CENTRAL FAULT DISPLAY SYSTEMS

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Abstract

Many Aircraft presently in service, including the early digital aircraft, have built-in test equipment (BITE) systems. However, these systems were designed independently, and thus use different design rules, without effective means of fault correlation. This has contributed to less-than-ideal fault diagnosis in service, resulting in waste of maintenance resources and reduction in regularity. The increasing use of avionic systems makes it important to avoid such waste.

The A320 is the first aircraft to enter service with BITE systems without these deficiencies, which have been avoided by adherence to a single set of BITE design rules, and the use of a common set of controls and displays for all the systems, integrated into a single Central Fault Display System (CFDS).

The CFDS allows fault data to be processed at all times, enabling fault reporting to be carried out in flight if required.

The design and operation of the CFDS is described and future developments are discussed.

Introduction

A characteristic of large commercial aircraft is that, over the years, increasing use is being made of electrical and electronic systems to provide efficient, reliable functions.

Starting with communication facilities, then with navigation and guidance, and continuing with information processing combined with improved control of "conventional" systems, electronics are now applied in almost all the facilities that aircraft rely on. The electronic technologies used are changing : electron tubes, magnetic devices, semiconductors, integrated circuits, analogue and digital computing having gradually given way one to the other, offering improvements in volume, weight, power consumption, and reliability.

These improvements are being utilised to increase functionality, better using the information available on the aircraft, as a means of improving efficiency.

However, there is a price to pay. The increasing functionality and higher use of data having made the systems concerned more efficient, have also made them less easy to understand and to trouble-shoot by the average mechanic. Also, the (desirable) greater reliability has led to fewer faults, reducing the mechanics' familiarity with the systems. Furthermore, electronic controls are being used in non-traditional applications, leading to fault-finding methods that differ from those habitually used by the mechanics concerned. The initial difficulty is thus compounded. The need to improve maintenance effectiveness has led to the development of an innovative concept, the Central Fault Display System. (CFDS).

Background

A300

When the A300 was entering service in 1974, it was realised that the increasing complexity of avionic systems on board the aircraft justified aircraft-wide maintenance facilities that went beyond the BITE that was implemented at the time. Airbus Industrie were already unique in having at the disposal of the airlines a shop test equipment, with a software suite that could check out almost all the avionics, and what was needed was a matching facility on the aircraft itself. A start had been made on the AFS, even on A300 and Concorde (1976). These complex, multi-LRU systems have central maintenance displays and controls, and experience has proven that, with proper attention to detail by the airline, they are indeed remarkably effective. However, they are not easy to use, and the requisite displays and data exchange networks do not exist on most other systems. What was needed were systems with more widespread application, which could be operated by less-skilled personnel. This meant that the systems had to behave in a similar fashion, and had to have easy-to-use controls.

A310

When the A310 (1983) was being designed, a number of other multi-unit and/or multi-sensor systems were introduced, such as EFIS, ECAM, and FMS. These systems have powerful displays, and sit in a data bus web. What was missing on previous generation aircraft was now becoming available. Simultaneously, the cost of computing and data storage was dropping fast.

The task of incorporating maintenance information facilities with common rules was added to the development tasks on these systems, and on other ones where displays were incorporated specifically for BITE. The rules stated that clear English text, rather than fault codes, should be used for fault location to LRU level, and that a certain amount of data on past flight legs had to be carried.

In spite of this effort, the disparity of designs and display media used, along with the limited applications selected have resulted in a jumble of maintenance facilities on all aircraft of this period. The A310 and A300-600 (1984) are only a little better than their contemporaries. It is still necessary to search among a number of facilities to obtain the fault-finding help that is available, and there is no means of correlating indications from several facilities, apart from establishing that the events happened on the same flight.

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The end result is fault-finding effectiveness that is no better than on previous aircraft, overall.

The systems of the A300 and of the A310/A300-600 are similar in many ways, but the later aircraft have greatly increased functionality in many areas. Both aircraft families have been in-service for several years in broadly comparable environments. A comparison of maintenance statistics carried out in 1988 showed that reliability of the later aircraft's avionic systems was greatly improved, that the cost of repair (when needed) was lower, but that the proportion of faults correctly diagnosed at the first attempt was also somewhat lower. (Table 2).

The advanced technology is thus achieving its objective, but its effectiveness is still being diluted by ineffective fault-finding.

A320

The A310 is, by contemporary standards, a highly-integrated aircraft. The experience gained on this aircraft showed that an even higher level of integration would be cost-effective, and the A320 systems have been designed accordingly.

The level of integration achieved has made it possible for all the systems on the aircraft that contain avionics to be connected to a single means of accessing maintenance information - eliminating the inconvenience of multiple displays.

It is to be noted that the overwhelming majority of the aircraft systems do use avionics, in one way or another, and are directly connected to CFDS.

The "common rules" used for selected A310/A300-600 BITE systems are expanded to include improved fault correlation means, principally time-of-occurrence, and memory has been added to record ECAM caution and warning messages.

The Multi-purpose Control and Display Units are the primary means of access to the data, with a printer available to produce permanent records.

Maintenance personnel thus have at their disposal clear, unambiguous data, in one place, in a uniform format, enabling them to trace faults and verify their repair on over 70 systems. (Table 3).

The maintenance panels used on previous aircraft have their functions carried out by the CFDS. As a contrast, compare the several square feet of panel area needed on A310 and contemporary aircraft, scattered over the flight compartment and the front faces of various equipment populating the avionics racks (Fig. 1), with the few square inches of MCDU area used on A320 (Fig. 3). The resulting simplicity in operation also does away with the need for the mechanic to carry a small library of trouble-shooting guides in his pockets. These are replaced by one, simpler, manual.

CFDS System Architecture

Characteristics

The architecture used allows :

- Standardisation of the failure record of each LRU.
- Use of plain text on the controls and displays, for less line maintenance personnel training and better understanding by everybody.
- Use of a single type of MCDU in the cockpit to access the BITE of each connected system, replacing the maintenance panel.
- Simplification of equipment front faces (most of them are blank).
- Provision for outputs to a PRINTER [1] and to ACARS [2], for efficient transmission of the CFDS information to maintenance personnel at the airport of arrival or at the maintenance base.

These characteristics were developed in close cooperation with the industry, and are now industry standards [3].

Implementation

The architecture used is shown in Fig. 2. The two MCDU's and the printer are shared with other systems, such as FMS, ACARS and AIDS, and are located in the cockpit.
The CFDIU has partial redundancy, to enable fault diagnosis in the critical systems even after a single CFDIU fault.
The CFDS includes the BITE portions of the connected systems.

It is to be noted that similar systems, using similar architectures, are used on all the large commercial transports (both new and derivative) that are presently planned to enter service after A320.

Operational Interface

The CFDS is a system that aims at simplicity of operation, but does <u>not</u> require very rapid response. Consequently a menu-driven design has been used for the MCDU, using 12 line-keys to enable the mechanic to select the desired function. Where standard features are used, their line keys have standard locations. The functions of the other line keys depend on the needs of the individual application.

Ease of operation is facilitated by :

- Use of plain English, with standard abbreviations, rather than fault codes.
- Display of data enabling faults to be correlated with pilots' reports (GMT, flight number and phase, ECAM cautions/warnings as displayed to the flight crew etc.). (Figs. 5 and 6).

- Clear identification of the faulty LRU by name, part number and FIN, as appropriate.
- A single report (the POST FLIGHT REPORT) which has all the information that is usually needed. (Fig. 7).
- Availability of a permanent record of anything displayed on the MCDU, using the printer. (Fig. 5 etc).
- Fault classification.

  Three fault classes have been defined.

  Class 1 faults may affect the flight in progress, or dispatch for the next flight, and are immediately displayed to the flight crew on their normal caution/warning system.

  Class 2 faults do not affect the flight in progress or dispatch, but require timely rectification. These are normally displayed to the crew after touchdown, but may be called-up at any time, as required.

  Class 3 faults may be deferred until routine maintenance and are not normally displayed to the crew. They may also be called-up at any time.

- Automatic test at power-up of most units after an LRU replacement, with display of the units that did not test satisfactorily on the AVIONICS STATUS page. (Fig. 9).
- Use of the MCDU to carry out any manual testing needed using the SYSTEM REPORT/TEST page, avoiding having to enter the avionics bay. (Fig. 10, 11), and enabling other controls to be manipulated as required.
- Availability of fault data for the 63 previous flight legs (Fig. 8).

The above facilities are intended for use by the line mechanic. Access to internal fault environment data is available for use by engineering technicians on the aircraft, and for shop mechanics in the LRU repair workshop. This information is somewhat detailed, and is normally coded.

