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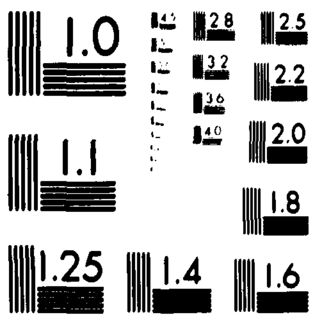

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DIAGNOSTIC & CONDITION MONITORING SYSTEM ASSESSMENT FOR ARMY HELICOPTER MODULAR TURBOSHAFT ENGINES.

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

Needs for and means of improving D&CM and troubleshooting to modules and LRUs for T700-GE-700 engine in Army environment were studied. Recommendations are: (1) Do not modify existing METS for modular fault isolation. However, do computerize the acquisition of the overall engine performance data, (2) introduce the slave chip detector to the depot, (3) expand evaluation of the control system analyzer by Black Hawk companies, (4) support the development of degaussing chip detector, (5) initiate Phase I of multipurpose airborne D&CM system which combines performance, life, overtemp and chip detector monitors, and (6) continue to acquire T700 field data and develop a method to quantify D&CM payoffs such as better engine availability.

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INTRODUCTION AND SUMMARY

The introduction of the T700-GE-700 Engine into operational Army units is the beginning of a new era in Army Aviation. These engines are a highly maintainable, modular design which provides the Army with a rapid repair and return to service capability. To fully realize this capability, the U. S. Army Advanced Technology Laboratories (ATL) of the Aviation Research and Development Command (AVRADCOM), has contracted with the General Electric Company to investigate and provide an assessment of a diagnostic and condition monitoring (D&CM) system for Army modular turboshaft engines. This report documents the methodology and results of the studies and analysis carried out under Contract DAAK51-C-79-0020. Prior D&CM analyses performed for ATL (AVRADCOM) under contract DAAJ02-77-C-0065 and for the NAVAIR T700-GE-401 LAMPS application under contract N00019-77-C-0065 provided valuable background data and experience which was utilized in this program. The contracted effort was conducted utilizing several organizations within General Electric and provides recommendations for further development. These recommendations are supported by the affected organizations within General Electric's Aircraft Engine Group (AEG) and Aerospace Instrument and Electrical Systems Department.

SUMMARY

A four-task analysis was conducted to assess the needs for and means of achieving improved D&CM capabilities for modular Army turboshaft engines. Primary emphasis was placed on the D&CM impact on maintenance at the Aviation Unit Maintenance (AVUM) and the Aviation Intermediate Maintenance (AVIM) levels using the modular engine test system (METS). The T700-GE-700 engine for the UH-60A and the UH-64 aircraft was used as an example of a modern modular turboshaft engine. The four tasks performed in numerical sequence as shown in the following paragraphs provided a simple, logical technique for assessing Army D&CM needs.

Task I - D&CM Approach Identification

This task selected candidate D&CM functions based primarily on analysis of T700 engine maintenance event history of Black Hawk and UH-64 Advance Assault Helicopter (AAH) flight test aircraft as documented by General Electric Field Service Reports, DV-7.

Task II - D&CM System Definition

This task defined in some detail, the hardware, software and/or diagnostic techniques to implement the candidate functions selected in Task I and provided the data needed for life cycle cost (LCC) analysis.

Task III - Life Cycle Cost (LCC) Assessment

In this task, life cycle cost analyses were performed on the candidate D&CM items as the criteria to determine which items were to be recommended for development.

Task IV - D&CM Hardware Development Requirements

The hardware and software development programs to implement the recommended D&CM systems are described in Task IV including program description, approximate schedule, and assessment of technical risks.

The following paragraphs contain a brief summary of the results of each task:

Task I Results - Candidate Functions

Seven D&CM functions were identified in the Task I analysis as candidate aids to improve T700 module and line replaceable unit (LRU) fault detection and isolation. The proposed D&CM approaches to performing these functions consisted of three ground support systems and four airframe mounted systems as shown in Table 1.

TABLE 1. D&CM SYSTEM CANDIDATE ITEMS - TASK I FINDINGS

GROUND SUPPORT FUNCTIONS	GROUND SUPPORT EQUIPMENT
1. Modular Performance Fault Isolation.	Modified METS for Gas Path Analysis.
2. Modular Oil-Wetted Parts Fault Isolation.	Slave Chip Detector for METS.
3. Control LRU Fault Isolation.	Control System Analyzer Set.
AIRBORNE FUNCTIONS	**AIRBORNE EQUIPMENT**
4. Computerize Engine Performance Measurement.	Automatic Performance Monitor.
5. Life Usage Measurement and Recording.	Engine Life Usage Monitor (ELUM).
6. Discriminating Chip Detection.	Degaussing Chip Detector System.
7. Overtemperature Caution.	Overtemperature Monitor.

Task II Results - D&CM System Definition

Three ground support systems, one unique sensor, and one airborne computer and display system were defined in Task II to meet the functional needs identified in Task I. This equipment is briefly described in the following paragraphs.

A modified modular engine test system (METS) for performing gas path analysis to isolate performance problems to the faulty module was defined including modifications to the six existing METS. This included computer hardware and software, main and inlet particle separator air flow m asurement, added instrumentation, and structural changes.

A slave chip detector system to determine the source of oil-wetted part failure debris by testing on METS was defined. The system currently being used successfully in the contractor's test cells was described and recommended to meet this need.

A control system analyser set to isolate the most commonly reported faults to LRU or aircraft system was defined. This is a ground support equipment set consisting of two "yellow boxes" for flight line use that can troubleshoot the system without the engine operating. One set which is currently undergoing field tests, has proven to be almost completely effective in isolating faults.

A multipurpose airborne D&CM system (MADACMS) was defined consisting of a six-pound central processor and memory unit and one-pound alphanumeric cockpit display that would meet all four primary airborne needs for two engines with the capability of performing additional aircraft and engine functions. Human factors considerations dictate highly visible dichroic LCD display, nonambiguous messages, and simple call-up control.

A degaussing discriminating magnetic chip detector having capture, count, and release capability by means of a built-in degaussing coil is described. Its purpose is to eliminate nuisance chip signals. Discriminating logic would be included in the MADACM's computer. Such a system is currently in the feasibility demonstration stage at GE.

Task III Results - LCC Assessment

Life cycle cost analyses were performed to evaluate each of the seven D&CM functions based on a ten-year Black Hawk projected service period from 1982 to 1992 with 5 million engine flight operating hours. The LCC analytical process provides an input for management decisions and is especially helpful in assessing the relative values of each D&CM function. There are, however, other extremely important aspects to the decision process that the contractor is currently unable to quantify; e.g. the benefits of increased aircraft availability, timely fault isolation, rapid repair and return to flight status in hostile environment, and safety. The quantitative results expressed as the ratio of cost savings to cost (CS/C) are shown on Table 2, are, therefore, very conservative. On this conservative basis, a CS/C ratio of 1.5/1 for a ten-year period was considered to be a favorable result. For the ten-year period used in the analyses, a CS/C ratio of 1.[illegible]/1 was considered to be a favorable result with CS/C ratios of 1.0-1.5/1 to be a gray area wherein management decisions could be determined by evaluation of the unquantifiable factors involved.

TABLE 2. D&CM LIFE CYCLE COST RESULTS

D&CM SYSTEM	CS/C*
Modified METS for MPFI	0.49
Slave Chip Detectors	1.69
Control System Analyser - Option 2	1.61
Multipurpose Airborne D&CM System	1.57
Automatic Performance Monitor Option 1	1.36
Degaussing Chip Detector	3.60
Engine Life Usage Monitor (ELUM)	1.89
Overtemperature Monitor (OTM)	N/A

* [Cost Savings]/[Cost (Development + Acquisition + Operation and Support)]

General Electric, on the basis of this D&CM program assessment, makes the following recommendations:

1. Add a computer to each of the six existing METS facilities for the purpose of obtaining overall engine performance. Do not modify METS to perform modular performance fault isolation by gas path analysis.

2. Equip METS with slave chip detectors for T700 oil-wetted part modular fault isolation.

3. Complete the field evaluation of the control system analyser and type-classify for Black Hawk and SOTAS deployment. Deployment to be the Army's choice; either one set per Battalion (Operation 3) or one sensor and circuit tester per Company, and one ECU tester per AVIM (Option 2).

4. Design, build, and evaluate by flight test the Multipurpose Airborne D&CM System (MADACMS).

Task IV Results - D&CM Hardware Development Requirement

General Electric Company recommends the following D&CM hardware development work based on the findings of this D&CM assessment program:

1. Modular Engine Test System. It is expected that the General Electric developed software would be provided by ATL to the successful bidder for a subsequent computer contract. This would allow for more tasks and capacity in the resultant computer.

2. Slave Chip Detector. No development required. General Electric will propose kit procurement to the proper AVRADCOM branch. The kits will identify the indicating magnetic chip detectors to fit T700 scavenge pump ports.

3. Control System Analyser Set. No further development is required for the control system analyser set. Procure enough sets to support an Army type-classification program. Initiate program to incorporate Operation and Maintenance Manual changes.

4. Multipurpose Airborne D&CM System. Design and develop flightworthy brassboard computer and display module hardware and software for the Multipurpose Airborne D&CM System. Build three sets for flight test evaluation. Develop and qualify the degaussing chip detector as part of the MADACM System.

5. Support hardware development with follow-on D&CM analysis including the following:

   a. T700 production engine field event analysis - 15,000 hours.

   b. Develop methodology to evaluate the effects of timely fault isolation and the repair and return to flight status of the LCC, considering aircraft availability and aircraft safety.

   c. Modify LCC model, if practical, utilizing up-dated Failure Modes, Effects, and Criticality Analysis (FMECA) and production engine field history.

   d. Refine T700 Automatic Performance Monitor LCC and perform Over-temperature Monitor LCC Analysis.

TASK I - D&CM APPROACH IDENTIFICATION AND ANALYSIS

This section documents the analysis of Black Hawk T700-GE-700 engine field service history for the purpose of identifying promising areas for improvement of T700 engine condition monitoring, LRU, and modular fault detection and isolation. Candidate D&CM techniques and/or equipment to implement the improved diagnostics and condition monitoring will be recommended if justified by life cycle cost analyses or other payoff considerations. The impact on current maintenance philosophy and on the tasks of the Aviation Unit Maintenance (AVUM) and modular engine test system (METS) are also assessed. A field event analysis of the T700-GE-700 engine covering the first 11,000 engine hours of Black Hawk and AAH flight testing from October 1974 to June 1977 was performed under Contract DAAJ02-77-C-0065, and reported in Report Number USARTL-TR-78-32. The present report covers the analyses of the next 15,000 engine hours of T700 flight test data as documented in General Electric Field Service Reports (DV-7) covering the period June 1977 to April 1979.

FIELD EVENT ANALYSIS AND D&CM APPROACH METHODOLOGY

The procedure used to arrive at the candidate D&CM approach is shown in Figure 1. A brief description of the procedure follows:

1. Reviewed approximately 500 DV-7s to eliminate all convenience removals, special engineering checks, and other nonfailure event records. One hundred twenty-eight recorded events remained representing all-cause maintenance actions to correct reported malfunctions or failures.
2. Segregated failures by component (Table 3).
3. Compared actual component failure rates with predicted rates. Reviewed the failure rates with T700 design engineering to discount those failures for which design fixes have been introduced (Table 4).
4. Revised predicted failure rates (Table 3).
5. Tabulated actual failures by symptoms and consequence (Table 5) and by affected component (Table 6).
6. Adjusted actual failure symptom rates from Table 6 to be compatible with revised predicted component failure rates (Table 3) to produce Table 7.
7. Constructed diagnostic needs tabulation based on predicted symptom frequency (Table 7) to make Table 8.
8. Defined D&CM approach.

FIELD EVENT ANALYSIS FINDINGS AND DISCUSSION

The results of the field event analysis covering all T700-GE-700 engine flight test experience between June 1977 and April 1979 (15,000 engine hours) are listed in Tables 3 through 8.

Following the methodology described above and shown in Figure 1, the actual component field failures were analyzed by T700 design engineering and compared with the original predicted rates to determine if any changes to current predictions should be made. Two changes were made as noted by the asterisk items in Table 3. Only one change was significant, lube oil debris. This field event, the occurrence of nuisance chip detector signals causing maintenance actions, was added as a conditional item and estimated at five events per 15,000 engine hours. Then, using Table 6, which defines the components causing the actual field events, the number of component failures were reduced to be consistent with the predicted component failure rates. The result of this process is Table 7.

Analysis of the actual and predicted field event data resulting in the major findings are summarized in the following paragraphs and from which the recommended D&CM approach was derived:

Inspection Finds

Maintenance action items detected by visual inspection (see Tables 5 through 7) as inspection finds, premature oil filter popouts, oil leaks, and erroneous engine history recorder display, comprised 26 to 38 percent of all field events. Frequent visual inspection is and will continue to be an important D&CM function that is not likely to be supplanted by electronic aids.

Nuisance Chip Signals

Nuisance chip signals as shown in Table 5 were the predominant cause of mission aborts, with 12 of 19 engine caused mission aborts (63%) caused by nuisance chip signals. Some of the other nuisance chip signals (there were 27 in all) may have caused ground mission aborts, however, the available data does not specify. This field data makes a strong case for a discriminating chip detector that would allow the flight crew to distinguish between benign and failure debris. It should be analyzed for cost effectiveness.

Control Problems

Nineteen control system problems such as torque splits, speed oscillations, low and erratic $T_{4.5}$ indications and other symptoms of control anomalies listed in Table 6 were detected and reported accurately by flight crews aided by cockpit

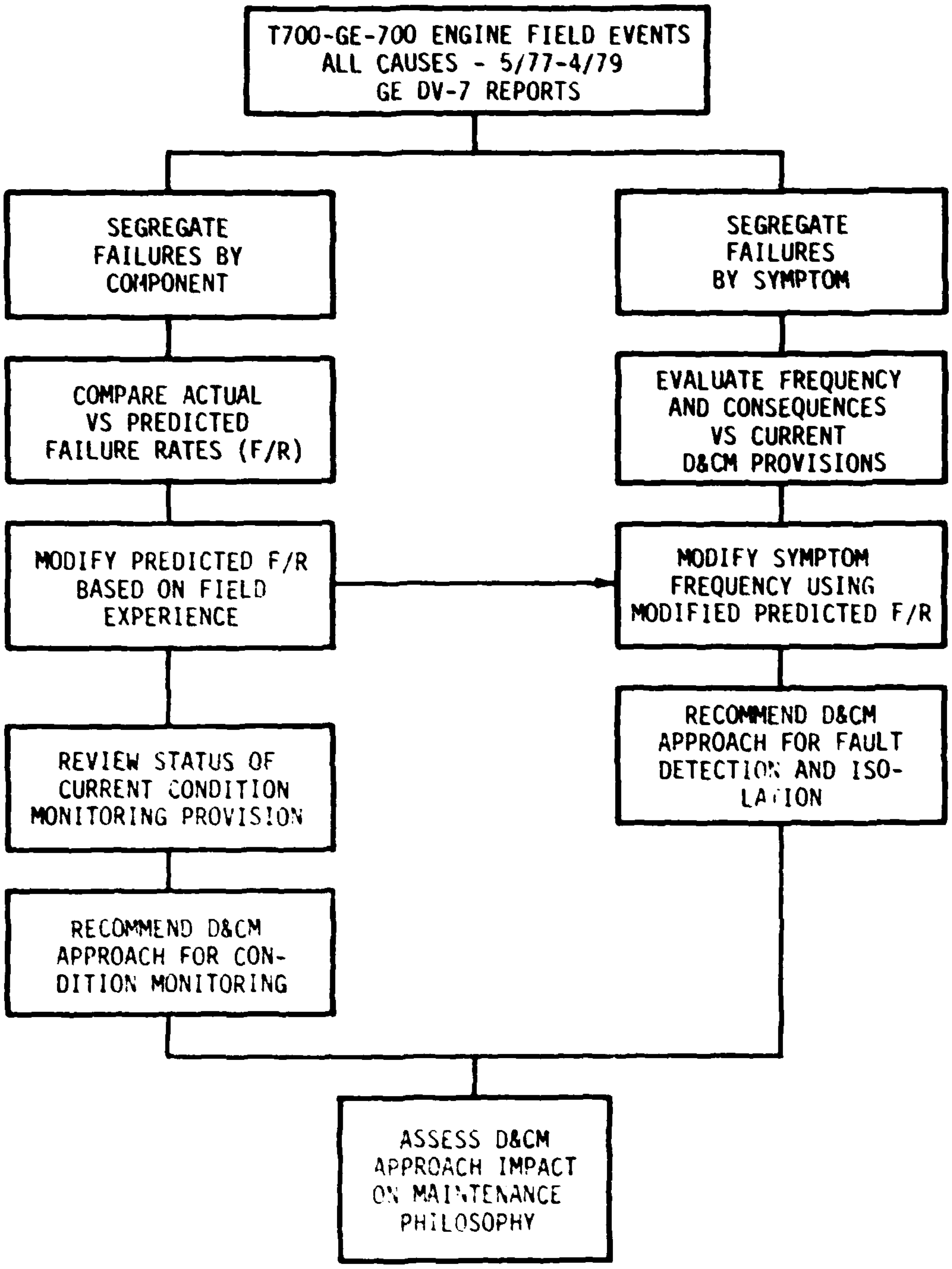

Figure 1. D&CM Approach Logic.

TABLE 3. T700 COMPONENT FAILURE ANALYSIS - 15,000 ENGINE OPERATING HOURS ALL-CAUSE PREDICTED VERSUS ACTUAL

	Failures per 15,000 Engine Operating Hours (EOH), All-Causes Discovered at AVUM		
	Original Predicted	Actual	Revised Predicted
Control and Fuel System			
Electronic Control Unit (ECU)	5	10	5
Hydromechanical Unit (HMU)	6	9	6
Sequence Valve	3	5	3
Fuel Boost Pump	2	5	2
Primer Nozzles	0	3	0
Fuel Filter Assembly	2	1	2
Anti-Icing and Starting Bleed Valve	2	1	2
Oil-Wetted Parts (OWP)			
Lube Filter Bypass Button	1	14	3*
No. 3 Bearing Labyrinth Seal	0	4	0
C-Sump Cover	0	3	0
Power Take-off Drive	0	3	3
Chip Detector	0	2	0
Lube and Scavenge Pump	2	2	2
No. 1 Bearing	1	1	1
No. 3 Bearing	1	1	1
No. 4 Bearing	1	1	1
Radial Drive Shaft	1	1	1
Accessory Gear Box	2	1	1
Electrical			
History Recorder	0	7	1*
Electrical Harnesses	1	7	1
Thermocouple Harness	2	6	2
Ignition Leads	1	3	1
Igniter	1	2	1
Exciter	1	1	1

*Revised based on field experience

TABLE 3. - Continued

	Failures per 15,000 Engine Operating Hours (EOH), All-Causes Discovered at AVUM		
	Original Predicted	Actual	Revised Predicted
External Configuration			
Separator Blower	2	2	2
Fuel Lines	1	1	1
Air Lines	1	1	1
Mounting Brackets	2	2	2
Compressor			
Variable Geometry Linkage	1	1	1
Compressor Rotor Assembly	0	1	0
TOTALS	42	101	44
Lube Oil Debris	0	27	5

TABLE 4. PREDICTED AND ACTUAL FAILURE RATE CORRELATION

ECU - Of the 10 actual failures, 3 are considered to have been fixed through redesign and three others were on developmental prototype units. The remaining 4 failures do not indicate that an adjustment in the predicted failure rate of 5 is warranted.

HMU - Of the 9 actual failures, 3 have been fixed through redesign. The remaining six actual failures equals the predicted failures, therefore, no change to the predicted failure rate is indicated.

Sequence Valve - Four of the 5 actual failures were associated with contamination. Redesign to reduce sensitivity to contaminate should reduce the actual failure rate to the predicted 3.

Fuel Boost Pump - Four of the 5 actual failures were with helicoils. This quality problem will be eliminated reducing the actual failure rate to the predicted 2.

TABLE 4. - Continued

Primer Nozzles - The mode of the 3 actual failures was clogging. Redesign is expected to eliminate this problem reducing the actual failure rate to the predicted failure rate of zero.

Lube Filter Bypass Button - Improved manufacturing methods and increased capacity should reduce the actual failures from 14. It is predicted that the failure rate will be 3 per 15,000 engine operating hours (EOH).

No. 3 Bearing Labyrinth Seal - Current redesign efforts will eliminate this problem. Predicted failure rate will remain at zero per 15,000 EOH.

Thermocouple Harness - Only 1 of the 6 failures was associated with connectors. The other 5 were quality problems that are expected to be reduced substantially; therefore, the predicted failure rate of 2 per 15,000 EOH seems appropriate.

Lube Oil Debris - Based on recent field experience the predicted rate for failures of this type will be assumed to be reduced to 20 per 15,000 EOH.

C-Sump Cover - These quality problems, missing retaining bolts and O-ring problems, will be eliminated reducing the actual failure rate to the predicted.

PTO Drive - These 3 failures are associated with a loosening of the PTO assembly on the front frame mounting pads. It is expected that this problem will be eliminated; therefore, the original predicted failure rate for this part should be maintained.

History Recorder - Of the 7 actual failures, 5 have been eliminated through redesign. Of the other 2, one was a broken window, the other was a broken mount. Based on evidence of susceptibility to mishandling damage, the predicted failure rate will be increased to one per 15,000 EOH.

Electrical Harnesses - Five of the 7 actual failures were associated with connectors (bent pins, contamination, and looseness). New scoop-proof connector design should eliminate these types of failures; therefore, the present predicted failure rate of one per 15,000 EOH will be maintained.

TABLE 5. T700 FIELD EVENT HISTORY (MAY 1977 - APRIL 1979) - 15,000 ENGINE HOURS
ALL-CAUSE FIELD FAILURE SYMPTOM AND CONSEQUENCE ANALYSIS

Frequency	Symptom	Consequence: Mission Abort	Unscheduled Engine Removal	Unscheduled Component Removal	Unscheduled Maintenance Action
27	Nuisance Chip Signals	12	-	-	27
21	Inspection Finds	-	-	21	-
14	Premature Oil Filter Popouts	-	-	-	14
11	Miscellaneous Control Anomalies	-	-	11	-
8	Starting Problems	-	-	8	-
7	Erroneous Engine History Recorder Display	-	-	7	-
7	Oil Leaks	-	-	7	-
5	T4.5 Overtemperatures	2	4	1	-
5	Stalls	3	5	-	-
4	Torque Splits	-	-	4	-
4	Ng Oscillations	-	-	4	-
4	Low Performance	-	1	3	-
4	Flameouts During Overspeed Checks	-	-	4	-
3	Bearing Failures	2	3	-	-
4	Miscellaneous	-	-	4	-
128	TOTAL				

TABLE 6. T700 FIELD EVENT HISTORY (MAY 1977 - APRIL 1979) - 15,000 ENGINE HOURS
ALL-CAUSE FIELD FAILURE SYMPTOM AND AFFECTED COMPONENT ANALYSIS

Frequency	Symptoms	Trouble-shooting Procedures	Module Affected	Actual Components Affected
27	Nuisance Chip Signals	Yes	None	Chip Detector
21	Inspection Finds	No	None	Miscellaneous External Components
14	Premature Oil Filter Popouts	No	None	Oil Filter
11	Miscellaneous Control Anomalies	Yes	None	Hydromechanical Unit (HMU), Alternator Stator, 3 Yellow (Y) Harnesses, 2 Electrical Control Units (ECU), 4 $T_{4.5}$ Harnesses
8	Starting Problems	Yes	None	Igniter, Sequence Valve, Primer Manifold, 3 HMU, 2 Primer Nozzles
7	Erroneous Engine History Recorder Display	No	None	Engine History Recorder
7	Oil Leaks	Yes	Cold Section	Axis-G Seal, 2 Sump Covers, 2 Chip Detectors, 2 Postnasal Drip
5	$T_{4.5}$ Overtemperature	Yes	Cold Section	Compressor Spacer, No. 4 Bearing ECU, 2 X-Bleed Valves
5	Stalls	Yes	Cold Section	2 Power Takeoff, Compressor Spacer, No. 4 Bearing, Diffuser

Frequency	Symptoms	Trouble-shooting Procedures	Module Affected	Actual Components Affected
4	Torque Splits	Yes	None	3 ECU, 1 Yellow Harness
4	N_g Oscillations	Yes	None	4 ECU, Yellow Harness
4	Low Performance	Yes	None	2 Anti-icing Valve, T_2 Sensor, Inlet Guide Vane (IGV) Rod End
4	Flameouts During Over-speed Checks	Yes	None	Sequence Valve
3	Bearing Failures	Yes	Cold Section	No. 1 Bearing, No. 3 Bearing, No. 4 Bearing
4	Miscellaneous		Cold Section	
128	TOTAL			

TABLE 6. - Continued

TABLE 7. PREDICTED ALL-CAUSE T700 FIELD EVENT SYMPTOMS - 15,000 ENGINE HOURS

Predicted Frequency	Symptom
5	Nuisance Chip Signals
10	Inspection Finds
3	Premature Oil Filter Popouts
6	Miscellaneous Control Anomalies
1	Starting Problems
2	Erroneous Engine History Recorder Display
5	Oil Leaks
4	$T_{4.5}$ Overtemperatures
3	Stalls
2	Torque Splits
3	N_g Oscillations
2	Low Performance
2	Flameouts
3	Bearing Failures
2	Miscellaneous
54	TOTAL

TABLE 8. T700 DIAGNOSTIC NEEDS BASED ON PREDICTED T700 FAILURE SYMPTOMS			
Predicted Frequency	Symptom	Detection Method	Isolation
5	Nuisance Chip Signals	$\boxed{\text{Discriminating Chip Detector}}$	Not Applicable
10	Inspection Finds	Visual	Visual
3	Premature Oil Filter Popouts	Visual	Not Applicable
6	Miscellaneous Control Anomalies	Cockpit Signals	$\boxed{\text{Control System Analyzer}}$
4	Starting Problems	Pilot and Cockpit Indicators	$\boxed{\text{Control System Analyzer}}$
2	Erroneous Engine History Recorder Display	Visual	Not Applicable
3	Oil Leaks	Visual	Visual
4	$T_{4.5}$ Overtemperature	$\boxed{\text{Time at Overtemperature Recorder or Display}}$	$\boxed{\text{Control System Analyzer and Borescope}}$
3	Stalls	Pilot	Not Applicable
2	Torque Splits	Cockpit Signals	$\boxed{\text{Control System Analyzer}}$
3	N_g Oscillations	Cockpit Signals	$\boxed{\text{Control System Analyzer}}$
2	Low Performance	$\boxed{\text{Automatic Performance (Health) Monitor}}$	$\boxed{\text{Control System Analyzer and Modified MFTS}}$
2	Flameouts	Pilot	$\boxed{\text{Control System Analyzer}}$
3	Bearing Failures	Chip Detector	$\boxed{\text{Slave Chip Detector}}$
2	Miscellaneous	Not Applicable	Not Applicable
54	TOTAL		

instruments. Control fault detection by an on-board monitor, therefore, is not required for those faults detectable by the flight crew. There is a definite need, however, for aids to control fault isolation as indicated by the "Actual Components Affected" column of Table 6. The data shows as many as five different causes for the same symptom. The time and parts expended by maintenance personnel to identify and replace the faulty components, even when following the troubleshooting procedures in the maintenance manual, may well justify the cost of the ground support control system analyzer developed by GE and under evaluation by the Army. This cost study should be performed.

Low Performance Events

Four low performance events in 15,000 hours (three percent of all field events) were detected by the daily HIT (Health Indication Test) check and confirmed by an in-flight maximum power check. In all four cases, the problems were control related, not caused by gas path or seal leakage degradation. Performance monitoring, therefore, will detect not only performance degradation but those control system problems that are not easily identified from cockpit instrument readings or from observed engine phenomenon such as slow acceleration, etc. Automated performance measurement would eliminate manual reading, recording, and computation of cockpit instrument data by the flight crew in the cockpit, would save time, fuel and engine operating costs, and produce more accurate and useful data. A LCC analysis should be performed to determine if automated performance monitoring is cost effective.

Engine Overtemperature Events

Five overtemperature events occurred in 15,000 hours on the T700 engine (see Table 6). The Black Hawk vertical scale cockpit engine instruments provide a red lighted scale when overtemperature of the engine hot section occurs. There is no annunciator panel caution signal for a turbine overtemperature, however. Hot section overtemperature damage will occur if specific time at overtemperature relationships defined by two curves (see Figures 28 and 29) are exceeded. The time functions are measured in seconds and can easily be inaccurately estimated by the flight crew. An automatic system that computes the time at overtemperature relationships and displays the overtemperature severity message would be a valuable maintenance tool and should be evaluated for cost effectiveness.

Modular Performance Fault Isolation (MPFI)

Performing MPFI on installed T700 engines was determined by analysis (see D&CM Monthly Report No. 7, January 15, 1980) to be impractical and should be done at AVIM on the modular engine test system (METS). Major modifications to the METS were defined to enable gas path analysis data of sufficient accuracy to be obtained for identifying the module or modules requiring replacement. Field event analysis (see Table 6) did not identify any low performance events caused by gas path performance degradation, however, GE agreed to conduct a LCC analysis of modular performance fault isolation on METS by gas path analysis and recommend an alternate method should gas path analysis not be cost effective. Status of Army METS is shown in Table 9.

TABLE 9. MODULAR ENGINE TEST SYSTEMS STATUS

System Configuration	Qty.	Located	Tests	Description
		METS		
Original Design	1	Germany	T53, T55, T63	Analog instruments, data taken, computed and evaluated manually.
	1	Air National Guard	T73, T74	
	1	Fort Hood		
	1	Fort Campbell		
Total	4			
Updated Design	1	Fort Rucker (Prototype)	All above plus T700 (see Below)	Digital indicators. Automatic Data Scanning. Data Acquisition System - calculates and prints performance data.
Total	2			
		T700 METS ADAPTER KITS		
T700 Adapter Kits	2	Installed on Updated METS	T700	Mounts, instruments, drive shaft, brackets, water brake, starter, etc.
	1	Unassigned		
Total	3			

Modular Oil-Wetted Part (OWP) Fault Isolation

Modular OWP fault isolation was considered practical by use of so-called slave chip detectors that would be installed at each scavenge pump inlet to determine which engine sump was the source of failure debris in the oil. Engine testing for OWP fault isolation was determined to be a METS facility function rather than one performed on installed engines for the following reasons:

1. OWP failures require engine removal regardless of which module is involved. Engine testing in the aircraft reduces aircraft availability.
2. Opening up the lube oil system at AVUM level to install slave chip detector exposes engine to the possibility of contaminating the oil system.
3. The character of the slave chip detector kit with a control unit and a six branch wiring harness makes the set very susceptible to handling damage at the AVUM level.

Engine Life Usage Monitoring (ELUM)

There were no low cycle fatigue or stress rupture related field events. This is to be expected, given the low average age of approximately 100 hours time since new (TSN) of the engines in this data sample and more importantly, the conservative design and long predicted hot part life of the present T700-GE-700 engine model. This assessment, however, is to cover all modern modular Army turboshaft engines, including for example, future growth versions of the T700. Maintenance and logistic experts in GE* and elsewhere have concluded that for most

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*AGARD Symposium Report, May 19. 1980, "The Application of Design-to-Cost Method to Aircraft Engine Design." Paper by G. Walker, Mgr. Logistics Analysis and Planning, G. E., AEG, Lynn, Mass. "Logistics Forecasting for Achieving Low Life Cycle Costs."

military engine applications, the efficient application of on-condition maintenance (to which all services are committed) requires a measurement of life usage more definitive than merely engine hours. GE has developed an engine life measurement concept called ELUM (engine life usage monitoring) and has implemented the concept in hardware and software specifically for Army T700 engine evaluation. It is recommended, therefore, that the ELUM concept be included as a candidate D&CM function and be evaluated for cost effectiveness.

D&CM APPROACH - SUMMARY AND DESCRIPTION OF CANDIDATE ITEMS

The results of the Task I definition of the D&CM approach are depicted graphically in Table 8 with the exception of the engine life usage function. All of the symptoms revealed by 15,000 hours of engine field operation are shown together with the methods for fault detection and isolation. D&CM candidate improvement items are highlighted as the boxed items. Missing by intent is a vibration monitoring item. There were no vibration events reported in the period studied. Nor has there been any significant vibration problem history during the entire program. A previous study for the NAVAIR Lamps program under Contract N00019-77-C-0201* concluded that neither an airborne vibration monitoring system nor dedicated T700 vibration ground support equipment at AVUM would be cost effective. There is vibration instrumentation equipment available on the METS facility if required for off-aircraft diagnosis.

A summary of the candidate D&CM candidate functions and items is presented in Table 10 and is briefly described in the following paragraphs.

TABLE 10. D&CM APPROACH - CANDIDATE D&CM IMPROVEMENTS ITEMS

Ground Functions	Ground Equipment
Modular Performance Fault Isolation	Modified METS
Modular Oil-Wetted Parts Fault Isolation	Slave Chip Detector
Control LRU Fault Isolation	Control System Analyzer
Airborne Functions	**Airborne Equipment**
Engine Health Measurement	Automatic Performance Monitor
Engine Parts Life - Measurement	Low Cycle Fatigue Monitor Degaussing
Oil-Wetted Parts Fault Detection	Chip Detector Overtemperature
Hot Part Condition	Monitor (Time at Overtemperature)

*GE Report R78AEG1023, "T700-GE-401 In-Flight Engine Analyzer Trade-Off Study." October 1978, pages 7-13 to 7-17.

Modified METS for Modular Performance Fault Isolation

NEED: To isolate a performance loss of 7% or more to the correct module or modules when the loss has been determined to be a gas path problem.

CONCEPT: A modification of the updated METS to add instrumentation, adapters, a computer, and air flow measurement capability to approach in the field equipment the capability of existing factory T700 facilities.

Slave Chip Detector GSE Kits

NEED: To isolate the source of oil system failure debris to the module involved.

CONCEPT: A GSE kit containing six magnetic chip detectors that could replace the six scavenge screens at the scavenge pump inlets. Engine operation on the METS would be expected to generate debris that would be captured and detected by these slave units.

Control System Analyzer

NEED: A diagnostic aid or technique for Army AVUM personnel that will isolate control related problems to engine or airframe, and if engine caused, isolate to the LRU with effectiveness at least as high as achieved in flight test with GE support.

