and manpower commitment
- High program priority at Langley/Dryden and FAA
- Develop instrumentation within 18 months

FIGURE 44

CONCLUDING REMARKS

The highly successful data acquisition is attributed to a design approach featuring:

- HIGH RELIABILITY CONCEPTS
  - Multi-Level Redundancy
  - Fault Tolerant Design Techniques
  - Aggressive Quality Assurance Program
- HIGH ENVIRONMENT CONCEPTS
  - Shock and Vibration Isolation Techniques
  - High "G" Components
  - Thermal Protective Covers
- HIGHLY DEDICATED TEAM OF PROFESSIONALS

In addition to successfully acquiring 343 out of 352 data channels, the electronic subsystems survived the post-crash fire and are operational.

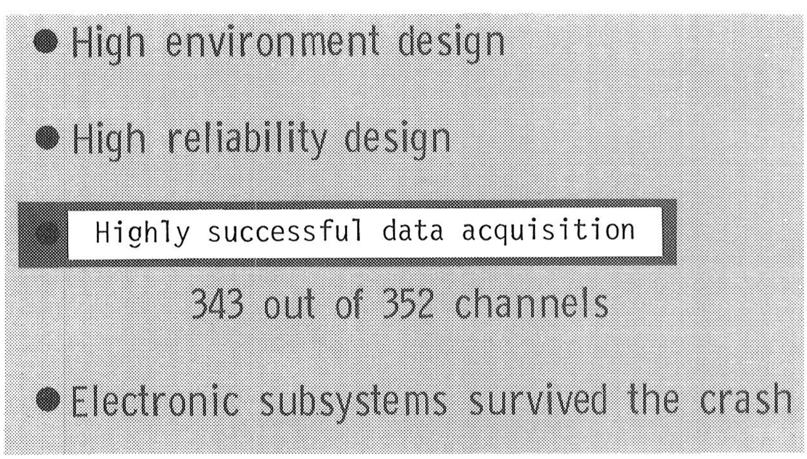


FIGURE 45