Diagnostic System Requirements for Helicopter Propulsion Systems

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Automatic diagnostic systems have proven effective in reducing accidents, maintenance costs, and operating costs associated with turbine powered equipment. Current diagnostic applications are generally limited to large aircraft and stationary power plants due to high initial cost. A need exists for a simple low-cost diagnostic system for "general aviation" category aircraft. This is especially true for helicopters due to their complex propulsion systems and frequent deployment with minimal crew into remote locations. Recent advances in electronic technology, as evidenced by the pocket calculator, make such a system feasible; however, the system must be carefully tailored to the requirements of the user. One such set of general requirements is presented, together with supporting rationale, from the viewpoint of a helicopter manufacturer. A conceptual diagnostic system design which meets these requirements is included.

I. Introduction

AUTOMATIC diagnostic systems are currently used in a variety of applications, some of which are listed in Table 1. As indicated by Table 1, diagnostic system development has been directed primarily toward relatively expensive aircraft and power plant applications. Even AIDAPS, although installed in a UH-1 helicopter for evaluation purposes, was developed to establish a concept for use in more advanced Army aircraft. Although these current systems may be cost effective in their intended application, they are much too complex and expensive to use in "under $1M" type aircraft. Diagnostic technology at this end of the spectrum is still pretty much that of the Wright brothers. Is this adequate? For piston-engined, fixed-wing aircraft, probably so. For light/medium turbine powered helicopters, probably not. These aircraft have complex propulsion systems—engines, driveshafts, transmission, gearboxes, driveshaft bearings—and are often deployed with minimal crew into remote areas where maintenance facilities range from little to none. The present solution is to require frequent inspections, overhauls, and part replacements, much of which would be unnecessary if the actual condition of the system could be determined. So the need for a simple, low-cost diagnostic system certainly exists, and when we consider the electronic evolution which gave us the pocket calculator, we can believe the technology exists also. The problem is to apply our technology to the need in a cost-effective manner. The "Autosense" automotive system shows that this can be done, if careful attention is paid to the user's requirements. The intent of this paper is to examine such requirements from the viewpoint of a helicopter manufacturer. These requirements have evolved during the course of some seven years of involvement in military diagnostic research programs, in-house studies, and evaluation of various diagnostic techniques.

II. Basic System Design Considerations

The following considerations define the broad framework within which the system should be designed.

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Operational Suitability

It may sound like "motherhood" to say that the system must be "operationally suitable," but many a device has ended up in the corner of the hangar because this requirement was lightly dismissed. We will consider operational suitability from the standpoint of our "toughest customer," the commercial helicopter operator. The typical operator has a sizeable investment in several helicopters which are available for hire to companies engaged in offshore drilling, mineral exploration, etc. He is not interested in frills or R&D programs. The monitoring system has to work and it has to pay off. In this environment, we can bias the system away from expensive, fully automatic features, and toward direct operator interfaces.

The system must reliably detect problems. As a rather arbitrary (but achievable) goal, there should be at least a 95% probability that the system will correctly diagnose the situations for which it is designed. It is most important that it not "cry wolf." In this regard, our goal is that not over 2% of the warnings be false. And of course, the system must require essentially no maintenance itself.

Inspection, Diagnostic, or Prognostic Capability

In order to determine what combination of these capabilities we want in our system, let us first consider the following definitions[1]:

Automatic Inspection—monitoring of an airshaft's condition by electronically controlled measurements of given parameters.

Automatic Diagnosis—parameter measurements being subjected to predetermined algorithms and logic which have been electronically implemented in terms of identification of a problem.

Automatic Prognosis—parameter measurements being subjected to predetermined trend analysis which has been electronically implemented and resulting information being displayed in terms of operating life remaining prior to exceeding predetermined limits which directly correlate to part condition.

