



# AEROSPACE INFORMATION REPORT

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Superseding AIR1266A

## Fault Isolation in Environmental Control Systems of Commercial Transports

### RATIONALE

This revision updates the text to reflect advances in technology for fault isolation. In addition, the referenced document section is updated for document availability and applicability. Several minor corrections to grammar, terminology, and document structure are also incorporated.

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## 1. SCOPE

This SAE Aerospace Information Report (AIR) outlines concepts for the design and use of fault isolation equipment that have general application. The specific focus is on fault isolation of environmental control systems (ECS) in commercial transports. Presented are general fault isolation purposes, design principles, and demonstration of compliance criteria. These are followed by three design examples to aid in understanding the design principles. Future trends in built-in-test-equipment (BITE) design are discussed, some of which represent concepts already being implemented on new equipment.

### 1.1 Purpose

This AIR provides a practical guide for the design and use of fault isolation systems for the ECS in commercial transports.

Airframe or system manufacturers may use this AIR for guidance in developing practical, efficient, and workable ECS fault isolation equipment. Equipment suppliers may use this AIR for guidance concerning their role with airframe manufacturers in the development and with the operators in the use of effective ECS fault isolation equipment. Operators may use this document to write future ECS fault isolation specifications against which the performance of the delivered system can be measured quantitatively. They may also obtain guidance for making more effective use of existing systems.

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

#### 2.1.1 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401-7435, Tel: 410-266-4000, [www.arinc.com](http://www.arinc.com).

ARINC Report 604-1 Guidance for Design and Use of Built-In-Test-Equipment, September 30, 1988

ARINC Report 624-1 Design Guidance For Onboard Maintenance System-1991; Includes Supplement 1, August 30, 1993

ARINC Report 429 Digital Information Transfer System (DITS)

### 2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

#### 2.2.1 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401-7435, Tel: 410-266-4000, [www.arinc.com](http://www.arinc.com).

ARINC Report 612 BITE Glossary, December 18, 1986

#### 2.2.2 Other Publications

AiResearch Manufacturing Company, "Environmental Control Systems Fault Isolation." Report 707022, 1970, Los Angeles, California.

Curtis, G. C., and Elgin, C. F., "The MAC MADAR System: An AIDS Model for Commercial Airlines." Paper 710425 presented at SAE National Air Transportation Meeting, Atlanta, May 1971.

Douglas Aircraft Company, "Description of ARINC 624 Onboard Maintenance System," August 22, 1990

Douglas Aircraft Company, "DC10 Fault Isolation." Douglas Service, November 1970.

Douglas Aircraft Company, "Fault Isolation Analysis (FIA)." Report DAC67297B, June 1969.

Douglas Aircraft Company, Flight Development Group, "Finding Faults with FEFI." DC Flight Approach, Second Quarter 1970.

Hamilton Standard, "Hamilton Standard Guidelines for Airborne Integrated Data Systems," Report HSPC 70E20, 1970.

Hawkins, Capt. F. H. and Vermeulen, H. C., "Aircraft Integrated Data Systems a Review of Their History and Current Status." Shell Aviation News, No. 4011971.

## 2.3 Definitions

**AIRCRAFT INTEGRATED DATA SYSTEM (AIDS):** A term (adopted by ARINC) in general use for airborne recording systems that include acquisition and signal conditioning.

**AUXILIARY POWER UNIT (APU):** An on-aircraft unit, usually a gas turbine, that supplies an auxiliary air source for the ECS and auxiliary electrical power generation.

**AUTOMATIC TEST EQUIPMENT (ATE):** General purpose, usually computerized test equipment that when connected to the unit under test through the necessary interface, automatically performs acceptance testing.

**BUILT-IN-TEST (BIT):** Tests performed by the system upon itself for the purpose of detecting faults, annunciating fault conditions, isolating faults, and possibly taking corrective action.

**BUILT-IN-TEST-EQUIPMENT (BITE):** That part of a system, usually sensors, electronics, and display, that are used as a tool to supplement maintenance procedures for isolating system faults.

**CENTRALIZED FAULT DISPLAY INTERFACE UNIT (CFDIU):** A unit (part of the CFDS described by ARINC 604) which interfaces aircraft operational subsystems to the display unit (CFDU).

**CENTRALIZED FAULT DISPLAY SYSTEM (CFDS):** A system described by ARINC 604 that uses a centralized fault command/display terminal to retrieve and display subsystem produced BITE display data.

**CENTRALIZED FAULT DISPLAY UNIT (CFDU):** A unit (part of the CFDS described by ARINC 604) which provides the actual display interface for the maintenance crew.

**ELECTRICALLY ALTERABLE READ-ONLY MEMORY (EAROM):** Nonvolatile computer memory devices whose memory content can only be changed by application of an electrical signal.

**ELECTROMAGNETIC INTERFERENCE (EMI):** Electromagnetic phenomena which, either directly or indirectly, can contribute to a degradation in performance of an electronic receiver or system.

