

AEROSPACE INFORMATION REPORT

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Methodology for Investigation of Flight Control System Anomalies

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1. SCOPE:

This SAE Aerospace Information Report (AIR) outlines comprehensive aircraft flight control system fault isolation methodology that has proven to be effective. The methodology presented in this Information Report has been used in several successful fault isolation efforts on military aircraft.

1.1 Purpose:

The purpose of this Information Report is to provide trouble shooting methodology to use for chronic problems that procedures contained in troubleshooting manuals or fault trees fail to fix. This shortcoming may have been due to multiple causal factors or design issues that were not realized by component or airframe manufacturers when the troubleshooting manuals were written.

1.2 Field of Application:

This report is written with military aircraft flight control system fault isolation in mind but the principles presented are equally applicable to other aircraft systems.

2. REFERENCES:

2.1 Applicable Documents:

There are no referenced publications specified herein.

2.2 Definitions:

ACCEPTANCE TEST PROCEDURE: A set of tests performed on every component that provides a level of confidence that the production process has not contained any event that could result in the component not meeting its design requirements.

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

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.

2.2 (Continued):

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

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.

FAILURE MODE, EFFECT AND CRITICALITY ANALYSIS (FMECA): 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 on the system of which it is a part and the vehicle.

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.

FOREIGN OBJECT DEBRIS (FOD): Substances that have entered an aircraft or aircraft system that are not intended to be present.

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.

IRON BIRD: Any aircraft systems integration and test facility.

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 REMOVAL (MTBR): 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.

3. GENERAL FAULT ISOLATION METHODOLOGY:

Figure 1 illustrates six processes that need to be performed to conduct an effective anomaly investigation. Each of these processes, in turn, require actions to gather information to support the decisions executed during the process. In each of the figures that illustrate a process, the number of the corresponding paragraph within this document that describes the process or action is referenced in the lower right hand corner of the process box or at the bottom of the decision box.

3.1 System Failure Definition (Figure 2):

3.1.1 Proper System Operation Understanding: In order to determine whether or not a system has malfunctioned, a thorough understanding of proper system operation and its failure modes is necessary. This understanding can be gained through the following:

a. Published Reference Material:

- (1) System Schematics and Wiring Diagrams: Schematics and wiring diagrams aid fault isolation because they depict functional relationships of the system components to one another and the system's functionality to the aircraft.
- (2) Engineering drawings: The engineering drawings will provide troubleshooting personnel with depictions of the correct installation and configuration of systems and their components.
- (3) System Failure Mode, Effects Analyses (FMEAs)/Failure Mode, Effects and Criticality Analyses (FMECAs): These analyses give troubleshooters insight into the cause and effects of known failure modes.
- (4) Maintenance and Troubleshooting Manuals: These manuals provide the proper troubleshooting methodology that is specific to systems and their known failure modes. Use of these tools is an important initial step in any troubleshooting process
- (5) System Operating Descriptions: System Operating Descriptions are useful because these publications describe, in words, the proper operation of a system.
- (6) System Safety Analysis: System Functional Hazard Analysis (FHA) and System Fault Tree Analysis (FTA)
- (7) Original Prime Contractor Reports of Iron Bird Tests and Flight Certification Test Results

b. Computational resources: Resources such as system models can further aid the trouble shooting effort by providing real time analysis tools.

3.1.1 (Continued):

- c. Flight Simulation: Flight simulators including iron birds can duplicate complex operating parameters and system behavior to determine whether crew action and system operation were proper.
- d. The Knowledge of Experts: Gaining the insight of experts such as design and software engineers, manufacturing and maintenance personnel and operators either through interviews or by enlisting their help directly in fault isolation is probably the most significant initial step in understanding the operation of complex aircraft systems.

3.1.2 Determine if a Malfunction Occurred: Compare actual system operation against known proper system operation to determine if a system malfunction actually occurred using the following resources:

- a. Flight Data: Data recovered from the aircraft integrated data system (AIDS) and other devices such as flight data recorders can be used to determine if systems operated properly.
- b. BIT data: Modern aircraft BITE can provide system failure detection and, in some cases, isolation of the failed system component through stored failure and/or maintenance codes.
- c. Operator/Maintainer/Witness Interviews and Reports: First hand descriptions from flight and ground crews, and in the case of mishaps, witnesses, of system behavior. It may be beneficial to construct standardized questionnaires that are to be filled out by witnesses with basic information when a system anomaly occurs.

