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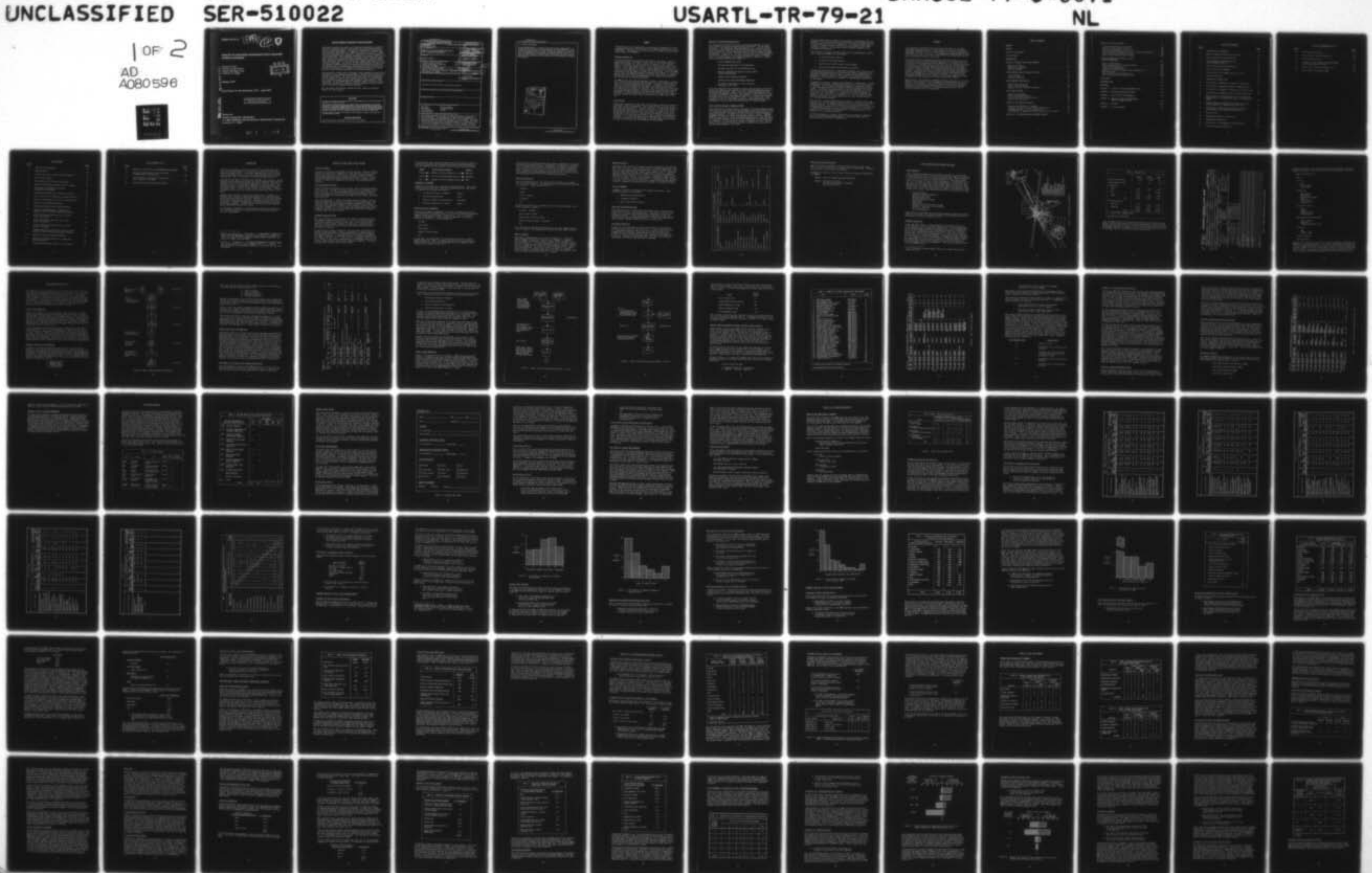

USARTL-TR-79-21

ANALYSIS OF HELICOPTER MAINTENANCE FAULT ISOLATION CRITERIA/TECHNIQUES

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October 1979

Final Report for Period October 1977 - April 1979

Approved for public release;
distribution unlimited.

Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report presents the results of a detailed investigation designed to identify and quantify specific deficiencies with fault isolation maintenance of Army helicopters. Although the investigation confirmed that fault isolation maintenance is a significant factor in the cost of operating Army helicopters, the frequency of occurrence of over 85 percent of the 542 individual failure symptoms identified was no greater than once in 2,000 flight hours. The deficiencies relating to fault isolation maintenance data were considered for further investigation in Task II because their elimination would provide the greatest overall improvement to fault isolation maintenance. As a result of this investigation, the fault isolation analysis technique (FIAT) was developed, which greatly facilitates the identification of symptom/cause relationship and the collection, processing and organization of information and data required for the preparation of fault isolation procedures for maintenance manuals.

This Laboratory concurs with the findings of this program and that FIAT is considered to be a significant improvement in the way fault isolation procedures are developed. The reader is cautioned that this investigation did not analyze the avionics and armaments subsystems of the helicopter and no attempt was made to relate the findings of this program to those subsystems. The USA DARCOM Materiel Readiness Support Activity is planning follow-on efforts to refine and possibly integrate the FIAT methodology in the logistic support analysis programs.

Mr. John Ariano, Aeronautical Systems Division, served as technical monitor for this contract.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: USARTL-TR-79-21
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): ANALYSIS OF HELICOPTER MAINTENANCE FAULT ISOLATION CRITERIA/TECHNIQUES
5. TYPE OF REPORT & PERIOD COVERED: Final Report – Octo[redacted]77 — Apr[redacted]978
6. PERFORMING ORG. REPORT NUMBER: SER-510022
7. AUTHOR(s): Thomas N. Cook
8. CONTRACT OR GRANT NUMBER(s): DAAJ02-77-C-0071
9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Sikorsky Aircraft Division
United Technologies Corporation
Stratford, CT 06602
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62209A 1L262209AH76 00 221 EK
11. CONTROLLING OFFICE NAME AND ADDRESS:
Applied Technology Laboratory, U.S. Army
Research and Technology Laboratories (AVRADCOM)
Fort Eustis, VA 23604
12. REPORT DATE: Oct[redacted]1979
13. NUMBER OF PAGES: 171
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopter
Maintenance
Fault Isolation
Troubleshooting
Failure Symptoms
Maintenance Costs
Failure

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The problems associated with fault isolation maintenance in Army aviation were investigated. The investigation included a detailed engineering analysis of historical maintenance data on the CH-54 helicopter and surveys of selected Army field activities throughout the United States. The investigation confirmed that fault isolation maintenance is a significant factor in the cost of operating Army helicopters. The most frequent criticism voiced by Army personnel in the field concerns the generally poor quality

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S/N 0102-014-6601

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. Abstract (continued)

of troubleshooting data in current aircraft maintenance publications. In response to this problem, an improved approach to the development of fault isolation maintenance data for complex systems was developed. Called FIAT (Fault Isolation Analysis Technique), the proposed approach greatly facilitates the identification of symptom/cause relationships and the collection, processing and organization of data required for the preparation of maintenance manuals.

SUMMARY

The objectives of this program were to investigate the problems with fault isolation maintenance in Army aviation and to develop solutions for future improvements. By direction, the study covered all systems of Army aircraft except avionics and armament.

Problem Investigation

The CH-54 helicopter was selected as the model for the study. Among the more sophisticated of the Army's current aircraft, the CH-54 possesses a number of subsystems not found on smaller helicopters in the inventory, making it a particularly good choice for the study of fault isolation maintenance. In the late 1960's, the U.S. Army contracted with Sikorsky Aircraft to collect R&M data on CH-54 helicopters operating here in the United States and at overseas bases in Europe and Southeast Asia. Called the ORME (Operations Reliability/Maintainability Engineering) Program, its objectives were to assess the R&M performance of the CH-54 in the field, to identify problem areas and to develop recommendations for improving the design of the aircraft and its supporting resources.

The ORME data was processed and analyzed. Records of maintenance involving fault isolation were extracted from the ORME files, and structured descriptions of the reported symptoms were prepared. A computer file containing 5,500 corrective maintenance actions known or believed to have involved some type of fault isolation was developed, and a detailed statistical analysis of the data was conducted. An analysis was also conducted to evaluate troubleshooting data contained in the maintenance manuals for the CH-54 helicopter. Troubleshooting data extracted from the manuals were compared with the symptoms and causes actually experienced with the CH-54 in the field.

Field Surveys

Surveys were conducted to investigate the experience of Army field personnel with fault isolation maintenance. The surveys covered the CH-54 and two other Army helicopter models: the AH-1 and CH-47. Six helicopter operating activities were visited, and a total of 41 mechanics, technicians, pilots and maintenance administrators were interviewed. Included in the field surveys was a visit to the U.S. Army Aviation Maintenance Training School at Fort Eustis, Virginia where training in fault isolation maintenance was discussed. Visits were also made to three Army agencies and one defense contractor to survey current technology in the development and publication of fault isolation data for the new-generation Army systems.

Results of the Problem Investigation

The investigation confirmed that fault isoltation maintenance is a significant factor in the cost of operating Army helicopters. For the CH-54 helicopter, it was determined that approximately 1 in 3 corrective maintenance actions on nonavionics systems of the helicopter involves some type of fault isolation. The average troubleshooting task was found to consume approximately 1.4 man-hours. The direct cost of fault isolation maintenance on nonavionics systems of the aircraft, including the cost of documented errors in troubleshooting, was estimated at $25 per flight-hour. Significant findings were obtained with respect to:

- Failure symptoms and causes
- Training and experience of field personnel
- Frequency and cost of troubleshooting errors
- Man-hour, downtime and logistics cost of fault isolation maintenance
- Combat versus noncombat experience
- Contract versus Army maintenance experience
- Availability and quality of fault isolation resources in the field

One of the complaints most frequently voiced by Army personnel in the field concerns the generally poor quality of fault isolation maintenance data on present-day Army systems. Major criticisms include widespread omissions of significant symptoms and causes, poor organization and indexing of information and inefficient troubleshooting procedures. Problems with language and communication are also frequently cited. In the latter part of the program, an effort was undertaken to develop an improved approach to the development of fault isolation maintenance data for complex systems.

Fault Isolation Analysis Technique (FIAT)

Called FIAT (Fault Isolation Analysis Technique), the evolved method greatly facilitates the identification of symptom/cause relationships and the collection, processing and organization of data required for the preparation of maintenance manuals. It reduces the task to a series of small, independent judgements and decisions which, when brought together, provide a working guide for preparation of system troubleshooting procedures. Most important, by allowing the engineer or writer to deal individually with discrete items of information, it relieves him of having to formulate an overall troubleshooting logic from the outset and lessens the demands on his personal experience and knowledge of the system.

The FIAT approach applies primarily to nonavionics systems whose modes and symptoms of failure do not generally lend themselves to automated test and the more sophisticated forms of diagnostics. The methods could be applied to avionics systems, however, either to provide a backup for the prmary diagnostics system or in applications where diagnostic hardware is not considered cost-effective.

FIAT involves four major tasks that culminate in the generation of outline fault isolation procedures for the system:

1. A system functional analysis

2. A system failure modes analysis

3. Description of fault isolation task candidates

4. Review, consolidation and editing of procedures

A system functional analysis is performed to establish the criteria for normal system performance and to identify potential modes of abnormal performance (the system malfunctions). Next, a system failure modes analysis is conducted to identify failures with a potential for causing each type of malfunction. This establishes a framework of symptom/cause relationships for the system.

A computer file of fault isolation task candidates is constructed. For each symptom/cause candidate, information pertinent to the fault isolation task is recorded. This includes the expected frequency of occurrence, methods of fault confirmation and fault isolation, and the estimated time to fault isolate. A computer program processes the data and generates two outputs that are used in the preparation of fault isolation maintenance data for the system. The first output is a comprehensive listing of symptoms and causes, the Fault Isolation Task Candidate List, which the analyst reviews, condenses and assigns to logical groups that will each form the content of a troubleshooting procedure.

After editing, a troubleshooting procedure number is assigned to each symptom/cause set, and the computer program outlines the content of each troubleshooting procedure. An algorithm defines the preferred troubleshooting strategy based on probabilities of failure and expected fault isolation times. The computer-generated Outline Fault Isolation Procedures List, the final product of FIAT, provides a working guide for the technical writer in the preparation of the maintenance manual.

The FIAT methodology is viewed as technically and procedurally compatible with existing Army program requirements in the areas of R&M, Logistics Support Analysis and Technical Publications.

PREFACE

This program was performed by the Sikorsky Aircraft Division of United Technologies Corporation under Contract DAAJ02-77-C-0071 for the Applied Technology Laboratory (ATL), U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia. The program was conducted under the technical direction of Mr. John Ariano of the Reliability, Maintainability and Mission Technology Technical Area of ATL.

The author wishes to acknowledge important contributions made to this program by the following Sikorsky Aircraft personnel. Mr. Richard Corbeille of the Reliability and Maintainability (R&M) Section of Engineering assisted with analysis of the ORME data and field survey results, and conducted the trial application of the FIAT methodology developed under this program. Mr. Michael Cohen of the R&M Section designed and wrote the FIAT computer programs. Mr. Maitland Hudson of Sikorsky's Product Support Department was primarily responsible for interpreting and coding the maintenance events comprising the ORME history on the CH-54 helicopter. Mr. Roland Blier, Mr. Raymond Johnson and Mr. Paul Shurko, all of Product Support, provided valuable advice and assistance at various stages of the program.

Appreciation is also gratefully extended to the many personnel at U.S. Army agencies and operating activities throughout the United States who participated in this program. Their professionalism and their patience during long hours of interviewing contributed greatly to the results achieved. The hospitality and cooperation of the Warren Defense Division of the Chrysler Corporation are also appreciated.

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INTRODUCTION

Previous investigations conducted by the Army[1,2] have determined that fault isolation maintenance is a significant contributor to the cost of maintaining Army aircraft. It has been shown that much of this maintenance is performed incorrectly and that troubleshooting tasks are often repeated many times in the process of isolating system malfunctions.

Substantial costs may be associated with improper fault isolation. At the operating level, maintenance actions that must be repeated waste man-hours, equipment and facilities and degrade operational readiness. When such maintenance causes the unnecessary replacement of good components, added costs are suffered in supply and in component processing at the higher maintenance levels. Mission reliability may also be affected. Frequently, confirmation that a fault still exists occurs after the aircraft is airborne.

Improper fault isolation is known to have many causes. Sometimes it is caused by the reluctance of maintenance personnel to follow prescribed troubleshooting procedures and to work instead by trial and error methods. Skills and training may be inadequate. Equipment and test points may be inaccessible. Aircraft indicators and fault warning devices may be inaccurate or misleading. Troubleshooting instructions and test equipment may be complicated and difficult to use.

This program was undertaken to investigate the problems associated with fault isolation maintenance in Army aviation and to develop solutions for future improvements.

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[1] Cook, T. N., Young, R. L., and Starses, F. E, MAINTAINABILITY ANALYSIS OF MAJOR HELICOPTER COMPONENTS, Kaman Aerospace Corporation, USAAMRDL-TR-73-43, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, August 1973, AD 769941.

[2] Holbert, C., and Newport, G., HELICOPTER MAINTENANCE EFFECTIVENESS ANALYSIS, Sikorsky Aircraft Division, USAAMRDL-TR-75-14, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, May 1975, AD A012225.

NATURE OF FAILURES AND FAILURE SYMPTOMS

TYPES OF FAILURES

Failures in a system are discovered in one of two ways: They are visually observed in the course of inspections or other activities on the aircraft, or they cause some type of malfunction or abnormal system performance. When the same malfunction can be produced by different failures, or the relationship between the malfunction and the failure is obscure, the malfunction is said to be a symptom of the failure, and troubleshooting is necessary.

Visually Observed Failures

Certain failures are discovered only by sight, never causing a malfunction of the aircraft. Airframe skin cracks and worn tires are examples of this type of failure. It is very improbable that either of these conditions could ever progress to the point of affecting the performance of the aircraft, and if they did, there would be no need to fault isolate; the cause would be obvious.

There are cases, however, where a discrepant condition normally found by inspection progresses to the point of causing a system malfunction. Corrosion of control rod bearings would normally be detected by inspection long before the stage that it began to cause binding or control travel restrictions. However, it is possible that such a discrepancy might escape inspection and, particularly in an extreme environment, be the cause of a problem requiring fault isolation.

Symptom-Producing Failures

Most fault isolation involves failures that cannot be detected visually, only sensed as some type of malfunction. Failure of internal components of electronic devices is typical of this type. Failed resistors and transistors cannot be seen, although in some cases it may be possible to test for the onset of failure and correct the condition before system performance is affected.

Of those failures normally detected via the occurrence of malfunctions or abnormal system performance, some are manifested in a symptom unique to that particular failure or in a symptom that can be easily investigated by a simple inspection. A mechanical lock for a swiveling nose wheel or tail wheel is of this class. If the lock fails to engage, either the lock pin is broken or there exists some binding or interference in the control linkage, either of which could be found simply by inspection. Failures of this type are relatively easy to fault isolate.

The more obscure the relationship between the failure and the evidence of failure (the symptom), and the greater the number of possible causes of that same symptom, the more complex the fault isolation problem becomes:

Simple		Fault Isolation Problem		Complex
Visual	◀—	Method of Failure Detection	—▶	Nonvisual
Unique	◀—	Failure-to-Symptom Relationship	—▶	Ambiguous
One	◀—	Number of Possible Symptom Causes	—▶	Many

PROPERTIES OF SYMPTOMS

A symptom is an observation of abnormal system performance. These observations, made by either the flight crew or maintenance crew, may consist of as many as four separate observations:

1. The observed system or component (what?)
2. The observed malfunction (how?)
3. Nature or degree of the malfunction (how much?)
4. Conditions under which it occurs (when?)

Observed System or Component

An intrinsic property of symptoms is the system or component of the aircraft observed to be malfunctioning or, in the case of instrument-indicated symptoms, conveying the message of a malfunction. This is the "what" property of the symptom. Typical systems or components that might be cited as the subject of a failure symptom are:

Aircraft

Cyclic Stick

Rotor Brake

Hydraulic Pressure Gage

Etc.

In some cases, the observation is of the failed item itself, as when a lamp bulb burns out. Here, the symptom and the failure are the same, although failure of the bulb to illuminate may also be a symptom of other failures (fuse, switch, wiring, etc.).

With most fault isolation problems, the system or component of the aircraft observed to be malfunctioning, or through which an indication of malfunction is conveyed, does not denote the failure. An example is a pressure switch failing, which prevents a valve from opening, which prevents the engine from starting (the symptom). Here, only an indirect association exists between the observed malfunction and the failure. Failures of this type constitute the more difficult troubleshooting problems.

<u>Observed Malfunction</u>

The observed malfunction is the second intrinsic property of a symptom. This is the "how" property. Observed malfunctions can usually be described in a few words. Typical descriptions are:

Vibrates

Creeps

Fail to release

Fluctuates

Etc.

The observed malfunction, in combination with the observed system or component, describes a symptom:

Aircraft - vibrates

Cyclic stick - creeps

Rotor brake - fails to release

Hydraulic pressure gage - fluctuates

Etc.

It is important to separate the description of the basic symptom from the nature or degree of the symptom and the conditions under which it occurs.

<u>Nature or Degree</u>

Some types of symptoms may vary in nature or degree, e.g., direction, speed, frequency or severity. Vibration, for example, is a general type of symptom, the specific nature or degree of which involves a number of variables, i.e., location (engine, tail, etc.), direction (lateral, vertical), frequency (low, high), amplitude (moderate, severe). Other types of symptoms are not variable in nature or degree but are rather of a go/no-go character. "Rotor brake fails to release" is an example. Here the symptom is completely described by the observed component (rotor brake) and observed malfunction (fails to release).

Symptom Conditions

The fourth factor that may be needed to describe a symptom is the conditions under which it occurs. Conditions may relate to weather (temperature, wind, etc.), aircraft configuration and weight (fuel load, sling load, etc.), and aircraft flight mode (attitude, speed, type of maneuver, etc.). Conditions may also relate to the operation or nonoperation of particular equipment (automatic flight controls on or off, etc.). Like nature or degree, conditions do not pertain to every type of symptom. "Windshield wipers inoperative" is an example. The only "condition" is an implied one (when the switch is thrown), and it need not be specifically stated to describe the symptom. A sample of symptoms illustrating the four elements is presented in Table 1.

TYPES OF SYMPTOMS

A symptom is basically an observation of abnormal performance. These observations may be of three types:

1. Observable System Malfunction

2. Instrument Indication

3. Other Crew Sensory Perception

Observable System Malfunctions

A system malfunction is witnessed by the operator when a system function either fails to occur or occurs abnormally. Engine fails to start, rotor brake fails to release, wheel brakes chatter are examples of observed system malfunctions. In each case the operator observes directly that a system function has not transpired normally, although the problem may be one of operator procedure rather than a fault in the system.

Instrument Indications

In the case of an instrument or warning light indication, the operator receives a signal that a system has failed, is in the process of failing, or is performing abnormally; but unless the instrument indication is accompanied by an observable system malfunction, he cannot be certain of this, since the indication may be false. Examples of instrument indications are: hydraulic pressure gage reads low, engine tach indicator fluctuating, fuel pressure warning light illuminated.

TABLE 1. TYPICAL FAILURE SYMPTOMS

Observed System or Component	Observed Malfunction	Nature or Degree	Conditions
Aircraft	Vibration	Vertical, low freq.	In hover
APU	Fails to start		
Cyclic Stick	Creeps	Aft	AFCS engaged
Rotor Brake	Fails to release		
Aircraft	Porpoising	Moderately	With Sling Load
EGT Indicator	Fluctuating		
Directional Control Pedals	Pulsing		Coordinated turn with AFCS
AFCS Bar Alt Mode	Will not hold		#2 AFCS engaged
Generator Light	Illuminated		On runup
Collective Stick	Creeps	Up	In hover
Collective Stick	Binding	Both directions	
Engine Oil Pressure Indicator	Fluctuating		Ground idle
AFCS Yaw Channel	Hardover	Left	
Aircraft	Yaw hunting		Straight and level flight
Engine	Hot starts		
Engine EPR Indicator	Reads high	Above 1.3	
Stick Trim Circuit Breaker	Pops		When trim engaged

Other Crew Sensory Perceptions

Other crew sensory perceptions relate to unusual sights, sounds, odors, etc., that may be indicative of a system failure or malfunction. Vibration, unusual noises, and fuel odors are examples.

A symptom will consist of one or more of these three types of observations. For example:

Symptom: Engine Oil Temperature Gage Reads High

Symptom: Engine Fails to Start
and Fuel Pressure Light Illuminated
and Engine Fuel Odor

STUDY CANDIDATE AND HISTORICAL DATA BASE

STUDY CANDIDATE

Fault isolation maintenance may reasonably be expected to vary with the relative complexity of an aircraft as reflected by the number of subsystems it comprises and the number of interfaces between them. Among the Army's current fleet of aircraft, the CH-54 (Figure 1) is a particularly good choice for the study of fault isolation maintenance. A single main rotor/tail rotor aircraft, the CH-54 is more representative of the Army's next generation of helicopters--Black Hawk and AAH--than either the two-bladed teetering rotor or tandem rotor aircraft that comprise a large part of the current fleet. Also, the CH-54 possesses a number of subsystems not found on most of the smaller, less sophisticated aircraft in the inventory,namely:

- Multiple Engines
- Engine Air Particle Separators
- Auxiliary Power Plant
- Wheeled Landing Gear
- Multiple Hydraulic Systems
- Rotor Brake
- Cargo Hoist
- External Pod and Load Leveler System
- Automatic Flight Control System (AFCS)
- Aft Pilot's Controls
- Voice Warning System

These additional subsystems also require more extensive electrical networks, plumbing and aircraft instrumentation, making the CH-54 among the most sophisticated of the Army's current aircraft.

HISTORICAL DATA BASE

In the late 1960's the U. S. Army contracted* with Sikorsky Aircraft to collect R&M data on CH-54 helicopters operating here in the United States and at overseas bases in Europe and Southeast Asia. Called the ORME (Operations Reliability/Maintainability Engineering) Program, its objectives were to assess the R&M performance of the CH-54 in the field, to identify problem areas, and to develop recommendations for improving the design of the aircraft and its supporting resources. Sikorsky technicians stationed at various Army field units collected data on CH-54A and CH-54B helicopters over approximately a 6-year period, beginning in 1968 and ending in 1974. More than 57,000 aircraft operating hours were monitored and more than 50,000 maintenance actions were documented. Table 2 gives important statistics on the ORME Program.

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* U. S. Army Aviation Systems Command Contracts No. DAAJ01-68-C-0512 and DAAJ01-71-C-0641

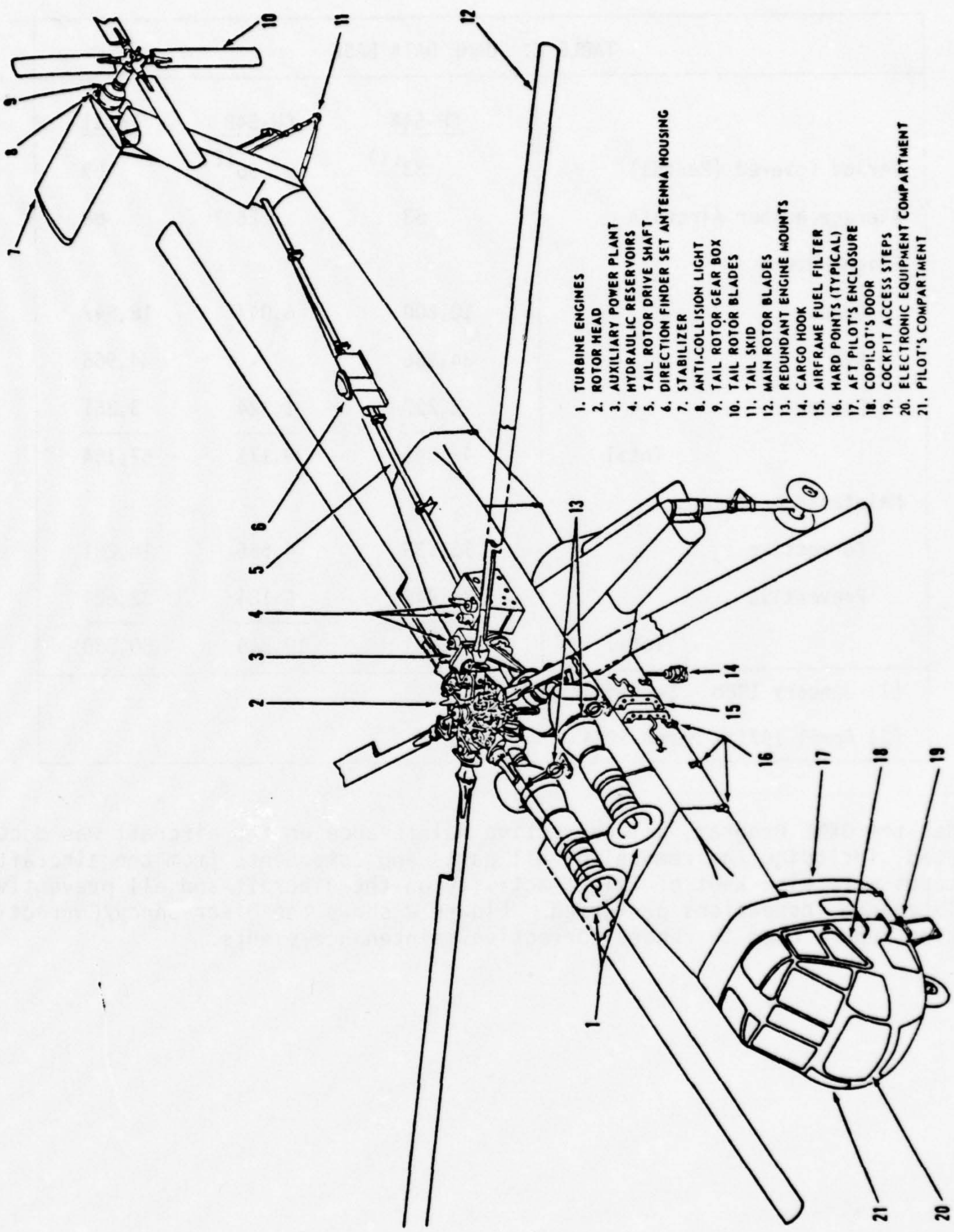


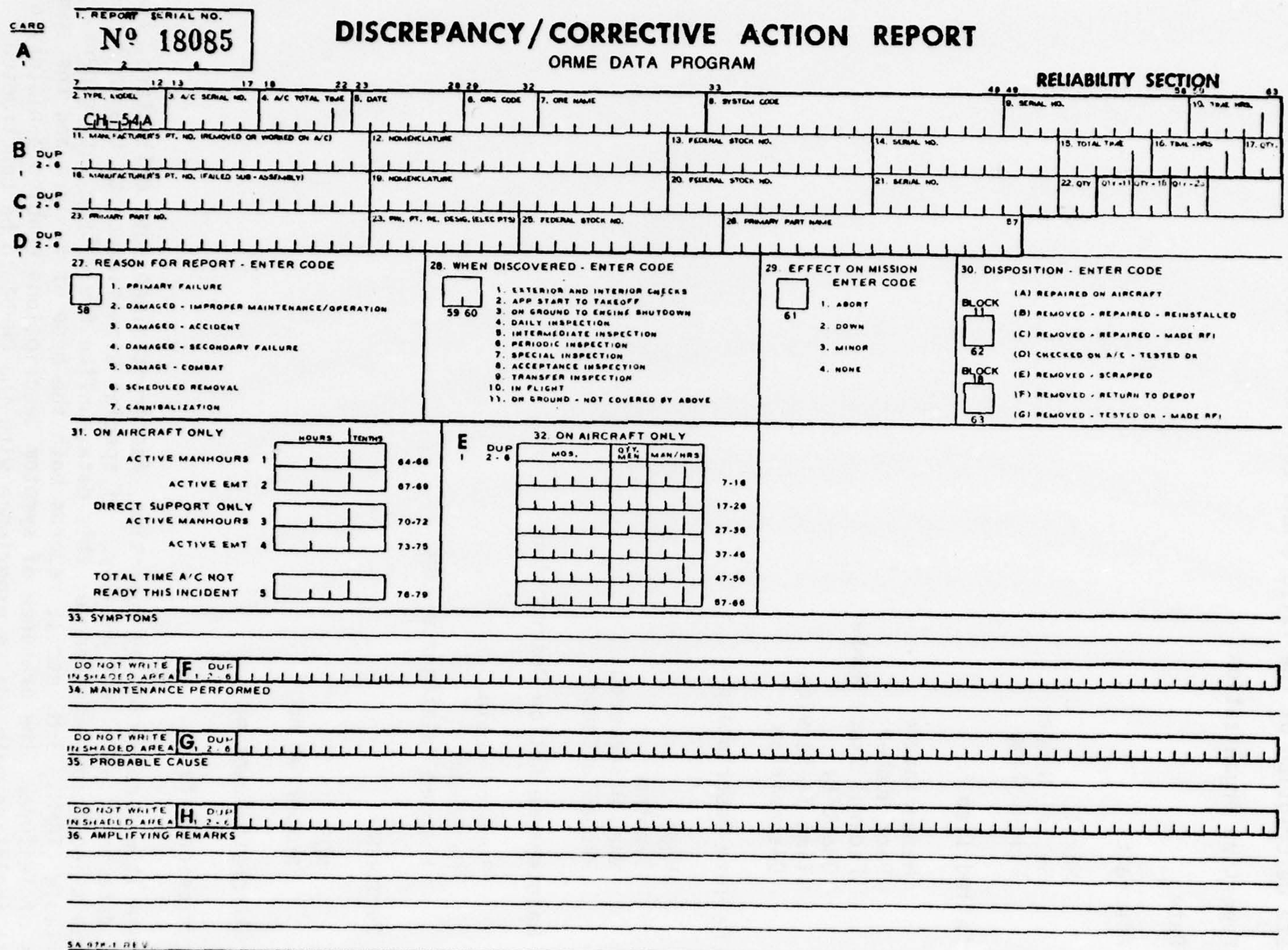
Figure 1. CH-54B General Arrangement

TABLE 2. ORME DATA BASE			
	CH-54A	CH-54B	Total
Period Covered (Months)	33(1)	36(2)	69
Average Number Aircraft	63	25	88
Flight-Hours			
Conus	10,800	8,047	18,847
RVN	34,966	-	34,966
Europe	2,227	1,124	3,351
Total	47,993	9,171	57,164
Maintenance Actions			
Corrective	13,536	4,665	18,201
Preventive	26,445	6,184	32,629
Total	39,981	10,849	50,830

(1) January 1968 - September 1970

(2) April 1971 - March 1974

Under the ORME Program, all corrective maintenance on the aircraft was documented, including the removal of all parts and components from the aircraft. Records were also kept of flight activity on the aircraft and all preventive maintenance inspections performed. Figure 2 shows the Discrepancy/Corrective Action Report used to record corrective maintenance events.



CARD A

1. REPORT SERIAL NO.
Nº 18085

DISCREPANCY/CORRECTIVE ACTION REPORT

ORME DATA PROGRAM

RELIABILITY SECTION

2. TYPE, MODEL — CH-54A
3. A/C SERIAL NO.
4. A/C TOTAL TIME
5. DATE
6. ORG CODE
7. ORE NAME
8. SYSTEM CODE
9. SERIAL NO.
10. TIME HRS.

B DUP 2-6
11. MANUFACTURER'S PT. NO. (REMOVED OR WORKED ON A/C)
12. NOMENCLATURE
13. FEDERAL STOCK NO.
14. SERIAL NO.
15. TOTAL TIME
16. TIME - HRS
17. QTY.

C DUP 2-6
18. MANUFACTURER'S PT. NO. (FAILED SUB-ASSEMBLY)
19. NOMENCLATURE
20. FEDERAL STOCK NO.
21. SERIAL NO.
22. QTY

D DUP 2-6
23. PRIMARY PART NO.
24. PRI. PT. RE. DESIG. (ELEC PTS)
25. FEDERAL STOCK NO.
26. PRIMARY PART NAME

27. REASON FOR REPORT - ENTER CODE (58)
1. PRIMARY FAILURE
2. DAMAGED - IMPROPER MAINTENANCE/OPERATION
3. DAMAGED - ACCIDENT
4. DAMAGED - SECONDARY FAILURE
5. DAMAGE - COMBAT
6. SCHEDULED REMOVAL
7. CANNIBALIZATION

28. WHEN DISCOVERED - ENTER CODE (59 60)
1. EXTERIOR AND INTERIOR CHECKS
2. APP START TO TAKEOFF
3. ON GROUND TO ENGINE SHUTDOWN
4. DAILY INSPECTION
5. INTERMEDIATE INSPECTION
6. PERIODIC INSPECTION
7. SPECIAL INSPECTION
8. ACCEPTANCE INSPECTION
9. TRANSFER INSPECTION
10. IN FLIGHT
11. ON GROUND - NOT COVERED BY ABOVE

29. EFFECT ON MISSION ENTER CODE (61)
1. ABORT
2. DOWN
3. MINOR
4. NONE

30. DISPOSITION - ENTER CODE
BLOCK 11 (62)
BLOCK 18 (63)
(A) REPAIRED ON AIRCRAFT
(B) REMOVED - REPAIRED - REINSTALLED
(C) REMOVED - REPAIRED - MADE RFI
(D) CHECKED ON A/C - TESTED OK
(E) REMOVED - SCRAPPED
(F) REMOVED - RETURN TO DEPOT
(G) REMOVED - TESTED OK - MADE RFI

31. ON AIRCRAFT ONLY — HOURS / TENTHS
ACTIVE MANHOURS 1 (64-66)
ACTIVE EMT 2 (67-69)
DIRECT SUPPORT ONLY
ACTIVE MANHOURS 3 (70-72)
ACTIVE EMT 4 (73-75)
TOTAL TIME A/C NOT READY THIS INCIDENT 5 (76-79)

E DUP 2-6
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17-26
27-36
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34. MAINTENANCE PERFORMED
DO NOT WRITE IN SHADED AREA G DUP 2-6
35. PROBABLE CAUSE
DO NOT WRITE IN SHADED AREA H DUP 2-6
36. AMPLIFYING REMARKS

SA 97R-1 REV.

Figure 2. ORME Discrepancy/Corrective Action Report

Information recorded on the Discrepancy/Corrective Action Report provides a complete description of the failure and corrective maintenance, including:

Reporting Organization

Date

Aircraft

Model
Serial Number
Flight Time

Failed Item

Nomenclature
Part Number
Federal Stock Number
Quantity
Time in Service
Disposition

Failure Description

Mode
Symptom
When Discovered
Probable Cause

Maintenance Action Description

Type of Action
Man-Hours
Elapsed Maintenance Time

Personnel

MOS
Number of Men

Aircraft Downtime

Mission Effect

Because it was collected by full-time, factory-trained data collectors, the ORME data is of excellent quality. Of special significance to the analysis of fault isolation maintenance, this data, unlike field-type data generally available (TAMMS, 3-M, etc.), records both the mode of failure and the symptoms of failure. The presence of symptom descriptions enabled a history of fault isolation maintenance experience with the CH-54 to be constructed.

DATA PROCESSING AND ANALYSIS

The ORME data on the CH-54, described in the preceding section of the report, was processed and analyzed to construct a history of fault isolation maintenance on the aircraft. The task was accomplished in two phases. In Phase I records of maintenance involving fault isolation were extracted from the ORME files and structured descriptions of the reported symptoms were prepared. In Phase II the structured symptom descriptions were added to the set of original ORME records, selected data was converted to coded form for processing by computer, and a computer program was written to generate statistical tabulations of the data for analysis.

PHASE I DATA PROCESSING

Figure 3 illustrates the flow of the Phase I data processing. The ORME data had been computer-processed by Sikorsky under the original contracts with the Army. At the conclusion of the ORME program, all of the data had been placed on magnetic tape files and stored in Sikorsky's data processing facility. The corrective maintenance records were stored on two magnetic tape reels, one covering the CH-54A and the other the CH-54B. Contained on the two reels of tape were records covering approximately 18,000 corrective maintenance actions on the aircraft.

It was recognized initially that only some of these actions could have involved some type of fault isolation maintenance. Many of the failures occurring in service, particularly with mechanical systems, are discovered by visual inspection. These are failures that either produce no observable malfunction of the aircraft when they occur or are found by visual means before they reach that stage. The first task of the analysis was to ferret out the corrective maintenance actions involving some type of crew-reported system malfunction and to ascertain which of these involved troubleshooting.

Computer Screening of the ORME Data

In order for a corrective maintenance action to have involved troubleshooting, it was reasoned that it would have had to occur as a result of a malfunction discovered during operation of the aircraft or ground operation of equipment. Screening rules were developed to extract from the ORME files records of maintenance meeting these criteria. First, a screening was conducted on the "Reason for Report" code, and records containing the following codes were removed from the file:

3 - Damaged Accident
5 - Damaged Combat
6 - Scheduled Removal
7 - Cannibalization

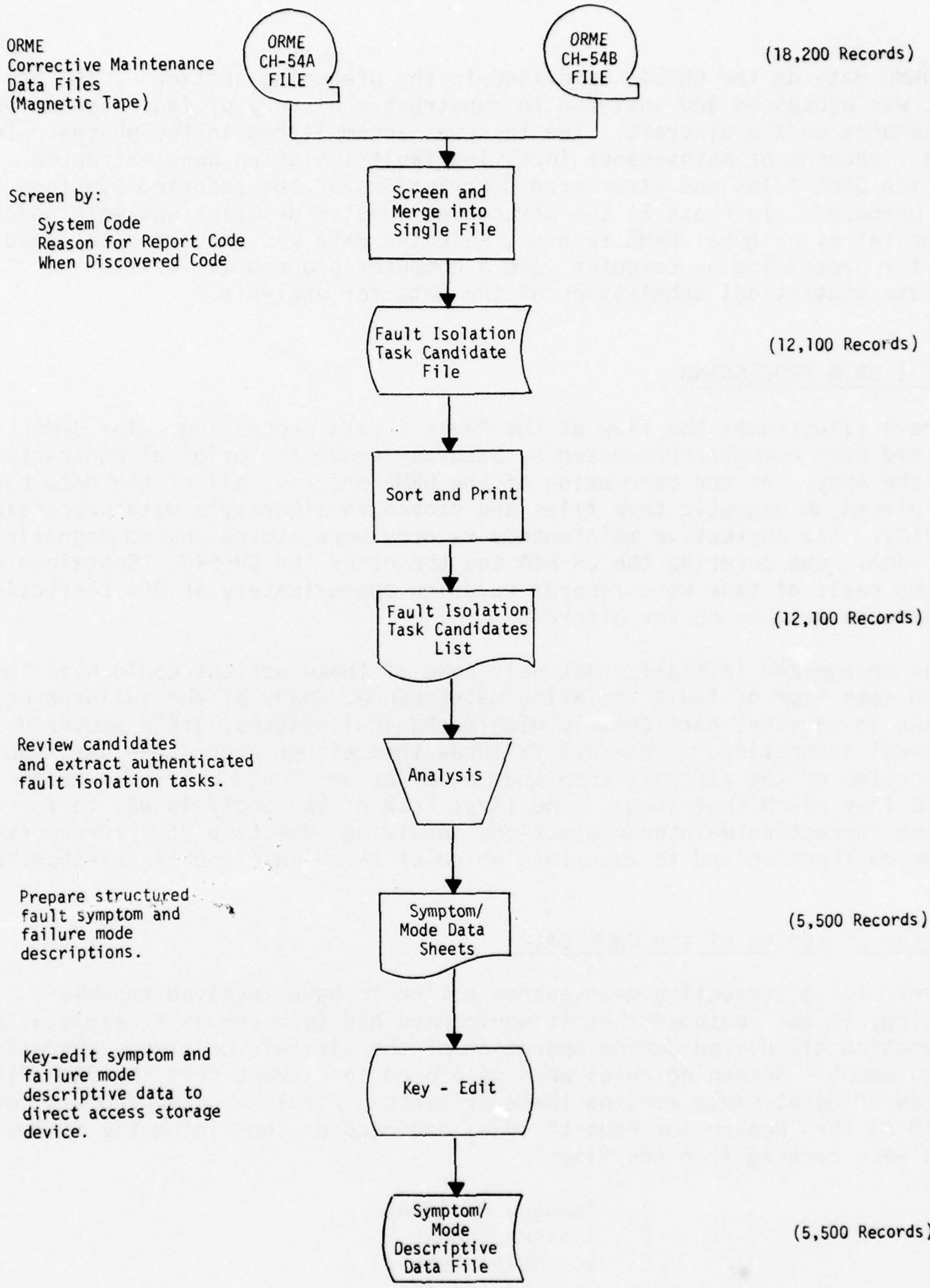

Figure 3. Phase I Data Processing and Analysis

Next, the "When Discovered" code was screened and records containing the following codes were removed from the file:

4 - Daily Inspection
7 - Special Inspection
8 - Acceptance Inspection
9 - Transfer Inspection

Records of maintenance to correct failures discovered during Intermediate and Periodic inspections were retained, because both of these inspections include power-on checks during which malfunctions requiring troubleshooting might have occurred.

Finally, since the contract statement of work excluded consideration of aircraft avionics, records containing the avionics system codes were removed from the file. Records covering aircraft instruments and the avionics portion of the AFCS (Automatic Flight Control System) were retained.

The two tape files were screened and simultaneously merged into a single file. As a result of the screening, the number of records was reduced by approximately 1/3, creating a file containing 12,100 corrective maintenance events potentially involving some type of fault isolation. A computer program was written to sort and print this group of records, called the Fault Isolation Task Candidates File. Figure 4 shows the format of the report.

Manual Screening of the ORME Data

Each record in the file of fault isolation task candidates was examined to determine whether fault isolation was involved with the maintenance action being reported. This determination was made on the basis of the symptom described and the failure reported. The process was basically one of removing from further consideration those maintenance events that corrected failures discovered by visual evidence. Worn tires, cracked fairings, and scratched windshields are examples of failures that obviously are seen rather than found by troubleshooting. Although other types of faults are not as obvious as these, the determination of whether or not troubleshooting was involved in locating the reported failure was usually straightforward. There was no way of ascertaining, absolutely, that troubleshooting was involved in a maintenance action, however. A fluctuating pressure gage should have required troubleshooting to determine whether the gage was at fault or the sensor, the pump, etc. It is conceivable that the mechanic guessed at the cause and arbitrarily replaced a component without troubleshooting, but there was no way of ascertaining that fact from the data.

Development of Structured Fault Symptom Descriptions

One of the important features of the ORME data was the inclusion of symptom descriptions in the corrective maintenance reports. These descriptions and descriptions of failure modes when recorded were contained

PROGRAM - E93AFA
03/03/78

FAULT ISOLATION TASK CANDIDATES FROM SCREENED ORME DATA BASE

REPRT SER NUMBR	ACFT MODEL	ACFT SER NO	ACFT TIME	DATE	ORG CODE	REPT REAS CODE	WHEN DISC CODE	MISN EFCT CODE	ORG/ DS MHRS	ORG/ DS EMT	ACFT DOWN TIME	1ST 2 MOS CODES	ASSY/SUB-ASY PART NUMBER	ASSY/SUB-ASSY NOMENCLATURE	QTY	DISP CODE
341	CH-54A	18428	56.4	680318	RO78	2	10	4	3.1	3.1		68F20	MS28034-1	BULB TEMP	1	A
	SYMPTOMS	XMSN OIL TEMP NOT FUNCTIONING														
	MAINT PERF	INSTL RETAINERS METAL + PHENOLIC STRAIGHTENED PINS														
	PROB CAUSE	IMPROPER MAINTENANCE														
355	CH-54A	18413	403.9	680219	COCM	4	11	4	21.0	23.0	23.0	CIV	S1510-25023	DROOP STOP PAD	1	B
													AN4H4A	BOLT	1	E
	SYMPTOMS	SHEARED BOLT														
	MAINT PERF	REP/PAD CLEANED														
	PROB CAUSE	STICKING DROOP STOPS ON ROTOR SHUT DOWN														
357	CH-54A	18413	403.9	680219	COCM	4	03	4	21.0	23.0	23.0	CIV	S1510-25020-2	RESTRAINER DROOP	6	E
													NAS464-10-40	BOLT	1	E
	SYMPTOMS	DROOP RETAINERS DID NOT RETURN ON ROTOR SHUTDOWN														
	MAINT PERF	ALL WERE REM/REPL														
	PROB CAUSE	HEAD IMPROPERLY INSTALLED														
365	CH-54A	18413	419.8	680226	COCM	1	02	1	.4	.4	.4	CIV	03S769-158	BOWL MAIN XMSN	1	D
													03T601-231	CARTRIDGE	1	B
	SYMPTOMS	COULD ONLY GET 40PSI/														
	MAINT PERF	REM CARTRIDGE AND CLEANED														
	PROB CAUSE	LINT IN CARTRIDGE														
366	CH-54A	18413	427.8	680229	COCM	1	02	1	56.0	14.2	18.0	CIV	571078	FUEL CONTROL	1	D
	SYMPTOMS	COLLECTIVE BIAS BINDS														
	MAINT PERF	CHANGED FUEL CONTROL														
	PROB CAUSE	BIAS STIFF														
372	CH-54A	18415	405.0	680304	COTS	1	10	2	9.0	2.0	2.2	CIV	NAS649B32S	TURNBUCKLE	4	A
													NAS651-16S	CLIP	8	
	SYMPTOMS	FEEDBACK THRU PEDDELS AT HIGH GROSS WEIGHT 40-70 KTS														
	MAINT PERF	CABLES ADJUSTED TENSION CHECKED														
	PROB CAUSE	IMPROPER CABLE TENSION														

Figure 4. Fault Isolation Task Candidates From Screened ORME Data Base

in narrative text included in each of the records. The narratives conformed to no specific construction and contained varied descriptions of the same or similar symptoms and failure modes. In order to be able to process these elements of data by computer, it was necessary to convert them to a structured and consistent format.

As discussed in the section entitled "Nature of Failures and Failure Symptoms", a symptom may consist of as many as four separate observations:

1. The observed system or component

2. The observed malfunction

3. Nature or degree of the malfunction

4. Conditions under which it occurs

For each of the maintenance events determined to have involved troubleshooting, the reported symptom was translated into a structured form consisting of as many of these four observations as were applicable. The structured fault symptom descriptions were recorded on forms for keypunching, together with several additional elements of data.

Where the narrative text contained in the ORME record described the mode of failure of the item repaired or replaced, the failure mode description was extracted from the text and recorded. Three-digit codes identifying the aircraft subsystem in which the symptom was observed and the aircraft subsystem in which the failure was found were also recorded. Appendix A lists these codes. The last element of data recorded on the form was the ORME report number, a unique key by which the transcribed data would later be matched to the original ORME record.

Review of the Fault Isolation Task Candidates File resulted in the extraction of approximately 5,500 corrective maintenance actions known or believed to have involved some type of fault isolation. The structured symptom descriptions and supplemental data just described were prepared for this group of actions, the data was key-edited into a computer file, and the file, called the Symptom/Mode Descriptive Data File, was stored on a direct-access storage device.

PHASE II DATA PROCESSING

Figure 5 illustrates the flow of the Phase II ORME data processing and analysis. A computer program was written to merge the Symptom/Mode Descriptive Data File with the Fault Isolation Task Candidates File, creating a new file containing the 5,500 selected maintenance actions, called the Fault Isolation Task Data File. In the process of creating this new file, selected fields of data from the original ORME records were combined with the data contained in the Symptom/Mode Descriptive Data File records and merged into a single record 269 characters in length.

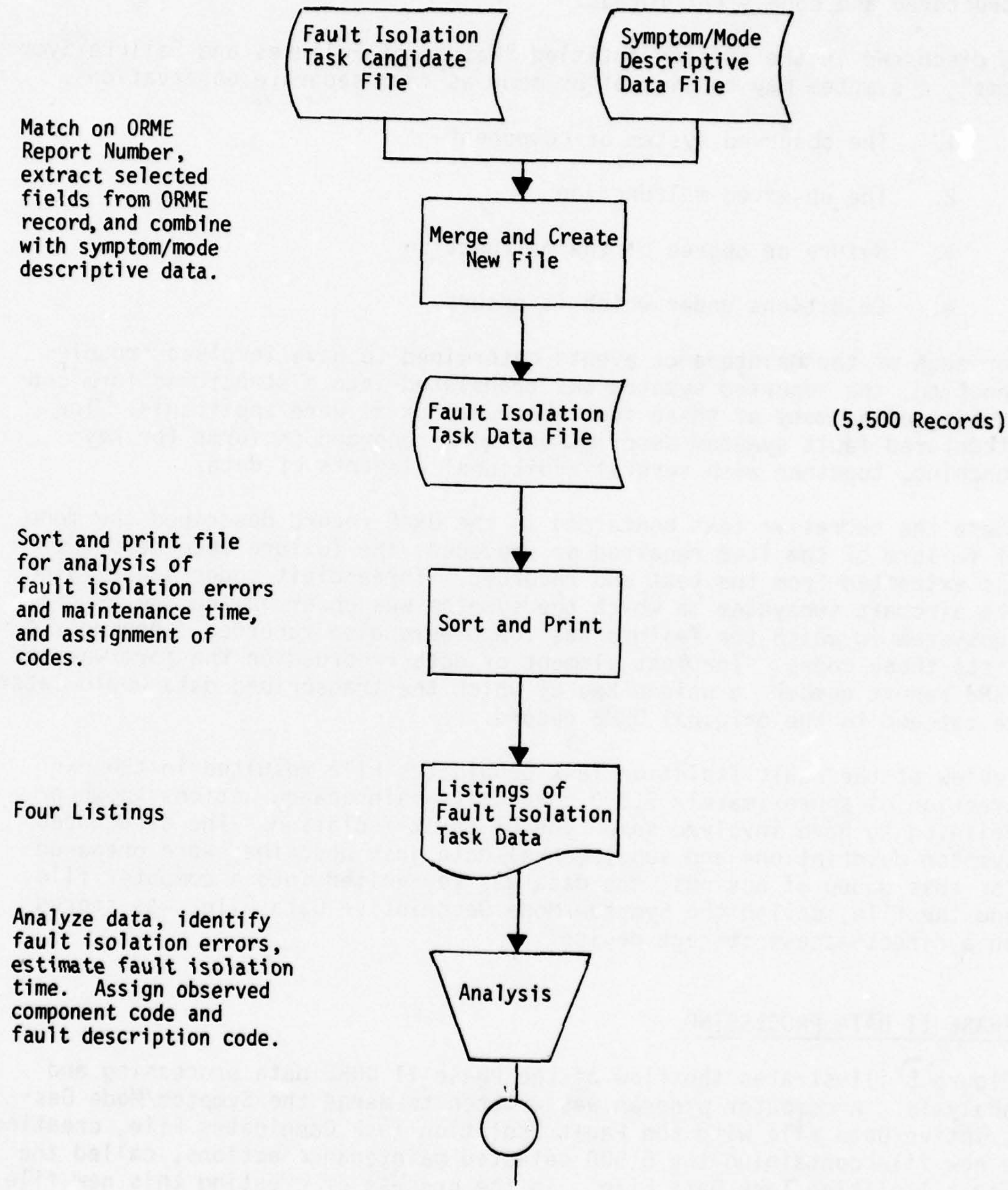

Figure 5. Phase II Data Processing and Analysis (1 of 2)

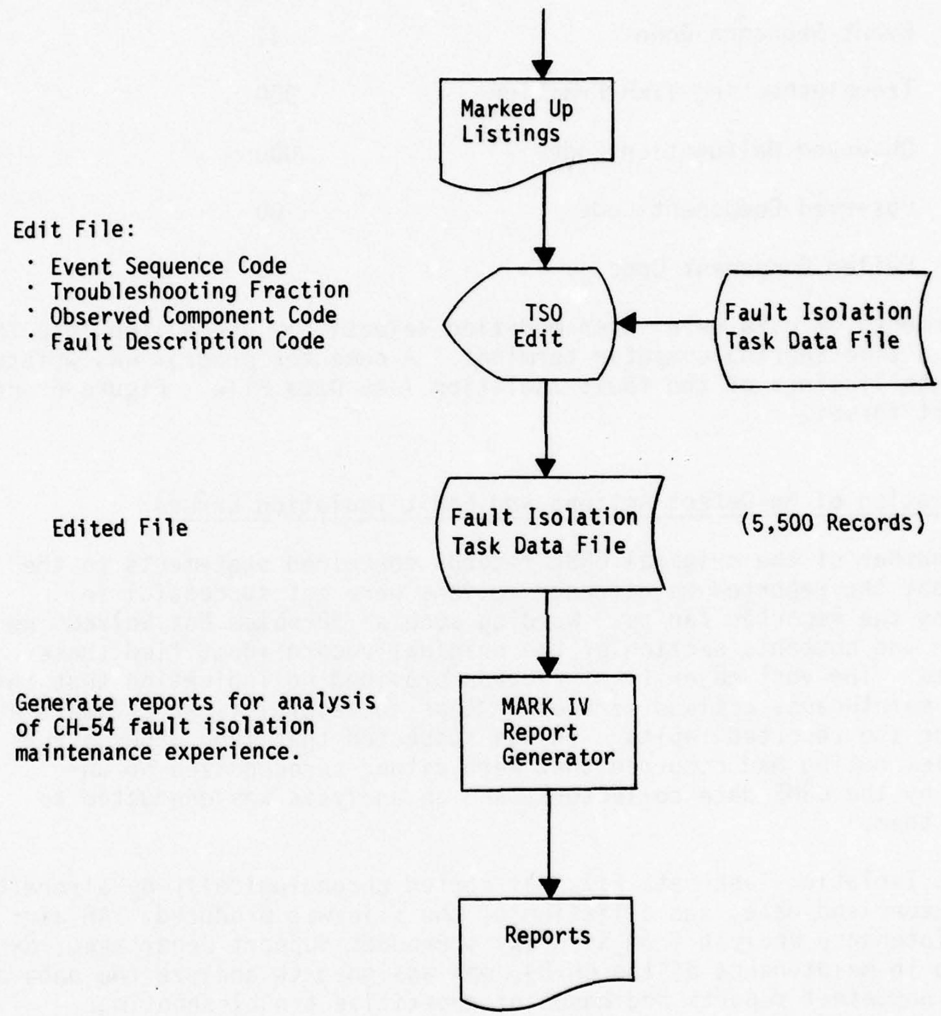

Figure 5. Phase II Data Processing and Analysis (2 of 2)

Table 3 shows the format of the Fault Isolation Task Data record and indicates the source of each field of data. Five fields of the record whose source is shown as "File Edit" were padded with constant data at this point as shown below.

Field	Initial Value
Event Sequence Code	11
Troubleshooting Time Fraction	050
Observed Malfunction Code	000
Observed Component Code	00
Failed Component Code	00

These elements of data were later modified selectively and edited into the file via a time-sharing computer terminal. A computer program was written to generate listings of the fault Isolation Task Data File. Figure 6 shows the report format.

Identification of No-Defect Actions and Fault Isolation Errors

A small number of the original ORME records contained statements to the effect that the reported maintenance actions were not successful in correcting the reported faults. Wording such as "Problem Not Solved" recorded in the comments section of the original record identified these few events. The vast majority of records provided no indication that the reported maintenance actions were other than successful first attempts at correcting the reported faults. It was suspected that many other errors in troubleshooting had occurred that were either unrecognized or unreported by the ORME data collectors, and an analysis was conducted to identify them.

The Fault Isolation Task Data File was sorted chronologically by aircraft serial number and date, and a listing of the file was produced. An aircraft maintenance analyst from Sikorsky's Product Support Department, experienced in maintenance of the CH-54, was assigned to analyze the data and identify no-defect reports and cases of repetitive troubleshooting.

No-defect actions, i.e., reports of symptoms that could not be confirmed by maintenance personnel, were identified by either or both of the following conditions:

1. Failure Disposition Code

   D (Checked On-Aircraft - Tested OK) or
   G (Removed - Tested OK - Made RFI)

TABLE 3. FORMAT OF THE FAULT ISOLATION TASK DATA RECORD

Field	Source	Length
1. ORME Report Number	ORME Record	5
2. Event Sequence Code	File Edit*	2
3. Troubleshooting Time Fraction	File Edit	3
4. Observed Malfunction Code	File Edit	3
5. Observed System Code	S/M Record **	3
6. Observed Component Code	File Edit	2
7. Failed System Code	S/M Record	3
8. Failed Component Code	File Edit	2
9. Aircraft Model	ORME Record	6
10. Aircraft Serial Number	ORME Record	5
11. Reporting Organization Code	ORME Record	4
12. Date	ORME Record	6
13. Aircraft Total Time	ORME Record	5
14. Reason for Report Code	ORME Record	1
15. When Discovered Code	ORME Record	2
16. Mission Effect Code	ORME Record	1
17. Organizational Level Man-hours	ORME Record	3
18. Organization Level Elapsed Time	ORME Record	3
19. Direct Support Man-hours	ORME Record	3
20. Direct Support Elapsed Time	ORME Record	3
21. Total Aircraft Downtime	ORME Record	4
22. Personnel MOS Code No. 1	ORME Record	5
23. Personnel MOS Code No. 2	ORME Record	5
24. Failed Assembly Part Number	ORME Record	16
25. Failed Assembly Nomenclature	ORME Record	16
26. Failed Assembly Quantity	ORME Record	2
27. Failed Assembly Failure Mode	S/M Record	20
28. Failed Assembly Disposition	ORME Record	1
29. Sub-Assembly Part Number	ORME Record	16
30. Sub-Assembly Nomenclature	ORME Record	16
31. Sub-Assembly Quantity	ORME Record	2
32. Sub-Assembly Failure Mode	S/M Record	20
33. Sub-Assembly Disposition	ORME Record	1
34. Observed System or Component	S/M Record	20
35. Observed Malfunction Description	S/M Record	20
36. Nature/Degree of Malfunction	S/M Record	20
37. Symptom Conditions	S/M Record	20
		269

* Edited into the record via computer terminal.

**Symptom/Mode Descriptive Data Record

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REPT NO/ EVENT	ORG CODE/ DATE	ACFT/ TIME/ MODEL	OBS/ FLD SYS	HARDWARE FAULT/ NATURE OR DEGREE	FAULT DESCRIPTION/ FAULT CONDITIONS	ASSY PART NO / NOMENCLATURE / FAILURE MODE DESCRIP	QTY / DISP	S-ASSY PART NO / NOMENCLATURE / FAILURE MODE DESCRIP	QTY / DISP	ORG/ D S MHRS	FLT ISOL MHRS	ACFT DOWN TIME	D A S B C T
"04533 1 1	COCM 681021	18412 826.7 A	100 151	AIRCRAFT MED FREQ	VIBRATION	6410-20004-015 HEAD ASSY MR REQD PURGING	1 A		0	4.0 .0	1.2	2	10
"01816 1 1	R078 680425	18416 510.8 A	100 151	AIRCRAFT	VIBRATION	6410-20004-015 HEAD ASSY MR MAIN RTR OUT OF TRCK	1 A		0	9.0 .0	.9	3	03
"00138 1 1	R073 680226	18419 201.5 A	100 151	AIRCRAFT LATERAL	VIBRATION INCREASNG W/SPEED	6410-20004-015 HEAD ASSY MR	1 A	S1510-21169 LOCKNUT IMPROPER TORQUE	1 A	12.0 .0	3.6	3	10
"08563 1 1	R073 690413	18419 1,015.2 A	100 151	AIRCRAFT UNUSUAL-ALL 3 AXES	VIBRATION	6410-20004-015 HEAD ASSY M/R	1 B	S1510-21058-1 CONE,UPPER SPLIT OVERTORQUED	1 F	18.0 .0	1.8	5	10
"08564 1 1	R073 690413	18419 1,015.2 A	100 151	AIRCRAFT ALL AXES	VIBRATION	6410-20004-015 HEAD ASSY MR	1 B	S1510-21059 CONE LOWER SPLIT OVERTORQUED	1 F	18.0 .0	1.8	4	10
"07682 2 1	R073 690711	18419 1,100.5 A	100 151	AIRCRAFT SEVERE	VIBRATION	6410-20004-015 HEAD ASSY MR	1 A	S1510-21059 CONE LOWER SPLIT HEAVILY SCORED	1 E	30.0 .0	9.0	48	10
"08556 1 0	R073 690411	18429 704.5 A	100 151	AIRCRAFT	VIBRATION	6410-20004-015 HEAD ASSY MR	1 A	S1510-23357 LOCK NUT IMPROPER TORQUE	6 A	5.0 .0	1.5	5	10
"08552 1 1	R073 690410	18437 596.6 A	100 151	AIRCRAFT EXCESSIVE	VIBRATION WITH LOAD	6410-20004-015 HEAD ASSY MR WEAR	1 F		0	26.0 .0	2.6	7	10
"10710 1 1	R073 690731	18444 634.6 A	100 151	AIRCRAFT	VIBRATION	6410-20004-015 HEAD ASSY MR	1 F		0	30.0 .0	3.0	24	10
"04248 1 1	COCM 680819	18446 86.2 A	100 151	AIRCRAFT MED FREQ	VIBRATION	6410-20004-015 HEAD ASSY MR REQD PURGING	1 A		0	5.0 .0	1.5	2	10
"04724 1 1	C095 690204	18448 99.6 A	100 151	AIRCRAFT MODERATE LATERAL	VIBRATION	6410-20004-016 HEAD,MAIN ROTOR LACK OF LUBE	1 A		0	2.5 .0	.3		10
"04680 0 0	C095 690116	18457 37.5 A	100 151	AIRCRAFT VERTICAL	VIBRATION	6410-20004-016 HEAD,MAIN ROTOR IMPROPER TORQUE	1 D		0	3.5 .0	.4	2	10

Figure 6. Fault Isolation Task Summary

2. Failure Mode Description contains the statement "Checked OK" or similar language

When events of this type were encountered by the maintenance analyst, he was instructed to change the Event Sequence Code to "00" on the computer listing with which he was working.

The analyst also studied the listing looking for reports of symptoms that were not properly corrected by maintenance personnel, as evidenced by either or both of the following:

1. Failure Mode Description contains the statement "Problem Not Solved" or similar language.

2. The same or a similar symptom was reported on the same aircraft within a few flight-hours.

When either of these conditions was encountered, the analyst was instructed to change the second digit of the Event Sequence Code to zero on the computer listing. Further, when repetitive occurrences of the same symptom were detected, the analyst was instructed to change the first digit of the Event Sequence Code to indicate the chronological sequence of events after the first. For example, if three maintenance events related to the same malfunction were detected, the first digit of the Event Sequence Code for the first action in the series would be left unchanged at "1" and the first digit of the Event Sequence Code for the second and third actions would be changed to "2" and "3" respectively. Upon completion of the analysis, the Event Sequence Codes provided a numerical key by which no-defect actions and fault isolation errors were identified, and by which repetitive actions related to the same symptom were linked. Examples of modified codes are shown below:

Event Sequence Code	Interpretation
0 0	No-Defect Action
1 0	Unsuccessful Fault Isolation Task - 1st Event
1 1	Successful Fault Isolation Task - 1st Event (All events initially assigned this code.)
2 0	Unsuccessful Fault Isolation Task - 2nd Event
3 1	Successful Fault Isolation Task - 3rd Event

Analysis of Troubleshooting Time Factors

The original ORME data reported the total man-hours and elapsed maintenance time expended on each maintenance action. No breakdown of maintenance time was given, however, and it was not possible to separate fault isolation time from the repair, replace, and checkout portion of individual maintenance tasks. All of the 5,500 corrective maintenance events that survived the screening to be included in the final file were known to have involved, or were suspected of having involved, some type of fault isolation. Therefore, it was assumed that some fraction of the total maintenance time reported on each action was devoted to troubleshooting. An analysis was conducted to estimate these troubleshooting time fractions.

The Fault Isolation Task Data File had a field reserved in each record for the Troubleshooting Time Fraction, the estimated part of the total ORME reported man-hours expended on troubleshooting. Initially, all of the 5,500 records in the file were assigned a Troubleshooting Time Fraction of .50, i.e., an initial estimate that half of the reported man-hours were expended on troubleshooting. These estimates remained unchanged unless analysis indicated that a higher or lower fraction should be assigned to a given task.

Allowable Troubleshooting Time Fractions ranged from a minimum value of .1 to a maximum value of .9, except in the case of no-defect actions which were assigned a value of 1.0. Assignment of the value .1 indicated the analyst's opinion that most of the reported man-hours (90%) were expended on performing the final corrective action, i.e., on repairing or replacing the failed item. It reflected the view that the faulty item was probably found rather quickly or that the item was repaired or replaced without troubleshooting. Assignment of a .9 Troubleshooting Fraction, on the other hand, indicated the opinion that only a small part of the reported man-hours was expended performing the final corrective action and that the fault was probably difficult to locate. Fractions between .1 and .9 reflected the analyst's judgement of the relative difficulty of the troubleshooting task between these limits.

The listing of the Fault Isolation Task Data File was organized by common faults and failed items, so that all repairs or replacements of a given component related to a specific symptom were grouped together. The analyst scanned each grouping to determine whether some or all of the actions in the group should be assigned Troubleshooting Fractions higher or lower than the .50 value initially assigned. Guidelines for making these estimates were provided to him. Troubleshooting Time Fractions were revised for more than 3/4 of the records in the file, and the revised estimates were edited into the file via a computer terminal.

Addition of Observed Component Codes

As explained earlier, during creation of the file of 5,500 maintenance actions, three-digit codes were added to each record to identify the aircraft system in which the malfunction was observed and the system in which the failure was found. Space was reserved in each record to expand these codes by two digits to identify (where possible) the specific component of the aircraft observed to be malfunctioning and the specific component that had failed. The purpose of these additional codes was to facilitate computer processing of the data. It was later decided that the part numbers of the failed components recorded with the original ORME data were sufficient for computer processing and that the addition of a failed component code would be unnecessary.

The file of 5,500 maintenance actions was sorted by Observed System Code and Observed System or Component Description, and a listing of the file was produced. An analyst reviewed each record and, wherever the described fault cited a specific component of the aircraft, marked the listing with a two-digit code identifying that component. If the reported symptom cited only a system of the aircraft, no entry was made. The Observed Component Codes were added to the file via a time-sharing computer terminal. Appendix A contains the list of codes that were used.

Addition of Malfunction Description Codes

During creation of the file of 5,500 maintenance actions, the symptom descriptions recorded in narrative form with the original ORME reports were translated into a structured format consisting of four individual observations, one of which was the type of malfunction observed. The observed malfunction was recorded in each record in a 20-character field called Observed Malfunction Description. To aid computer processing of the data, a three-character field was reserved in each record for the addition of a numerical malfunction description code.

The file was sorted by Observed Malfunction Description and a listing of the file was produced. An analyst reviewed each entry and marked the listing with a three-digit numerical code corresponding to the described malfunction. Appendix B lists the Malfunction Description Codes. When slightly different descriptions of the same malfunction were encountered, the analyst combined them under a single code. The codes were added to the file via a computer terminal.

Generation of Reports

The computer program used to generate file listings for the various analyses just described was modified to print the following totals at specified changes in key fields as shown in Figure 7.

Total Organizational Level Man-hours (OHRS)

Total Direct Support Man-hours (DHRS)

Total Aircraft Downtime (DOWN)

Total Mission Aborts (ABT)

REPT NO/ EVENT	ORG CODE/ DATE	ACFT/ TIME/ MODEL	OBS/ FLD SYS	HARDWARE FAULT/ NATURE OR DEGREE	FAULT DESCRIPTION/ FAULT CONDITIONS	ASSY PART NO --- NOMENCLATURE -- FAILURE MODE	QTY DISP DESCRIP	S-ASSY PART NO - NOMENCLATURE -- FAILURE MODE	QTY DISP DESCRIP	ORG/ D S MHRS	FLT ISOL MHRS	ACFT DOWN TIME	D S C	A B T
"24696 1 1	COCH 730309	18485 528.2 B	220 291	ENGINE #1	SURGING WHEN BEEPING DOWN	6430-80326-102 ACTUATOR,SPEED INT FAILURE	1 F		0	1.5 .0	.5		10	X
"03357 1 1	R055 681015	18438 250.6 A	220 291	ENGINE	SURGING	6430-80332-041 SYNC ASSY COLL OUT OF RIG	1 A		0	9.0 .0	2.7	3	10	
"22553 1 1	C091 730928	18478 514.7 B	220 221	ENGINE	SURGING	658705 FUEL CONTROL INTERNAL FAILURE	1 F		0	.0 16.0	8.0	828	11	
"21713 1 1	C073 731227	18479 642.0 B	220 221	ENGINE 5-10 PERCENT	SURGING ENG UNLOADED	658785 FUEL CONTROL INTERNAL FAILURE	01 E			.0 17.0	8.5	36	11	
"21629 2 1	C091 731026	18480 497.0 B	220 221	ENGINE NO 1	SURGING DURING RUN-UP	658785 FUEL CONTROL INTERNAL FAILURE	1 F		0	.0 18.5	5.6	48	11	
"20237 0 0	C073 740315	18469 836.0 B	220 221	ENGINE NO 2 6 PERCENT	SURGING AT FLAT PITCH	658785 FUEL CONTROL CHECKED OK	01 D			.0 1.0	1.0	4	02	X
"21703 1 1	C073 740204	18487 600.4 B	220 221	ENGINE NO 2 5 PERCENT	SURGING HI & LOW PWR SETTNGS	658785 FUEL CONTROL INTERNAL FAILURE	01 F			.0 17.0	5.1	8	11	
"24288 0 0	COCH 721114	18484 366.7 B	220 220	ENGINE	SURGING	662000 ENGINE ASSY #2 CHECKED OK	1 D		0	.0 3.0	3.0	1	03	
"21664 1 1	C073 731114	18469 768.7 B	220 220	ENGINE NO 1 7 PERCENT	SURGING DURING GRND RUN	662000 ENGINE ASSY #2	1 F		0	.0 27.0	8.1	120	11	
"22377 1 1	COCH 720204	18486 287.0 B	220 221	ENGINE NO 2	SURGING	739240-1 FUEL CONTROL	1 F		0	36.2 .0	10.9	78	02	X
"23704 1 1	C091 730110	18487 401.1 B	220 221	ENGINE NO 2 2 PERCENT	SURGING WITH NO LOAD	739240-1 FUEL CONTROL	1 F		0	.0 16.0	4.8	8	06	

SUMMARY BREAK :
* OBSERVED FAULT OHRS: 405.9 DHRS: 383.3 ISOL: 325.0 DOWN: 2,430.4 ABT: 27

Figure 7. Fault Isolation Task Summary With Total Lines

When the file editing was complete, a series of reports was generated for analysis of fault isolation maintenance experience on the CH-54.

ANALYSIS OF FAULT ISOLATION PROCEDURES

An analysis was conducted to evaluate troubleshooting data contained in the maintenance manuals for the CH-54 helicopter. Troubleshooting data extracted from the manuals were compared with the symptoms and causes actually experienced with the CH-54 in the field, as documented in the ORME records. Each symptom reported in the ORME data was cross-referenced to the troubleshooting table(s) in which it was covered. Symptoms listed in the manuals but not experienced in the field were noted. A population of symptoms experienced in the field was examined in detail to determine the extent to which significantly occurring causes are covered by the manuals and the efficiency of the troubleshooting instructions relative to isolating the most probable causes.

FIELD SURVEY METHODS

The original plan for this program called for surveying fault isolation maintenance experience with the CH-54 helicopter at representative field operating activities. The objective of the surveys was to obtain information on fault isolation maintenance problems with Army aircraft in the field. After the CH-54 field surveys were completed and the results of the surveys were analyzed, it was concluded that the CH-54, because of the exceptionally high experience level of the crew chiefs and flight engineers doing the majority of troubleshooting on the aircraft, may not have been representative of other helicopters in the Army inventory. It was decided at that point to modify the program to include surveys of two other current-inventory helicopters. The AH-1 and CH-47 helicopters were selected for these additional surveys because these two models are expected to remain in the inventory for many years. The purpose of the additional surveys was to attempt to determine if the conclusions about helicopter fault isolation maintenance arrived at through study of the CH-54 were applicable to the Army helicopter fleet as a whole.

Table 4 lists the dates and locations of the surveys and the number of people interviewed at each survey. Interviews were conducted with a total of 35 maintenance personnel and 6 pilots. Table 5 lists the MOS and rank of the survey participants.

TABLE 4. FIELD SURVEY SCHEDULE

Date	Location	Unit	Acft. Model	Acft. Qty.	Persons Interviewed
April 18-20	Fort Sill, Oklahoma	273rd Transportation Company	CH-54B	9	7
May 3-4	Fort Rucker, Alabama	Northrop Worldwide Aviation Services	CH-54B	3	3
May 15-18	Topeka, Kansas	137th Aviation Co. Army National Guard	CH-54A	9	7
June 5-8	Fort Wainwright, Alaska	343rd Aviation Detachment	CH-54B	4	9
October 11-12	Fort Campbell, Kentucky	A Company, 159th Aviation Bn, 101st Airborne Division	CH-47C	16	8
October 18-19	Fort Bragg, North Carolina	A and B Troops, 1/17 Air Cavalry, 82nd Airborne Division	AH-1G/ AH-1S	5 13	7

TABLE 5. MOS AND RANK OF FIELD SURVEY PARTICIPANTS

Military Occupational Specialty (MOS)/Job Title		Pay Grades				
		E-4 E-5	E-6 E-7	CW-2 CW-3 CW-4	Cap-tain	Civil-ian
35K	Avionics Mechanic		1			
35L	Avionics Communications Equipment Repairman	1				
35P	Avionics Equipment Maintenance Supervisor		1			
67U	Medium Lift Helicopter Repairman	2	4			
67W	Aircraft Quality Control Supervisor		2			
67X	Heavy Lift Helicopter Repairman	4	9			
67Y	Attack Helicopter Repairman	1	1			
67Z	Aircraft Maintenance Senior Sergeant		2			
68B	Aircraft Power Plant Repairman	1				
68F	Aircraft Electrician	3				
	Master Mechanic					1
	Avionics Technician					1
100	Pilot			5	1	1
	Total	12	20	5	1	3

GENERAL SURVEY METHOD

Each interview was attended by a group of from two to three maintenance personnel. Most sessions were attended also by at least one pilot. At the start of each session with a new group, the objectives of the program were explained. The participants were advised that the purpose of the interviews was to learn what the experience of people working in the field had been relative to certain maintenance problems with the aircraft, and that the questions they would be asked were not intended to test their knowledge or ability. Further, it was explained that many of the symptoms to be discussed were known to occur infrequently and that they may, therefore, not have experienced a given problem or may not have experienced it recently enough to recall the needed information. Whenever they felt unsure about discussing a particular area of maintenance, they were instructed to state so, and that topic would be omitted.

Prior to the start of each session, a personnel data sheet was filled out for each person in the group. Shown in Figure 8, the data sheet recorded information relative to each individual's training, maintenance experience, and present job assignment.

CH-54 SURVEY QUESTIONNAIRE

The CH-54 surveys were organized into three sections. The first section consumed a major part of each survey and covered a detailed discussion of typical symptoms and their causes and the problems involved with troubleshooting these symptoms. The second section required much less time and explored the participant's knowledge of symptoms associated with the failure or malfunction of various aircraft components. At the close of each survey, a brief period was spent with some general questions related to fault isolation maintenance. Overall concerns and recommendations were also solicited.

In preparation for the surveys, the processed ORME data on the CH-54 was examined, and a population of symptoms having a high frequency of occurrence, a significant troubleshooting error rate, and/or requiring a high average number of man-hours to fault isolate were selected for study. Several infrequently occurring symptoms were included in the sample to test the ability of field personnel to recognize problem frequency. A total of 36 symptoms comprised the selected sample.

CH-54 Survey, Part I

A three-page questionnaire, shown in Appendix C, was developed to collect data on the sample of 36 symptoms. Each symptom was covered by a separate questionnaire. Part A of the questionnaire described the symptom. Part B contained six questions related to the detection and reporting of the symptom and its frequency of occurrence. Questions pertaining to confirmation of the symptom and the occurrence of no-defect reports were covered in Part C.

PERSONNEL DATA

Name: ______________________ MOS: ________ Rank: ________

Unit: ______________________ Location: ______________

TRAINING:

All Helicopter: ______________________________

Survey Model: ______________________________

MAINTENANCE EXPERIENCE (YEARS):

All Helicopter: ____________ Survey Model: __________

TROUBLESHOOTING EXPERIENCE (YEARS):

All Helicopter: ____________ Survey Model: __________

SYSTEM EXPERIENCE:

☐ Airframe ☐ Rotors ☐ Fuel

☐ Landing Gear ☐ Power Plant ☐ Hydraulics

☐ Flight Controls ☐ Drives ☐ Electrical

☐ Utilities ☐ Instruments ☐ Avionics

CURRENT ASSIGNMENT:

☐ AVUM ☐ AVIM Function: ______________

Figure 8. Personnel Data Sheet

In Part D, field personnel were asked to list, in order of probability, known causes or possible causes of the symptom. As many as five causes (failed or defective components) could be listed, and the participants were asked to rank the relative ease or difficulty of diagnosing each cause. The ranking considered both the ease of checking the component in place or, in the absence of a method of checking the component, the ease of replacing it as a method of confirming or eliminating the cause. Also in Part D the participants were asked to judge from their own experience whether the fault isolation error rate related to that symptom, as reflected by the ORME data, was high, low, or average.

Part E of the questionnaire asked the participants to describe their approach to troubleshooting the symptom and to estimate the relative difficulty of the task and the time involved. Part F covered resources used in the troubleshooting task and asked the participants to assess their adequacy.

The questionnaires were filled in by the Sikorsky engineer conducting the interviews. Questions were asked in the context of an informal discusssion, and the participants were encouraged to volunteer opinions and to make recommendations.

CH-54 Survey, Part II

Part II of the CH-54 survey was concerned with assessing the ability of field personnel to recognize symptoms associated with the failure or malfunction of specific aircraft components. Prior to the start of the surveys, the processed ORME data was searched for components which had caused varied malfunctions of the aircraft, i.e., had exhibited multiple symptoms in service. A sample of 30 components was selected.

Forms were prepared on which to record the nomenclature and part number of the 30 components, and the symptoms of failure related to each that were suggested by field personnel during the interviews. The form is shown in Appendix C. Illustrations taken from the aircraft parts catalogs were shown to the people being interviewed when they had trouble recognizing a particular component from the nomenclature and part number.

CH-54 Survey, Part III

The concluding part of each CH-54 survey involved a general discussion of fault isolation maintenance during which the participants were encouraged to comment on any subject of concern or interest to them. In addition, two general questions designed to assess field personnel's perception of fault isolation work, relative to their other duties, were asked:

1. On average, what percentage of your working time is spent on troubleshooting versus all other types of maintenance (servicing, inspection, repair, replacement, etc.)? People experiencing difficulty arriving at a percentage

value were asked to estimate in such terms as the number of hours per week, number of days per month, etc.

2. What percentage of the total failures (repairs and replacements) occurring on the aircraft would you estimate are discovered via inspection versus troubleshooting?

Visit to the Aviation Maintenance Training School

Included in the CH-54 field surveys was a visit to the U. S. Army Aviation Maintenance Training School at Fort Eustis, Virginia, to discuss training in fault isolation maintenance. Interviews were conducted with two instructors teaching the Heavy Lift Helicopter Repairman's Course (MOS 67X), one of whom was a former CH-54 flight engineer and the other a former CH-54 crew chief. Discussions covered the scope of training in fault isolation maintenance, the nature of the training, and the use of training aids and materials. Opinions concerning deficiencies with current instruction and methods of improving fault isolation skills in the field were solicited. The prospect of creating a troubleshooting specialist MOS for Army aviation was explored.

AH-1 AND CH-47 SURVEY QUESTIONNAIRE

The study of fault isolation maintenance experience with the CH-54 involved both an analysis of recorded maintenance data on the aircraft and surveys of representative CH-54 operating bases. The field surveys were structured along specific lines of inquiry that analysis of the historical data had indicated were fault isolation problem areas. Lacking an equivalent source of data for the AH-1 and CH-47 helicopters, it was necessary to develop a more general survey method for these aircraft.

The primary objective of surveying these two aircraft was to determine whether the scope of nonavionics systems troubleshooting established for the CH-54 and its cost to the Army in terms of man-hours, error rate and improper parts replacements were typical of other helicopters in the inventory. There was reason to suspect that the exceptionally high experience level of the CH-54 crew members minimized the problems they had with troubleshooting. The second objective was to determine whether criticisms voiced by CH-54 maintenance personnel related to such topics as technical manuals and training were shared by maintenance personnel assigned to other aircraft in the inventory.

Assessing the magnitude and cost of fault isolation maintenance on the AH-1 and CH-47 helicopters presented a greater problem than it had on the CH-54, since it required that all of the quantitative data be obtained through interviews. (With the CH-54, the interviews were used only to supplement quantitative data developed through analysis of the ORME records.) It was known at the outset that field personnel would have difficulty making quantitative estimates of problem frequency, error rates, etc. An effort was made to facilitate this task by requesting that the estimates be given in terms to which field personnel could most easily relate, such as the number of times they would expect to perform a given task in a month or a year, and by bracketing estimates in terms such as the percentage of tasks requiring more than 8 hours, less than 1 hour, etc. The second objective was one that could be met using basically the methods that had been used to survey maintenance experience on the CH-54. Because the surveys of the AH-1 and CH-47 were to be less detailed than the survey of the CH-54, it was possible to expand somewhat that part of the survey dealing with these topics.

A copy of the AH-1/CH-47 field survey questionnaire is contained in Appendix C. The questionnaire contains 50 questions organized into eight general topic areas. Part I covers statistical data on the numbers and utilization of aircraft at the survey site. Parts II and III address the detection, reporting and troubleshooting of symptoms experienced on the aircraft. Instrument-related symptoms were found to be a significant contributor to fault isolation problems on the CH-54, and Part IV of the AH-1/CH-47 questionnaire contains several questions on this subject. Troubleshooting resources (technical data, training and test equipment) are covered in Parts V through VII. Part VIII concludes the questionnaire with questions related to two major recommendations evolving from the CH-54 surveys.

STATE-OF-THE-ART SURVEY

Visits were made to three Army agencies and one defense contractor to survey current technology in the development and publication of fault isolation maintenance data for the new-generation Army systems. The following offices were visited:

U.S. Army Material Readiness Support Activity (MRSA),
Lexington, Kentucky

AAH Program Office, St. Louis, Missouri

U.S. Army Tank-Automotive Readiness Command (TARCOM),
Sterling Heights, Michigan

Warren Defense Division, Chrysler Corporation, Warren, Michigan

Discussions centered on the SPA (Skill Performance Aids) concept in the technical publications field, and specifically the extent to which the Front End Analysis (FEA) technique required by SPA was affecting the scope and content of troubleshooting procedures. MRSA, the agency with cognizance over SPA, was visited first to discuss the overall concept and its application. The effects of SPA on troubleshooting procedures for the Army's Advanced Attack Helicopter (AAH) and XM-1 Tank were investigated in the remaining three visits.

RESULTS OF THE ORME DATA ANALYSIS

ANALYSIS AND TABULATION OF SYMPTOMS

The first step in analysis of the ORME data was to sort the file of 5,500 maintenance actions by Observed System Code, Observed Component Code, and Malfunction Description Code. This sequenced the file by symptoms and collected together the ORME records associated with each symptom.

The file was listed and analyzed, and a tabulation was made of the recorded symptoms. Whenever the same symptom, or essentially the same symptom, was found described in different ways, the two or more descriptions were combined into a single symptom description. As reported earlier, some combining of differently described symptoms had been accomplished when the Malfunction Description Codes were being assigned during creation of the file.

Each of the tabulated symptoms was listed in the standard format as follows:

Observed System or Component/
    Observed Malfunction; Alternate Malfunction Description*
    (Nature, Degree, Conditions)*

*where applicable

Typical symptom descriptions derived from the ORME data are listed below:

Aircraft/
    Vibration (High Frequency)

Collective Stick/
    Creeps; Light; Heavy

EPR Indicator/
    Fluctuating; Erratic

Cargo Hook/
    Will Not Release

Symptoms were then grouped according to general types of system malfunctions, and tables summarizing the principal ORME-recorded statistics were prepared. A section from one of these tables is shown in Figure 9. The right-most column of the table contains the number of different causes recorded in the ORME data for each symptom.

Type of Symptom: Wheel Brake Malfunctions								
Symptom	Maintenance Events Total	No Defect	Error	Man-Hours Total	Fault Isol.	Acft. Down Time	Mission Aborts	No.of Causes
Wheel Brakes/ Soft; Spongy	10			18	5	11		2
Wheel Brakes/ Binding; Grabbing; Chattering	15	2		58	16	54		2
Wheel Brakes/ Locked Up; Will Not Release	11	1	5	37	9	25		1
Parking Brake/ Inoperative; Will Not Hold; Will Not Release	19		1	42	13	31		6
Total	55	3	6	155	43	121		11

Figure 9. Sample Fault Symptom Table

Symptom Grouping and Classification

An effort was made at two different stages of the analysis to group together multiple descriptions of the same symptom. In many cases it was obvious from the descriptions themselves that exactly the same symptom, or essentially the same symptom, was being reported. "Collective stick stiff" and "collective stick binding" are two different descriptions of essentially the same malfunction. It may be assumed in cases such as these that the two descriptions would be used interchangeably and that field personnel would view either report as the same troubleshooting problem.

In many other cases it was suspected that different descriptions were being used to report the same symptom, but there was no way of establishing that fact from the data. A typical example is the symptom "engine surging" and the symptom "engine tach indicator fluctuating". It is logical to believe that a surging engine would be detected by, or accompanied by, fluctuation or surging of the tach indicator. But it cannot be concluded definitely that the symptoms are the same. If the pilot observed a fluctuating tach, he would probably report the problem that way, not knowing if he was experiencing a surging engine or a faulty indicator. The report "engine surging" can almost definitely be regarded by maintenance personnel as an engine problem, whereas the report "tach indicator fluctuating" may be either an engine problem or an instrument problem. Of course some pilots may have reported known engine surging as a fluctuating tach. In these cases the reports should properly have been included under the engine surging symptom, but there was no way of separating these events from the others.

Another example wherein two symptoms may be describing the same malfunction but sufficient evidence is lacking to combine them occurs with the symptoms "low hydraulic pressure" and "hydraulic pressure gage reads low". Here, in addition to observing an instrument indication, the pilot may have known that his hydraulic pressure was low, due to slow or sluggish operation of some system or equipment, or may have merely observed a low pressure reading on the gage. In one case the problem is definitely with the hydraulics system, whereas in the other it may be a problem with either hydraulics or instruments. Again, there is no way of telling from the description given whether the symptoms being reported are the same or different.

Rather than err by grouping together similar-sounding but different symptoms, when doubt existed they were treated separately. To some extent this may have resulted in the appearance of more symptoms than were actually experienced with the CH-54 and may, as a result, have influenced some of the statistics generated from this analysis. This will be commented upon later in the report when the respective data are presented and discussed.

A total of 57 general types of symptoms and 542 individual symptoms were found reported in the ORME data for the CH-54. Table 6 summarizes overall statistics for the 57 general types of symptoms, which are tabulated in descending order by average frequency of occurrence.

Distribution of Symptoms by Aircraft System

During creation of the Fault Isolation Task Data File, codes were inserted into each record to identify the aircraft system in which the symptom was observed and the aircraft system in which the failure was found. Table 7 shows the distribution of symptoms by observed system and failed system.

- The cause of approximately 1/3 of all symptoms was found in an aircraft system other than the one in which the symptom was observed.

The aircraft systems having some modes of failure appearing as symptoms in other systems are indicated by the column entries in Table 7. Drives, Powerplant Installation, Electrical and Hydraulics are four systems with symptoms of failure appearing in more than 50% of all aircraft systems. The aircraft systems having some symptoms of failure traced to failure modes in other systems are indicated by the row entries in Table 7. Air-

TABLE 6. SUMMARY OF ORME DATA BY GENERAL TYPES OF SYMPTOMS

General Type of Symptom	No. of Fault Symptoms	Rate per 100 Flight Hours							Per Action Average	
		Total Actions	No-Defect Actions	Fault Isol. Errors	Total Man Hrs.	Fault Isol. Man Hrs.	Acft. Down-Time	Mission Aborts	Fault Isol. Man Hrs.	Fault Isol. Errors %
APP Starting and Engagement Problems	13	1.093	.011	.104	3.534	1.350	6.664	.286	1.2	9.5
AFCS Malfunctions	52	1.061	.070	.082	2.221	1.216	4.382	.042	1.4	7.7
Flight Instrument Malfunctions and Abnormal Indications	50	.994	.051	.045	1.182	.672	1.016	.019	0.7	4.5
Engine Controls Malfunctions	12	.858	.019	.085	3.558	1.642	4.024	.090	1.9	9.9
Aircraft Vibration	10	.725	.029	.112	6.387	1.795	1.1442	.064	2.5	15.5
Abnormal Engine Speed or Acceleration	7	.678	.018	.131	3.606	1.467	8.227	.109	2.2	19.3
Fuel Supply System Caution Lights	20	.675	.014	.034	.936	.336	.915	.018	0.5	5.0
Abnormal Engine Tach Indications	28	.627	.006	.040	2.022	.616	2.643	.059	1.0	6.4
Improper Rotor System Speed or Track and Main Rotor Droop Stop Malfunctions	7	.611	.003	.056	3.021	.389	3.008	.030	0.6	9.2
Abnormal Engine Torquemeter Indications	10	.478	.006	.030	1.198	.538	1.605	.011	1.1	6.4
Rotor Brake Malfunctions	8	.440	.014	.026	.837	.309	.750	.014	0.7	5.8
Engine Starting Problems and Inadvertent Engine Motoring	14	.434	.018	.019	2.658	1.053	10.125	.098	2.4	4.4
Abnormal T5 (Exhaust Gas Temperature) Indications	6	.389	.008	.042	2.254	.362	2.360	.056	0.9	10.7
Flight Control System Binding, Interference and Restricted Travel	7	.336	.008	.051	2.291	1.176	5.925	.034	3.5	15.2

TABLE 6 (Continued)

General Type of Symptom	No. of Fault Symptoms	Rate per 100 Flight Hours							Per Action Average	
		Total Actions	No-Defect Actions	Fault Isol. Errors	Total Man Hrs.	Fault Isol. Man Hrs.	Acft. Down-Time	Mission Aborts	Fault Isol. Man Hrs.	Fault Isol. Errors %
Abnormal Engine Fuel Flow and Fuel Pressure Indications	11	.331	.008	.030	1.619	.470	3.562	.029	1.4	9.2
Cargo Hoist Malfunctions	10	.294	.006	.048	1.818	.896	4.024	.045	3.0	16.3
Cargo Hook Malfunctions	8	.294	.006	.034	1.912	1.251	1.731	.051	4.3	11.4
Drive System Caution Lights	10	.294	.019	.003	1.240	.246	1.709	.062	0.8	1.1
Cabin Heating System Malfunctions	3	.254	0	.022	.398	.149	.378	0	0.6	8.8
Abnormal EPR (Engine Pressure Ratio) Indications	8	.250	.008	.022	.482	.266	.728	.003	1.1	9.0
Electrical System Caution Lights	6	.232	.003	.018	1.050	.238	1.709	.104	1.0	7.6
Engine Caution Lights	13	.227	.014	.011	.347	.174	.328	.022	0.8	4.9
Inadvertent or Unintentional Control System Movement	10	.216	.006	.030	1.083	.624	3.254	.019	2.9	14.1
Landing Gear Malfunctions	6	.216	.003	.008	.731	.250	.445	0	1.2	3.7
Abnormal Engine Oil Pressure and Temperature Indications	10	.213	0	.006	.546	.123	1.059	.034	0.6	3.0
Rotor Brake Caution and Advisory Lights	5	.208	.006	.006	.331	.112	.320	.014	0.5	3.1
Engine Air Particle System (EAPS) Malfunctions	7	.182	0	0	.310	.118	.235	.008	0.6	0.0
Abnormal MGB (Main Gearbox) Oil Temperature and Oil Pressure Indications	6	.176	.003	.029	.862	.182	1.362	.048	1.0	16.4

TABLE 6 (Continued)

General Type of Symptom	No. of Fault Symptoms	Rate per 100 Flight Hours							Per Action Average	
		Total Actions	No-Defect Actions	Fault Isol. Errors	Total Man Hrs.	Fault Isol. Man Hrs.	Acft. Down-Time	Mission Aborts	Fault Isol. Man Hrs.	Fault Isol. Errors %
Erratic or Uncontrolled Aircraft Motion and Unusual Aircraft Noises	7	.176	.014	.003	1.213	.642	1.378	.022	3.6	1.8
Abnormal APP (Auxiliary Powerplant) Instrument Indications and Caution Lights	10	.171	.003	.022	.261	.160	.246	.014	0.9	13.1
Abnormal Hoist System Instrument Indications	6	.171	.008	.008	.235	.074	.186	0	0.4	4.7
AC/DC Electrical Systems Malfunctions	7	.160	.006	.014	.779	.232	.978	.029	1.5	9.0
Wheel Brake Malfunctions	4	.152	.008	.018	.434	.120	.339	0	0.8	10.9
APP Speed or Acceleration Problems; Power Losses and Shutdowns	7	.149	0	.006	.432	.202	.571	.030	1.4	4.3
APP (Auxiliary Powerplant) Caution and Advisory Lights	7	.146	.003	.018	.154	.045	.146	.003	0.3	12.1
Four-Point Cargo System Malfunctions	11	.146	0	0	.331	.142	.216	0	1.0	0.0
Cyclic Trim System Malfunctions	4	.120	.006	.029	.344	.182	.328	0	1.5	24.0
1st and 2nd Stage Servo System Malfunctions	9	.075	.003	.022	.280	.152	.339	.029	1.3	18.7
Utility and Hoist Hydraulic System Malfunctions	12	.115	.014	.011	.350	.118	.373	.029	1.0	9.5
Hydraulic System Caution and Advisory Lights	6	.107	.003	.006	.194	.067	.190	.011	0.6	6.0
Abnormal Fuel Quantity Indications	8	.101	.003	.006	.675	.090	.230	0	0.9	6.3

TABLE 6 (Continued)

General Type of Symptom	No. of Fault Symptoms	Rate per 100 Flight Hours							Per Action Average	
		Total Actions	No-Defect Actions	Fault Isol. Errors	Total Man Hrs.	Fault Isol. Man Hrs.	Acft. Down-Time	Mission Aborts	Fault Isol. Man Hrs.	Fault Isol. Errors %
Engine Power Losses, Flame Outs and Shutdowns	3	.101	.003	.006	.702	.235	1.104	.040	2.3	6.3
Miscellaneous Caution Lights	8	.093	.006	0	.152	.086	.198	0	0.9	0.0
Cargo Hoist and Load Leveler Caution and Advisory Lights	8	.085	0	.003	.238	.120	.134	.003	1.4	25.0
Inadequate or Improper Control System Response	5	.078	.008	.003	.272	.086	.765	.006	1.1	4.1
Fuel System Malfunctions	12	.070	.003	0	.246	.118	.232	0	1.7	0
Miscellaneous APP Problems	6	.064	0	0	.485	.141	.712	.008	2.2	0.0
Miscellaneous Engine Malfunctions	9	.064	.008	.003	.802	.232	1.669	.019	3.6	5.0
Windshield Wiper and Windshield Washer Malfunctions	3	.062	.003	.003	.085	.030	.082	0	0.5	5.1
Landing Gear Caution and Advisory Lights	5	.040	.003	.003	.022	.011	.018	.003	0.3	8.0
Abnormal Hydraulic Pressure Readings	6	.034	0	.003	.029	.008	.299	0	0.2	9.5
Transmission Oil System Malfunctions	3	.022	0	0	.120	.045	.090	0	2.0	0.0
Voice Warning System Malfunctions	4	.022	0	.006	.026	.011	.026	0	0.5	28.6
Gearbox and Clutch Malfunctions	3	.019	0	.003	.040	.019	.026	.003	1.0	16.7

TABLE 6 (Continued)

General Type of Symptom	No. of Fault Symptoms	Rate per 100 Flight Hours							Per Action Average	
		Total Actions	No-Defect Actions	Fault Isol. Errors	Total Man Hrs.	Fault Isol. Man Hrs.	Acft. Down-Time	Mission Aborts	Fault Isol. Man Hrs.	Fault Isol. Errors %
Flight Control Servo Malfunctions	6	.018	0	0	.048	.022	.051	0	1.3	0.0
Inadvertent or Unintentional Control System Movement	3	.018	.006	0	.146	.082	.082	.008	4.6	0.0
Makeup Hydraulic System Malfunctions	3	.011	0	0	.022	.011	.029	.003	1.0	0.0
TOTAL	542	15.421	.468	1.320	57.551	21.503	94.970	1.629	1.4	8.6

TABLE 7. DISTRIBUTION OF SYMPTOMS BY OBSERVED SYSTEM AND FAILED SYSTEM (PERCENT OF OBSERVED SYMPTOMS)

Aircraft System in Which Symptom was Observed	Aircraft System in Which Failure was Found														% of Symptoms Observed
	10	13	14	15	22	24	26	29	42	45	46	49	51	57	
10 Aircraft General		3.6	3.6	51.3	1.3		15.9	12.3	0.3			0.6	0.3	10.6	5.5
13 Landing Gear		98.5								1.5					2.4
14 Flight Controls			50.2	2.3	2.5		1.1	23.5		2.8				17.9	5.1
15 Rotors				98.2				1.8							4.0
22 Turbo Shaft Engines					45.1	2.7	1.1	44.0	0.7	6.3			0.2		8.1
24 Auxiliary Powerplant						83.8	14.9	0.2	0.4		0.7				9.8
26 Drives & Transmissions							96.5	1.7	1.2				0.6		3.1
29 Powerplant Installation					2.9		0.3	94.8		2.1					6.9
42 Electrical Power Supply									100.0						1.0
45 Hydraulic Power Supply			1.1							97.8				1.1	1.7
46 Aircraft Fuel									7.4		70.4		22.2		0.5
49 Miscellaneous Utilities							0.3		0.5	14.9		84.3			6.9
51 Instruments		0.6	0.5	0.1	10.6	2.1	9.2	3.0	3.7	1.9	8.4	5.0	52.6	2.3	38.3
57 Automatic Flight Control			1.6	0.3					0.8	0.3			1.3	95.7	6.7
Percent of Failures Found	0.0	2.8	3.2	6.9	8.1	9.2	9.1	13.2	2.7	4.2	3.6	7.8	20.4	8.8	100.0

craft General, Flight Controls, Engines and Instruments are four aircraft systems exhibiting symptoms of failure whose cause was found in other aircraft systems 50% or more of the time. Of greatest significance:

- Approximately 50% of all symptoms observed via aircraft instruments and warning devices indicated a failure of the instrument or warning device rather than a failure of the monitored system.

- Approximately 20% of all symptoms exhibited by nonavionics systems of the helicopter were caused by the failure of aircraft instruments and warning devices.

Distribution of Symptoms by When Discovered

Symptoms were tabulated by when-discovered category with the following result:

When Discovered	% of Symptoms
APP Start to Takeoff	10.9
APP Start to Takeoff (Abort)	5.6
In-flight	49.9
In-flight (Abort)	4.4
On-ground to Engine Shutdown	9.0
Inspection	7.9
Other	12.3
	100.0

- More than 50% of all symptoms were exhibited during flight of the aircraft.

- Ten percent of all symptoms resulted in an aborted mission.

FREQUENCY AND COST OF FAULT ISOLATION MAINTENANCE

Frequency of Fault Isolation Maintenance

More than 80% of the ORME data covers the CH-54A aircraft. The mean time between corrective maintenance actions on the CH-54A, as calculated from the ORME data, is approximately 3.5 flight-hours. Army published statistics (Reference 3) for a more recent period of operation reveal a mean time between corrective maintenance of 2.2 flight-hours for the CH-54A.

In order to reflect the frequency of maintenance demonstrated by the more recent Army statistics, a scaling factor of 1.6, representing the ratio be-between these two values, has been applied to the frequency-related factors developed from the ORME data. The effect of applying this factor is to increase the calculated frequency of maintenance by 1.6 times the value observed in the ORME data.

The ORME files for the CH-54 contained records covering a total of 18,200 corrective maintenance actions on the aircraft. Of these, approximately 7-1/2% or 1,385 actions were involved with the Navigation and Communications Systems of the aircraft, neither of which the Army required to be evaluated under this contract. Screening and analysis of the remaining 16,815 corrective maintenance actions revealed that 5,495 of them involved some type of fault isolation.

- Approximately 1/3 of all corrective maintenance actions on nonavionics systems of the CH-54 helicopter involved some type of fault isolation.

The ORME data on the CH-54 represents a period of operation during which 57,164 flight-hours were accumulated. Based on the 5,495 fault isolation maintenance events and the 1.6 maintenance frequency adjustment factor:

- Approximately every 6.5 flight-hours, a fault isolation maintenance action was conducted on nonavionics systems of the CH-54 helicopter.

Figure 10 shows the distribution of frequency of occurrence for the 542 symptoms derived from the ORME data, as adjusted by the maintenance frequency factor.

- Fewer than 15% of the symptoms experienced with nonavionics systems of the CH-54 occurred more frequently than once in 2,000 flight-hours.

- Over 55% of the symptoms experienced with nonavionics systems of the CH-54 occurred more frequently than once in 8,000 flight-hours.

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[3] MANAGEMENT SUMMARY REPORT, VOLUME III, ORGANIZATIONAL AND SUPPORT MAINTENANCE OPERATION AND COST, Report Number RCS AMCQA-113, Product Assurance Directorate, U. S. Army Aviation Systems Command, St. Louis, Mo., September 1973.

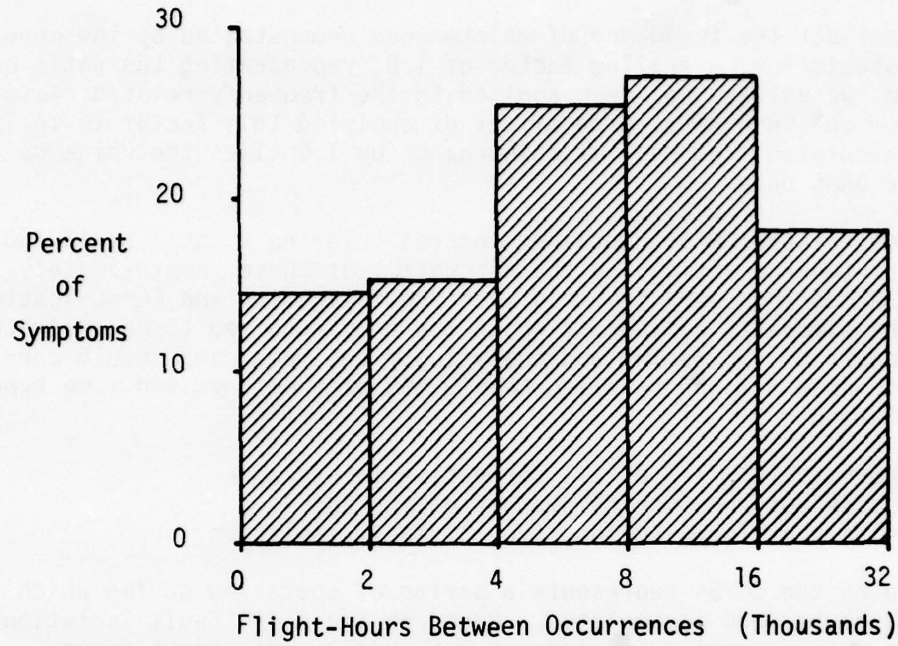

Figure 10. Distribution of Symptoms by Frequency of Occurrence

Symptom Cause Frequency

The number of different causes (failed or defective parts and components) associated with each symptom were identified. The 542 symptoms recorded in the ORME data were tabulated by number of reported causes as shown in Figure 11.

- Almost 40% of the symptoms experienced with nonavionics systems of the helicopter had only one reported cause.

- Approximately 25% of the symptoms experienced with nonavionics systems of the helicopter had four or more reported causes.

In almost every case, the number of ORME-reported causes for the symptom are probably fewer than the number of possible causes of the symptom. A larger data base would probably introduce not only a greater number of symptoms but also other causes for symptoms that were reported.

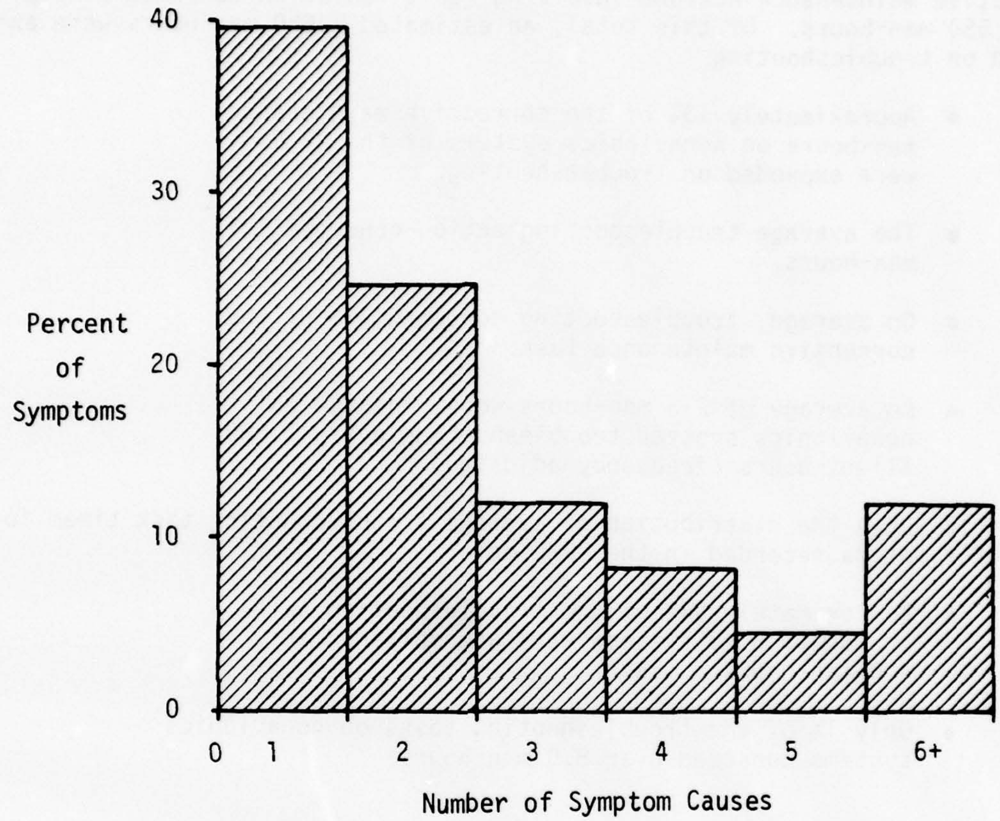

Figure 11. Distribution of Symptoms by Number of Reported Causes

<u>Symptoms Causing Aborts When No Defect Was Found</u>

Only 17 instances were discovered where a mission was aborted for a symptom for which no failure or defect could be found.

- Symptoms causing aborted missions of the CH-54 for which no defect could be found occurred less frequently than once in 2,000 flight-hours.

Man-Hour Cost of Fault Isolation Maintenance

During the period covered by the ORME program, a total of 59,660 man-hours were expended on corrective maintenance of nonavionics systems. The 5,495 corrective maintenance actions involving fault isolation consumed a total of 20,550 man-hours. Of this total, an estimated 7,680 man-hours were expended on troubleshooting.

- Approximately 13% of the corrective maintenance man-hours on nonavionics systems of the CH-54 were expended on troubleshooting.
- The average troubleshooting action consumed 1.4 man-hours.
- On average, troubleshooting consumed 37% of the corrective maintenance task.
- An average of 215 man-hours were expended on nonavionics systems troubleshooting every 1,000 flight-hours (frequency adjusted).

Figure 12 shows the distribution of average troubleshooting task times for the 542 symptoms recorded in the ORME data.

- Approximately 94% of the troubleshooting tasks on nonavionics systems were accomplished in 4.0 man-hours or less.
- Only 1% of the troubleshooting tasks on nonavionics systems consumed over 8.0 man-hours.

Man-Hour and Downtime Cost of No-Defect Actions

A tabulation was made of the man-hours and aircraft downtime associated with no-defect actions, i.e., symptoms reported by the flight crew that could not be duplicated or confirmed by the maintenance crew. The results are shown in Table 8.

- A reported symptom for which no defect could be found was reported against nonavionics systems of the helicopter approximately every 220 flight-hours.
- Approximately 87 man-hours were expended every 10,000 flight-hours to check reported symptoms for which no defect could be found.

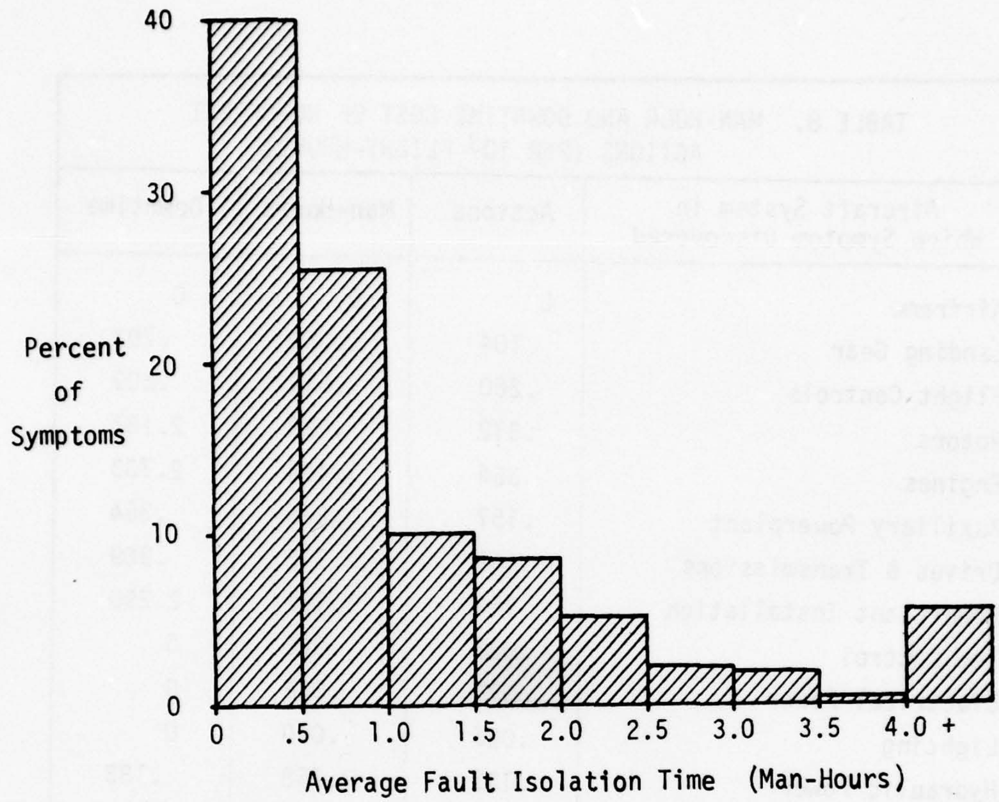

Figure 12. Distribution of Symptoms by Average Fault Isolation Time

FREQUENCY AND COST OF FAULT ISOLATION ERRORS

Frequency of Fault Isolation Errors

Of the total 5,495 fault isolation maintenance actions on the CH-54, 468 were determined to have been improperly performed.

- Approximately 8-1/2% of all fault isolation maintenance actions on nonavionics systems of the CH-54 were accomplished incorrectly.

Based on the 57,164 flight-hours in the ORME data base and the maintenance frequency adjustment factor:

- An improperly performed fault isolation task on nonavionics systems of the helicopter occurred approximately every 76 flight-hours.

TABLE 8. MAN-HOUR AND DOWNTIME COST OF NO-DEFECT ACTIONS (PER 10^3 FLIGHT-HOURS)

Aircraft System in Which Symptom Discovered	Actions	Man-Hours	Downtime
Airframe	0	0	0
Landing Gear	.104	.059	.703
Flight Controls	.260	.619	.209
Rotors	.312	.729	2.187
Engines	.364	1.494	2.733
Auxiliary Powerplant	.157	.576	.364
Drives & Transmissions	.442	.716	.989
Powerplant Installation	.364	1.182	2.290
Ice Control	.026	.006	0
Electrical Power	.078	.065	0
Lighting	.026	.010	0
Hydraulic Power	.183	.258	.183
Fuel	.157	.209	.104
Miscellaneous Utilities	.183	.210	.078
Instruments	1.093	.589	.104
AFCS	.858	2.007	2.134
Total	4.607	8.729	12.078

These statistics are much more significant than they appear, since they account for only a portion of the errors made. There are two types of fault isolation errors. The first are those made in the process of troubleshooting that are recognized immediately by maintenance personnel when the repair or replacement fails to correct the problem. Errors of the second type are those made in the erroneous belief that the troubleshooting task has been successfully completed and not discovered until the same symptom is reported again. The ORME data essentially records errors of the second type only.

In the process of troubleshooting, maintenance personnel will frequently swap suspect parts in an effort to correct a problem, particularly when there is no method of testing the parts in place. Usually a check or test is made at that time and the mechanic discovers immediately if the replaced part has corrected the problem. If not, after reinstalling the original part or turning it in to supply, he continues troubleshooting. Errors of this type are believed to be very common but are rarely documented, since the record prepared at the conclusion of the maintenance action has no provisions for recording parts replaced in the process of troubleshooting. The final part replaced (the one concluded to have caused the problem) is the only one recorded.

Except in a very few cases the ORME records disclosed no errors of this type. The vast majority of the 468 fault isolation errors found in the ORME data were identified through analysis of recurring symptoms on the aircraft. These are errors that were made primarily when maintenance personnel believed that a problem had been corrected and cleared the aircraft for flight, only to have the problem recur in subsequent operation. While these are the more significant of the two types of fault isolation errors, since they present a risk to mission reliability and safety, the in-process errors that this program was unable to document are also costly in terms of man-hours, downtime, and unnecessary parts replacements.

Figure 13 shows the distribution of fault isolation error rates for the 542 symptoms recorded in the ORME data.

- Slightly more than 25% of the symptoms associated with nonavionics systems of the CH-54 involved one or more errors in troubleshooting.
- Approximately 17% of the symptoms experienced fault isolation error rates of up to 20%.
- Approximately 5% of the symptoms experienced error rates exceeding 30%.

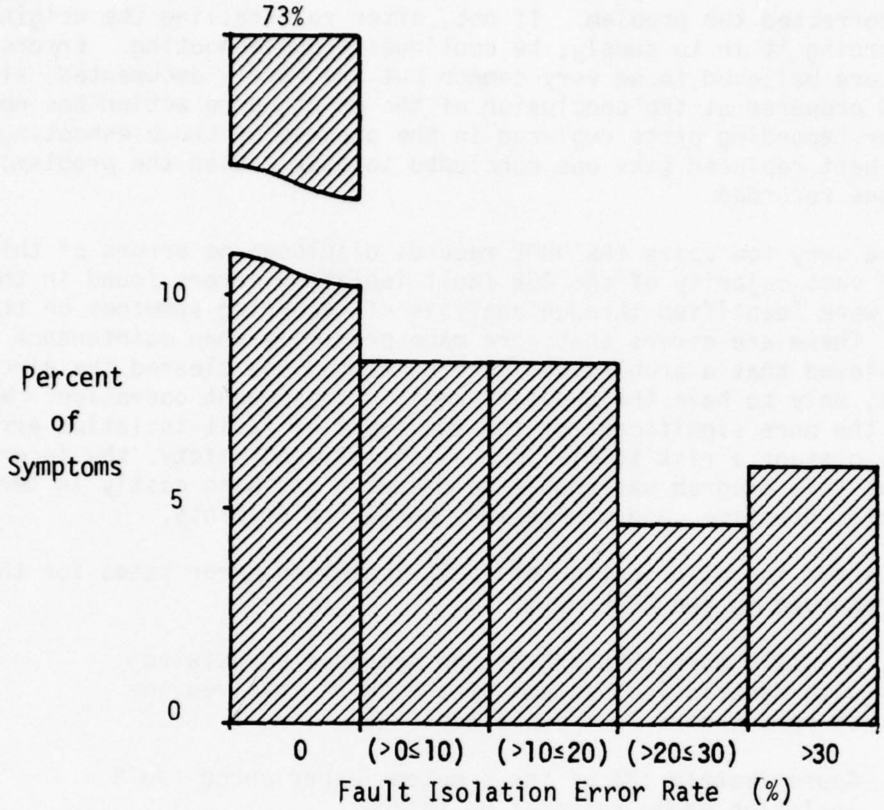

Figure 13. Distribution of Symptoms by Fault Isolation Error Rate

Fault Isolation Errors Resulting in Aborts

Fault isolation errors resulting in aborted missions were identified. A total of 54 such events were discovered as shown in Table 9.

- Approximately 12% of fault isolation errors resulted in aborted missions.

TABLE 9. FAULT ISOLATION ERRORS RESULTING IN ABORTED MISSIONS	
Type of Symptom	Number of Events
APP Starting and Engagement Problems	11
Engine Speed and Power Losses	9
Aircraft Vibration	7
Cargo Hoist Malfunctions	6
Engine Controls Malfunctions	5
Abnormal Engine and Drive Train Instrument Readings	4
Flight Controls Malfunctions	3
Engine Fire Warning Lights	2
Inoperative Generator	2
Main Rotor Droop Stop Engagement Problems	2
Flight Instrument Malfunctions	1
Low Hydraulic Pressure	1
AFCS Hardover	1
	54

Man-Hour and Downtime Cost of Fault Isolation Errors

The man-hours and aircraft downtime associated with fault isolation errors are shown in Table 10.

- Approximately 62 man-hours were expended every 1,000 flight-hours on fault isolation errors related to nonavionics systems of the helicopter.
- Approximately 75 downtime hours were incurred every 1,000 flight-hours on fault isolation errors related to nonavionics systems of the helicopter.

TABLE 10. MAN-HOUR AND DOWNTIME COST OF FAULT ISOLATION ERRORS (PER 10^3 FLIGHT-HOURS)				
Aircraft System in Which Symptom Discovered	Actions	Man-Hours		Downtime
		Total	Fault Iso.	
Airframe	.052	.099	.081	.078
Landing Gear	.364	1.363	.413	.703
Flight Controls	.494	5.523	3.750	10.124
Rotors	1.250	8.471	1.496	6.870
Engines	1.431	9.181	4.521	10.566
Auxiliary Powerplant	1.301	2.688	1.504	3.956
Drives & Transmissions	1.093	8.187	2.754	5.986
Powerplant Instl.	2.239	10.457	7.276	17.905
Ice Control	0	0	0	0
Electrical Power	.338	1.705	1.288	1.614
Lighting	0	0	0	0
Hydraulic Power	.832	2.756	2.023	5.258
Fuel	.286	.619	.226	.442
Miscellaneous Utilities	.858	4.257	2.348	3.097
Instruments	1.536	4.902	3.157	6.922
AFCS	1.146	1.988	1.286	1.405
TOTAL	13.220	62.196	32.123	74.926

Dollar Cost of Fault Isolation Errors

From analysis of the ORME data, it was possible to identify aircraft parts and components that were suspected of being unnecessarily repaired or replaced because of fault isolation errors. A total of 525 such repairs and replacements, involving 192 different parts and components, were identified. An analysis was made to estimate the cost of labor and materials expended on fault isolation errors.

The selling price to the Army of each part and component was retrieved from historical records at Sikorsky Aircraft. In some cases these prices dated back several or more years, and it was necessary to escalate them to 1978 price levels. A 10% per year inflation factor was used. Prices were unavailable for some of the 192 parts and components. Price estimates were obtained for these items by comparing them to similar items for which prices had been obtained.

A code contained in the ORME records showed the disposition of each of the 525 repairs and replacements made as a result of fault isolation errors. The breakdown by disposition is as follows:

	% of Total
On-aircraft Repair	19.8
Local Shop Repair	31.4
Depot Repair	29.6
Scrap	19.2
	100.0

The presumption is that these parts and components were improperly diagnosed as failures and that this fact was discovered when items removed from the aircraft were checked at a higher maintenance level. For those nondefective items repaired on the aircraft, it is presumed that some parts were replaced, probably consumables such as seals and bearings, although in some cases the "repair" may have consisted simply of an adjustment of some kind. For the nondefective components removed from the aircraft and sent to a higher maintenance level for repair, it is presumed also that some worn and marginal parts were replaced before returning the component to supply. In some cases the component, although not failed, may have been sufficiently deteriorated to have required major rework or overhaul to restore it to an RFI (Ready for Issue) condition. For the nondefective parts and components removed from the aircraft and scrapped, it is presumed that the items were either consumables or that they showed evidence of damage or deterioration that caused local maintenance personnel to judge them uneconomical to repair.

To assess the labor and material costs of fault isolation errors, it was necessary to develop factors that could be applied to the purchase price of the parts and components to reflect the expenditures assumed above. For the on-aircraft repairs, the ORME records provided a separate accounting of man-hours, and it was necessary to develop a factor for the average material costs only. In Table 10 the man-hour cost of fault isolation errors was estimated at .062 man-hours per flight-hour, exclusive of the troubleshooting time which is accounted for separately in a later part of this analysis. An average hourly rate of $15 per man-hour was used to derive the dollar cost of this labor.

The ORME program did not cover off-aircraft maintenance, so the factors developed for shop repair, depot repair, and scrap had to account for the average cost of labor and materials. For the depot repairs, the cost of packaging and transportation also had to be included. The following cost factors were used:

	% of Purchase Price
On-Aircraft Repair	
Materials	10
Local Shop Repair	
Labor and Materials	20
Depot Repair	
Packaging and Transportation, plus Labor and Materials	30
Scrap	
Labor plus Unused Service Life	50

The above factors multiplied by the purchase price of each item and the number of repairs and replacements of each disposition yielded a per flight-hour cost of fault isolation errors:

	Dollars per Flight-Hour
On-Aircraft Repair	2.50
Shop Repair	6.15
Depot Repair	12.05
Scrap	.50
	21.20

- The estimated labor and material costs of fault isolation errors on nonavionics systems of the CH-54 helicopter are approximately $21 per flight-hour.

This is a conservative estimate. It does not include the costs of aircraft downtime and aborted missions and such added costs as indirect labor and spares pipeline requirements. Nor does it include the cost of in-process troubleshooting errors which may be as significant as the errors that have been documented by this analysis. The true cost of fault isolation errors may therefore be several times the cost estimated above.

Total Cost of Fault Isolation Maintenance

The total cost of fault isolation maintenance includes, in addition to the cost of fault isolation errors, the cost of the man-hours expended on troubleshooting. Earlier, the maintenance time expended on troubleshooting nonavionics systems of the CH-54 was calculated at .215 man-hours per flight-hour. At an average hourly rate of $15 per man-hour for field-level maintenance, the per flight-hour cost of troubleshooting is estimated at $3.25.

- The total cost of fault isolation maintenance on nonavionics systems of the CH-54 is estimated at approximately $25 per flight-hour.

Again, this estimate is conservative, including only the direct costs that could be measured with the available data.

INVESTIGATION OF COMBAT AND CONTRACT MAINTENANCE EXPERIENCE

Combat Versus Noncombat Maintenance

Approximately 60% of the ORME data was collected on CH-54 helicopters operating in Viet Nam during the war. An analysis was made to determine whether fault isolation maintenance performed under combat conditions differs significantly from that performed under noncombat conditions. Table 11 summarizes the results of this analysis.

The combat aircraft show a significantly lower frequency of maintenance and man-hours per flight-hour for fault isolation maintenance than is shown for the noncombat aircraft. This is believed to be due to differences in the level of reporting rather than to any real difference in the amount of maintenance the respective aircraft required.

Earlier in this section of the report, a maintenance frequency adjustment factor was introduced to account for the difference in corrective maintenance frequency observed between the ORME data and more recent data on the CH-54 collected by the Army. It is believed that this difference is due primarily to less than 100% maintenance reporting from combat zones during the ORME program. At some of the CH-54 units operating in Viet Nam, a single data collector was assigned to cover a large number of aircraft flying a heavy mission schedule. Under these conditions, 100% reporting was impossible, and the ORME data collector concentrated on documenting the most important failures and maintenance actions. It was comparatively less difficult to record the flight time on the aircraft, and this very likely accounts for the low ratio of maintenance actions to flight-hours for the combat aircraft.

TABLE 11. COMBAT VERSUS NONCOMBAT MAINTENANCE	Combat	Noncombat
Flight-Hours	34,966	22,198
Fault Isolation Actions/Flight-Hour	.115	.219
Fault Isolation Man-Hours/Flight-Hour	.157	.275
Mission Aborts/Flight-Hour	.013	.021
No-Defect Rate (No-Defects/Action)	.006	.053
Average Fault Isolation Task Time (Man-Hours)	1.45	1.33
Downtime Hours/Flight-Hour	.635	1.387
Fault Isolation Error Rate (Errors/1,000 Actions)	73	95

The combat aircraft exhibit an abort rate that is substantially lower than that exhibited by the noncombat aircraft. This might be explained by the reluctance of pilots to abort urgent combat missions for the less serious types of symptoms that would prompt them to abort routine missions such as training.

The no-defect rate (frequency of unconfirmed crew reports) is also substantially lower for combat aircraft than for noncombat aircraft. Here again, pilots in combat are probably much less inclined to report minor problems than they would be if they were flying routine missions.

A comparison of combat and noncombat maintenance experience shows no significant difference with respect to average fault isolation task time. Downtime is appreciably lower for the combat aircraft, however, due probably to the high priority attached to keeping aircraft ready in combat.

The fault isolation error rate is also lower for the combat aircraft. While this may be due to normal statistical deviation with the sampled data, it may reflect the higher skill level and efficiency of maintenance personnel assigned to combat units.

Contract Versus Army Maintenance

Approximately 15% of the ORME data was collected on CH-54 helicopters being maintained under a contract maintenance system. An analysis was conducted to determine whether fault isolation maintenance performed by contract maintenance personnel differs significantly from that performed by Army personnel. Table 12 summarizes the results of this analysis.

TABLE 12. CONTRACT MAINTENANCE VERSUS ARMY MAINTENANCE

	Contract	Army
Flight-Hours	8,141	49,023
Fault Isolation Actions/Flight-Hour	.299	.131
Fault Isolation Man-Hours/Flight-Hour	.342	.179
Mission Aborts/Flight-Hour	..030	.013
No-Defect Rate (No-Defects/Action)	.041	.029
Average Fault Isolation Task Time (Man-Hours)	1.22	1.44
Downtime Hours/Flight-Hour	.862	.939
Fault Isolation Error Rate (Errors/1000 Actions)	103	78

Aircraft maintained by contract personnel show a significantly higher task frequency and man-hours per flight-hour for fault isolation maintenance than do aircraft maintained by the Army. This again is believed to be due to less complete reporting from the combat zones. Nearly 3/4 of the data covering Army maintenance activities came from combat operations in Viet Nam where conditions precluded 100% reporting under the ORME program. The higher maintenance frequency and man-hours associated with the aircraft maintained under contract maintenance is attributed to the more complete maintenance reporting that existed at these activities.

The mission abort rate and no-defect rate are also substantially higher for the aircraft maintained under contract maintenance. These rates mirror the respective maintenance frequencies; here also, the higher values are attributed to more complete reporting rather than to any differences in performance.

Average fault isolation time and downtime per flight-hour are significantly lower for aircraft maintained under contract than they are for aircraft maintained by the Army. The downtime ratio is opposite to what would be expected based on the level of reporting discussed before. The data appears to indicate that contract personnel accomplish fault isolation work more efficiently than do Army personnel. This is not unexpected in view of the greater pressure on efficiency in a commercial, profit-making operation.

In apparent contradiction to this conclusion is the high fault isolation error rate experienced under the contract maintenance system. This may be due entirely to statistical deviation, especially in view of the relatively small sample of events that comprises the contract maintenance experience. There is no other obvious explanation for contract maintenance personnel to be more error-prone than Army maintenance personnel. In fact, considering the typically greater skill level and experience of contract personnel, just the opposite should be expected.

RESULTS OF THE TROUBLESHOOTING PROCEDURES ANALYSIS

Handbook-Covered Symptoms Experienced in Service

Troubleshooting tables in the Aviation Unit and Intermediate Maintenance Manual for the CH-54A Helicopter (TM 55-1520-217-23-1) were analyzed and compared with actual fault isolation maintenance experience as documented by the ORME program. Table 13 gives a breakdown of the maintenance manual by chapter, showing the percentage of symptoms referenced in the manual that were reported from the field during the period of the ORME program.

- Approximately 2/3 of the symptoms covered by the maintenance manual were experienced in actual service.

The ORME data base represents 57,000 flight-hours of operation with the CH-54 over a period of roughly five years. Although this is a substantial amount of experience with the aircraft, it still represents an incomplete sample of system failures and maintenance events. Many symptoms develop only with a particular kind of failure under a particular set of conditions. It is probable, therefore, that 57,000 flight-hours did not provide the opportunity for some symptoms to occur. A larger flight-hour base would likely have increased the number of handbook-covered symptoms experienced in service.

Coverage of Service-Experienced Symptoms in the Handbooks

The handbook troubleshooting tables were examined for the presence of symptoms reported under the ORME program. The following results were obtained:

	% of Reported Symptoms	% of Covered Symptoms
Not listed in troubleshooting tables	67.7	
Listed in two tables	24.7	76.5
Listed in two tables	5.9	18.3
Listed in three or more tables	1.7	5.3
	100.0	100.1

- Approximately 2/3 of the symptoms reported under the ORME program were not found listed in the maintenance manual troubleshooting tables.
- Approximately 25% of the symptoms reported under the ORME program and covered by the maintenance manual were found listed in two or more troubleshooting tables.

TABLE 13. COMPARISON OF ORME-REPORTED SYMPTOMS WITH SYMPTOMS LISTED IN CH-54A TROUBLESHOOTING TABLES				
Chapter of the Maintenance Manual	No. of Symptom Tables/ Chapter	No. of Symptoms Covered in Tables	No. of ORME Reported Symptoms*	% of Handbook Symptoms Reported
Airframe	0			
Landing Gear	2	7	4	57
Power Plants	5	35	26	74
Rotors	2	3	2	67
Drive Train	10	34	20	59
Hydraulics	13	90	56	62
Instruments	21	71	68	96
Electrical**	4	39	9	23
Fuel	5	22	15	68
Flight Controls	0			
Utility Systems	5	19	14	74
Environmental Control	1	8	4	50
Hoists and Winches	2	23	12	52
Auxiliary Power Plant	1	15	14	93
AFCS	1	26	16	62
Total	72	392	260	66

* Number of symptoms covered in handbook tables actually reported under the ORME program.

**Excluding lighting.

In the discussion of the results of the ORME data analysis, it was explained that in some cases the information provided in the ORME records was not adequate to determine whether similar-sounding descriptions were in fact describing the same symptom. When this determination could not be made, the symptoms were judged to be different. The total number of symptoms recorded in the ORME data may therefore be larger than the number of symptoms actually experienced. Were it possible to interpret each symptom description precisely, the list of recorded symptoms would probably be reduced, increasing the percentage of symptoms found in the handbook troubleshooting tables.

Coverage of Fault Causes in the Handbooks

A group of 20 symptoms, each occurring with relatively high frequency in the ORME data and each reportedly having been caused by the failure of different components, was compared with the respective troubleshooting procedures in the maintenance manual. A typical analysis is shown in Figure 14. With respect to the coverage of symptom causes reported in the ORME data, the following results were obtained:

	% of Symptoms Examined
The most frequently reported cause in the ORME data is among the possible causes listed in the manual.	50.0
The two most frequently reported causes are among the possible causes listed in the manual.	30.0
The three most frequently reported causes are among the possible causes listed in the manual.	15.0

- For 50% of the symptoms in the selected sample, the most frequently reported cause was not found listed in the maintenance manual.
- For 85% of the symptoms in the selected sample, one or more of the most frequently reported causes were not found listed in the maintenance manual.

Fault Symptom: EPR Indicator Inoperative				
Discovered Fault (Failed Item)		Number of Reports	Fre-quency Rank	Handbook Table Step No.
Part Number	Nomenclature			
6445-61207-101	Transducer	18	1	
6445-61234-101	Damper, Fluid Pressure	9	2	1
6440-61206-101	EPR Indicator	5	3	2
6430-62087-053	Tube Assembly	1	4	

Figure 14. Sample Tabulation From the Analysis of the Coverage of Symptom Causes in the Maintenance Manual Troubleshooting Tables

These results are based on a very small sample of symptoms and may therefore not represent accurately the overall content of the complete set of troubleshooting tables contained in the manual. Not only is the sample of symptoms small but also the number of occurrences of some of the symptoms in the sample (as few as 21). A larger number of maintenance events would probably have introduced other causes of the symptoms, altering their respective rankings and possibly increasing the percentage of symptom causes found in the manual. The results obtained from the examination of 20 symptoms may also be distorted by the possibility that some of the causes recorded in the ORME data are invalid. The sample of 20 symptoms was also examined with respect to the placement of possible causes in the maintenance manual troubleshooting tables, relative to their probability of occurrence as reflected by the ORME data. The following results were obtained:

	% of Symptoms Examined
The most frequently reported cause is among the first three possible causes listed in the manual.	35.0
The most frequently reported cause is the first possible cause listed in the manual.	15.0

With respect to the poor correspondence of symptom cause frequency with the ordering of possible causes in the manual, two comments are appropriate. First, for reasons just given, the data may not accurately represent the true frequency of the reported causes. Second, the most efficient fault isolation procedure is not necessarily the one that lists the possible causes of a symptom in exactly the order of their probability of occurrence. The ease and confidence with which each of the possible causes can be checked must also be considered.

For all of the above reasons, this study of 20 fault symptoms provides only a very general indication of the quality of the handbook troubleshooting procedures.

RESULTS OF THE FIELD SURVEYS

TRAINING AND EXPERIENCE OF PERSONNEL

In the course of the CH-54 field surveys, 4 CH-54 operating bases were visited, 4 weeks were spent in the field and a total of 22 maintenance personnel and 4 pilots were interviewed. Table 14 shows the formal training and experience level of the field personnel participating in these surveys.

TABLE 14. FORMAL TRAINING AND EXPERIENCE LEVEL OF CH-54 SURVEY PARTICIPANTS

Function	Number of Persons	Formal Training (Weeks)		Experience (Years)	
		CH-54	Other Helo.	CH-54	Other Helo.
Crew Chief	6	9	11	6	5
Flight Engineer	8	16	10	7	2
Electrical/Avionics Repairman	7	1	6	4	4
Technical Inspector	1	-	11	8	-
Avg. Maint. Personnel	22	8	9	5	3
Pilot/Test Pilot	4	6	52	7	6

The survey of the CH-47 helicopter at Fort Campbell, Kentucky, included interviews with 8 aircraft maintenance personnel over a period of 2 days. The survey of the AH-1, also 2 days in duration, included interviews with 4 maintenance personnel, 3 pilot/maintenance supervisors, and 1 maintenance officer. Tables 15 and 16 show the formal training and experience level of the AH-1 and CH-47 survey participants.

TABLE 15. FORMAL TRAINING AND EXPERIENCE LEVEL OF AH-1 SURVEY PARTICIPANTS					
Function	Number of Persons	Formal Training (Weeks)		Experience (Years)	
		AH-1	Other Helo.	AH-1	Other Helo.
Maintenance Officer	1	2	26	2	2
Maintenance Supervisor	2	2	16	7	8
Technical Inspector	1	8	8	3	14
QC Officer/Pilot	1	4	40	4	-
Maintenance Technician/ Pilot	1	4	36	4	7
PE Team Leader	1	11	-	2	-
Average	7	5	20	4	6

TABLE 16. FORMAL TRAINING AND EXPERIENCE LEVEL OF CH-47 SURVEY PARTICIPANTS					
Function	Number of Persons	Formal Training (Weeks)		Experience (Years)	
		CH-47	Other Helo.	CH-47	Other Helo.
Platoon Sergeant	2	8	22	6	7
Technical Inspector	1	16	6	8	-
Flight Engineer	4	6	2	5	5
Engine Repair Shop Supervisor	1	11	-	-	-
Average	8	9	7	5	4

The training and experience level of the AH-1 and CH-47 field survey participants is very close to that of the personnel who participated in the CH-54 surveys. However, while the CH-54 participants were said to be typical of all personnel maintaining the CH-54, the AH-1 and CH-47 participants were among the more senior people in their respective organizations. At the two units surveyed, the average experience level of crew chiefs on the AH-1 and CH-47 helicopters was estimated by the participants to be between one and two years. Crew chiefs and flight engineers on the CH-54 average over five years experience with the aircraft and have more than ten years of total helicopter experience.

CH-54 Skills and Experience Level

The experience level of pilots and maintenance personnel in CH-54 units is concluded to be on average much higher than that of personnel assigned to other types of aircraft. There are two basic reasons for this. First, the population of CH-54s in the Army inventory is small and the personnel who operate and maintain them form a relatively small, close-knit community. When personnel are transferred or rotated, they tend to move from one CH-54 unit to another, a situation less prevalent with other types of aircraft. Secondly, the CH-54 carries two enlisted personnel in the aircraft flight crew: the flight engineer and the crew chief, both having rank in the E-5 to E-6 pay grades. The additional crew member position creates greater opportunity for advancement, retaining a larger number of people in the maintenance organization and resulting in a high ratio of senior personnel.

Except for electrical and avionics problems, aircraft troubleshooting is done mainly by the CH-54 crew members. Since the CH-54 has both a flight engineer and a crew chief, each aircraft has two primary troubleshooters. Coupled with the experience level of the people, this gives the typical CH-54 unit a much better capability in fault isolation maintenance than prevails with other Army aircraft. The experience level of CH-54 pilots enhances this capability, since it is the pilot who usually observes and reports the problem and assists his crew members with troubleshooting. These factors tend to make fault isolation maintenance on the CH-54 somewhat untypical of Army aviation in general.

AH-1 and CH-47 Skills and Experience Level

At both the AH-1 and CH-47 units it was reported that the crew chiefs were primarily responsible for troubleshooting on their aircraft and that they were encouraged by their superiors to do as much troubleshooting as they could. However, because of the limited experience of most of the AH-1 and CH-47 crew chiefs, they were able to accomplish only the simpler, more routine troubleshooting tasks themselves and almost always referred the more difficult problems to their supervisors or the TI (Technical Inspector). This differs substantially from the situation with the CH-54, where the crew chiefs and flight engineers are all highly experienced and do most of the nonavionics systems troubleshooting themselves.

It was also discovered with the CH-47 and AH-1 units, contrary to findings with the CH-54, that the TIs do get actively involved with troubleshooting. At the CH-47 unit, the TI was a principal troubleshooter. At the AH-1 unit, TIs were involved with troubleshooting to varying degrees and, when asked why some were more involved than others, indicated that is very much a matter of personal initiative. It was explained that troubleshooting is not a specifically defined responsibility of the TI, and only those that wished to got actively involved with it.

Key troubleshooters were asked how often they called for assistance by maintenance specialists in power plants, hydraulics, etc. Estimates ranged between 20% and 30%. It was pointed out by some of the respondents that component specialists often could not help with on-aircraft troubleshooting because they lacked an overall understanding of the operation of the system.

COMPARISONS WITH CH-54 STATISTICS

One objective of conducting the AH-1 and CH-47 surveys was to determine whether the scope of nonavionics systems troubleshooting on the CH-54 as documented in the ORME records was typical of other helicopters in the inventory.

Fault Isolation Maintenance Frequency

One part of the AH-1 and CH-47 surveys attempted to establish the frequency of fault isolation maintenance related to nonavionics systems of the aircraft. The purpose was to compare the frequency of maintenance on these aircraft with the 6.5 flight-hours between fault isolation tasks calculated from the ORME data for CH-54. The results of these inquiries are presented in Table 17.

TABLE 17. ESTIMATES OBTAINED FROM THE AH-1 AND CH-47 SURVEYS RELATED TO FAULT ISOLATION MAINTENANCE FREQUENCY

	AH-1		CH-47	
	1st Group	2nd Group	1st Group	2nd Group
Estimated percentage of flights involving crew-reported discrepancies	75%	75% - 90%	90% - 95%	100% approx.
Estimated average number of discrepancies reported per flight	2	2	3 - 4	2 - 3
Estimated percentage of discrepancies related to avionics and weapons	75%	75%	50% - 75%	65%

The original estimates for the frequency of problem writeups by AH-1 flight crews were much lower than the 75% to 90% values given in Table 17, averaging more in the range of 30% to 50%. When questioned, the participants said that most of the AH-1S models were new aircraft (the high-time aircraft having flown just over 200 hours) and that relatively few problems were being experienced compared with the older AH-1G models they had been operating. It was felt that insufficient experience had been acquired with new AH-1S to provide representative statistics, so the respondents were asked to give estimates for the AH-1G with which they were more familiar.

Average utilization of the AH-1 at Fort Bragg was said to involve two basic types of flying: garrison missions, consisting of local area (airport to airport) flights at altitudes over 500 feet, and field missions, consisting mainly of nap-of-the-earth flying with hot refueling. Garrison missions were estimated to involve 2 to 4 flight-hours and field missions 6 to 8 flight-hours. Using 5 hours as an average mission length, and the estimated frequency of flight crew writeups given by the survey participants, a crew-reported discrepancy might be anticipated on nonavionics systems of the AH-1 approximately every 6 to 8 flight-hours.

Utilization of the CH-47 at Fort Campbell was said to involve missions of 4 to 5 hours duration. Based on the estimated frequency of flight crew writeups given by the CH-47 survey participants, a crew-reported discrepancy might be anticipated on nonavionics systems of the CH-47 approximately every 5 flight-hours.

When asked what percentage of crew writeups involve discrepancies that are either seen or whose cause is known by the flight crew, most participants estimated 10% to 20%. Assuming the higher value, a nonavionics system troubleshooting action might be anticipated on the AH-1 every 7 to 9 flight-hours and on the CH-47 every 5 to 6 flight-hours. These are admittedly very crude estimates, but based on the relative complexity of the aircraft, they appear to be consistent with the 6.5 flight-hour frequency of nonavionics system troubleshooting calculated for the CH-54.

Time of Occurrence of Symptoms

The AH-1 and CH-47 survey participants were asked to estimate the percentage of crew-discovered problems occurring in each of three mission phases: (1) engine start to takeoff, (2) in-flight, and (3) on ground to engine shutdown. ORME data on the CH-54 indicated that approximately half of all reported symptoms occurred in flight. Widely varying responses were obtained. Aircraft crew chiefs tended to place the majority of symptoms in the engine start to takeoff category, presumably because these are the types of problems with which they are most directly involved. Maintenance supervisors and Technical Inspectors tended to place the majority of reported symptoms in the in-flight category, the category comprising the more difficult troubleshooting problems referred to them by the crew chiefs. It is apparent that the position of the individual in the maintenance organization greatly influences his perception of when problems with the aircraft most often occur. No valid conclusions could be drawn from the survey responses.

Abort Rate

The AH-1 and CH-47 survey participants were asked to estimate the frequency of crew-reported malfunctions of nonavionics systems that result in aborted missions. Approximately 10% of the ORME-reported symptoms on the CH-54 were found to have caused aborts. For the CH-47, fewer than one percent of malfunctions were estimated to cause aborts. For the AH-1, estimates of five percent or less were given. The lower abort frequency estimates for the CH-47 may be related to the amount of time that the maintenance crew is allowed to correct a problem before cancelling or aborting a mission. The CH-47 personnel said that they would often spend up to an hour correcting a malfunction before or during a mission without recording an abort. Abort frequency estimates given for the AH-1 and CH-47 are both substantially lower than the 10% rate calculated for the CH-54. This may be due to differences in local policy concerning the criteria for recording aborts and/or to misjudgements on the part of the survey participants.

No-Defect Rate

An estimate of the percentage of flight crew reports for which no failure or defect can be found was requested. Estimates ranged from one to five percent, with the majority under two percent. Vibration and abnormal flight performance were cited as the most frequently reported problems of this type. The estimates given by the AH-1 and CH-47 survey participants agree well with the 3% no-defect rate calculated for the CH-54 from the ORME data.

Troubleshooting Error Rate

The AH-1 and CH-47 survey participants were asked to estimate how often the average troubleshooter makes an error in troubleshooting. The word average was stressed to avoid having people make judgements that were critical of themselves. Error rates of 25% were estimated for the average crew chief, while error rates of 10% to 25% were estimated for senior troubleshooters. Asked what percentage of troubleshooting errors are undetected until the aircraft is operated or flown again, estimates ranged from 2% to 5%. It is somewhat difficult to compare the AH-1 and CH-47 estimates with the 8 1/2% error rate calculated for the CH-54, since the participants were including in their estimates the in-process troubleshooting errors that the ORME data was unable to document.

Instrument-Related Symptoms

Estimates were requested of the percentage of all flight crew reported symptoms on the aircraft that were observed either as abnormal instrument readings or as caution lights or warning lights in the cockpit. Instruments and warning lights were estimated to be the source of from 2/3 to 3/4 of all flight crew reported symptoms on the aircraft. This compares with an approximate ratio of 40% calculated for the CH-54 from the ORME data. Asked to estimate the percentage of abnormal instrument readings that are traced to a failure of the instrument or its sensor rather than a failure of the monitored system, estimates of 65% to 90% were given. This compares with an approximate ratio of 50% calculated for the CH-54 from the ORME data.

Warning lights and caution lights were said to be much more reliable than the aircraft instruments, with false indications occurring less frequently than 5% of the time. Estimates of instrument-related symptoms supplied by the AH-1 and CH-47 survey participants tend on average to be significantly higher than the equivalent values calculated for the CH-54, but confirm that instruments and warning devices are a major factor in the fault isolation maintenance of nonavionics systems of the helicopter.

POLICIES AND PROCEDURES IN THE FIELD

One portion of the field surveys of the three aircraft models was concerned with policies and procedures in the conduct of fault isolation maintenance. The responses to this area of inquiry are summarized in the following paragraphs. The quantitative tabulations are derived mainly from the CH-54 surveys, which covered in detail 36 specific symptoms selected from the ORME reports.

Flight Crew Reporting

Several of the field survey questions dealt with the reporting of symptoms by the flight crews. One question asked if the symptom being discussed might be otherwise described by the flight crew. The responses from the CH-54 survey of 36 symptoms are tabulated below.

Number of Suggested Alternate Symptom Descriptions	% of Responses
None	58.6
One	25.7
Two	10.0
Three or more	5.7
	100.0

For more than 40% of the symptoms, at least one alternate description was given. Two or more alternate descriptions were given for 15% of the symptoms.

Another question asked about the accuracy and completeness of symptom descriptions provided by the flight crews. The results of the CH-54 survey are tabulated below.

Accuracy and Completeness of Symptom Descriptions	% of Responses
Usually accurate and complete	81.5
Information frequently lacking	17.1
Information always lacking	1.4
	100.0

In more than 80% of the cases, the CH-54 survey participants rated flight crew writeups as accurate and complete. However, this response appears to conflict with the response to a question concerning additional information required to troubleshoot the same symptoms, as later discussion will cover.

The AH-1 and CH-47 survey participants were asked if flight crew reports of symptoms were generally accurate and complete. The majority of responses said that they were, although it was felt that the quality of the reports was a direct reflection of the experience of the pilots. At both the AH-1 and the CH-47 units, the majority of pilots were highly experienced, averaging 1,500 hours or more in the aircraft.

When asked how often it was necessary to consult with the flight crew before beginning a troubleshooting action, CH-47 personnel estimated 5% to 10% of the time while AH-1 personnel estimated up to 90% of the time. This difference is not unexpected, since the flight engineer and crew chief of the CH-47 are normally on board the aircraft to experience the symptoms first hand, while the AH-1 crew chiefs are not.

Asked to name the most frequent problem encountered with flight crew writeups, most of the participants cited the tendency of some pilots to report what they believed to be the cause of a problem rather than the symptom i.e., to troubleshoot by seat of the pants. This problem was also cited by several of the CH-54 survey participants.

The participants were asked to estimate how often each of the 36 sampled symptoms was reported but unconfirmed. The responses are tabulated below.

Frequency at Which Symptom is Reported but Unconfirmed	% of Responses
Sometimes	32.9
Rarely	30.0
Never	37.1
	100.0

The large percentage of responses indicating that symptoms are sometimes reported when no failure or defect is found appears at odds with the low percentage of no-defect reports found in the ORME data. One possible explanation for the apparent discrepancy is that many unfounded gripes are resolved between the crew chief and the pilot without being officially documented.

Methods of Confirming Symptoms

The survey participants were asked the methods they would use to confirm that a symptom reported by the flight crew was valid. Responses from the CH-54 survey are categorized in Table 18.

TABLE 18. METHODS OF CONFIRMING REPORTED SYMPTOMS

Method of Confirming Symptom	% of Responses
Wait until next scheduled flight and see if symptom reported again	2.9
Discuss problem with pilot and/or flight engineer	1.4
Ask maintenance check pilot to discuss problem with pilot	1.4
Ground test	52.9
Flight test	18.6
Ground check and test fly if necessary	17.1
Begin troubleshooting immediately	5.7
	100.0

The method of symptom confirmation depends to a great extent on the nature of the symptom and the expectation, based on prior experience, that a pilot's complaint may be invalid. In about 3% of the cases, field personnel had sufficient doubt about the validity of reports of a given symptom that they would take no action until the symptom was reported again. (This presumes, of course, that the reported symptom had no safety implications.) In slightly more than 5% of the cases, field personnel had sufficient confidence that reports of a symptom would be valid that they said that they would begin troubleshooting immediately.

For each of the symptoms covered by the CH-54 surveys, the survey participants were asked to indicate the information, in addition to the symptom description, they would need to troubleshoot the problem. The response is presented in Table 19.

TABLE 19. ADDITIONAL INFORMATION REQUIRED TO TROUBLESHOOT REPORTED SYMPTOMS

Additional Information Required to Troubleshoot Symptoms	% of Responses
None	27.1
Flight Conditions (Speed, Altitude, Flight Maneuvers, etc.)	28.6
Weather Conditions (Wind, Precipitation, etc.)	10.0
Aircraft Configuration (Fuel Load, Sling Load, Pod on/off, etc.)	11.4
Instrument Readings and Caution Lights	31.4
Terrain Conditions	1.4
Systems Operative (AFCS, Stick Trim, Remote Controls, etc.)	27.1
Symptom Conditions (Nature, Severity, etc.)	28.6
Other Observations (Sound, Vibration, etc.)	10.0

Only 27% of the responses indicated that the symptom description alone was sufficient information upon which to begin troubleshooting. When asked how the additional information they required would be obtained, most people replied that they would consult with the flight crew. This response appears to contradict the opinion that crew reports are usually accurate and complete, given in response to an earlier question.

Troubleshooting Methods

The CH-54 survey participants were asked to describe generally the methods they would use to troubleshoot each of the 36 sampled symptoms. From their responses specific types of tests and inspections were identified as shown in Table 20.

TABLE 20. TROUBLESHOOTING METHODS CITED BY FIELD PERSONNEL

Troubleshooting Methods Cited by Field Personnel	% of Responses
Functionally check	60.7
Swap components and check	50.8
Visually inspect	34.4
Call specialist	18.0
Observe instruments and caution lights	13.1
Listen/feel while operating	11.5
Check adjustment	11.5
Test	8.2
Bleed/service system	4.9
Measure wear or play	3.3
Check torques	3.3
Replace marginal or suspect parts	1.6

Troubleshooting methods are of course dependent upon the type of symptom. As might be expected, visual inspections and functional tests are used to troubleshoot a large percentage of the symptoms. Of some significance is the large number of responses that included swapping of components in the troubleshooting procedure. When questioned, the CH-54 respondents defended this practice as being the most efficient method (in many cases the only method) of troubleshooting a symptom.

The participants were also questioned about the practice of parts swapping as a method of troubleshooting. Estimates of the percentage of troubleshooting actions that involve swapping one or more parts or components to isolate a fault ranged from 25% to 75%, with the majority of respondents citing avionics and instruments as the systems with which the practice is most prevalent. Asked if stocks of inexpensive, frequently used parts were maintained for this purpose, only the CH-47 flight engineers acknowledged the practice. Supervisory personnel in both units indicated that the practice was officially prohibited. Questioned about the number of times that a swapped component fails to correct the problem, estimates ranged from 25% to 50%. Good parts replaced during troubleshooting were either reinstalled or returned to supply as serviceable all respondants indicated.

FIELD PERSONNEL'S PERCEPTIONS OF FAULT ISOLATION MAINTENANCE

The CH-54 surveys concentrated on a very detailed examination of 36 symptoms having a high frequency of occurrence, a significant troubleshooting error rate, and/or requiring a high average number of man-hours to fault isolate. Because of limitations on time, it was not possible to cover all 36 symptoms at each of the four CH-54 survey sites. Further, those symptoms which had not been experienced by field personnel participating in a given survey were omitted from that survey. Table 21 shows the number of surveys at which symptoms were covered and the number of surveys at which symptoms had been experienced by the participants.

TABLE 21. RESPONSE TO CH-54 SURVEY OF 36 ORME-REPORTED SYMPTOMS

Surveys at Which Symptom Covered	Surveys at Which Symptom Experienced					
	4	3	2	1	0	Total
4	4	5	4	6	1	20
3		1	2	4		7
2			4	4		8
1				1		1
0						
Total	4	6	10	15	1	36

- Twenty-seven of the 36 symptoms were covered at three or more survey sites; 35 of the 36 were covered at two or more survey sites.

- Twenty of the 36 symptoms were experienced at two or more of the survey sites; 35 of the 36 were experienced at one or more survey sites.

Perception of Troubleshooting Task Frequency

At each survey session the participants were asked the percentage of the total failures (repairs and replacements) that are discovered via troubleshooting versus inspection. Crew chiefs and flight engineers on the CH-54 estimated that fewer than 10% of all failures are found by troubleshooting, more than 90% by inspection. Participants in the AH-1 and CH-47 surveys estimated that 10% to 20% of nonavionics systems failures are found by troubleshooting versus inspection.

These estimates do not agree well with the ORME service experience which indicates that more than 1/3 of the corrective maintenance actions involved some type of troubleshooting. There may be an explanation for this disparity, however. It is more likely that a greater number of failures involving multiple parts (worn bearings, corroded fasteners, etc.) will be found via inspection that via troubleshooting. It is probable, therefore, that the corrective maintenance reports involving troubleshooting reflect on average fewer parts repaired or replaced, which could account for the above-noted discrepancy. Electricians and avionics specialists estimated generally that over 90% of the parts and components they replace are found by troubleshooting, and this is consistent with the ORME service experience.

Perception of Symptom Frequency

One of the survey questions asked the CH-54 survey participants to estimate the frequency at which each of the discussed symptoms occurred. These estimates were usually given in terms of yearly occurrences per aircraft or per squadron and were later converted to flight-hours on the basis of the average aircraft utilization at that base. The purpose of the question was to compare field personnel's perception of problem frequency with actual service experience documented in the ORME records. Figure 18 makes this comparison.

- Field personnel consistently overestimate the frequency of occurrence of aircraft symptoms.

This is a predictable outcome. As reference to Figure 15 indicates, the great majority of symptoms included in the sample occur less frequently than once per 1,000 flight-hours. Only 11% of the symptoms in the sample occur as frequently as once per 500 flight-hours. These frequencies are indicative of the overall population of symptoms as developed from the ORME data and discussed earlier in the report.

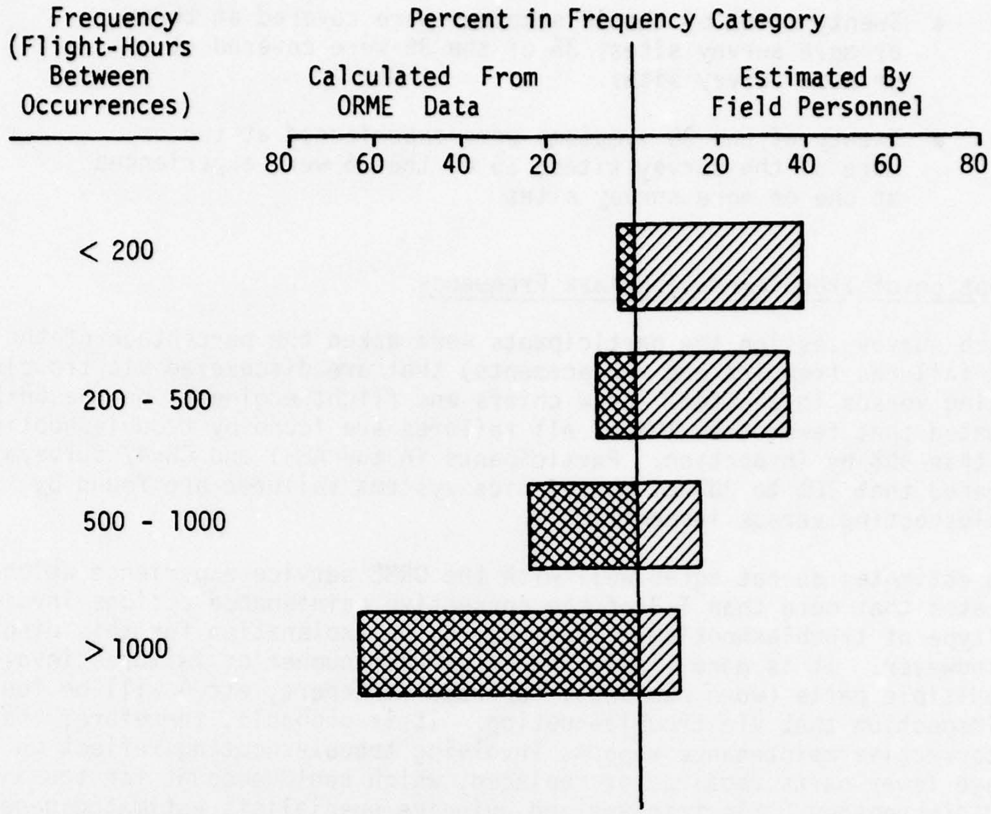

Figure 15. Symptom Frequency of Occurrence Estimates From Field Survey Compared With ORME-Generated Statistics

Over recent years the four CH-54 field activities covered by the survey have averaged aircraft utilization rates of from 125 to 200 flight-hours per aircraft per year. At this level of utilization, a symptom occurring an average of once every 1,000 flight hours would not be expected to occur on a particular aircraft more often than once in five years. Therefore, the majority of symptoms have probably not been observed by even the most experienced aircraft crews. And many symptoms probably are not experienced on any aircraft in an entire unit for a year or more.

To have been able to discuss a symptom, the participants would have to have experienced the symptom recently enough to recall the circumstances. It is natural that people recently experiencing a given symptom would tend to overestimate its frequency of occurrence. It was improbable that frequency estimates as low or lower than once in 1,000 flight hours would ever be given, since for the average crew member, this is tantamount to no experience at all.

Perception of Fault Isolation Time

Another survey question asked the participants to estimate the average time required to troubleshoot each of the discussed symptoms. The purpose of the question was to compare field personnel's perception of fault isolation time with actual service experience documented in the ORME records. Figure 16 makes this comparison.

- Field personnel are able to estimate fault isolation times that are consistent with actual service experience.

It is reasonable that field personnel have a better perception of fault isolation time than they do of symptom frequency. Whereas estimating symptom frequency requires a knowledge of all occurrences of the event over a long period of time, estimating fault isolation time requires only a small sample of events on which to base the estimate. Good time estimates can often be arrived at through judgement alone.

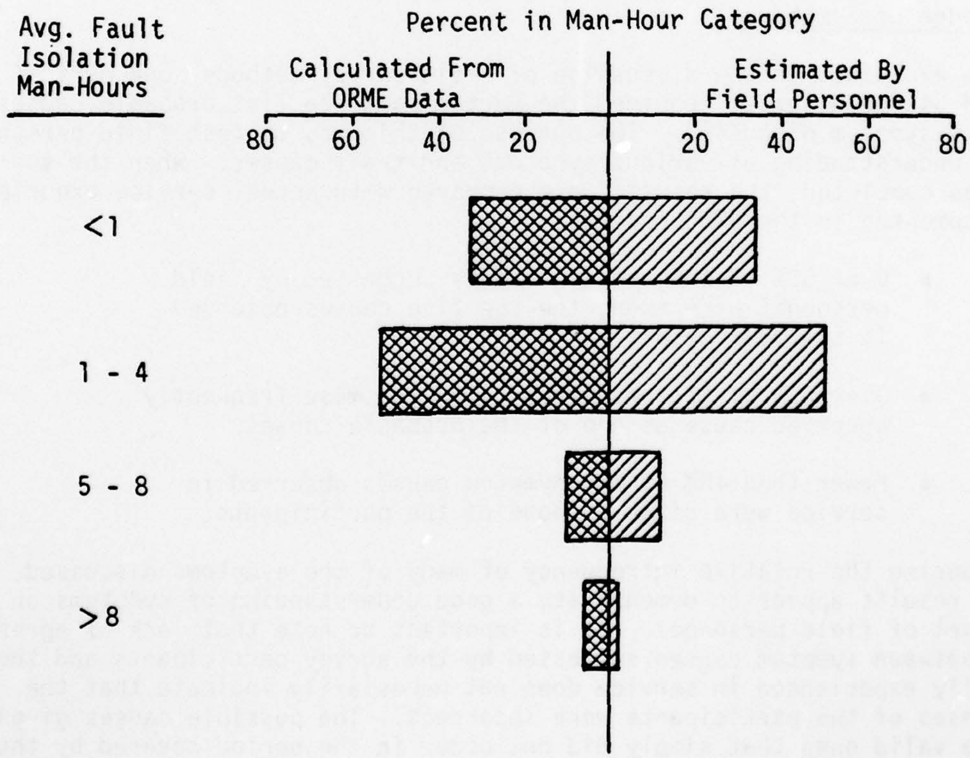

Figure 16. Average Fault Isolation Time Estimates From Field Survey Compared With ORME-Generated Statistics

At the close of each survey session, the participants were asked to estimate the average percentage of their working time that was spent on troubleshooting versus all other types of maintenance. Crew chiefs and flight engineers on the CH-54 consistently estimated that 10% or less of their time was spent on troubleshooting. Only one respondent estimated as high as 20%. The electricians and avionics specialists, on the other hand, estimated almost the opposite ratio; i.e., 80% to 90% of their time spent on troubleshooting. These estimates are all consistent with actual service experience as depicted by the ORME data.

For the AH-1 and CH-47, crew chief's estimates of the time spent on nonavionics systems troubleshooting ranged from 5% to 10%, while the estimates of maintenance supervisors and technical inspectors averaged 25% to 30%. This difference is not unexpected since supervisory personnel have many troubleshooting problems referred to them by their subordinates, while the crew chiefs (especially the less experienced ones) attempt to troubleshoot only the simpler problems. This is not the case with the CH-54, where the crew chiefs and flight engineers do almost all of the nonavionics systems troubleshooting themselves.

Knowledge of Symptoms

As was explained in the discussion of field survey methods, one part of the CH-54 field survey required the participants to list probable causes of each symptom discussed. The purpose of this was to test field personnel's understanding of various symptoms and their causes. When the survey was completed, the results were compared with actual service experience as documented in the ORME records.

- Over 50% of the symptom causes suggested by field personnel were among the top-five causes observed in the ORME data.
- Over 65% of the responses cited the mose frequently observed cause as one of the probable causes.
- Fewer than 45% of the symptom causes observed in service were cited by none of the participants.

Considering the relative infrequency of many of the symptoms discussed, these results appear to demonstrate a good understanding of symptoms on the part of field personnel. It is important to note that lack of agreement between symptom causes suggested by the survey participants and those actually experienced in service does not necessarily indicate that the responses of the participants were incorrect. The possible causes given may be valid ones that simply did not occur in the period covered by the ORME reporting. Moreover, the high-ranking symptom causes observed in the ORME data encompassed in most cases a relatively small number of events. A larger data base would likely alter these rankings with the possibility that more of the symptom causes given by field personnel would have matched the predominant causes experienced in service.

After listing in order the probable causes of each symptom, the survey participants were asked to rank the probable causes on the basis of the ease with which each could be checked during troubleshooting. An analysis was made of the responses to determine whether field personnel tend to correlate probable causes with ease of checkout; i.e., to regard as most likely those causes that are easiest to check. The results seem to suggest that field personnel are inclined to troubleshoot first the items that are easiest to check, proceeding then to the more difficult ones, irrespective of the probability of each being the cause of the symptom. While this may be the most efficient procedure in some cases, it may be the cause of many fault isolation errors and improper parts replacements, particularly when swapping of parts is the only method of troubleshooting.

Part II of the CH-54 field survey requested field personnel to list the symptoms that they would associate with the failure or malfunction of specific aircraft components. The purpose of this was to test field personnel's knowledge of failure-to-symptom relationships. Their responses were compared with symptoms observed in actual service as documented in the ORME records.

- Approximately 3/4 of the symptoms suggested by field personnel were among the top-five symptoms experienced in service.

- Approximately 2/3 of the survey responses cited the most frequently occurring symptom as one of the possible symptoms.

- Only 1/3 of the symptoms observed in service were cited by none of the participants.

Again, these results appear to demonstrate a good understanding of symptoms on the part of field personnel. For reasons mentioned above, the symptoms suggested by field personnel may be more in agreement with actual experience than this sampling of data would indicate. It should be remembered, however, that because of the high average experience level of CH-54 maintenance personnel, their knowledge of symptoms and causes may not be typical of aircraft maintenance crews throughout the Army.

Perception of Fault Isolation Task Difficulty

The CH-54 survey participants were asked to rate the task of isolating each symptom as not difficult, difficult, or very difficult. Table 22 shows the response to this question. Approximately 3/4 of the responses rated the troubleshooting task as not difficult; none of the troubleshooting tasks were rated as very difficult. Classification of the responses by fault isolation time category shows a tendency to rate the more time-consuming tasks as difficult. The fact that none of the troubleshooting was judged to be very difficult may be attributed to the tendency to view familiar tasks as routine, despite their complexity.

TABLE 22. PERCEIVED TROUBLESHOOTING DIFFICULTY VERSUS ESTIMATED FAULT ISOLATION TIME (PERCENT OF FAULT ISOLATION TIME CATEGORY)

	Perceived Fault Isolation Difficulty			
Estimated Fault Isolation Time (Hrs.)	Not Difficult	Difficult	Very Difficult	Percent of Symptoms*
<1	100.0	-	-	34.8
1 - 4	69.7	30.3	-	50.1
5 - 8	37.5	62.5	-	12.1
>8	-	100.0	-	3.0
Percent of Ratings	74.2	25.8	-	100.0

*in sample

Perception of Fault Isolation Error Rate

The CH-54 survey participants were told the average fault isolation error rate derived from the ORME data for each symptom and were asked to judge, based on their own experience, whether the statistical error rate was high, low, or about average. Table 23 shows the response to this question.

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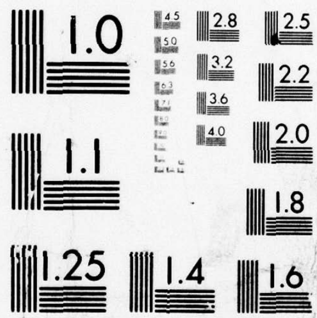

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 23. FIELD PERSONNEL'S PERCEPTION OF STATISTICAL FAULT ISOLATION ERROR RATES (PERCENT OF ERROR RATE CATEGORY)

Error Rate	Perception of Error Rate			Percent of Symptoms*
	High	Average	Low	
0 - 20%	44.1	44.1	11.8	54.0
21 - 40%	51.9	40.7	7.4	42.9
40% +	100.0	-	-	3.1
Percent of Ratings	49.2	41.3	9.5	100.0

*in sample

Approximately an equal number of responses judged the statistical error rates to be high or average; less than 10% of the responses judged them to be low. Classification of the responses by error rate category shows no significant tendency to judge large error rates as high and small error rates as low. The small number of responses assessing the statistical error rate as low may be attributed to a normal reluctance to admit mistakes and also to the fact that many errors in fault isolation maintenance are not recognized as such.

FAULT ISOLATION MAINTENANCE RESOURCES

A portion of each field survey was devoted to a discussion of fault isolation maintenance resources, i.e., troubleshooting data, training and test equipment.

Troubleshooting Data

The CH-54 survey participants were asked to rate the accuracy and completeness of the maintenance manual troubleshooting instructions related to each symptom. The following response was obtained:

Accuracy and Completeness of Troubleshooting Instructions	% of Responses
Accurate and complete	27.1
Some deficiencies	12.9
Inadequate	21.4
Symptom not covered	2.9
Not sure/don't remember	35.7
	100.0

The responses were given from memory and in approximately 1/4 of the cases the instructions were remembered as being accurate and complete, although in no instance could anyone recall the specific content of the maintenance manual. Almost an equal number of responses cited the instructions as inadequate or missing entirely from the manual. Again, specific deficiencies could not be recalled. In more than 1/3 of the cases, the respondent could not remember if the symptom was covered in the manual and/or if the instructions were adequate.

Most of the AH-1 and CH-47 survey respondents believed that the majority of symptoms occurring on the aircraft were covered by the maintenance manual; estimates of 90% or greater were typically given. However, the manuals were thought to be deficient with respect to how thoroughly the possible causes of typical problems were covered. Asked to rate the content of the typical troubleshooting table in the aircraft maintenance manual, a majority felt that only the obvious causes were covered, while a minority thought that most of the possible causes were covered.

The survey participants were asked to estimate the percentage of all flight crew reported problems on the aircraft whose cause they can pinpoint confidently simply on the basis of the symptom described. Estimates ranged from 5% or less to a maximum of 10%, except for one individual who estimated 50%. Asked how often they would repair a suspected malfunction without troubleshooting and without consulting the manual, most replied "very rarely", although it was sensed in some cases that the respondents were merely echoing Army policy. Apparently, the manuals are used consistently for troubleshooting despite the deficiencies that field personnel contend they suffer.

Almost everyone participating in the surveys was critical of the organization and format of troubleshooting data in current Army technical manuals. A frequent complaint is the random placement of troubleshooting tables throughout the manuals and the lack of an index to these tables. To locate troubleshooting data related to a given symptom, mechanics claim that it is necessary to search page by page through one or more chapters of the maintenance manual. Nearly everyone recommended that troubleshooting data be provided in a separate manual or in a separate chapter of the maintenance manual and that the data be efficiently indexed.

Another complaint with troubleshooting data in current manuals is the fact that it is aircraft system oriented rather than symptom oriented. When symptoms occur whose cause may involve multiple systems of the aircraft, maintenance personnel claim that it is necessary to guess which system is causing the problem before the manuals can be used. The manuals would be much more useful, they said, if they were oriented by symptoms rather than by systems.

Frequent complaints were also voiced about the scope and content of troubleshooting data in current Army manuals. One complaint is that the manuals cover only the most obvious symptoms and causes and never seem to get updated when new knowledge is acquired through service experience with an aircraft. The order in which possible causes are listed in many of the troubleshooting tables was also criticized. Often the troubleshooting sequence prescribed by the manuals is felt to improperly reflect the relative probability of the possible causes listed. Troubleshooting tables that list possible causes of a problem without providing instructions for checking them were also a source of criticism. Current manuals are said to be inconsistent in the way troubleshooting data is presented and to require that many unnecessary checks and tests be made in the process of troubleshooting.

Fault Isolation Maintenance Training

Nearly all of the participants in the surveys reported that they had little or no formal training in fault isolation maintenance. The training that was received consisted mainly of learning to use the troubleshooting data in the manual. With one exception no one had received any "hands on" instruction troubleshooting real or simulated faults with the aircraft. Asked whether they thought Army aircraft maintenance personnel would benefit from formal training in fault isolation maintenance, most said yes, although everyone agreed that such training should be given only after an individual has several or more years of experience in aircraft maintenance.

Problems in troubleshooting also arise, according to some of the field personnel, because specialists are not cross-trained in other aircraft systems. A frequently cited example is that of aircraft flight control malfunctions whose origin may be in any one or a combination of aircraft subsystems: flight controls, hydraulics, or the AFCS (Automatic Flight Control System). Because the AFCS specialist is not trained in flight controls or hydraulics, he must work closely with the crew chief or flight engineer during troubleshooting; because of their different backgrounds, communication is often a problem. In some cases the avionics repairman will troubleshoot the AFCS, and failing to locate the fault, turn the problem over to the crew-chief and a hydraulics specialist who troubleshoot the other systems independently. This is both inefficient and often unproductive. It was recommended that the avionics people be trained in flight controls and hydraulics so that they could do most of the troubleshooting themselves or at least be able to work more effectively with the crew chief and other specialists.

The statements of field personnel relative to the lack of formal training in fault isolation maintenance were confirmed by a visit to the U.S. Army Aviation Maintenance Training School at Fort Eustis, Virginia. Interviews were conducted with two instructors teaching the Heavy Lift Helicopter Repairman's Course (MOS 67X).

The 67X Course is a 14-week course attended primarily by new recruits. It covers basic fundamentals (about 20 hours) and primarily remove-and-replace type maintenance. A limited amount of system theory is taught, and each student receives 6 hours of flight duties training including several flights in the aircraft. Very little system troubleshooting is taught. Each block (system) includes 3-4 hours of instruction in troubleshooting, all of it in the form of lectures. The school has very little capability for simulating faults and giving the students hands-on experience with troubleshooting. Instructional material for training in troubleshooting consists mainly of the troubleshooting tables in the maintenance handbook.

With respect to improving troubleshooting skills in the field, both instructors felt that there was little the school could do, especially in view of prevailing practices in the assignment of personnel. They cited a recent case where 45 of 50 mechanics completing the CH-54 maintenance course were assigned to other types of aircraft. Of the five that did make it to a CH-54 unit, they guessed that none got to actually work on the aircraft for at least a year. Real maintenance skills are acquired on the job over a period of several years, they contended, and it is pointless for the school to teach anything beyond basics. Troubleshooting is a particularly difficult skill for new students to learn and retain. Attempting to improve maintenance skills is also frustrated, it was explained, by what both instructors perceived as a gradual decline in the caliber of maintenance personnel entering the aviation maintenance field.

Test Equipment

It was learned in the course of the field surveys that test equipment, other than common hand-held meters and gages, is rarely used to troubleshoot nonavionics systems of the helicopter. Items of equipment such as Pitot/Static System Testers, Jet Cal Analyzers and Fuel Quantity Calibration Sets are often available, usually at AVIM level, but are rarely used to troubleshoot systems of the aircraft. Most survey participants contended that it is easier to swap instruments or black boxes rather than call on specialist personnel to troubleshoot with test equipment.

Flight Crew Debriefing Checklist

Deficient crew writeups were a complaint of some of the CH-54 survey participants (although when asked about crew reports as related to specific symptoms, the great majority of people rated them adequate). The complaint is that many reports are vague and incomplete and that some pilots tend to report what they suspect to be the cause of faulty performance rather than to describe the symptoms. Problems of this type are rarely encountered with the very experienced pilots, however. One recommendation of some of the CH-54 survey participants is that the Army adopt the use of a flight crew debriefing checklist like the one employed by the Air Force. It was suggested that a checklist would tend to produce consistently good writeups.

This recommendation was proposed to the AH-1 and CH-47 survey participants. No one supported the idea. The concensus is that flight crew reports are generally adequate and that the debriefing checklist, while possibly providing some improvements, would introduce another unwanted piece of paper into the system. The fact that the maintenance personnel in the AH-1 and CH-47 units are working with a cadre of highly experienced pilots may have formed this opinion, however. The quality of flight crew reports would not be as good if green pilots were flying the aircraft, and the debriefing checklist might look more attractive in these circumstances.

Troubleshooting Specialist MOS

The two instructors at the Aviation Maintenance Training School were asked whether the Army, as part of the solution to current problems in fault isolation maintenance, might create a separate MOS: Aircraft Troubleshooting Specialist, similar to that established for the Aircraft Technical Inspector (TI). This they thought was an excellent idea. If the pay grades were high enough, they felt it would be as easy to attract people to the job of troubleshooting specialist as it has been to attract people to the jobs of flight engineer and crew chief to which many in the enlisted ranks now aspire.

Part of the problem in aviation maintenance today, they contended, is that with the exception of flight engineers and crew chiefs, maintenance personnel are not allowed to progress beyond pay grade E-6 unless they move into an administrative position. This siphons off the most experienced and skilled people, many of whom would prefer to stay in active maintenance. For the professional troubleshooter idea to work, it will be necessary to allow advancement within the MOS into the E-7 and E-8 pay grades, they seemed convinced.

The instructors were asked their opinion of how many different models a single troubleshooter might cover and the total number of aircraft he might support. They felt that there was enough similarity in the troubleshooting problems on different aircraft that a single troubleshooter might cover several models and that the troubleshooting workload was such that one individual might cover 100 or more aircraft. They were asked if instructors at the school were able to identify students with a particular aptitude for troubleshooting. They said that some students were obviously brighter and more ambitious than others, but that aptitude testing would be the only way to ferret out promising candidates. It would be wise to require that candidates have several years of maintenance experience before being considered for such advanced training, however.

The recommendation that the Army create a Troubleshooting Specialist MOS for aviation was also proposed to the AH-1 and CH-47 survey participants. Everyone supported the idea enthusiastically. In their concensus a professional troubleshooter is a much more practical approach to aircraft systems troubleshooting than attempting to train everyone in maintenance to perform this function. Under the current system, few individuals spend enough time with troubleshooting to become expert. As a result, many people of marginal capability are all troubleshooting and all making the same mistakes. The survey participants confirmed the opinion of the instructors at the training school that the job of troubleshooter would be very appealing to many career-oriented personnel in aviation.

At the AH-1 units it was suggested for the first time that creation of another MOS would not be needed if the TI's functions were expanded to include a principal role in troubleshooting. This is already being done in some areas, and now that the TI is being trained to specialize with a single model aircraft rather than to be an aircraft generalist, he becomes very knowledgeable of that model and could, in the opinion of the AH-1 people, act as the principal troubleshooter. It may be necessary to increase the number of TIs in a unit in order to absorb this added responsibility. One drawback to making the TI the professional troubleshooter is the amount of time that he would probably have to spend away from the unit for training. Because the TI is such a key individual in the maintenance organization, having him absent for even the abbreviated TI course that is now given frequently poses a hardship.

One other concern expressed by the Cobra people, which may be somewhat unique to the Air Calvary mission, is that of creating small numbers of specialists who may be lost or incapacitated in combat. When everyone is capable of doing some troubleshooting, they observe, that skill would not be lost when casualties were suffered by the maintnenance organization, as could happen if a troop or aviation company relied on a single individual for this work.

RESULTS OF THE STATE-OF-THE-ART SURVEY

Visits were made to three Army agencies and one defense contractor to survey current technology in the development and publication of fault isolation maintenance data for the new-generation Army systems. The surveys centered on the SPA (Skill Performance Aids) concept in the technical publications field and specifically the extent to which the Front End Analysis (FEA) technique required by SPA is addressing the problems with fault isolation data uncovered by the field surveys.

It was found that SPA, formerly called ITDT (Integrated Technical Documentation and Training), is concerned primarily with format and the communication of information to mechanics and technicians. The FEA does require a more structured approach to the development of data for maintenance manuals, but is confined mainly to the objectives to be met rather than specific procedures. Discussions with individuals involved with the application of SPA to new systems disclosed that improvements in format and communication have been achieved, but that the actual content of troubleshooting procedures has not been significantly affected. The concensus seems to be that deficiencies remain with respect to the development of fault isolation criteria for the manuals.

IMPROVED METHODS FOR DEVELOPERS OF FAULT ISOLATION PROCEDURES

NATURE OF THE PROBLEM

One conclusion of the surveys conducted under this program is that the quality of fault isolation maintenance data on present-day Army systems is generally poor. Major criticisms include widespread omissions of significant symptoms and causes, poor organization and indexing of information, and inefficient troubleshooting procedures. Problems with language and communication are also frequently cited.

It is not surprising, considering the complexity of the task, that deficiencies such as these are common. The development of fault isolation procedures for complex systems is probably the most difficult task the logistics engineer and writer of maintenance handbooks is required to perform.

Complex systems can contain hundreds of parts and components whose failure might produce a symptom requiring fault isolation. The symptom produced in each case can vary with the mode of failure, the degree of failure, and the conditions under which it occurs. For complex systems, simple statistics will easily demonstrate the possibility of an enormous number of combinations and permutations of these variables.

It is small wonder that an engineer or technical writer, given a set of specifications, drawings, and schematics for a system, and tasked with preparing fault isolation procedures, often experiences difficulty. He must anticipate the failures the system will experience in service, the conditions under which they will likely occur, and their effects on the system. The physical effects of failure must be translated into observable effects or symptoms. Symptoms of the same or similar nature must be collected together and a logical organization of symptoms and causes developed.

Having accomplished this task and identified the expected sources and symptoms of failure, the engineer or writer is confronted next with developing logical and efficient troubleshooting procedures for the system. He must weigh the relative probability of the possible causes of each symptom, devise inspections or tests with which to investigate them, and organize them into a procedure that will provide a high expectation of locating the fault with a minimum expenditure of time and resources. The possibility and consequences of error, and of inducing additional faults in the process of troubleshooting, must also be considered.

The final task for the writer is to convey instructions to the mechanic. Since symptoms of failure are usually acquired through personal observation, the writer must anticipate how the pilot or mechanic is likely to perceive and describe a symptom and attempt to communicate with him in language he is accustomed to using. Providing well-organized, properly worded indexes with which to locate data in the manual is an important part of this communication.

It is apparent from discussions with persons involved with the development of fault isolation procedures for major systems that the quality of the product is considerably dependent upon the skill and experience of the individual engineer or technical writer. While it may be said that the quality generally improves with experience, relying heavily on the experience of the individual can also lead to bias and stereotyping. In fact, it was the opinion of some of the people interviewed that better troubleshooting procedures sometimes evolve when inexperienced people are assigned to develop them, because they tend to be more objective and more original in their approach.