**ENVIRONMENTAL CONTROL SYSTEM (ECS):** That aircraft equipment responsible for maintaining proper cabin ventilation airflow, temperature, and pressure. It usually comprises engine air source control; air conditioning packs and their control; cabin inflow, ventilation, and temperature control; and cabin pressure control. It sometimes includes avionics, cargo, and galley ventilation and temperature control.

**FAILURE MODE AND EFFECT ANALYSIS (FMEA):** An analysis of a particular design for describing, as a minimum, the most probable ways an equipment can fail and the consequences of such failure.

**FAULT ISOLATION:** The process and actions, following equipment failure, that are involved in the identification of the unit, assembly, or piece part that has failed.

**FAULT ISOLATION ANALYSIS (FIA):** A systematic evaluation of failure causes, indications and probabilities to determine the level of Fault Isolability provided for in the system design.

**GROUND SUPPORT EQUIPMENT (GSE):** As used in this report, it is ground-based equipment not carried on-board the aircraft that is used to inspect, test, or troubleshoot aircraft equipment.

**LINE REPLACEABLE UNIT (LRU):** A component or assembly of components that by design, is packaged to be removed and replaced as a single item.

**MEAN-TIME-BETWEEN-FAILURES (MTBF):** A measure of actual hardware reliability, determined by summing operating time on all units and dividing by the number of confirmed failures.

**MEAN-TIME-BETWEEN-UNSCHEDULED-REMOVALS (MTBUR):** A measure of apparent hardware reliability or actual operational reliability, determined by summing operational flight time on all units and dividing by the number of unscheduled and unplanned unit removals, regardless of cause.

**MINIMUM EQUIPMENT LIST (MEL):** Refers to the minimum aircraft system hardware that must be operational prior to safe aircraft dispatch. Appropriate procedural limitations may be enacted to account for inoperative equipment to maintain safe, airworthy operation.

**ON-BOARD MAINTENANCE SYSTEM (OMS):** A system described by ARINC 624 that provides a centralized location on the aircraft for electronically furnishing all the aircraft maintenance information.

**RANDOM ACCESS MEMORY (RAM):** Volatile computer memory devices whose read/write memory content is only active while electrical power is applied.

**READ-ONLY MEMORY (ROM):** Nonvolatile computer memory devices whose contents can only be read, not written in normal operation. The memory contents remain intact with or without power applied.

**ROOT SUM OF SQUARES (RSS):** A calculation of the square root of the summation of the squares of individual variables or constants. In this report it is used to determine practical system-level tolerances composed of more than three component tolerances.

### 3. GENERAL FAULT ISOLATION INFORMATION

This section first discusses the purpose of ECS fault isolation. The design of an effective fault isolation system is then discussed followed by criteria for demonstrating compliance to fault isolation specification requirements.

#### 3.1 Purpose of ECS Fault Isolation

The primary purpose of fault isolation is to minimize the total cost of aircraft maintenance by reducing flight delays, out-of-service incidents, and spares requirements.

Commercial jet transports represent a large investment both to the airlines and airframe manufacturers. The airlines have a high investment in direct costs of the aircraft and in costs of flight delays due to the large number of passengers carried per aircraft. The airframe manufacturers (and their subcontractors) have a large investment in guarantees on unscheduled removals of components from the aircraft in service. To ensure safety of flight and to protect these investments, it is important that the flight and ground crews be able to identify an improperly operating aircraft system and that ground crews can isolate and correct the malfunctioning component(s) as quickly as possible with a high level of confidence. To reduce flight crew workload, fast and accurate identification of faults in primary systems is required so that appropriate crew alerts can be provided and backup system(s), either automatic or manual, can be employed with a minimum of flight crew effort. This requirement to minimize crew workload has special importance for two-man crew operations.

A systematic method of fault isolation is required to assure the needed speed and accuracy of fault identification. Historical problems have produced the need for fault isolation methods and equipment on-board the aircraft that operates quickly, accurately, and requires the minimum of maintenance crew training.

##### 3.1.1 Historical Problems

Historical discussion of past fault identification problems is necessary to better recognize the need for accurate, reliable, and readily available fault isolation procedures and equipment.

Historically, the major problem areas aggravating the high cost of aircraft maintenance are:

- a. Excessive time to properly isolate system faults
- b. Excessive unscheduled removal of line replaceable units (LRUs) which are not faulty
- c. Excessive time required to remove many LRUs

#### 3.1.1.1 Excessive Time to Properly Isolate System Faults

Excessive times to properly isolate faulty components are caused by several factors in the absence of effective onboard fault isolation equipment:

- a. Inexperienced ground crew
- b. Ground support equipment (GSE) to aid the ground crew not available
- c. GSE not functioning properly
- d. Ground crew unfamiliar with GSE operation (takes too long to set up and operate)
- e. Maintenance manuals (publication software) not readily accessible
- f. Maintenance publications incomplete, unwieldy, or out of date

#### 3.1.1.2 Excessive Unscheduled Removal of Line Replaceable Units (LRUs) Which Are Not Faulty

Ease of LRU removal can contribute to increased erroneous LRU removal rates. The erroneous removal rates of refrigeration units which are physically large is typically low because sufficient troubleshooting time has to be spent to ensure that the unit being pulled is actually faulty. Electronic units such as the cabin temperature or auxiliary power unit (APU) controller are relatively easy to remove. Almost any cabin temperature or APU problem is, therefore, likely to be treated first by replacing the controller. For aircraft without fault isolation systems, this easy accessibility contributes to high erroneous removal rates.