Federated CFDS

During early studies of the concept, federated and centralized CFDS's were envisaged. Federated systems rely on decision-making within the individual connected sub-system, and need little computing power in the central means of access. Central systems place the intelligence in the central means of access, and rely on sub-systems to do little more than send data.
The dividing line is somewhat broad, as can be imagined.

Experience on certain A310 systems with similar, but less widespread, features showed that major configuration control complexities could be expected from a centralized system, due to its sheer size and interdependence with connected sub-systems. These complexities were expected to inhibit development, both as regards improvements in the sub-systems themselves, and improvements in their CFDS features over the life of the aircraft.

A federated CFDS is used in the A320, with the Central Unit (the CFDIU) being little more than a message switching and storage centre.

ACARS Interface

The CFDS may be connected to an ACARS data link. Its connection enables the maintenance needs of the aircraft to be known in detail prior to arrival of the aircraft, and engineering assistance at outstations is eased since the operator's engineering specialists can see the same thing that the mechanic is seeing, if needed. At least one airline anticipates being able to obtain gains in maintenance productivity and regularity by having A320 CFDS data available throughout their network via ACARS.

Each airline has differing ACARS requirements, and as a result an industry standard installation has been developed for A320 (ARINC characteristic 724B) that enables each user to supply his own ACARS unit, editing and formatting CFDS and other information in accordance with his own needs. This standard is now also used on a number of other large commercial transports.

CFDS Developments

Further improvements in fault correlation, extension of the CFDS task to cover servicing needs and technological improvements are to be expected on future aircraft. Experience also shows that further standardisation in text displays is desirable. In a longer time-scale, the areas where BIT and BITE lack teeth will need to be addressed, such as the following.

- Performance-related faults are not amenable to machine detection at present. One of the problems is that technology now allows the designer to do more than in the past, with more complex (and less easily understandable) systems, and increased scope for design errors, or software bugs.
- Machine fault identification is not perfect (almost by definition), leading to many more unjustified removals than a system's fault detection probability would lead one to believe ! This is because the small number of mis-identified faulty units are each responsible for a large number of unjustified removals, as mechanics then have to resort to "shotgun" techniques to restore serviceability. One "difficult" fault can occasionally result in over a dozen removals of healthy equipment before the culprit is finally found.
- However good a fault identification system may be, as long as it is not perfect, there may be still be a chance of achieving an on-time departure by changing a readily accessible computer in the avionics compartment, whereas changing the "correct" LRU, if it is in a less accessible area will almost always result in a departure delay.

The avionics compartment being dry and temperate, may or may not have anything to do with the mechanics decision !

Conclusion

Centralized on board maintenance data processing brings the following main advantages :

- For the line mechanic :

Less training required and faster repairs because there are :

. No more inconsistency problems (the same control display unit is used for all electronic systems)

. Messages in plain English with standard abbreviations (no specialized documentation is required to use the CFDS and maintenance manuals are simplified).

. A reduction of the number of operations in the avionics bay since all electronic systems can be interrogated from the cockpit.

- For aircraft components :

. Allows blank front faces on electronic units.
. Avoids duplication of diagnosis in case of failure
. Improves MTBF/MTBUR ratio thanks to a more coherent maintenance philosophy.

- For dispatch regularity :

. Allows shorter duration of operations and so shorter times-to-repair, usually within the scheduled turn-around time.
This is further improved if CFDS is coupled to an ACARS system for in-flight real time failure transmission.

Acknowledgements

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Thanks are due to the many colleagues who provided information and assistance with this paper, particularly J.F. Desmoulins and F. Bachellerie.

References

(1) ARINC Equipment Characteristic 740 : Multiple Input Cockpit Printer.

(2) ARINC Equipment Characteristic 724B : Aircraft Communications and Reporting System (ACARS).

(3) ARINC Report 604 : Guidance for Design and Use of Built-In Test Equipment (BITE).

ACARS - Aircraft Communication and Addressing System (An air-ground data link).

AIDS - Aircraft Integrated Data System.

BIT - Built In Test.

BITE - Built In Test Equipment.

CFDIU - Central Fault Data Interface Unit.

CFDS - Central Fault Display System.

ECAM - Electronic Centralized Aircraft Monitor (includes the Master Warning System and other functions).

EFIS - Electronic Flight Instrument System.

EIS - Electronic Instrument System.

FIN - Functional Identification Number.

FMS - Flight Management System.

LRU - Line Replaceable Unit (or removable aircraft component).

MCDU - Multipurpose Control and Display Unit.

MTBF - Mean Time Between Failures.

MTBUR - Mean Time Between Unscheduled Removals.