FAULT ISOLATION ANALYSIS TECHNIQUE (FIAT)

The following pages describe a new approach to the development of fault isolation procedures for complex systems. Called FIAT (Fault Isolation Analysis Technique), the proposed approach greatly facilitates the identification of symptom/cause relationships and the collection, processing, and organization of data required for the preparation of maintenance manuals. It reduces the task to a series of small, independent judgements and decisions which, when brought together, provide a working guide for preparation of the troubleshooting procedures. Most important, by allowing the engineer or writer to deal individually with discrete items of information, it relieves him of having to formulate an overall troubleshooting logic from the outset and lessens the demands on his personal experience and knowledge of the system.

The FIAT approach applies primarily to the nonavionics systems of helicopters where the modes and symptoms of failure do not generally lend themselves to automated test and the more sophisticated forms of diagnostics. The methods could be applied to avionics systems, however, either to provide a backup for the primary diagnostics system or in applications where diagnostic hardware is not considered cost-effective. Some compromise in the level to which faults can be isolated would have to be accepted, e.g., limiting troubleshooting to the level of black boxes versus modules.

FIAT General Outline

FIAT involves four major tasks that culminate in the generation of outline fault isolation procedures for the system (Figure 17). First, a system functional analysis is performed to establish the criteria for normal system performance and to identify potential modes of abnormal performance (the system malfunctions). Next, a system failure modes analysis based on the FMEA is conducted to identify failures with a potential for causing each type of malfunction. This establishes a framework of symptom/cause relationships for the system.

A computer file of fault isolation task candidates is constructed. For each symptom/cause candidate, information pertinent to the fault isolation task is recorded. This includes the expected frequency of occurrence, methods of fault confirmation and fault isolation, and the estimated time to fault isolate.

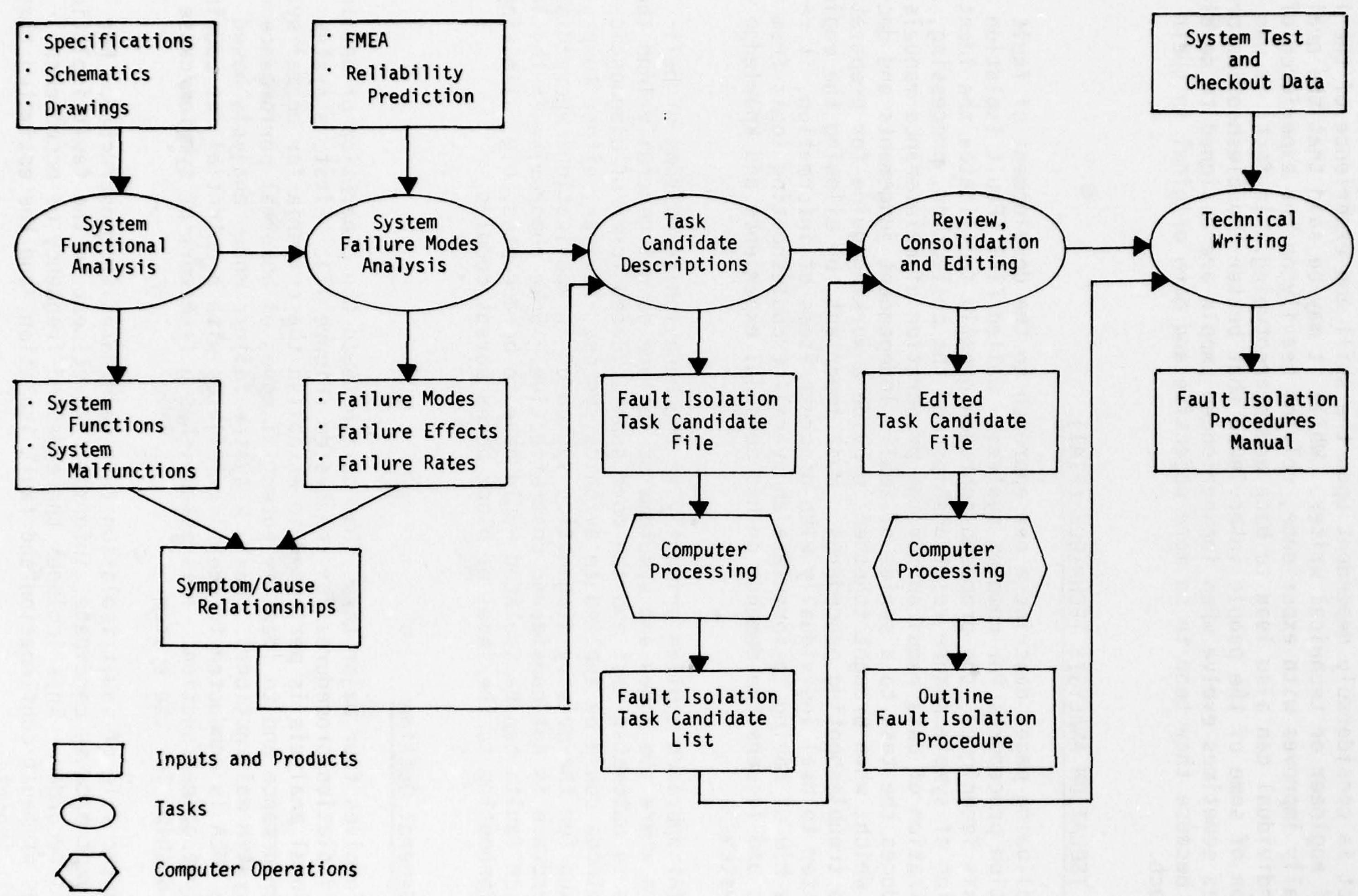

Figure 17. FIAT Task Flow

A computer program processes the data and generates two outputs that are used in the preparation of fault isolation maintenance data for the system. The first output is a comprehensive listing of symptoms and causes (the candidate list) which the analyst reviews, condenses, and assigns to logical groups that will each form the content of a troubleshooting procedure.

After editing, a troubleshooting procedure number is assigned to each symptom/cause set, and the computer program outlines the content of each troubleshooting procedure. This provides a guide for the writer to follow in preparation of the fault isolation procedures manual.

SYSTEM FUNCTIONAL ANALYSIS

A functional analysis of the system is conducted to establish the criteria for normal system performance and to identify potential sources of abnormal performance. This type of analysis is already accomplished to a significant degree as part of other engineering and logistics activities, e.g., preparation of specifications and test plans and development of system operating procedures. Under the FIAT approach, the analysis is developed in a highly structured form and recorded in a format that facilitates its application to the development of fault isolation procedures.

System-Level Functions

The operation of a system is defined in terms of two types of functions:

System-Level Functions

Contributing Functions

System-level functions describe the principal operating states of a system or the modes of transition from one principal operating state to another. By definition, a system-level function is observable by the operator, i.e., he is aware that the system is operating in a defined state or is transitioning between states.

The system-level functions for simple, self-contained systems often consist of a single operating mode. For a wheel brake system, the system-level functions are basically two:

Rolling aircraft brought to rest

Aircraft held at rest

The operation of other systems is less clearly defined in terms of discrete functions. The main rotor of the aircraft, for example, has one basic function: to provide directed thrust for lifting and propelling the aircraft.

This overall function might be defined in terms of two system-level functions:

Vertical Thrust

Horizontal Thrust (forward, rearward, sideward)

While supplying the required thrust is not a discrete function in the sense of the wheel brakes operating to stop the aircraft, it is the one type of function that can be ascribed to operation of the rotor.

The power plant system of the aircraft has been selected to illustrate the FIAT method, and for it the following system-level functions are defined:

Engine Starting

Ground Idle

Operation at Normal Rated Power

Engine Shutdown

Contributing Functions

Each of the system-level functions has associated with it one or more contributing functions. A contributing function is a physical process or operation performed by the system or an interfacing system, with or without operator intervention, that is required for execution or maintenance of the system-level function. By definition, a contributing function is observable by the operator, i.e., he is aware that the process or operation is being executed or is being maintained. In the case of the wheel brake system, the functions contributing to the system-level function of stopping the aircraft are:

Brake pedal depressed

Wheel brakes engage

It is understood that other functions are executed in the process of wheel brake operation, i.e., actuation of the master cylinder, pressurization of the brake lines, and actuation of the wheel cylinders, but the operator is not specifically aware of their occurrence. He is able to observe that the brake pedal depresses when force is applied and that the brakes engage, but nothing more. Conversely, in the context of malfunctions the operator is able to observe that the brake pedal will not depress or that the brakes do not engage, but is unable to relate the malfunction to operation of the master cylinder, wheel cylinders, etc. This is a key element of the concept. In order for a contributing function to be valid, it must be observable by the operator, either directly or via an instrument indication.

For the main rotor's system-level function "vertical thrust", the contributing functions involve other systems of the helicopter and are in some cases system-level functions for those systems. The functions contributing to main rotor vertical thrust might be defined as:

Main rotor speed within limits

Main rotor torque within limits

Collective stick positioned

Main rotor blades achieve uniform pitch angle

The first two contributing functions, main rotor speed and torque within limits, are products of other system-level events, i.e., engine operation at normal rated power and the main transmission supplying the required torque to the rotor.

Again, as was true of the wheel brake system example, other functions are executed in the process of producing main rotor vertical thrust, but without the specific awareness of the operator. He is able to observe by monitoring the instruments that main rotor speed and torque are within limits, and also that the rotor responds predictably to a given control input. He is not able to observe such functions as actuation of the main rotor servos and vertical displacement of the swashplate, although the proper execution of these functions is assumed if the desired main rotor response is obtained. The key idea is that the operator is able only to report as a malfunction one or more of the functions he is able to observe (the contributing functions).

For the power plant functional analysis being used for illustration, the system-level function "engine starting" is selected for further development, and for it the following contributing functions are defined:

APU Normal Operation

Air Source Switch Positioned (to "ENG")

Fuel Selector Switch Positioned (to "XFD")

Start Button Depressed

Power Control Lever Positioned (to "IDLE")

Engine Fuel Flow Within Limits

Engine Oil Pressure Within Limits (25 to 65 PSI Within 30 Sec)

Starter Dropout (at 48% - 55% N_G)

N_G Stabilized Within Limits

TIT Within Limits (800°F Max)

Again, it is seen that some of the functions contributing to the system-level function "engine starting" are in themselves system-level functions for other aircraft systems. APU normal operation is one example.

Judgement will play an important part in the system functional analysis, and for that reason several iterations may be necessary to arrive at a satisfactory result. Later in the procedure when failure modes are analyzed relative to their effects on system functions, it will be shown how networks of symptom/cause relationships are developed and how omissions and anomalies in the original functional analysis are surfaced and corrected.

Redundant Modes of Operation

A special situation exists when a system has redundant or parallel modes of operation. This occurs when a system-level function can be accomplished via different processes. In the case of engine starting, three modes of operation are possible:

1. APU start
2. Ground power start
3. Cross bleed air start

Each of these functions contributes to the system-level function "engine starting", but none can occur together in the same start cycle. Redundant modes of operation such as these create parallel rather than series paths in the system functional analysis network.

Parallel paths culminating in a common contributing function (three modes of starting independently leading to starter engagement) create one type of requirement with respect to the organization of troubleshooting procedures. Symptoms occurring upstream of starter engagement belong to one of three chains of events that can be treated as separate troubleshooting procedures. A mechanic attempting to troubleshoot symptoms such as

Starter fails to engage

Starter engages late

Engine fails to motor

Engine motors slowly

Engine accelerates slowly

all of which are indicative of inadequate starter cranking power, should be queried first about the mode of starting used and directed to one of the three applicable troubleshooting procedures. The fault may lie with the starter itself or with the engine, but ascertaining that the starter is adequately powered is probably the logical beginning point for these symptoms.

Redundant modes of operation are treated at this point in the analysis like any other system functions. Later it will be shown how the contributing function implies the condition under which the symptom occurs and effectively separates redundant modes of operation for the purpose of constructing fault isolation procedures.

System Malfunctions

The final task of the system functional analysis identifies possible malfunctions associated with each contributing system function. A system malfunction takes place when the operator observes that a contributing function fails to occur, or that it occurs early, late, incompletely, etc. Consistent with the definition of contributing functions given earlier, a system malfunction must be observable by the operator. Malfunctions that occur with no outward evidence perceptible to the operator are not system malfunctions in this context. Failure of a valve in the closed position may, for instance, prevent fuel flow to the engine. The operator may perceive this as failure of the engine to start or, if instrumentation is present, more specifically as a lack of fuel flow to the engine. Either of these events would be classified as system malfunctions within the given definition, whereas failure of the valve to open would not be, since the operator could not perceive that specific occurrence.

The definition of system malfunctions is made initially without regard to whether failure modes exist that could produce such malfunctions. In the case of the function "brake pedal depressed" contributing to the system-level function "rolling aircraft brought to rest" the system malfunctions might be defined as:

Brake pedal bottoms

Brake pedal low

Brake pedal spongy

Brake pedal travel restricted

For the second contributing function, wheel brake engagement, the malfunctions might be defined as:

Wheel brakes fail to engage

Wheel brakes grab

Wheel brakes chatter

Wheel brakes noisy

It is important to note how the potential system malfunctions would differ for the second system-level function of the wheel brakes: holding the aircraft at rest. In this case, the only malfunctions the operator might observe are a loss of pedal and/or failure of the brakes to hold.

To repeat, system malfunctions are defined without regard to the existence of failure modes or other defects that might produce them. Hypothetically, it might be found upon an analysis of system failure modes that no modes exist that could cause restricted travel in the brake pedal, one of the defined malfunctions. But this should not be anticipated beforehand, and all of the conceivable malfunctions should be recorded.

System malfunctions related to the function "main rotor speed within limits" contributing to the system-level function "main rotor vertical thrust" might be defined as:

Main rotor RPM low

Main rotor RPM high

Main rotor RPM fluctuating or erratic

In many cases the possible ways in which functions may occur abnormally will be obvious; in others not. One of the ways in which this task can be aided is to examine past experience with similar systems to ascertain whether malfunctions occurring with those systems are pertinent to the one under development. There are generic similarities among many aircraft systems, and while the types of failure experienced will vary with individual designs, the manifestations of those failures in terms of abnormal system performance will often be the same. Main rotor RPM low, engine fails to start, brakes fail to engage, are types of abnormal performance that can occur with these systems irrespective of their individual designs. That may not be true for the failures underlying these events, however.

As part of the FIAT methodology it is recommended that the experience with prior models be examined when conducting the system functional analysis. As will be shown later, implementation of the proposed methodology creates a data bank that can be updated over the life of the aircraft, providing a well-documented history of fault isolation maintenance experience for use on subsequent models. Caution is needed, however, when extrapolating experience with one aircraft to another to be sure that the system functions and malfunctions are applicable.

For our power plant example, the potential malfunctions related to engine starting are defined in Table 24.

Nonassociated System Malfunctions

There are some types of system malfunctions that are not associated with an expressly stated system function. Vibration is an example. There is an implied requirement for the aircraft to operate vibration-free or at an

TABLE 24. ENGINE STARTING SYSTEM FUNCTIONAL ANALYSIS

Contributing Function	Potential Malfunction
APU Normal Operation*	APU Fails to Operate*
Air Source Switch Positioned (to 'ENG')	
Fuel Selector Positioned (to 'XFD')	Fuel Selector Binding Fuel Selector Travel Restricted
Start Button Depressed	Engine Fails to Motor Engine Motors Slowly
Power Control Lever Positioned (to 'IDLE')	Power Control Lever Binding Power Control Lever Travel Restricted Engine Fails to Start
Engine Fuel System Flow Within Limits	Fuel Pressure Light Illuminated Engine Fails to Accelerate Engine Accelerates Slowly Engine Stalls Engine Shuts Down Engine Fuel Filter Bypass Light Illuminated Prime Boost Pump "On" Light Illuminated Prime Boost Pump "On" Light Fails to Illuminate
Engine Oil System Pressure Within Limits	Engine Oil Pressure Gage Reads Low Engine Oil Pressure Gage Reads High Engine Oil Pressure Gage Fluctuating Engine Oil Pressure Light Illuminated Engine Oil Filter Bypass Light Illuminated Engine Chip Detector Light Illuminated
Engine Starter Dropout (at 48% - 55% N_G)	Engine Starter Advisory Light Fails to Extinguish
Engine Dual Gas Generator Tach Stabilized Within Limits	N_G Tach Indicator Reads Low N_G Tach Indicator Reads High N_G Tach Indicator Fluctuating
Engine Dual TIT Indicator Within Limits (800°F Max.)	Engine Oil Temp Light Illuminated TIT Indicator Reads High Engine Hot Starts

* Contributing functions and malfunctions related to APU starting and operation treated under the APU functional analysis.

acceptable level of vibration. But normal or acceptable vibration is not a discrete system function in the sense that it can be initiated through operator action as was true of the functions suggested earlier. Freedom from instability and erratic performance are other examples. A surging engine is a malfunction, but smooth running would not normally be listed as system function.

In addition to abnormal occurrences of system functions, the dictionary of system malfunctions therefore contains such conditions as:

Vibrates

Unstable

Fluctuates

Surging

Erratic

etc.

Reference to Appendix B reveals a number of malfunctions of this type.

System Functional Analysis Coding Scheme

The three types of functions described by the system functional analysis are coded in a standard format which identifies the aircraft system or component involved and the type of function or malfunction. A work unit code (WUC) is used to identify the aircraft system or component, as shown by the following partial listing:

22100	Turboshaft Engine
22111	Hydromechanical Unit
2211111	N_G Governor
2211112	N_G Feedback Linkage
22112	Electrical Control Unit
2211211	Module A1
2211212	Module A2
29510	Engine Start System
29511	Engine Starter
29515	Check Valve

Work unit codes frequently are extended to six and seven digits to identify subassemblies and modules of larger assemblies. Use of the first five digits should suffice as descriptors of system functional events, however, since invariably the lowest functional levels of the aircraft whose operation can be observed are the subsystems and major components of subsystems.

Utilizing the work unit code as part of the description of system functional events and failure symptoms offers several benefits. As the common identifier of systems and components, the work unit code is frequently used both for maintenance and logistics planning and for reporting failures and maintenance in service. Having a common link with these other maintenance-related activities provides a measure of continuity and the ability to relate fault isolation tasks directly to inspection requirements, test and checkout procedures, etc. Access to spare parts requirements, test equipment lists, etc., is also facilitated.

The first part of the system function code, the work unit code, describes a system or component of the aircraft. The second part of the code describes the nature of the function. Examples are:

Code	Description
220	Starting
221	Idle
223	Shutdown
230	Acceleration
231	Engagement
232	Disengagement
240	Positioning
	Etc.

The FIAT method requires that a dictionary of coded generic function descriptions such as these be developed.

Later in the procedure it will be explained how the coded function descriptions are combined with other elements of information to describe the symptoms the technical writer will address in preparation of the maintenance manual. In order that the function descriptions read properly when interpreted and printed by computer, the generic function descriptions should be phrased as nouns. The proper construction will be assured if the description is assumed to be prefaced by the word "during" as follows:

		Function Description
(During)	(APU)	Starting
(During)	(Engine)	Idle
(During)	(Throttle Lever)	Positioning
		etc.

Combined with the work unit code, the function code describes a system-level function or contributing function:

SF-22100-220	Engine-Starting
CF-29411-240	Throttle Lever - Positioning
CF-22160-251	Engine Oil System - Pressure Within Limits
CF-29511-265	Engine Starter - Dropout
Etc.	

It is recognized that in some cases system functions will be of a relatively complex nature and not easily reduced to such simple terms as a work unit code and function code. The FIAT approach depends on relatively strict adherence to the coding scheme, however. One of the problems with current methods mentioned earlier is the subjective, inconsistent and often vague and ambiguous use of terms. The FIAT method overcomes some of these problems by requiring a consistent definition and format throughout the analysis. If the tasks of fault isolation cannot be reduced to simple terms at the early stages of analysis, communicating effectively to the mechanic during preparation of the maintenance manual will probably also be difficult.

If the coding system for system functions is too restrictive to describe some of the more complex functions of the aircraft, the problem can be remedied when the troubleshooting instructions are written. At this time descriptions can be altered or amplified as necessary to convey information clearly.

Coding of system malfunctions follows the same format except that a malfunction rather than a function is described. Earlier in this report it was explained how symptoms reported in the field were transcribed into a structured format, one element of which was the description of the observed malfunction. Appendix B contains a list of the malfunction descriptions actually reported on the CH-54.

A dictionary of system malfunction codes is required. The "How Malfunctioned" code lists contained in work unit code manuals cannot be used for this purpose directly. While some of the codes in the "How Malfunctioned" lists describe conditions that could relate to an observable system malfunction (drifting, out of track, etc.), the majority describe conditions of failure or physical defect (burned, cracked, shorted, etc.). The malfunction in these cases relates to the condition of the discrepant or failed part rather than to its effect on the performance of the system and therefore is not pertinent to describing abnormal system performance.

The dictionary of system functions used to construct system-level functions and contributing functions provides the foundation for the dictionary of system malfunctions. A system malfunction can very often be described in terms such as improper, inaccurate, incomplete, etc., accomplishment of a system function. Reference to the list of observed malfunctions reported on the CH-54 contained in Appendix B will show the vast majority to be of this form.

Most system malfunctions can therefore be constructed as modifications of system functions as follows:

Code	Description
015	Accelerates, slowly
456	Motor, fails to
594	Pressure, fluctuating
715	RPM, low

A preliminary partial listing of coded malfunction descriptions is presented in Appendix B. A sample of engine starting malfunctions taken from Table 24 is shown in coded form below:

Code			Description	
WUC		MAL	System/Component	Malfunction
24000	-	508	Auxiliary Power Plant	Fails to Operate
22100	-	456	Engine	Fails to Motor
29411	-	082	Power Control Lever	Binding
51377	-	385	Prime Boost Pump Light	Fails to Illuminate
51313	-	635	Dual TIT Indicator	Reads high

SYSTEM FAILURE MODES ANALYSIS

The second stage of the proposed approach entails a detailed analysis of system failure modes and the association of failure modes with the system malfunctions defined by the preceding analysis. All current engineering development programs for new aircraft require as part of the R&M activity the preparation of a Failure Modes and Effects Analysis (FMEA). Information required for the system failure modes analysis required by FIAT is derived primarily from the FMEA.

Identification of Pertinent Modes

There are basically two types of failures experienced with a system. One type occurs when an item of hardware, although performing acceptably, is damaged, worn, or deteriorated beyond acceptable limits and must be repaired or replaced. This type of failure usually is not a candidate for inclusion in a troubleshooting procedure, since the failure is normally found by inspection rather than sensed as a malfunction of the system. Normal wear-and-tear (corrosion, surface cracks, fastener damage, etc.) typically constitutes this category of failure. The types of failures that are candidates for inclusion in a fault isolation procedure are those that are discovered via their effect on the system rather than by their visible condition.

The immediate effect of a failure of this type is to prevent, interrupt, degrade, or terminate some physical process necessary for the proper operation of the system, e.g., to cause a loss of pressure, loss of signal, low voltage, etc. If the ultimate effect of a failure is to produce some observable malfunction or abnormal performance of the system, that failure is a candidate for inclusion in a system troubleshooting procedure. The FMEA may record either or both of these effects.

If the FMEA records only the physical effect of a failure, an assessment must be made of the system malfunction that would result. Assume in the case of a fuel valve failing closed, that the immediate effect is to prevent fuel flow to the engine. If the operator is able to observe that fuel is not flowing (via a warning light or gage), the immediate effect of the failure equates directly with a system malfunction: No fuel flow. If fuel flow cannot be observed, the abnormal system event associated with that failure is less well defined, e.g., Engine fails to start. The failure has the same physical effect in both cases, but the observed malfunction (symptom) differs.

Association of Failure Modes With System Malfunctions

The system failure modes analysis is conducted by examining the FMEA and extracting from it all failure modes having a significant potential for causing a system malfunction. Each of the selected failure modes is then associated with one or more of the system malfunctions documented in the system functional analysis. Possible effects of the failure outside of the immediate system are considered, and no attempt is made at this stage to eliminate failure modes on the premise that the malfunction they produce will be so unique as to avoid the need for a troubleshooting procedure. Such determinations are made later when all of the pertinent symptoms and causes have been collected together.

Coding of Failure Modes

Under the FIAT approach, failure modes are coded in a form similar to that used to code system functions and malfunctions. The code consists of two parts: the work unit code, which identifies the failed part or component, and the failure code, which describes the mode of failure.

For purposes of fault isolation it is necessary only to trace symptoms to the level of on-aircraft replaceable parts and components. Repairable components may have multiple modes and symptoms of failure, but the individual modes of failure are not of concern except to the extent that they affect the symptoms produced and the method of troubleshooting. Assume, for example, that a component has 20 individual failure modes. If all of these modes produce the same symptom and are each detected via the same test, they can be treated collectively as an "internal failure" of that component. The mechanic need not know the specific failure mode that has occurred, provided he is able to interpret the symptom and fault isolate to that component whenever any of the modes occur. Occasionally, however, a single component will have variable symptoms of failure and different troubleshooting procedures will be necessary to isolate to the component depending on the symptom.

The coding scheme for failure modes uses the same set of work unit codes used to identify system functions and malfunctions. To identify failure modes related to internal parts of a repairable component, the sixth and seventh digits of the WUC are used. Often, WUC manuals will contain codes for repairable subassemblies and modules of major components. Where failure modes relate to smaller internal parts of a component not covered by a WUC, it will be necessary to expand the codes to encompass these items. The list below illustrates a typical breakdown.

Work Unit Code	Description
22111	Hydromechanical Unit
2211111	N_G Governor
2211113	N_G Speed Servo
2211117	Metering Valve
2211122	Shutoff Valve

Multiple Failures and Maintenance-Induced Faults

There are two types of symptoms that cannot, as a practical matter, be analyzed or treated in a fault isolation procedures manual. First are symptoms produced by multiple failures. These are cases where two or more failure modes, each having particular symptoms of their own, produce distinctively different symptoms when they occur together.

The number of multiple failure modes possible in most systems is very large. In a system with six failure modes, there are 15 possible combinations of two simultaneous failures that might occur. In a system with 10 failure modes, the combinations of two increase to 45. Not only are the possible combinations of multiple failures very large, but their probability of occurrence (unless a dependent secondary failure situation exists) is also very remote. Even if it were possible to anticipate the symptoms of multiple failures, it would rarely be cost-effective to devote space in the manual to them.

Most symptoms occurring as a result of maintenance error are also impractical to consider in the development of fault isolation procedures. They are potentially very numerous and, as is the case with multiple failures, usually very remote. The possible exceptions are errors made in the process of a rigging or alignment procedure which can be expected to occur with some regularity and whose symptoms are relatively predictable.

Complementary Nature of the Analyses

The system functional analysis and system failure modes analysis tend to complement each other and bring to light inconsistencies and omissions in either analysis (Figure 18). When, for example, failure modes are matched against the listing of malfunctions derived from the system functional analysis, types of malfunctions not thought of originally will often be revealed. A number of such omissions were actually discovered in the experimental application of the method to engine starting problems. Conversely, deficiencies in the failure modes analysis may become evident when, upon completing the work, valid malfunctions exist for which no failure modes have been identified. Conducting the system functional analysis first and independently provides the greatest opportunity for uncovering such errors.

CREATION OF THE FAULT ISOLATION TASK CANDIDATE FILE

The system functional analysis and system failure modes analysis just described identify the principal symptoms and causes of system malfunctions. The next step in the FIAT procedure integrates the symptom/cause descriptions with other information pertinent to the fault isolation task. For complex systems the elements of data involved are numerous enough to require processing by computer.

Figure 19 shows the form used to enter data into the computer file. Each form records data pertinent to a single symptom/cause relationship. The information actually extracted from the form for computer storage is that recorded in coded form in the blocks to the right of each column. Other fields in the form are provided for readability purposes only. Figure 20 shows schematically the source of the data used to construct the first six blocks of information on the form. The form is completed as explained below.

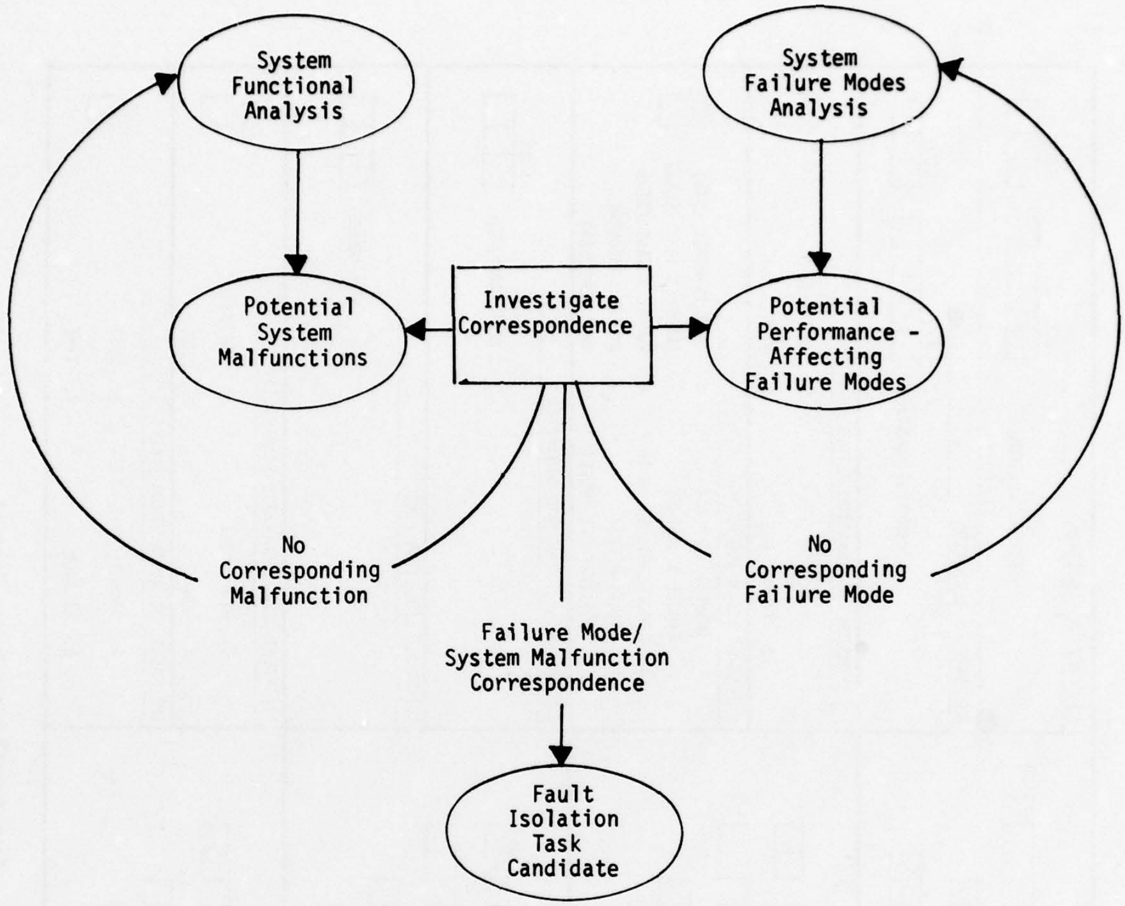

Figure 18. Complementary Nature of the Analyses

Block 1, Failure Mode/Defect. The failure mode or defect constituting the source of a symptom, as documented by the system failure modes analysis, is recorded in Block 1 of the form. The failure mode is described by two codes: the work unit code (WUC), identifying the failed part or component, and the failure mode code. The failure mode's estimated rate of occurrence derived from the reliability prediction for the system is also recorded.

Block 2, Symptom - Observable System Malfunction. The observable system malfunction associated with the failure mode is recorded in this block. Three codes are used: the work unit code, identifying the system or component that the operator will observe malfunctioning, the malfunction code

SYMPTOM/CAUSE DATA RECORD

1 FAILURE MODE/DEFECT

FAILED ITEM ________ WUC ☐☐☐☐☐☐☐

FAILURE MODE ________ CODE ☐☐☐

FAILURE RATE ($X 10^6$) RATE ☐☐☐☐

2 SYMPTOM - OBSERVABLE MALFUNCTION

FAULT ISOLATION PROCEDURE NO. ☐☐-☐☐

SYSTEM OR COMPONENT ________ WUC ☐☐☐☐☐

OBSERVED MALFUNCTION ________ CODE ☐☐☐

NATURE OR DEGREE ________ CODE ☐☐

3 SYMPTOM - INSTRUMENT INDICATION

FAULT ISOLATION PROCEDURE NO. ☐☐-☐☐

SYSTEM OR COMPONENT ________ WUC ☐☐☐☐☐

OBSERVED MALFUNCTION (INDICATION) ________ CODE ☐☐☐

NATURE OR DEGREE ________ CODE ☐☐

4 SYMPTOM - OTHER CREW PERCEPTION

SYSTEM OR COMPONENT ________ WUC ☐☐☐☐☐

PERCEPTION ________ CODE ☐☐☐

NATURE OR DEGREE ________ CODE ☐☐

5 SYMPTOM CONDITION

SYSTEM-LEVEL FUNCTION WUC ☐☐☐☐☐ CODE ☐☐☐

6 SYMPTOM CONDITION

CONTRIBUTING FUNCTION WUC ☐☐☐☐☐ CODE ☐☐☐

7 SYMPTOM CONFIRMATION METHOD

1. POWER-ON CHECK
2. GROUND RUN
3. TEST FLIGHT
4. INSPECTION

CODE ☐

8 FAULT ISOLATION METHOD

1. INSPECT IN-PLACE
2. REMOVE & INSPECT
3. REMOVE, DISASS. & INSP.
4. BUILT-IN TEST
5. TEST IN-PLACE (PGSE)
6. TEST IN-PLACE (STD)
7. REMOVE & TEST (PGSE)
8. REMOVE & TEST (STD)
9. BYPASS COMPONENT
10. SWAP COMPONENT

CODE ☐

9 FAULT ISOLATION TEST PARAMETER

TEST PARAMETER CODE ☐☐☐

10 FAULT ISOLATION TIME

MAN-HOURS ☐☐☐

11 FAULT ISOLATION ERROR PROBABILITY

1. NEGLIGIBLE
2. LOW
3. MODERATE
4. HIGH

CODE ☐

12 FAULT ISOLATION ERROR EFFECT

1. SAFETY
2. MISSION
3. COST
4. TIME

CODE ☐

Figure 19. Symptom/Cause Data Record

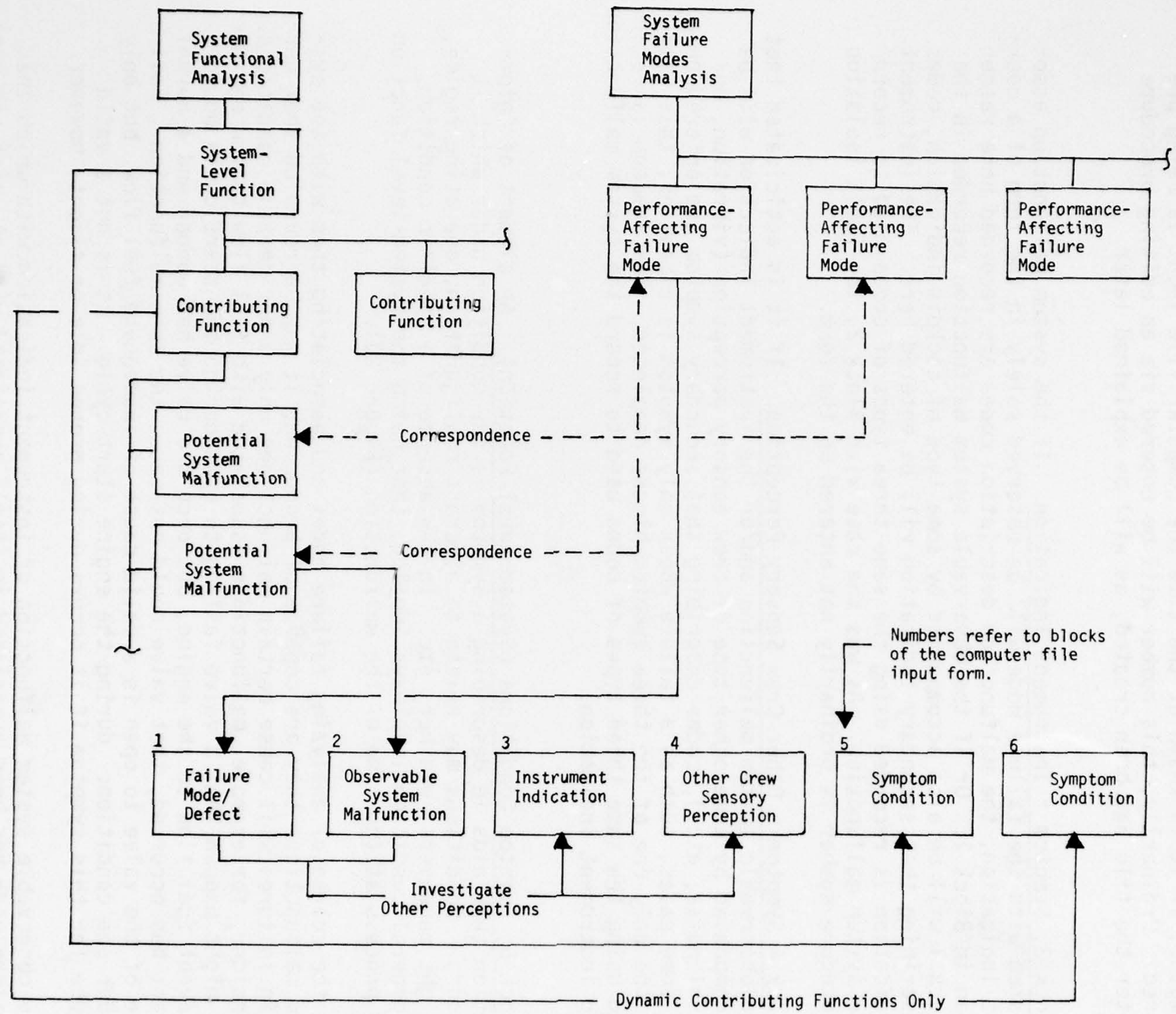

Figure 20. Construction of the Computer File Input Record

and, where applicable, the code describing the expected nature or degree of the malfunction. A partial listing of codes for generic nature or degree descriptions is contained in Appendix D. Block 2 also provides a field for entering the number of the fault isolation procedure that will cover the symptom, if it is known at the time the computer file input is being prepared. Ordinarily, this number will be entered via an editing procedure after the file has been created, as will be explained later.

Block 3, Symptom - Instrument Indication. If the system malfunction associated with the failure mode will be observed solely in the form of a cockpit indication, the malfunction description codes are recorded here rather than in Block 1. Or if the observable system malfunction recorded in the Block 1 will be also accompanied by some type of cockpit indication, codes describing that secondary indication will be entered here. The instrument indication is recorded using the same three types of codes used to record the system malfunction. As was the case with Block 2, the fault isolation procedure number is ordinarily not entered on the form.

Block 4 Symptom - Other Crew Sensory Perception. If it is anticipated that the observable system malfunction and/or the instrument indication will be accompanied by some other type of crew sensory perception (vibration, unusual noise, etc.), codes describing that secondary symptom are entered here. In some cases, such as a failure whose only symptom is vibration, this will be the only one of the three symptom blocks completed. The symptom is recorded using the same three types of codes used to record the system malfunction and instrument indication.

Block 5, Symptom Conditions (System-Level Function). An element of information that aids in describing a symptom is the condition under which it occurs. Conditions may relate to aircraft configuration, operating regime, flight maneuvers, weather, etc. In the absence of a specific condition, a general condition is always implied, that being the system-level function in process at the time of the malfunction (Figure 20).

In the course of analyzing failure modes and associating them with the system malfunctions they are capable of producing, it may be revealed that certain failures will cause certain malfunctions only under certain conditions. Consider, for example, malfunctions associated with fuel flow to the engine. It might happen that a valve failing to open during the start cycle would prevent fuel flow to the engine, but once the valve has opened and a normal start has occurred, that valve could not cause the same malfunction. Failure of the valve to open is a valid cause of inadequate fuel flow, but only under one condition: during the engine start cycle. It is not a valid cause for this symptom if it occurs during ground idle or flight, however.

The observable system malfunction or instrument indication with which the failure mode has been associated is itself associated with at least one contributing system function and its corresponding system-level function. (A system malfunction is the abnormal occurrence of a contributing function.)

Block 5 is completed by entering the work unit code and function code that describe that system-level function.

Block 6, Symptom Condition (Contributing Function). The contributing system functions describe two types of processes: steady-state processes (fuel flow) or dynamic processes (starter engagement). Any contributing function involving the direct intervention of the operator is dynamic in character, i.e., some system state must be in the process of change. There are other contributing functions, dynamic in character, that occur automatically but with the operator's awareness (starter disengagement for example). Since a contributing system function is observable by the operator, any dynamic contributing function will be initiated by and/or witnessed by the operator.

The implied condition under which a symptom occurs may be stated more specifically than the system-level function in process at the time of the malfunction, if a dynamic contributing function is also in process at the time of the malfunction. Assume that an engine fuel pressure light illuminates when the throttle is moved to ground idle position. The condition under which the light is observed could be stated correctly as "during engine start" since that is the system-level function in process. However, a more specific statement of the condition is "as throttle is moved to ground idle during engine start".

When the observable system malfunction recorded in Block 2 is associated with a dynamic contributing function, that contributing function is recorded as a symptom condition in Block 6. The Work Unit Code and Function Code create this entry.

Block 7, Symptom Confirmation Method. There may be cases where it is desirable to have the symptom confirmed before troubleshooting is initiated. This is frequently done by personnel in the field, whether or not instructed by the manual, especially when flight crew procedure or environmental factors are suspected or when symptoms are vaguely defined. Block 7 provides the opportunity to specify one of four methods of symptom confirmation which the technical writer may consider for inclusion in the manual.

Block 8, Fault Isolation Method. One of the criteria to be used in developing a fault isolation strategy for a symptom is the method and time required to inspect or test for the presence of individual failure modes representing possible causes of the symptom. Other factors being equal, failure modes that are quick and easy to check will be scheduled ahead of those that are difficult and time-consuming. This block records the method of fault isolation to be used to investigate the failure mode identified in Block 1. This may be a preliminary judgement pending an analysis of system test requirements.

Block 9, Fault Isolation Test Parameter. In this block is recorded the operating parameter or physical condition that will be used as the criteria for investigation of the failure mode (continuity, pressure, flow rate, etc.). A partial preliminary list of coded generic test parameters is contained in Appendix D.

Block 10, Fault Isolation Time. This block records the estimated time in man-hours required to inspect or test for the failure mode recorded in Block 1.

Block 11, Fault Isolation Error Probability. Another factor that might be significant in development of the fault isolation strategy is the probability of a diagnostic error, i.e., that the mechanic concludes incorrectly that the failure mode he is checking for does exist and replaces the wrong part or component. Where a high probability of error exists, it may be desirable to schedule the testing of failure modes with a lower probability of occurrence and/or higher fault isolation time ahead of the high risk tests. The probability of an error is related to the ability to conduct a test that produces consistent and nonambiguous results. A high level of confidence in the test may not always be possible, especially in cases where the only method of checking for a failure is to substitute another component. This block records an estimate of the error probability, based on the failure mode recorded in Block 1 and the fault isolation method indicated in Blocks 8 and 9.

Block 12, Fault Isolation Error Effect. The effect of a fault isolation error may also be a factor in development of the fault isolation strategy. If the only effect of an error is lost time, it is of much less concern than if mission or safety are affected. This block records a judgement of the most serious consequences of an error in fault isolation

DATA PROCESSING

The data processing system for FIAT consists of two PL/1 computer programs and a number of utility sort routines as shown in Figure 21. The File-Generator program merges the sorted keypunched data records into a disk file called the Fault Isolation Task Candidate File. Simultaneously it generates a working file that becomes the primary input for the Report-Generator program. Other inputs to the Report-Generator program include the Work Unit Code File and the four code table files: Function Description, Malfunction Description, Nature or Degree Description and Test Parameter Description.

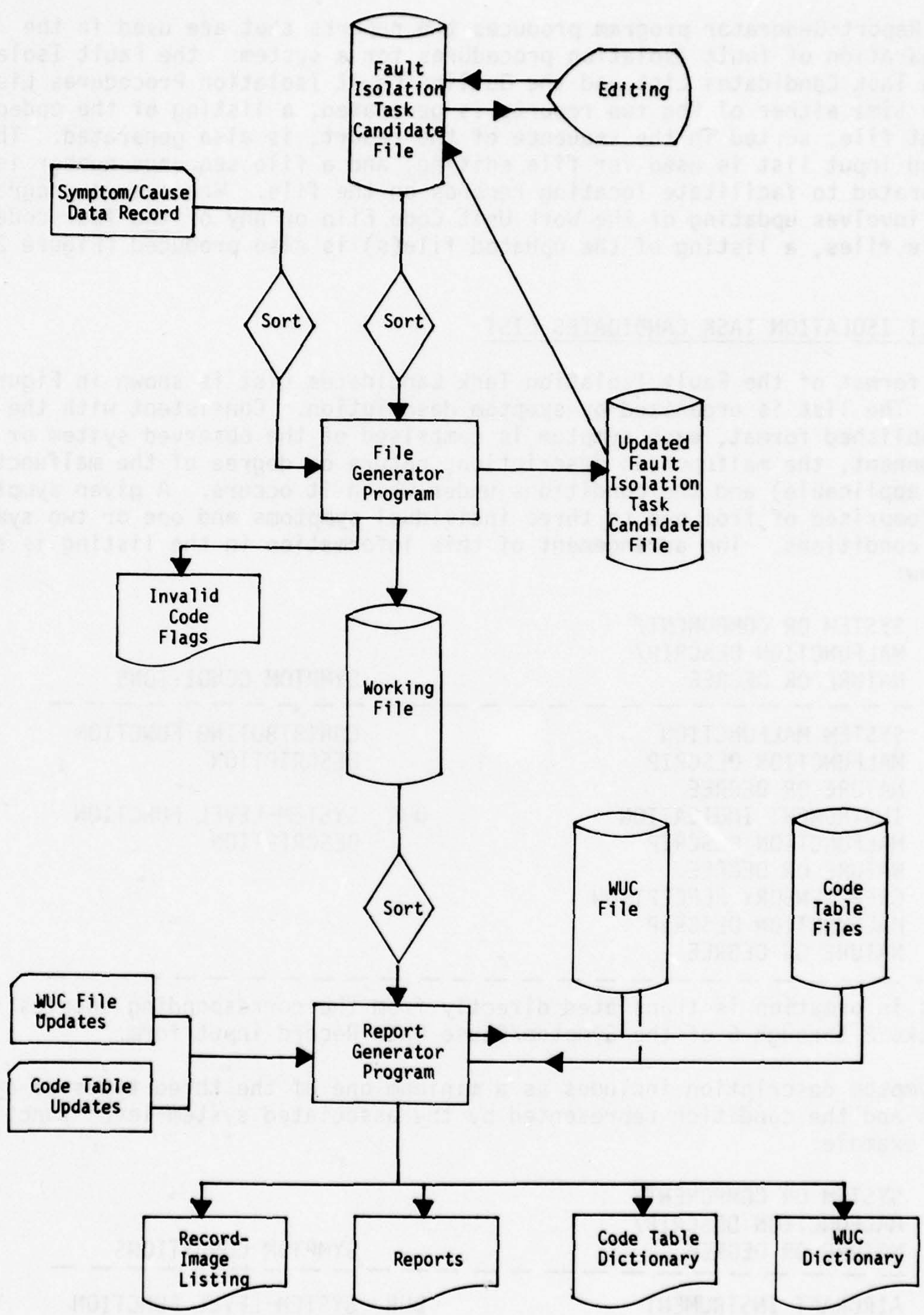

Figure 21. FIAT Data Processing System Flow

The Report-Generator program produces two reports that are used in the preparation of fault isolation procedures for a system: the Fault Isolation Task Candidates List and the Outline Fault Isolation Procedures List. Each time either of the two reports is generated, a listing of the coded input file, sorted in the sequence of the report, is also generated. The coded input list is used for file editing, and a file sequence number is generated to facilitate locating records on the file. Whenever a program run involves updating of the Work Unit Code File or any of the four code table files, a listing of the updated file(s) is also produced (Figure 22).

FAULT ISOLATION TASK CANDIDATES LIST

The format of the Fault Isolation Task Candidates List is shown in Figure 23. The list is organized by symptom description. Consistent with the established format, each symptom is comprised of the observed system or component, the malfunction description, nature or degree of the malfunction (if applicable) and the conditions under which it occurs. A given symptom is comprised of from one to three individual symptoms and one or two symptom conditions. The arrangement of this information in the listing is shown below:

```
     SYSTEM OR COMPONENT/
     MALFUNCTION DESCRIP/
     NATURE OR DEGREE                        SYMPTOM CONDITIONS
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     SYSTEM MALFUNCTION                      CONTRIBUTING FUNCTION
     MALFUNCTION DESCRIP                     DESCRIPTION
     NATURE OR DEGREE
AND  INSTRUMENT INDICATION               DUR SYSTEM-LEVEL FUNCTION
     MALFUNCTION DESCRIP                     DESCRIPTION
     NATURE OR DEGREE
AND  CREW SENSORY PERCEPTION
     MALFUNCTION DESCRIP
     NATURE OR DEGREE
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

This information is translated directly from the corresponding entries in Blocks 2 through 6 of the Symptom/Cause Data Record input form.

A symptom description includes as a minimum one of the three types of symptoms and the condition represented by the associated system-level function. For example:

```
     SYSTEM OR COMPONENT/
     MALFUNCTION DESCRIP/
     NATURE OR DEGREE                        SYMPTOM CONDITIONS
     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     AIRCRAFT INSTRUMENT                 DUR SYSTEM-LEVEL FUNCTION
     INDICATED MALFUNCTION                   DESCRIPTION
     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
WORK UNIT CODE DICTIONARY

     WUC - DEFINITION
---------------------------------------

  22100   - ENGINE
  22111   - HYDROMECHANICL UNIT
  2211111 - NG GOVERNOR
  2211112 - NG FEEDBACK LINKAGE
  2211113 - NG SPEED SERVO
  2211114 - SPEED SET LINKAGE
  2211115 - NP SERVO SYSTEM
  2211116 - MULTIPLYING LINKAGE
  2211117 - METERING VALVE
  2211118 - POWER AVAILABLE SPN
  2211121 - NG OVERSPEED VALVE
  2211122 - SHUTOFF VALVE
  2211123 - PRESSURE REG VALVE
  2211124 - T2 SENSOR
  22112   - ELECTRICAL CONT UNT
  2211211 - MODULE A1
  2211212 - MODULE A2
  2211213 - MODULE A3
  2211214 - MODULE A4
  2211215 - MODULE A5
  2211216 - MODULE A6
  2211217 - FILTER HOUSING
  2211218 - EMI FILTER BOX
  22113   - ACCESSORY MODULE
  2211312 - IGNITION LEADS
  2211314 - CONT INPUT DRIVE SH
  2211321 - RADIAL DRIVE SHAFT
  2211322 - OIL COOLER
  2211323 - IGNITION EXCITER
  2211324 - ALTERNATOR
  2211325 - ELEC CABLE ASSY
  2211326 - SEQUENCE VALVE
  2211327 - FUEL BOOST PUMP
  22121   - COLD SECTION MODULE
  2212112 - OUTPUT SHAFT
  2212118 - INLET GUIDE VANE
  2212135 - MAIN FUEL MANIFOLD
  2212137 - FUEL INJECTOR
  2212145 - ANTI-ICE DUCTING
  2212146 - VAR GEOM LINKAGE
  2212147 - P3 SENSOR
  2212148 - PRIMER FUEL NOZZLE
  22122   - HOT SECTION MODULE
  2212211 - GAS GENERATOR ROTOR
  2212231 - TURBINE STATOR ASSY
  2212233 - PRIMER FUEL NOZZLE
  22123   - IGNITORS
  2212300 - IGNITORS
  22150   - ENGINE FUEL SYSTEM
  22160   - ENGINE OIL SYSTEM
  24110   - APU
  24150   - APU FUEL SYSTEM
  2415000 - APU FUEL SYSTEM
  24156   - APU FUEL CONTROL
```

```
CODE DICTIONARY

CODE TYPE -  2, OBSERVED FAULT

     CODE - DEFINITION
----------------------------------------

        0 -
        1 - LOUD NOISE
        2 - UNUSUAL NOISE
        8 - FAILS TO ACCELERATE
       15 - ACCELERATES SLOWLY
       82 - BINDING
      212 - FAILS TO DROPOUT
      283 - FAILS TO EXTINGUISH
      315 - FUEL FLOW ERRATIC
      316 - FUEL BOOST INDICATN
      318 - INSUFFICIENT FUEL
      320 - NO FUEL FLOW
      350 - HOT STARTS
      385 - FAILS TO ILLUMINATE
      387 - ILLUMINATED
      395 - NO SIGNAL INDICATN
      456 - FAILS TO MOTOR
      457 - MOTORS SLOWLY
      508 - FAILS TO OPERATE
      594 - FLUCTUATING
      596 - HIGH PRESSURE
      603 - READS ZERO
      606 - LOW PRESSURE
      615 - NO START AIR
      635 - READS HIGH
      636 - READS LOW
      715 - RPM ERRATIC
      717 - RPM HIGH
      718 - RPM LOW
      735 - SHUTS DOWN
      768 - STALLS
      772 - FAILS TO START
      778 - STARTS SLOWLY
      842 - READS HIGH
      862 - FAILS TO XFER FUEL
      878 - TRAVEL RESTRICTED
      940 - VIBRATION
      941 - LOSS OF POWER
```

SAMPLE DATA ONLY

Figure 22. FIAT Dictionary Printout

PROCEDURE NO: -

F I A T REPORT - 1 , FAULT ISOLATION TASK CANDIDATES

SYSTEM OR COMPONENT/ FAULT DESCRIPTION/ NATURE OR DEGREE	SYMPTOM CONDITION	FAULT CONFIRM. METHOD	SYMPTOM POSSIBLE CAUSES	FAULT PROB.	FALUT ISOL. TIME	FAULT ISOL. METHOD/ TEST PARAMETER	ERROR PROB/ EFFECT
SYMPTOM NUMBER - 1 / EST FREQ (*)= 500000							
ENGINE HOT STARTS	DUR ENGINE START	GROUND RUN	HYDROMECHANICL UNIT INTERNAL FAILURE	1.00	0.50		
AND DUAL TIT INDICATOR READS HIGH			* MULTIPLYING LINKAGE WORN	0.50	0.50	SWAP/SUBSTITUTE COMP	MOD/ COST
			* METERING VALVE DISTORTED	0.50	0.50	SWAP/SUBSTITUTE COMP	MOD/ COST
SYMPTOM NUMBER - 2 / EST FREQ (*)= 3448							
ENGINE FAILS TO MOTOR	START BUTTON ENGAGEMENT	GROUND RUN	START CONTROL VALVE BINDING,SEIZED,JAM	0.33	0.70	SWAP/SUBSTITUTE COMP	MOD/ COST
AND DUAL GAS GEN TACH READS ZERO	DUR ENGINE START		START MOTOR INTERNAL FAILURE	0.57	1.50		
			* CLUTCH SLIPS	0.57	1.50	SWAP/SUBSTITUTE COMP	MOD/ COST
			AIR SOURCE SWITCH SHORT CIRCUIT	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			AIR SOURCE SWITCH OPEN	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			START BUTTON SHORT CIRCUIT	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			START BUTTON OPEN	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			ENGINE INTERNAL FAILURE	0.03	1.00	SWAP/SUBSTITUTE COMP	MOD/ COST

SAMPLE DATA ONLY

(*) - FLT-HRS BETWEEN OCCURANCES

Figure 23. Fault Isolation Task Candidates List

An example of a symptom description entailing all of the possible elements of information is given below:

	SYSTEM OR COMPONENT/ MALFUNCTION DESCRIP/ NATURE OR DEGREE		SYMPTOM CONDITIONS
	CARGO HOIST CABLE BINDING INTERMITTENTLY		CARGO HOIST SWITCH ENGAGED
AND	HOIST HYD PRESSURE LT ILLUMINATED INTERMITTENTLY	DUR	CARGO HOIST OPERATION
AND	CARGO HOIST WELL UNUSUAL NOISE HIGH PITCHED		

Symptoms will infrequently involve all of these elements of information, however, and a more typical symptom description is given below:

SYSTEM OR COMPONENT/ MALFUNCTION DESCRIP/ NATURE OR DEGREE		SYMPTOM CONDITIONS
TURBINE INLET TEMP IND READS HIGH	DUR	ENGINE IDLE

When a symptom includes both an observable system malfunction and an instrument indication, the symptom appears twice in the Candidate Listing, once in the order of system malfunction, followed by instrument indication, and once in the order of instrument indication, followed by system malfunction. This is done to provide to the technical writer the option of covering the symptom either with other system malfunctions of that type, with other instrument indications of that type, or both ways. In the case of an engine starting malfunction accompanied by a fuel pressure warning light, for example, the technical writer could elect to cover the symptom with other engine starting problems or with fuel pressure light indications occurring under other circumstances. The Candidate List includes the symptom with the other engine starting problems and with the other fuel pressure light indications to facilitate making this determination.

The next field of the Candidate List contains the estimated flight-hour frequency between symptom occurrences. This estimate is obtained by summing the predicted failure rates for all of the failure modes identified as possible causes of the symptom. In cases where a symptom is caused by failure modes that are also causes of other symptoms, the estimated frequency of occurrence of the respective symptoms will be overstated. This happens because the entire failure rate is accounted for in the predicted frequency of each symptom rather than apportioned among the relevant symptoms.

To apportion the failure rate in this manner would require a knowledge of the circumstances under which the failures are likely to occur or be discovered. For example, related to engine failures, it would be necessary to know how often given failures would occur or be found during engine starting versus engine idle, etc. This information is not normally available.

The method of fault confirmation (derived from Block 7 of the input data record) is recorded in the next field of the Task Candidates List.

Possible causes of the symptom are listed in the order of minimum to maximum expected fault isolation time. The expected fault isolation time is obtained as a product of the probability of that failure mode causing the subject symptom and the estimated time to inspect or test for the presence of that failure. The probability of each of the listed failure modes being the cause of the symptom is obtained as a ratio of the failure rate associated with that mode to the sum of the failure rates for all failure modes related to that symptom.

Where failure modes relate to internal parts of an LRU (seven-digit WUC), the probability and fault isolation time associated with each failure mode are listed individually, and the contribution of all internal part failure modes to the parent LRU is shown. This situation is presented in the following format:

POSSIBLE CAUSES	CAUSE PROB.	FAULT ISOL. TIME
LRU COMPONENT INTERNAL FAILURE	.80	.95
*INTERNAL PART FAILURE MODE	.35	.25
*INTERNAL PART FAILURE MODE	.45	1.50

Internal part failure modes are identified by the computer program via the presence of a seven-digit WUC in the failure mode description field of the input record. When a seven-digit WUC is encountered, the program looks up the nomenclature of the next higher LRU, which is identified by the first five digits of the WUC. A cause probability for the LRU is obtained by summing the cause probabilities of the internal failure modes, and an average LRU fault isolation time is calculated as a weighted average of the internal part fault isolation times.

The cause probability and average fault isolation time calculated for the LRU are used to determine its placement in the ordering of possible symptom causes, and the LRU is always listed as a group with its respective internal part failure modes. If a single inspection or test can be used to check for the presence of any of the internal part failure modes, the LRU is properly ordered with respect to the other LRU-level causes listed for the symptom. If different inspections or tests would be used to check the LRU, depending on the internal part failure mode, the internal part failure modes should be treated independently or in sub-groups as individual symptom causes. In these cases, the internal part failure mode may not be properly ordered with respect to other LRU-level causes. The engineer or technical writer will have to account for these situations in development of the fault isolation strategy.

The sequence in which the possible symptom causes are listed constitutes the most efficient fault isolation procedure, based on the estimated probability and fault isolation time and the assumption that each of the possible causes would be investigated independently in the process of isolating the fault. In practice the possible causes of a symptom will often not be investigated independently, one at a time, but rather in logical groups or sets. It is often possible to devise single inspections or tests that will rule out a number of possible causes or, alternatively, indicate that the fault exists among a select few of the possible causes. Other factors, such as the probability and consequences of a diagnostic error, may also influence the sequence in which troubleshooting is conducted. These are determinations that must be made by the engineer or technical writer during preparation of the troubleshooting procedure.

Review and Consolidation of the Task Candidates List

The Fault Isolation Task Candidates List displays as a separate symptom every unique combination of symptom descriptors, i.e., observable system malfunction, instrument indication, crew sensory perception, and symptom conditions. A change in any of these descriptors is recognized by the program as a unique symptom. In many instances, variations that distinguish one symptom from another are not significant insofar as fault isolation is concerned. A warning light appearing during ground idle will initially be interpreted as a different symptom than the same warning light appearing in flight. A flickering light will be interpreted as a symptom different from a continuous light, etc. From the standpoint of troubleshooting the condition under which the light appears and the quality of light may be irrelevant, and all of the symptoms can be condensed into one. An analysis of the Fault Isolation Task Candidates List is made to combine similar or identical symptoms and to organize the symptoms into logical sets for coverage by fault isolation procedures.

Editing of the Task Candidate File

As he reviews the list of fault isolation task candidates, the engineer or writer annotates the listing to modify, condense and regroup symptoms and causes. These changes are then transferred to the companion listing of data printed in file-image code form (Figure 24) and the file is updated via an on-line computer terminal.

In some cases it may be desirable to physically alter the file to condense two or more symptoms into one. A case where this might be done is one in which two symptoms having identically the same causes differ only in the conditions under which they occur, and the conditions are deemed irrelevant to troubleshooting the symptom. The two symptoms could be replaced by one by removing the condition description from one set of symptom/cause records and eliminating the other set of symptom/cause records entirely. The change is shown schematically below:

RECORD	SYMPTOM	CONDITIONS	CAUSES
1	CAUTION LIGHT	~~GROUND IDLE~~	SWITCH
2	CAUTION LIGHT	~~GROUND IDLE~~	VALVE
3	CAUTION LIGHT	~~GROUND IDLE~~	RELAY
~~4~~	~~CAUTION LIGHT~~	~~IN FLIGHT~~	~~SWITCH~~
~~5~~	~~CAUTION LIGHT~~	~~IN FLIGHT~~	~~VALVE~~
~~6~~	~~CAUTION LIGHT~~	~~IN FLIGHT~~	~~RELAY~~

——— indicates deletions

The effect of this type of change is to remove as symptom criteria the conditions under which the symptom occurs. When the file is processed after editing only one symptom, having no condition associated with it, will appear:

RECORD	SYMPTOM	CONDITIONS	CAUSES
1	CAUTION LIGHT		SWITCH
2	CAUTION LIGHT		VALVE
3	CAUTION LIGHT		RELAY

```
PROCEDURE NO:    -
                 F I A T  REPORT- 3 ,    FAULT ISOLATION TASK CANDIDATE INPUT CODES
                 ---------------------   ---------------------------------------
     : CAUSE INPUT-    : SYMPTOM INPUT-                                                      : FAULT ISOLATION INPUT-      :
     :                 :                                                                     :                             :
     :FAILED  FAIL FAIL:SYSTEM MALFUNCTION:INST. INDICATION  :CREW PERCEP. :SYMPTOM CONDITIONS :                   FLT  FLT :
 LINE:ITEM    MODE RATE:      COMP  OBS NAT:          OBS NAT:          OBS NAT:SYSTEM    :CONTRIB  :CONF ISOL ISOL TEST ERR  ERR :
  NUM:WUC     CODE     :PROC WUC    FLT DGR:PROC WUC  FLT DGR:WUC       FLT DGR:WUC    CD :WUC   CDE:METH METH TIME PARAM PROB EFF :
------------------------------------------------------------------------------------------------------------------------------
  COL:2       9    12  :16  20    25  28 :30   34    39  42 :44     49  52 :54    59 :62    67 :70   71   73   76   79   80  :
FORMT:99AAAAA 999  9999 AAAA 99AAA 999 99  AAAA 99AAA 999 99  99AAA 999 99  99AAA 999 99AAA 999 9    99   999  999  9    9
------------------------------------------------------------------------------------------------------------------------------

SYMPTOM NUMBER -     1 /  EST FREQ (*) = 500000

      22111     0            22100 350  0        51313 842  0            0  0  22100 220            0 2   0         0    0    0

   41 2211116  20  0001      22100 350  0        51313 842  0            0  0  22100 220            0 2   10   0    0    3    3

   42 2211117 118  0001      22100 350  0        51313 842  0            0  0  22100 220            0 2   10   0    0    3    3
------------------------------------------------------------------------------------------------------------------------------
SYMPTOM NUMBER -     2 /  EST FREQ (*) =   3448

   49 29517   135  0095      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   10   0    0    3    3

      29511     0            22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   0         0    0    0

   46 2951113 735  0165      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   10   0    0    3    3

   48 29512   615  0005      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   6    0    1    1    4

   47 29512   450  0005      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   6    0    1    1    4

   45 29412   615  0005      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   6    0    1    1    4

   44 29412   450  0005      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   6    0    1    1    4

   43 22100     0  0010      22100 456  0        51312 603  0            0  0  22100 220 29412 231 2   10   0    0    3    3
------------------------------------------------------------------------------------------------------------------------------
SYMPTOM NUMBER -     3 /  EST FREQ (*) =   8333

      29511     0            22100 456  0        51312 603  0  22100     2  0  22100 220 29412 231 2   0         0    0    0

   50 2951111  70  0045      22100 456  0        51312 603  0  22100     2  0  22100 220 29412 231 2   10   0    0    3    3

   51 2951114 135  0075      22100 456  0        51312 603  0  22100     2  0  22100 220 29412 231 2   10   0    0    3    3
------------------------------------------------------------------------------------------------------------------------------
```

SAMPLE DATA ONLY

Figure 24. File Image Code Listing

Changes such as this should be made cautiously because, while the conditions under which the symptom occurs may not affect the troubleshooting procedure, knowing these conditions may be of value to the technical writer in preparation of the procedure. Once the file has been physically altered in this way, the information is lost. If a need for such information is likely, it would be preferable to have the symptom tabulated twice in the Outline Fault Isolation Procedure. After symptoms have been assigned troubleshooting procedure numbers, they will be grouped in the report under that procedure so that the technical writer will be easily able to detect such duplications.

Assignment of Fault Isolation Procedure Numbers

In the final task related to review and consolidation of the Fault Isolation Task Candidates List, the technical writer decides on the content of the various troubleshooting procedures that will comprise the manual and groups symptoms according to the procedure under which they will be covered. This is done by assigning to each symptom a fault isolation procedure number which is added to the respective computer file record via an editing procedure.

The computer file record has a field reserved in two locations for entry of the fault isolation procedure number, one field following the system malfunction description codes and one following the instrument indication description codes. As was explained earlier, when a symptom includes both an observable system malfunction and an instrument indication, the symptom is generated twice in the Fault Isolation Task Candidates List. The engineer or technical writer decides to cover the symptom primarily as a system malfunction or primarily as an instrument indication and designates this choice by entering a fault isolation procedure number in one of the two available locations in the computer file record. When the program generates the Outline Fault Isolation Procedures List, the final output of FIAT, it locates the symptom under the designated fault isolation procedure, printing the system malfunction description first or the instrument indication description first, depending on which of the two record locations contains the procedure number (Figure 25). In the unusual situation where the engineer or technical writer decides to cover the same symptom under two different fault isolation procedures, both procedure numbers are entered in the record. If it is decided for any reason to omit a symptom from the manual entirely, both procedure number entry locations in the file record are left blank, and the symptom is grouped with other unassigned symptoms in the Outline Fault Isolation Procedures List.

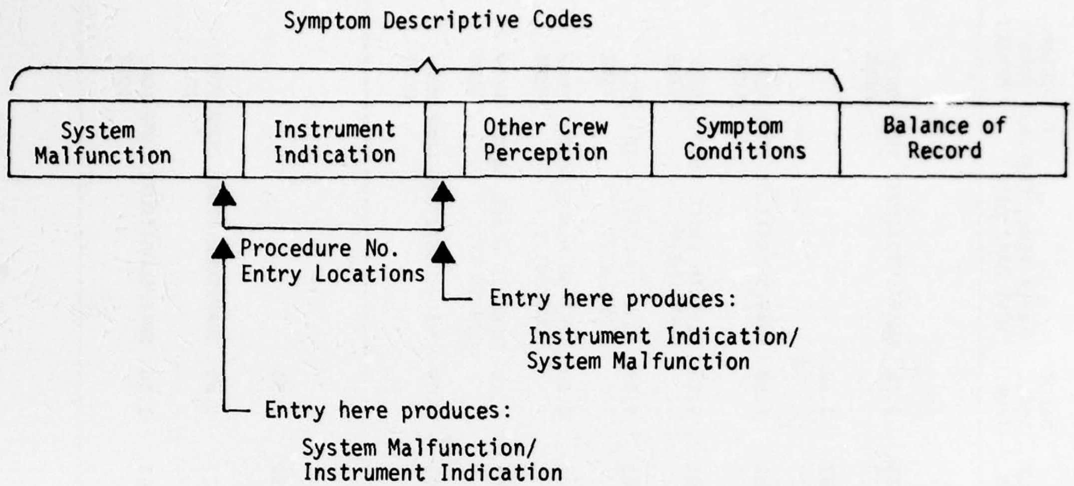

Figure 25. Location of Fault Isolation Procedure Number Establishes Symptom Hierarchy

OUTLINE FAULT ISOLATION PROCEDURES LIST

When the file editing and assignment of fault isolation procedure numbers has been completed, the computer program is run again to generate outline fault isolation procedures and related indexes for the system. The Outline Fault Isolation Procedures List (Figure 26) has the same format as the Fault Isolation Task Candidates List except that it is organized by the fault isolation procedure number appearing in the upper left corner of the page. The listing is sorted by symptom within procedure number, and each change in procedure number begins a new page.

The Outline Fault Isolation Procedures List is the technical writer's guide for preparing the maintenance manual. It provides him a comprehensive description of the symptoms and possible causes that will comprise the content of each fault isolation procedure. The possible causes of each symptom are listed in a suggested order of troubleshooting, and key elements of information such as test methods and estimated troubleshooting times are given.

The Outline Fault Isolation Procedures List is a working guide; additional work must be done by the technical writer to prepare the text and illustrations that will make up the maintenance manual. Further, while bringing together much of the information he will need to write the fault isolation procedures, the guide does not relieve the technical writer of the need to exercise independent judgement and depart from the guide where suggested by individual experience.

PROCEDURE NO: 11-01

F I A T REPORT - 2 , OUTLINE FAULT ISOLATION PROCEDURES

SYSTEM OR COMPONENT/ FAULT DESCRIPTION/ NATURE OR DEGREE	SYMPTOM CONDITION	FAULT CONFIRM. METHOD	SYMPTOM POSSIBLE CAUSES	FAULT PROB.	FALUT ISOL. TIME	FAULT ISOL. METHOD/ TEST PARAMETER	ERROR PROB/ EFFECT
SYMPTOM NUMBER - 1 / EST FREQ (*)= 3448							
ENGINE FAILS TO MOTOR	START BUTTON ENGAGEMENT	GROUND RUN	START CONTROL VALVE BINDING,SEIZED,JAM	0.33	0.70	SWAP/SUBSTITUTE COMP	MOD/ COST
AND DUAL GAS GEN TACH READS ZERO	DUR ENGINE START		START MOTOR INTERNAL FAILURE	0.57	1.50		
			* CLUTCH SLIPS	0.57	1.50	SWAP/SUBSTITUTE COMP	MOD/ COST
			AIR SOURCE SWITCH SHORT CIRCUIT	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			AIR SOURCE SWITCH OPEN	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			START BUTTON SHORT CIRCUIT	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			START BUTTON OPEN	0.02	0.20	TEST IN PLACE (STD) CONTINUITY	NEG/ TIME
			ENGINE INTERNAL FAILURE	0.03	1.00	SWAP/SUBSTITUTE COMP	MOD/ COST
SYMPTOM NUMBER - 2 / EST FREQ (*)= 8333							
ENGINE FAILS TO MOTOR	START BUTTON ENGAGEMENT	GROUND RUN	START MOTOR INTERNAL FAILURE	1.00	1.50		
AND DUAL GAS GEN TACH READS ZERO	DUR ENGINE START		* GEARS FRACTURED	0.37	1.50	SWAP/SUBSTITUTE COMP	MOD/ COST
AND ENGINE UNUSUAL NOISE			* BEARINGS BINDING,SEIZED,JAM	0.62	1.50	SWAP/SUBSTITUTE COMP	MOD/ COST

SAMPLE DATA ONLY

(*) - FLT-HRS BETWEEN OCCURANCES

Figure 26. Outline Fault Isolation Procedures List

Symptom/Cause Indexes

After incorporation of the fault isolation procedure numbers, the Fault Isolation Task Candidates File contains the information that the program uses to generate an index of symptoms cross-referenced to the procedures in which they are covered. A sample is shown in Figure 27. Because of changes that are likely to take place in the content and organization of individual procedures in the process of preparing the manual, the computer-generated symptom index may require some modification before incorporation in the manual. Also, the generic terms that are used to translate coded information into symptom descriptions may be highly condensed and require expansion and/or editing.

Troubleshooting Procedure Entry Points

For complex sequences of events such as the one associated with engine starting, a given fault may be reported a number of different ways. With respect to engine starting, the most general symptom that can be reported is "Engine fails to start". There are a host of more specific symptoms that might be reported, however, and one aim of the troubleshooting procedure should be to require the mechanic to identify the symptom as specifically as possible. This having been done, troubleshooting can commence at the most efficient entry point in the procedure.

Failure to describe a symptom as specifically as it might be described may be due to carelessness on the part of the observer or to poor communication between the observer and the mechanic. Where it is known that a symptom that might be reported can always be described more specifically, that symptom should not be listed as a valid symptom in the troubleshooting procedure. In the case of engine starting problems, the symptom "Engine fails to start" would be considered invalid, since the fault can always be described more specifically. For example,

Starter fails to engage

Engine fails to motor

Engine motors but fails to start

Etc.

The troubleshooting procedure should always require that the symptom be described as specifically as the available information permits, requiring if necessary that the function be attempted again to acquire that information. In the case of engine starting, if the mechanic lacks information needed to pinpoint the symptom he should be directed to attempt an engine start and duplicate the reported fault, recording pertinent observations and instrument readings in the process.

F I A T REPORT 4- INDEX OF PROCEDURES BY SYMPTOM NAME

SAMPLE DATA ONLY

SYMPTOM					PROCEDURE
DUAL GAS GEN TACH	FLUCTUATING	AND AND	ENGINE ENGINE	STALLS LOUD NOISE	- 30-09
DUAL GAS GEN TACH	READS HIGH				- 30-08
DUAL GAS GEN TACH	READS LOW				- 30-08
DUAL GAS GEN TACH	READS LOW	AND	ENGINE	LOSS OF POWER	- 30-08
DUAL GAS GEN TACH	READS LOW	AND	ENGINE	MOTORS SLOWLY	- 30-08
DUAL GAS GEN TACH	READS LOW	AND AND	ENGINE ENGINE	MOTORS SLOWLY UNUSUAL NOISE	- 30-08
DUAL TIT INDICATOR	READS HIGH	AND	ENGINE	HOT STARTS	- 30-07
ENG START ADVSRY LT	FAILS TO EXTINGUISH				- 30-10
ENGINE	FAILS TO MOTOR	AND	DUAL GAS GEN TACH	READS ZERO	- 11-01
ENGINE	FAILS TO MOTOR	AND AND	DUAL GAS GEN TACH ENGINE	READS ZERO UNUSUAL NOISE	- 11-01
ENGINE	FAILS TO START				- 11-06
ENGINE	HOT STARTS	AND	DUAL TIT INDICATOR	READS HIGH	- 11-05
ENGINE	LOSS OF POWER	AND	DUAL GAS GEN TACH	READS LOW	- 11-03
ENGINE	MOTORS SLOWLY	AND	DUAL GAS GEN TACH	READS LOW	- 11-01
ENGINE	MOTORS SLOWLY	AND AND	DUAL GAS GEN TACH ENGINE	READS LOW UNUSUAL NOISE	- 11-01
ENGINE	SHUTS DOWN				- 11-03
ENGINE	STALLS	AND AND	DUAL GAS GEN TACH ENGINE	FLUCTUATING LOUD NOISE	- 11-03

Figure 27. Fault Isolation Procedures Index

There may be rare cases where attempting to duplicate a fault for the purpose of acquiring more information may present a risk of injury or damage to equipment. This would be true of serious flight control problems. In such cases, mandatory inspections and checks would be performed without regard to efficiency or cost.

CONCLUSIONS

1. Fault isolation maintenance is an important contributor to the cost of operating Army helicopters. For the CH-54 helicopter, which served as the model for this study, it was determined that approximately 1 in 3 corrective maintenance actions on nonavionics systems involves some type of fault isolation. The average troubleshooting task was found to consume approximately 1.4 man-hours. The direct cost of fault isolation maintenance on nonavionics systems of the CH-54, including the assessed cost of documented errors in troubleshooting, was estimated at $25 per flight-hour. It is believed that the cost of undocumented errors and of indirect maintenance expenses (administration, quality control, etc.) would, if known, add substantially to this cost.

2. A large proportion of the fault isolation maintenance on nonavionics systems of the helicopter stems from the failure of aircraft instruments and warning devices. It was found with the CH-54 that approximately 50% of all symptoms observed via aircraft instruments and warning devices were attributed to a failure of the instrument or warning device rather than to a failure of the monitored system. Approximately 1 in 5 of all troubleshooting actions on nonavionics systems of the aircraft involved these modes of failures.

3. Field personnel receive minimal formal training in fault isolation maintenance; troubleshooting skills are mainly acquired on the job. Test equipment other than hand-held meters and gages is rarely used for troubleshooting.

4. Fault isolation maintenance data on present-day Army systems is generally poor. Major criticisms involve widespread omissions of significant symptoms and causes, poor organization and indexing of information, and inefficient troubleshooting procedures. Problems with language and communication are also frequently cited.

5. The development of a Troubleshooting Specialist MOS similar to that of the Aircraft Technical Inspector appears to offer the potential for alleviating many of the skill-related problems in fault isolation maintenance.

6. An improved method of developing fault isolation maintenance data for complex systems was formulated and applied under this program. The method is called FIAT (Fault Isolation Analysis Technique).

RECOMMENDATIONS

The FIAT method developed under this program appears to be technically and procedurally compatible with existing Army requirements in the areas of R&M (Reliability and Maintainability), LSA (Logistics Support Analysis) and SPA (Skill Performance Aids). If, in the judgement of the Army, FIAT merits further development, it is recommended that a program be undertaken to integrate the technique into the engineering development process for new systems. As part of this effort, certain refinements to FIAT and an expansion of its capability beyond that permitted by the scope of this current program should be considered.

For future use, a detailed user's guide should be published, and the FIAT methodology should be integrated into existing R&M and LSA programs. The dictionaries of terms and parameters shown in sample form in this report should be expanded to facilitate employing FIAT and to promote standardization in its use. Several refinements to the FIAT computer programs also appear desirable.

It is recommended that the algorithm for the preferred troubleshooting strategy incorporated in FIAT be expanded to include consideration of the discrimination capability of the available tests. With this addition, the analyst would define one or more tests with which to investigate the symptom and would determine the discrimination capability of the test relative to each of the possible symptom causes (eliminates the cause, confirms the cause, fails to discriminate). This would be documented via simple checklist-type decisions and entered into the FIAT data base. With this additional information, FIAT will analyze the probability of each symptom cause and such factors as the time to perform each test, the overall discrimination capability of and confidence level in each test, and the possible redundancy among tests. FIAT will then eliminate unnecessary tests, select the best order for the remaining tests, and establish the troubleshooting strategy that provides the lowest expected time and cost to fault isolate. Computer graphics could be used to produce troubleshooting tables and/or logic trees, eliminating a large part of the technical writing task.

REFERENCES

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2. Holbert, C., and Newport, G., HELICOPTER MAINTENANCE EFFECTIVENESS ANALYSIS, Sikorsky Aircraft Division, USAAMRDL-TR-75-14, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, May 1975, AD A012225.

3. MANAGEMENT SUMMARY REPORT, VOLUME III, ORGANIZATIONAL AND SUPPORT MAINTENANCE OPERATION AND COST, Report No. RCS AMCQA-113, Product Assurance Directorate, U.S. Army Aviation Systems Command, St. Louis, Missouri, September 1973.

APPENDIX A

AIRCRAFT SYSTEM AND COMPONENT CODES

100 AIRCRAFT GENERAL

110 AIRFRAME SYSTEM

130 LANDING GEAR SYSTEM

131 Nose Landing Gear
- 01 Nose Wheel
- 02 Nose Wheel Lock

132 Main Landing Gear
- 01 Main Landing Gear Strut

133 Wheel Brakes
- 01 Parking Brake
- 02 Wheel Brake

140 FLIGHT CONTROLS SYSTEM

141 Collective Controls
- 01 Collective Stick

142 Cyclic Controls
- 01 Cyclic Stick
- 02 Aft Pilot's Cyclic

143 Directional Controls
- 01 Directional Control Pedals
- 02 Directional Control Pedal Adjustment

144 AFCS Servo

145 Main Rotor Primary Servo

146 Tail Rotor Servo

147 Stick Trim System
- 01 Stick Trim Switch
- 02 Stick Trim Release
- 03 Stick Trim Circuit Breaker

150 ROTOR SYSTEM

151 Main Rotor System
- 01 Main Rotor Droop Stop

152 Tail Rotor System

220 TURBOSHAFT ENGINES

221 Engine Fuel System
01 Fuel Control

222 Engine Lube System

223 Engine Electrical System

224 Engine Ignition System

225 Engine Bleed Air System
01 Engine Bleed Air Strap
02 Engine Bleed Air Circuit Breaker

240 AUXILIARY POWER PLANT (APP)

241 APP Fuel System
01 Fuel Control

242 APP Lube System

243 APP Electrical System

244 APP Ignition System

245 APP Controls System

246 APP Start System
01 Accumulator
02 Start Motor
03 Start Circuit Breaker

247 APP Instruments System
01 EGT Indicator
02 Hour Meter
03 Tach Indicator
04 Temperature Indicator
05 Panel Lights
06 Fuel Pressure Warning Light

260 DRIVES AND TRANSMISSIONS

261 Gearboxes/Clutches/Shafts
01 Main Gearbox
02 APP Clutch

262 Transmission Oil System
01 Main Gearbox Oil Pump
02 Oil Cooler Blower

263 Rotor Brake System
01 Rotor Brake Motor
02 Rotor Brake Relay

290 POWER PLANT INSTALLATION

291 Power Plant Controls
01 Collective Bias Control
02 N1 Lever
03 N2 Control
04 Trim
05 Engine Overspeed Test
06 Engine Overspeed Circuit Breaker
07 Fuel Shutoff Lever

292 Aircraft Engine Lube System

293 Engine Ignition/Start System
01 Starter
02 Start Abort Switch

294 Engine Air Particle Separator (EAPS)
01 EAPS Blower
02 EAPS Door
03 EAPS/Anti-Ice Valve
04 EAPS Circuit Breaker

295 Engine Mounts

296 Engine Exhaust System

410 ICE CONTROL SYSTEMS

411 Engine Anti-Ice System
01 Engine Anti-Ice Valve
02 Engine Anti-Ice Circuit Breaker

420 ELECTRICAL POWER SUPPLY SYSTEM

421 AC Power Supply System
01 Generator

422 DC Power Supply System
01 Battery
02 Rectifier

423 Pod Power Supply System

440 LIGHTING SYSTEM

441 Exterior Lighting System

442 Interior Lighting System

443 Pod Lighting System

450 HYDRAULIC POWER SUPPLY SYSTEM

451 Tandem Servo Hydraulic System
    01 1st Stage System
    02 2nd Stage System

452 Utility Hydraulic System
    01 Utility System Filter D/P Indicator

453 Cargo Hoist Hydraulic System
    01 Cargo Hoist Hydraulic Pump
    02 Hoist Filter D/P Indicator
    03 Hoist Isolation Valve
    04 Makeup Hydraulic System
    05 MLG Jack/Kneel System

454 Rotor Brake Hydraulic System

460 AIRCRAFT FUEL SUPPLY SYSTEM

461 Main Fuel Supply System
    01 Aft Fuel Tank
    02 Forward Fuel Tank
    03 Aux Tank
    04 Range Extension Tank
    05 Fuel System Circuit Breaker
    06 Fuel Tank Crossfeed

490 MISCELLANEOUS UTILITIES

491 Fire Detector System

492 Fire Extinguisher System

493 Windshield Wiper System

494 Windshield Washer System

495 Heating and Ventilating System
    01 Cabin Heater
    02 Fan

496 Defroster System

497 Cargo Hoist System
01 Cargo Hoist Pump
02 Cargo Hoist Circuit Breaker
03 Cargo Hook
04 Cargo Hook Electrical Release
05 Cargo Hook Circuit Breaker
06 Cargo Hook Decoupler
07 Hoist Switch
08 Hoist Down Actuator
09 Hoist Temperature Circuit Breaker

498 Load Leveler System
01 Four Point Cargo System
02 Four Point System Emerg. Air Bottle
03 Load Leveler
04 Load Leveler Accumulator
05 Cargo Lashing Reel

510 INSTRUMENTS SYSTEM

511 Flight and Navigation Instruments
01 Flight Director Indicator
02 Roll Indicator
03 Airspeed Indicator
04 Altimeter
05 Attitude Indicator
06 Course Indicator
07 Hover Indicator
08 Outside Air Temperature Indicator
09 Performance Indicator
10 Radio Magnetic Indicator
11 Standby Compass
12 Turn and Slip Indicator
13 Vertical Velocity Indicator
14 Aft Pilot's Roll Indicator

512 Hydraulic System Instruments
01 Utility Hydraulic Pressure Indicator
02 2nd Stage Hydraulic Pressure Indicator

513 Engine and Fuel System Instruments
01 Aux Fuel Quantity Indicator
02 Engine Fuel Pressure Indicator
03 Engine Oil Pressure Indicator
04 Engine Oil Temperature Indicator
05 EPR Indicator
06 Fuel Flow Indicator
07 Fuel Pressure Indicator
08 Fuel Quantity Indicator
09 N1 Tach Indicator
10 N2 Tach Indicator

513 Engine and Fuel System Instruments (Cont'd)
- 11 Torquemeter
- 12 Triple Tach Indicator
- 13 EGT (T5) Indicator

514 Drive and Rotor System Instruments
- 01 NR Tach Indicator
- 02 MGB Oil Temperature Indicator
- 03 MGB Oil Pressure Indicator

515 Advisory and Warning Lights
- 01 Airframe Fuel Filter Light
- 02 AFCS Auto Fail Light
- 03 Anti-Ice Light
- 04 APP EGT Light
- 05 APP Fire Light
- 06 APP Fuel Pressure Light
- 07 APP Hydraulic Pressure Light
- 08 APP Oil Pressure Light
- 09 Aux Fuel Pressure Light
- 10 Boost Pump Light
- 11 Cargo Hook Unlocked Light
- 12 Gearbox Chip Light
- 13 CIPR Light
- 14 EAPS Pressure Light
- 15 EAPS/Anti-Ice Light
- 16 Fuel Pressure Light
- 17 Engine Fire Warning Light
- 18 Engine Flame-Out Light
- 19 Engine Oil Pressure Light
- 20 Fuel Bypass Light
- 21 Fuel Flow Light
- 22 Fuel Low Level Light
- 23 Fuel Temperature Low Light
- 24 Generator Warning Light
- 25 Heater Hot Light
- 26 Hoist Isolation Warning Light
- 27 Hoist Low Pressure Light
- 28 Hoist Oil Hot Light
- 29 Cargo Hook Open Light
- 30 IGB Chip Light
- 31 IGB Oil Pressure Light
- 32 Landing Gear Kneel Light
- 33 Load Leveler Unlocked Light
- 34 Master Caution Light
- 35 MGB Chip Light
- 36 MGB Oil Pressure Light
- 37 Parking Brake Light
- 38 Rectifier Warning Light
- 39 Rotor Brake On Light
- 40 Rotor Brake Pressure Light

515 Advisory and Warning Lights (Cont'd)
- 41 Rotor Droop Light
- 42 Tail Skid Advisory Light
- 43 TGB Oil Pressure Light
- 44 MGB Oil Temperature Light
- 45 Turn and Slip Light
- 46 Utility Hydraulic Warning Light
- 47 VWS Warning Light
- 48 1st Stage Servo Light
- 49 2nd Stage Servo Light

516 Utility System Instruments
- 01 Cargo Hook Temperature Indicator
- 02 Clock
- 03 Hoist Cable Length Indicator
- 04 Hoist Oil Temperature Indicator
- 05 Winch Tension Indicator

517 Pitot Static System

518 CIPR/VWS Systems

570 AFCS System
- 01 Yaw Channel
- 02 Yaw Channel (NORM)
- 03 Yaw Channel (REM)
- 04 Yaw and Roll Channels
- 05 Roll Channel
- 06 Roll Channel (NORM)
- 07 Roll Channel (REM)
- 08 Pitch Channel
- 09 Pitch Channel (AUX)
- 10 Pitch Channel (NORM)
- 11 Pitch Channel (REM)
- 12 Pitch and Roll Channels
- 13 Bar Alt Mode
- 14 AFCS Trim
- 15 AFCS Trim Circuit Breaker
- 16 Remote Stick
- 17 Auto Fail Reset
- 18 Control Switch
- 19 Circuit Breaker

APPENDIX B - MALFUNCTION DESCRIPTION CODES

003	Abort Start, Fails to	131	Charge, Fails to Hold
005	Abort Test, Fails to	133	Charge, Loss of
008	Accelerate, Fails to	140	Chattering
010	Acceleration Erratic	145	Clicking
013	Acceleration Fast	150	Close, Fails to
015	Acceleration Slow	153	Close, Unable to
020	Actuate, Unable to	160	Come on Line, Fails to
023	Actuation, Inadvertent	163	Come on Line, Slow to
025	Adjust, Unable to	168	Compress, Fails to
028	Adjustment Improper	175	Contaminated
035	Agree, Fail to	178	Control Authority Inadequate
040	Attitude, Fails to Hold	180	Control Feel Strange
042	Attitude Improper	182	Control, Loss of
050	Autorotation RPM High	185	Control Response Improper
055	Autorotation RPM Low	190	Creeping
070	Backfires	195	Cycling On and Off
075	Beep, Unable to	200	Decelerates Too Fast
080	Biased	204	Depressed, Fails to Remain
082	Binding	208	Discharged
090	Bottoms	212	Disengage, Fails to
095	Bounces	213	Disengage, Unable to
120	Cage, Fails to	214	Disengages Inadvertently
122	Calibrate, Unable to	216	Displaced
125	Center, Fails to	220	Dragging
130	Charge, Fails to	224	Drifts

228 Droops

232 Drops Off Line

245 Engage, Fails to

248 Engage, Late to

250 Engage, Slow to

251 Engages Erratically

253 Engages Inadvertently

256 Engages Incompletely

260 Erect, Fails to

263 Erect, Fails to Remain

266 Erect, Slow to

267 Erects Off Center

270 Erratic

274 Extend, Fails to

276 Extended

280 Explosion

283 Extinguish, Fails to

286 Extinguishes

289 Fails Repeatedly

290 Feedback, Abnormal

293 Filling, Stops

295 Fire

297 Flag Displayed

298 Flag Fails to Display

300 Flame Out

302 Flaming

304 Flashing

308 Flickering

312 Flow, Erratic

315 Flow, Fluctuating

316 Flow Indicated, Valve Closed

317 Flow, Intermittent

318 Flow, Restricted

320 Flow, Zero

324 Fluctuating

328 Friction, Inadequate

330 Friction, Uneven

334 Frozen

336 Fuel Dumping

337 Fumes/Odor

340 Hangs up

343 Hardover

346 Heading, Fails to Hold

347 Heavy

348 Hold, Fails to

350 Hot Start

352 Hunting

360 Grabbing

365 Idle Improper

367 Idle, Unable to Adjust

380 Idles Fast

382 Idles Slow

385 Illuminate, Fails to

387 Illuminated
390 Illuminated, Remains
394 Inaccurate
395 Indication, No
396 Inoperative
398 Intermittent
405 Jack, Unable to
406 Jack's Slowly
407 Jammed
410 Jumps
413 Kicks
415 Kneel, Fails to
420 Lagging
424 Leaking
428 Limits, Improper
430 Limits, Out of
435 Lock, Fails to
438 Locked, Fails to Remain
440 Locked, Remains
445 Malfunctioning
450 Motion Erratic
453 Motor, Continues to
456 Motor, Fails to
460 Motoring
465 Needle Displaced
468 Needles Split

472 Noise, Unusual
475 Noisy
480 Null, Fails to
483 Null, Remains at
484 Null, Unable to
490 Oil Consumption Excessive
492 Oil Discharge
494 Open, Fails to
497 Open, Unable to
500 Opens Inadvertently
505 Operate, Continues to
508 Operate, Fails to
512 Operating, Stops
515 Operation, Fast
518 Operation, Inadvertent
522 Operation, Intermittent
525 Operation, Slow
530 Oscillates
534 Output Inadequate
538 Overfills
542 Overspeed
550 Park, Fails to
554 Pegged
557 Phase, Out of
560 Pitches
562 Play Excessive

563 Popped
565 Popping
570 Power, Fails to Reach Full
572 Power, Lags
574 Power, Loss of
578 Power, Low
582 Precesses
585 Pressure Buildup Slow
588 Pressure Drops to Zero
590 Pressure, Erratic
594 Pressure, Fluctuating
596 Pressure, High
600 Pressure, Incorrect
603 Pressure, Loss of
606 Pressure, Low
610 Pressure, Low Indication
612 Pressure, Surging
615 Pressure, Zero
620 Pumping
630 Racheting
635 Reading, High
637 Reading, Incorrect
640 Reading, Low
642 Reading, Over Limit
645 Reading, Drops to Zero
647 Reading Zero
649 Reel, Fails to
650 Reeling Stops
653 Reels, Continues to
655 Reels Slowly
658 Reference, Fails to Hold
659 Release, Fails to
660 Release, Inadvertent
663 Release, Unable to
665 Releases Intermittently
670 Reset, Unable to
674 Respond, Fails to
676 Response, Improper
678 Response, Lack of
680 Response, Slow
684 Retract, Fails to
687 Retracted, Fails to Remain
690 Retracts Inadvertently
692 Retracts Slowly
695 Return, Fails to
698 Returns Slowly
702 Rewind, Fails to
703 Rig, Unable to
704 Rolls
708 Rotate, Fails to
712 RPM Decay
715 RPM Erratic

717 RPM High
718 RPM Low
725 Seized
727 Setting, Fails to Hold
730 Shut Down, Fails to
733 Shut Down, Unable to
735 Shuts Down Inadvertently
738 Shut Off, Fails to
739 Shut Off, Unable to
742 Slave, Fails to
746 Slipping
750 Sluggish
755 Smoking
758 Soft
760 Sparking
763 Speed, Low
766 Spongy
768 Stalling
772 Start, Fails to
774 Start, Premature
776 Starts Late
778 Starts Slow
782 Sticking
785 Stiff
790 Stop, Fails to
794 Stops Early
798 Stops Suddenly
810 Surging
815 Switch Off, Unable to
818 Switches Off Inadvertently
822 Switch On, Unable to
826 Synchronization, Out of
830 Temperature, Drop In
835 Temperature, Low
838 Temperature, Low Indication
842 Temperature, Over Limit
845 Temperature, Rise In
850 Test, Fails to Pass
855 Track, Fails to Maintain
858 Track, Out of
862 Transfer, Fails to
864 Transfer Improper
870 Travel, Inadequate
875 Travel, Limited
878 Travel, Restricted
881 Trim Out of Limits
882 Trim, Unable to
885 Trims Slowly
890 Tumbles
895 Underfills
900 Unlock, Fails to
910 Unreliable

920 Unstable

930 Unwinds

940 Vibration

950 Wobbling

980 Yaws

APPENDIX C - FIELD SURVEY QUESTIONNAIRES

A. FAULT SYMPTOM:

Observed Hardware ______________________ Fault Description ______________________

Nature/Degree ______________________ Fault Conditions ______________________

B. FAULT DETECTION AND REPORTING:

1. This symptom is experienced an estimated __________ times/aircraft/year.

2. How else might this symptom be described? ______________________

3. This symptom is usually detected by: ☐ Crew Chief ☐ Flight Eng. ☐ Pilot/Co-Pilot ☐ Maint. Crew

4. This symptom is usually discovered during:

   ☐ APP Start ☐ Power on Checks ☐ Engine Start ☐ Ground Running ☐ Flight ☐ Shut Down

5. What additional information is required to interpret the symptom?

6. Are descriptions of the symptom usually accurate and complete? ☐ Yes ☐ No

   Deficiency: ______________________

C. FAULT CONFIRMATION:

1. What specific observations or tests would you make to confirm the fault?

2. Is this symptom reported at times when there is no fault?

   ☐ Sometimes ☐ Rarely ☐ Never

CH-54 FIELD SURVEY QUESTIONNAIRE

D. **FAULT ISOLATION EXPERIENCE:**

1. When this symptom occurs, what component or components are usually at fault? (List in order of probability).

	Component	Failure/Malfunction	Rank Check	Rank Replace
1.	______	______	☐	☐
2.	______	______	☐	☐
3.	______	______	☐	☐
4.	______	______	☐	☐
5.	______	______	☐	☐

2. Rank each of the above components with respect to (1) ease of checkout, (2) ease of replacement. (1 = easiest; 4 = most difficult)

3. Statistics show that this fault is not corrected on the first attempt % of the time. From your experience this estimate is:

☐ High ☐ Low ☐ About Average

E. **FAULT ISOLATION PROCEDURE:**

1. How would you proceed to isolate this fault?

2. When checking components, is it difficult to ascertain if components are serviceable?

☐ Yes ☐ No Difficulty: ______

3. Troubleshooting this symptom is: ☐ Not Difficult ☐ Difficult ☐ Very Difficult

4. On average, how many manhours are required? ______

CH-54 FIELD SURVEY QUESTIONNAIRE

F. FAULT ISOLATION RESOURCES:

1. Who normally troubleshoots this symptom? ☐ Crew Chief ☐ Flt. Eng. ☐ T.I. ☐ Elec-trician ☐ Avionics Tech.

   Other: ____________

2. What test equipment is used? ____________

3. Is troubleshooting hampered by inaccessibility to equipment or test points?

   ☐ Yes ☐ No Problems: ____________

4. Are troubleshooting instructions accurate and complete? ☐ Yes ☐ No

   Specific improvements needed: ____________

NOTES AND COMMENTS:

CH-54 SURVEY PART II

Component: ______________________ ______________________

Nomenclature | Part Number

Mode: ______________________

______________________ ______________________

Observed System/Component | Observed Malfunction

______________________ ______________________

Nature/Degree | Conditions

Mode: ______________________

______________________ ______________________

Observed System/Component | Observed Malfunction

______________________ ______________________

Nature/Degree | Conditions

Mode: ______________________

______________________ ______________________

Observed System/Component | Observed Malfunction

______________________ ______________________

Nature/Degree | Conditions

Component: ______________________ ______________________

Nomenclature | Part Number

Mode: ______________________

______________________ ______________________

Observed System/Component | Observed Malfunction

______________________ ______________________

Nature/Degree | Conditions

Mode: ______________________

______________________ ______________________

Observed System/Component | Observed Malfunction

______________________ ______________________

Nature/Degree | Conditions

Mode: ______________________

______________________ ______________________

Observed System/Component | Observed Malfunction

______________________ ______________________

Nature/Degree | Conditions

AH-1/CH-47 FIELD SURVEY QUESTIONNAIRE

PART I - AIRCRAFT UTILIZATION DATA

Unit: ____

Location: ____

Aircraft Model: ________________ Number of Aircraft: ____________

Current Utilization: ____________ Flight-Hours/Aircraft/Year

Average of Past Five Years: ______ Flight-Hours/Aircraft/Year

PART II - SYMPTOM DETECTION AND REPORTING

1. On what percentage of flights are discrepancies written up by the flight crew?

2. What would you estimate is the average number of discrepancies reported per flight?

3. What percentage of flight crew reported discrepancies are related to the avionics and weapons systems of the helicopter?

4. What perventage of flight crew reported discrepancies are discovered during:

	%
Engine Start to Takeoff	
In-Flight	
On-Ground to Engine Shutdown	

5. What percentage involve aborted missions?

PART II (Cont'd)

6. Are flight crew reports usually accurate and complete?

7. What are the most common deficiencies?

8. How often is it necessary to consult with the flight crew to obtain needed information not contained in the written report?

9. How frequently are symptoms reported when no fault can be found?

10. What types of symptoms are most prevalent in this regard?

PART III - TROUBLESHOOTING

1. What percentage of your time on the job is spent on:

   Crew Duties

   Aircraft Maintenance

   Other Duties

2. What percentage of the maintenance time is spent on:

   Cleaning, Servicing, Ground Handling

   Inspection

   Repair and Replacement

3. Of the time spent on repair and replacement, what percentage is spent on troubleshooting, i.e., looking for problems versus fixing problems?

4. What percentage of all defective or failed components are found by troubleshooting versus inspection?

5. How many flight crew writeups would you estimate you check out in the course of a year?

PART III (Cont'd)

6. For what percentage of flight crew reports are you able to pinpoint the problem without troubleshooting?

7. How many troubleshooting actions would you estimate you perform in the course of a year?

8. Who does most of the nonavionics systems troubleshooting?

9. How often are specialists (hydraulics, powerplant, etc.) called to assist?

10. Do tech inspectors ever assist with troubleshooting?

11. How frequently does a troubleshooting action involve the following:

    - Discussion of problem with flight crew
    - Ground operation of the aircraft
    - Discussion of problem with other crew chiefs or maintenance personnel
    - Discussion of problem with the maintenance officer
    - Consulting the maintenance manual
    - None of the above

12. There is no method of checking many components while installed in the aircraft. What percentage of troubleshooting actions involve swapping of components as a method of verifying or eliminating possible causes?

13. For which systems of the aircraft is this practice most prevalent?

14. Are stocks of frequently used, inexpensive parts maintained for this purpose?

PART III (Cont'd)

15. How much time would you estimate you spend on the average troubleshooting action?

16. Who makes the decision to replace a high-value component only suspected of causing a problem?

17. Do you recall any instances when an aircraft was down for an extended period because the cause of a problem could not be found? What was the nature of the problem(s) and how long was the aircraft down?

18. Based on your experience in the Army, how often would you estimate the average Army crew chief makes an error in troubleshooting, i.e., replaces the wrong part or component?

PART IV - INSTRUMENT RELATED SYMPTOMS

1. What percentage of flight crew writeups involve symptoms observed via aircraft instruments or warning devices?

2. When abnormal instrument readings are experienced, how often does it reflect a defect or failure of the instrument rather than a failure of the monitored system?

3. What types of instruments are the most unreliable?

4. How often do warning lights give false indications and which are the most unreliable?

PART V - TROUBLESHOOTING INSTRUCTIONS

1. Are most troubleshooting problems sufficiently familiar to your that you can begin troubleshooting without reference to the maintenance manuals?

PART V (Cont'd)

2. How often do you refer to troubleshooting instructions in the maintenance manuals?

   Always Frequently Occasionally Rarely

3. What percentage of the symptoms occurring on the aircraft would you estimate are covered by TM troubleshooting instructions?

   over 90% over 2/3 over 50% less than 50%

4. How thoroughly does the typical TM troubleshooting table cover the possible causes of a symptom?

   nearly all most majority only obvious ones

5. When an unfamiliar symptom occurs on the aircraft, can troubleshooting instructions usually be found quickly?

6. One criticism of current troubleshooting instructions is that they are oriented by systems of the aircraft, rather than by symptoms of failure. Have you found this to be a problem?

7. Do you have any specific recommendations for improving troubleshooting instructions for Army helicopters?

PART VI - TEST EQUIPMENT

1. What types of test equipment are routinely used in troubleshooting?

2. How extensively is manufacturer supplied flight line test equipment used?

PART VII - TRAINING

1. How much training have you received in fault isolation maintenance?

   Classroom:

   OJT:

PART VII (Cont'd)

2. Do you think that Army mechanics would benefit from more extensive formal training in fault isolation?

PART VIII - GENERAL RECOMMENDATIONS

1. One recommendation for improving the quality of flight crew writeups is for the Army to adopt the use of a post-flight debriefing checklist. What are your views on this recommendation?

2. Another recommendation for improving fault isolation maintenance is for the Army to create a Troubleshooting Specialist MOS similar to that of the Aircraft Tech Inspector. What are your views on this recommendation?

APPENDIX D
PARTIAL PRELIMINARY LISTINGS OF NATURE/DEGREE AND TEST PARAMETER CODES

Nature/Degree Codes

13	Aft
19	Circular
20	Constantly
11	Down
14	Fore and Aft
12	Forward
32	Heavily
21	Intermittently
18	Lateral
15	Left
30	Lightly
31	Moderately
04	N Per Rev
22	Randomly
03	Rapidly
16	Right
01	Slowly
02	Sluggishly
23	Sporadically
05	Suddenly
10	Up
17	Vertical

Test Parameter Codes

051 Acceleration
014 Actuation Time
030 Adjustment
031 Alignment
056 Balance
005 Capacitance
033 Clearance
040 Contamination
001 Continuity
004 Current
021 Extension
012 Flow Rate
036 Force
006 Frequency
043 Friction
042 Interference
011 Leakage
041 Obstruction
022 Preload (Static Load)
013 Pressure
008 Pulse Rate
002 Resistance
034 Rigging
037 Security
050 Speed
020 Spring Rate
053 Temperature
054 Temperature Rise
052 Time
055 Timing
032 Tolerance
035 Torque
003 Voltage
007 Wave Form

APPENDIX E - GLOSSARY

There are a number of terms that take on a special connotation when used in the context of fault isolation maintenance. Defined below are terms, either generic in nature or originated under this program, that are used throughout this report.

Contributing Function. A physical process or operation performed by the system or an interfacing system required for the execution or maintenance of a system-level function. By definition, a contributing function is observable by the operator. A contributing function may itself be a system-level function for another system.

Defect. A condition other than failure, such as improper alignment or adjustment, that causes a system malfunction.

Diagnose. Troubleshoot. Fault isolate.

Failure. The inability of an item to perform within specified limits. Failures that are manifested in a type of abnormal system performance unrelated to the failure or that are common to other failures are said to exhibit symptoms of failure and must be located through the process of fault isolation. In these cases, the failure is the "cause" of a symptom.

Failure Mode. The manner in which an item or function can fail.

Fault. The failure or defect causing a symptom. Also, less accurately, the symptom itself.

Fault Isolation. Maintenance procedures involving inspections, tests and/or substitution of equipment for the purpose of locating the failure or defect causing a system malfunction. Fault isolation is synonymous with troubleshooting.

Fault Isolation Procedure. A set of instructions prescribing sequential inspections, tests and/or substitutions of equipment for the purpose of locating the cause of a symptom.

Fault Isolation Task Candidate File. A set of records, each containing a symptom/cause relationship and related troubleshooting task data, that provides the source material for a fault isolation procedures manual.

Fault Isolation Task Candidate Listing. A computer-generated listing of the fault isolation task candidate file, sequenced by symptoms and causes, that the technical writer uses to establish fault isolation procedures.

Instrument Indication. An indication of malfunction conveyed via an aircraft instrument, warning light or other diagnostic device.

LRU. Line replaceable unit. The lowest level part or component that can be replaced to correct a system malfunction.

Malfunction. Abnormal performance. A malfunction is a symptom when it is observable by the operator and its cause cannot be determined without troubleshooting.

Observable System Malfunction. A system malfunction that the operator observes directly rather than via an instrument indication or symptomatic sensory perception.

Observer. A member of the aircraft flight crew or maintenance crew who observes a symptom.

Operator. A member of the aircraft flight crew or maintenance crew who operates a system.

Other Crew Sensory Perception. Unusual sights, sounds, odors and vibrations symptomatic of a malfunction.

Outline Fault Isolation Procedure. A computer-generated listing of the fault isolation task candidate file, organized into fault isolation procedures, that guides the technical writer in preparation of the maintenance manual.

Symptom. Any evidence of abnormal system performance whose cause cannot be determined without troubleshooting. A symptom may be an observable system malfunction, an instrument indication of a malfunction, other crew sensory perception of a malfunction, or a combination of the three. A symptom is described by as many as four separate observations: the system or component observed to be malfunctioning or indicating the presence of a malfunction, the observed type of malfunction, nature or degree of the malfunction, and the conditions under which it occurs.

Symptom Cause. A failure or defect constituting the source of a symptom.

Symptom Cause Probability. The probability, based on predicted or observed failure rates, that a given failure or defect is the cause of a symptom. Cause probability equals failure probability when a failure or defect always produces the same symptom.

System Failure Modes Analysis. An analysis of a system whose purpose is to identify failure modes with a potential for causing system malfunctions.

System Functional Analysis. An analysis of a system whose purpose is to identify the principal modes of operation and potential sources of malfunction.

System-Level Function. One of the principal operating states of a system or the mode of transition from one principal operating state to another. A system-level function is observable by the operator.

System Malfunction. Any form of abnormal system performance, real or indicated. A system malfunction is a symptom when the cause of the malfunction cannot be determined without troubleshooting.

Trouble. Symptom.

Troubleshooting. Maintenance procedures involving inspections, tests and/or substitution of equipment for the purpose of locating the failure or defect causing a system malfunction. Troubleshooting is synonymous with fault isolation.

WUC. Work Unit Code. A code system used to identify systems, equipment, components and parts of the aircraft.

APPENDIX F - LIST OF ACRONYMS

AAH	Advanced Attack Helicopter
AFCS	Automatic Flight Control System
APU	Auxiliary Power Unit
AVIM	Aviation Intermediate Maintenance
FEA	Front End Analysis
FIAT	Fault Isolation Analysis Technique
FMEA	Failure Modes and Effects Analysis
LRU	Line Replaceable Unit
MOS	Military Occupational Specialty
MRSA	Material Readiness Support Activity
ORME	Operations Reliability/Maintainability Engineering
RFI	Ready for Issue
R&M	Reliability and Maintainability
SPA	Skill Performance Aids
TAMMS	The Army Maintenance Management System
TARCOM	Tank-Automotive Readiness Command
TI	Technical Inspector
WUC	Work Unit Code
3-M	Maintenance and Material Management