#### 3.1.1.3 Excessive Time Required to Remove Many LRUs

Excessive time to remove the faulty component involves accessibility and removal ease of each LRU. Historically, these factors have seldom received adequate consideration in the overall system design. Difficulty in reaching and replacing certain LRUs has resulted in delays or, more frequently, unduly long down time. Positive, accurate fault isolation of these hard-to-replace components is required so that time consuming replacements are not made in error. Although they have a secondary impact on fault isolation, the subjects of accessibility and removability will not be discussed in further detail.

### 3.1.2 Impact of Fault Isolation

Fault isolation has an impact on aircraft dispatchability and maintainability as well as airline spares provisioning.

#### 3.1.2.1 Dispatchability

Dispatchability or dispatch reliability of aircraft is very important for the airlines operating on a regularly scheduled basis. Dispatch delays of any aircraft with a load of passengers can be very expensive if rescheduling of other aircraft is involved.

Good dispatch reliability requires the proper fault isolation of malfunctioning equipment as well as proper design of backup systems that can be readily employed.

#### 3.1.2.2 Maintainability

Maintainability is a subject covering the effectiveness of properly identifying faulty LRUs, readily replacing those units, and of being able to repair or overhaul the faulty units and return them to service. The scope of this report limits itself to properly identifying in order to properly replace faulty LRUs.

### 3.1.2.3 Spares Provisioning

Costly unnecessary spares requirements at many terminals result from high erroneous removal rates. If units that are not actually faulty are removed, often due to "shotgun" fault isolation techniques (randomly replacing units), costly additional spares must be maintained by the airlines to replace the removed units.

### 3.1.3 Purpose of Fault Isolation Equipment

The purpose of fault isolation equipment (hardware, electronic software, and publication manuals) is to minimize the historical problems discussed above and, thereby, reduce the total maintenance cost and increase the dispatch reliability. This is accomplished by reducing delays and costly airplane out-of-service incidents, by providing faster and more accurate means to isolate faulty LRUs to increase mean time between unscheduled removal (MTBUR) performance, and by reducing spares and GSE requirements. A secondary purpose is to properly identify faulty subsystems or LRUs inflight so that backup subsystems can be employed automatically or by the flight crew. This is a result of LRU fault isolation functions and will only be discussed in general in this report.

## 3.2 Fault Isolation System Design

A "fault isolation system" may be defined as the total process necessary to identify faulty LRUs. The finished product includes all the hardware and software necessary to meet this objective.

This process is applied to a functional system of the aircraft. All interrelated components are a part of the functional system and must be considered. For example, a cabin pressurization system is a single system from the circuit breaker(s) to the outflow valve. It includes all flight deck indicators that provide status information and ground shift or mode change hardware, i.e., relays, switches, mechanical levers/cables, along with the primary LRUs - controllers, valves, motors, and control panels.

The principle of fault isolation design is that for every failure mode of a particular LRU there is an abnormal characteristic which can be detected, indicated, and isolated from other failures. Certain failure modes may be passive by not exhibiting functional degradation at certain conditions, but all are detectable by some means at some conditions. Measurable fault isolation goals must be specified at the beginning of the design process. The design process includes understanding the design principles, then performing the necessary tradeoffs and analysis. Practical tolerance limits must be set considering the hardware requirements and the interfaces to other systems.

### 3.2.1 Fault Isolation Design Principles

The ultimate purpose of fault isolation systems may be achieved by cooperative effort between the airline operators, airframe manufacturers and the system or LRU suppliers. Practical design requirements and objectives must be initially determined that include certain principles to be followed during the conception and the implementation of the ECS and fault isolation system design. Among these are:

- a. Measurable goals should be established before the beginning of design. They are valuable first, to verify the validity of the maintenance requirements, and second, to demonstrate the benefits that result from meeting those requirements.

For example, three goals utilized in a recent design were:

1. The fault isolation system and LRU remove/replace design must enable identification and replacement of aircraft dispatch critical components during the minimum turn-around time at the gate, 35 minutes or less. This must be accomplished to prevent a subsequent aircraft dispatch delay time of greater than 15 minutes.
2. The fault isolation system must allow identification of the faulty component in 10 minutes with 95% accuracy, using little or no GSE for test.
3. Another measurable goal that has been utilized is to minimize the BITE hardware added by planning to use only the sensors required for system control or crew indication. Adding unnecessary sensing only for BIT reduces the overall system reliability. In this example, no sensing is added to achieve a goal of fault isolation to one LRU with 90% accuracy, isolation to either of two LRUs with 95% accuracy, or isolation to any of three LRUs with 100% accuracy.