CONCEPT: An AVUM level GSE control system analyzer utilizing available engine and aircraft interfaces will check cockpit instruments and aircraft electrical wiring between engines, check engine wiring and LRU's and isolate faults with an estimated effectiveness of at least 90%.

Automated Performance Monitor

NEED: Reduce or eliminate preflight checkout time for HIT check, simplify and improve accuracy and consistency of HIT and maximum power checks and provide data to support MPFI or other performance analysis such as trending.

CONCEPT: An airframe-mounted unit that will, on command, provide a cockpit go-no-go signal for preflight HIT or in-flight maximum power checks and also produce a record of the performance measurements.

Low Cycle Fatigue Monitor

NEED: An accurate means of measuring mission load profiles and cyclic life on key engine parts exposed to a wide range of missions and environmental conditions. Recent advances in analytical techniques for cyclic life usage computations will improve cyclic life measurement over that possible with the present engine history recorder (EHR).

CONCEPT: A microprocessor-based unit that measures 20 partial and full speed and thermal cycles (versus 2 for present EHR) and computes equivalent full cycles on each of five key parts on each of two engines.

Degaussing Discriminating Chip Detector

NEED: Reduce or eliminate mission aborts and unscheduled maintenance actions caused by nuisance chip signals.

CONCEPT: A chip detector similar to the current T700 device but with the addition of a degaussing coil that releases the chips after capture and provides a suitable cockpit signal.

Time at Temperature Overtemperature Caution

NEED: A latching-type caution indication of potentially damaging overtemperature where the occurrence or duration are not observed by the flight crew.

CONCEPT: A persisting or latching-type signal available to the aircraft crew and requiring some maintenance action is currently the only information which could be derived from the T700 engine history recorder time at temperature counts by computing the difference between the preflight and postflight readings.

ESTIMATED IMPACT OF D&CM APPROACH ON EXISTING MAINTENANCE PHILOSOPHY

Existing AVUM Tasks

1. Ten-hour five-day inspection.
2. 500-hour inspection.
3. Troubleshooting fault isolation.

4. Line replaceable unit removal (LRU) replacement.

5. Engine removal/replacement.

6. HIT checks and maximum power tests.

D&CM Impact on AVUM Tasks

1. Performance - go, no-go, decision with aircraft installed automated performance monitor replaces manual HIT check and maximum power check.

2. LRU troubleshooting and fault isolation. Improve accuracy with control system analyzer.

3. Utilize discriminating chip detector to minimize or eliminate ground engine runs.

4. Increase LCF counting capability for life-cycle limited components.

5. Overtemperature caution provides accurate time-at-temperature measurement for better maintenance decisions.

6. Preventive inspection - no change (see above).

7. Corrective maintenance tasks - no change (see above).

Existing AVIM Tasks

1. Troubleshoot using METS.

2. Module removal or replacement.

3. Component removal or replacement.

4. Repair verification using METS.

D&CM Impact on AVIM Tasks

1. Troubleshoot to module for performance and mechanical problems utilizing METS modification per GE proposal dated 10/17/79 and slave chip detector.

2. Control system analyzer set for control fault isolation.

3. Corrective maintenance tasks - no change.

4. Preventive maintenance tasks - no change.

Existing Depot Tasks

1. Repair modules.
2. Repair LRU's.
3. Repair damaged or worn parts.

D&CM Impact on Depot

1. Control system analyzer set for LRU fault isolation.
2. Repair and test functions - no change.
3. OWP fault isolation with slave chip detector.

D&CM IMPACT OF TASKS PERFORMED AT AVIM UTILIZING THE MODULAR ENGINE TEST SYSTEMS

If the recommendations resulting from this D&CM assessment are implemented for both AVUM and AVIM organizations, METS tasks will be affected as follows:

1. Fewer T700 engines will be shipped to AVIM and tested on METS.
   a. More accurate and faster maximum power and HIT checks will reduce the number of marginal engines sent to AVIM.
   b. Much more accurate and faster control LRU fault isolation using the control system analyzer set at AVUM may result in fewer engines returned to AVIM for diagnosis which, because of time, facilities or personnel limitations could not previously be diagnosed at AVUM.
2. Faster METS diagnostic and check-out tests.
   a. Computerized data processing as recommended will produce more accurate results faster than with the present manual data recording and computation.
   b. The use of the same type control system analyzer set as used at AVUM will also speed up troubleshooting at METS.

NOTE: For METS Status, see Table 9.

TASK II - D&CM SYSTEM DEFINITION

The D&CM approach developed in Task I requires equipment for three ground support D&CM systems: a modified METS for performance fault isolation, a slave chip detector system for oil-wetted parts (OWP) fault isolation, and the Control System Analyzer. In addition, the following non-GSE systems were identified: one engine mounted sensor; the discriminating chip detector to replace the present master chip detector; and an airframe-mounted D&CM system consisting of one cockpit digital indicator, one microprocessor based data computer and one free air temperature sensor resistance temperature device (RTD) (probably airframe-mounted). These systems are described herein. Table 11 categorizes the means by which the functions are performed, i.e., by manual means, computer-aided, or automated.

TABLE 11. HOW CANDIDATE D&CM FUNCTIONS ARE ACCOMPLISHED

D&CM Function	Computer Aided	Automated	Manual
Modular Performance Fault Isolation (Modified METS)	X	X	-
Oil-Wetted Part Fault Isolation (Slave Chip Detector)		X	-
Multipurpose Airborne D&CM			
Automatic Performance Indication	X	X	-
Degaussing Discriminating Chip Detection	X	X	-
Overtemperature Caution	X	X	-
Engine Life Usage, Computation and Recording	X	X	-

MODIFIED METS FOR MODULAR PERFORMANCE FAULT ISOLATION (MPFI)

Description of METS Modification for MPFI

Modification of the basic METS for performing MPFI means, in essence, reproducing in the six METS in the field the capability of a computerized GE, Lynn, Mass., T700 test facility complete with a GE systems engineer for data analysis. The basic improvements to METS are the following:

1. Accurate measurement of total inlet and scavenge blower air flow.
2. New high accuracy pressure transducer package.
3. Suitable microcomputer with recording, display, and printout capability.
4. Miscellaneous mechanical and electrical modifications to accomplish the above.
5. Computer program (software) and comprehensive operators instructions for gas path analysis.

Hardware Required

In order to provide the desired inlet air flow measuring capability, new designs and hardware are required for the bellmouth, inlet fairing, torque tube, torque shaft, inlet duct and screen, inlet baffle, engine mount frame, and inlet pressure and temperature probes. The longer bellmouth and fairing will require the new torque shaft and tube designs. The inlet duct, screen, and baffle will provide temperature probe mounts and shielding from the sun. The longer bellmouth will also require that the water brake be located further from the engine, which modifies the forward mount frame. An instrumented scavenge blower flow measurement section and environmentally protected pressure transducer assembly are also required. The control console will be modified to accept the new microcomputer, display, and printer.

Software and Engineering Support

The following software and engineering support are required for the modified METS for MPFI:

1. Prepare flow charts (algorithms) describing the executive program; data acquisition, smoothing and/or averaging; computations, error auditing, plotting and display for each of the following:

a. Overall engine performance.
b. Compressor efficiency.
c. HP (gas generator) turbine efficiency.
d. LP (power) turbine efficiency.

2. Prepare computer programs in the appropriate machine language for the above functions.
3. Perform computer simulation of engine operation to debug the programs.
4. Prepare detailed user's manual.
5. T700 performance and systems analysis support on bellmouth and scavenge flow sections definition.
6. Aerodynamic instrumentation unit support for services, to approve and qualify new inlet temperature and pressure problems.
7. Engine evaluation and test cell work for calibration of the inlet particle separator and the bellmouth.
8. Structural stress analysis support to perform a VAST study to analyze the system resonances.
9. Vibration survey as a part of engineering checkout of the prototype hardware.
10. Prepare computer system specification, obtain competitive bids, and procure computer system.
11. Modify TM55-2840-248-23, Aviation Unit and Intermediate Maintenance Instructions for the T700-GE-700 Engine.

STANDARD METS WITH COMPUTERIZED OVERALL PERFORMANCE MEASUREMENT

Hardware Required

The following hardware is required for the standard METS with computerized overall performance measurement.

1. Suitable computer with display, record, and printout capability.
2. Control console modification for computer system.

The following software and engineering support are required for standard METS with computerized overall performance measurement.

1. Prepare computer system specification, obtain competitive bids, and procure computer system.

2. Modify TM55-2840-248-23, Aviation Unit and Intermediate Maintenance Instructions for T700-GE-700 Engine.

3. Compare flow charts (algorithms) describing the executive program, data acquisition, smoothing and/or averaging; computation, error editing, plotting, and display for overall engine performance.

4. Prepare computer program in appropriate machine language.

5. Perform computer simulation of engine operation to debug the program.

6. Prepare user's manual.

SLAVE CHIP DETECTORS

Modular fault isolation of oil-wetted part (OWP) problems on T700 and other turboshaft engines can be accomplished by means of simple electrical indicating system utilizing magnetic chip detectors installed at the scavenge pump inlets and used only on the ground.

Factory and field experience on the T700 engine has proven that the master chip detector will detect approximately 85% of all bearing and seal problems. Currently, however, the only means of isolating the problem to the correct module, once it has been detected, is to run the engine and then remove and visually inspect each of the six debris screens on the scavenge pump inlets (see Figure 2). If the failure debris is larger than 0.040 inches (approximately) the debris may be caught on the scavenge screens and its source determined. Much of the debris, however, will be smaller than 0.040 inches (100 microns) and will pass through the screens undetected. Furthermore, running an engine that has a failing part such as a bearing involves some risk in that, without some indication of accumulating debris, the engine could be run too long and suffer secondary damage. Chip detection at the scavenge pump inlet provides the earliest possible debris signal.

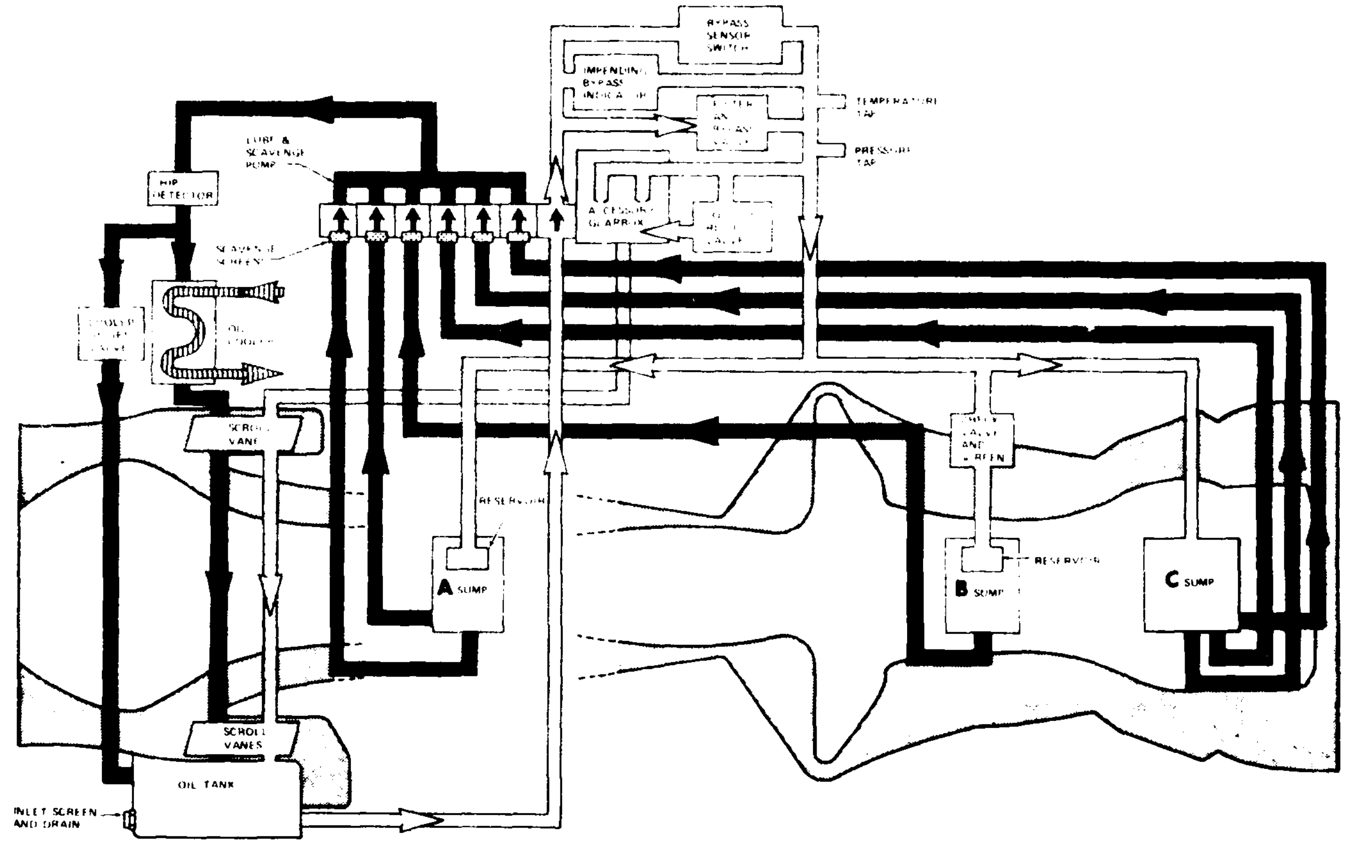


Figure 2. Lubrication System Schematic.

D&CM Approach

The D&CM approach for oil-wetted parts fault isolation proposed in Task I for further study and evaluation was the use of so-called "slave" chip detectors. These devices are conventional magnetic chip detectors designed to be installed at the six scavenge pump inlets in place of the scavenge screens. The detectors would have electrical connectors for connection to a transistorized chip detector monitoring unit. The detector design would be similar to the interim T700 B-sump chip detector, which has proven very satisfactory. The concept and hardware would be identical with that used with excellent results for several years in Lynn GE TF34 and F404 test cells. Although this concept could be applied at the AVUM level and fault isolation ground runs made with an installed engine, it is not recommended for the following reasons:

1. Decreases aircraft availability.
2. Creates opportunity for introducing contamination into the oil system.
3. Requires a slave detector system for each helicopter company rather than for each METS - a ten or fifteen fold increase in GSE costs.
4. Requires a calibration circuit checker for each helicopter company.
5. Creates a situation wherein it is likely that parts of the little used equipment may be lost or damaged in storage and the time required to set up and run the fault isolation checks correctly may be excessive due to their infrequent occurrance.

The practical application of this technique, if it is adopted, would be at the AVIM level utilizing the METS for engine run-ups. Only six sets of detector systems would be required. Systems could be permanently installed and the METS operating personnel servicing engines from many helicopter companies would be more adept at using and maintaining this equipment.

There are four principal sources for failure debris in the basic engine, excluding the LRU's:

		Detectable . . Scavenge Screen Detectors
A-Sump	Cold Section Module	Yes
Accessory Gear-box (AGB)	Accessory Module	No*
B-Sump	Cold Section Module	Yes
C-Sump	Power Turbine Module	'es

*The design of the T700 engine does not provide any conveni means for chip detection of oil coming from the accessory gearbox as this oil drains by gravity directly into the engine oil tank. Although there is a threaded oil drain plug at the bottom of the oil tank, installation of an indicating chip detector at this point is not feasible because of false signals that will be caused by system debris that will collect at this, the lowest point in the system. The factory and field experience on the T700 engine covering approximately 75,000 engine hours without any AGB bearing or gear failures indicates no real need for AGB chip detection.

Oil-Wetted Parts Fault Isolation Procedure Utilizing the Proposed Transistorized Chip Detector Circuit (TCDC) System

In the event of an OWP failure detected by the master chip detector on an installed engine, AVUM troubleshooting Procedure 39 in TM55-2840-248-23*, should be followed and engine removed and sent to AVIM if failure is confirmed. To determine the source of the debris at AVIM, the six scavenge screens should be removed and inspected before preparing engine for METS installation. A significant accumulation of chips on one or more screens from the same sump would be a clear indication of the source of the problem and the engine would be either sent to the depot if debris is from A- or B-sumps, or have its power turbine module changed if the debris is from the C-sump. If there is no clear indication of failure location, the indicating chip detectors should be installed on the six scavenge pump inlets and the engines run on METS until a TCDC chip signal is generated. The test would then be terminated immediately and the appropriate action taken based on the indicated source of the debris. If no chips are detected, the engine would be returned to service following TM55-2840-248-23 procedures.

Hardware Description Cost

The components required to equip one METS facility for oil-wetted part fault isolation are as follows:

1. One transistorized chip detector circuit (TCDC) unit containing power supply, and adjustable detection circuits with provisions for processing six chip detectors. The TCDC operates on 60 Hz, 115 V ac power in a standard 5-1/4 in. x 19 in. rack mounting panel, and weighs 47 pounds (see Figure 3).
2. Six magnetic chip detectors for scavenge pump inlet installation.

*Aviation Unit and Intermediate Maintenance Instructions for the T700-GE-700 Engine.

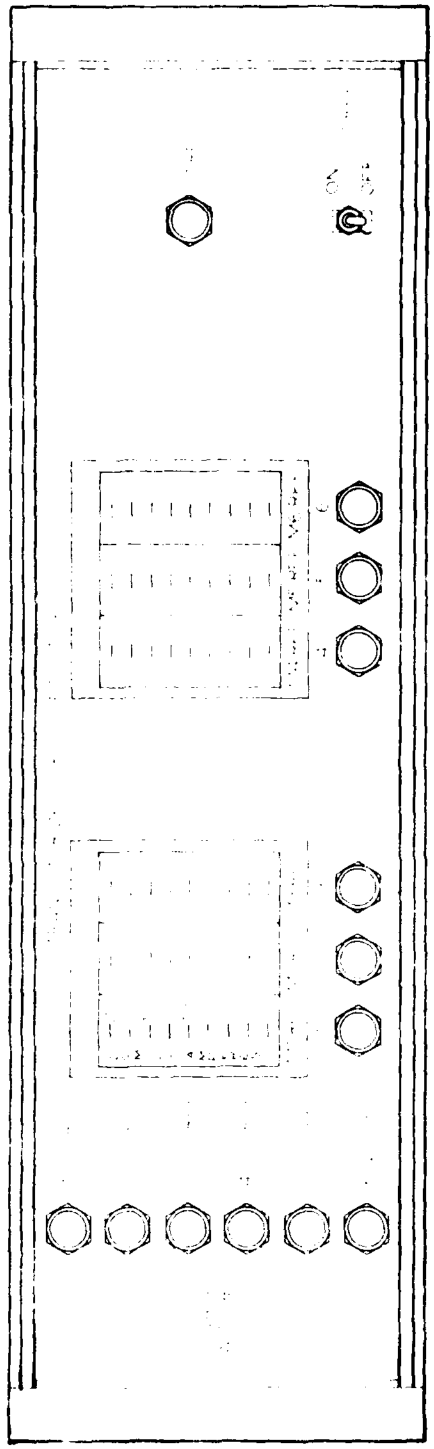


Figure 8. Transistorized Chip Detector Assembly.

3. Six cable sets - TCDC to chip detector.

4. One portable calibration box unit.

Estimated "ball park" cost is $10,000-15,000 per system plus a nonrecurring cost for MIL specification conformance and engineering support for installation check-out and operating instructions of $15,000-30,000 per system.

Software Required

No software is required for oil-wetted part fault isolation.

General Specifications

Specifications for the transistorized chip detector system, Part No. 17A112-611 Group 02, are as follows:

Part No. 17A112-611 Group 2:

Power Requirements:

105-125 V ac, 47-63 Hz
Derate 10% at 50 Hz

Dimensions (in.):

19.0 x 5.25 x 13.0.

Power Supply Rated Output:

Voltage (nom.) +24 V dc, ±5%
adjustment
Current (max.) 1.6 A

Net Weight (lb):

47

Temperature Range:

Operating: 32°F to 158°F
Rating: Derate 2% of above 104°F

Theory of Operation

The chip detector utilizes the voltage divider network triggered by foreign magnetic material collecting on the chip detector. This provides a low current sensing circuit to detect chips. Three milliamps indicates a clean detector. Twenty milliamps, a full scale reading, indicates the chip detector gap is filled with a solid chip or many chips. The TCDC will draw a maximum of 20 mA under short-circuit conditions. The system is set to indicate chip conditions visually when the meter reads 12.5 mA, this is the equivalent of one hundred ohms of material across the chip detector gap.

For normal operation, refer to GE Dwg. 17A126-113 (see Figure 4). The cable to the chip detector must be plugged in to provide a ground for switching transistor Q1. When power is turned on, relay K is energized through Q1 and Q2 which open the circuit to L1 (chip indicator light) and closes interlock circuit to cell chip status light relay. The milliammeter reads about 3 mA. If the cable is not plugged into the chip detector, Q1 will not turn on to provide power to Q2 and relay K, L1 will be on and the cell chip status light will be on. This condition is recognized by a milliammeter reading of zero. To correct, the harness must be plugged in or the disable switch must be turned on. During normal operation when chips cause the resistance across the chip detector to drop to 100 ohms, trip set point, transistor Q4 is turned on which turns on Q3, this turns off Q2 and relay K drops out causing L1 to turn on and cell chip status light to turn on. The milliammeter will read 12.5 mA or higher. To reduce meter reading, the chip detector must be cleaned.

The disable switch is a two pole manual toggle switch with one circuit across the relay K contacts which is in series with the cell chip status light relay. The other circuit lights the disable lamp and picks up relay K. The disable switch can be used to bypass (not correct) a fault at the chip detector or a circuit component failure.

Noise interference is filtered by capacitor C and resistor R9. When Q2 is driven off the effect on the speed of response would delay the time required to discharge capacitor C in about 2.5 seconds. This action allows any sharp signal or pulse of short duration (noise) to be ignored by Q2 consequently keeping relay K energized.

CONTROL SYSTEM ANALYZER SET

Background

During the Black Hawk development and government competitive test (GCT) phase of field testing, a requirement was identified for improved engine and control system troubleshooting and rapid isolation to the faulty component. During discussions at technical reviews and Integrated Logistics Support Management Team (ILSMT) meetings, the GE recommended the development of a suitcase-type tester which could be readily connected to the helicopter and engine to identify a malfunction within the engine control system or in the interfacing airframe system.

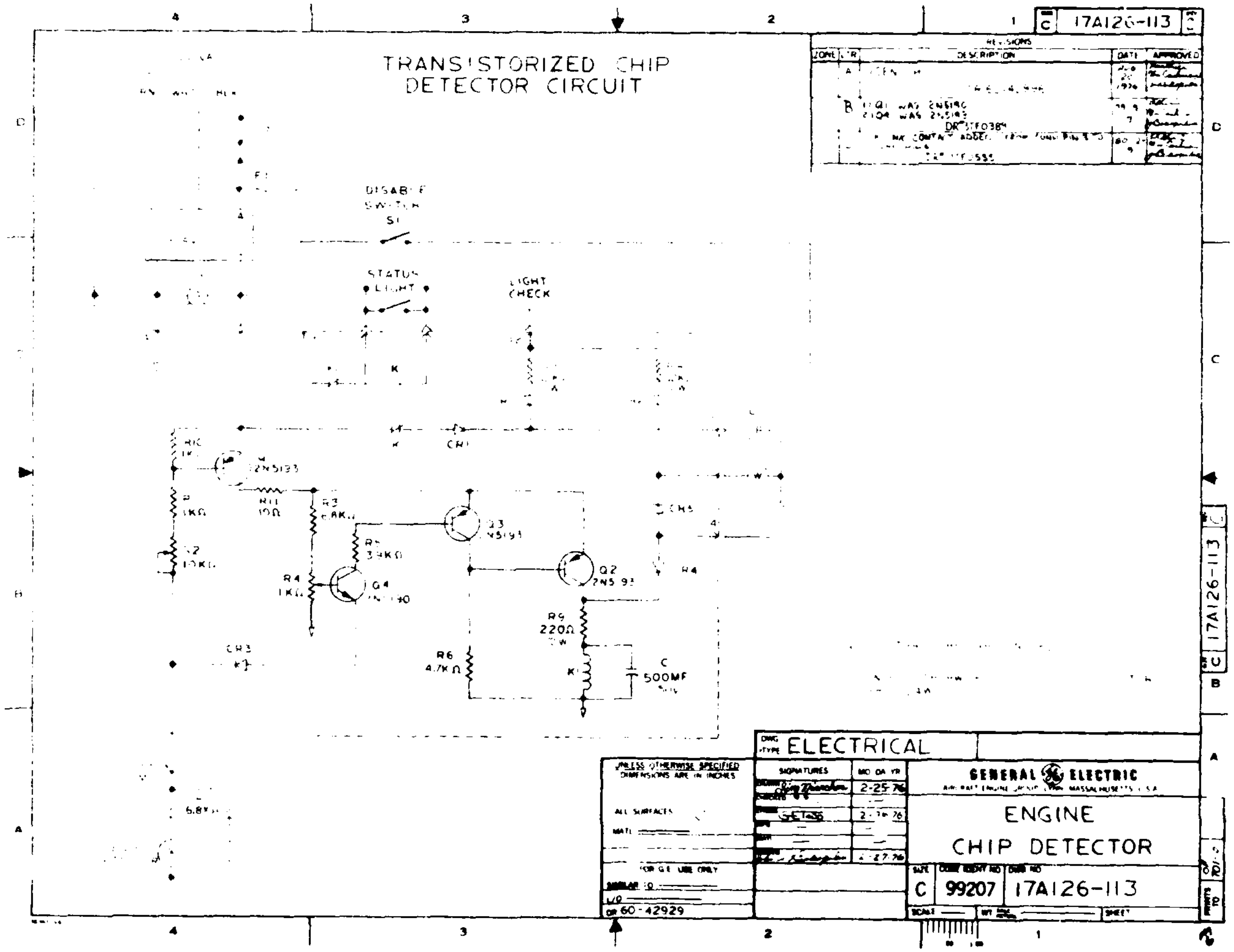


Figure 4. Engine Chip Detector.

In January 1978, GE proposed the development and evaluation of a prototype field unit suitcase tester to be used in troubleshooting and fault isolation of the T700 engine and control electrical system on the Black Hawk and AAH helicopters. Subsequently, funding for a prototype units was provided and one unit was built and sent to the field for evaluation. This tester is in use at Ft. Rucker and is undergoing Army and GE evaluation. A second prototype incorporating modifications based on first unit experience was shipped in August 1980.

General Description

The T700 control system analyzer set is a portable test set built of rugged solid state electrical components. The test set can be powered by the Black Hawk's APU power supply and does not require engine operation. The unit has built in comparator currents to give go or no-go indications eliminating the requirement for a meter reading. The test set consists of two portable units which are:

		Weight (lb)*
1.	T700 Engine Harness and Sensor Circuit Tester (Figure 5).	20
2.	T700 Electrical Control Unit (ECU) Systems Tester (Figure 6).	30

*Including all cables and test pieces.

Features

The control system analyzer set has the following features:

1. Single-point connection utilizing ECU's S-39 diagnostic connector.
2. Used with engines in nonoperating mode (APU must be operating for electrical power or ground power required).
3. Nonengineering displays - go or no-go logic.
4. Self-check circuits (bite).
5. Environmentally packaged.

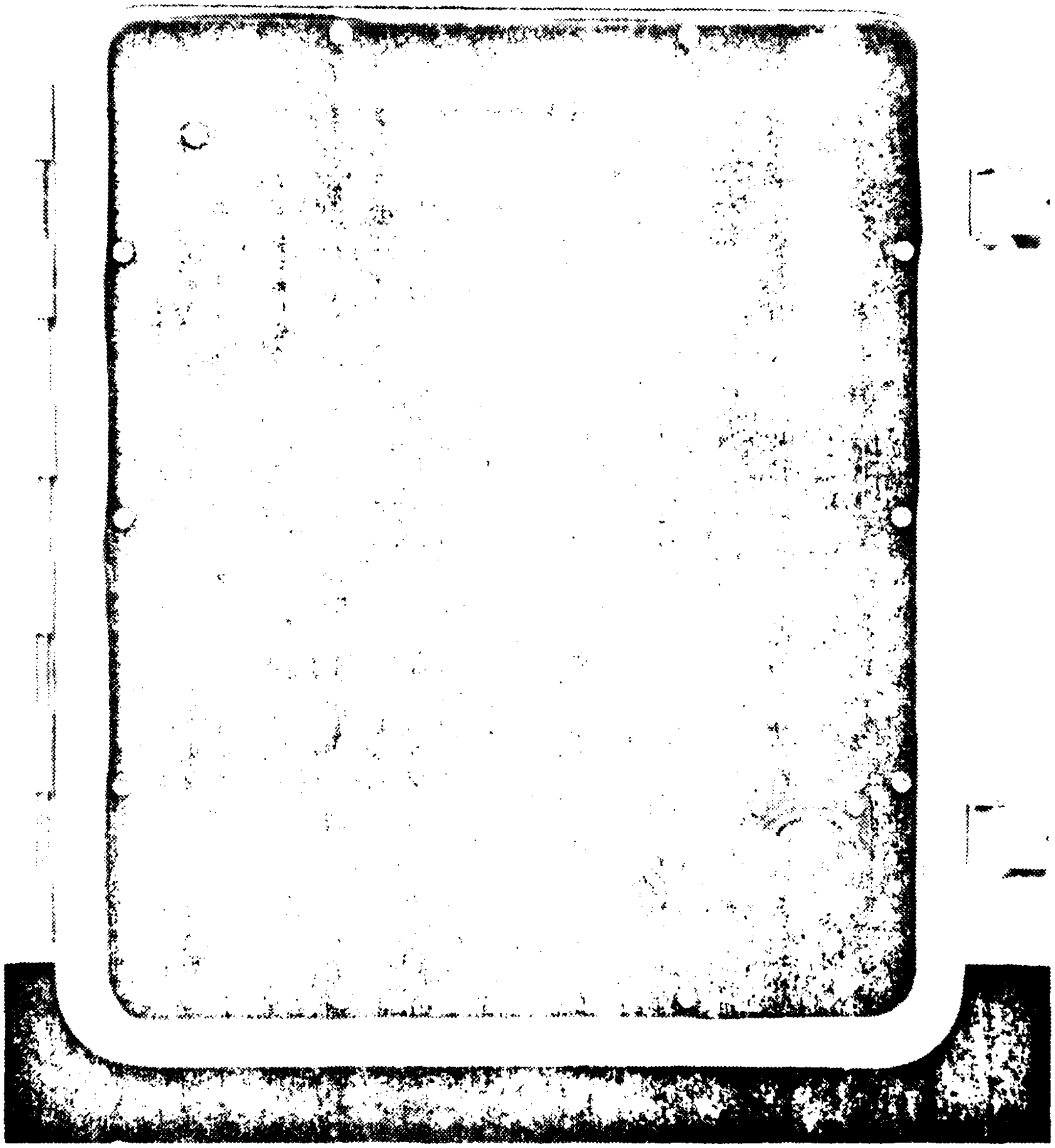


Figure [illegible] [illegible] Local Control Unit (LCU) Systems Tester

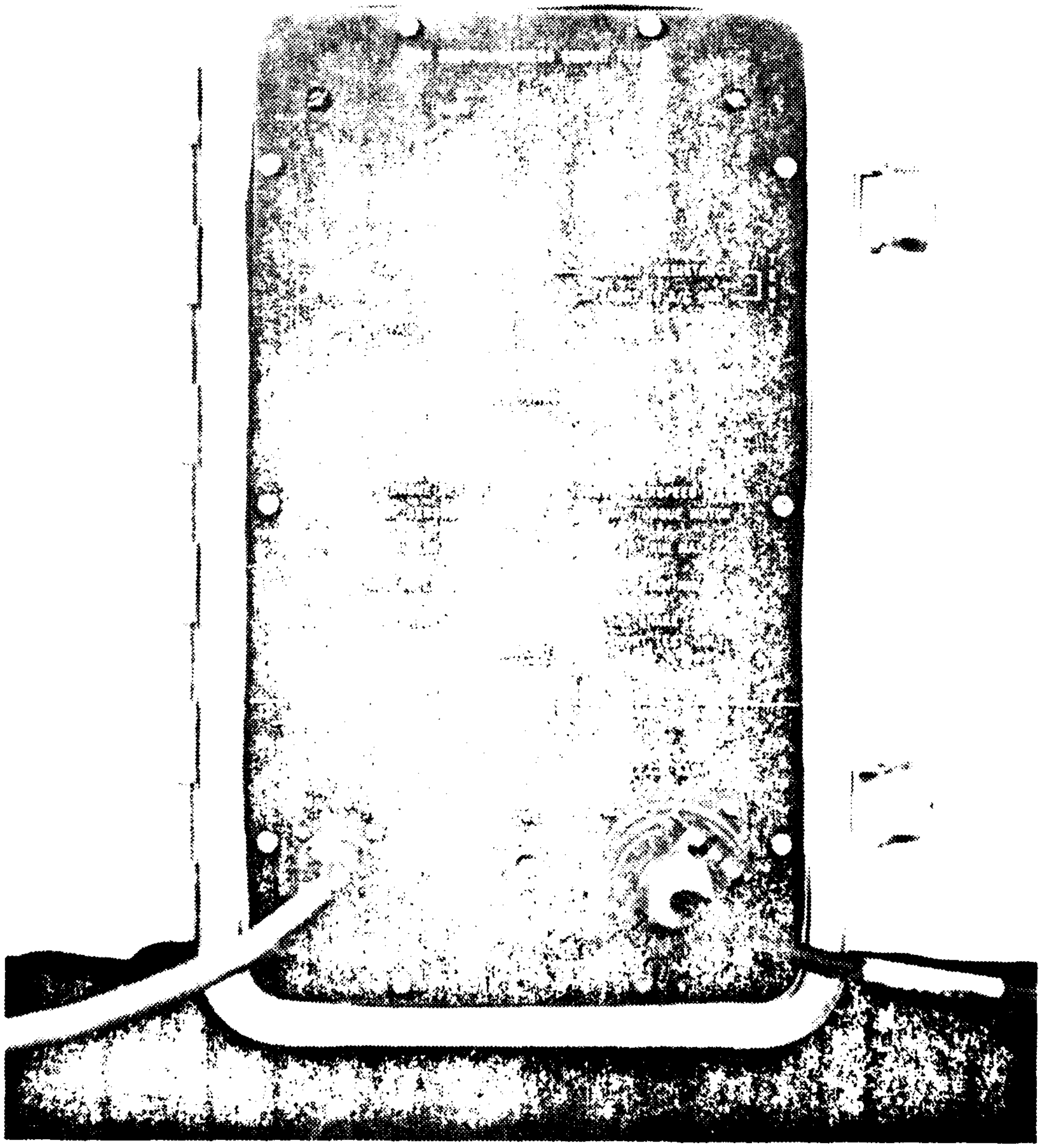


Figure 6. [illegible] Engine Harness and Sensor Circuit Tester.