TABLE 1 - GLOSSARY

	A300	A310/A300-600
Reliability (MTBF)	2710 HRS	4560 HRS
Average Shop Cost (Confirmed Removal)	3200	2300
Average Shop Cost (Unconfirmed Removal)	1200	400
Fault-finding effectiveness (MTBUR/MTBF) (Typical)	75 %	67 %

TABLE 2 - EFFECT OF INCREASING FUNCTIONALITY AND RELIABILITY ON ELECTRONICS MAINTENANCE

Air Conditioning

Pressurisation Systems
Air Conditioning System
Equipment Cooling System
Cargo Heating Systems.

Autopilot

Autoflight and
Flight Management Systems.

Communications

Cabin Intercommunication Data Systems
Audio Management System
Radio Management Panels
HF Systems
VHF Systems
ACARS.

Electrical Power

Main Electrical Generating System
Emergency Electrical Generating System
D.C. Power System.

Fire Protection

Engine Fire Detection Systems
APU Fire Detection Systems
Smoke Detector Systems.

Flight Controls

Electronic Flying Control Systems
Flap and Slat Systems.

Fuel

Fuel Quantity Indicating system.

Hydraulic Power

Reports via other systems.

Ice and Rain Protection

Window Heat Systems
Probe Heat Systems.

Indicating/Recording Systems

Flight Warning Systems
Electronic Instrument Systems
Flight Recorder System
Airborne Integrated Data System
Weight and Balance Systems
Printer.

Landing Gear

Landing Gear Control Systems
Brake and Steering Control Systems
Tyre Pressure Indicating System.

Navigation

Air Data Systems
Inertial Reference Systems
ILS's
VOR's
DME's
ATC Transponders
MLS's
Radio Altimeters
Weather Radars
ADF's
Head Up Display.

Pneumatic

Bleed Control Systems.

Water/Waste

Toilet System.

Airborne Auxiliary Power

Auxiliary Power Unit.

Engines

Engine Control Systems
Engine Vibration Monitor.

Note : Directly connected systems only listed. One, two or several sub-systems are connected as appropriate. Not all LRU's within a sub-system are directly connected to the CFDS - typically, one L.R.U. reports for several others.

TABLE 3 - CFDS USER SYSTEMS

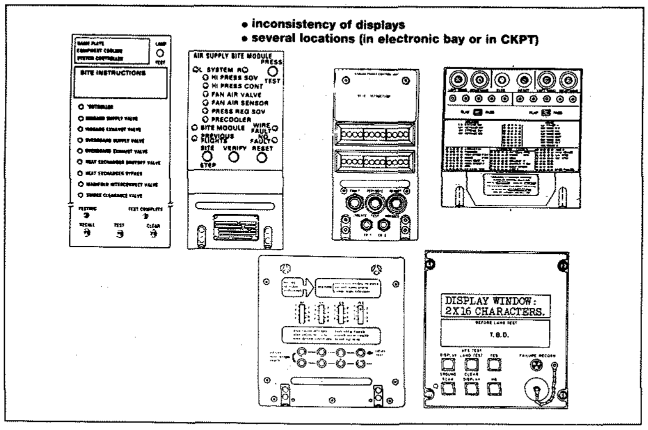

Figure 1. BITE Controls and Displays (1983)

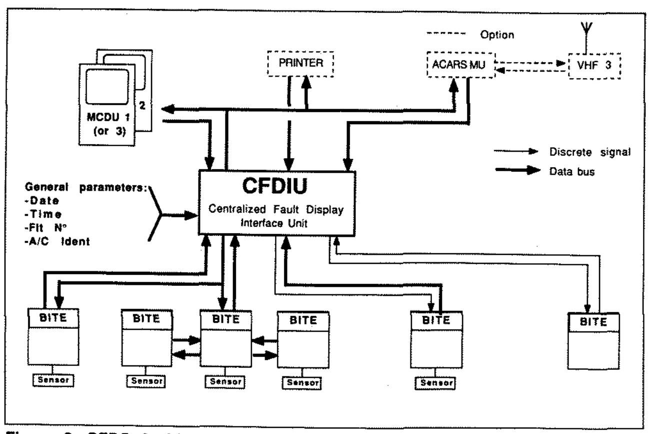

Figure 2. CFDS Architecture

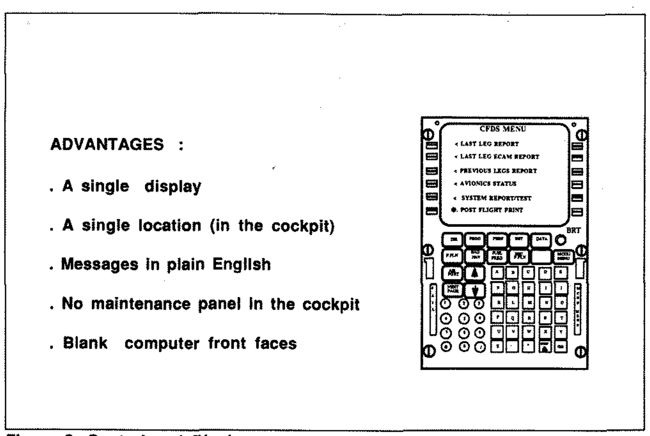

Figure 3. Control and Display

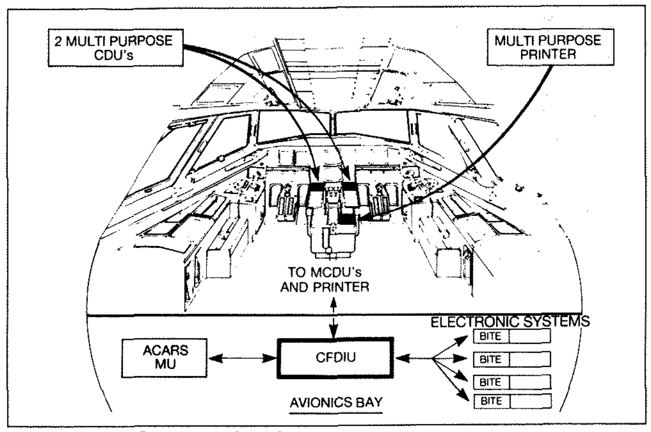

Figure 4. CFDS Component Location

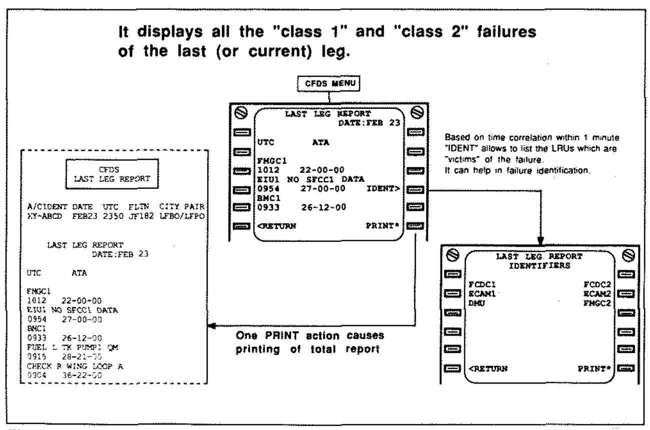

Figure 5. Last / Current Leg Report

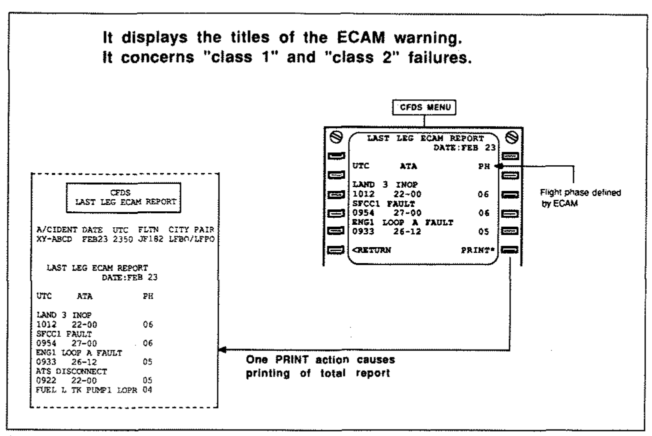

Figure 6. Last / Current Leg ECAM Report