- b. Consideration of fault isolation must be given importance throughout all stages of the design of an ECS from the conceptual to the final design and testing phases. In particular, fault analysis techniques must be considered during preliminary design so that:
  - 1. Predominant failures are to a failsafe operation mode.
  - 2. Means for detection and isolation of all predominant failure modes are provided.

These analyses must consider both steady-state operational tolerances and normal/abnormal system dynamic responses (including electrical system transients) to prevent nuisance fault messages.

- c. Means must be provided throughout the functional system design and service introduction whereby it can be examined as a complete whole, including its maintenance and operating environment in scheduled service. In some cases, this may mean a fault isolation and maintainability demonstration for compliance with specified goals be performed prior to introduction into service, followed by in-service analysis of equipment, procedures, and maintenance crew performance.
- d. As much as possible, the system should provide fault isolation without engine operation and with minimum APU operation. This implies electrical checkout only or utilizing memory recording of electrical, mechanical, and pneumatic faults that occur in flight.
- e. Throughout the design the airframe manufacturer and the equipment suppliers must weigh the economic benefits and penalties of their particular system against the overall purpose of a fault isolation system.

### 3.2.2 Total System Tradeoff Analysis

One of the first steps when designing an ECS with effective fault isolation is properly defining the system requirements (overly severe requirements result in overly complex systems with poor effectiveness). This can be done by determining:

- a. The primary operational requirements of the ECS (cooling criteria, heating criteria, flow, and pressure criteria, etc.)
- b. The design boundaries (operating envelope and acceptable operational tolerances)
- c. The secondary system requirements, i.e.,
  - 1. System and LRU MTBUR and MTBF guarantees

$$\text{Fault isolation accuracy \%} = \frac{\text{MTBUR}}{\text{MTBF}} \times 100 \quad (\text{Eq. 1})$$

- 2. Likelihood and acceptability of:
  - (a) Flight squawks which the ground crew is unable to duplicate
  - (b) Intermittent type faults (un-annunciated intermittent faults are generally not acceptable and must be minimized)
- 3. Time limitations for fault isolation, turnaround time guarantees (this includes time to fault isolate, remove, and replace LRUs)
- 4. AIDS provisions, central fault display system (CFDS) provisions, on-board maintenance system (OMS) provisions, or other system status indication requirements

NOTE: AIDS is a term adopted by Aeronautical Radio, Inc. (ARINC) in general use for airborne recording systems that include acquisition and signal conditioning. CFDS and OMS are terms (adopted by ARINC) that refer to centralized computer retrieval and display of maintenance data and BIT results from the aircraft subsystems.

5. Special installation environmental conditions that affect the fault isolation design (location, access, temperature)
6. Maintenance training level or skills in scheduled service (in general the design must be adequate for the least qualified maintenance personnel)

### 3.2.2.1 Available Concepts

Methods of fault isolation include:

- a. Manual BIT (commonly called self-test) - is usually one or a combination of switches, magnetic latching indicators, lights, and meters used by ground crews in performing tests on the system to identify which LRU has failed. One of the advantages of using manual self-test is that those minor faults are ignored which have insignificant effect on system operating performance. This is based on the philosophy that the only time manual BIT is used is when the pilot has written a squawk and maintenance personnel are attempting to determine what LRU to replace to correct the squawk. It may also be used to test the system after maintenance has been performed to verify corrective action. This technique is generally used with relatively simple systems.
- b. Automatic BIT - there are basically two methods of implementation:
  1. Fully Automatic: A test is performed continuously or periodically or initiated by an event (e.g. upon weight on wheels at landing) when the aircraft system is operating with no personnel involvement required. This approach normally includes "memory" of status information that is retained when electrical power is removed from the system. The most elaborate form of these systems uses microprocessor-digital controllers and data bus communication (per requirements such as ARINC 429) both for receipt of data from the aircraft and for communication with a CFDS or OMS. Failure isolation data may be retrieved by the ground team on the system electronic controller face, and/or at a centralized maintenance panel which communicates with the system controller(s), or at a ground station which receives fault isolation data from the aircraft systems by means of wireless communication, or with the system components directly.
  2. Automatic Test Manually Initiated: Requires manual start by maintenance personnel of automatic test (usually pushing a button). Tests will be done automatically that may cause actual system functions to be exercised to check operation. A "go" or "no-go" status indication will give results of the test and what LRU is at fault if "no-go" This test can also be used for verification of proper connection and operation of replacement LRUs and for flight readiness testing.

Many systems and/or LRUs use a combination of automatic BIT noted.