Fault Isolation Capability

The control system analyzer set has the following fault isolation capability:

1. Electrical Control System LRU's:

   a. N_p and torque sensors.
   b. Sequence valve overspeed solenoid.
   c. Alternator.
   d. Thermocouple harness.
   e. Aircraft N_p demand potentiometer.
   f. Hydromechanical unit (HMU) torque motor.
   g. Hydromechanical unit linear variable differential transformer.
   h. Yellow harness.
   i. Blue harness.
   j. Aircraft E-1 harness.

2. Electrical control unit.

3. Engine system dynamics.

4. Cockpit engine instruments.

T700 Engine Harness and Sensor Circuit Tester

The T700 engine harness and sensor circuit tester Part No. 1013145-833 has been specifically designed for use with the electrical control unit's S39 diagnostic connector for troubleshooting control system problems with the aircraft and engine in the nonoperating mode.

Through the diagnostic connector, control system electrical harnessing, interconnecting components and aircraft interface connections can be tested for opens, shorts, and nominal resistance values when troubleshooting engine control system problems as directed in Section I of TM55-2840-248-23 maintenance manual. The tester operates on 115 V, 60 to 400 Hz power which is available at the aircrafts J-257 utility receptacle in the cockpit or from external sources and will display a pass or fail logic with no additional instrumentation or test equipment required.

A built-in test (BIT) or self-check feature has been incorporated which tests the internal circuitry for all functions in both the pass and fail modes.

The go or no-go logic is accomplished and displayed through the use of resistance comparator circuits whose values are set at the minimum and maximum tolerance range of the circuit being tested. Circuits which exceed the minimum or maximum allowable ranges will illuminate the failed red light. Circuits that are within the allowable range will illuminate the pass or green light. The tester also checks each circuit for a short to aircraft ground. Shorts to ground will illuminate the red fail light. If all circuits are normal, the green pass light will illuminate for each circuit being tested.

The following engine and aircraft components can be checked using the tester:

Alternator	HMU Torque Motor
Thermocouple Harness	Yellow Harness
HMU LDT	Blue Harness
N_p Sensor	N_p Demand Circuit (Aircraft)
Torque and Overspeed Sensor	Load-Share Circuit (Aircraft)
Sequence Valve Overspeed Solenoid	

The important human factors features are designed into the harness and sensor circuit tester and greatly enhance its effectiveness as follows:

1. Elimination of the need to look up the correct value of electrical resistance for each pair of electrical pins or sockets to be tested, and then correctly read the multimeter to determine if the readings are within limits.

2. Elimination of the need to use multimeter and needlepoint probes to check for opens, shorts, and out-of-limits resistance within each of 18 electrical multipin connectors as well as between connectors. The need to read the pin numbers and e contact with the correct pins is now very difficult and subject to human error.

T700 ECU Systems Tester

The T700 ECU systems tester Part No. 4013145-834 is a self-contained test unit specifically designed to perform functional closed loop tests of the various ECU functions, HMU feedback system, aircraft N_p speed trim system, and provide cockpit readout of the TGT, % N_p, and % torque instruments. All tests are accomplished with the engine in the nonoperating mode B7 connection to the ECU S39 diagnostic connector.

The ECU tester performs the following specific functions:

1. Tests the ECU and HMU channel by simulating the linear voltage differential transformer (LVDT) characteristics. This test, by utilizing the LVDT secondary voltage, will detect and correct the HMU torque motor current level and confirm proper excitation voltage to the LVDT.

2. Tests the ECU's TGT limiter channel by driving the engine's thermocouple harness to the level of the ECU's TGT limiter reference circuit and displays the limiter value on the cockpit instrument.

3. Tests the ECU's N_p governor channel by providing a simulated N_p speed signal to the ECU which is compared to the aircraft N_p demand speed control system. Adjustment of the speed control system will cause the ECU's governor circuitry to respond to the speed reference and display the value on the N_p cockpit instrument. Also check the N_p demand circuit in the aircraft.

4. Tests the ECU's torque computer and load share circuitry by providing fixed values of simulated torque to the input of the ECU. These signals are then computed by the ECU and displayed on the cockpit % torque instrument. In addition, a load share error signal is provided at S39 which drives the ECU torque circuitry and the resultant N_p speed change is displayed on the cockpit % N_p instrument.

The above tests check all of the ECU's major control functions and provides pass or fail criteria in addition to functionally checking the cockpit instruments of TGT, % N_p, and % torque.

MULTIPURPOSE AIRBORNE D&CM SYSTEM

Background

As a result of work performed during Task I of the D&CM System Assessment, four airborne elements of a condition monitoring system were identified as likely candidates for further investigation. These elements include:

1. An automatic performance monitor.

2. A degaussing discriminating chip detector.

3. Engine life usage monitor.

4. An overtemperature monitor.

During Task II of this program, each of the above elements were assessed in order to:

1. Define system hardware and software.

2. Define system operation.

3. Estimate hardware and software costs.

Two particular helicopter configurations were addressed. The first was the UH-60A utility aircraft and the second a UH-XX which we envision as an advanced utility or attack helicopter. In addition, three D&CM configurations were evaluated:

1. All D&CM hardware engine-mounted with the exception of a cockpit display.

2. All D&CM hardware airframe-mounted with the exception of engine sensors. This configuration would feature removable, airframe-mounted history memory modules.

3. All D&CM hardware airframe-mounted with the exception of engine sensors and on-engine, engine history memory modules.

High level block diagrams of these configurations are shown in Figures 7 through 9.

Configuration 1 (Figure 7) was examined in some detail during work performed under Contract DAAK50-79-C-008* and was found to be suboptimum in several respects. First, separate on-engine computers are required for each engine, resulting in cost and weight penalties. Second, the higher component count degrades system MTBF and thus increases aircraft maintainability costs. Finally, each engine held in storage for logistics support would likely be stored with an on-engine computer installed, thus impacting the overall cost of implementing such a system.

Under one condition the on-engine configuration could be effective. If the engine's electronic control unit were implemented with digital hardware, and if excess

*See General Electric Report TIS R79AEG8036 entitled Design Alternatives for a T700 Engine Life Usage Monitor.

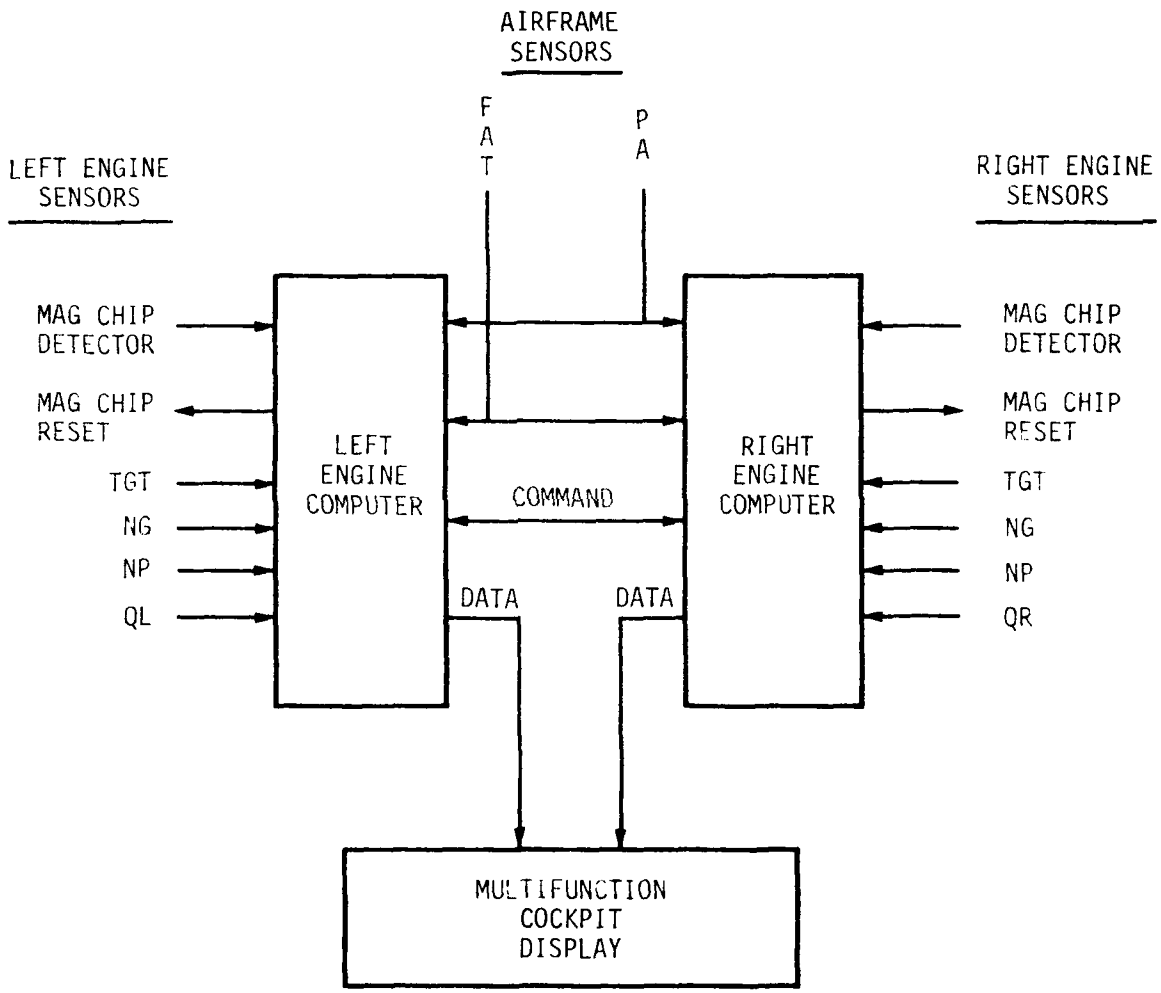


Figure 7. Diagnostic and Condition Monitoring System Configuration 1 - Engine Mounted Hardware.

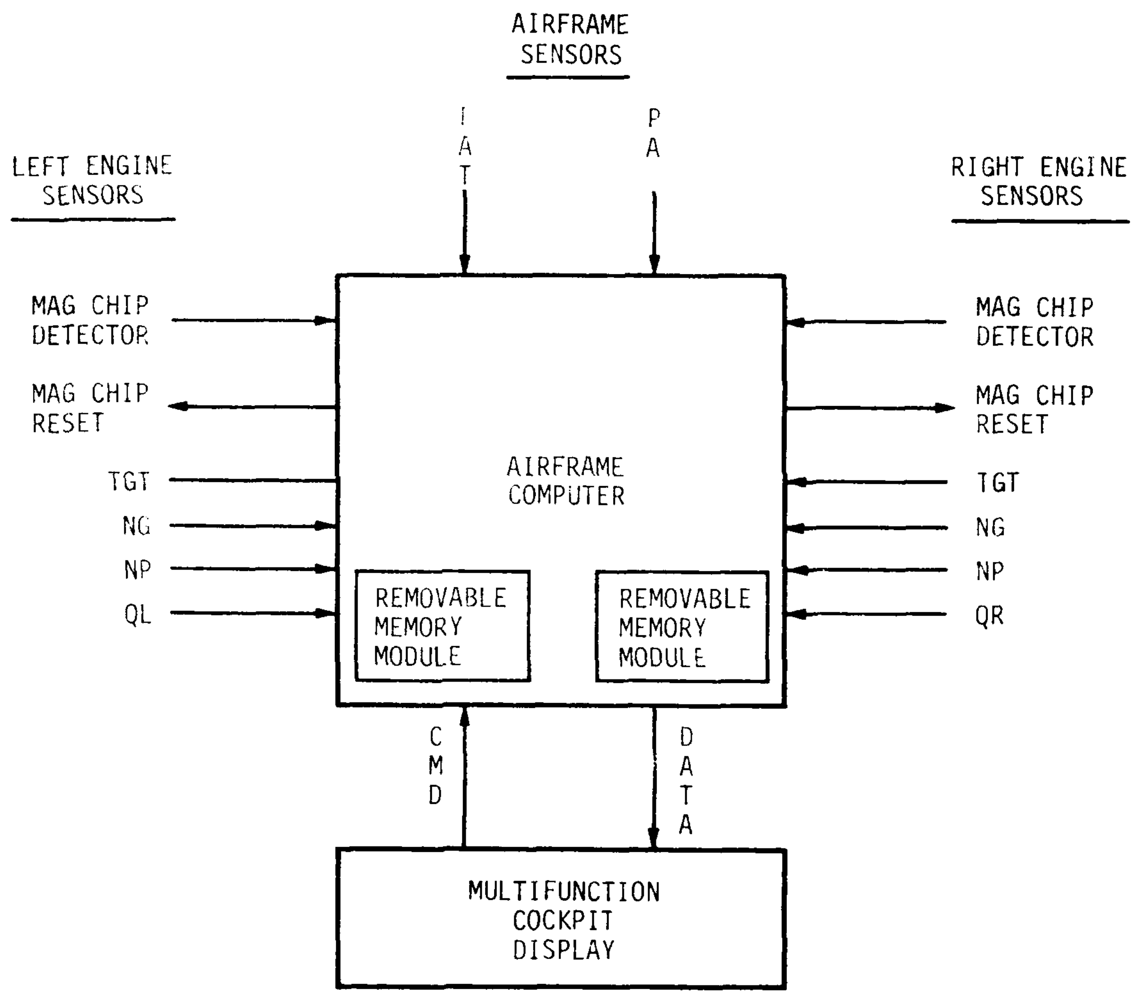


Figure 8. Diagnostic and Condition Monitoring System Configuration 2 - Airframe Mounted Hardware.

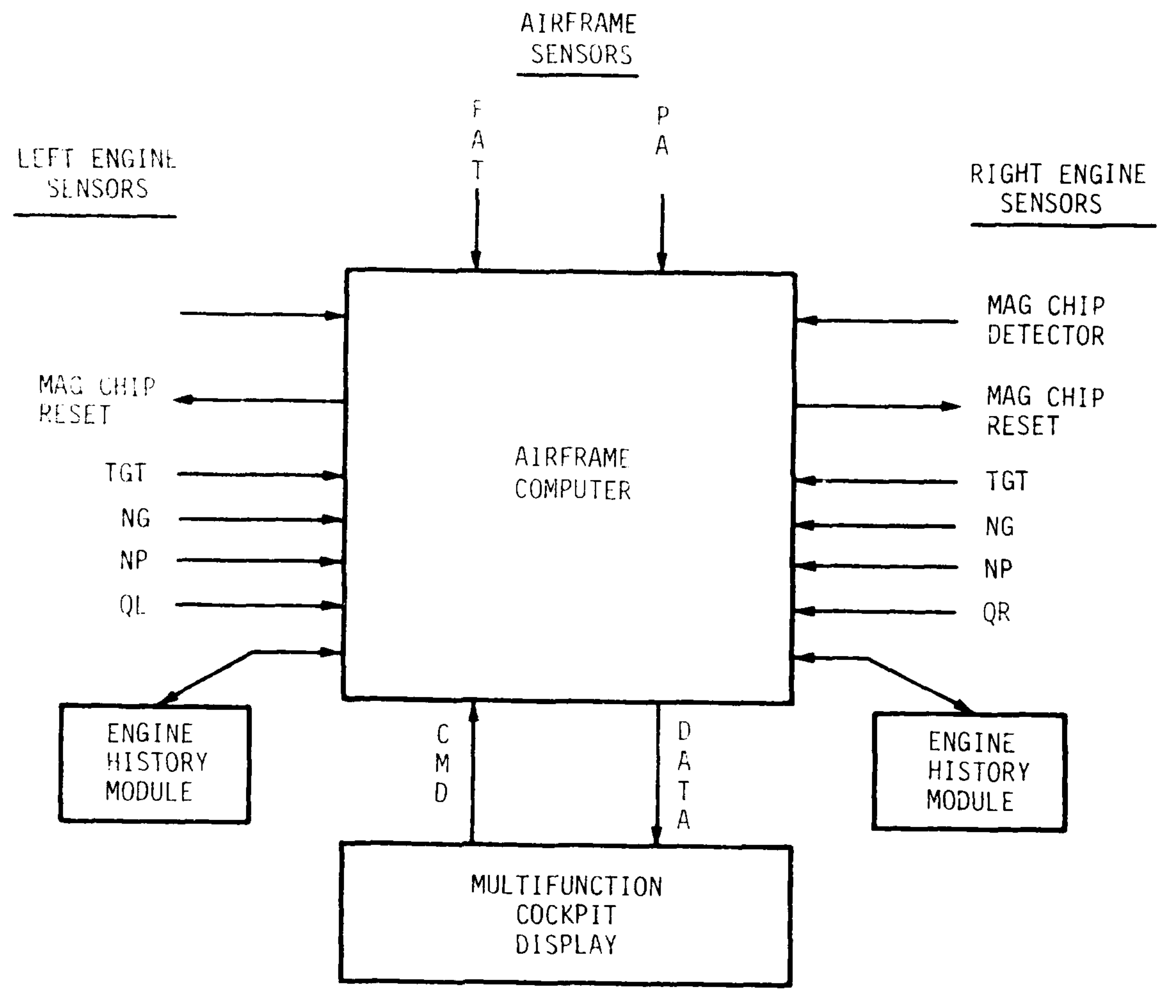


Figure 9. Diagnostic and Condition Monitoring System Configuration 3 - Airframe Computer, Engine Memory.

processing time and memory were available, most engine health and history data could be performed by the ECU. Because such controllers have not yet been implemented, this possibility will not be explored under this contract. At a later time, as digital ECU's begin to emerge, it should be re-evaluated.

Configuration 2 (Figure 8) has been selected as the most advantageous of the three systems. It features a single airframe-mounted avionics module and a small programmable cockpit display. This configuration results in the least costly hardware package and provides for the dynamic communication of flight safety, engine health, and engine history information to flight and ground crews.

Important submodules of the computer include removable memory elements, one for each engine. These contain a full description of each engine's usage profile and may be shipped with each engine as it is transported to or from intermediate or depot repair facilities.

A third configuration (Figure 9) was briefly considered and is similar to configuration 2, except that the engine-history memory modules are engine-mounted. The singular advantage of this approach is that engine history data is hard-mounted to the engine and is unlikely to be lost when the engine is transported. Acquisition and installation costs of such a system are greater than that of configuration 2 and reliability is lower. An important assumption of this study is that airframe-mounted history modules can be transported with the engine with the same degree of security as manually recorded records are presently.

Description

The balance of this section of Task II describes configuration 2 in detail. This system is composed of the three primary elements covered in the following paragraphs.

Engine-Airframe Sensor: Current engine and airframe sensors are generally satisfactory for effective engine monitoring, however, a free air temperature (FAT) signal must be provided. There are two opportunities for sensor cost savings: the chrome-alumel turbine gas temperature (TGT) signal is now compensated for cold junction effects within the engine's electronic control unit. If this buffered signal is transmitted to the D&CM system, rather than the unbuffered chrome-alumel signal, then the need for duplicate cold junction compensation circuits is eliminated. Additionally, a significant cost saving can be achieved by avoiding the use of a dedicated pressure transducer within the D&CM computer and extracting pressure altitude data instead from the altimeter-transponder interface.

The Task I portion of this study indicated that numerous UH-60A operations were interrupted by false or misleading signals from the magnetic chip detector. This report specifically recommends that the present blind chip detector be replaced with a discriminating detector. The ideal device will sense the presence of each chip as it circulates through the oil path and subsequently capture it for on-the-ground analysis. Interfacing this type of detector through a computer to a cockpit display presents a unique opportunity to provide truly reliable, quantitative assessments of engine bearing condition. The display possibilities are discussed in a later section of this report.

Computer Functional Requirements: Primary computer functions include the conditioning, multiplexing, conversion and smoothing of input data, the storage of this data in appropriate files, the processing of data via appropriate algorithms, the transfer of data to the cockpit display, and finally, the storage of historical information in nonvolatile memory. Ancillary functions include self-calibration and self-test.

This computer is the basis of the recommended D&CM system. A small, low-cost, airborne processor dedicated to engine history measurements and health indicator test (HIT) check calculations. Because these tasks utilize only a small fraction of the computer's processing power, it is important to consider other functions that might be performed at a very modest increase in recurring system costs. In addition to the specialized engine monitoring functions addressed here, a generalized monitor might examine these subsystems as well:

1. Hydraulic
2. Fuel
3. Rotor
4. Electrical
5. Transmission
6. Stabilization Augmentation
7. Speed Trim.

A number of helicopter performance capabilities can also be calculated and displayed, providing fast access to an electronic, on-board operator's manual. Although these require effective weight and true-airspeed transducers, it seems likely that sensors of this type, acceptable to the Army, will emerge in the coming years. Examples of the local and remote site parameters that might be computed by the hardware described in this report include, for normal and for engine-out conditions:

1. Hover Out-of-Ground Effect Weight Margin.
2. Hover In-Ground Effect Weight Margin.

3. Hover In-Ground Effect Power Margin.
4. Power Available.
5. Vertical Climb.
6. Best Airspeed Climb.
7. Obstacle Clearance.
8. Weight and Balance.
9. Hook Load.
10. Wind and True Air Speed (TAS).

Finally, the application of this computer to basic navigation calculations is both feasible and cost effective, and may increase aircraft utility under infrared radiation (IFR) conditions. Possibilities include the computation of fuel used, remaining, range remaining and multidimensional area navigation.

Computer Hardware Requirements: A detailed block diagram of a system which will meet the above goals is illustrated in Figure 10, while a potential package for avionics bay-mounting appears in Figure 11. Removable memory modules for use with this package are shown in Figure 12. This is only one of many configurations that could be effective; and as the number of microprocessors, data acquisition and memory elements proliferate rapidly, no attempt is made here to identify individual components. It does seem likely that the D&CM system, when implemented, will incorporate twelve-bit analog-to-digital conversion, one (or possibly two) eight- or sixteen-bit microprocessors, and a serial data link to the cockpit display.

Software Requirements

High level software functions of the D&CM system are described below:

1. Synchronous Software: The synchronous software modules are timer-driven and perform the executive and task oriented D&CM functions. These include the acquisition, smoothing and conversion of raw data, self-calibration, display updating and refreshing plus D&CM status monitoring and fault isolation.

2. Data Base: A major portion of the D&CM software consists of tables, conversion factors, set points and display formats. Of these, stored, alterable, data tables will require the greatest memory capacity. These tables include low-cycle fatigue, time-temperature integration, and power margin characterization.

3. Asynchronous Software: The interrupt-generated processes required for D&CM operation include calculations to derive and display crew-requested engine-airframe status, to compute and transfer to memory weighted fatigue cycles, and to annunciate time-temperature extremes plus magnetic chip anomalies.

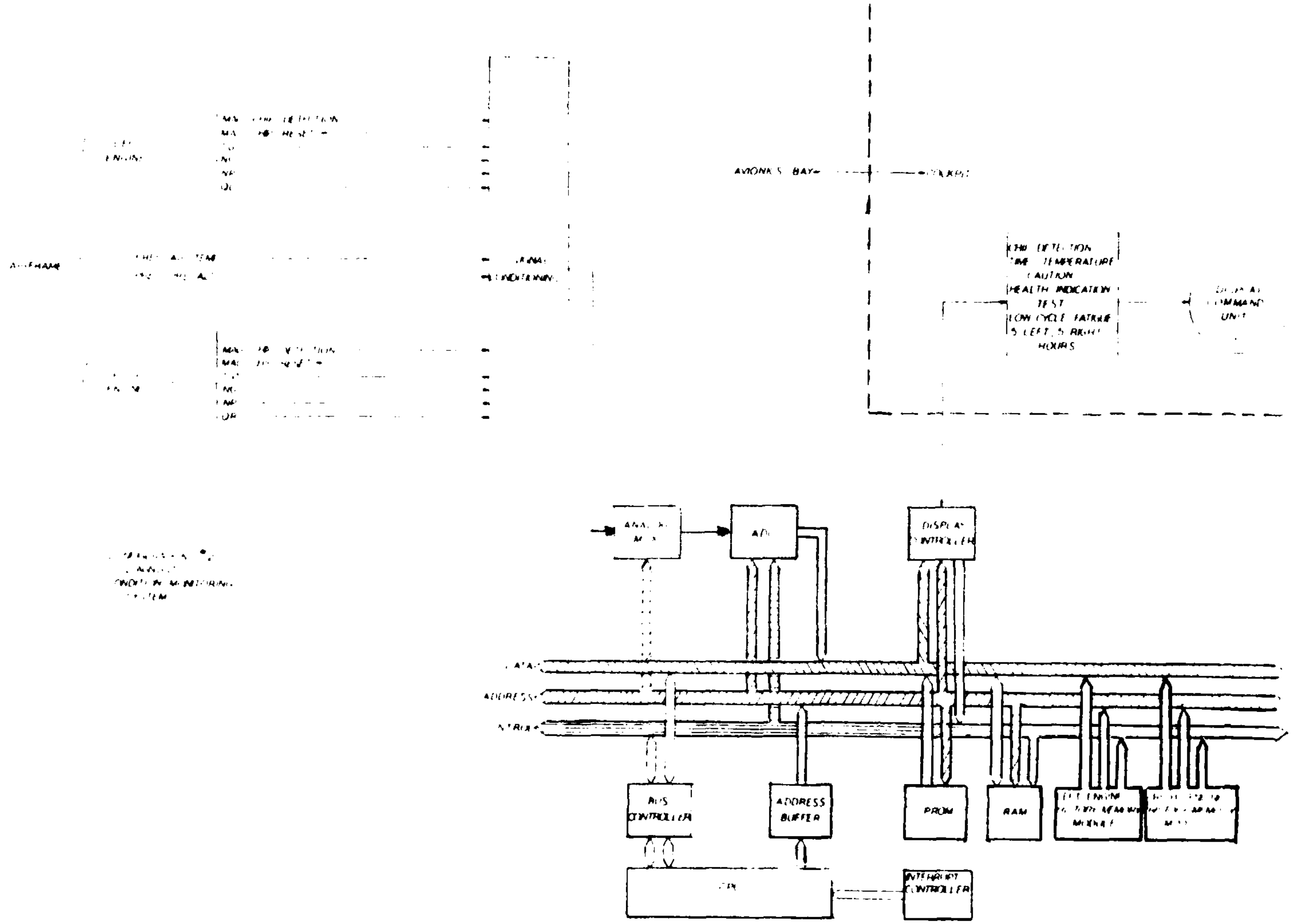


Figure 10. Multipurpose Airborne Diagnostic and Condition Monitoring (MADACM) System Block Diagram.

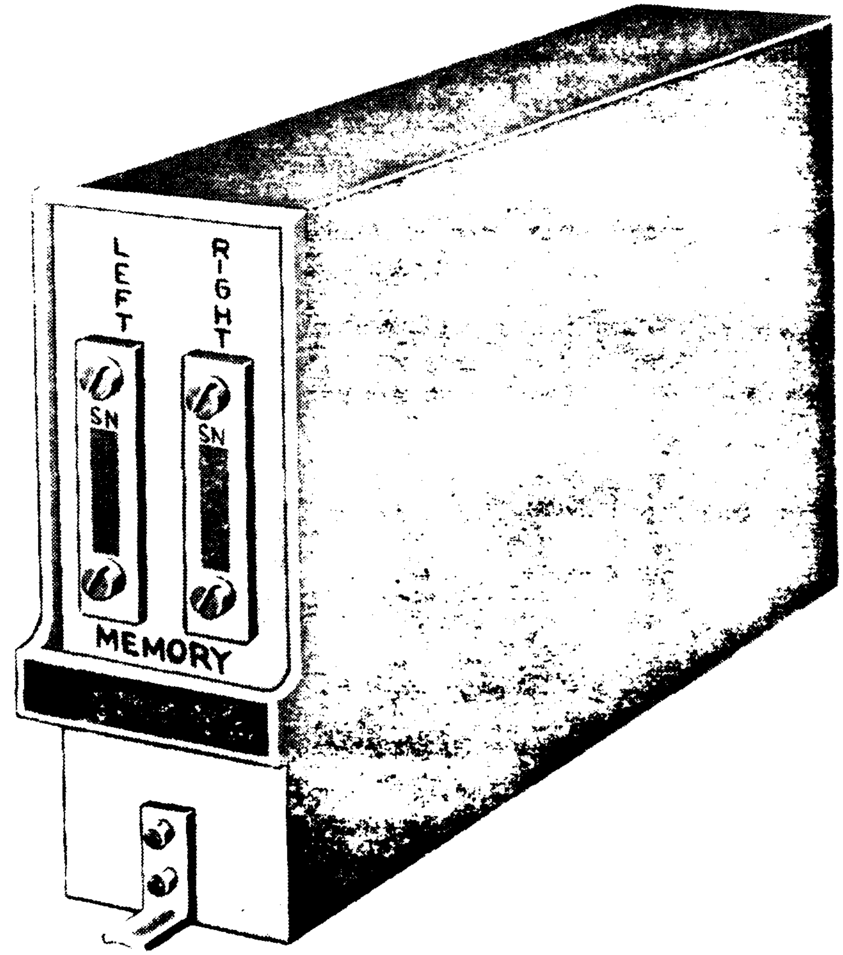


Figure 11. D&CM Electronic Airborne Module.

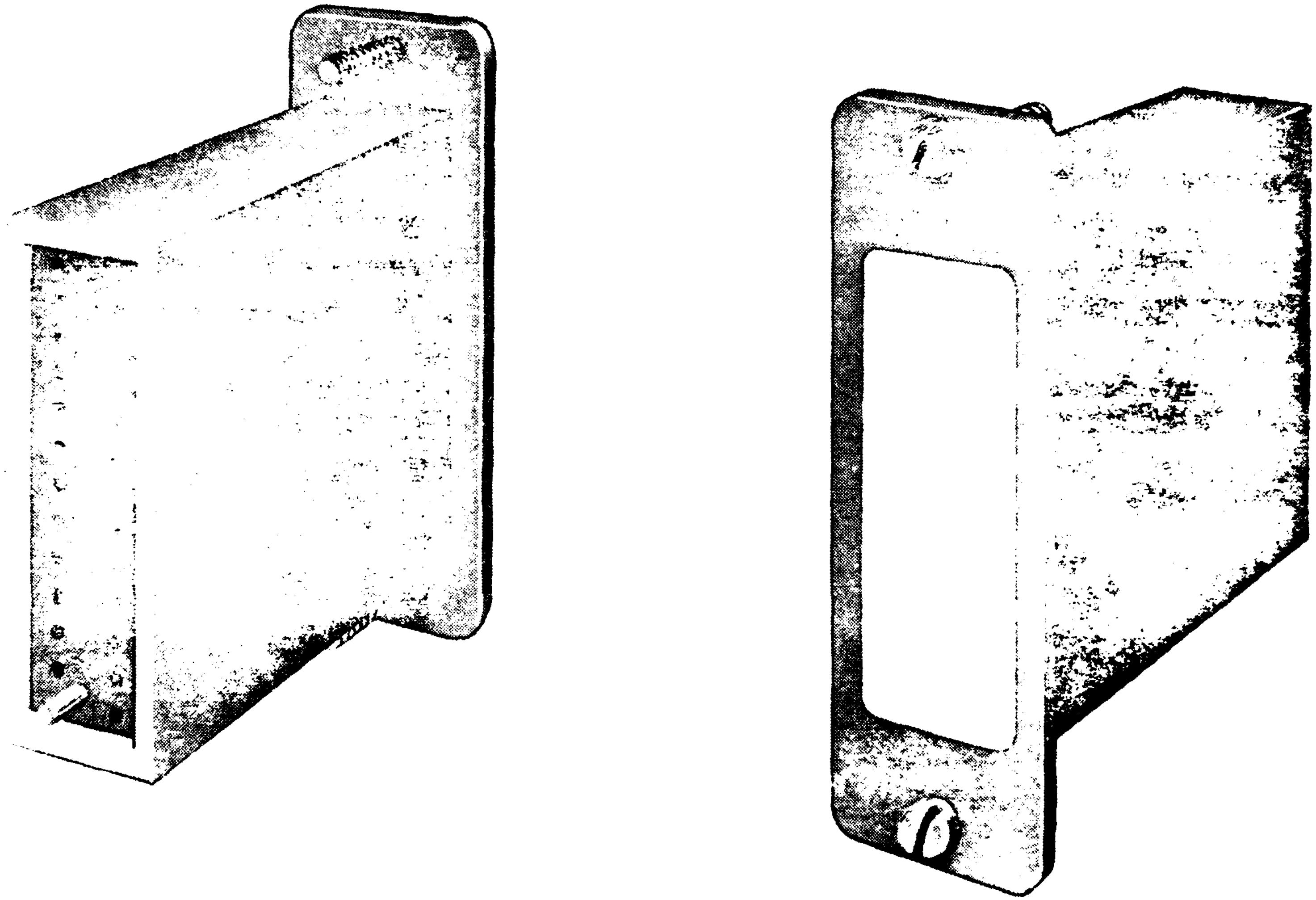


Figure 12. Removable Memory Module

Data Buses

Engine-side communications with the D&CM computer are expected to be similar to those that now exist in the present UH-60A, at least for the near term. The UH-60A data that is normally routed to the cockpit indicators would simply be extended to the computer.

On the cockpit-side a straightforward, low-speed serial data link is anticipated; however, the system is amendable to any communication protocol likely to emerge. Possibilities include 1553B, r-f frequency-division multiplexing and fiber optics. The latter seem likely only if a successful helmet mounted display can be developed.

Cockpit Display Systems

General Electric envisions marked advances in helicopter instrumentation and display media during the coming years. These advances will largely be driven by ever increasing nap-of-the-earth flight operations and the increasing complexity of helicopter subsystems. Particular risk areas include overtorque and over-temperature situations that arise during potentially hazardous flight conditions.

Four types of cockpit display are possible candidates for advanced helicopter applications. All are multifunction, computer driven devices which differ largely in the scope of data that might be displayed. The penetron color (cathode ray tube) is a likely candidate and the helmet mounted display, if it can gain pilot acceptance, is another. The use of audio advisories has received some acclaim from helicopter pilots interviewed by us and deserves further investigation. Each of these alternatives relate to the entire airframe as a system and to address them individually is beyond the scope of this report. A single, dedicated display is best used as an example of how an effective D&CM system might be used and serves as a baseline for the following discussion.

Due to space limitations and environmental conditions, any CRT display dedicated only to engine monitoring is not acceptable. Reasonable alternatives include gas plasma devices which have inherent problems under bright light conditions and liquid crystal displays. The latter have emerged as the best candidates for Boeing 767 engine monitoring and are recommended for dedicated military helicopter applications. An illustration of a cockpit display employing this media is shown in Figure 13. A detailed description of its operation follows:

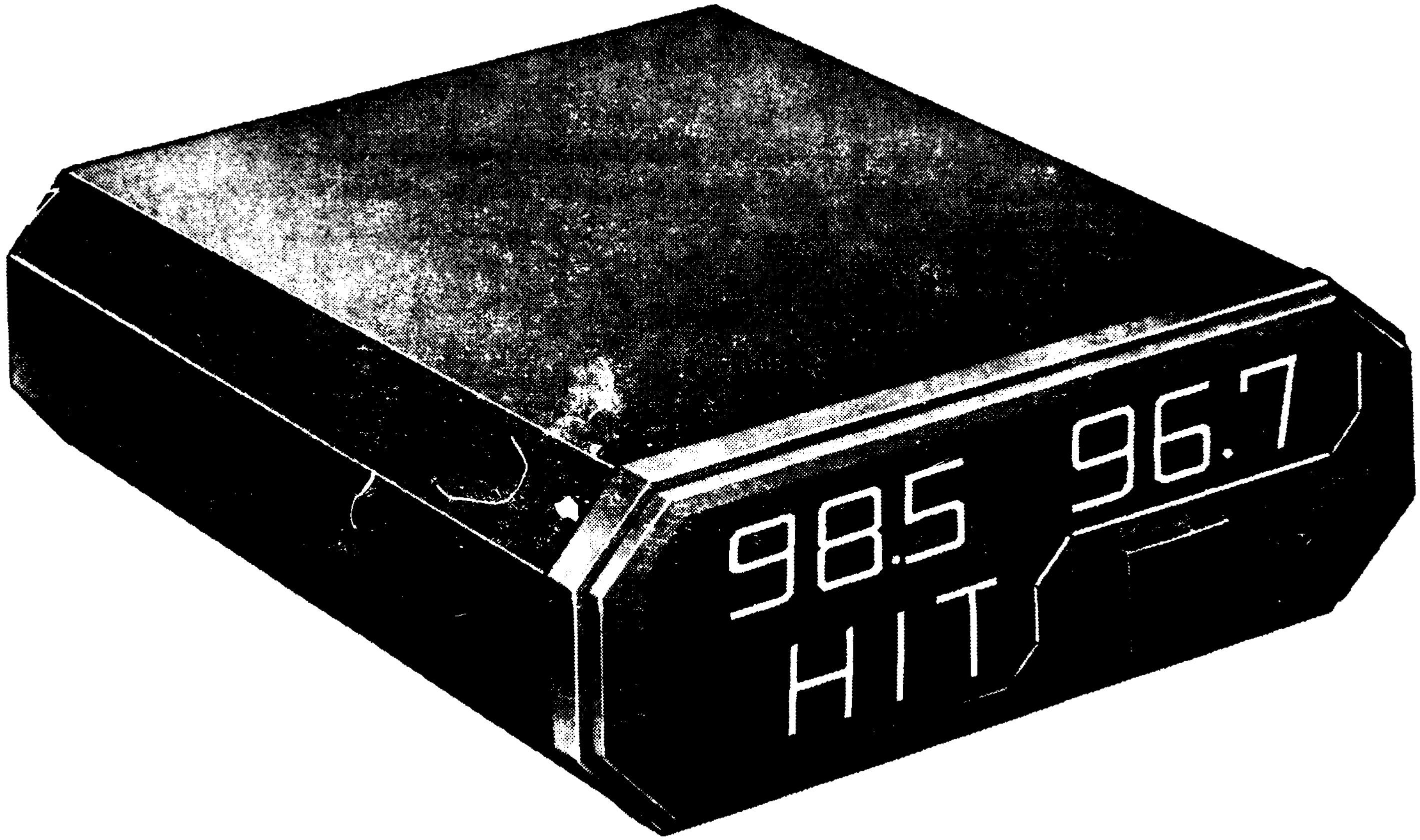


Figure 13. Cockpit Display Module.

System Operation

As noted earlier five parameters for each engine are continuously monitored as are two airframe signals. These are:

1. Magnetic Chip Detector
2. Turbine Gas Temperature
3. Gas Generator Speed
4. Power Turbine Speed
5. Torque
6. Free Air Temperature
7. Pressure Altitude

These signals are sequentially scanned each 250 milliseconds and the resultant data transferred to memory. Subsequently this data is processed and the results, tabulated below, are also stored:

1.	Health Indication Test	- HIT
2.	Magnetic Chip Tally	- CHIPS
3.	Power Margin	- PM
4.	Low-Cycle Fatigue	- LCF
5.	Time at Temperature Index	- TTI
6.	Engine Hours	- HRS

Three of these parameters, power margin and health indication (automatic performance monitor), and chip tally (discriminating chip detector) are of primary interest to the flight crew, while low-cycle fatigue, time at temperature index, and engine hours would normally be accessed only by the ground crew.

Figure 14 illustrates possible data formats that might be accessed from memory via the cockpit display. After power turn-on the D&CM system is active but the display is blank. Sequentially depressing the square switch in the lower, right-hand corner of the indicator produces the following data outputs:

BLANK
HIT
CHIPS
PM
BLANK
HIT
.
.
.

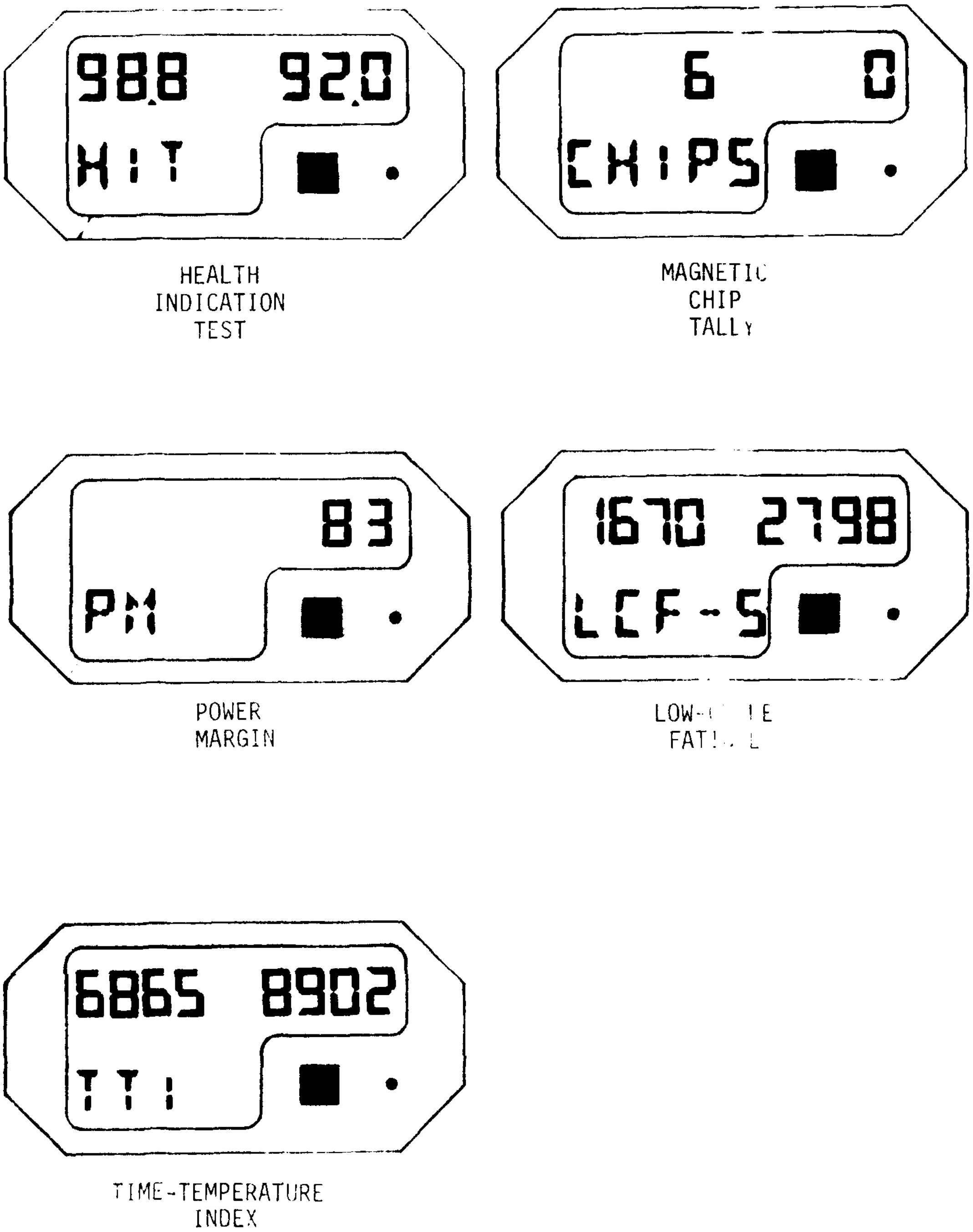


Figure 14. Typical Cockpit Readout - MADACM Display Module.

The interpretation of each of these displays is discussed in the following paragraphs.

To the right of the square pushbutton is a smaller round switch mounted nearly flush with the panel. This would normally be used by ground crew personnel to sequentially access the following data:

BLANK
LCF-1
LCF-2
LCF-3
LCF-4
LCF-5
TTI
HRS
BLANK
LCF-1
.
.
.
.

In addition to the manual selection of data, an automatic call-up feature is also recommended. As one example, chip warning would flash on the display regardless of what information was being normally displayed. A summary of each functional output is described in the following paragraphs.

Health Indication Test (Automatic Performance Monitor): As shown in Figure 14(A) this mode of operation is identified by the letters HIT and two three-digit numbers which represent engine power degradation from an as-new or as-installed baseline. In computing these numbers measured torque is corrected for standard day conditions and compared with the original torque associated with the corresponding turbine gas temperatures. These computations are valid only when the engine has stabilized at a particular operating point. As a result the percent degradation that is displayed is a measure of engine health at the last point in time when the engine was determined (by the processor) to be in a steady state condition.

There are several methods of loading baseline data into the processor. The first is to design in a fixed baseline that is representative of all engines. This method is not favored due to the known variances between similar engines.

A second method is to trim the processor via thumbwheel switches when the engine is installed so as to display 100 percent power (or 0 percent degradation).

Finally, a third method is to switch the processor into a baseline data mode and run the engine through its torque range to acquire the baseline data.

A combination of the first and third methods is preferred, using a designed-in power performance limit augmented by measured, as-installed torque.

Magnetic Chip Tally (Degaussing Discriminating Chip Detector): Task I of this study noted that the false alarm rate for UH-60A aircraft was inordinately high. The degaussing discriminating chip sensor described at the end of this section partly alleviates this problem and in conjunction with the proposed display should virtually eliminate false alarms.

The recommended system maintains a tally of the number of chips detected during the past hour of engine operation and can be displayed by the crew if desired. Should the number of chips detected during the past hour exceed a preset level, this information would flash on the display. At power shutdown the tally would be stored in nonvolatile memory and subsequently referenced during the next hour of operation.

Power Margin (Automatic Performance Monitor): Power margin is easily computed from D&CM system inputs and is included here as a cost-free benefit. As used here power margin is a measure of the surplus or deficit of power necessary to transition out of ground effect under no-wind conditions.

Available power is easily computed from health indication data, and gross weight is calculated while hovering in ground effect. One method of indicating this flight condition is to pull the square sequencing switch on the cockpit indicator.

Although not specifically addressed here, the usefulness of the power margin display could be enhanced by an additional airframe input, true air speed. This possibility should be evaluated if future aircraft are equipped with such sensors.

Low Cycle Fatigue (Engine Life Usage Monitor): Five low cycle fatigue tallies are maintained for each engine and can be accessed in two ways. The data can be directly read from the cockpit display or, alternately, the memory module that holds the data can be physically removed. The latter feature is desirable if an engine is removed from an aircraft for shipment to intermediate or depot facilities.

Time at Temperature Index (TTI) (Overtemperature Monitor): Similarly, a tally of time-temperature index counts is maintained for each engine. The information is accessed in the same fashion as low-cycle fatigue data and share the same memory modules.

This is the one maintenance parameter that should be flashed to the cockpit: first, if TTI counts exceed a predetermined total and second, if the TTI total is being incremented above a certain rate.

Engine Hours (Engine Life Usage Monitor): Engine hours are read in the same fashion as LCF and TTI data and are stored in the same memory modules.

Ground Support Equipment

Although the airborne portion of the D&CM system is self-supporting at the unit level, there is a need at intermediate and depot facilities to read memory modules that have been returned with engines and to program modules that are being returned to the field with repaired engines. The associated ground support equipment is expected to closely resemble the airborne system except that the hardware will be packaged as a single unit for ground use and that a small keyboard will be added for data entry.

Systems Parameters

The following parameters are forecast for the Diagnostic and Condition Monitoring System:

	Airborne Computer	Display Module	Total System
Dimensions (H x W x D) - in.	7 x 2 x 8	1-1/2 x 3-1/8 x 4-1/2	--
Volume - cu in.	112	21	--
Weight - pounds	6.0	0.7	--
Power - Watts	--	--	10
MTBF - hours	--	--	9000
MTTR - hours	--	--	--
Unit	--	--	0.3
Depot	--	--	4.0

DEGAUSSING DISCRIMINATING CHIP DETECTOR

Background

The Task I findings reported at Ft. Eustis in the December 5, 1979 presentation and documented in D&CM Report 7, January 1980 clearly showed the major cause of UH-60A engine-caused mission aborts to be chip detector nuisance signals. The need for a means to reduce or eliminate these events while retaining the capability of the master chip detector to warn of impending oil-wetted part failures was evident. Engineering investigations performed two years ago concluded that the degaussing type detector concept had the best probability of success for the T700 engine. This conclusion still prevails. At that time, a CIP program was initiated to select a vendor and recommend a hardware development program. Funding priorities caused the program to be terminated before the proposal evaluation was made. If justified by LCC analysis, the recommendation would be made to reactivate the program.

General Description

The degaussing type discriminating or "smart" chip detector concept is a design to capture, count, release, and then save magnetic debris. For the T700 engine used in the Black Hawk it is assumed that a single capture and release event in one flight or in one or more hours of engine operation would be considered a random or nuisance event requiring a visual chip detector inspection but not causing a mission abort. Three or more chip signals, however, in one flight or one hour of operation would trigger a fault signal indicating a possible failure in process and requiring a power reduction and possibly a precautionary landing with the pilot making the final decision based on his assessment of the situation. This relatively simple concept can be an important tool for increasing Black Hawk mission effectiveness and availability.

Nuisance chip signals from the master chip detector are caused by the detection of benign magnetic debris in the engine's lube oil system. There are two main sources of this debris:

1.	Manufacturing debris	Machining curls and shavings Hair-like brazing slivers
2.	Benign wearmetal	"Normal" fuzz Labyrinth seal rubbings

Nuisance chip signals then result from either: (1) a single random chip or sliver that is captured by the magnetic chip detector that bridges the magnet gap; or (2) the slow accumulation of metallic fuzz (wearmetal) that in many hours may form a bridge across the magnetic gap (not likely in the T700 because of 3-micron filtration). A chip signal resulting from either the random sliver or the slow debris buildup will normally not occur more than once in any flight. By comparison, failure debris from a bearing or gear will be continually generated as the failure progresses. The present master chip detector cannot differentiate between a random event and the continuous debris generation situation and, therefore cannot discriminate between benign debris and failure debris. Nuisance chip signals are the greatest contributor to UH-60A engine caused aborts.

The following technical description is based on material from a vendor's brochure and is used with his permission as being representative of the type of hardware required to perform the degaussing function. The description also is based on a "stand-alone" system with a separate electronic signal processing module, whereas the D&CM approach is based on processing the chip detector signals in a microprocessor based box that performs several other functions. Both designs are practical.

Hardware Description

Magnetic Particle Sensor: The magnetic particle detector is a contact shorting, resetable design which employs a high energy samarium cobalt permanent magnet to produce the strong, high collection efficiency magnetic field needed to pull magnetic debris from the rapidly moving oil stream. Contact spacing is such that a magnetic particle 0.065 inches in maximum dimension will bridge the contacts and produce a partial short circuit.

The detector reset feature is a coil wound around the detector core. When energized with a current pulse of the correct polarity, the field produced by the permanent magnet is momentarily forced to zero. When this occurs, a captured particle is released and entrained in the oil stream. A second nonresetable calibration gap is contained within the detector and positioned downstream relative to the resetable gap so that particles will be permanently captured and not allowed to float free within the detector screened area.

Samarium cobalt permanent magnet material was selected for this detector application because of its unique ability to withstand a degaussing (opposite polarity magneto-motive force) field and spring back to its full magnetic strength once the degaussing field is removed.

The reset feature described above is unique because only a short current pulse of less than 1 amp and 15 seconds duration is required to release a captured particle. Energy consumption and dissipation is therefore very small compared to alternate approaches which use a continuously excited coil to produce the collection field. The pulse reset feature allows a higher continuous level of capture field than would be possible with a continuously excited electromagnet approach because the pulse reset coil can be driven to a much higher instantaneous degaussing current level without causing overheating. Further, the proposed approach is fail-safe since particles will always be collected across the permanent magnet field whereas the electromagnet approach would not collect particles if the excitation current line was shorted or open circuited.

Figure 15 shows the detector cross section. The unit has a three-wire electrical interface and has mechanical interface details identical to the nonresettable device currently used on the T700 engine.

Electronic Module: The electronic module senses when a particle has bridged the detector contacts, initiates the reset function, and turns on one of three one-hour countdown timer chips. An energized counter runs for the one hour period and automatically resets. If successive particles are collected such that all three counters are operating at once, a warning circuit is turned on and remains on until manually reset. No warning occurs if the first counter runs through its one-hour countdown cycle before the third counter is turned on.

Circuit components used in the electronics module are high reliability, off the shelf, low cost devices. For prototype flightworthy units, only one printed circuit board measuring 3 inches by 4 inches will be required because of the minimum of components involved. Circuitry is contained within a gasketed, drawn aluminum enclosure, as shown in Figure 16. A block diagram and circuit schematic for the electronic module are provided in Figures 17 and 18. Possible production configurations for the electronic module, containing electronics for two engines, are shown in Figure 19.

System Operation

The magnetic debris detection system is an engine condition monitoring aid for determining the health of oil-wetted parts in the T700 engine. The system is a two-component configuration consisting of a detector which mounts into an existing cavity in the accessory gearbox of the T700 engine and an electronic module which is mounted at some remote location in the airframe (see Figure 20).

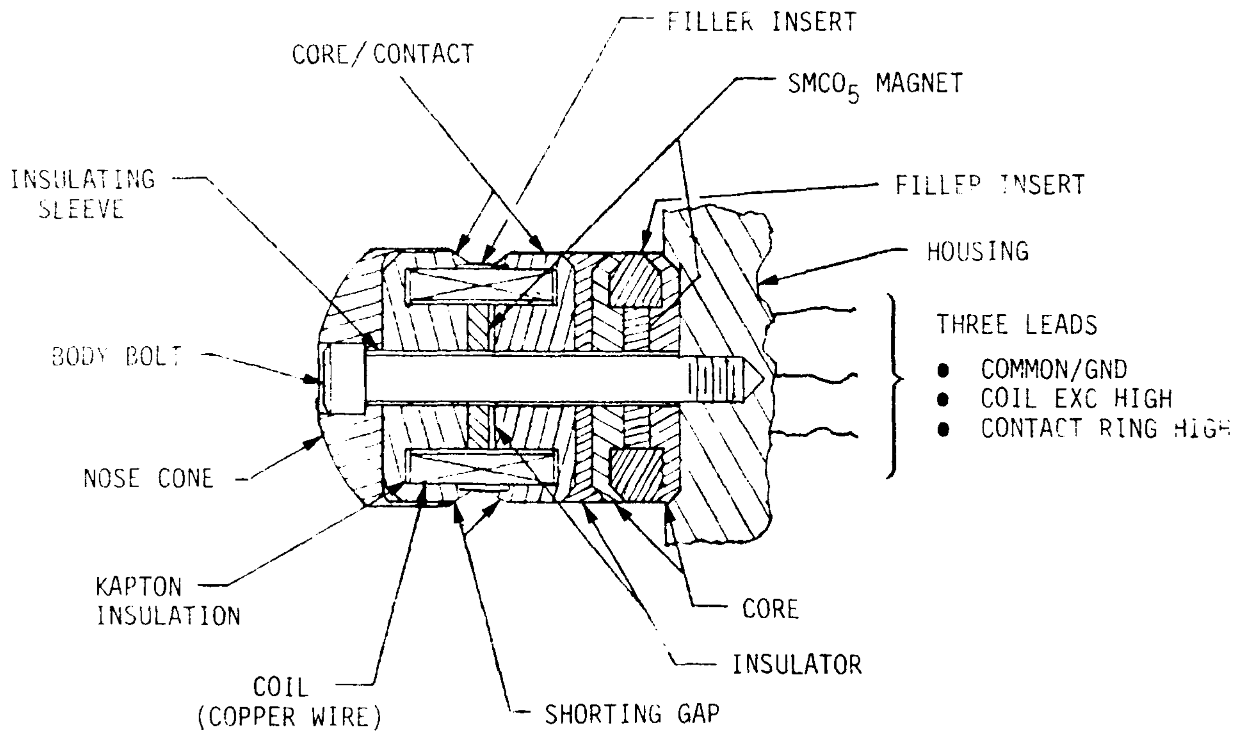


Figure 15. Magnetic Particle Detector Assembly.

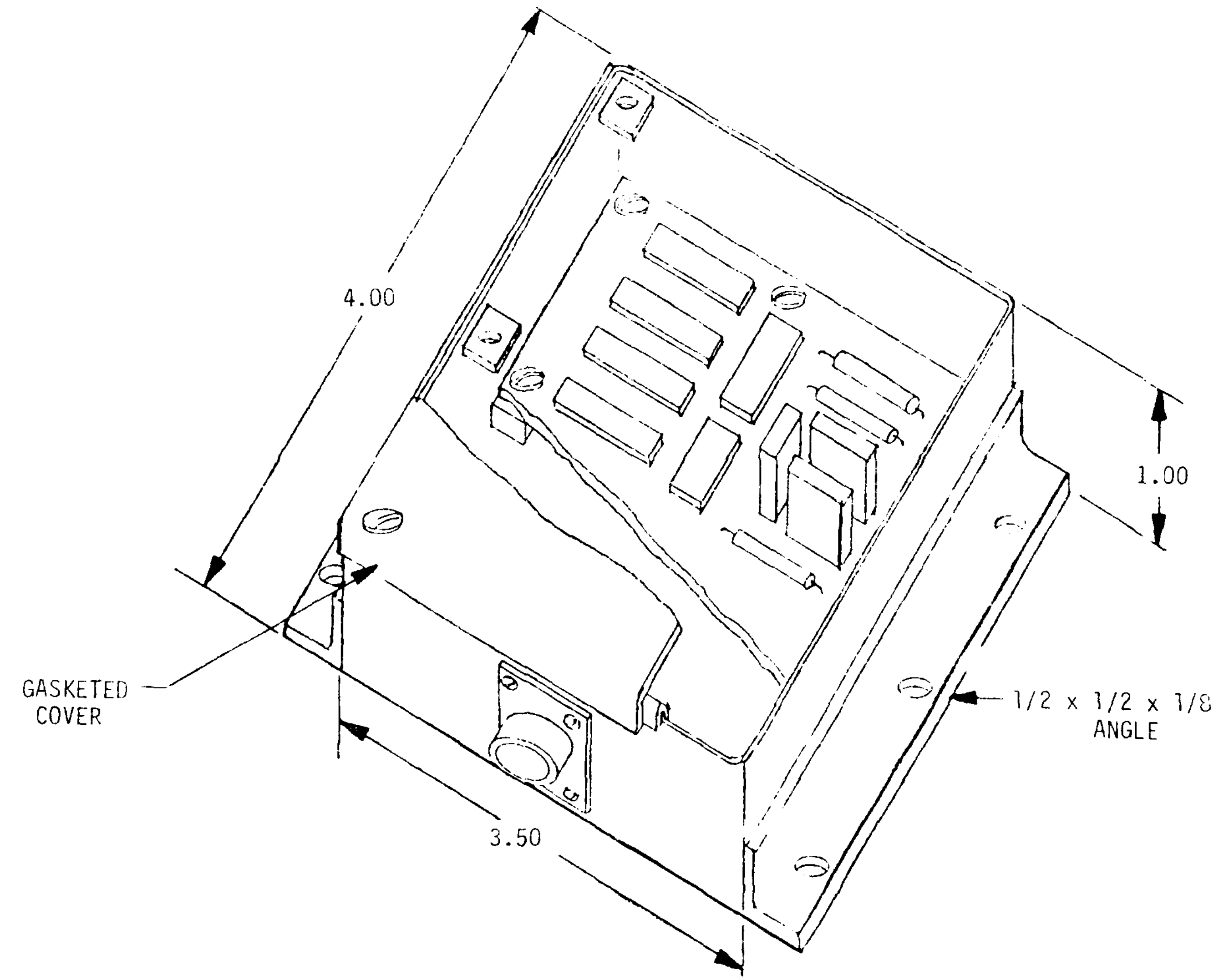


Figure 16. Electronic Module Packaging Concept - Prototype.

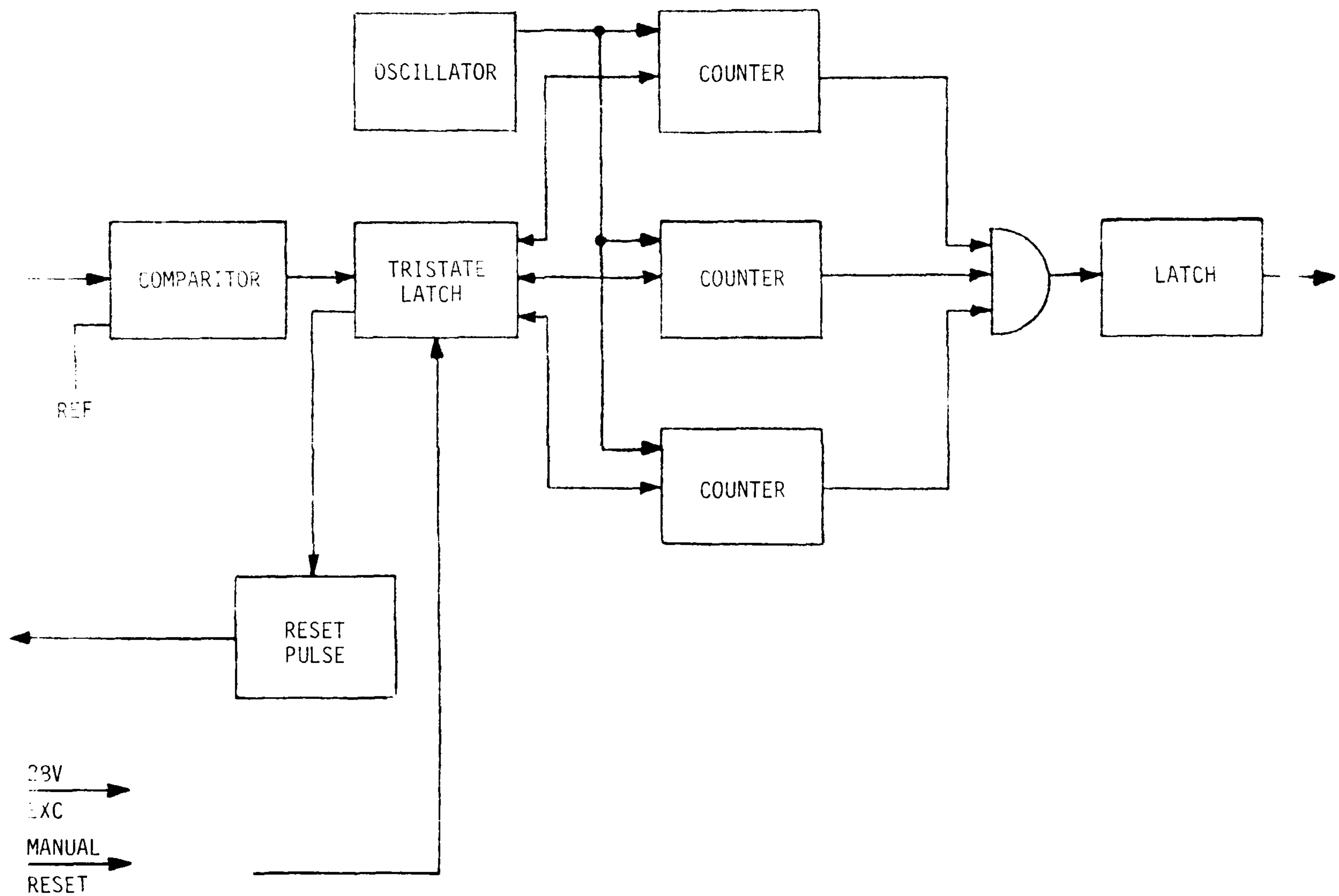


Figure 17. Electronic Module for Lube Oil Magnetic Particle Detection System - Block Diagram.

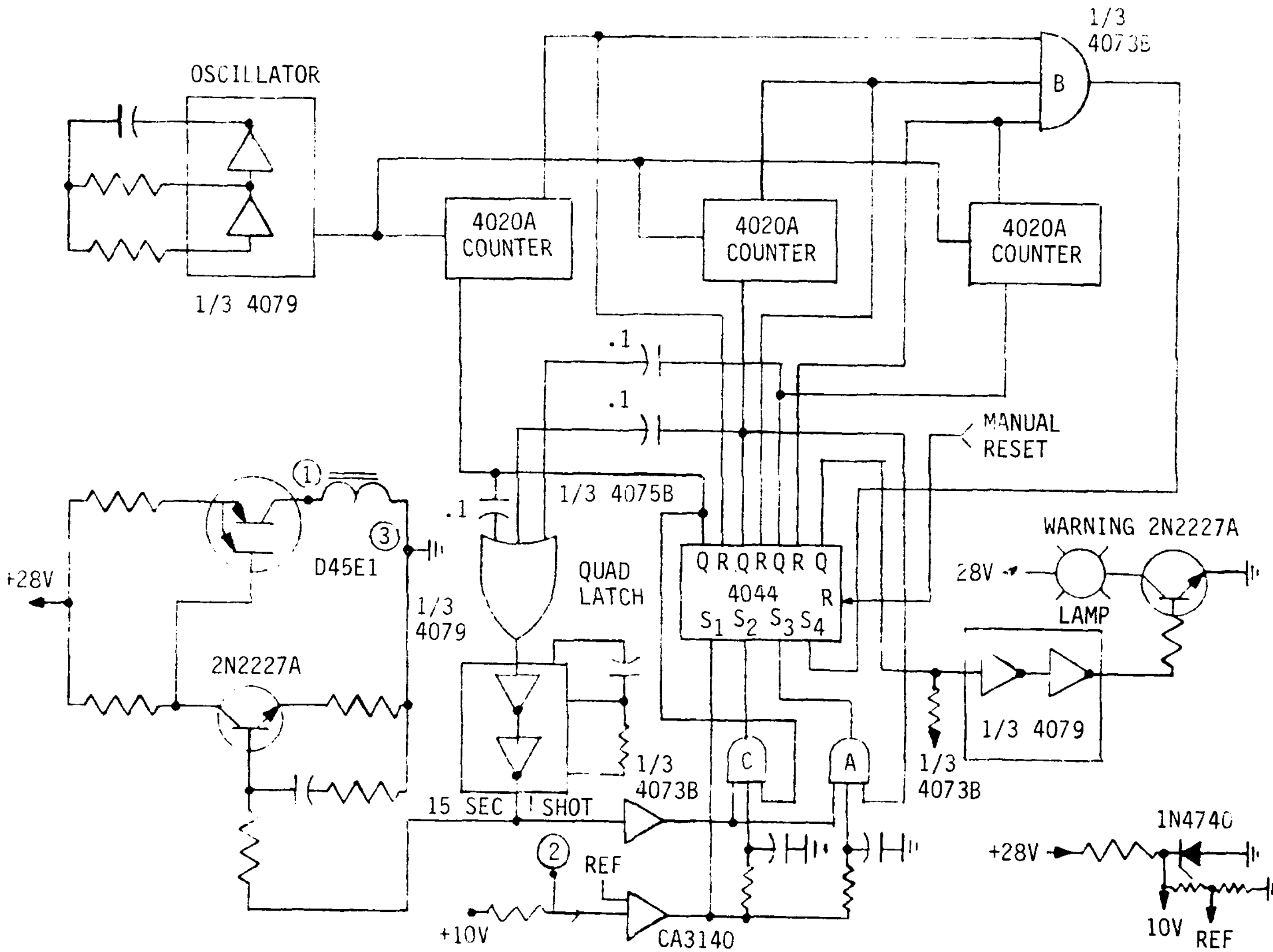


Figure 18. Electronic Module Schematic.