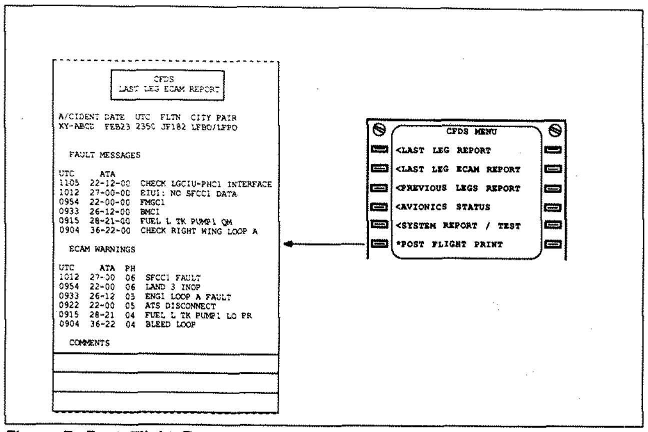

Figure 7. Post Flight Report

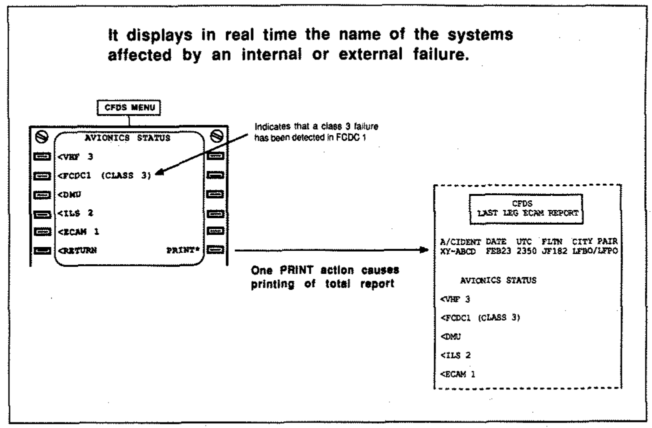

Figure 9. Avionics Status Facility

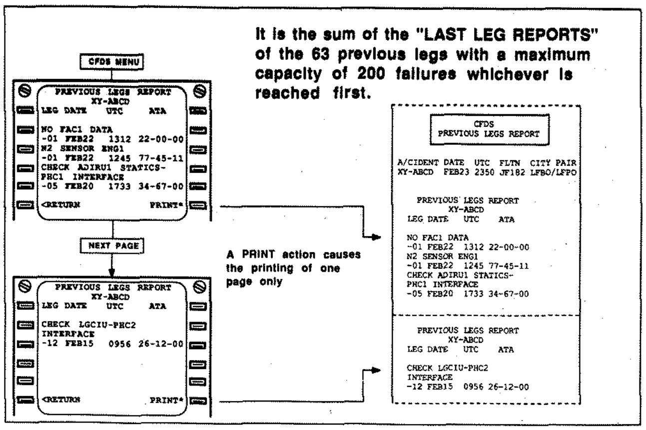

Figure 8. Previous Legs Report

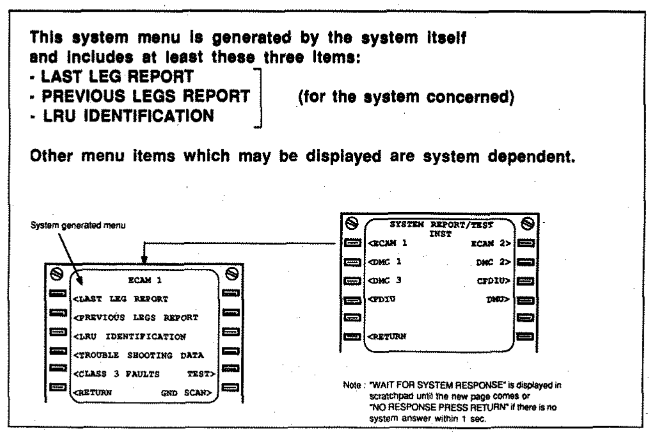

Figure 10. System Report / Test (1)

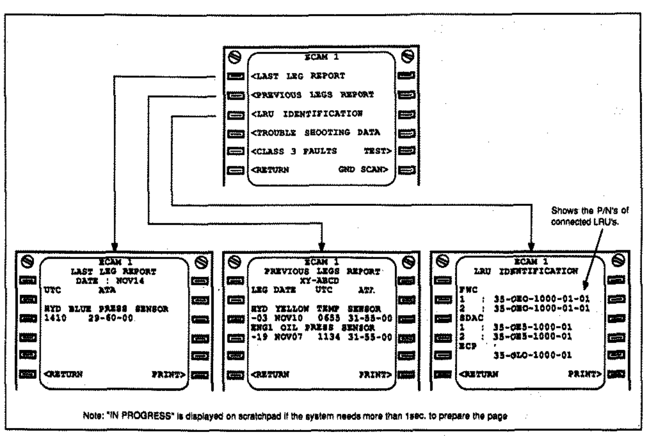

Figure 11. System Report / Test (2)