- c. Tests Using GSE - GSE should be considered as a last resort for troubleshooting. For GSE to be effective it must be available at every airport where flight squawks may have to be corrected. This becomes costly. For example, an airline fleet may travel into 60 airports where maintenance can occur. All 60 airports must stock that particular piece of GSE. In addition to the cost of purchasing 60 units of GSE, the cost for transportation and periodic calibration or certification would have to be considered, plus cost of replacement parts, stocking, and training of maintenance personnel in the use of particular GSE units.

Some forms of GSE are practical for checking those mechanical or pneumatic units (heat exchangers, air cycle machines, pneumatic valves) that are not cost effectively checked by BIT. These include special equipment to test the system performance while it is operating under controlled conditions on the ground. These tests are most practically performed during regularly scheduled aircraft maintenance checks.

When GSE is used, it should be:

1. Very reliable.
  2. Simple to operate, not requiring special training.
  3. Built with instructions in placard form on the unit, written in a language the average technician or mechanic can understand.
  4. Thoroughly tested in its working environment to assure that it will do the intended job in airline turnaround and through-flight environment.
  5. Cost-effective - A well designed GSE unit can be used in many different fault isolation roles and many different systems. One of the most common and effective (although usually not considered GSE) is the electricians' portable multimeter that measures voltage, current, and resistance in a variety of ranges.
  6. Compact and portable, not requiring electrical or pneumatic power. If electrical power is required on the airplane, it should obtain the power from either batteries built into the GSE or use standard aircraft power.
- d. Publication Methods - On some simple or highly reliable systems, BITE cannot be justified, as was the case on early environmental systems. One method of providing fault isolation on such systems is by utilizing a software logic program in a maintenance manual publication. To be effective, the software program design should be managed by the aircraft manufacturer who has the greatest interface with the LRU suppliers and the airline and can best integrate all inputs.

There are many software logic publication concepts available. Various aircraft manufacturers have developed individual programs that are similar. Usually there are two manuals involved (see Example, Figures 1, 2, and 3). One manual is used by the flight crew (Figure 1) and one manual is used by maintenance personnel (Figures 2 and 3) for through or turnaround maintenance. The manual for the flight crew shows normal system indications and tolerances. It also shows various abnormal indications and each abnormal indication is given a code number.

When a system abnormality (commonly referred to as a flight squawk) occurs the flight crew member enters a code number in the airplane logbook instead of some abbreviated description, such as, "Flight Compartment Temp Control Inop in Auto." The appropriate fault code is selected from the flight crew manual. The fault code number represents a complete and accurate description of what was actually observed. For example, fault code 2160E1 describes the following condition: cockpit temperature control inoperative in auto, OK in manual; all circuit breakers OK; valve position indicator, hot; duct temperature, high; compartment temperature, high; all abnormal lights, off; trim air switch, on. The flight crew would then radio the code number to the next maintenance station where the maintenance personnel have a similar book, but which contains additional information. For a given code number it will indicate what checks are to be done rapidly to isolate to a given LRU. The checks are usually given in detail with pictures showing location and necessary part numbers. From an airline standpoint, the software logic publication is the nucleus for all system fault isolation because of the following advantages:

1. Eliminates vague flight squawks written by flight crew.
2. Provides an efficient way of transferring information of flight squawks to maintenance personnel before aircraft arrival thereby giving maintenance personnel adequate time to obtain replacement parts and review fault isolation procedures.
3. Provides maintenance personnel with one manual for the entire airplane for fault isolation.
4. Provides a convenient, economical, centralized method for updating, improving, and correcting flight squawk reporting and maintenance fault isolation procedures.