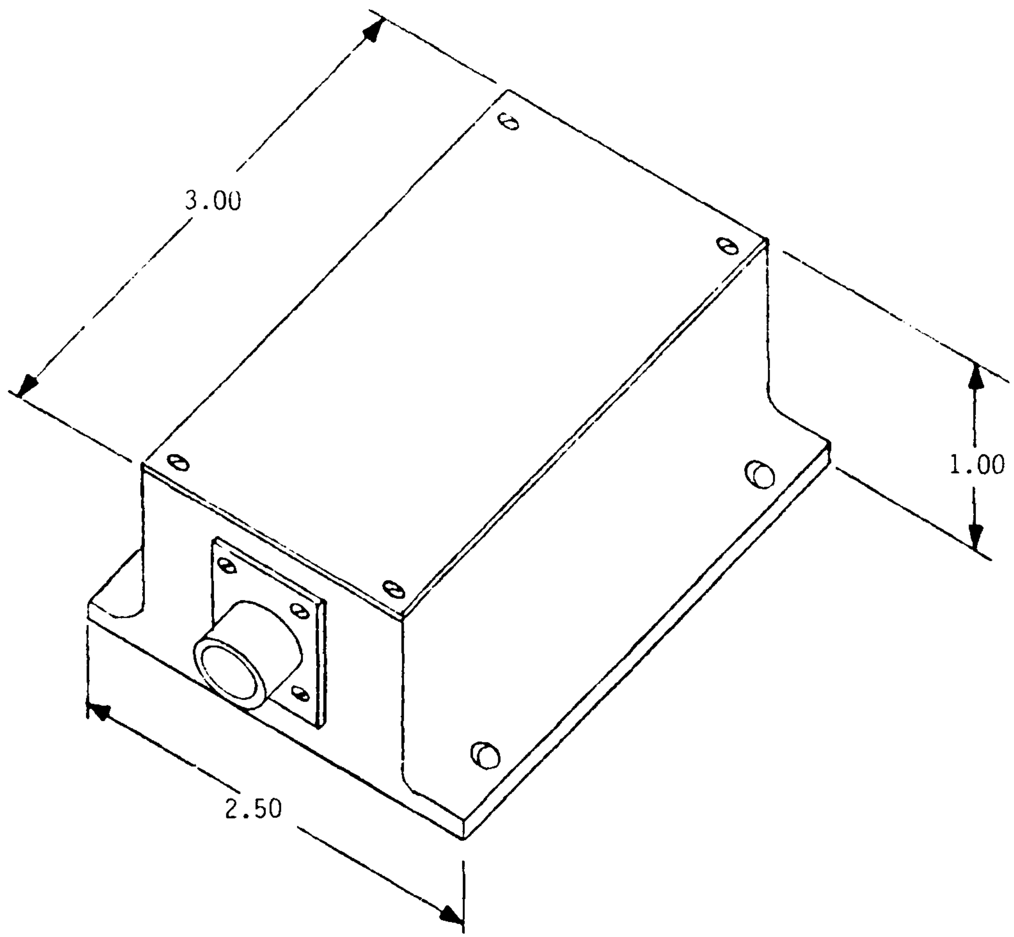


Figure 19. Electronic Module Production Package - Configuration 1.

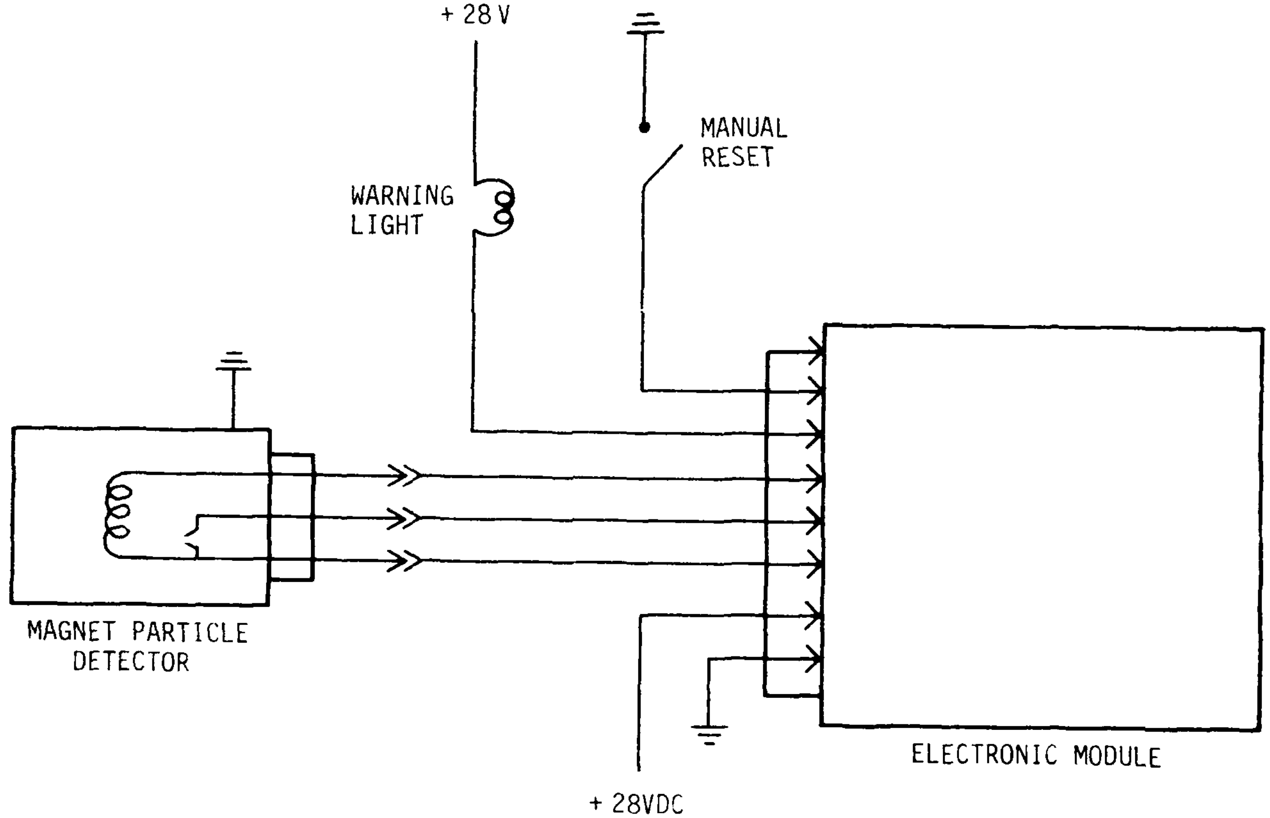


Figure 20. Magnetic Particle Detection System Electrical Interface Diagram.

Magnetic particles carried by the engine lubrication stream are collected by a strong permanent magnet field in the detector. Electrically isolated circumferential contacts are configured as part of the magnetic circuit as shown in Figure 15. Because the highest gradient magnetic field area is arranged to be directly across the contacts, magnetic particles that enter the field are pulled out of the oil stream and collect across the gap. Debris of sufficient size will bridge the contact gap and yield a partial short circuit.

The partial shorting condition is sensed by a comparator circuit in the electronics module. Other circuitry in turn initiates detector reset (particle release) and energizes one of three, one-hour countdown timers. A warning signal in the form of a solid state switch closure is established if the collection rate for a specific size range of debris is three particles per hour or greater. Warning switch closure can be used to turn on a remote master warning lamp and the system remains in the warning mode until reset manually by a push button or other switch closure means.

The detector reset feature is an important part of the proposed system. Reset is accomplished by energizing a coil in the detector with a current pulse. When energized, the coil produces a magnetomotive force in direct opposition to the permanent magnet field, forcing the field momentarily to zero. At zero field, any particles collected across the contact area are released, entrained by the oil stream and then recaptured by a second nonresettable permanent magnet field, as shown in Figure 15. Detector reset does require a moderately flowing oil stream past the collection gap to carry released particles down stream. A released particle is otherwise immediately recaptured under static oil conditions and this must be avoided. A system 28 V dc excitation lockout will, therefore, be required for engine OFF or subidle situations.

Operation of the resettable magnetic circuit can best be described by referring to Figure 21. The solid arrows shown in View A of Figure 21 are representative of magnetic flux produced by the thin cylindrical samarium cobalt permanent magnet located at the center of the core. This material has extremely high energy compared to Alnico 5 (see B-H curve comparison in View B of Figure 21). For an operating load line of 0.8, the samarium cobalt magnet generates flux densities higher than 8000 gauss whereas a conventional magnet would produce below 500 gauss. Samarium cobalt also has a unique characteristic associated with its intrinsic B-H curve. Basically, because of its intrinsic properties, the material can be subjected to a demagnetization force (dashed lines in View A of Figure 21) that drives the magnet field to zero without loss of original magnetic strength once the degaussing

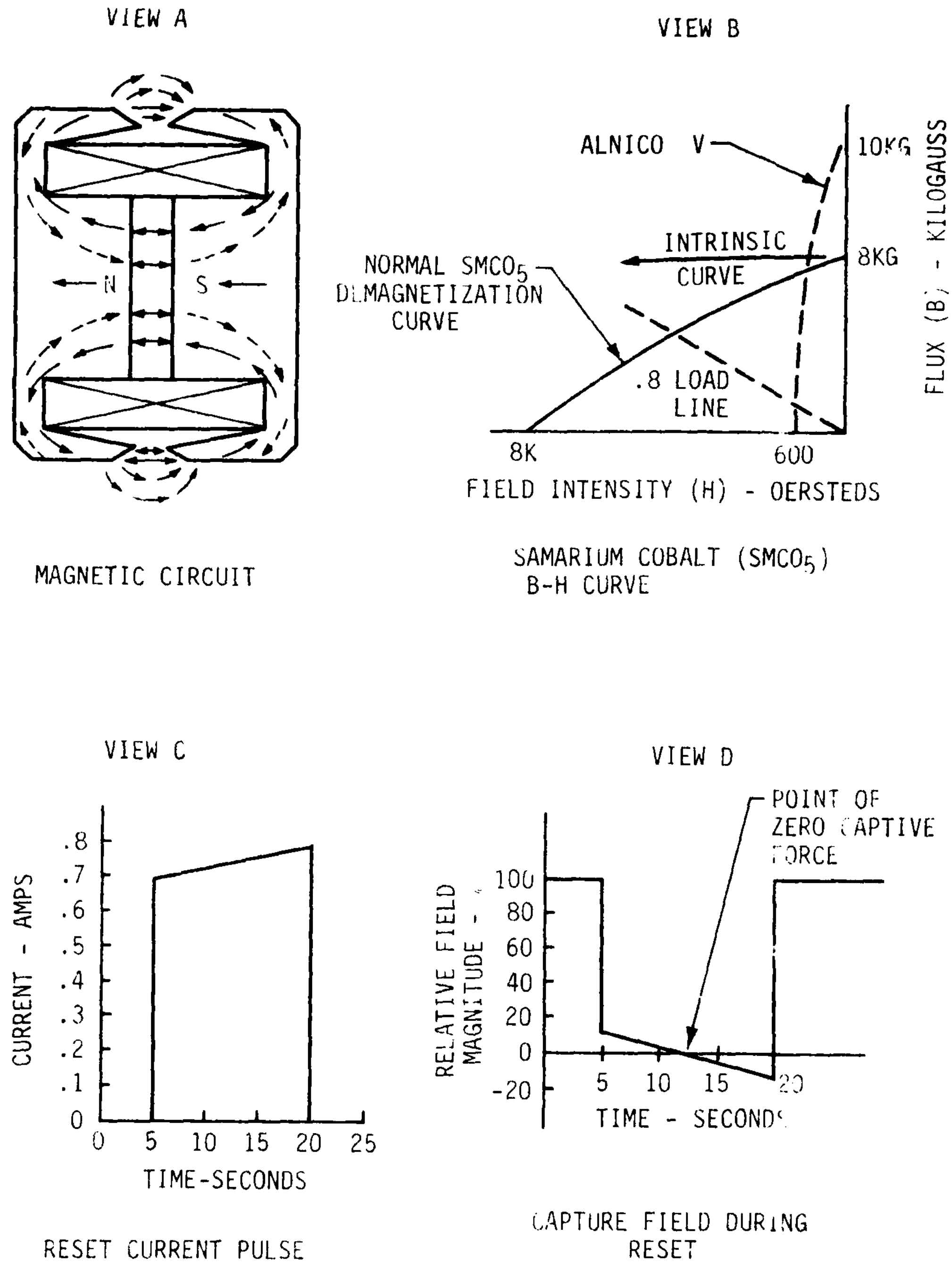


Figure 21. Magnetic Particle Detector.

field has been removed. This spring back feature makes the proposed degaussing approach possible. Alnico 5, on the other hand, would be completely dead or even reverse polarized if subjected to similar treatment.

Software

No software is required for the electronic module.

TASK III - LIFE CYCLE COST (LCC) ASSESSMENT

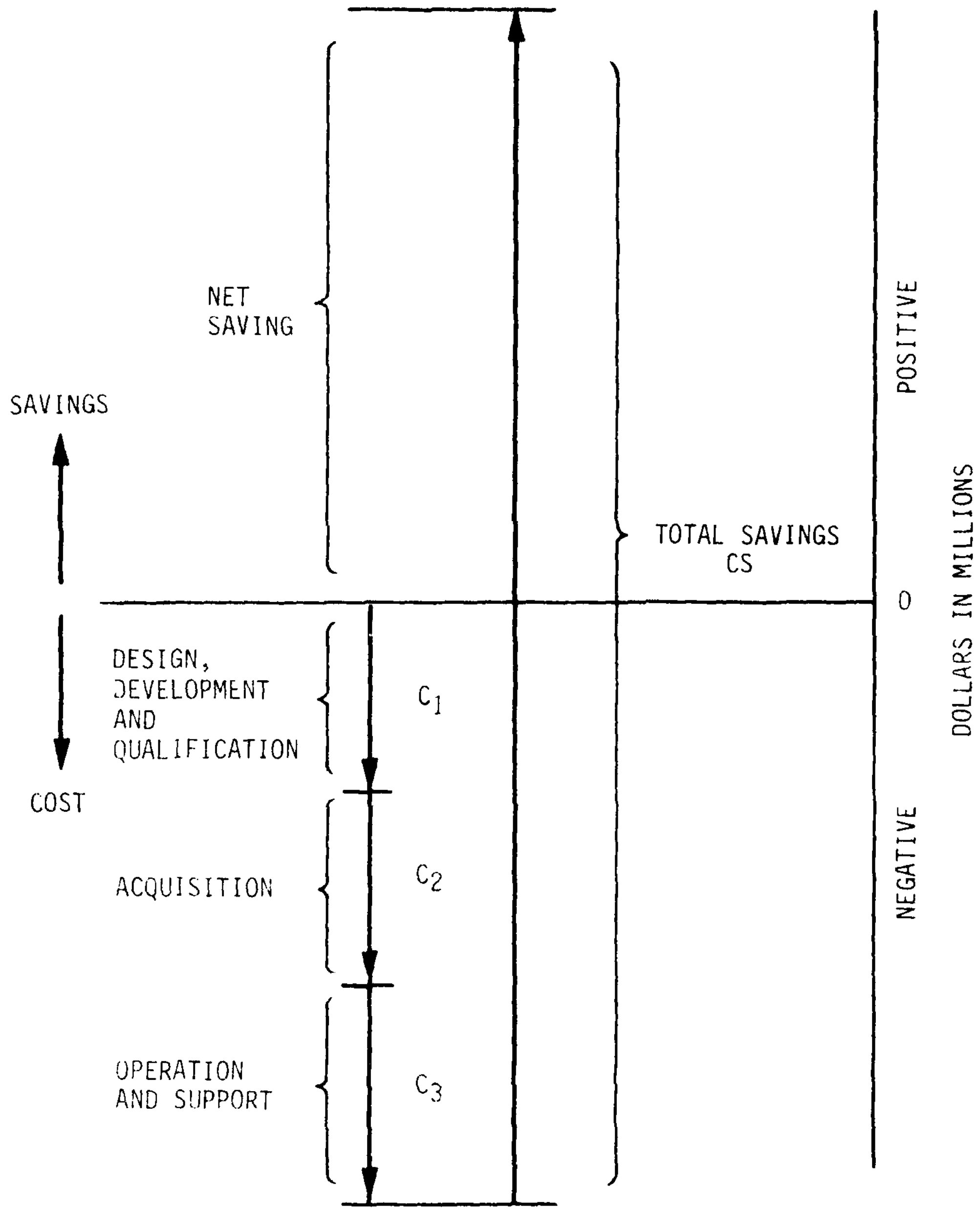
INTRODUCTION

Life cycle cost (LCC) analysis is a valuable technical discipline that leads the investigator to consider and quantify as many cost and savings factors as possible in evaluating two or more alternative designs or courses of action. The D&CM assessment reported herein includes seven LCC analyses that, in each case, estimate the added costs of candidate D&CM equipment and procedures and the added maintenance savings and other benefits the candidate systems are estimated to produce. From these estimates, a judgment is then made as to whether the projected savings are sufficient to justify the added costs. These LCC costs normally include nonrecurring design and development costs, production acquisition costs, and operation and support costs.

The equivalent dollar value of the D&CM system contributions to Black Hawk operational readiness has not been assessed in this LCC analysis. For this reason, the LCC results may not accurately reflect the true value of D&CM improvements to the Army. For example, a D&CM system that saves four hours of labor for two AVUM mechanics would show a labor saving of eight manhours at $37.00/hour or $296.00 plus whatever saving in engine operating costs and parts replacement costs are estimated. The cost, however, of making available another aircraft to replace the downed aircraft for that four-hour period may be many times the maintenance cost savings. The need for a method of assigning a dollar value to military aircraft availability, or conversely, the cost of unavailability has existed for several years.

On this and previous GE LCC analyses of diagnostic systems, an LCC evaluation ratio has been used as a measure of cost effectiveness. This ratio - CS/C - gross cost savings (CS) divided by LCC cost (C) - is defined graphically in Figure 22. Previous analyses of D&CM systems covering a 20-year projected program life have used a CS/C ratio of 3 or more as an arbitrary indicator of a cost effective system. Ratios below 1 would be a questionable investment unless there are overriding considerations which are not readily quantifiable such as aircraft availability and flight safety considerations. Ratios between 1 and 3 define a gray area in which judgment, based on experience and the assessment of the nonquantifiables involved determine the decision. In the following LCC analyses, a 10-year period was used rather than 20 years simply because the 20-year projection was not available. For a 10-year period 1.5/1 CS/C would appear to be representative of a cost effective system, with the CS/C of 1 to 1.5 being in the gray area.

LCC computer models are available for most GE engines including the T700 and are commonly used to evaluate engine design changes. Experience has shown, however, that LRU fault isolation is the only D&CM function for which the engine LCC computer models are useful. Therefore, only one LCC analysis was done using the T700 LCC model - the control system analyzer assessment, and with that analysis, some of the savings were [illegible] manually. All of the other analyses were formulated by the contractor [illegible] this study.



$$\frac{CS}{C} = \frac{CS}{C_1 + C_2 + C_3} = \text{COST SAVING/COST RATIO}$$

Figure 22. Life Cycle (Cost Savings)/(Cost) Ratio Definition.

D&CM LCC Assessment Basis

The following assumptions were used as the basis for D&CM LCC assessment:

1. 100 Army Black Hawk (UH-60A) Companies by 1990.
2. 6 METS Facilities.
3. 1 AVIM shop and 3 UH-60A Companies per Army Battalion.
4. 15 UH-60A aircraft per Company.
5. 10 years of Army Field Service - 5,235,000 engine flight hours.
6. Engine hours and shop visit rate per Table 12 and Figure 23.

TABLE 12. 10-YEAR PREDICTED ENGINE HOURS AND SHOP VISITS (ALL CAUSES)

Year	Shop Visit Rate Predicted (Visits/1000 hr)	Engine Hours/Year** Predicted Average	Removals/Year
1982-2	1.35	185,000	250
83-4	1.20	235,000	282
84-5	1.00	300,000	300
85-6	.90	385,000	346
86-7	.85	485,000	412
87-8	.75	585,000	439
88-9	.70	680,000	475
89-90	.65	780,000	507
90-1	.55	800,000	440
91-2	.50	800,000	400
10-YEAR TOTALS		5235	3852

**Ref. Figure 23.

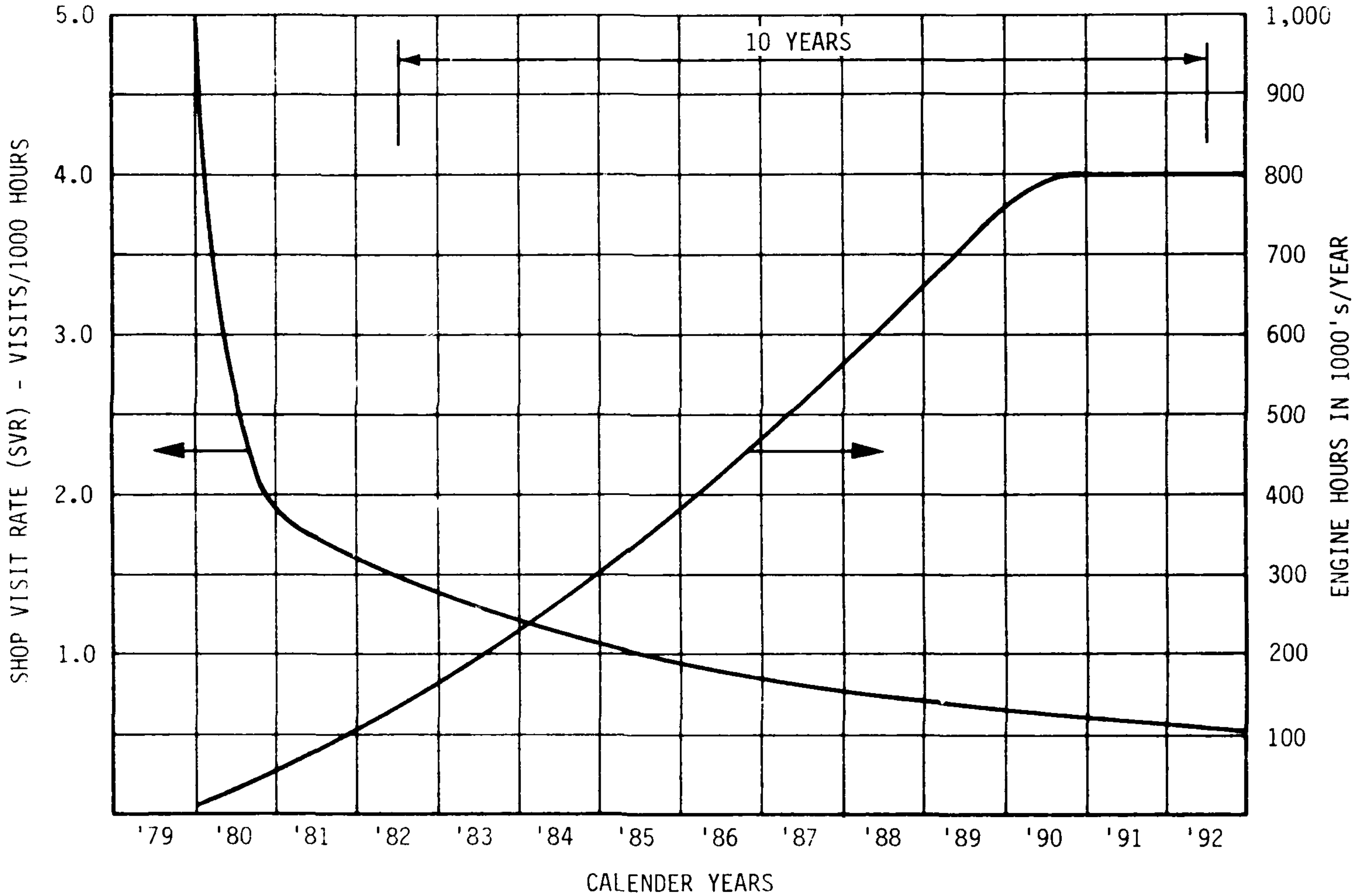


Figure 23. T700-GE-700 Predicted All-Cause Shop Visit Rate (SVR) and Engine Hours per Year.

LCC ANALYSIS OF MODIFIED METS FOR MPFI

Purpose

The purpose of this study is to compare the cost and operational effectiveness of two proposed methods of performing the modular performance fault isolation (MPFI) of T700 engines sent to AVIM for reported low performance that is 7% or more below minimum specification requirement as installed in the Black Hawk (as compared to 5% uninstalled). Specifically, the study is to assess the practicality of modifying the METS stand to perform computerized MPFI in the same manner as it is performed in GE factory test cells as compared to utilizing the existing METS, but equipped with a minicomputer capable of processing and printing out overall engine performance. Modules would be changed to correct performance loss based on engine history and accumulated field data. The ease of HP turbine and LP turbine module changes for this highly maintainable engine makes the latter method worthy of consideration

Methodology

The following methods were used for the modified METS LCC Analysis.

1. Analysis was performed in accordance with the logic flow chart shown in Figure 24.
2. Development, acquisition, and operation and support costs and savings differences were computed for modified versus standard METS.
3. METS test times and cost were estimated for standard and modified METS for 10 different low performance conditions (see Tables 13 and 14).
4. Five combinations of low performance engine causes were analyzed for test cost differences between standard and modified METS.
5. Savings by use of modified METS were compared to LCC costs.

T700 METS Analysis Assumptions

The following assumptions were used in this T700 METS analysis:

1. Six METS stands will handle all T700 AVIM requirements through 1992. All six METS facilities will be equipped with T700 adapter kits. The cost of T700 adapter kits is not charged against MPFI.

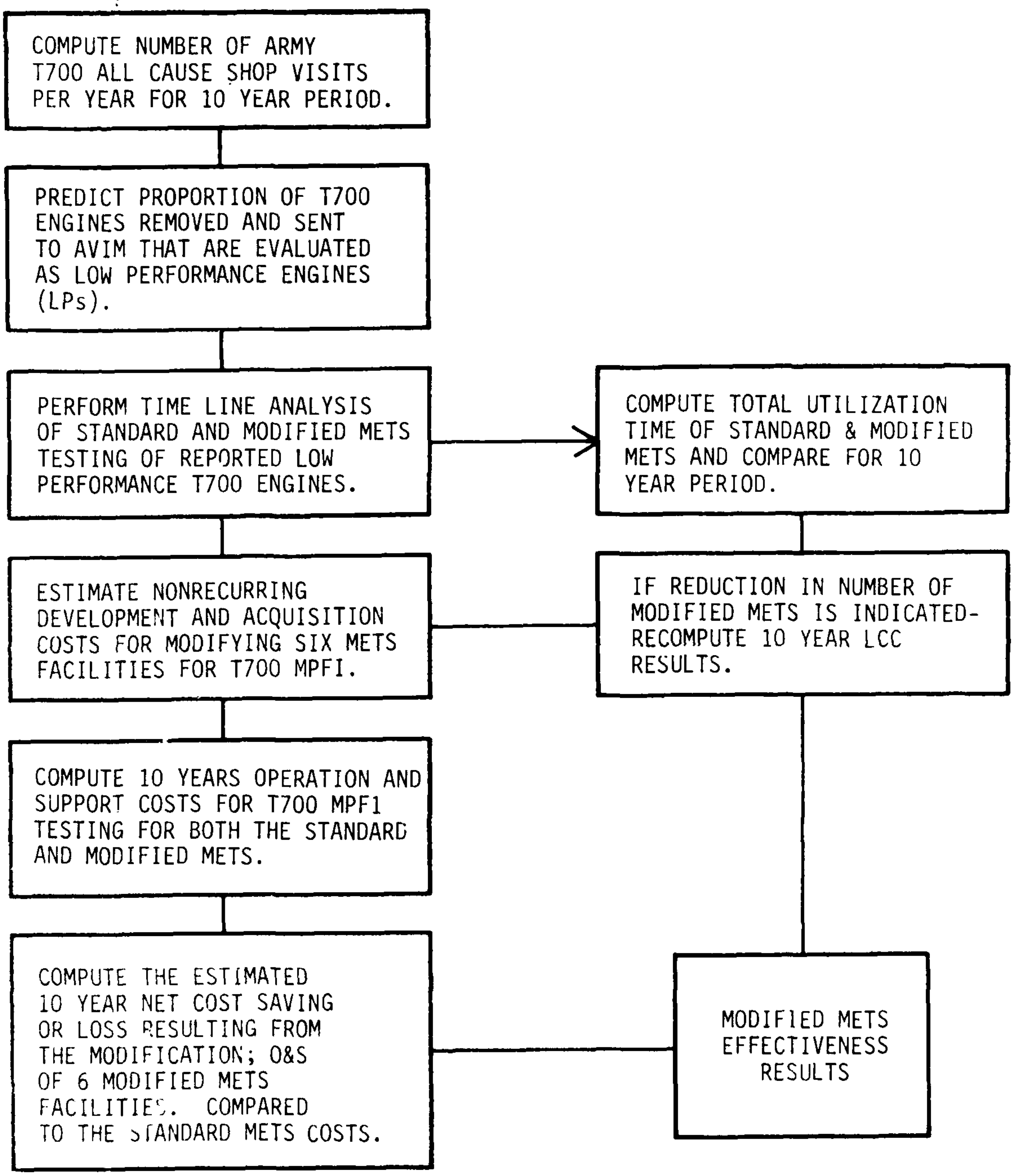


Figure 24. Logic Flow Chart for Effectiveness Analysis of Modified METS for Modular Performance Fault Isolation.

TABLE 13. T700 METS MODULAR PERFORMANCE FAULT ISOL

	Standard METS Manual Data Overall Performance	Standard METS Computerized Overall Performance	Modified METS Overall Performance	Bad HPT METS		Bad LPT METS		Bad Co METS	
				Std (C)	Mod.	Std (C)	Mod.	Std (C)	
	1	2	3	4	5	6	7	8	
Prep and Install T700	4	4	5	4	5	4	5	4	
Facility Check-Out and Water-Wash	1	1	1-1/2	1	1-1/2	1	1-1/2	1	1-
Tests - First	2	1-1/2	1	1-1/2	1	1-1/2	1	1-1/2	
Data Computation	1	-	-	-	-	-	-	-	
Remove and Replace HP Turbine	-	-		1-1/2	1-1/2	1-1/2	-	1-1/2	
1st Retest or Final Test	-	-		1	1	1	1	1	
Remove and Replace LP Turbine	-	-		-	-	1	1	1	
2nd Reset						1		1	
Reinstall Removed Modules								1-1/2	
Remove Engine and Prep/Ship	2	2	2-1/2	2	2-1/2	2	2-1/2	2-1/2	
TOTALS	10	8-1/2	10.0	11	12-1/2	13	12	15.0	10

-	1-1/2		1-1/2	1-1/2	1-1/2		1-1/2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
1	1		1	1	1		1		1	1	1	1	1		1	1
1	1		1	1/2	1		1		1	1	1	1	1		1	1
	1		1		1		1		1	1	1	1	1		1	1
	1-1/2				1-1/2		1-1/2		1-1/2	1-1/2	1-1/2	1-1/2	1-1/2		1-1/2	1-1/2
-1/2	2-1/2	3	2	2-1/2	2-1/2	3	2-1/2	3	2-1/2	3	2-1/2	3	2-1/2	3	2-1/2	3
12	15.0	10.5	13	13.0	15.0	10.5	15.0	10.5	15.0	18.5	15.0	18.5	16.0	10.5	15.0	18.6

TABLE 14. T700 METS MODULAR PERFORMANCE FAULT ISOLATIO

	Standard METS Manual Data Overall Performance	Standard METS Computerized Overall Performance	Modified METS Overall Performance	Bad HPT METS		Bad LPT METS		Bad C ME
				Std (C)	Mod.	Std (C)	Mod.	Std (C)
	1	2	3	4	5	6	7	8
Elapsed Time Hours (1)	10.0	8.5	10.0	11.0	12.5	13.0	12.0	15.0
Labor Cost $'s	350	298	350	385	438	455	420	525
METS Operating Hours	3	2.5	2.5	3.5	2.5	4.5	3.5	4.5
METS Operating Cost/Hour	255	260	300	260	300	260	300	260
METS Operating Cost	766	650	750	650	750	1625	1050	1170
Test Cost $'s/Test	1116	948	1100	1035	1188	1625	1470	1695

NOTE: (1) From Table I

OLATION (MPFI) - 10-YEAR OPERATING AND SUPPORT COST ANALYSIS

	Bad Comp METS		Bad HPT & LPT METS		Bad HPT & Comp METS		Bad LPT & Comp METS		Bad HPT & Seals METS		Bad LPT & Seals METS		Bad Comp & Seals METS		Bad Seals METS	
d.	Std (C) 8	Mod. 9	Std (C) 10	Mod. 11	Std (C) 12	Mod. 13	Std (C) 14	Mod. 15	Std (C) 16	Mod. 17	Std (C) 18	Mod. 19	Std (C) 20	Mod. 21	Std (C) 22	Mod. 23
0	15.0	10.5	13.0	13.0	15.0	10.5	15.0	10.5	15.0	16.5	15.0	16.5	15.0	10.5	15.0	16.5
0	525	368	455	455	525	368	525	368	525	578	525	578	525	368	525	578
5	4.5	2.5	4.5	3.5	4.5	2.5	4.5	2.5	4.5	4.5	4.5	4.5	4.5	2.5	4.5	4.5
0	260	300	260	300	260	300	260	300	260	300	260	300	260	300	260	300
0	1170	750	1170	1050	1170	750	1170	750	1170	1350	1170	1350	1170	750	1170	1350
0	1695	1118	1625	1505	1695	1138	1695	1138	1695	1928	1695	1928	1695	1118	1695	1928

2. The METS must be converted to T700 configuration for each test. Note: Since METS service five different engines (T53, T55, T63, T73, and T74) in addition to T700 engines, for several years there will be more "other" engines in service than T700s, therefore, the shared use of one METS at any given location will require frequent changes in test adapters.

3. As a minimum, every engine returned for low performance will be visually and borescope inspected for FOD, external damage and discrepancies. If okay, the engine will be:

   a. Installed on METS and water-washed.

   b. Tested for overall performance.

4. For the purpose of this analysis, all engines returned for low performance are tested for performance only, even though in practice some engines with low performance may have control problems rather than gas path or air seal problems.

5. The percentage of T700 engines removed for low performance is assumed not to exceed 10% of all engine removals. Thirty percent is also used for this study as a worst case condition.

6. The standard METS can and will be modified to include a small computer suitable for processing overall engine performance without requiring major facility modifications. This computer system will correctly and accurately measure and print out overall T700 engine performance.

7. Present predictions by the T700 Systems Analysis are that the most probable cause of low performance (LP) will be high-pressure turbine problems and second most probable cause will be the compressor. Consequently, with the standard METS facility, the MPFI procedure on every low performance engine will be as follows:

   a. Confirm low performance with an overall performance test.

   b. Change the HP turbine with the engine mounted on the METS.

   c. Check overall performance with a second test. If performance is below specification, change the LP turbine and make another test run. If performance is still low, send engine to depot.

8. The modified METS will correctly isolate low performance HP turbines, LP turbines, and compressors.

9. Neither the standard METS or the modified METS can isolate seal wear problems. Seal losses may appear to be compressor, HP turbine or LP turbine problems from the modified METS MPFI computer output. Engines with seal or compressor problems will be sent to the depot.