In this context, it is evident that our system must have some level of inspection and diagnostic capability. The specific items to be inspected and diagnosed will be covered subsequently. Prognosis, however, is another matter, because this requires that we not only determine that something is wrong, but also the degree of "badness," the rate at which it is getting worse, and the probable life remaining. This may be nice to know, but is somewhat academic, since once a problem is diagnosed, some action must be taken in any event. A

Table 1 Typical current diagnostic system applications

Acronym	Designation	Application
AIDS	Airborne Integrated Data System	Commercial airliners
IECMS	In-Flight Engine Condition Monitoring System	A7E
MADARS	Malfunction Dection, Analysis, and Recording System	C5A
CITS	Central Integrated Test System	B1
AIDAPS	Automatic Inspection, Diagnostic, and Prognostic System	UH-1H
EHMS	Engine Health Monitoring System	T38
TCIS	Tubine Condition Instrumentation System	Peak power electrical generating stations
AUTOSENSE	(Trade name)	Automobile engine diagnosis

requirement for prognostic capability will obviously increase the cost and complexity of the diagnostic system. The main problem, though, is in developing the prognostic data, i.e., trend analysis into the diagnostic system logic. For example, during the AIDAPS development program, literally hundreds of hours of degradation rate tests of engine and drive train components failed to produce the type of repeatable failure pattern data required for prognosis. Therefore, given the present state-of-the-art, we will orient our requirements toward inspection and diagnosis only.

Baseline Data Requirements

In order to determine if something is faulty, it must be compared against some standard of performance or "baseline." For the more complex diagnostic analyses such as engine performance and vibration analysis, the establishment of the proper baseline is of crucial importance. Baselines come in two basic styles: customized and universal. A customized baseline applies only to one specific *serial number* component, and consists of recorded performance, vibration, or other data as applicable, obtained from that component "when new." A universal baseline is applicable to all components having the same *part number*, such as all T-53-L-13B engines. From a purely diagnostic standpoint, customized baselines are generally preferred. However, customized baselines must be individually formed and stored by the diagnostic system. The requirement for this capability in the diagnostic equipment adds considerable complexity and cost. Also, whenever an engine, gearbox, or other component is changed, the baseline data stored in the diagnostic systems must also be changed. This causes operational and logistic problems for the operator which may make the diagnostic system more trouble than it is worth. Therefore, we will make every effort to select diagnostic techniques which do not require customized baselines.

Ground Based, Airborne, or Hybrid

There are three basic system configurations, the relative advantages of which are extensively considered in Ref. 2. For the ground-based system, sensors and wiring are permanently installed in the aircraft, terminating in a test connector. The diagnostic equipment is essentially a test set, which is periodically connected to the test connector for a ground run-up or maintenance test flight. Therefore, one diagnostic unit can service several aircraft. Even though this is the least expensive approach as regards the initial cost of the diagnostic equipment, system capability is so limited that overall cost effectiveness is highly doubtful. Many of the features which make a diagnostic system cost effective require full-time monitoring, as will be subsequently discussed. A fully airborne system, however, may be too large and expensive for the type of application considered here. This leads us to a hybrid-type configuration, consisting of a basic airborne system with optional ground-based accessory equipment for extended capability as required. The remainder of this discussion will concentrate primarily on the requirements of the basic airborne system.

System Applicability

If cost and complexity are to be minimized, the system must be applied only to those subsystems which warrant monitoring. There is no point in "fishing in a pail," i.e., installing expensive equipment to monitor events which are improbable, noncritical, or otherwise obvious. One way to approach this problem is to consider the relative involvement of the various subsystems in material failure related accidents. Table 2 shows a set of such data for a typical light helicopter. In this case, it appears that the most effective application of automatic diagnosis would be the propulsion systems. A similar study should be made for each specific aircraft application.

III. Functional Requirements and Methodology

The next step in our design is to define the specific functional requirements of the diagnostic system, together with feasible methods for meeting these requirements.

Engine Health Check

Many of the current diagnostic systems provide for the detection of deterioration in engine gas path components—compressors, combustors, turbines, and nozzles—by means of gas path analysis. One of the analytical techniques for making this determination is described by Ref. 3. Using this technique, component condition is inferred from changes in certain performance characteristics such as airflow, component efficiencies, and nozzle areas. These characteristics are not directly measured, but their changes from "baseline" condition are calculated, based on measured changes in parameters such as gas temperature and pressure at various stations, rpm, and fuel flow.

Good as it is, there are certain practical problems which make gas path analysis of questionable feasibility in a simple, low-cost diagnostic system. These problems include additional instrumentation requirements (both in quantity and quality) and the necessity to gather and store baseline data, with the attendant problems previously noted with regard to custom baselines. Also, the degree of analysis may overkill the problem. What the operator really wants to know is whether

Table 2 Material failure related mishaps by subsystem—typical light turbine helicopter

Subsystem	Major mishaps, %	Minor mishaps, %[a]
Engine	56	30
Transmission and drive train	23	19
Airframe	9	1
Hydraulic	0	13
Other subsystems	0	9
Unknown	12	28

[a] Minor mishaps are those involving little or no damage to the aircraft, such as precautionary landings.

or not his engine is "sick," i.e., will it deliver at least the minimum specification performance upon which his aircraft performance charts are based. There are existing manual power check procedures described in the individual flight manuals for making this determination which can be automated in the diagnostic system. Since the power check can be made manually, why do it automatically? The reason is that the manual operations involved are awkward and time consuming, and the results are of questionable accuracy. It is usually necessary to read several gages with "eyeball accuracy" while hovering the aircraft, and to enter these readings into tables or charts, to determine engine condition. A typical flight manual procedure consists of a check of referred output torque as a function of referred gas generator speed, against "min. spec." installed performance. This type of check does not require a custom baseline, and can be readily automated using existing instrumentation, plus inlet air temperature and pressure measurements for use in calculating the referral parameters.

Engine Stall Detector

An engine stall is especially bad in a helicopter because of the rapid load reversals which occur in the rotor drive systems, generally requiring a special inspection. The reason for the stall detector is that it is not always obvious that a stall has occurred, and conversely, a stall may be suspected when none has occurred. A stall may be unnoticed, unrepeatable, or unreported. In a multiengined aircraft, it may be difficult to determine which engine stalled. The stall detector will help insure that necessary inspections are performed, while "precautionary" inspections are avoided. A stall is indicated by a sudden drop in compressor discharge pressure (CDP) accompanied by an increase in exhaust gas temperature (EGT). The pressure change can be detected by a pressure switch, both sides of which sense CDP, but with high-side pressure routed through a small accumulator and orifice. The orifice is sized such that during normal operation, essentially the same pressure is sensed on both sides of the switch. If the pressure suddenly decreases, high-side pressure is momentarily trapped in the accumulator, and the switch is tripped. It is essential that a concurrent increase in EGT be sensed, otherwise a normal shutdown might be interpreted as a stall.

Engine Coastdown Check

Another simple test which can be easily incorporated is to check the time required for the engine to coast to a stop on shutdown. At least one engine manufacturer now requires that a log of coastdown times be kept as part of an "on-condition" maintenance program. An abnormally short coastdown time indicates a tip rub, defective bearing, or other mechanical problem in the gas generator rotor. (The power turbine rotor cannot be checked this way because it is mechanically connected to the main helicoptor rotor.) For the coastdown check, it is not necessary to time the entire interval from throttle cutoff to rotor stoppage. During the initial portion of the coastdown, braking is primarily aerodynamic, and mechanical condition has little effect on the rate of deceleration. As the rotor slows, frictional forces become increasingly predominant. Therefore, the latter portion of the coastdown is preferred for diagnostic purposes. It may be difficult to sense absolute stoppage, therefore the check should be made between two low-rpm points, such as 30% and 10% rpm.

Engine Vibration Check

Engine vibration provides an excellent indication of mechanical problems such a foreign object damage, missing blades, and rotor unbalance. Engine mounted accelerometers, with signal conditioning circuitry in the diagnostic unit, can continuously check for exceedance of the manufacturer's limits. A new high-frequency analysis technique (subsequently described under transmission and gearbox monitoring), may be employed to detect bearing defects.

Transmission and Gearbox Monitoring

Transmissions and gearboxes are currently monitored by various combinations of magnetic chip detectors, oil pressure and temperature instrumentation, oil filter condition checks, and spectrometric oil analysis. Each of these methods involves some measure of individual expert interpretation, and may only indicate failures which are well advanced. This has led to extensive research into the use of vibration signal analysis for early detection of bearing and gear defects. We all have a "feeling" that an increase in vibration is an indication of trouble. Implementing this simple phenomenon into a diagnostic system can be deceptively difficult. One problem is that a complex mechanism such as a helicopter transmission, which may be transferring several hundred horsepower, is a fairly noisy machine at best. Therefore, the existence of a small defect has negligible effect on the overall noise level. Reference 4 summarizes many of the signal analysis techniques which have been developed in an attempt to extract

Table 3 Typical engine operating limits—light turbine helicopter

Turbine outlet temperature limits		
Starting	Power transient	Steady state
Maximum (no time limit)	Maximum (no time limit)	Maximum cruise
10 second limit	5 minute limit	Maximum emergency
Turbine inspection limit	6 second limit	30 minute maximum (one engine inoperative)
Turbine removal limit	Turbine removal limit	Takeoff (5 minute) limit

Gas generator rpm	Output torque
Maximum continuous	Maximum continuous
15 second limit	Emergency limit
Absolute limit	30 minute limit
	10 second limit

Power turbine rpm				
Output torque	No limit	15 second limit	Turbine removal required	Gearbox removal required
	Power turbine speed			

defect signals from background noise. One of these techniques, which Ref. 4 calls Bearing "Ring" Analysis, shows particular promise, and has been the subject of further research[5] This technique, which involves the demodulation of a high-frequency carrier signal, has been applied by BHT to the detection of implanted defects in UH-1 drive train components with excellent results. These tests indicate that a "baseline" vibration signature is not required if the carrier frequency, bandwidth, and gain settings are properly chosen. Therefore, the diagnostic system should incorporate vibration analysis of the transmission and gearboxes, preferably using a high-frequency demodulation technique. Testing will be required to adapt the technique to each specific application.

Tail Rotor Drive Shaft Bearings

In-flight failure of one of the hanger bearings which support the tail rotor driveshaft could result in failure of the drive shaft and consequent loss of tail rotor thrust, which is an emergency situation. These bearings could be monitored by vibration; however, considering several bearings per aircraft and accelerometer cost in the range of $200 to $300 each (plus signal conditioning equipment), it is desirable to use a less exotic method if possible. Since the hanger bearings are not buried in a gearbox, the desired effect can be achieved by a simple thermocouple arrangement with appropriate logic within the diagnostic unit. If the temperature of one of the bearings exceeds the average temperature of the set of bearings by a predetermined amount, a failure is indicated.

Operational Limit Monitoring

One of the most useful functions of a diagnostic system is continuous monitoring of operational limits. This is illustrated by Table 3, which shows the types of operating limits which are imposed by the manufacturer for a typical light helicopter engine. When we consider that the aircraft may have more than one engine, and in addition rotor, drive train, and other restrictions, it is evident that mental bookkeeping of operational limits is a formidable task. The diagnostic system can continuously monitor all critical parameters, record any exceedances, and indicate the proper maintenance actions.

Maintenance Data Recording

A natural fallout of a diagnostic system installation is accurate, automatic recording of historical maintenance data. This includes engine operating time, number of starts, number of overtemperature events, and transmission overtorque events. An especially important feature is automatic computation and recording of engine operating cycles. The service life of certain engine rotating components is expressed in terms of operating cycles in accordance with cycle count criteria established by the engine manufacturer. Manual calculation and recording of operating cycles can be difficult, especially in a multiengine aircraft.

Engine Performance Trend Data Collection

"Trending" is a diagnostic technique which utilizes a long-term time history of critical parameters for the detection of degradation. A simplified set of trend data might consist of a log of referred values of exhaust gas temperature, compressor discharge pressure, and output torque, obtained on a daily basis at a constant value of referred gas generator speed. To implement this capability, our system must perform the following functions: 1) display the actual gas generator speed which will give the desired referred value, to the pilot upon command; 2) record a frame of data upon pilot command; and 3) refer the recorded data to sea-level standard conditions, and store for postflight recall. In its simplest form, trending will be accomplished by manually plotting and interpreting the recorded data on a daily basis. However, if more sophistication is desired, the data can be off-loaded for ground processing at a central computer facility.

IV. Conceptual Design

There are numerous equipment configurations which can be devised which will integrate the various requirements into a total system design. Figure 1 shows a block diagram of a possible system, together with optional accessory equipment. Signals from the sensors would be received, conditioned, and analyzed by the Central Microprocessor Unit (CMU). A maintenance panel on one face of the CMU would display maintenance data. A cockpit panel would provide pilot interface with the system. Configuration details must be tailored to each application, but the individual units could appear as follows.

Cockpit Panel

Figure 2 shows a conceptual cockpit panel arrangement. Pushbuttons enable the pilot to call the value of gas generator speed to be used for trend data collection, engine health test results, and real-time values of certain parameters. Results are shown by an alpha-numeric display. The "Trend Record" button causes a frame of data to be recorded on pilot command.

Central Microprocessor Unit with Maintenance Panel

The Central Microprocessor Unit (CMU) receives and conditions sensor input signals, performs the necessary calculations and logic, provides outputs to the cockpit display, and stores data and maintenance messages for ground readout. This unit would probably be located in an electronic equipment compartment, accessible to the ground crew. Figure 3 shows a possible maintenance panel configuration. Data and maintenance messages are displayed in sequence, and identified by "identification number." Only those maintenance messages which are pertinent to the flight will be displayed. Table 4 show a typical set of identification numbers, and the corresponding data or message.

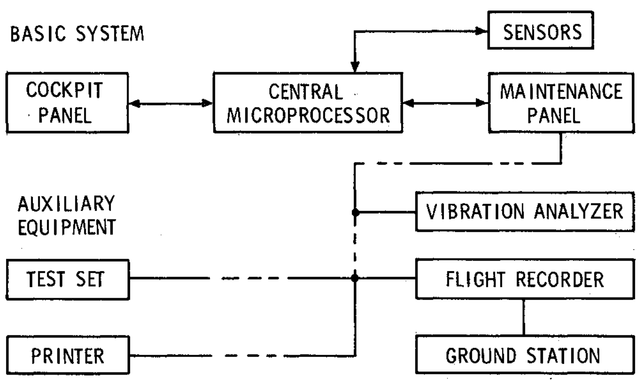

Fig. 1 System concept schematic.

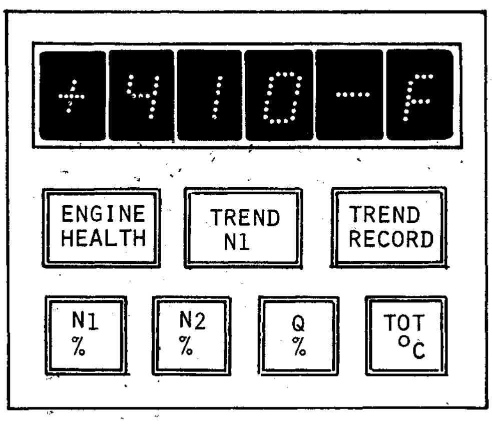

Fig. 2 Cockpit panel.

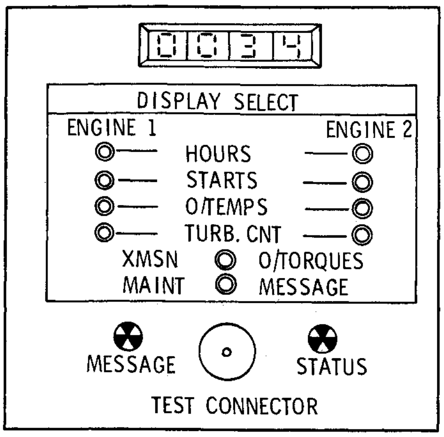

Fig. 3 Maintenance panel.

Table 4 Typical recorded data and message output format

Identification no.		Data or message
00	Trend data	Reference number
01		Engine inlet pressure, psia
02		Engine inlet temperature, °C
03		Referred gas generator rpm
(04-10)		(Additional trend data)
11	Maintenance data	Operating time, h
12		Operating cycles
(13-15)		(Other maintenance data)
16	Maintenance messages	Start temperature limit exceeded
17		No. 2 hanger bearing running hot
18		Transmission power limit exceeded
19		Engine stall experienced
(20-100)		(Additional maintenance messages)

Accessory Equipment

The capability of the basic system can be extended by means of accessory equipment such as airborne recorder, ground playback system, maintenance data printer, and vibration analyzer, all of which are off-the-shelf items. A test set could also be provided for use in troubleshooting the system.

V. Cost Effectiveness

It is now time to consider the system cost and how much it will save.

Cost

The system described would have been prohibitively expensive only a few years ago. However, when one considers the electronic technology evolution which has taken us from the tube-type computer to the pocket calculator, we can appreciate the potential which now exists for low-cost diagnostic hardware. Both in-house and outside studies indicate the following costs to be reasonable:

Cockpit panel & CMU	$6000.00
Special sensors	$1150.00
Installation	$1000.00
Profit	$2000.00
Installed price	$10,150.00

System Savings

The actual saving which any one operator will realize is a function of many variables. Therefore, we will examine the areas in which savings will occur, and illustrate the magnitude, where possible, by means of examples and reasonable assumptions. It should also be noted that "effectiveness" can mean more than savings in dollars. There are certain convenience and customer appeal features which are a natural fallout of a diagnostic installation. These too will be considered.

Overhaul Costs

Current general aviation practice is to overhaul propulsion system components on a "hard-time" TBO (time between overhaul) basis, i.e., overhauls at fixed operating time intervals, regardless of condition. The TBO's are established by the manufacturers so as to preclude wearout and fatigue failures, usually under "worst case" conditions. The practice of overhauling at fixed TBO intervals is very simple to implement operationally; all that is needed is a good log of operating time. Unfortunately a lot of money is spent on overhauls which are, at best, premature with respect to the actual condition of the components. Worse yet, there is evidence that excessive overhaul frequency may actually increase the number of failures, due to the introduction of a new infant mortality period following each overhaul.[6] Of course, there may be considerable loss of revenue while the aircraft is grounded for an engine or transmission change. These considerations are causing increasing interest in "on-condition" maintenance, i.e., maintenance based on actual condition rather than operating hours. "On-condition" maintenance is an obvious choice, provided there is a method of determining what the condition is. A diagnostic system can certainly help in making that determination, at least to the extent of extending, if not eliminating, the TBO intervals. The system can also gather the additional data which the engine and airframe manufactuer may require as part of an "on-condition" program. To assess the potential savings involved, consider the following hypothetical example of the overhaul costs for the components of a "light twin" helicopter:

Engines, 2@$20K	$40K
Transmission	$10K
Tail rotor gearbox	$0.5K
Total propulsion system	$50.5K

Prorated cost, 1500 h TBO = 50,500/1500 = $33.33/h

Now, assuming that the diagnostic system has been proven at least to the extent that the manufacturers are willing to recommend a TBO extension to 2000 h:

Prorated cost, 2000 h TBO = 50,500/2000 = 25.25/h

Saving = $8.08/h

Of course, this highly simplified case overlooks several variables. For one thing, not all overhauls are for TBO compliance. The diagnostic system cannot postpone an engine overhaul due to foreign object damage, for example. By the same token, the cost of a premature removal should be minimized by the diagnostic system's ability to detect an incipient failure in its early stages, rather than waiting until the component is a "basket case."

Accident Costs

Reducing the number of material failures which actually occur, by means of early detection, should certainly reduce the number of material failure-related accidents. Some of the costs incurred when an accident occurs are covered by insurance, so reducing the accident rate does not have an immediate effect on the operator's cash flow. This does not mean that accidents are of no consequence. Insurance rates are ultimately based on experienced losses. Further, certain losses, such as loss of revenue, are not covered by insurance.

To get an order-of-magnitude feel for the numbers involved, let us assume a $750K helicopter, with a 6% annual hull insurance premium of $45K. Assuming that 25% of the premium covers propulsion system related accidents, the cost for this category is $11.25K per year. If the diagnostic system is even 50% effective in preventing these type accidents, the potential savings is $5.62K per year or $5.62 per hour, at 1000 h/yr utilization.

Special Inspections

Certain events such as engine overtemp, engine stall, overspeed, and transmission overtorque necessitate special inspections to determine the extent of damage, if any. As previously noted, it is sometimes extremely difficult to know for sure when one of these events occurs. The diagnostic system can make this determination and thus match the maintenance action to the event. Essential inspections are made, but time is not wasted on precautionary inspections due to suspected exceedances which did not, in fact, occur.

Increased Operational Limits

Experience with current monitored applications indicates that some of the various operational limits can be safely increased, when the actual degree of exceedance is accurately known. Some of the engine manufacturers, for example, are allowing higher overtemperature limits for specific, monitored situations. This, in turn further reduces the number of special inspections.

Troubleshooting

It is often difficult to isolate the source of a noise, vibration, or malfunction. The usual result is "shotgun maintenance," i.e., best-guess substitution of good parts until the trouble disappears. This is obviously wasteful of both time and material, and increases inventory requirements. The diagnostic system can greatly assist in localizing a problem and in determining whether or not the corrective action taken was effective.

Warranty Terms

The problem with warranties is separating use from abuse. Continuous monitoring can greatly reduce warranty claims due to abuse, thus enabling the manufacturer to offer better warranty terms. Precedents are presently being established in this area. Of course it is possible to "cheat," with or without a diagnostic system, but assuming that most warranty claims which result from abuse are inadvertent, the diagnostic system can reduce such claims, with long-term benefits for all.

Customer Satisfaction

This may be the most nebulous, yet most important category of all. The operator who has fewer accidents, emergency landings, precautionary landings, and unscheduled removals will gain a reputation for efficient, on-time service. His customers will appreciate the added margin of safety provided by continuous, automatic monitoring. Ultimately, his customers will be the beneficiaries of lower cost of ownership.

Savings Summary

Considering only overhaul and accident costs, a potential saving of over $13.00/h has been shown for the simple example cited. An annual utilization of 1000 h gives a saving of $13K per year. This means that the system can more than recover its cost during the first year of operation from these savings alone. Even greater savings can be expected due to fewer special inspections, extended operating limits, reduced troubleshooting time, better warranty terms, and customer satisfaction.

VI. Future Expansions and System Integration

Diagnostic systems are inherently well suited to integrate with other advanced concepts which are currently in development. Some such concepts, in brief, include electronic engine fuel controls, advanced chip detectors, structural integrity recording, vertical scale instruments, cathode ray tube cockpit displays, multiplex data busses, and computer sharing. In each case, integration of a diagnostic system works to the mutual advantage of both systems.

VII. Conclusions

A cost-effective diagnostic system for helicopter propulsion systems is currently feasible, using microprocessor-based electronic technology, provided the system is carefully tailored to the user's requirements. These requirements define a basic airborne system, with provisions for accessory equipment, oriented toward inspection and diagnosis of those subsystems which are most prone to failure. Customized baselines should be avoided if possible. System functions should include engine health, stall, coastdown, and vibration monitors, drive train vibration analysis, hanger bearing temperature check, operational limit monitor, and maintenance data recording.

References

[1]"System Specification for Army Aircraft Automatic Inspection, Diagonstic, and Prognostic System (AIDAPS)," U.S. Army Aviation Systems Command, St. Louis, Mo., Jan. 1973.

[2]"Concept Formulation Study for Automatic Inspection Diagnostic, and Prognostic System (AIDAPS)," U.S. Army Aviation Systems Command, St.Louis, Mo., USAAVSCOM TR 72-20, Sept. 1972.

[2]Urban, L.A., "Gas Path Analysis Applied to Turbine Engine Condition Monitoring," *Journal of Aircraft,* Vol. 10, July 1973, pp. 400-406.

[4]Houser, D.R. and Drosjack, M.J., "Vibration Signal Analysis Techniques," U.S. Army Air Mobility Research and Development Laboratory, Ft. Eustis, Va., USAAMRDL TR 73-101, Dec. 1973.

[5]Darlow, M.S., Badgley, R.H., and Hogg, G.W., "Application of High-Frequency Resonance Techniques for Bearing Diagnostics in Helicopter Gearboxes," U.S. Army Air Mobility Research and Development Laboratory, Ft. Eustis, Va., USAAMRDL TR 74-77, Oct. 1974.

[6]Dougherty, J.J. and Blevitt, S.J., "Analysis of Criteria for On-Condition Maintenance for Helicopter Transmissions," U.S. Army Air Mobility Research and Development Laboratory, Ft. Eustis, Va., USAAMRDL TR 73-58, Sept. 1973.