## AIR CONDITIONING TEMPERATURE CONTROL

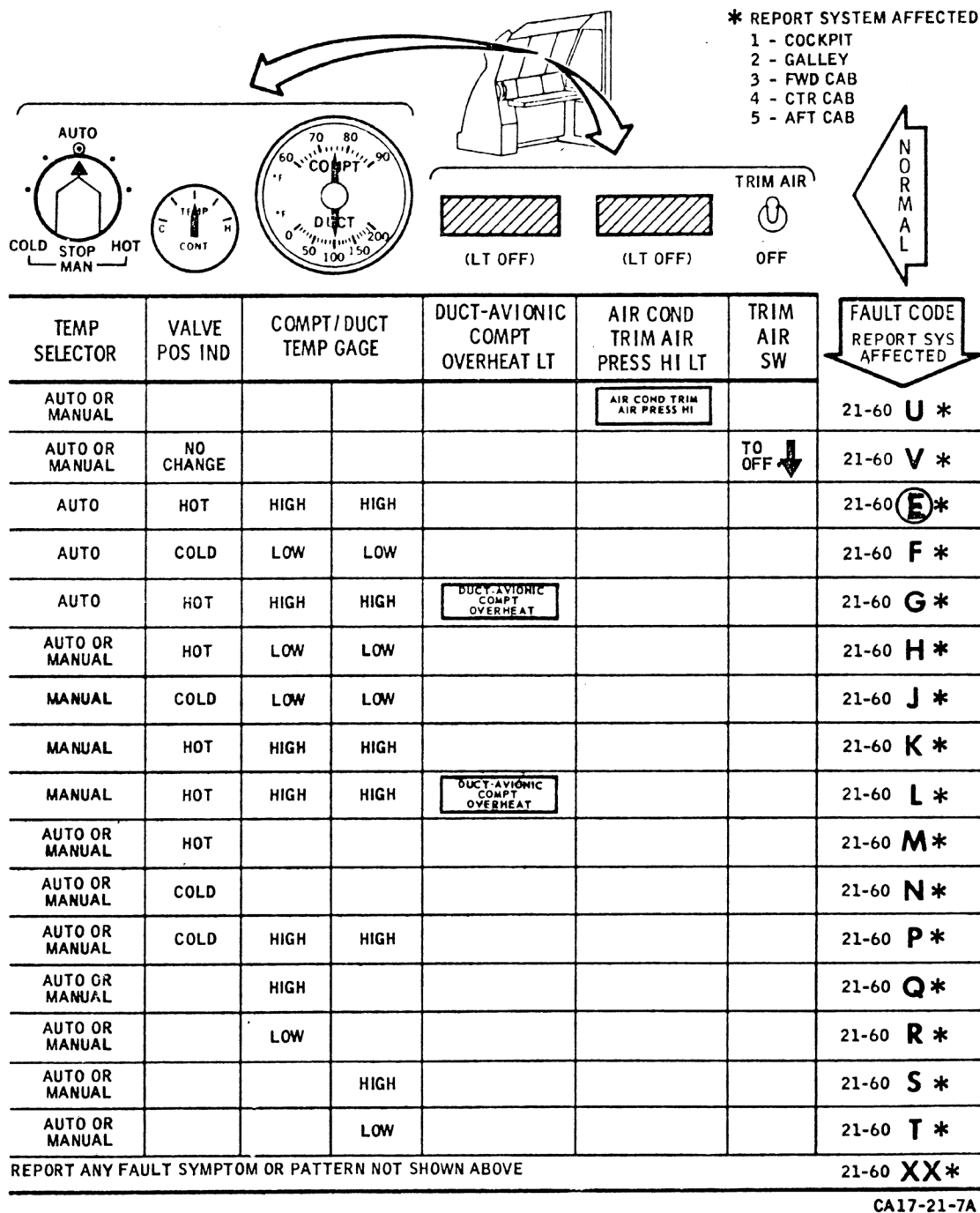


**Figure 1 - Flight fault isolation  
air conditioning temperature control**

## TURN AROUND FAULT ISOLATION (AIR CONDITIONING) TEMPERATURE CONTROL

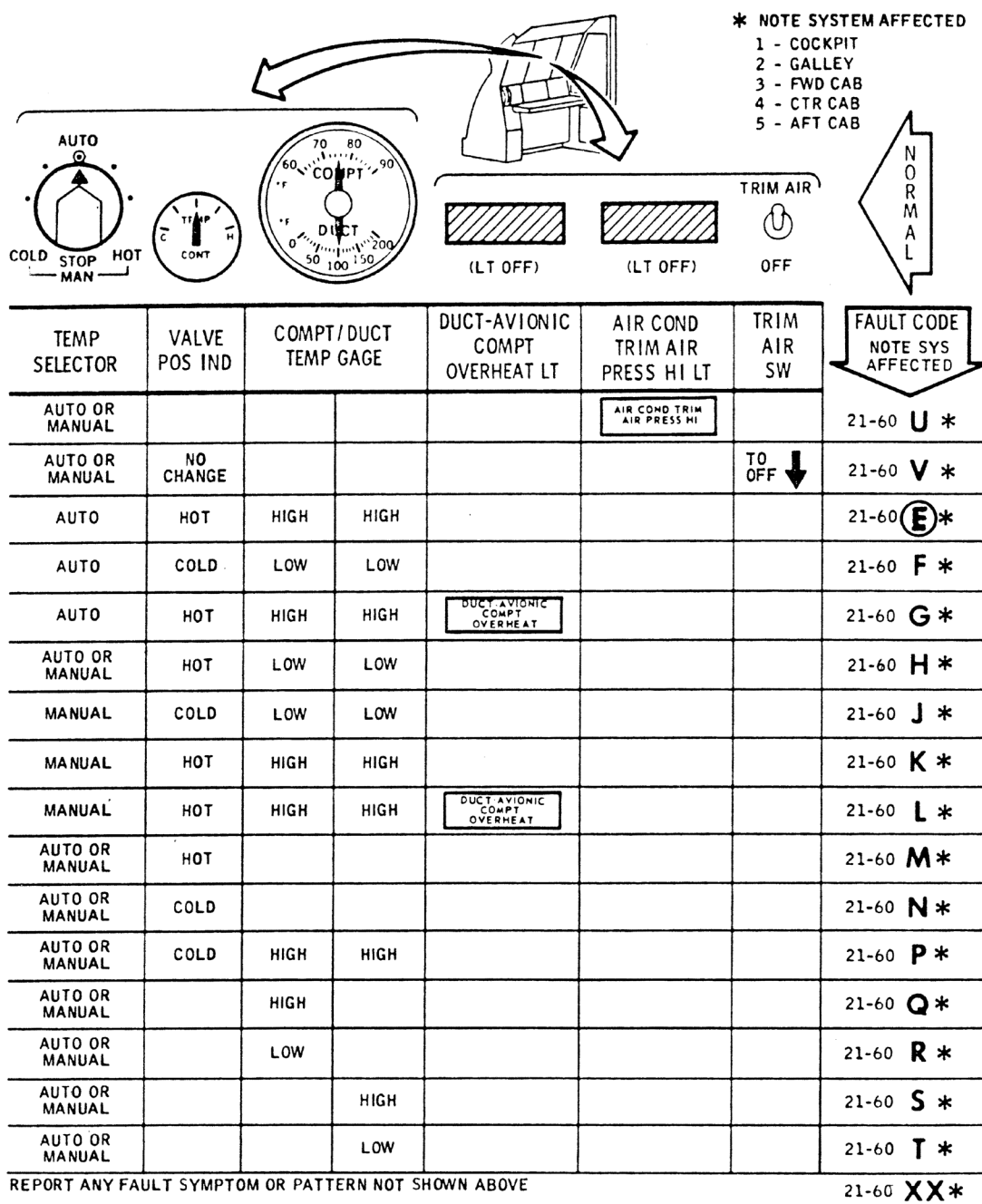


**Figure 2 - Turnaround fault isolation  
air conditioning temperature control**

## TURN AROUND FAULT ISOLATION (AIR CONDITIONING) TEMPERATURE CONTROL

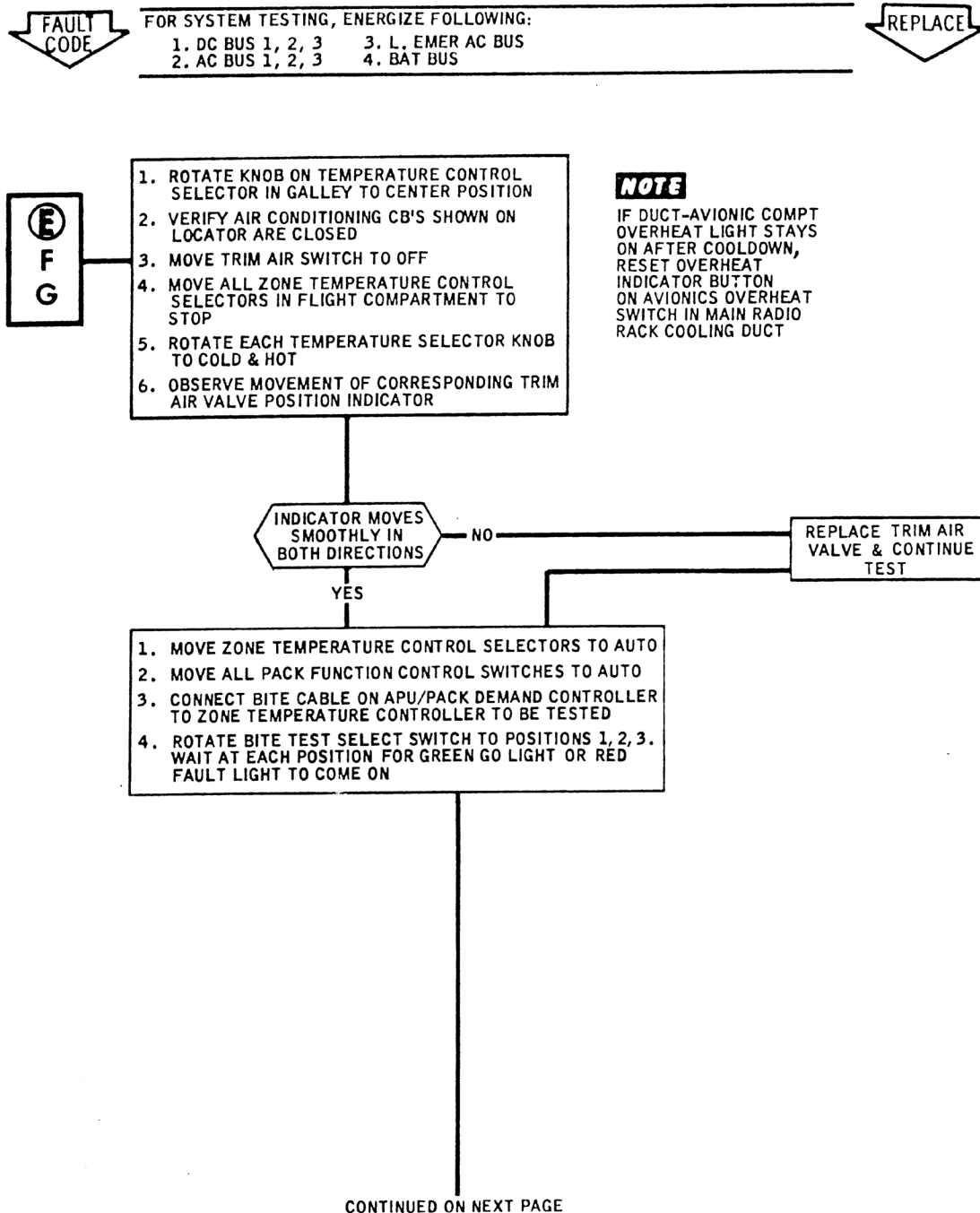


**Figure 3 - TAFI fault tree  
air conditioning temperature control**

## TURN AROUND FAULT ISOLATION (AIR CONDITIONING) TEMPERATURE CONTROL

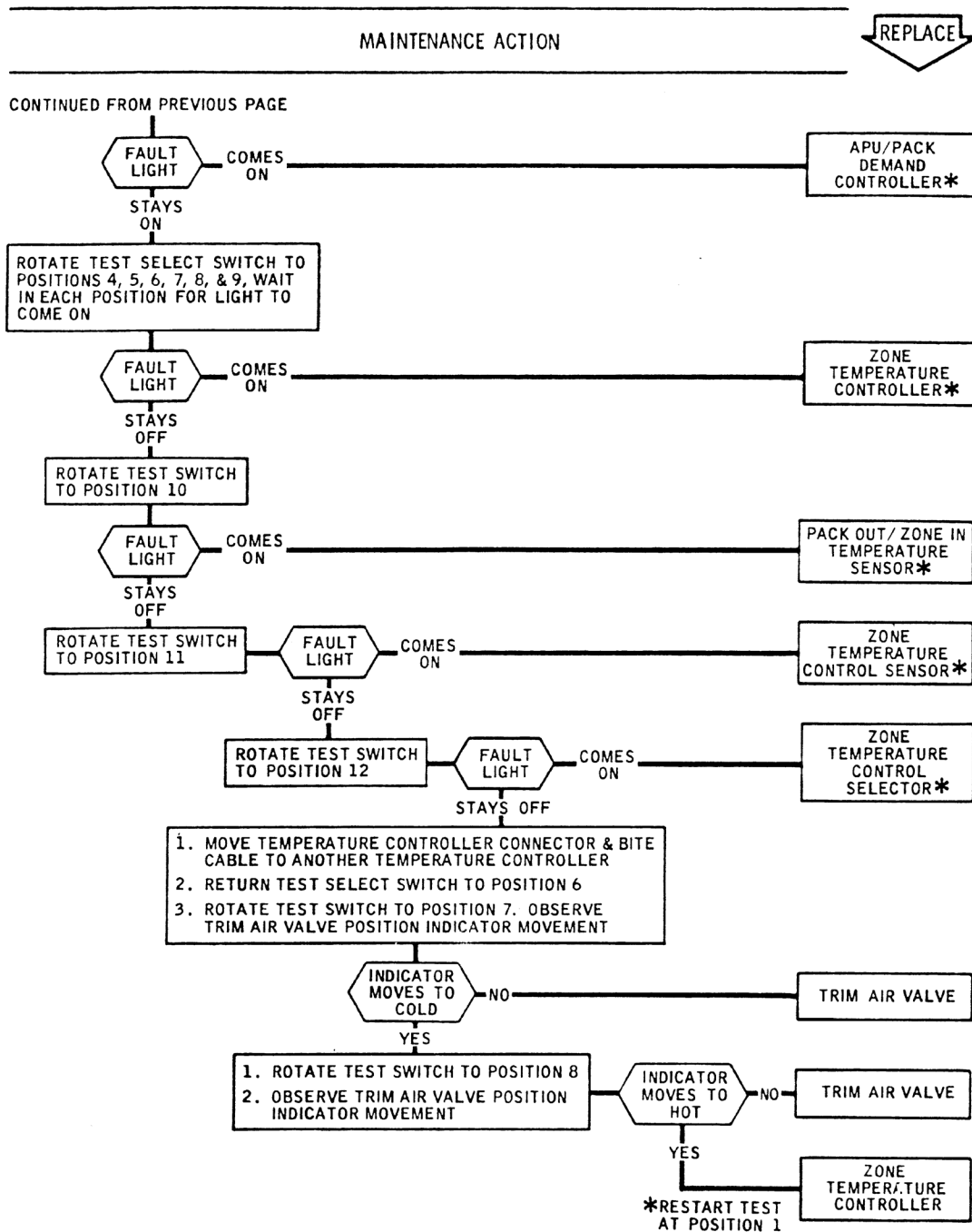


**Figure 3 - TAFI fault tree  
air conditioning temperature control (continued)**