10. The same number of engines with performance problems will go to the depot whether the standard or modified METS is used.

11. Depot prep to ship takes 1/2 hour more than for return to service.

12. Engines to be sent to the depot will be shipped with the same HP and LP turbine modules that were on the engines as received at AVIM.

13. The Army will provide calibration facilities and personnel to perform instrument and system calibration tests of either the standard or modified METS facilities and take the necessary corrective action to maintain all METS data accuracy within required limits.

14. Performance fault isolation of the T700 compressor using instrumentation available in the standard METS is theoretically possible. It is not included in this analysis because an estimate of its effectiveness is not available and is outside the scope of this contract.

Summary - T700 METS MPFI Cost Effectiveness Analysis

The following contains a summary of the T700 METS MPFI cost effectiveness analysis:

Cost Element	Standard METS (dollars)	Modified METS (dollars)	Difference (dollars)
DEVELOPMENT			
Computer Specifications	25,000	25,000	
Software	25,000	50,000	
Operating Instructions	25,000	75,000	
Facility Design	10,000	75,000	
Check-out and Software Modifications	15,000	50,000	
	100,000	275,000	175,000

Cost Element	Standard METS (dollars)	Modified METS (dollars)	Difference (dollars)
ACQUISITION			
Buy Computer	25,000	75,000	
Facility Modifications and C. O.	50,000	200,000	
Total Each	75,000	275,000	
x 6	450,000	1,650,000	+1,200,000
Cost Difference (Added Development and Acquisition Cost of Modified METS)		D& A	$ 1,375,000

OPERATION AND SUPPORT

Maintenance: Assume 500 hours/year average T700 usage and maintenance cost (including calibration) labor and material at 5% of METS replacement cost. (Estimated at $1,250,000)

T700 adapter kit installed	$ 350,000
METS Computer (overall performance only)	75,000
METS MPFI Modification for each facility	275,000
MPFI Computer Software Maintenance	15/hour
Miscellaneous Materials	10/hour

Standard METS (1,250,000 + 350,000)(0.05/500) + 10 = $170/hour

Standard METS with simple computer (1,250,000 + 350,000 + 75,000) (0.05/500) + 10 = $177.50/hour

Modified METS (1,250,000 + 350,000 + 275,000) (0.05/500) + 25 = $212.50/hour

Fuel: Average power setting 900 hp at SFC of 0.55, 7 lb/gal
JP-4 at 1.18/gallon, JP-5 at 1.32/gallon. Use 1.20/gallon.
900 x 0.55 x 1/7 x 1.20 = $84.84/hour. Use $85/hour.

Cost/ Operating Hour*:	Standard METS - 170 + 85 + $225/hour Standard METS with computer 178 + 85 = $263/hour Modified METS 212.5 + 85 = $297.50. Use $300/hour.

Savings

Case 1	70% - Low performers (LPs) have bad HP turbine 20% - LPs have bad compressor 10% - Miscellaneous faults
Result:	10-year operation and support cost saving for Black Hawk fleet with modified METS if: a. 30% of removed engines have low performance-$27,977 b. 10% of removed engines have low performance-$ 9,326.
Case 2	70% - LPs have bad compressor 20% - LPs have bad HP turbine 10% - Miscellaneous use average - all others.
Result:	10-year operation and support cost saving for Black Hawk fleet with modified METS if: a. 30% of engines are removed for low performance-$449,912 b. 10% of engines are removed for low performance-$166,304
Case 3	Average of all ten cases (see Table 13).
Result:	10-year operation and support cost saving for Black Hawk fleet with modified METS if: a. 30% of engines are removed for low performance-$184,960 b. 10% of engines are removed for low performance-$ 61,653
Case 4	Bad LP turbine and compressor
Result:	10-year operation and support cost saving for Black Hawk fleet with modified METS if: a. 30% of engines are removed for low performance-$603,432 b. 10% of engines are removed for low performance-$201,144

*NOTE: It is assumed that the same two men will perform all engine and facility preparation, assembly operation and evaluation tasks at METS. Their labor cost at $17.50/hour each will be applied to the whole MPFI process, not just to the time METS is running and is, therefore, not included here.

Case 5 All LP engines have degraded compressors

Result: 10-year operation and support cost saving for Black Hawk fleet with modified METS if:

a. 30% of engines are removed for low performance-\$667,012
b. 10% of engines are removed for low performance-\$222,337

Results - Operation and Support Cost Savings

Ten-year operation and support METS costs savings for modular performance fault isolation using modified METS with MPFI capability have been compared with use of standard METS with computerized overall performance measurement. The following tabulation of types and frequency of problems that could exist in the T700 engines returned to AVIM for low performance are listed in decreasing probability of occurrence.

Case 1b - 10% of shop visits are low performance engines -	\$ 9,326
Case 2b - 10% of shop visits are low performance engines -	\$166,304
Case 3b - 10% of shop visits are low performance engines -	\$ 61,653
Case 4b - 10% of shop visits are low performance engines -	\$201,144
Case 5b - 10% of shop visits are low performance engines -	\$222,337
Case 1a - 30% of shop visits are low performance engines -	\$ 27,977
Case 2a - 30% of shop visits are low performance engines -	\$498,912
Case 3a - 30% of shop visits are low performance engines -	\$184,960
Case 4a - 30% of shop visits are low performance engines -	\$603,432
Case 5a - 30% of shop visits are low performance engines -	\$667,012

Cost Savings/Cost Ratio

Most probable Case 1b $= \dfrac{\$9,326}{1,375,000} = 0.006/1$

Maximum possible (least likely) Case 5a $\dfrac{667,012}{1,375,000} = 0.49/1$

Conclusions

The results of this preliminary analysis clearly shows that it is not cost effective to employ a modified METS for performing T700 modular performance fault isolation by automated gas path analysis at the AVIM level. Probably not more than ten to fifteen percent of the estimated $1.4 million nonrecurring cost differential would be recovered in 10 years of operation. Several additional factors not included in the analysis could further reduce the payoffs are:

1. The probability that the modified METS will not be 100% correct in performance fault isolation.

2. The difficulty in maintaining calibration of the sophisticated MPFI instrumentation and data processing systems in widely separated AVIM locations.

3. The probable increase in facility down time resulting from added maintenance required for the more complex facility.

4. The accumulation of engine historical data with time and the possibility of isolating low performance compressors may improve the effectiveness of the standard METS.

The modified METS will shorten the time estimated to perform MPFI on T700 engines for many of the cases considered in the time-line analysis of Tables 13 and 14. No allowance, however, was included for the additional maintenance time probably required for the more complex facility. A worst case estimate of 10.4% time saved probably represents the best that could be expected. Some added improvement in modified METS utilization may occur as experience is gained in use of the facility, particularly with regard to detecting seal leakage if its occurrence should become a significant factor in future T700 performance loss events.

Recommendations

1. Do not modify the Army METS facilities with the special instrumentation and computer hardware and software necessary to isolate by test and gas path analysis the module or modules causing low T700 engine performance.

2. Implement a program to equip each METS facility with a computer and automated data acquisition system to perform overall engine performance computation, display, and recording.

3. Utilize troubleshooting logic as in Assumption 7 (pg 89), or as future field and factory experience dictates.

4. Fund a GE engineering field service representative who will analyze field service reports in order to determine the T700 engine performance deterioration trends. These data and their evaluation by GE systems and performance engineers will improve the likelihood of pinpointing defective modules based on overall engine performance data.

   NOTE: This same representative would cover the acquisition of life usage data for the existing Engine Life Usage Monitors (ELUMS).

LCC ANALYSIS OF SLAVE CHIP DETECTORS FOR T700 OIL-WETTED PART FAULT ISOLATION

Background

The performance of modular fault isolation for T700 engine oil-wetted part problems was identified in Task I as a candidate D&CM function worthy to be evaluated. A method of performing this function and specific hardware recommended for its implementation was described in Task II. The equipment, an existing GE designed system called the transistorized chip detector system (TCDS), has been in successful use in GE's Lynn plant in TF34 and F404 engine test cells and is easily adaptable to T700 engines and the Army METS facilities. It is also adaptable for use in installed engines at AVUM but is not recommended because of the cost of equipping all Black Hawk Companies with TCDS kits at $10,000-15,000 each plus the aircraft down time that would be required to install the system on a suspect engine and perform the testing. This LCC assessment therefore, is related to the use of the TCDS at the AVIM level.

The master chip detector is the primary detector of oil-wetted part failures. The probable sources of magnetic failure debris are cold section, AGB or LP turbine modules. (The hot section contains no oil-wetted parts.) Modular oil-wetted part fault isolation of failures occurring in any of the three bearing sumps - A-, B-, or C-, can be done by detecting the presence of metal debris in the six scavenge pump filters. There is no scavenge line from the AGB - only a gravity drain to the oil reservoir. It is not feasible to fault isolate AGB failures in the same fashion as could be done for the three sumps.

The current maintenance policy for engine oil-wetted parts events at AVIM is as follows:

1. Engine having cold section oil-wetted parts problems - bearing, seal or PTO drive failures go to depot for repair.

2. Engines with AGB or LP turbine module oil-wetted parts problems may have that module replaced at AVIM provided the engine tests specified in the Maintenance Manual (TM55-2840-248-23) are followed.

Maintenance Options With TCDS

Upon receipt of engines at the AVIM shop with reported oil-wetted part failures, detected and/or confirmed by AVUM Troubleshooting Procedure 39 (Figure 26). The following maintenance actions could be taken at AVIM:

1. Inspect scavenge screens for indications of debris. If debris is on scavenge screens 4, 5, or 6, replace PT module and test per Troubleshooting Procedure 27 (Figure 27).

2. If debris is on screens 1, 2, or 3 indicating A- or B-sump failure location, ship engine to the depot.

3. If no debris is found on any screen or there is no report of debris found on screens at the AVUM level, there are two options:

    a. Ship the engines to depot as specified in Maintenance Manual.

    b. Install TCDS sensors and wiring harness on engines and run METS test to isolate debris source. If there is no debris on any of the six chip detectors, remove and inspect the AGB module.

        (1) If debris source is A- or B-sump, ship engine to depot.

        (2) If debris source is C-sump, replace PT module.

Trade-offs of Option a vs Option b is the subject of the LCC Assessment.

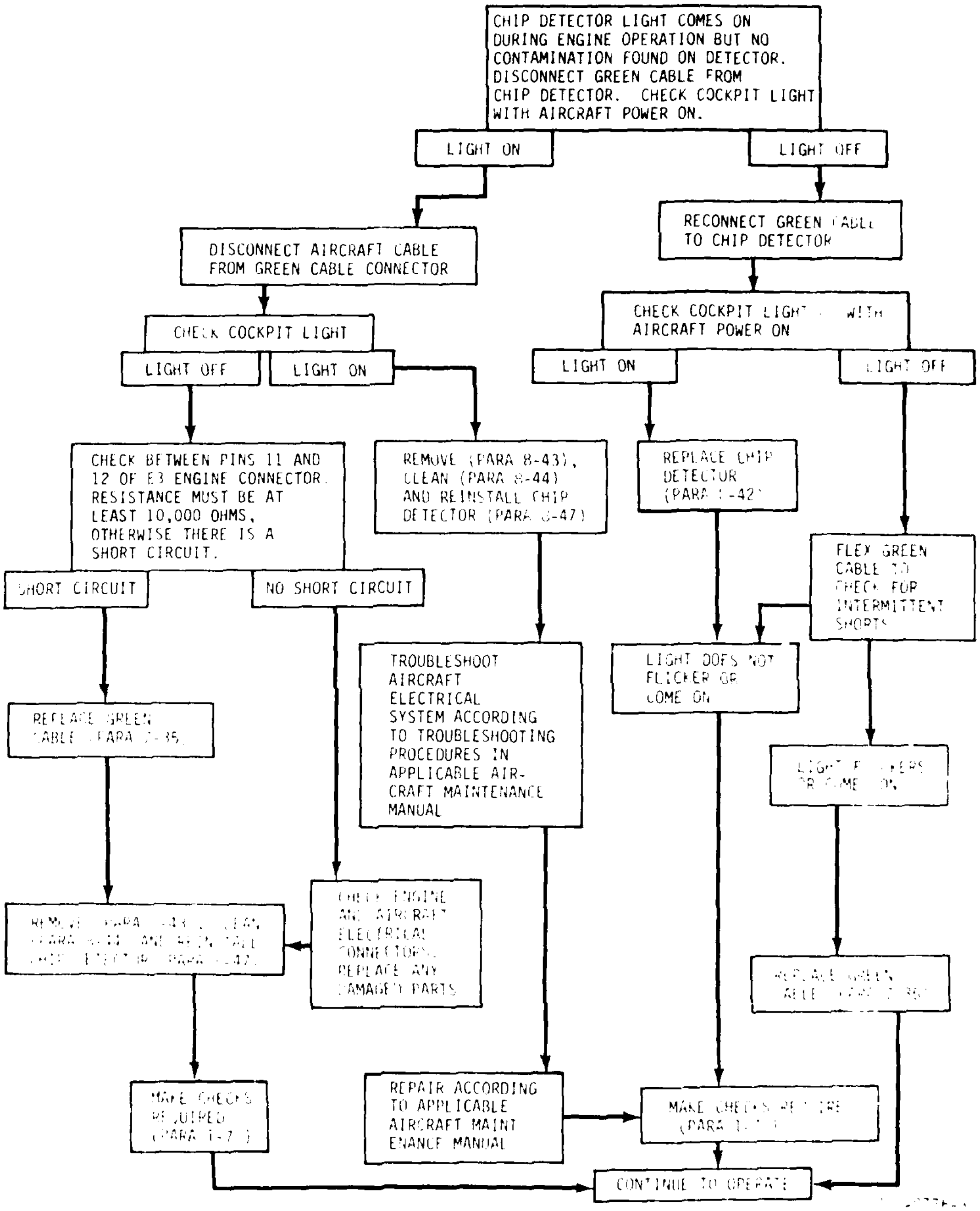


Figure 25. AVUM Troubleshooting Procedure 39 - Electrical Chip Detector Light (No Contamination Found).

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DIAGNOSTIC AND CONDITION MONITORING SYSTEM ASSESSMENT FOR ARMY --ETC(U)
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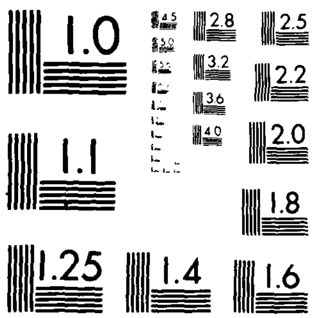

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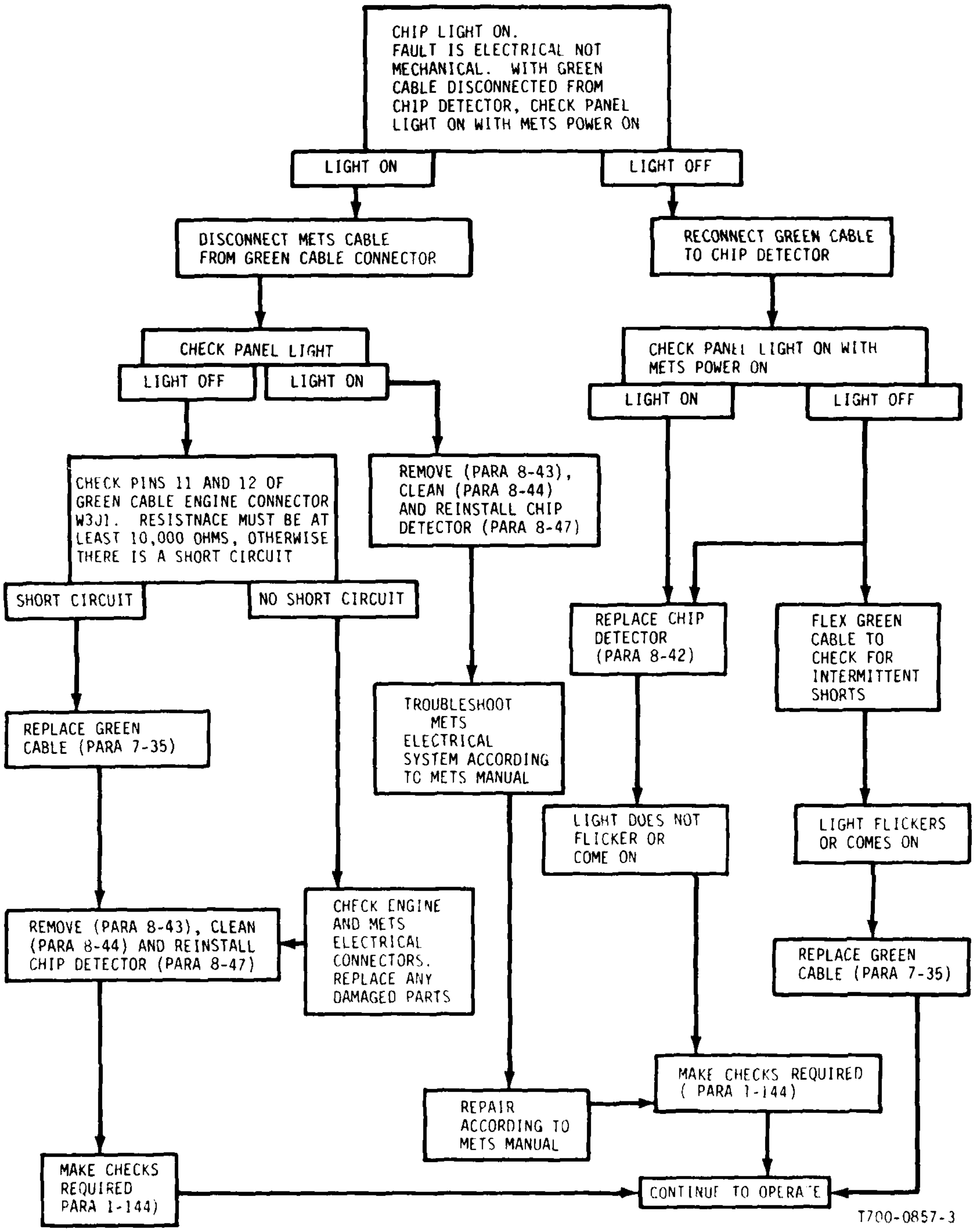

Figure 26. AVIM Troubleshooting Procedure 27 - Electrical Chip Detector Light (No Contamination Found).

Oil-Wetted Part Predictions and Assumptions

1. For a ten-year period - mid 1982 to mid 1991 - there are predicted to be 3852 engine removals resulting in shop visits to AVIM and/or depot. Refer to Table 12 and Figure 23.

2. T700 predictions based on service engineering data show oil-wetted part components all-cause failures resulting in 32% of T700 shop visits (SVs) or 1233 SVs for the ten-year period.

3. The presence or lack of metallic debris on the six scavenge screens has a major effect on the procedures and costs to fault isolate oil-wetted part problems. However, little hard data is available on the subject. Working with available information, the following is the basis for this analysis:

Oil-Wetted Part Component	% Failures Resulting in Scavenge Debris
Bearings No. 1, 2, 3, 5, 6	20%
No. 4	90%
Seals for A-, B-, C-sump	20%
PTO Drive	20%

4. The cost of one METS test for oil-wetted part fault isolation is $1000. Refer to METS MPFI analysis below.

5. The cost of one depot test for oil-wetted part fault isolation using the TCDS is $1250 computed as follows:

   Assume depot test cell is roughly comparable to the modified METS as described in the METS effectiveness analysis for modular performance fault isolation.

	METS		Depot	
Elapsed prep and test time	10 hr		10 hr	
Manpower	2 men		2 men	
Labor Cost - 2 men	$ 35/hr		$ 50/hr	
Total Labor Cost		350		500
Facility Operation and Support Cost/Hour	$ 260		$ 300	
Test Hours	2-1/2		2-1/2	
Total Facility Cost		650		750
		$1000		$1250

6. The average cost of shipping one T700 from any AVIM to depot and return is $1.00/pound or $1000/engine.

7. The same number of spare engines and modules are required with either Option a or Option b. No AGB will be replaced at AVIM, only AGB modules.

8. The costs of the TCDS Military specifications qualifications and kit acquisition are as follows:

TCDS engineering and qualification	$ 30,000
Kit Cost	15,000
Operation and Support Cost at 5% year*	750 ea/year

9. Oil-wetted part fault isolation testing does not result in secondary engine damage.

10. The cost of module replacement at AVIM and depot are the same. It is expected that although the labor cost at depot is higher than at AVIM the depot production facilities and methods are more efficient so that the overall cost is approximately the same at AVIM.

Cost Comparison of Options a. and b

A cost comparison to evaluate cost differences between Option a where engine is sent directly to Depot without troubleshooting, and Option b which utilizes slave chip detector system is as follows:

	Option a	Option b
TCDS Engineering and Qualification	30,000	30,000
Procure TCDS Kits at $15,000 + 50 spares	30,000 (2)	135,000 (9)
TCDS Operation and Support at 5%/yr - 10 years	15,000	68,000
Depot Diagnostic Tests (977 at $1250)	1,221,000	
AVIM Diagnostic Tests (977 x 1000)		977,000
Return PT Modules to Depot -		
(54 x 415 lb)	22,000	
(271 x 415 lb)		112,000
	1,318,000	1,322,000

*TF34-GE-400 General Electric trim box experience.

	Option (a)	Option (b)
Cost Saving of post module change tests at AVIM (217 x 250)	-	54,000
Cost avoidance - 217 shipping costs at $1000/each	-	217,000
	$ 1,318,000	$1,051,000

Saving: 1318
1051

$ 267,000 net saving by Option (b) in ten years.

Cost Differentials:	Option (a)	Option (b)	Difference
	$ 75,000	$ 233,000	$ 158,000

$$CS/C = \frac{267}{158} = 1.69$$

Conclusions and Recommendation

The estimated saving of $267,000 in ten years by adopting Option (b) at an added cost of $158,000 over Option (a) provides a favorable CS/C ratio of 1.69. The slave detector system is recommended for use at both depot and METS facilities.

LCC ANALYSIS OF CONTROL SYSTEM ANALYZER SET

Background

The purpose of this study is to determine the long term effectiveness of the Control System Test Set in the Army environment in reducing engine/airframe troubleshooting maintenance time and prevention of unnecessary removals of high value components. The T700 Life Cycle Cost Model developed for the Army by GE and used to evaluate ECP submittals has been utilized in this analysis.

Assumptions and estimates have been made based on predicted mature component (engine and suitcase tester) reliability rates and limited operating experience accumulated on the engine to date.

Control System Analyzer Description

The control system set consists of two separate units: the T700 engine harness and sensor circuit tester and the T700 ECU systems tester.

T700 Engine Harness and Sensor Circuit Tester:

The T700 engine harness and sensor circuit tester has been specifically designed for use with the electrical control unit's S39 Diagnostic Connector for troubleshooting control system problems with the aircraft and engine in the nonoperating mode.

Through the diagnostic connector, control system electrical harnessing, interconnecting components and aircraft interface connections can be tested for opens, shorts and nominal resistance values when troubleshooting engine control system problems as directed in Section I of TM55-2840-248-23 maintenance manual. The tester operates on 115 V 60-to 400 Hz power which is available at the aircrafts J-257 utility receptacle in the cockpit or from external sources and will display a "pass or fail" logic with no additional instrumentation or test equipment required.

T700 ECU Systems Tester:

The T700 ECU systems tester Part No. 4013145-834 is a self-contained test unit specifically designed to perform functional closed loop tests of the various ECU functions, HMU feedback system, aircraft N_p speed trim system and provide cockpit readout of the TGT, % N_p and % torque instruments. All tests are accomplished with the aircraft and engine in the nonoperating mode.

Assumptions and Methodology

The following assumptions and methods were used for LCC analysis of the control system analyzer set.

1. Control troubleshooting will be performed with the control system analyzer set following GE supplied procedures.

2. The LCC savings will be computed based on reductions in the following areas affected by use of the control system analyzer set:

   a. Number of lay-in spare LRU's.
   b. Cost of flightline LRU removed and replaced.
   c. Engines shipped to AVIM for METS and control diagnosis.
   d. Personnel training.
   e. LRU Depot transportation and testing.
   f. AVUM engine troubleshooting labor.
   g. AVUM aircraft-engine troubleshooting labor.
   h. Engine tests following LRU replacement.
   i. Control troubleshooting at AVIM using METS.

3. The troubleshooting effectiveness at AVUM of the control system harness and sensor tester is 75% of the effectiveness (and gross saving) of the control system analyzer set.

4. A favorable LCC cost saving to cost ratio for a ten-year period is 1.5/1 or greater. Results between 1/1 - 1.5/1 may be acceptable dependent on value placed on nonquantifiable benefits.

5. The number of false removals for each engine component capable of being checked by the tester was determined. The number of non-failures was estimated from reliability estimates for a mature (1×10^6 engine flight hours) T700 engine. The rates are summarized in Table 15.

6. Based on production engine component removal data, it is estimated that approximately 95% of false component removals can be prevented by use of the test set. It is felt that a prevention rate of 95% can be realized in the field if the test set is fully utilized in conjunction with the troubleshooting logic charts.

TABLE 15. COMPONENT CHARACTERIZATION UTILIZED IN COST EFFECTIVENESS STUDY FOR CONTROL SYSTEM TESTER

Component	Predicted False Removal Rate Per 10^6 Hrs.	Depot Repair Time (man-hr)	Component Cost (Spare Parts at Selling Price)	Component Remove and Replace Time (actual man-min)	Test Set Effectiveness (% of False Removals Avoided)
ECU	152	20	$ 20,000	13	95
HMU (LVDT and Torque Motor only)	33	75	40,000	24	
Blue Harness	15	2	2,500	9	
Yellow Harness	15	2	4,900	11	
Torque and N_p Sensor	50	2	2,100	9	
TGT Thermocouple Harness	14	4	2,420	24	
Alternator Stator	16	2	2,100	7.5	
Sequence Valve	90	2	2,400	15	

7. The checkout test time at the depot was estimated for components removed and returned as the result of improper troubleshooting. These values are shown in Table 16.

8. The cost of components used to determine the cost of additional lay-in spares required as the result of false removals is shown in Table 17. These costs are at the selling price in 1980 dollars.

9. Component removal and replacement task times are taken from the T700 Prime Item Development Specifications (PIDS) for LRU replacement and multiplied by 1.84 to reflect expected hours.

10. A ten-year period, 1982-1992, in which approximately 5.5×10^6 engine flight hours are accumulated was utilized in the life cycle cost study. All other factors used in the LCC model such as labor rates, transportation costs, etc., are the same as those being used for life cycle cost analyses of proposed engineering change proposal (ECP) submittals to the Army.

11. Cost of control system tester maintenance has been estimated at 5% of the selling price per year or approximately $1500/unit/year. This estimate is based on experience with GE-built TF34 trim checker which is a modern solid state tester similar to the T700 unit. The experience to date on this analogous unit indicates 5% to be a reasonable allowance. On the TF34 trim checker, most of the maintenance problems are related to cable and connector damage and it is likely to be similar on the T700 tester.

12. Three deployment plans for the control analyzer sets will be considered:

    a. Option 1 - 110 control analyzer sets will be procured and distributed, 1 to each Black Hawk Company and AVIM shop plus 4 spare sets in a rotatable pool.

    b. Option 2 - 110 harness and sensor circuit testers procured and distributed, 1 to each Black Hawk Company and AVIM shop plus 4 spares in a rotatable pool and 10 ECU system testers procured and distributed, 1 to each AVIM shop plus 4 spares at AVIM.

TABLE 16. ENGINE TESTS REQUIRED AFTER LRU REPLACEMENT - FALSE LRU REMOVALS ONLY

	Failures Rate Per 10^6 Hours	Failures Per 5.5 x 10^6 Hours	Checkout Test (1) Hours	Cost at $225/Hr.
Electrical Control Unit	152	836	.5	94050
Hydromechanical Control Unit	33	182	.7	28665
Yellow Harness	15	82.5	None	-
PT Torque and Speed Sensor	50	275	.5	30937
Gas Generator Turbine	14	77	None	-
Sequence Valve	90	495	.7	77963
Blue Harness	15	83	.5	9338
				$240, 953

1. NOTE: From TM55-2840-248-23, Table 1-7 "Checks Required Following Replacement of Parts." Pg 1-142.

TABLE 17. LIFE CYCLE COST SUMMARY FOR T700 CONTROL SYSTEM ANALYZER SET - PREDICTED SAVINGS

COST ELEMENT	Cost Saving 1980 Dollars
C_2 - Cost of Spare Components (lay-in spares)	- 744, 623
C_3 - Cost of Flight Line Maintenance (Remove and Replace Components and Engines)	- 12, 511
C_4 - Cost of Off-Equipment Maintenance (Transportation of Components to depot, checkout and return to service)	- 959, 070
C_7 - Cost of Personnel Training	- 35, 645
TOTAL (Engine Components Only)	- 1, 751, 849

TABLE 17 - Continued		
		Cost Saving 1980 Dollars
OTHER COST SAVINGS		
Eliminate 1 engine/company/year shipped to AVIM for Diagnosis		
1/Company x No. of Companies x No. of Years ($1000/ transportation + $1000/test)		
1 x 100 x 10 (2000)		- 2,000,000
Reduce Aircraft-Engine Troubleshooting 2 Company/Year x No. of Companies x No. of Years x 6 hours x $35/hr		
2 x 100 x 10 x 6 x 35		- 420,000
Unnecessary Engine Test for Falsely Removed LRU's (see Table 16)		- 240,953
Reduce AVUM Troubleshooting Time at $35/hr -		
2118 x 1/2 x 35.00		- 37,066
Reduce AVIM Test and Labor Cost for Control Troubleshooting - 200 engines save 1 test hour, 2 labor hours each. (263 + 35) x 200		- 59,600
Total Cost Saved Using	LCC Model	- 1,751,849
Control System Analyzer Set	Other	- 2,757,619
At All AVUM and AVIM Stations	TOTAL	- 4,509,468

c. Option 3 - 40 control analyzer sets procured and deployed as follows:

1 to each Black Hawk Battalion AVIM -	30
1 to each METS	6
Spares in a rotatable pair	4
Total	40 Control Analyzer Sets

13. It is assumed that an average of one engine per Company per year will be shipped to AVIM for control system diagnosis if the control system analyzer sets are not available at AVUM.

14. The estimated selling prices of the two control system analyzer units in 1980 dollars are as follows:

ECU Systems Tester	$17,684
Harness and Sensor Circuit	11,771
Set Total	$29,455

15. Methodology for the above assumptions were used in the T700 life cycle cost model developed by the General Electric Company for the Army and utilized on ECP and CIP program evaluations and submittals. The model was used for engine components since no data is available to the engine manufacturer on the interfacing aircraft components which form part of the engine control and monitoring system.

Additional factors affecting overall system cost effectiveness which cannot be evaluated by the LCC model are computed separately.

Conclusions

1. The 10-year saving that can be predicted from use of the control system analyzer sets in all 100 planned operational Black Hawk Companies and 6 AVIM shops for Option 1 is $4.5 million with a comparable cost of $4.3 million (see Table 18). The cost saving to cost ratio of 4.5/4.3 or 1.04 may not justify Option 1 deployment, however, field experience with additional control system analyzer sets could generate data to change this conclusion.

TABLE 18. CONTROL SYSTEM ANALYZER (OPTION 1) - COST AND RESULTS

110 Control System Analyzer Sets Deployed -		Totals
1 to each Black Hawk Company		100
1 to each AVIM Shop		6
4 Spare Sets		4
		110
Estimated Selling Prices		
Circuit-Sensor Tester		$ 11,771
ECU Tester		17,684
		$ 29,455
Development and Qualification		$ 100,000
Maintenance and Manual Revisions		100,000
Acquisition - 110 x 29,455		3,240,050
Operation and Support Cost at 5%/year for 10 years		1,000,000
		$ 4,440,050
Less 110 Continuity Testers at $700 + 5%/year Operation and Support Cost for 10 years		115,500
		$ 4,324,550
LCC Results		
Cost Saving	4,509,468	
Cost	4,324,550	
	$ 184,918	

$$\text{CS/C Ratio} = \frac{4,509,468}{4,324,550} = 1.04/1$$

2. The 10-year saving predicted for Option 2 of $3.9 million at a cost of $2.1 million and a cost saving to cost ratio of 1.61/1 is an indication of program viability (see Table 19).

3. The 10-year saving predicted for Option 3 of $4,509,468 (same as Option 1) at a cost of $1,950,200 and a cost saving to cost ratio of 2.31/1 makes this, along with Option 2, a viable program (see Table 20). Option 3 requires approximately $300,000 less investment than Option 2.

4. There are several benefits that the Army will gain from the use of the control system analyzer set that are difficult to quantify; these include:

   a. Per hour cost of added aircraft availability because of more efficient (faster) control troubleshooting.

   b. Fewer false removals of interfacing high value components such as the Marconi VIDS (visual information display system) and the SDC (signal data conditioner) and the N_p demand potentimeter.

   c. Improvement in troubleshooting due to the ability to test the interfacing airframe system while fully powered, rather than simple resistance and ground checks (particularly TGT indicating systems).

5. The control system analyzer set has several features that make it ideally suited to the rugged field usage it will receive if adopted by the Army:

   a. Both units of the set utilize solid state electronics for reliability and survivability under hard usage.

   b. All readouts are simple go or no-go signals - red and green lights. No meters to read.

   c. Diagnostic routines do not require engine operation.

   d. All ECU fault isolation closed loop systems testing and some of the sensor and circuit testing can be accomplished with the mechanic and test box inside the aircraft.

TABLE 19. CONTROL SYSTEM ANALYZER (OPTION 2) - COST AND RESULTS

110 Control System Sensor/Harness Testers	Totals
1 to each Black Hawk Company	100
1 to each AVIM Shop	6
4 Spares	4
	110
Estimated Selling Price	$ 11,771
10 Close Loop ECU Testers	
1 to each AVIM Shop	6
4 Spares	4
	10
Estimated Selling Price	$ 17, 684
Estimated Program Cost	
Qualification	100, 000
Maintenance Manual Revisions	75, 000
Sensor and Harness Tester Acquisition 110 x 11, 771	1, 294, 810
Operation and Support Cost at 5%/yr - 106 units	400, 000
ECU Tester - Acquisition 10 at 17, 684	176, 840
Operation and Support Cost at 5% - 6 units	53, 052
	2, 099, 702

LCC Results

Saving - 4, 509, 468 x .75 =	3, 382, 101
Cost	2, 099, 702
Net Saving	$ 1, 282, 499

CS/C Ratio = $\frac{\$3,382,101}{\$2,099,702}$ = 1.61/1

TABLE 20. CONTROL SYSTEM ANALYZER (OPTION 3) - COST AND RESULTS

40 Control System Analyzer Sets Deployed	Totals
1 to each Black Hawk Battalion	30
1 to each AVIM Shop	6
4 Spare Sets	4
	40
Estimated Selling Price	
Circuit-Sensor Tester	$ 11,771
Closed Loop Test	17,684
	29,455
Development and Qualification	$ 100,000
Maintenance Manual Revisions	100,000
Acquisition - 40 x 29,455	1,178,200
Operation and Support Cost at 5%/year	600,000
	$1,978,200
Less 40 Continuity Testers at $700	-28,000
	$1,950,200

LCC Results

Cost Saving	$4,509,468*
Cost	1,950,200
Net Saving	$2,559,268

$$\text{CS/C Ratio} = \frac{4,509,468}{1,950,200} = 2.28$$

*Assumes no reduction in effectiveness in prevention of unnecessary removals as compared to Option 1.

Recommendations

1. Continue current two-set field evaluation program at Ft. Rucker and Ft. Campbell to collect data on troubleshooting time and effectiveness as well as reliability and durability of the test set.

2. Obtain funding to modify the AVUM and AVIM troubleshooting flow charts and written procedures for future incorporation in the T700 maintenance manual.

3. Procurement of four additional sets of analyzers for use at an AVIM, the Army mechanics training school, one operational company, and the factory. Perform the required Military specification tests on one set.

4. Conduct an in-depth study of the control analyzer set utilizing field data from production engines, field experience of the deployed test sets, and an update on the LCC analysis for the purpose of determining the optimum usage of the equipment, that is, Option 2 or Option 3.

LCC ANALYSIS OF MULTIPURPOSE AIRBORNE D&CM SYSTEMS

Each of the elements of the Multipurpose Airborne D&CM System defined in the section entitled Task II - D&CM System Definition, is subjected to an LCC analysis described in the following section. These elements include:

1. Automatic Performance Monitor.

2. Discriminating Chip Detector (Degaussing).

3. Engine Life Usage Monitor.

4. Overtemperature Monitor.

The summary of the LCC Analysis Results of each of the four MADACMS functions as well as the cost effectiveness of the System as a whole, is tabulated below. This is followed by the four sub-system analyses.

LCC Analyses Summary of the Multipurpose Airborne D&CM System

Results	Costs	Cost Savings	CS/C
Automatic Performance Monitor (APM) (Option 2)	$ 7, 200, 000	$12, 168, 263	1. 69/1
Discriminating Chip Detector (DCD)	663, 000	2, 389, 750	3. 60/1
Engine Life Usage Monitor (ELUM)	6, 572, 000	12, 661, 250	1. 93/1
Overtemperature Monitor (OTM)	1, 428, 458	-	-
	$ 15, 863, 458	$ 27, 219, 263*	1. 89/1*

*Calculated without overtemperature monitoring program savings not now available.

Conclusions

The Multipurpose Airborne D&CM System is a cost effective system.

Recommendation

It is recommended that the Army award a contract to initiate the development and evaluation testing of the Multipurpose Airborne D&CM System.

LCC ASSESSMENT OF AUTOMATIC PERFORMANCE MONITOR

Introduction

The purpose of this LCC assessment is to evaluate the cost and operational benefits of an aircraft-mounted electronic engine performance monitoring system for Army turboshaft helicopter engines. The analysis is restricted to the benefits associated with the performance of the three traditional installed performance tests by use of an automated electronic system as compared with the existing methods utilizing cockpit indicator readings as specified in the aircraft operator's manual and engine maintenance manual.

The measurement of installed engine performance in Army helicopters has been performed for many years by the flight crews using the readings taken from the cockpit engine instruments, outside thermometer for free air temperature (FAT) and barometer or altimeter for pressure altitude. This data is then manually recorded and referred to performance curves in the aircraft operating manual to obtain a determination of engine performance compared to a specification or prior satisfactory status. Three types of performance checks are performed in this manner:

1. Operational health indication test (HIT) done on the ground prior to the first flight of the day for each engine at 60% engine torque and 100% shaft speed (see Table 21).
2. Maximum power check done in flight by the maintenance test pilot at 100% output shaft speed, maximum engine power and 110 knots indicated air speed (KIAS) (see Table 22). The HIT procedure provides an approximate indication of engine condition and, if below limits, requires the more accurate maximum power check to be run. The latter test becomes the pass or fail test that demands engine maintenance or removal when failed.
3. The baseline HIT check is performed on the ground by the maintenance test pilot immediately after the maximum power check to establish a new baseline for future operational HIT checks (see Table 23).

Automatic Performance Monitor (APM) Description

The automatic performance monitor is one of several proposed functions that can be performed by an airframe-mounted digital computer and a simple cockpit alphanumeric digital display unit. The same functions proposed for this digital

TABLE 21. OPERATIONAL HEALTH INDICATOR TEST - CURRENT PROCEDURE*
Estimated Time - 5 Minutes

1. Position helicopter into the wind.
2. Record FAT and pressure altitude (PA).
3. Turn anti-icing and heater to off.
4. Set one engine to idle.
5. Set other engine to 100% N_p.
6. Use collective pitch to increase torque to 60%.
7. Hold at 60% for 30 seconds.
8. Record aircraft hours, FAT, PA, and TGT on HIT Test Log (see Appendix*).
9. Repeat steps 4 through 8 for other engine.
10. Calculate average TGT indicated.
11. Find TGT from Table 1-9 (Appendix pg 1-148).
12. Subtract indicated TGT from table TGT (Table 1-8).
13. Compute and record TGT acceptance limits.

*Reference TM55-2840-248-23, para 1-88 and Appendix, pg 1-147.

TABLE 22. MAXIMUM POWER CHECK - CURRENT PROCEDURE*
Estimated Time - 30 Minutes

1. Set both power available levers in the FLY position, and 110 knots level flight at 100% N_p.
2. Retard one engine to 0% torque and increase other engine to TGT 835^o - 845^oC.
3. Stabilize for 10 seconds. Increase collective pitch until N_p drops 2%.
4. Stabilize for 30 seconds.
5. Read and record N_g, TGT, % torque, FAT, PA, EOT, and EOP.
6. Reduce collective pitch until N_p = 100%.
7. Increase other engine power level to maximum power. Repeat steps 1 through 4.
8. Plot FAT and PA. Determine minimum torque from Figure 1-38 (see Appendix*).
9. Compare results of step 8 with torque in step 5.

*Reference TM55-2840-248-23, para 1-85 and Appendix, pg 1-146.

TABLE 23. BASELINE HEALTH INDICATOR TEST - CURRENT PROCEDURE* Estimated Time - 5 Minutes
1. Position helicopter into the wind. 2. Record FAT and pressure altitude (PA). 3. Turn anti-icing and heater to off. 4. Set one engine to idle. 5. Set other engine to 100% N_p. 6. Use collective pitch to increase torque to 60%. 7. Hold 60% for 30 seconds. 8. Record aircraft hours, FAT, PA, and TGT on HIT baseline sheet (see Appendix*). 9. Repeat steps 4 through 8 twice. 10. Calculate average TGT indicated. 11. Find actual TGT from Table 1-9 (Appendix pg 1-148). 12. Subtract indicated TGT from table TGT (Table 1-8). 13. Compute and record TGT acceptance limits.
*Reference TM55-2840-248-23, para 1-86 and Appendix, pg 1-147.

system were successfully demonstrated in Lynn T700 test cells with the engine health monitor, a portable analog device built as a demonstrator during the T700 engine development and qualification program (reference GE Report R78AEG032, 28 April 1978). The current GE concept is a six-pound airframe-mounted computer-processor and a simple one-pound dichroic liquid crystal cockpit display unit servicing two engines and having two push button controls. It provides a simple means of obtaining both HIT and maximum power check data without the problems associated with obtaining and recording cockpit instrument readings and using engineering curves and tables to determine engine performance.

LCC Analysis Rationale

The APM characteristics that can be qualified with assurance for evaluation of cost and operational effectiveness are related to the engine and aircraft operating time, costs, and fuel saved in more efficient conduct of HIT and maximum power checks as compared to the current methods. A number of other APM potential benefits may ultimately prove to have greater impact on weapon system cost and operational effectiveness but are not quantifiable for lack of operational service experience. These "other" benefits would be derived from the following system characteristics:

Other Benefits - Not Quantified

1. More accurate HIT check data:

   a. Fewer maximum power checks.
   b. Reduced mission aborts and better fault detection
   c. "Trendable" data for degradation tracking.
   d. Better data for factory analysis.

2. More accurate maximum power checks:

   a. Reduced mission aborts and better fault detection.
   b. Fewer maximum power reruns.

3. Simplified cockpit procedure - eliminates reference to charts and tables:

   a. Reduces flight crew workload.
   b. Reduces chances for human error.
   c. Simplifies pilot training.

Alternate Rationale - Eliminate (Some or All) Daily HIT Checks

Instead of traditional operational HIT check, the pilot could, with APM, call up the performance status of both engines as measured and stored in high-volatile computer memory from the last flight. This data together with the pilots knowledge of recent history of the aircraft and/or his general assessment of engine status as they are started may convince him that HIT check is not required. A continuation of the excellent record of negligibly low performance problems of the T700 engines could also influence a future change in Army policy in this area.

An important consideration, perhaps the overriding one for HIT, is the added confidence a good preflight check may instill in the flight crew; that is an important human factors item. It is conceivable, however, that when the automatic performance monitor is proven to be accurate and reliable, daily HIT checks might be eliminated as a requirement and left to the pilot's discretion.

Assumptions

1. The maximum power check as presently performed by the maintenance test pilot is done satisfactorily. The computations to determine performance status are done inflight to check data validity before terminating flight. The average maximum power check flight is of 1/2-hour duration.

2. Current HIT takes approximately 5 minutes including computation, recording, and data "look up" time. Engine remains in operation during entire HIT procedure.

3. HIT checks to confirm engine condition each day before first flight will continue to be performed.

4. The automatic performance monitor is the principal function of a digital airframe-mounted computer-processor and display system which has a number of ancillary functions utilizing a common microprocessor and related electronics.

5. Ten percent of daily HIT checks require reruns because of human error or marginal results.

6. For purposes of this and the other effectiveness studies of the airframe-mounted D&CM systems, the costs and failure rate of the common computer-processor unit, cockpit display unit, and software are apportioned as follows:

Automatic Performance Monitor	50%
Life Usage Monitor	30%
Discriminating Chip Detector	10%
Overtemperature-Time-at-Temperature Monitor	10%
	100%

7. The cost of aircraft flight time is \$1500/hour*. The cost of ground operation is \$225/hour (15% of flight cost)*.

*Derived in LCC Analysis for Discriminating Chip Detector in TM80AEG1163.

8. The average engine power output (for fuel consumption computation) during installed T700 performance checks is as follows:

Maximum Power Checks	900 HP at .50 SFC
HIT Check	600 HP at .55 SFC

9. Estimated engine operating time saved with automatic performance monitor*:

   a. Operational HIT check - 2-2/3 minutes.
   b. Maximum power check - 3 minutes.
   c. Baseline HIT check - 3-3/4 minutes.

*Reference TM80AEG1181 entitled LCC Analysis of T700/UH-60A Automatic Performance Monitor.

10. The LCC analysis will be carried out for the following automatic performance monitor options:

Option 1 - assumes that all HIT and power checks will be carried out at the currently established frequency.

Option 2 - assumes that favorable engine experience may justify in the future, the elimination of 2/3 of the HIT checks.

Estimated Savings Using Automatic Performance Monitor Option 1

1. Operational HIT Checks:

Number of tests - Each engine HIT tested on first flight of the day.

$$\text{Number of sorties} = \frac{5,090,000 \text{ engine hours } \times 1}{2 \text{ engines/aircraft} \times 1.5 \text{ hr/sortie}} =$$

1,696,667 sorties

Assume 1/2 of sorties are first flights of the day.

$$\frac{1,696,667}{2} = 848,333 + 10\% \text{ reruns} = 933,167 \text{ HIT Checks/10 Years}$$

a. Time saved by automatic performance monitor in HIT checks at 2-2/3 minutes for each check:

$$\frac{2\text{-}2/3}{60} \times 933,167 = 41,526 \text{ hours aircraft ground test time}$$

$$= 83,052 \text{ hours engine ground test operation.}$$

b. Total cost saved by automatic performance monitor:

41,526 hrs x $225/hr. = $9,343,350*.

c. Fuel saved (savings included above):

$$\frac{83,052 \text{ eng hrs} \times .55 \text{ lb/hr} \times 600}{6.5 \text{ lb/gal}} = 4,216,486 \text{ gallons}$$

*Savings will increase as fuel costs rise above the average figure of $1.20/gal assumed in this analysis.

2. <u>Maximum Power Checks:</u>

a. Number of checks in 10 years:

1 for each shop visit	3852
1 for each failed HIT check (Use 2/1500 hours - reference Task I analysis)	678
	4530
10% miscellaneous control caused performance losses	450
Use 5000 Maximum Power Checks	4980

b. Time saved:

$$\frac{3}{60} \times 5000 = \begin{array}{l}\text{250 hours aircraft flight time} \\ \text{500 hours engine flight time}\end{array}$$

c. Total cost saved:

250 x \$1500/hr = \$375,000

d. Fuel saved (included above):

$$\frac{250 \times 2 \text{ engine hours} \times .50 \times 900}{6.5} = 34,605 \text{ gallons}$$

3. <u>Baseline HIT Checks:</u>

a. Time saved:

$$5000 \times \frac{3\text{-}3/4}{60} = 312.5 \text{ aircraft hours, } 625 \text{ engine hours.}$$

b. Cost saved:

312.5 hours x \$225/hr = \$70,313

c. Fuel saved (included above):

$$\frac{625 \times 500 \times .55}{6.5} = 31,731 \text{ gallons.}$$

Option 1 Automatic Performance Monitor Cost Computation in 1980 Dollars

1. Electronic Hardware and Software Design and Development: $415, 040

   a. Acquisition cost:

      $8260 x . 5 = $4130 per Aircraft System

      1500 systems at $4130 -- $6, 195, 000

   b. Operation and Support Cost based on system MTFB of 9000 hours:

      $$F/R = \frac{1,000,000 \text{ hr*}}{9000} = 111 \ F/10^6 \text{ hours System Failure Rate - F/R}$$

      *See Assumption 6 (pg 119).

   c. Apportioned failure rate for automatic performance monitor:

      $$F/R \ 111/100 \times .50 = 56/10^6/\text{aircraft system}$$
      $$= 28/10^6/\text{engine hours}$$

      $$5,090,000 \text{ engine hours} \times \frac{28}{10^6} = 143 \text{ failures at } \$4130 = \$590,600.$$

   d. Cost of total program:

Dev.		$ 415, 000
Acq.	- 1500 x 4130 =	6, 195, 000
O&S		590, 600
		$7, 200, 600

2. Results (Assumes all HIT and maximum power checks are carried out):

   a. Cost:

Gross Savings	$9, 788, 663
Total Cost	7, 200, 600
Net Saving	$2, 588, 063

      $$\frac{\text{Cost Saving Ratio}}{\text{Cost}} = \frac{9,788,663}{\$7,200,600} = 1.36/1$$

   b. Time:

      84, 177 engine operating hours saved.

   c. Fuel:

      4, 282, 822 gallons saved.

Estimated Savings Using Automatic Performance Monitor Option 2

1. Results:

   Assume 2/3 of all HIT checks are eliminated.
   Assume no change in maximum power checks.

   a. HIT check savings:

   Time - $2/3 \times 933,166 \times \frac{5}{60} =$ 52,102 hours aircraft ground test x 2
   104,204 engine hours

   Cost - 52,102 x $225/hr = $11,722,950

   Cost Savings -

	$11,722,950	$12,168,263	
	70,313	7,210,600	
	375,000	$ 4,957,663	Net
Gross	$12,168,263		

   $$\text{CS/C Ratio} = \frac{12,168,263}{7,210,000} = 1.69/1$$

   Fuel (Savings included above)

   $$\frac{\text{1 HIT Check} - 5 \times 600 \times .55 \times 2}{\text{(2 Engines)} \quad 60 \quad 6.5} = 8.46 \text{ gallons}$$

   10 Years = 2/3 x 933,166 x 8.46 = 5,263,056 gallons.

Discussion of LCC Analysis Results for Automatic Performance Monitor

The basis for this analysis is believed to be conservative in the following respects:

1. The projected 10-year estimate of 5,090,000 engine hours is lower than current estimates.
2. The result of assigning a dollar cost per flying hour based on aircraft LCC divided by aircraft flying hours is believed sound but probably low for lack of up-to-date information using current projected fuel costs.
3. The estimate of 10% reruns of HIT checks in the first 10 years of Black Hawk service may be low because, during this period, 100 new Black Hawk Companies will be activated with many new and inexperienced personnel.

There are also assumptions that may tend to inflate automatic performance monitor benefits. These are:

1. Average Black Hawk flies two flights or missions a day with every other flight requiring a HIT check.

2. Average mission length is 1-1/2 hours. If the average is longer, there would be fewer HIT checks.

Summary of 10-Year LCC Analysis Results for the Automatic Performance Monitor

LCC Characteristic	Option 1	Option 2
Dev. Cost	$ 415,000	$ 415,000
Acquisition Cost	6,195,000	6,195,000
O&S Cost	591,000	591,000
LCC Cost	7,201,000	7,220,000
Gross Cost Savings	9,789,000	12,168,000
Net Cost Saving	2,588,000	4,957,000
CS/C Ratio	1.36/1	1.69/1
Engine Run Time - Hours Saved	84,177	104,204
Fuel Savings - gallons	4,282,822	5,263,056

Conclusion

The potential cost, fuel and engine run time savings by use of the simple GE concept of Automatic Performance Monitor for making daily HIT checks justifies its development and provides the opportunity in the future for added savings by eliminating the mandatory daily HIT tests.

Recommendations

1. Conduct a comprehensive survey and analysis of HIT check practices, data validity, benefits, flight crew, and maintenance officer attitudes and suggestions.

2. Initiate the development and evaluation testing of the multipurpose airborne D&CM (MADACM) system by the Aircraft Engine Group of General Electric Company as a generic Army helicopter engine system to be evaluated in Black Hawk aircraft.

3. Develop the Automatic Performance Monitor functions as the primary function of the MADACM system.

4. Provide hardware and software for such ancillary functions as can be incorporated in MADACM without degrading its reliability and human factors advantages of simplicity of operation and nonambiguous readout.

5. Implement the Option 2 approach following satisfactory results from the above steps.

LCC ANALYSIS FOR A DEGAUSSING-TYPE DISCRIMINATING CHIP DETECTOR

Methodology

For this analysis, the cost of developing and introducing the "smart" chip detector into the UH-60A fleet will be compared with the savings achieved by the reduced number of nuisance signals causing a reduction in mission aborts, aircraft down time, and maintenance costs.

Analysis Basis and Assumptions:

1. Derived from Figure 23 data for a 10-year period from 1982 to 1992 for 5, 090, 000 engine hours assuming, 3150 engines at average hours/engine of 2700 for 10 years.

2. Each nuisance signal will cause a one-hour maintenance check per Table 24, and 75% of the nuisance signals will cause a mission abort.

TABLE 24. NUISANCE SIGNAL MAINTENANCE CHECKS

Maintenance Action	Individual Elapsed Time (minutes)	Total Elapsed Time (minutes)
Shutdown Engine	2. 0	2. 0
Obtain Materials and Tools	10. 0	12. 0
Access Engine	5. 0	17. 0
Disconnect Chip Detector Cable	0. 5	17. 5
Remove and Inspect Chip Detector	1. 5	19. 0
Clean and Reinstall Chip Detector	3. 0	22. 0
Close Engine Access	5. 0	27. 0
Start Engine and Run 15 Minutes	17. 0	44. 0
Access Engine and Leak Check	7. 0	51. 0
Close Engine Access	5. 0	56. 0

Although the frequency of nuisance chip signals is often expressed as a ratio of nuisance to true signals, 5 or 6:1 being not uncommon, there is little direct relationship between the two. The frequency of nuisance signals is more likely to be a function of: (1) engine operating hours, (2) time since new or repair, and (3) the cleanliness discipline exercised in the manufacture or repair of the engine. Available data on the T700-GE-700 engine seems to bear this out. Figure 25 depicts these trends. Explanation follows:

Point 1	Early flight test data reported in Report USARTL-TR-78-32, December 1980-11,000 engine hours, average engine time since new was 118 hours.
NCR* 2.4	27 nuisance signals, time period 1974 - 77.
Point 2	Full scale development of flight test data reported in Report No. 7 DAAK-51-79-C-0020, January 1980-15,000 engine hours, average engine time since new was 127 hours.
NCR* 1.8	27 nuisance signals, time period 1977 - 79.
Point 3	Army service at Ft. Campbell for Production Engines in GE DV-7 Field Service Reports-5811 engine hours, average engine time since new was 109 hours.
NCR* 1.45	8 nuisance signals, time period January - May 1980.
Point 4	Army service at Ft. Rucker for Production Engines in GE DV-7 Field Service Reports-4397 engine hours, average engine time since new was 363 hours.
NCR* 0.68	3 nuisance signals, time period January - May 1981.

*NOTE: NCR - Nuisance Signals/1000 Engine Hours.

The data definitely indicates a very favorable trend in decreasing nuisance signal ratio (NCR) over the 6-year period, 1974-1980; showing that cleaning-up of the engine manufacturing debris and a reduction in detection system sensitivity has been effective from early preliminary flight rating test (PFRT) engines to the current production engines: Points 1 to Point 3 of Figure 24; all of these engines being of about the same average age in terms of time since new (TSN).

The second example shown by comparing Points 3 and 4 shows a very favorable trend of decreasing NCR with increasing TSN. The data sample, however, is small and may not be an accurate quantitative representation of what may occur in later service. The trend, however, is logical and probably indicates that with increasing engine hours, the efficient 3 micron filters are gradually cleaning up residual debris.

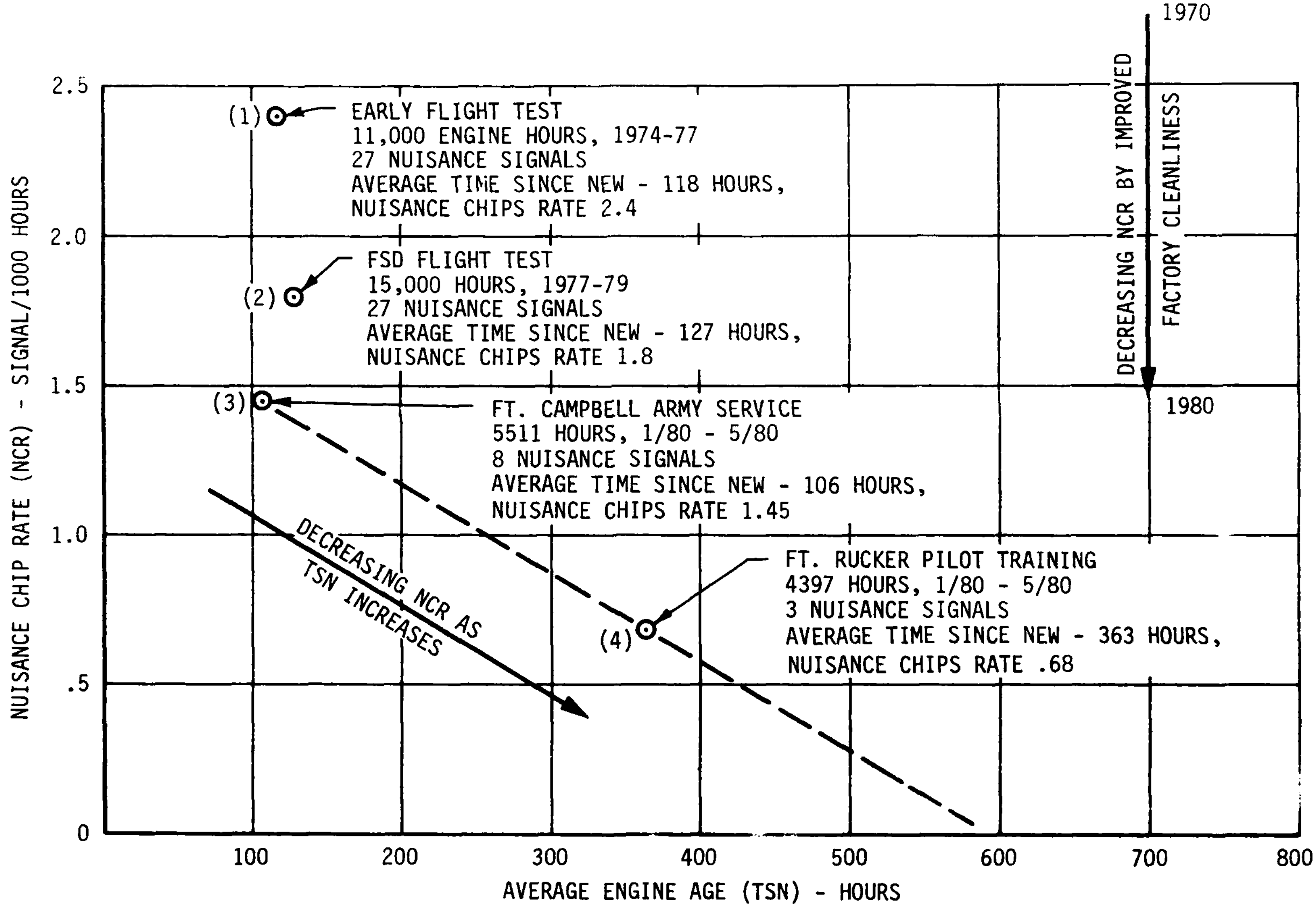

Figure 27. T700-GE-700/UH-60A Nuisance Chip Signal Trends.

Nuisance Chip Rate Future Prediction

There does not appear to be any mathematical method to predict the future NCR rate that can be achieved with the present chip detector. A linear extrapolation of Points 3 and 4 would show NCR approaching zero when those engines reached an average TSN of 600 hours. Such a conclusion based on only a four-month period with a small number of engines would be unsound. Several factors will prevent the achievement of the ideal condition.

1. There is now and will probably continue to be, some internally generated debris of the types cited above.

2. LRU replacement, module replacement, and depot repair of LRU's, modules, and engines will introduce debris to some degree yet to be determined.

3. Future service conditions, introduction of second source component suppliers, and future design changes for such things as cost reductions may affect the NCR.

4. Past history of engines of all types equipped with magnetic chip detectors would not lead one to predict that the nuisance chip problem would go away.

On the positive side, however, it is also recognized that there is no long-term experience with engines having 3 micron filters in their lubrication systems.

For the purposes of this study, therefore, it will be assumed that the NCR for the present master chip detector will reach 0.4/1000 hours on 100 hour TSN engines by 1982 and would ultimately reach 0.3/1000 hours. The average NCR for the 10-year period will reach 0.35/1000 hours. Likewise, it will be assumed that the average NCR for the discriminating chip detector will fall in a band of 0.05 - 0.1/1000 hours for the ten-year period.

Computation of Degaussing Discriminating Chip Detector Cost Effectiveness

1. Cost of a Nuisance Signal. Assume the following:

   Average Mission - 1.5 hours
   75% of nuisance signals result in aborts plus chip inspection check.
   25% of nuisance signals result in chip inspection only.

UH-60A Cost - $ 200,000 - Development
4,000,000 - Acquisition
4,000,000 - Operation and Support cost at 5%/year for 20 years

$8,200,000/2 = $4,100,000 for 10 years

Aircraft hours flown per year = 270 hours/year = 2700/10 years

$$\frac{\text{Cost of one UH-60A for 10 years}}{\text{Total Service Hours for 10 years}} = \text{Cost per hour for UH-60A operation}$$

$$\text{Cost/Hour} = \frac{4,100,000}{2700} = \$1519\text{/Hour (Use \$1500/hr)}$$

Cost/Mission = 1.5 x 1500 = $2250/mission

Nuisance Signal Cost = (Cost/Mission + Cost/Chip Inspection) x 0.75
+ Chip Inspection Cost x 0.25

Cost/Nuisance Signal - Average

2. Chip Inspection Cost:

Labor - 2 men at $17.50/hour x 1 hour = $35

$$\text{Fuel} - \frac{600\text{ hp} \times 0.55 \times 1.20\text{/gal}}{6.5\text{/gal.}} \times \frac{15}{60} = \$15 \text{ for 15 minute run}$$

$50 total

3. Nuisance Signal Cost:

Mission	- 2250
Chip Inspection	- 50

2300 x 0.75 = 1725
50 x 0.25 = 13

Average Cost: $1738/signal

4. Nuisance Signal Loss of Availability:

Mission Abort	-(1.5 + 1.0)	0.75 =	1.875
Chip Inspection	+ 1.0	0.25 =	0.25
	Average		2.13 hours

5. Cost of Degaussing Discriminating Chip Detector:

Apportioned Cost of Sensors, D&CM Display and Computer Development	=	$220,000
Acquisition Differential Cost per Aircraft is $200 for 1575 Systems	=	315,000
Opperation and Support Cost for Spares at F/R of $30/10^6$ hours is 150 x $850	=	128,000
		$663,000

6. Number of Nuisance Events for 10 Years:

Present System	Discriminating System	Reduction
Average 0.35 x 5 x 10^6 Hours = 1750	Maximum 0.1 x 5 x 10^6 Hours = 500	1250
	Minimum 0.05 x 5 x 10^6 Hours = 250	1500

Median - 1375 Nuisance Events Avoided

7. Savings in Ten Years:

1375 Events at $1738	=	2,389,750
System Cost		- 663,000
		$1,726,750

Time Average - 1375 x 2.13 = 2929 Hours Aircraft Availability

Savings/Cost Ratio $\frac{2390}{663} = 3.60/1$

Conclusions

The degaussing type discriminating chip detector system with a CS/C ratio of 3.6/1 indicate it is cost effective. In terms of the Army's operational effectiveness, the savings in aircraft availability and reduction in mission aborts will be quite significant and measurable. In the combat situation even one mission abort avoidance or one correct pilot decision on engine condition aided by the "smart" detector could more than justify the system.

The system cost and savings should be approximately the same whether built as a stand-alone system or integrated into the airborne D&CM system.

Recommendation

The GE degaussing discriminating chip detector development program for the T700 and future Army engines conducted in logical phases with discrete decision points should be funded, either as a stand-alone system or as part of an airframe-mounted integrated D&CM system.

LCC ANALYSIS FOR THE ENGINE LIFE USAGE MONITOR (ELUM)

Background

One of the principal functions of the multipurpose airborne D&CM (MADACM) system described in this section is the measurement and recording of temperature, time, and speed related parameters whose cyclic variations have a major effect on the life of key rotating and hot parts. An on-going CIP funded program has authorized the construction and flight test of three airframe-mounted ELUM development units. Two of these units measure, compute, and display life usage measures for five key parts on each of the two Black Hawk engines. Data is read manually from electro-mechanical counters and recorded by hand. If this system were to be adopted the concept might be changed as suggested in GE Report R79AEG1036, 31 December 1979 to incorporate solid state memory modules on each engine whose stored data would be periodically extracted electronically. The ELUM concept analyzed herein would measure, compute, and record the same life usage parameter with the same logic (software) that is being developed from the current program; the data display would be by cockpit LCD unit on pilot or mechanic demand instead of by electromechanical "wheels"; and the recording would be by solid state memory modules as suggested for present units. The current program results are directly applicable and relevant to the D&CM ELUM concept. The principal advantage of the candidate D&CM ELUM function over the present dedicated ELUM is that it would share the use of a common computer, display, and wiring system on the aircraft with three or more other cost effective functions with resulting cost, weight, and volume savings.

Assumptions

1. The D&CM ELUM function is chargeable with 30 percent of the MADACM development cost, acquisition cost, and failure rate.

2. The D&CM ELUM would replace the present engine-mounted engine history recorder (EHR).

3. The hot part cost figure for the T700-GE-401 engine hot parts (1975 dollars) cited in GE LAMPS Report R78AEG1023 "Inflight Engine Analyzer Study" can be updated, extrapolated, and utilized in this analysis.

4. The Army will utilize the ELUM data in their future maintenance and ILS program to determine when and/or if key hot parts should be replaced.

5. The present EHR can save 2% on hot parts replacement costs.

6. The ELUM or D&CM ELUM can save 7% on hot parts cost or 5% above the savings of the present EHR.

7. The present EHR cost (including wiring, etc.) to the Army in 1980 dollars is $4500. Three-quarters of the T700 engines shipped in the ten-year period between mid-1982-1992 would be shipped without EHR, a saving of 3/4 x 3150 x $4500, or $10, 631, 250. The remaining 25% would be retrofitted to remove the EHRs and replace one wiring harness at $2000/engine.

8. The cost of hot parts has escalated from 1975 to 1980 at the same ratio as the engine cost.

Program Costs

Development	$ 280, 000
Acquisition	
1500 x 0. 3 x 0. 8260	3, 717, 000
GSE - 10 x 50, 000	500, 000
Operation and Support	500, 000
Retrofit	
25 x 3150 x 2000	1, 575, 000
	$6, 572, 000

Program Savings

Reduction in Hot Parts and Labor

$$\$4.02 \times \frac{275}{150} \times \frac{5235}{950} \times 0.05 = 2,030,000$$

Elimination of EHR Engines to be Shipped Between 1982 and 1992

	10, 631, 250
Gross Savings -	$12, 661, 250

Results

Net Savings	12, 661, 258
	6, 572, 000
	$ 6, 089, 250

$$CS/C = \frac{12,661,250}{6,572,000} = 1.93/1$$

Conclusions

1. The incorporation of the sophisticated ELUMS life usage measurements, recording, and display system into the multipurpose airborne D&CM system provides the opportunity for the T700 and other Army engines to have the life usage measurement function at the lowest possible cost. This digital programable microprocessor based system has the flexibility of reprogramming to new or revised life measurement logic and/or limits to suit the engine or application. In the case of the T700-GE-700 engine, substantial cost savings will be realized due to the lower-per-engine cost of ELUM as compared to the cost of the present engine history recorder.

2. The use of engine life usage data for engine maintenance and logistic management in the Army needs to be studied in-depth and related to the ELUMS concept.

3. This cost effectiveness study is a first approximation and should be redone with emphasis on fleet introduction timing, retrofit plan, if any, and transition from the engine history recorder to ELUM.

Recommendations

1. Proceed with the development of the ELUM concept as an integral part of the multipurpose airborne D&CM system through flight test.

2. Concurrently, initiate an analysis of methods of engine life management in the Army environment.

3. Refine the ELUM cost effectiveness study to include the effects of fleet introduction, retrofit, transition schedules, and detailed cost savings.

LCC ANALYSIS FOR THE OVERTEMPERATURE MONITOR

Background

The field event analysis reported in Task I indicated a predicted 4 overtemperatures per 15, 000 hours. If this is representative of the average rate of occurrence for the next 5 million hours, there would be approximately 1400 occurrences in the ten-year period covered by this study. To determine the appropriate reaction to a cockpit instrument indication of overtemperature, both temperature and the number of seconds at that temperature must be known fairly accurately. For example, in Figure 28, an overtemperature at 910^{o}C for 40 seconds requires troubleshooting; for 45 seconds or more, overtemperature requires an engine removal and a shop visit to AVIM or Depot. The consequences of underestimating the overtemperature time can be severe; a mission abort, secondary engine damage, etc. Overestimation can result in an unnecessary engine removal. There is no system intelligence on Black Hawk now to compute the time-at-temperature relationship represented by Figures 28 and 29.

Rationale

There is not sufficient data to perform a meaningful LCC analysis at this time. However, overtemperatures have continued to occur with the production engines resulting in engine removals. It is reasonable to assume that the overtemperature function will be cost effective though not quantifiable at this time. Later, when more data are available, particularly from the Depot, an LCC analysis can be performed. Assuming that either or both the performance and life usage monitoring functions are provided, processing and computation capabilities will be available to perform the overtemperature function at no additional cost, other than provision of its software for its implementation.

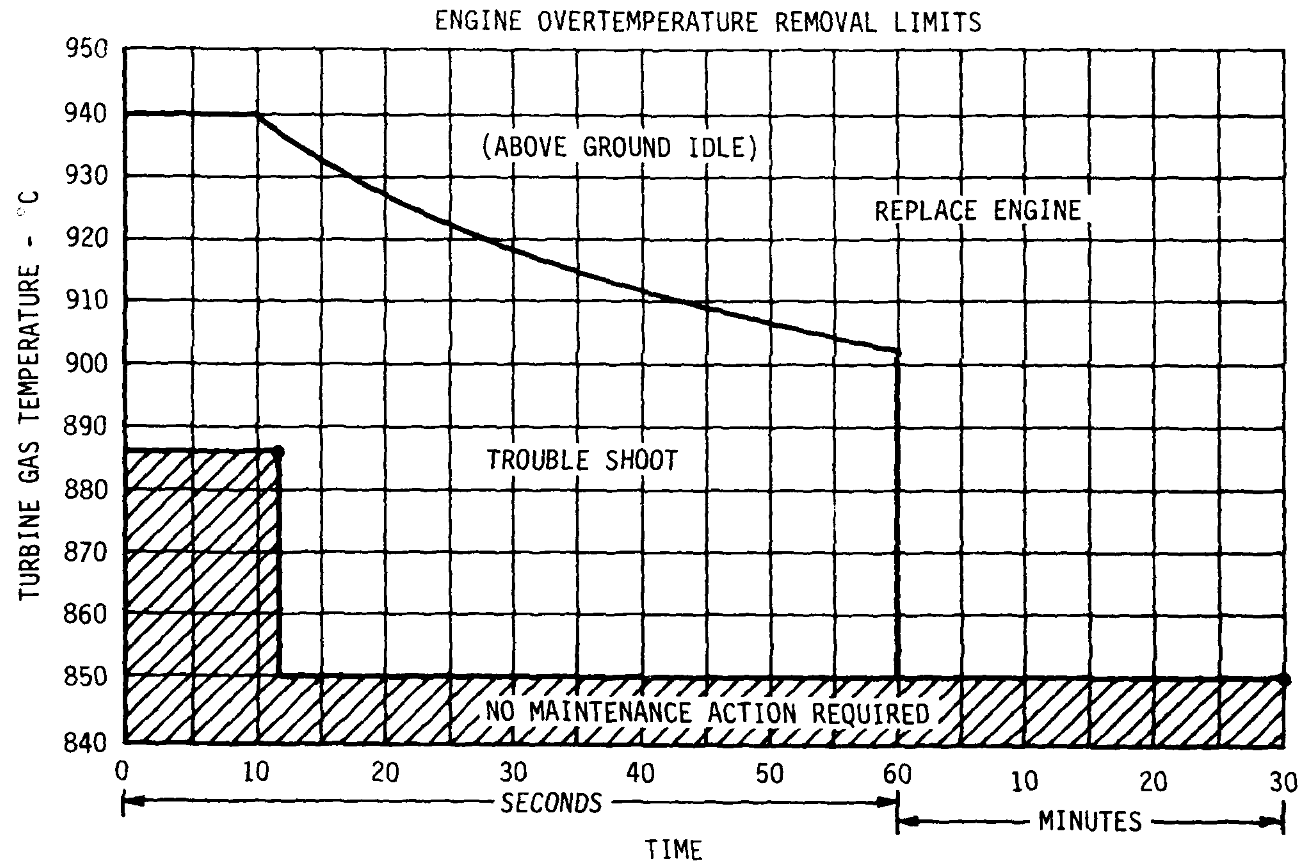

Figure 28. Above Ground Idle Engine Overtemperature Removal Limits.

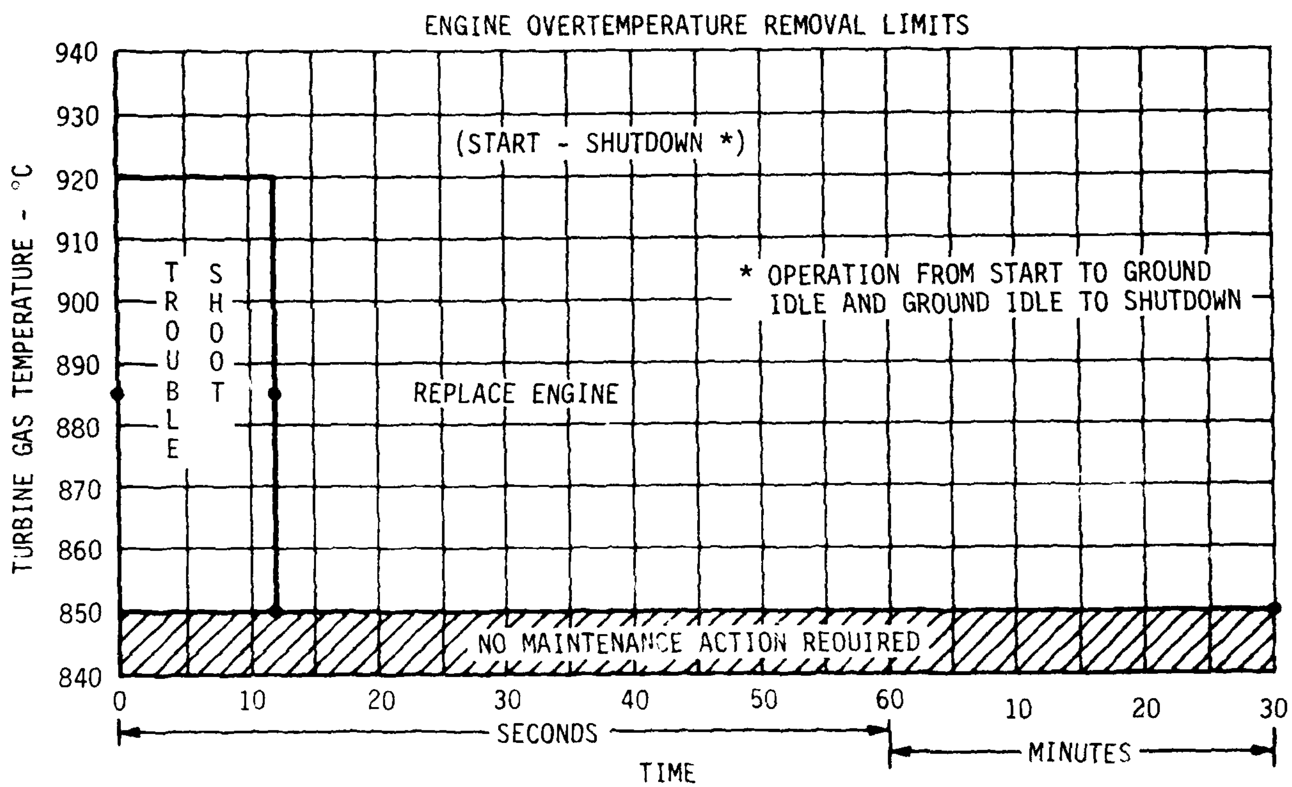

Figure 29. Starts and Shutdown Engine Overtemperature Removal Limits.

LCC Assessment Results

Program Cost

Development	$ 90,300
Acquisition	1,126,000
Operation and Support	212,158
TOTAL	$1,428,458

D&CM Saving

(Insufficient data to estimate savings.)

Conclusions

The overtemperature function is a valuable contributor to flight safety, aircraft availability and reduced maintenance costs and should be part of any future Black Hawk monitoring system.

Recommendations

Include overtemperature monitoring as going "piggy-back" on a basic MADACM requirement. Quantify overtemperature savings as part of any follow-on D&CM analysis based on latest field and Depot data.

TASK IV - D&CM HARDWARE DEVELOPMENT REQUIREMENTS

The engineering development work required to implement the D&CM programs recommended in accordance with this technical assessment is outlined below. The requirements for software and/or any additional data collection or analysis will be addressed in addition to that of hardware.

MODIFIED METS FOR MODULAR PERFORMANCE FAULT ISOLATION

Not recommended for development. No hardware, software, or further analytical work required.

COMPUTER FOR STANDARD METS OVERALL ENGINE PERFORMANCE

Computerized measurement of overall engine performance was recommended as the cost effective means of acheiving modular performance fault isolation for modern modular Army turboshaft engines. GE would be required to provide technical assistance to the government agency or contractor chosen to define the hardware and software to perform the signal conditioning, computation, etc., for T700 performance measurement. Presumably a similar effort would be required from other Army engine suppliers. The GE effort could amount to several man-months of engineering support to the computer hardware and software contractor.

SLAVE CHIP DETECTORS

Recommended for OWP modular fault isolation for METS and depot.

The Transistorized Chip Detector System (TCDS) electronic signal processing, detection and display module is fully developed and requires no further design or test effort for depot use. Six chip detector sensors, similar to the T700 B-sump interim chip detector and a suitable wiring harness would have to be defined, procured and packaged as a set or kit. There is no software involved.

To equip each METS facility with the TCDS, the electronic module might require MIL-STD tests for humidity, and/or mechanical shock.

Procurement for T700 applications would be through GE's Aerospace Ground Equipment Operation in Lynn, Massachusetts.

CONTROL SYSTEM ANALYZER (CSA)

Recommended for deployment to AVUM (Black Hawk companies), and/or AVIM (Black Hawk Battalions and METS), Options 2 or 3 per LCC analysis.

Hardware development essentially completed. Two sets deployed and in use for field evaluation. Design and/or quality refinements were incorporated in the second unit which is a production prototype.

Software Development - Electronic circuit design is solid state analog type. No software required.

Type Certification - In order for the Control System Analyzer to be authorized for issue to the operational units, the equipment must be Type Certified. Type Certification of ground support equipment (GSE) can be accomplished either by:

1. Completion of a series of environmental and simulated operational laboratory tests in accordance with MIL-STD specifications, or

2. Certifying the GSE along with the weapon system by deploying and using the equipment as the aircraft is subjected to the variety of environmental and operational conditions required for Type Certification. Although the Black Hawk is already Type Certified, the certification for SOTAS, the Black Hawk derivative, has not begun. There is time available to procure Control System Analyzers for Type Certification with the SOTAS aircraft after which these GSE units could be procured for both weapon systems.

MULTIPURPOSE AIRBORNE D&CM (MADACM) SYSTEM

Recommended for development. Development of the Multipurpose Airborne D&CM System involves four closely related tasks as follows:

Hardware - Airborne Computer-microprocessor based
- Sensors-Degaussing Chip Detector
  - Free Air Temperature Sensor - RTD Type (Commercial item - no development required)
- Display Module - Alphanumeric Dichroic LCD

Software - Algorithms, data tables, computer programming for monitoring performance, life usage, overtemperature and oil-wetted parts.

Program Structure and Timing

The MADACM System Development program logically fits into two ph ,ses. Phase I proves out the software and functional design of hardware with two sets of brassboard electronics and factory testing using T700 engine signal inputs. Phase II produces three sets of production prototype hardware for flight test. The Degaussing Chip Detector development, because of GE funded development already underway, would produce flight-worthy sensors in Phase I with no development envisioned in Phase II. Phase III is for preparation of hard tooling and qualification of units built from this tooling. The MADACMS and degaussing chip detector programs are depicted in Figures 30 - 33, and further described below.

Phase I

During Phase I of the development program, the major portions of the electrical design, display evaluation and software development tasks will be completed. The objective is to deliver to General Electric/Lynn, three D&CM brassboard systems suitable for test cell and flight test evaluation. During this phase of the program, a fourth system shall be fabricated and retained by GE/Wilmington for detailed bench evaluations. The fabrication techniques shall be based upon solderless-wrap technology. Field support for GE/Wilmington personnel are included in the Phase I. It is expected that the Phase I Program would require 21 months to complete.

Phase II

Phase II of the follow-on program will build upon lessons learned during brassboard evaluation and result in the delivery of three sets of production prototype hardware for test cell and flight evaluation. These prototypes will meet the form, fit and function requirements of production systems. They shall be proven flight-worthy; however, formal qualification tests will be performed only on the chip detector. Field support is included in the Phase II for GE/Wilmington personnel. It is expected the Phase II portion of this effort would have a 9 month overlap with Phase I and will require a total of 48 months to complete.

Phase III

Phase III can be concurrent with Phase II as shown in Figure 32.

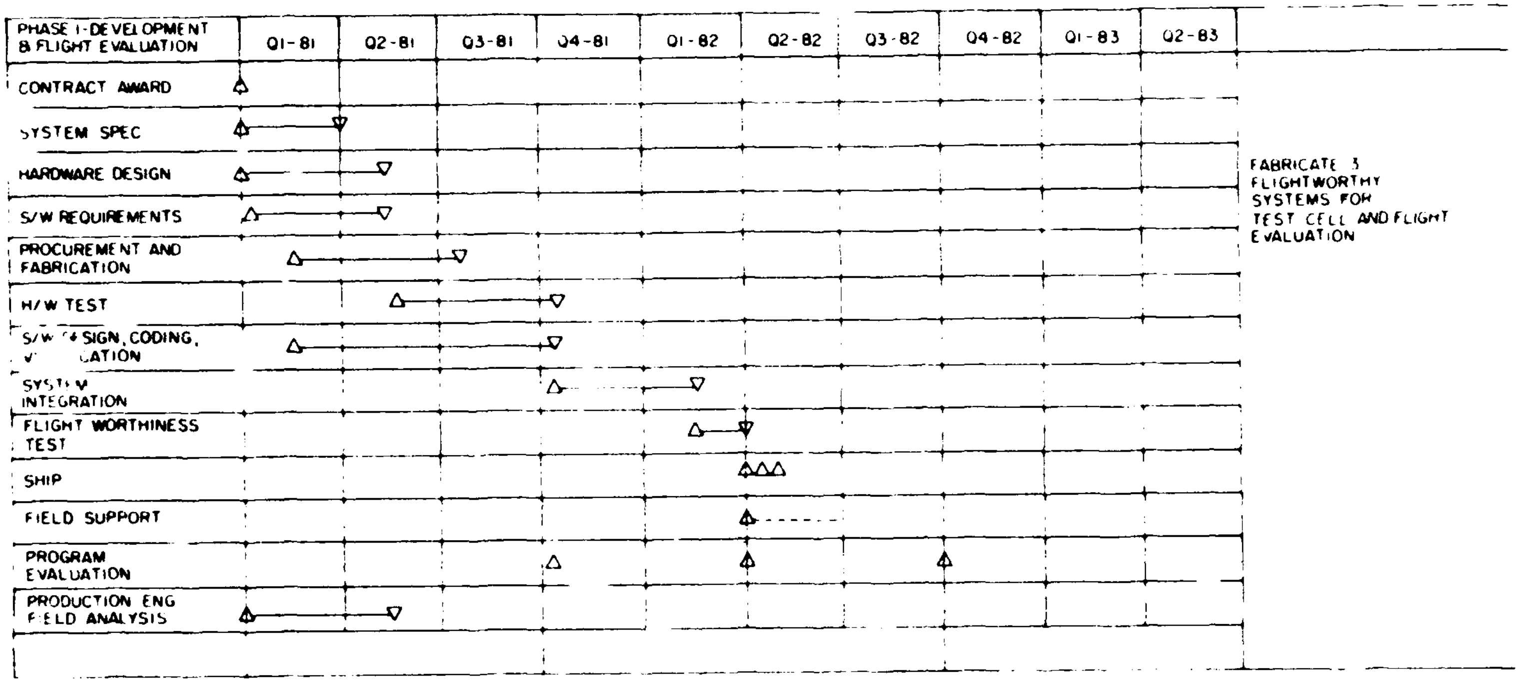

Figure 30. Development Multipurpose Airborne D&CM Schedule - Phase I.

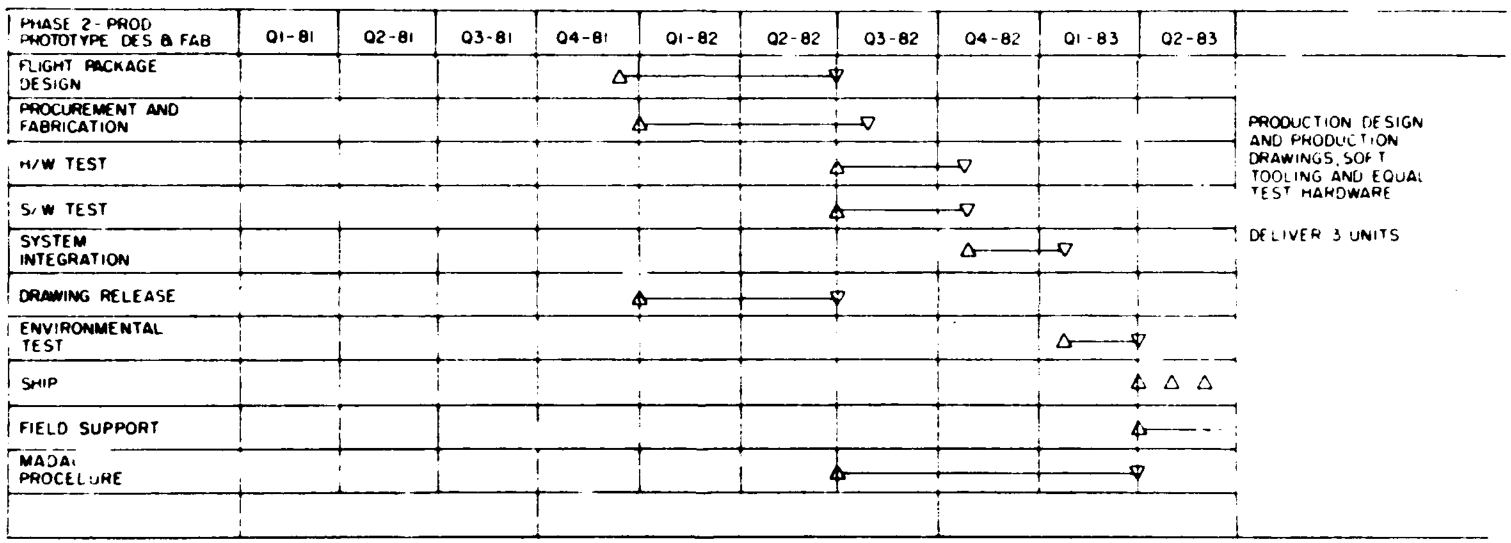

Figure 31. Development Multipurpose Airborne D&CM Schedule - Phase II.

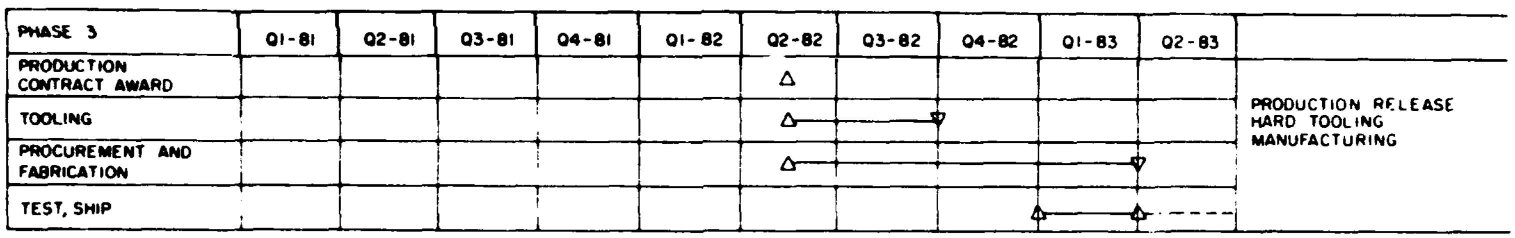

Figure 32. Development Multipurpose Airborne D&CM Schedule - Phase III.

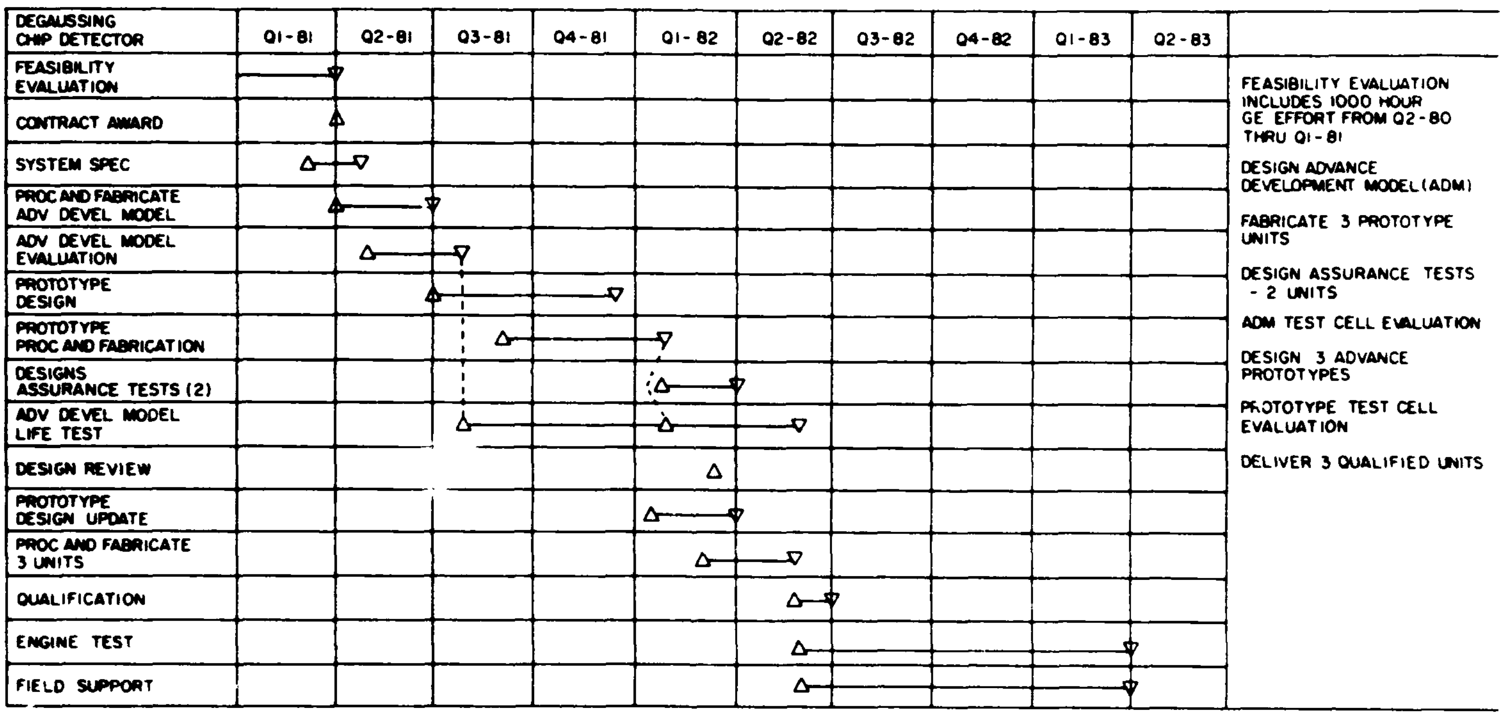

Figure 33. Development Degaussing Chip Detector.

DEGAUSSING CHIP DETECTOR DEVELOPMENT

The initiation of the Chip Detector Development is predicated upon the successful completion of the contractor funded Degaussing Chip Detector Feasibility Evaluation scheduled for the first quarter of calendar 1981 as shown in Figure 33. Three units to be delivered will be production prototypes.

Hardware Development

Hardware development is proposed to be done by GE's Aerospace Instrument and Electrical Systems Department of Wilmington, Massachusetts - the organization and people responsible for the design and construction of the current Engine Life Usage Monitor (ELUM) now being flight tested by the Army. Previous T700 D&CM hardware by the AI&ES Department include the Engine Health Monitor, Oil Monitor, FOD and Bearing Monitors and a bread-board digital combined Health and Life Usage Monitor. A description of the hardware to be developed for MADACM is found in the preceeding section covering Task II.

Software Development

Software development is the responsibility of the electronic systems designer based on the logic flow charts (Algorithms), curves and data tables provided by T700 Engineering. The major software task is programming for the Automatic Performance Monitor functions or Maximum Power Checks, Operational and Baseline HIT checks, and Power Margin. Of probably equal or greater complexity are the ELUM functions. This work, however, was already accomplished for the ELUM boxes currently being flight-tested and will essentially be duplicated for MADACM. Software logic for overtemperature monitoring and chip detection, as well as for BIT and the executive routine are considered relatively simple and straightforward.

Software development is a significant portion of projected costs. Based upon recent experience, it is estimated that this effort would be apportioned as follows:

Software Requirements	- 20%
Design	- 20%
Coding	- 20%
Verification/Validation	- 40%

Initial work would include comprehensive hardware and software systems analysis and result in a firm system specification. From this, detailed software requirements would be developed and, subsequently, detailed design initiated. During this process formal reviews of requirements, quality assurance and overall design would occur.

As the program continues through coding and unit evaluation, detailed test plans would be developed. These would be applied prior to and following the integration of hardware and software.

Memory requirements are expected to total 7 to 10 thousand words, of which some 5 thousand will be parameter values. Although the source code could be written in FORTRAN, for programs of this type and size it is more effective to use assembly language. A microcomputer development system appropriate for the processor selected would be used for program assembly.

FOLLOW-ON D&CM ANALYSIS

The comprehensive analyses performed under the current Contract DAAK51-79-C-0020, enabled GE to arrive at definitive conclusions, based on quantitative LCC analysis of available data. In this process, however, several areas were identified where follow-on analytical work is needed to further verify and update the conclusions. These analyses would cover the following areas:

1. Extend the T700 field event analysis from the period ending May 1979 covered by current contract, to some point encompassing at least 15, 000 hours of production engine field operation. This analysis is shown as a line item in MADACM Phase I, Figure 30, but could be authorized separately.

2. Develop methodology to evaluate the effects of timely fault isolation, repair and return to flight status on LCC considering:

   a. Aircraft availability.
   b. Aircraft safety.

3. Modify LCC model, if practical. (Utilize up-dated FMECA and production engine field history to establish component contribution to each symptom.)

4. Refine T700 APM LCC and perform O/T LCC analysis.

CONCLUSIONS

General

The conduct of this D&CM assessment by the Aircraft Engine Group was an excellent experience for those who were involved in it. The effort, by utilizing the T700 as typical of future Army Modular engines, involved the functions of Design, Maintainability, Service, Support, Systems, Product Assurance and Instrument Department personnel from several functions. The approach was to identify the expected problems/symptoms, and define the most reasonable way to diagnose and/or monitor the expected occurrences in operational use. This approach was not directed toward new equipment development, but attempted to utilize available assets, e.g. Manpower, Technical Manuals, and Test Stands with a minimum of new equipment to be carried on board the helicopter. As such, the results and recommendations are equally oriented toward development of ground support and helicopter on-board equipment.

One of the disappointments with this effort was the contractors' inability to apply sufficient time and effort toward quantifying the pay-off for the Army to develop this equipment. The LCC studies were a sufficient first order conservative approach for early management decisions, however, it was recognized that some of the more important aspects, such as availability, were not quantified and as such, the pay-off computations are low and incomplete.

Specific:

1. Modular Performance Fault Isolation (MPFI) by component and gas path analysis performed in the field on specially modified METS facilities would not be cost effective and would be difficult to implement under Army field maintenance conditions.

2. Automating the present METS data acquisition and processing functions to improve the evaluation of engine overall performance is the practical and cost effective approach to MPFI at the AVIM level.

3. The Slave Chip Detector (SCD) concept applied to METS at the AVIM level is cost effective based on predicted OWP failure rates.

4. The Control System Analyzer (CSA) set is a useful and necessary tool for aircraft and engine control system fault isolation at both AVUM and AVIM levels. The deployment plan for the CSA set, however, is critical to its cost effectiveness.

5. The Degaussing Chip Detector (DCD) is clearly cost effective either by itself or as part of MADACM and has a great potential for reduction of mission aborts and maintenance at the AVUM level due to nuisance chip signals.

6. The Multi-purpose Airborne D&CM (MADACM) System is cost effective using a common micro-processor for the following four major functions:

   a. Automatic Performance Monitor (APM) - savings in fuel and engine operating time.
   b. Engine Life Usage Monitor (ELUM) - savings by replacement of two EHRs with one MADACM.
   c. Degaussing Discriminating Chip Detector (DCD) - savings by reduction in nuisance signals and mission aborts.
   d. Overtemperature Monitor (OTM) - potential savings by automatic time-temperature monitoring (not yet quantified).

7. The effective implementation of the MADACM concept dictates a simple system which will have a low risk development program and produce a system adaptable to other applications. In addition the MADACM must have:

   a. Easy to read cockpit display.
   b. Operating simplicity.
   c. Simple software and hardware for reliability.

8. The T700 Black Hawk field event analysis by D&CM Symptom should be continued to cover production aircraft and engines in the Army operating environment and include refinement of the LCC analysis of the Automatic Performance Monitor and completion of the LCC analyses of the Overtemperature Monitor.

9. The LCC Analyses performed under this contract resulted in dollar cost pay-offs that, in most cases, did not fully reflect the operational benefits the use of the proposed D&CM improvements would produce. To improve the accuracy of Army LCC analyses, a method of quantifying several measures necessary for improving the validity of LCC analyses and should be developed and tested by applying them to one or more T700 LCC analysis using the T700 LCC computer model. Included would be dollar savings for ground test, mission aborts, aircraft and engine availability, ultimate reduction of spares, and reduced flight time.

RECOMMENDATIONS

1. Do not modify the six existing METS facilities for performing Modular Performance Isolation by gas path analysis.

2. Initiate a program to provide computerized overall engine performance data acquisition and processing on all Army METS facilities.

3. Procure and install T700 Slave Chip Detector sets at each Army METS facility and at the T700 depot facility for Oil-Wetted Part Modular Fault Isolation.

4. Complete the field evaluation of the Control System Analyzer Set and Type Classify.

5. Support the development and evaluation of the T700 Degaussing Chip Detector as soon as the G.E. funded feasibility demonstration is successfully completed. (First quarter of calendar 1981).

6. Initiate the Phase I MADACM development program.

7. Contract for a follow-on to the current D&CM contract DAAK-51-79-C-0020 to cover production Black Hawk/T700 field event symptom analysis and refinement of LCC analysis.

8. Request a G.E. proposal for development of a method for quantifying several measures necessary for performing Army helicopter engine LCC analyses. Use T700 as example. Measures to be quantified include installed engine ground test, mission aborts, aircraft and engine availability and aircraft and engine flight time.

LIST OF ABBREVIATIONS

A/C	Aircraft
AGB	Accessory Gearbox
APU	Auxiliary Power Unit
AVIM	Aviation Intermediate Maintenance
AVUM	Aviation Unit Maintenance
B-H	Flux-Field Intensity
CHIPS	Magnetic Chip Tally
CIP	Component Improvement Program
CMD	Command
D&CM	Diagnostics and Condition Monitoring
ECU	Electrical Control Unit
EOP	Engine Operating Pressure
EOT	Engine Operating Time
EXC	Excitation
FAT	Free Air Temperature
GCT	Government Competitive Test
GSE	Ground Support Equipment
H	Flux
HIGE	Hover In Ground Effect
HIT	Health Indicator Tests
HMU	Hydromechanical Unit
HOGE	Hover Out of Ground Effect
HP	High Pressure
HPT	High Pressure Turbine (Gas Generator Turbine)
HRS	Engine Hours
IFR	Infrared Radiation
ILS	Integrated Logistics Support
KG	Kilogauss
KIAS	Knots Indicated Air Speed
LCC	Life Cycle Cost
LCF	Low Cycle Fatigue
LDT	Linear Differential Transformer
LP	Low Pressure
LPT	Low Pressure Turbine (Power Turbine)
LRU	Line Replaceable Unit
LVDT	Linear Variable Differential Transformer

LIST OF ABBREVIATIONS - Continued

MA	Mission Abort
MADACM	Multipurpose Airborne Diagnostics and Condition Monitoring
METS	Modular Engine Test System
MPFI	Modular Performance Fault Isolation
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NG (N_g)	Gas Generator Speed
N_p (NP)	Power Turbine Speed
N_r	Aircraft Rotor Speed
OWP	Oil-Wetted Parts
PA	Pressure Altitude
PIDS	Prime Item Development Specification
PM	Power Margin
PTO	Power Take Off
QL	Torque - Left Engine
QR	Torque - Right Engine
RID	Resistance Temperature Device
TAS	True Air Speed
TCDC	Transistorized Chip Detector Circuit
TCDS	Transistorized Chip Detector System
TGT	Turbine Gas Temperature
TRQ	Torque
TTI	Time at Temperature Index
UCR	Unscheduled Component Removal
UER	Unscheduled Engine Removal
UMA	Unscheduled Maintenance Action
SOTAS	

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