3.1.3 Determine if System Was Maintained and Used Properly: Determine if systems were maintained and used properly using the following resources:

- a. Flight Data: Data recovered from flight data and voice recorders as well as other system monitors can be used to determine if flight crew action was proper for flight/system conditions present leading up to and following a system malfunction.
- b. Maintenance Records: Maintenance records can reveal whether or not proper and timely maintenance actions were performed and if improper or neglected maintenance contributed to the system failure.

An example of this type of information is examining the aircraft's maintenance log book to find no record of a scheduled inspection of the hydraulic filters being performed prior to a pump failure.

3.1.3 (Continued):

- c. Operator/Maintainer Interviews and Reports: First hand descriptions from flight and ground crews can provide insight into how the system was used and maintained.

An example of this insight is learning from ground crews that a piece of GSE was not used or not used properly.

- 3.1.4 Audit of System Manuals: An audit of system and support equipment manuals to determine whether or not concise and correct operating instructions were provided to the operators can uncover a documentation deficiency or point up the possibility of human error.

- 3.1.5 Audit of Training Materials: An audit of flight crew operating and maintenance manuals to determine whether or not complete and accurate training materials were provided to the operators can uncover a documentation deficiency or point up the possibility of human error.

3.2 Risk Assessment and Mitigation (Figure 3):

Until final corrective actions based on root cause findings can be enacted, assessment of consequences and mitigation of further failures must be addressed.

- 3.2.1 Risk Assessment: A risk assessment based on flight safety analysis including: system functional hazard analysis (FHA), fault tree analysis (FTA) and the probability and severity of hazards if the system failure reoccurs before corrective action is implemented is used to formulate a damage control plan. The risk assessment also addresses malfunctions that result in a known degraded mode for which instructions and limitations have been provided.
- 3.2.2 Risk Mitigation: The course of action to mitigate risk depends on whether or not the risk assessment finds that system failure affects safety of flight. The appropriate action depends on whether or not safety of flight is affected and other factors:
 - 3.2.2.1 Safety of Flight is Affected: If the system failure affects safety of flight, analysis must be performed to determine if the system has sufficient control capability for an emergency landing and to determine if the existing emergency procedures are adequate. The analysis may result in imposing operating restriction placards that can be as unobtrusive as flight envelope restrictions or as significant as grounding of a fleet of aircraft.
 - 3.2.2.2 Safety of Flight Not Affected: If the system failure does not affect safety of flight, determine whether or not the system failure presents hazards to personnel and equipment and act accordingly.

- 3.2.2.2.1 No Hazards: If the system failure does not present a hazard to equipment or personnel, no damage control plan is necessary.
- 3.2.2.2.2 If the system failure presents hazards to equipment only, at a minimum, the following actions must be performed:
 - a. Impose scheduled inspections and/or maintenance to verify flight readiness and determining the chronocity of the problem if previous failures of the malfunctioning system show a specific symptom
 - b. Notifying flight and ground crews of hazards to equipment and personnel and the consequences of not performing recommended risk mitigation.
- 3.2.2.2.3 If the system failure presents hazards to personnel, it must be determined if the hazard can be mitigated by procedural change/safety equipment:
 - a. If the hazard can be mitigated by procedural change/safety equipment at a minimum, the following actions must be performed:
 - (1) Enact Procedural Change/Safety Equipment Requirement: Requirements for procedural changes and the use of safety equipment can mitigate or eliminate successive system malfunctions.
 - (2) Publicizing the procedural change/safety equipment requirement through the use of publications, videotapes or computer based learning aids.
 - b. If the hazard cannot be mitigated by procedural change/safety equipment, at a minimum, personnel must be notified in writing of the hazard.
- 3.3 System Failure Duplication and System Failure Isolation to Individual Components (Figure 4):
 - 3.3.1 Collect Data While Attempting to Duplicate the System Failure: A pivotal event in a successful fault isolation effort is duplication of the malfunction. Duplication of a system malfunction allows the investigator(s) to study data collected during repetition of the failure that is used to isolate the system failure to one or more component failures. It is important that all data that can be captured, even items that initially may not appear relevant, be collected while attempting to duplicate the system failure. Sometimes the failure of apparently unrelated systems can have unexpected consequences. It is prudent to capture all available information for future analysis and brainstorming. Collection of this data can come from one or more of the following sources: