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U. S. ARMY

TRANSPORTATION RESEARCH COMMAND

FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 63-48

PORTABLE AIRCRAFT CONDITION EVALUATOR RECORDER

Project PACER

Project 9R89-02-015-16
Contract DA 44-177-TC-750

December 1963

prepared by:

THE BENDIX CORPORATION
York Division
York, Pennsylvania

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HEADQUARTERS
U S ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

This report is a discussion of the Contractor's study and investigation of the present Army aircraft maintenance system and, as a result of this study, the design of a portable, automatic evaluating/recording system (PACER) which would improve and automate the Army aircraft maintenance complex.

This command concurs in the conclusions contained in the report. However, this Command does not concur in the Contractor's recommendation that a follow-on contract be awarded for the fabrication of the PACER system. This Command is of the opinion that normal operating levels of vibration, pressures, and temperatures must be established prior to the development of specific hardware.

This Command recommends that the next step taken in the program to derive an electronic maintenance inspection and diagnostic system be an experimental study program which will lead to the formulation of go/no-go limits for normal operation. This Command further recommends that this experimental study be conducted on each of six Army aircraft of the same model instrumented with an automatic light aircraft readiness monitoring (ALARM) system modified to read out levels of vibration, temperature, and pressures.

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Task 1D141812D18416
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Contract DA 44-177-TC-750
TRECOM Technical Report 63-48
December 1963

PORTABLE AIRCRAFT CONDITION EVALUATOR RECORDER
(Project PACER)
Final Report

Prepared by
York Division of The Bendix Corporation
York, Pennsylvania

for

U.S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

FOREWORD

This document, TRECOM Technical Report 63-48, represents the final report for Project PACER. The project code name, PACER, is derived from the nomenclature for the electronic checkout system, which is "Portable Aircraft Condition Evaluator/Recorder". The program was conducted by the York Division of The Bendix Corporation for the United States Army Transportation Research Command: C. A. Malami, Project Officer. The over-all project was under the direct supervision of K. S. Walmer, Project Engineer.

The program was initiated June 28, 1961, under contract DA 44-177-TC-750 and was organized to support the determinations set forth in Staff Study, Project 9R-38-01-017, House Task 12.129, dated February 1960, and Project ALARM, contract DA 44-177-TC-641.

Special acknowledgement is made of the technical support provided by USATRECOM during the course of Project PACER. Acknowledgement is also made of the support provided by the following companies: Lycoming Engine Division, AVCO Corporation; Vertol Division, Boeing Company, Morton, Pa.; Bell Helicopter, Fort Worth, Texas; and Grumman Aircraft, Bethpage, L.I., N.Y.

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INTRODUCTION

This report covers the objectives and results of the PACER program as they were evolved during the course of the project. The purposes of the program were (1) to investigate the present Army aircraft maintenance and inspection system to determine the advantages of an automatic, evaluating, recording system over the present system; (2) to determine present aircraft problem areas; (3) to design a portable, automatic, evaluating, recording system which would improve and automate the Army aircraft maintenance complex.

It was determined (1) that the PACER System would eliminate needless removal, teardown, inspection, and reassembly of good components and thus measurably reduce the over-all maintenance man-hour requirements; (2) that the PACER System would effectively monitor most problem areas; (3) that the PACER System would facilitate the measurement of the deterioration, or wear-rate, of aircraft components and, from this, predict component malfunction or failure.

CONCLUSIONS

The program results indicate that the signals obtained from the recommended sensors will be of useable levels and contain the necessary information to determine the condition of an aircraft by PACER application. The results further indicate that portions of the present Army aircraft maintenance techniques and procedures can be modernized and reduced with PACER type equipment. The ability to predict component failures from the data collected by the PACER System will provide an improved maintenance procedure with substantial economies and resultant dollar savings.

RECOMMENDATIONS

Based on the results of the study and design phases, it is recommended that a follow-on contract be awarded to fabricate a PACER System to demonstrate the feasibility and potential value of this equipment. This would allow component wear-rate data to be accumulated; this type of data was conspicuous by its lack of availability throughout the study phase. It is recognized that the potential of the designed equipment justifies its further development to provide statistical data to the Army logistics areas concerned with spare parts procurement. The application of a PACER System would also be used to determine limits for the ALARM System. The use of a PACER System would give the advantage of "built-in" test equipment and the feature of recording the information on punch tape as well as on printed tape.

STUDY PHASE

GENERAL

The study phase of this program has been based primarily on documents and discussions with personnel on trips to various military bases, aircraft and component manufacturers. Also included are the results of the various trips and documentation that were compiled during the Project ALARM Study Phase.

Documentation from Project ALARM can be found in the bibliography of the September 1960 report on Automatic Light Aircraft Readiness Monitor Project 9R38-01-017-55, Contract DA 44-177-TC-641.

ALARM AND PACER RELATIONSHIP

The PACER System proposed under contract DA 44-177-TC-750 has been designed for compatibility with an ALARM System (Project 9R89-02-015-16) installed in a test-bed aircraft. However, the PACER System is not wholly dependent upon an ALARM System for operation. The only portions of ALARM required by the PACER are the sensors utilized during dynamic and in-flight modes of the ALARM operation. These sensors are employed to monitor vibration signatures, pressure, flow, and temperature. No part of the ALARM control/display unit is used by PACER. The sensor outputs from an ALARM implemented aircraft are disconnected at the control/display input connector and mated to the PACER System. Therefore, this type of design allows for maximum use of the sensors to determine aircraft condition. (See Figure 1.)

The basic difference between the ALARM and PACER design lies in the number of sensors employed and in the manner in which the sensor output signal is processed and evaluated. The ALARM System is a go/no-go device while the PACER System is a comparator as well as a go/no-go indicator.

The PACER System can be employed for any aircraft condition evaluation and may be utilized in conjunction with any type of checkout system provided that proper sensors and connectors are used to supply inputs to the PACER System in a manner similar to the ALARM System. Thorough studies must be made of any system, however, to determine precise location and number of appropriate sensors required to provide the desired inputs to the PACER System.

PRESENT ARMY AIRCRAFT MAINTENANCE

The Army aircraft maintenance system is divided into three broad categories of organizational, field, and depot maintenance (ref. AR 750-5).

Organizational maintenance is that maintenance authorized for, performed by, and the responsibility of a using organization on its own equipment. This maintenance shall be defined as inspecting, cleaning, servicing, preserving,

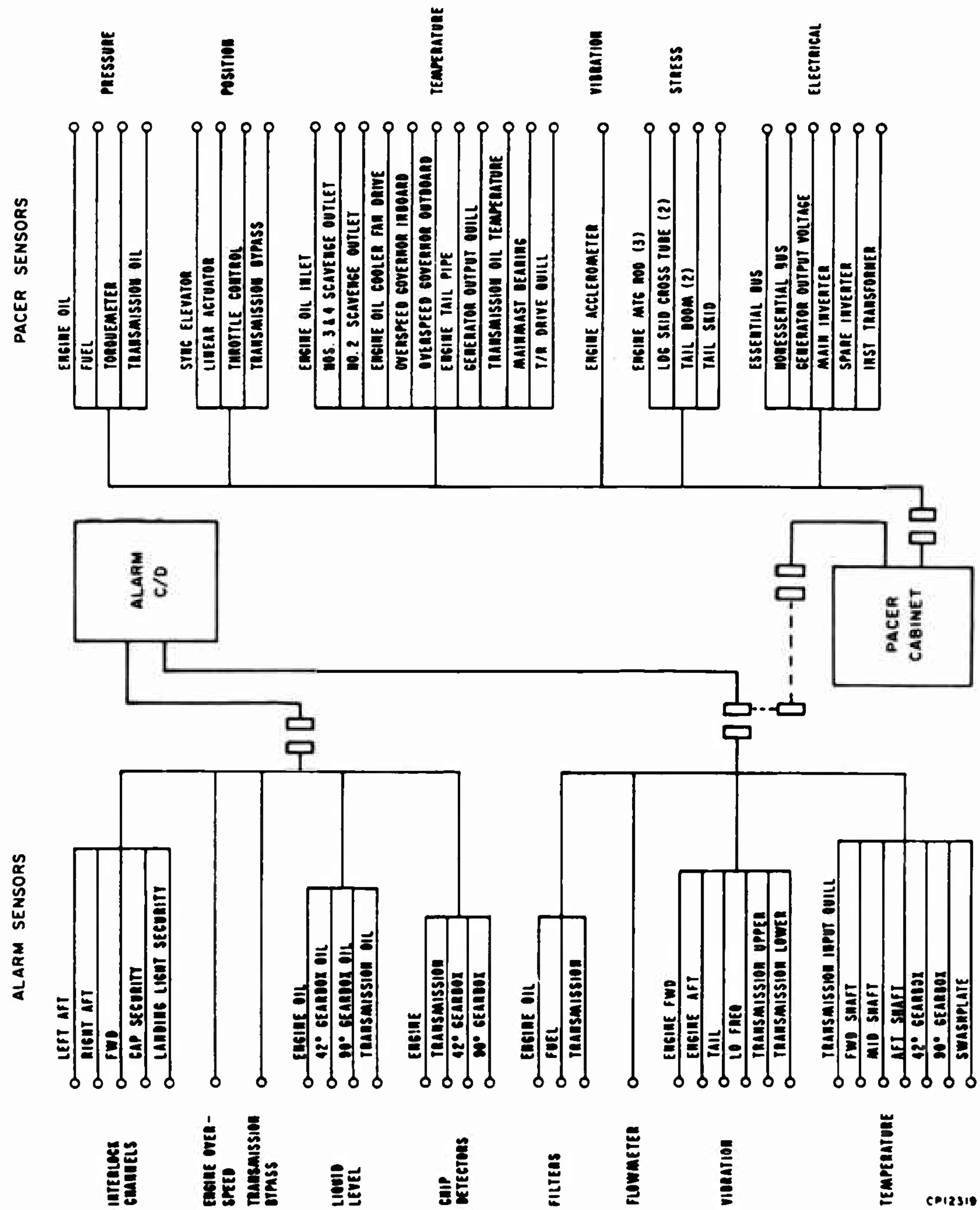


FIGURE 1. ALARM/PACER INTERCONNECTING RELATIONSHIP

lubricating, and adjusting as required; it may also include minor parts replacement not requiring high technical skills or expensive complicated or bulky test equipment or tools. This category shall include first- and second-echelon maintenance.

a. First-echelon maintenance shall be defined as organizational preventive maintenance only. This shall include proper care, use, operation, cleaning preservation, lubrication and such adjustment, minor repair, testing and parts replacement as prescribed by pertinent technical publications, tool lists and part lists.

b. Second-echelon maintenance shall be defined as corrective maintenance at the organizational level. This shall include maintenance performed by personnel trained beyond the capabilities and facilities of first-echelon maintenance according to appropriate publications authorizing additional tools together with the necessary parts, supplies, test equipment, and skilled personnel.

Field maintenance shall be defined as that maintenance authorized for and performed by designated maintenance personnel in direct support of using organizations. This shall be limited to repair and/or replacement of unserviceable parts, assemblies or components. This shall include third- and fourth-echelon maintenance.

a. Third-echelon maintenance shall be defined as the direct support of organizational maintenance by specially trained units which shall repair components and assemblies and perform repairs for lower echelons within limits imposed by specific authorization of tools, parts, and test equipment. These units also support the lower echelons by providing maintenance assistance, mobile repair crews, and repair parts as required.

b. Fourth-echelon maintenance shall be defined as the support of lower echelons of maintenance by units organized as semi-fixed or permanent shops. The principal function is to repair assemblies, components and end items for return to the user or to maintenance float stock.

Depot maintenance shall be defined as that maintenance required for major overhaul or complete rebuilding of assemblies, components and/or end items. This shall be defined as including fifth-echelon maintenance.

Fifth-echelon maintenance shall be defined as the rebuilding of major items, assemblies, tools and test equipment, and the fabrication of parts peculiar to the support of such rebuild.

A concise summary of the five echelons of maintenance follows:

First Echelon - Preventive maintenance

Second Echelon - Inspection and corrective maintenance

Third Echelon - Inspection and replacement

Fourth Echelon - Inspection and repair

Fifth Echelon - Rebuilding and overhauling

The PACER System would be utilized at the third and/or fourth echelon of maintenance.

Discussion of skill level and special test equipment at each echelon will be covered elsewhere in this report.

DETERMINATION OF AIRCRAFT CONDITION

Aircraft condition is presently determined by the inspection requirements set up for the first and second echelons of maintenance. According to the breakdown of maintenance as previously discussed under the Army maintenance system, first echelon is classed as preventive maintenance, and second echelon as corrective maintenance. First and second echelons determine whether the aircraft and/or component is serviceable for aircraft flight. The third echelon is used as a back-up for the second, but the main requirement is replacement of components, with the fourth echelon as repair. This, then, leaves the inspection requirements of the aircraft to first- and second-echelon maintenance. Component inspections are then relegated to the third and fourth echelons.

The degree to which each echelon overlaps is spelled out by the Maintenance Allocation Chart. The echelon to which a maintenance function may be assigned is, to a large degree, determined by the skill level and the test equipment that is available.

Test equipment at the first and second-echelon level is elementary and very portable. A list of typical first and second-echelon test equipment may contain the following items:

Rule, Measuring
Gauge, Feeler
Stop Watch
Dye Penetrant
Wrench,Torque
Indicator, Dial
Multimeter
Tensiometer

In addition to the foregoing items, equipment for manual blade tracking and a low-pressure air supply for fuel tank testing is also required. In addition to this equipment are the requirements for a delicate sense of touch and trained eyes. The sense of touch is required for investigations of rough bearing operation and temperature changes. The trained eye is necessary to pick up a flaw or minute change that would not be obvious to a casual observer.

Third- and fourth-echelon maintenance test equipment can become very complex, bulky, and specific in purpose. One piece of test equipment may be multipurpose and another may be for a specific test for one component, such as tachometer tester.

A list of typical test equipment as supplied to a third- and fourth-echelon maintenance group would contain the following items:

Inspection Kit, Magnetic
Test Stand, Hydraulic
Tester, (Fuel Quantity and/or Fire Detector Test) MD-1 or MD-2A
Tester, (Seat Belts) Weight
Kit, (7 Hel 053) Tail Rotor Balance
Kit, (7 Hel 054) Main Rotor Balance
Kit, CO, Colorimetric Detector
Analyzer, Ignition
Scale, Aircraft Weighing
Tensiometer
Tester, Material Hardness
Resistance Bridge
Hydrometer
Barometer
Pyrometer
Stroboscope
Fluorescent Inspection Kit
Stand, Test, Aircraft Generator
Stand, Test, Electrical
Test Set, Armature
Test Set, Battery
Test Stand, Ignition, Magneto
Tester, Starter Torque
Resistor, Decade
Test Set, Electron Tube
Test Set, Synchro
Tester, Electrical Thermometer
Tester, Pyrometer and Thermocouple
Tester, Tachometer
Tester, Torque Wrench and Tensiometer
Tester, Slaving Gyro
Test Set, Automatic Pilot
Tester, Gyro Loop and Roll
Tester, Pitot and Static Systems

The preceding is not a complete list but only a typical example of those pieces of equipment which are required beyond the scope of first- and second-echelon maintenance. Every third- or fourth-echelon group would not necessarily be assigned all of the above. In fact, many of the items are authorized only at fourth echelon. There are many bases, however, at which both third and fourth echelon are set up as a unit. This discussion will then concern itself with the over-all picture rather than with the third and fourth echelons of maintenance test equipment separately.

As previously stated, much of the test equipment for third- and fourth-echelon maintenance becomes complex, bulky and specific in purpose. This means, then, that the equipment becomes less portable and less versatile and requires a skilled operator. Some of the test equipment must, in fact, be kept in controlled atmospheric conditions to perform its function. This group includes the instrument test equipment in particular.

There are pieces of test equipment which are capable of being transported to an aircraft and then used for inspection of portions of the aircraft component or system without removal of the system or component. A portable hydraulic test stand would be in this category.

Equipment that would be portable and yet would require removal of the component for inspection would include such equipment as the tail and main rotor balance kits and fluorescent inspection kit.

One purpose of this program is to increase the effectiveness of the maintenance of Army aircraft. To achieve better economic utilization of Army aircraft, it becomes necessary to provide a system that would ideally combine all of the inspection tools into a single unit and have the unit automatically perform the inspection, determine deficiencies and with these data predict the future requirements.

Another objective of this program is to reduce the number of inspection tools to a minimum, to raise the effectiveness of the proposed equipment to a higher level, if possible, and to reduce the skill level. It becomes apparent at the beginning that it will be impossible to eliminate the requirement for the various different pieces of equipment. It is also apparent that many portions of the inspection requirements may be improved to provide a more reliable determination of aircraft condition.

Determination of aircraft condition is dependent to a great degree on the ability of the maintenance personnel. The degree to which an individual is proficient in his assigned responsibilities is almost as varied as the number of personnel. Two individuals with identical backgrounds may make different decisions concerning the same piece of equipment. As a result, the limits imposed on an aircraft and/or components as being serviceable or not are subject to a wide range of interpretations.

These variations in interpretations are costly to the maintenance program in at least two ways. One, a decision to remove a component for overhaul before it is required is an unnecessary expense. Two, a decision to hold a component in service when an overhaul should have been made can be expensive both in material and in flying personnel casualties.

With the PACER concept of automatic checkout procedure, the inspection becomes a stable procedure. The possibility of premature and "too late" removals is lessened and a more effective inspection of dynamic components is made.

PRESENT AIRCRAFT PROBLEM AREAS

Discussion of problem areas includes only the general areas of the various aircraft. New aircraft such as the HU-1, AO-1, and HC-1 have not had a sufficient background to determine all problems. The HU-1 was represented by numerous unsatisfactory reports but is not well represented in the Unsatisfactory Report Digest.

Problem areas were established by unsatisfactory reports, the Unsatisfactory Report Digest, discussion with project personnel at TMC, St. Louis, Logistical Evaluation Reports, and discussion with maintenance personnel at NCGD, New Cumberland, Pa., and TRECOM, Ft. Eustis, Va.

Reciprocating Engines

Excessive engine oil consumption was the main problem for all engines. The primary cause was an ineffective air filter on the carburetor. Introduction of fine, abrasive material into the fuel system via the air filter caused excessive wear, and subsequently, excessive oil consumption. Projects concerned with improvement of the air filter to eliminate this problem are underway.

Another major problem area is premature engine removal. This problem has been due primarily to insufficient follow through when discrepancies are found during routine inspection (TB AVN 23-5-1 Unsatisfactory Report Digest). All authorized maintenance required to return engines to a serviceable condition is not being performed. Engines are taken out of service when an authorized replacement or repair of a subassembly would have been sufficient. The basis for discrimination between an authorized subassembly replacement or engine removal may be loosely defined or be determined on the basis of "the way it has always been done". With no absolute limits, decision then must be based on indefinite and loose terms. The interpretation of such definitions then may be as varied as the interpretor. The experienced mechanic would probably make a better decision. He may also tend to follow the "we have always done it this way" attitude, whereas an inexperienced mechanic would probably base his decision primarily on the technical manual instructions. With no definite limits, the inexperienced mechanic would probably tend to be overcautious in his decisions. Under these conditions, the percentage of premature engine removals would undoubtedly increase.

Fuel System

Most of the problems in this area have been in the fuel pumps. This has been a problem for particular aircraft, and each problem has been resolved after the aircraft has become operational. However, there is still some degree of malfunctioning in the bypass valve operation. The contamination of fuels with water and/or foreign solid particles is still a problem. Fuel leaks due to cracks, weld failures, and mating of dissimilar metals are a problem.

Oil System

Malfunctioning pumps and minor leaks still occur frequently enough to be a problem. Determination of problems due to contamination of the oil systems normally is more readily defined in that temperature and magnetic chip detectors are used in conjunction with pressure. These additional sensors allow for fault isolation in the various components; a single pressure sensor would not do this.

Hydraulic System

The major problem in this area has been "O" ring failure. Most of the "O" ring failures have been attributed to two causes: faulty installation and abrasive action. Installing "O" rings without following the instructions pertaining to the necessary precautions causes many failures. These could include tearing the "O" rings with tools or fingernails, sharp-edged shoulders, metal threads, etc. Abrasive action might be the result of dirt or foreign particles being introduced both internally and externally by accidental means during repair or refill of the hydraulic system, or by atmospheric conditions. Atmospheric conditions would include such factors as desert operation, dusty operation, unprepared airstrips, etc.

Not included in the hydraulic system, but related to it, is the brake system, which has been troublesome in that the brake system may have been inadequate. This type of problem would normally be solved by redesign or product improvement.

Electrical System

Unsatisfactory report history indicates that the main problem is circuit overload due to failure or shorting of electrical apparatus. Fraying and/or wearing of insulating material causing electrical breakdown is not the major problem; rather the basic electrical problem is the failure of apparatus to which the power is sent or from which a signal is received. This apparatus includes fuel quantity indicators, tachometers, generators, and practically all instruments.

The problem of instrument failure may not be quite as serious as has been indicated. Discussions with N.C.G.D. maintenance instrument repair personnel have indicated that an estimated 60 percent of all instruments turned in are not defective but that some part of the circuit is defective. If the instrument fails to indicate, it is a simple procedure to remove the instrument and repalce it with a known good instrument and, thereby, determine if the instrument be defective. The instrument which has been removed, however, is now in the repair category whether repair is warranted or not. This additional teardown, test, and rebuild is due to insufficient maintenance follow-through. The maintenance personnel did not check the system thoroughly. Fault isolation using this method is not an effective maintenance procedure.

Control System

Maintenance problems in the control system area appear to be created by insufficient or improper maintenance. Over- and under-torquing of cable bracket mountings, lack of bearing lubrication and improper rigging are the major faults. These are due primarily to the basic requirement and habit of visual inspection: "If it looks good, it must be ok". There are many instances of control system components that are inaccessible and, therefore, difficult to inspect. Mounting-bracket hole elongation due to insufficient torque on the mounting bolts is a problem that occurs frequently. Visual inspection for security is the inspection requirement, and torque on the bolts cannot be checked by visual inspection.

Power Train

Premature transmission removal, hanger shaft bearing failures and tail rotor drive shaft misalignment form the greater proportion of problems in this area.

Sikorsky performed a study on transmission and gearbox removals and found that almost 90 percent of all removals were unnecessary. The greater portion of removals were due to scheduled time-before-overhaul (TBO) procedures and not malfunction. However, even with the malfunction, the only way to determine if the transmission or gearbox required an overhaul was to tear it down. No percentage was indicated for this portion; but it can be assumed that even for an indicated malfunction, such as chip detection, this still does not automatically indicate a need for overhaul. To estimate that 20 percent of all indicated malfunctions would not require an overhaul would appear to be conservative.

Hanger bearing failures included over-and under lubrication of the bearing and cracked mountings due to excessive torque and/or vibration. Misalignment of the drive shaft has caused some coupling separations and may have contributed, at least to some extent, to hanger bearing failure.

Rotors and Blades

Blade tracking is still a real problem, although in some aircraft, built-in tracking ability alleviates the problem. However, hand or manual blade tracking is still the prevalent method and at best it is time consuming and dangerous to personnel.

Separation of rotor blade skin from body due to defective bonding is also a problem. Bond in the wooden blade also may be troublesome especially in dry areas.

Various other problems which occur in the rotor head and tail rotor yoke are excessive wear because of loose bolts and lack of lubrication on control bearings and yoke bushings. Insufficient torque or excessive torque has also caused hole elongation or cracked mountings.

Turbine Engines

Problems in the turbine engine have been primarily in the hot end exhaust section. High temperature plus vibration and high speed have caused breakdown of the "T" canes, combustor housing, and turbine wheel blades. Internal oil leak into the compressor bleed section has caused a smoke problem in the cabin area. Vibration has also been a problem, but this has normally been a reaction due to other deficiencies. The torque-meter assembly and the automatic fuel control unit have also been sources of trouble. Many of the problems have been assigned to projects for investigation and discussion for product improvement. This is a relatively new engine in the Army aircraft system; therefore, some of these problems must be considered as applicable to engine development.

Air Frame

Approximately 30 percent of all projects (excluding engines) in the Unsatisfactory Report Digest TB-AVN 23-5-1 are based on some portion of the air frame. This in itself indicates that maintenance on the airframe consumes a great deal of inspection and maintenance repair time.

Skin and bracket cracks head the numerous reasons for malfunction or failure reports. Causes vary from excessive vibration to insufficient or excessive torque and loose rivets. Other air frame deficiencies include loose mounting bolts, mounting hole elongation, cowling deformation, chafing of lines due to insufficient ties, and poor design of cowling and access panels.

Summary of Problem Areas

A discussion of the various sensors and the areas for which they have been assigned will be covered in a later section. The discussion will include sensor selection for various applications in the PACER System. As was discussed in the aircraft condition determination section, the areas to which the greatest project efforts have been directed have been those areas specifically called for by the inspection requirements. The flight safety aspect has also been stressed. Many of the problems that have been covered by the unsatisfactory reports and discussed with maintenance personnel have very little or no effect on flight safety.

Some deficiencies, as detailed by project engineers for corrective action, were not applicable to functional parts. The corrective action for some deficiencies was to eliminate the defective part (TB-AVN 23-51-H21C-13 8.18, H-37A-7 16.12). Some deficiencies, such as skin cracks in nonstressed areas, may be severe, with no corrective action other than stop drilling.

Because of product improvement and standardized repair procedures, problem areas continually change. Because of this fact, general areas or types of deficiencies are considered, not specific ones.

The areas considered are monitored by the following modes: temperature, pressure, flow, strain, vibration and electrical analysis by measurement of voltage, current, resistance, etc. With the above mentioned monitoring modes, it becomes possible to monitor very closely the condition of most areas of an aircraft. The decision as to whether the area is critical and warrants the installation is covered elsewhere in this report.

FUTURE AIRCRAFT

Because of their differences in purpose, size, range, and capability, present Army aircraft present a wide variety of maintenance problems. There are now 11 different aircraft in the Army system with just 2 aircraft using the same basic engines; the HU-1 Iriquois and AO-1 Mohawk both use the Lycoming T-53 engines. But these engines are not interchangeable because the HU-1 uses the L-1 and L-3, and the AO-1 uses the L-5. The HU1-D uses the L-9 engine. This obviously presents a supply problem for maintenance due to the variety and number of spare parts and replacements required in reserve. The announced Army goal is to reduce the number of aircraft types from 11 to 6, to convert from piston to turbine engines, and to standardize fuels used by all Army aircraft.

The present Army system now has 5500 aircraft, of which about 50 percent are helicopters. By 1970, the total is expected to be 8000 aircraft, with 75 percent to be helicopters. This means that if the maintenance problem is to be alleviated, inspection procedures and requirements must be reduced and/or more reliable equipment must be designed.

The tri-service VTOL becomes an extremely complicated machine because of size and because of new concepts used in the design. Reliability is stressed in design; and the addition of overrunning clutches, shafting and numerous gearboxes requires that manual inspection procedures be increased or that automatic inspection be performed.

The "Hummingbird", a VTOL research aircraft, also introduces new concepts which may, in turn, require new approaches to the maintenance problems. The state of the art in sensors may have to be advanced to keep pace with the new concepts.

The Hummingbird uses diverter valves which operate in extremely high temperatures and require revolving shafts in this atmosphere. Temperatures are in the 1300 to 1500°F range at 8,000 to 10,000 r.p.m. Environments of this nature are not found in the aircraft of today.

Another new concept is the Ryan Flex wing. This is, at present, a research type vehicle. Again new concepts of flight modes will require ingenuity on the part of design engineers to keep the maintenance problems to a minimum.

The location of sensors in future aircraft for PACER System application will be determined by the final design configuration of the aircraft. The aircraft concepts as now proposed are varied in propulsion systems, control, and physical shape.

PACER sensor locations will be determined by the requirements, capability, and feasibility of each component. Each component will be studied to determine the best possible means of projecting the component condition into a useable form by the PACER equipment. The parameters now used in the PACER concept will still be valid for future aircraft.

The PACER concept presently involves reading, recording and evaluating the parameters of vibration, pressure, flow, temperature, strain, and linear measurement. The future aircraft concepts do not appear to introduce requirements for new methods of monitoring components.

Additional sensors which may at a future data warrant further application study may be an optical type sensor (such as the proposed blade tracker), sensors using sound as the medium and the "sniffer" type system used for fuel and oil leak detection.

Presently developed sensors in conjunction with those developed in the future should adequately cover the requirements of the PACER concept of automatic inspection procedures.

SELECTION OF PACER MONITOR POINTS

This section discusses the HU-1 periodic inspection check list as it pertains to the PACER equipment. The HU-1 check list was chosen because it is represesentative of all Army aircraft inspection procedures. In addition, more technical data were available to the contractor for the HU-1 than for other aircraft in the Army system. A brief explanation is given for accepting or rejecting check list items or for including additional monitor points for PACER instrumentation. Discussions are also included for the generalized application of the PACER techniques and for some desirable monitor areas which would require additional sensor development. Excessive instrumentation would be necessary to automate and replace most manual inspections and still be conclusive for each aspect of the check list requirements. The resulting low information/instrumentation ratio would not be feasible from an aircraft space-weight-cost standpoint. The inaccessibility and functional importance of a component, however, would be a factor in justifying the instrumentation required for supplementary PACER evaluation.

HU-1 Periodic Inspection

1.0 Air Frame - System No. 3

1.1 Seat - The most economical method of inspection would be by manual means. Automatic evaluation could be instrumented by interlocks, continuity devices, strain gages, or vibration sensors. The instrumentation required by these devices to replace adequately and conclusively a manual inspection, under most circumstances, would not be justified from an aircraft space-weight-cost standpoint. This is particularly true in very accessible or relatively minor inspection areas. In addition, adequate sensors are not presently available to replace most visual phases of a manual inspection.

1.2 Safety Belts and Shoulder Harness - For reasons advanced in paragraph 1.1, this inspection is most economically and conclusively performed by manual means.

1.3 Inertia Reels - For reasons advanced in paragraph 1.1, this inspection is most economically and conclusively performed by manual means.

1.4 Sound Proofing - For reasons advanced in paragraph 1.1, this inspection is most economically and conclusively performed by manual means.

1.5 Windows - For reasons advanced in paragraph 1.1, this inspection is most economically and conclusively performed by manual means.

1.6 Forward Fuselage - Critical cowlings and doors are monitored by ALARM instrumentation. Inspection items involving visual checks were not considered because of the lack of an adequate sensor and because of the large fuselage surface area. The air-frame vibration spectrum monitored by PACER will provide a supplementary evaluation of fuselage structural integrity to augment the manual inspection.

1.7 Tail Boom - Security of attachment will be monitored by PACER strain gages. The quick-disconnect nature of the tail section (four bolts) and its cantilever geometry make this assembly highly susceptible to damage on hard landings. Thorough inspection of this assembly dictates supplementary PACER evaluation. This evaluation also serves as a test case for the strain measurement technique.

The remaining inspection items, primarily visual, were not covered because of the lack of an adequate sensor and because of the large surface area involved in the inspection.

1.8 Synchronized Elevator - PACER instrumentation will check this control surface for proper length of travel. The instrumentation required was economical and this evaluation would eliminate a measurement that inspection personnel must perform. Secondary information concerning security and damage to this part of the cyclic control linkage and tail boom fittings will be derived from this measurement and the PACER analysis of the air-frame vibration spectrum.

The remaining inspection items, primarily visual, were not covered because of the lack of an adequate sensor.

1.9 Tail Skid - PACER instrumentation will check this item for strain damage caused by tail down landing or abnormal handling. This PACER evaluation will provide information not always manifested in component physical appearance. For reasons advanced in paragraph 1.1, the remainder of the inspection is most economically and conclusively performed by manual means.

1.10 External Cargo Suspension - PACER evaluation of this assembly has been temporarily eliminated. Strain gage monitoring may be applicable if the technique feasibility is demonstrated on other strain monitor points. Completely automatic evaluation of this assembly is not feasible because of the lack of adequate sensors.

2.0 Landing Gear - System No. 4

2.1 Landing Gear - PACER strain gage instrumentation will monitor the cross tubes for bends and proper spread. The instrumentation required was economical and this evaluation will eliminate a measurement that inspection personnel must make. Secondary information concerning aircraft loading will also be derived from this measurement. The remaining inspection items are best performed manually because of the lack of adequate sensors.

3.0 Hydraulic - System No. 5

3.1 Hydraulic Reservoir -Filler cap security is presently monitored by ALARM instrumentation. The fluid level indicator is readily accessible and does not require additional monitoring. An adequate sensor is not available to determine system leakage.

3.2 Hydraulic Components and Lines - Adequate sensors are not available to implement this inspection.

4.0 Utility System - System No. 6 - Components of this system are only conditionally present in the aircraft and are, therefore, not applicable to PACER evaluation.

5.0 Power Plant - System No. 7

5.1 Engine Mounts - PACER strain gages will monitor the load carrying ability of the mounting rods. This measurement (strain distribution pattern) will also relate to the engine short shaft alignment, if the strain technique is conclusive. Visual inspection must still be performed because of the lack of adequate sensors.

5.2 Engine Oil Filter - Oil filter element condition is monitored by ALARM instrumentation. PACER will also monitor this filter by using a variable reluctance type sensor. PACER flowmeter instrumentation will monitor engine oil flow characteristics. This measurement will provide information characteristic of engine bearing and oil system condition. A filter with built-in condition evaluators is now under development. Its characteristics should be considered for future applications.

Adequate sensors are not available to replace a manual security and leakage inspection.

5.3 Additional Visual Inspections - Adequate sensors are not available to replace these visual inspections. Secondary information concerning the integrity of these items will be obtained from the engine and air-frame vibration spectrum monitored by PACER.

5.4 Removal and Cleaning of Lube Oil Filters - This is a maintenance operation and not applicable to PACER evaluation.

5.5 Retorque Compressor Bolts - This is a maintenance operation and not applicable to PACER evaluation.

5.6 Accessory Gearbox - This point is presently monitored for metal chips by ALARM instrumentation. An adequate sensor is not available to replace the visual inspection for cleanliness.

6.0 Fuel System - System No. 8

6.1 Inlet Filter - The filter inlet screen condition is presently monitored by ALARM instrumentation. PACER will monitor this point without additional instrumentation. The developmental filter mentioned in paragraph 5.2 could have applications in this inspection item.

Adequate fuel vapor detectors require excessive instrumentation and are not considered feasible for PACER applications at the present time.

For reasons advanced in paragraph 1.1, the remaining inspection items are best performed by manual means.

6.2 Fuel Lines - An adequate sensor is not available to replace these visual inspection items.

6.3 Fuel Control and Linkage - PACER monitors for correct travel of the throttle control rod passing through the engine deck. This is not an output termination but is a point presently used for checking control adjustment. This will, therefore, permit automatic and nearly instantaneous monitor of travel which reflects adjustment and security of interconnecting linkage between the throttle grip and the particular rod. Because of economic reasons and lack of suitable instrumentation, the inspection for security and ease of operation will not be implemented.

6.4 Fuel Tanks, Lines and Fittings - For reasons advanced in paragraph 1.1, the condition of this system is most economically determined by manual means.

6.5 Auxiliary Fuel System - For reasons advanced in paragraph 1.1, the condition of this system is most economically determined by manual means.

7.0 Oil System - System No. 9

7.1 Oil Lines - For reasons advanced in paragraph 1.1, the condition of this item is most economically determined by manual means.

7.2 Engine Oil Tank - Filler cap security and proper oil level are monitored by ALARM instrumentation. An adequate sensor is not available to replace the manual leakage inspection.

8.0 Electrical System - System No. 14.

8.1 External Lights - For reasons advanced in paragraph 1.1, the condition and operation of these items are most economically determined by manual means.

8.2 Thermocouple Leads - PACER will monitor the output of the aircraft thermocouples. This measurement will determine open or short circuits in the thermocouple wiring and will aid in evaluating aircraft condition. An adequate sensor is not available to replace the remaining visual inspections.

8.3 Starter-Generator - For reasons advanced in paragraph 1.1, these inspection items are most economically performed by manual means. An adequate sensor is not available to monitor brush or commutator wear. Proper monitors in this area would considerably reduce the inspection time of the starter-generator.

8.4 Generator - This item is similar to those in paragraph 8.3, and the same discussion is offered.

8.5 Electrical System Components - Adequate sensors are not available to replace these inspection items.

PACER instrumentation will monitor the generator system output voltages. This measurement will determine proper operation of critical system components.

8.6 Cabin and Instrument Lights - For the reasons advanced in paragraph 1.1, the condition and operation of these items are most economically determined by manual means.

8.7 Voltage Regulators - The PACER monitoring of generator system voltages will indicate the condition and operation of the voltage regulators. For reasons advanced in paragraph 1.1, the remaining inspection items are most economically performed by manual means.

8.8 Battery - Battery rate of charge is monitored by ALARM instrumentation. An adequate sensor is not available to replace the visual items of this inspection; however, a practical electrolyte level and specific gravity sensor could considerably reduce the time required for the inspection of this component. Open-circuit terminal voltage is not an indication of battery condition. Monitoring under induced load conditions is electrically abortive because of the high test current requirements. Test results are also generally dependent on previous battery usage. These disadvantages eliminated feasible additional monitoring by PACER.

8.9 Tachometer, Thermocouples, and Inverters - PACER instrumentation will monitor and record the aircraft temperature sensor outputs. They are already included as part of the aircraft instrument panel display, and PACER monitoring will not require additional instrumentation.

The main and spare inverter output voltages will also be monitored and recorded to check for proper operation and adjustment of these components.

Aircraft tachometers are not included in PACER evaluations because engine speed will be specified and held constant during the PACER test. Requirements for absolute r.p.m. and critical limits are best established by a study of test data to justify further instrumentation. An adequate sensor is not available to replace the visual inspection items.

8.10 Transformer - PACER will monitor the transformer output voltage under load to evaluate component condition. An adequate sensor is not available to replace the visual inspection items.

9.0 Instruments - System No. 15.

9.1 Instruments - Adequate sensors are not available to replace manual inspection of the specified items.

Information concerning calibration and operating condition of the respective instrument panel indicators will result from PACER measurements at the following points:

1. Engine oil inlet temperature

2. Transmission oil temperature

3. Engine oil pressure

4. Transmission oil pressure

5. Fuel pressure

6. Torque pressure

7. Tail pipe temperature

These measurements are made for purposes of condition evaluation, failure prediction, and fault isolation. The instrument check data are derived as by-product information. Calibration of all instruments would require specialized equipment beyond the scope of PACER.

10.0 Radio and Radar - System No. 16

10.1 Radio and radar equipment are not considered for PACER implementation, since inspection of these items is not considered as part of the responsibility of the U. S. Army Transportation Research Command.

11.0 Drive System - System No. 19

11.1 Cooling Fan Drive and Mounting - A PACER temperature sensor will monitor the drive portion of this assembly for worn or damaged gears and bearings and/or inadequate lubrication. The air-frame vibration spectrum monitors will also provide information on security and proper operation of this component. These measurements will provide an economical degree of component evaluation, failure prediction, and fault isolation. Adequate sensors are not available to replace the visual aspects of the check list items.

11.2 Transmission - Oil level, filler cap security, and magnetic plug are monitored by ALARM instrumentation. Transmission-oil-filter blockage and relief-valve operation will be monitored by PACER instrumentation. The vibration spectrum monitored by PACER will provide a direct evaluation of transmission wear as well as mounting and accessory drive security. Additional PACER monitoring will determine bearing temperature at input, output, and generator drive quills, and the transmission oil temperature and pressure. These measurements produce maximum information for minimum instrumentation and provide component evaluation, failure prediction and fault isolation capabilities. Adequate sensors are not available to replace superficial visual inspection items.

11.3 Tail Rotor Drive Shaft - PACER monitoring of the aircraft vibration spectrum will provide secondary information on drive shaft security and balance. An adequate sensor is not available to replace the visual aspects of this inspection. PACER sensors will also monitor the operating temperature of the three shaft hanger bearings to evaluate bearing operating conditions.

11.4 42^{o} and 90^{o} Gearbox - Oil-level and chip detectors are monitored by ALARM instrumentation. PACER sensors will monitor the gearbox vibration spectrums and operating temperatures to provide component evaluation, failure prediction, and fault isolation. Adequate sensors are not available to replace the remaining visual inspection items.

12.0 Main Rotor Group - System No. 20.

12.1 through 12.9 Assembly Inspection - Adequate sensors are not available to replace visual inspection of these items. Secondary information on the over-all condition of the main rotor group will be reflected by the PACER vibration sensors.

Electronic fluid-level indicators and other direct instruments are impractical in this inspection because of the assembly motion requirements.

13.0 Main Rotor Control System - System No. 21.

13.1 Main Rotor Control - Security can best be checked visually as presently accomplished. PACER vibration monitors may reveal latent defects and damage which are not made apparent by existing procedures.

13.2 Cyclic Control System - Inspection of the cycle control system from stick to swashplate will remain a visual inspection with the exception of synchronized elevator travel as noted in paragraph 1.8. It would be advantageous to measure automatically the travel of left and right swashplate horns. This should be done with quick-disconnect type sensors because of assembly motion requirements. Because of installation and adaptability difficulties, these quick-disconnects are considered impractical with the present state of the art sensors.

13.3 General - Security of tube attachments, corrosion, scratches, safetying and minor damage to the control tubes and links cannot be thoroughly checked in the field by practical electronic means at the present time.

14.0 Tail Rotor System - System No. 22.

14.1 Tail Rotor Hub - Motion requirements of this assembly prohibit feasible automatic evaluation.

14.2 Tail Rotor Blades - Motion requirements and lack of adequate sensors prohibit direct instrumentation of this system. PACER vibration sensors will provide an indication of blade balance conditions and general assembly security.

14.3 Hub, Blade, and Controls - Adequate sensors are not available to replace the visual inspection items. System motion requirements prohibit feasible instrumentation to monitor the end result of control movements. Monitoring of intermediate links would not provide an adequate evaluation. PACER vibration sensors will provide a secondary indication of assembly security.

14.4 Collective Pitch System - PACER will monitor the travel of the governor linear actuator, which is connected to the collective system through bellcranks, links, and control tubes. Excessive cam-follower wear, proper adjustment, and travel will be checked and recorded.

Monitoring of the collective sleeve pin and level motion is considered desirable in order to detect changes in control adjustments due to damage and/or wear. Implementation proved impractical due to the assembly configuration. While motion could be monitored further back on the collective stick side of this point, data obtained would be of questionable value since the end result (or output travel) is not obtained.

For reasons discussed in paragraph 13.3, other inspection items should remain visual.

14.5 Mast Control System - PACER temperature sensors will monitor the swashplate carrier bearing. This, with vibration monitoring, will supplement the inspection for bearing condition. Nut and bolt security; corrosion, cracks, and scratches on control horns; damage to rubber boots; clearances; and inspection of gimbal bearings cannot be adequately evaluated electronically and, therefore, must remain visual checks.

15.0 Tail Rotor Controls - System No. 23.

15.1 Tail Rotor Controls - The tail rotor controls will not be monitored by PACER. A study of the system indicated that, while monitoring of blade pitch change travel was desirable, no practical instrumentation could be adapted to reduce inspection time satisfactorily or to improve inspection effectiveness. Use of quick-disconnect sensors in the 90^{o} gearbox area was abandoned, since a ladder would have to be used for installation and, further, a visual inspection would still be required to examine for sprocket wear, end play, and other items not feasibly checked electronically.

16.0 PACER monitor points not suggested by the periodic inspection check list.

16.1 Power Plant

16.1.1 Temperature Monitors - Additional PACER temperature sensors will monitor and record the temperatures of the scavenge oil at the number 2, 3, and 4 bearing locations and at the inboard and outboard locations of the overspeed governor and tachometer drive assembly (bearings). These measurements will provide for evaluation, failure prediction, and fault isolation of the major bearings and lubrication system of these components.

16.1.2 Vibration Monitors - PACER vibration sensors will monitor and record the engine vibration spectrum. Three sensors should provide adequate coverage of this major assembly. Two low frequency (velocity) sensors will monitor fore and aft on the power plant system. A single high-frequency (acceleration) sensor will provide adequate component coverage. These vibration measurements will evaluate the operating condition and security of gears, bearings, and turbine wheels of the power plant. The sensor locations and data will provide fault isolation and failure prediction for this system.

16.2 Drive System

16.2.1 Main Transmission

16.2.1.1 Temperature Monitor - An additional PACER temperature sensor will monitor the main mast bearing operating condition. The location and lubrication method (jets) of this major component suggested supplementary PACER evaluation.

16.2.1.2 Vibration Monitors - Two PACER sensors will monitor the transmission vibration spectrum. The sensor locations and data will evaluate performance and will provide for failure prediction and fault isolation in this assembly. The vibration spectrum is expected to be indicative of worn or damaged gears and bearings and/or of inadequate lubrication.

16.2.2 Tail Section

16.2.2.1 Vibration Monitors - A PACER sensor will monitor the vibration spectrum of the 90^{o} and 42^{o} gearboxes. A single sensor should adequately cover both components because of their proximity to the sensor and the small component size. This vibration measurement will provide component evaluation, failure prediction, and fault isolation; it will also reflect the integrity of the complete tail section, including tail rotor blade balance.

16.3 Air Frame

16.3.1 Vibration Monitor - The air-frame vibration sensor will monitor over-all air-frame structural integrity, main and tail rotor blade balance, and general air-frame vibrations induced by attached components. This sensor will be located on a principal member of the air-frame structure to provide good coupling to major aircraft components.

17.0 Monitor Areas Not Presently Feasible - The following paragraphs list areas that were investigated for PACER but which would require additional sensor development before practical usage would be possible.

17.1 Fuel Vapor Detector - Present sensors in this area require complex instrumentation. A practical application of this device could considerably reduce the leakage inspection time and contribute to aircraft operating safety.

17.2 Generator Brush Wear Detector - Available displacement sensors are difficult to apply to this area. A practical brush wear detector could eliminate the process of removing covers or complete assemblies to perform this inspection.

17.3 Improved Oil System Particle Detector - A device that could sense the quantity of oil system metallic (ferrous and nonferrous) and organic contaminants would provide an evaluation of component and lubricant condition.

17.4 Control Linkage Cable Tensiometer - Available load cell (strain) devices could monitor absolute cable tension. The signal conditioners for these devices, however, would require complex circuitry to adjust the tension limits for ambient temperature or to normalize the input data to a standard reference temperature. This would be necessary because cable tension is a function of ambient temperature.

Other desirable monitor devices in the control linkage area would be cable alignment detectors, frayed or broken strand detectors, and motion monitors.

17.5 Control Linkage Motion Monitor - The condition of the control linkage could be determined in terms of efficiency of transfer of motion.

A linkage lever or rod may be used as the driver element. The displacement of other elements within the control linkage system can be compared to the displacement of the reference element, driven by the PACER equipment, to provide an indication of the transfer of motion efficiency. The characteristics of the motion transfer to the various sensors within the control linkage reflect the lost motion due to play and binding resistance within the linkages.

This technique was rejected because of excessive solenoid driver power requirements and the bulk and difficulty of instrumenting. Use could be possible with proper sensors and application techniques.

17.6 Security Monitor - A practical sensor to determine adequately component security would virtually eliminate a major portion of inspection checklist items. These devices were considered, and took the form of continuity ribbons, bifilar lock wire, and interlocks; however, these devices introduced installation and adjustment problems that would negate their benefit. Excessive instrumentation and input channel space would be required to give adequate security coverage and to provide even a reasonable degree of fault isolation.

17.7 Surface Flaw Detector - A practical sensor in this area would considerably expedite visual surface inspections. This device could use light, r-f energy, electrostatic, magnetic, radioactive, vibration, ultrasonic, vacuum, or pressure techniques. Some of these media are capable of considerable penetration and sensitivie detection of surface and subsurface flaws, cracks, or voids.

A practical portable generator-detector would require extensive development.

17.8 Integrated Sensors - In many instances, the instrumentation required for adequate component monitoring or for more direct or complete monitoring would be considerably reduced if the sensors were integrated into the component fabrication. This issue seems best resolved by a study of the significance and validity of test data obtained with present instrumentation.

17.9 Quick Disconnect Sensors - A practical quick disconnect sensor would greatly reduce the aircraft monitor point instrumentation. Problem areas existing for temporary devices include installation time, the possibility of sensor damage or misalignment during installation, and the requirement for numerous mounting adaptors or different types of sensors. An available quick-disconnect sensor that could overcome these deficiencies would be considered for future use.

This device would be particularly helpful for evaluating components normally in motion but not requiring motion for adequate evaluation (example; rotor control length of travel). This scheme would eliminate slip-ring arrangements required by a permanent sensor installation, which normally prohibits even permanent sensor use.

18.0 Generalized Applications of PACER Monitor Techniques - The basic monitor techniques used in the PACER instrumentation are adaptable for practically all aircraft, fixed or rotary wing, with piston or turbine engines.

Discussions offered in conjunction with the HU-1 aircraft are representative for virtually any rotary-wing and/or turbine-powered machine.

PACER evaluation also appears readily adaptable to piston-engine and fixed wing aircraft. Preliminary aircraft analysis may reveal the importance of monitoring some conditions that are unique to this particular class of aircraft.

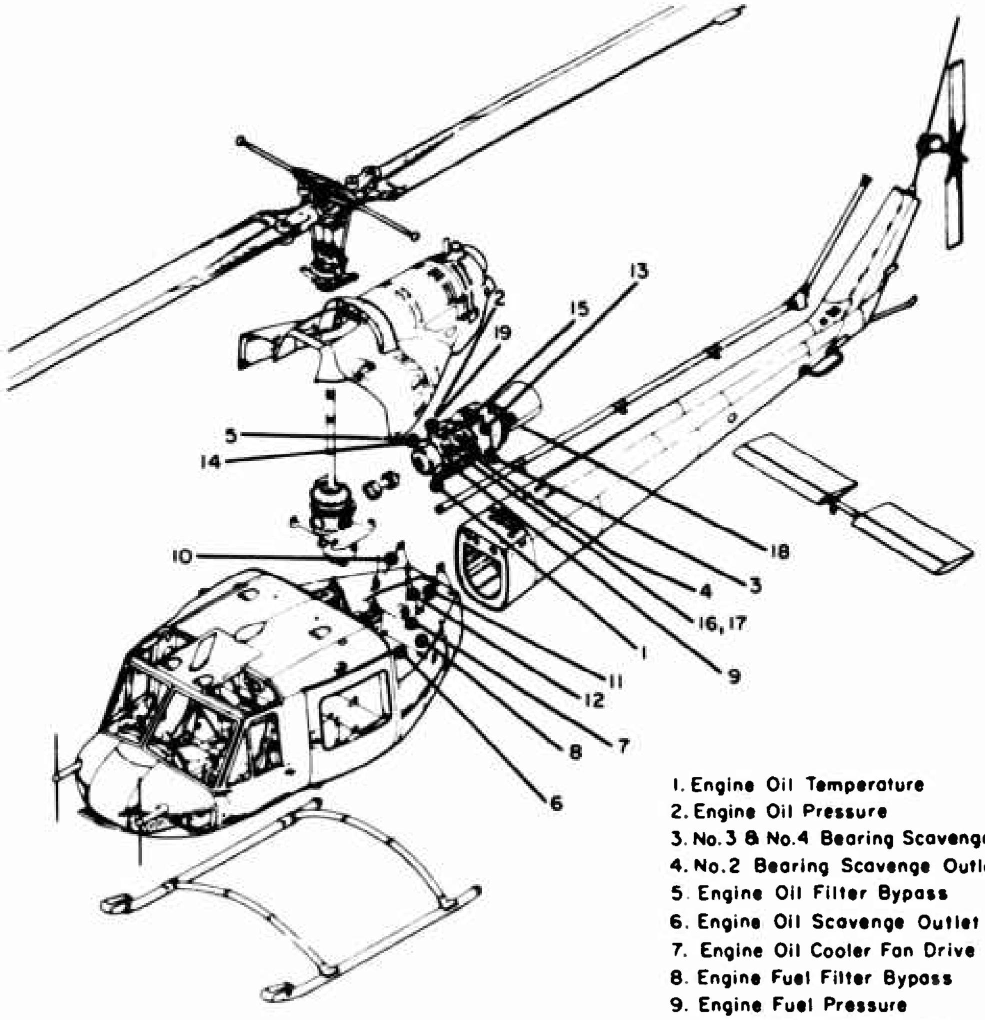
An example of this might be to monitor the time relationship between ignition pulses or power cycle and valve operation in a reciprocating engine. The PACER equipment contains spare input lines and signal conditioner space to accommodate these situations. This space capability is also maintained to permit adding monitor areas previously rejected because of inadequate sensor development. An example of this might be to include a fuel vapor detector when a feasible sensing element becomes available.

The selection of monitor points and sensor types must be based on an individual aircraft study in order to be consistent with the specific aircraft geometry and the basic PACER signal conditioners. There does not appear to be any great difficulty in establishing the compatibility of these two conditions.

The use of the PACER equipment is not necessarily restricted to aircraft evaluation. Additional usage is conceivable on many complex machines or components. A few potential use areas might be in rotor, transmission, gearbox, or engine test stands: dynamic shaft balancing: or load measuring (weighing) operations.

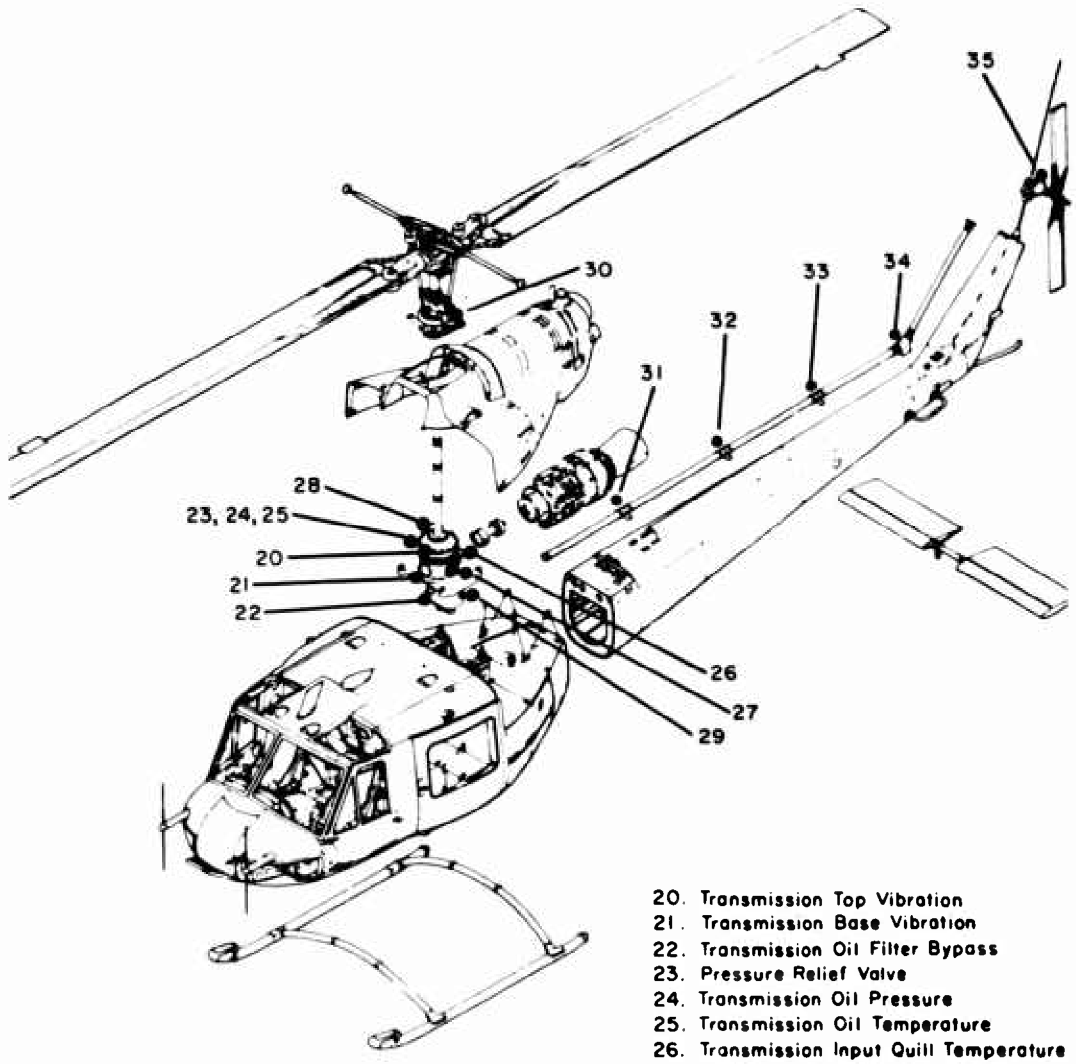
Sensor Locations

Figures 2, 3, 4, and 5 show the approximate sensor locations for an HU-1A aircraft implemented for PACER application.



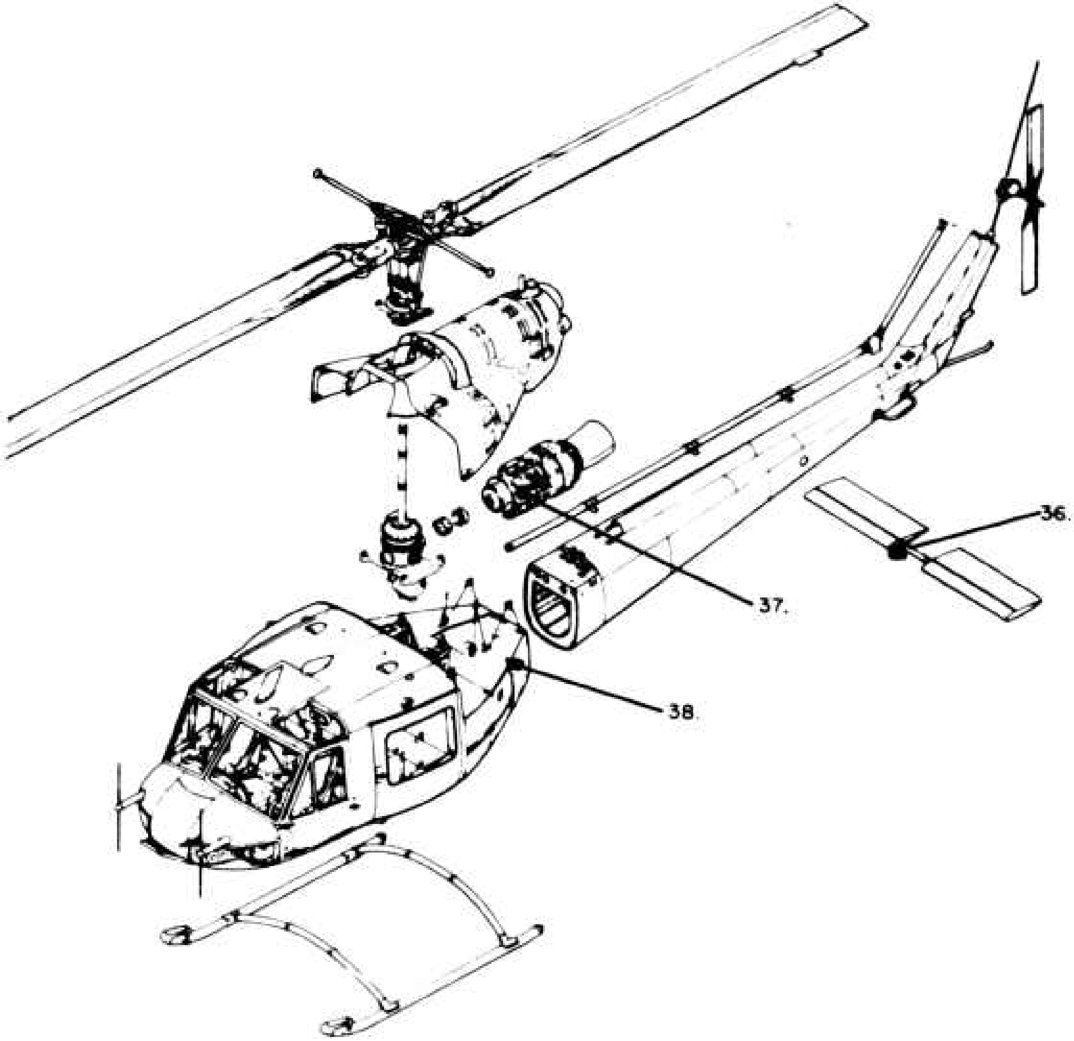
1. Engine Oil Temperature
2. Engine Oil Pressure
3. No. 3 & No. 4 Bearing Scavenge Outlet
4. No. 2 Bearing Scavenge Outlet
5. Engine Oil Filter Bypass
6. Engine Oil Scavenge Outlet
7. Engine Oil Cooler Fan Drive
8. Engine Fuel Filter Bypass
9. Engine Fuel Pressure
10. Engine Mount Rod Stress
11. Engine Mount Rod Stress
12. Engine Mount Rod Stress
13. Engine Vibration
14. Engine Vibration Fwd.
15. Engine Vibration Aft
16. Overspeed Gov. & Tach. Drive Assy. Inboard Temperature
17. Overspeed Gov. & Tach. Drive Assy. Outboard Temperature
18. Tailpipe Temperature
19. Torquemeter Pressure

FIGURE 2. PACER SENSOR LOCATION, POWER PLANT



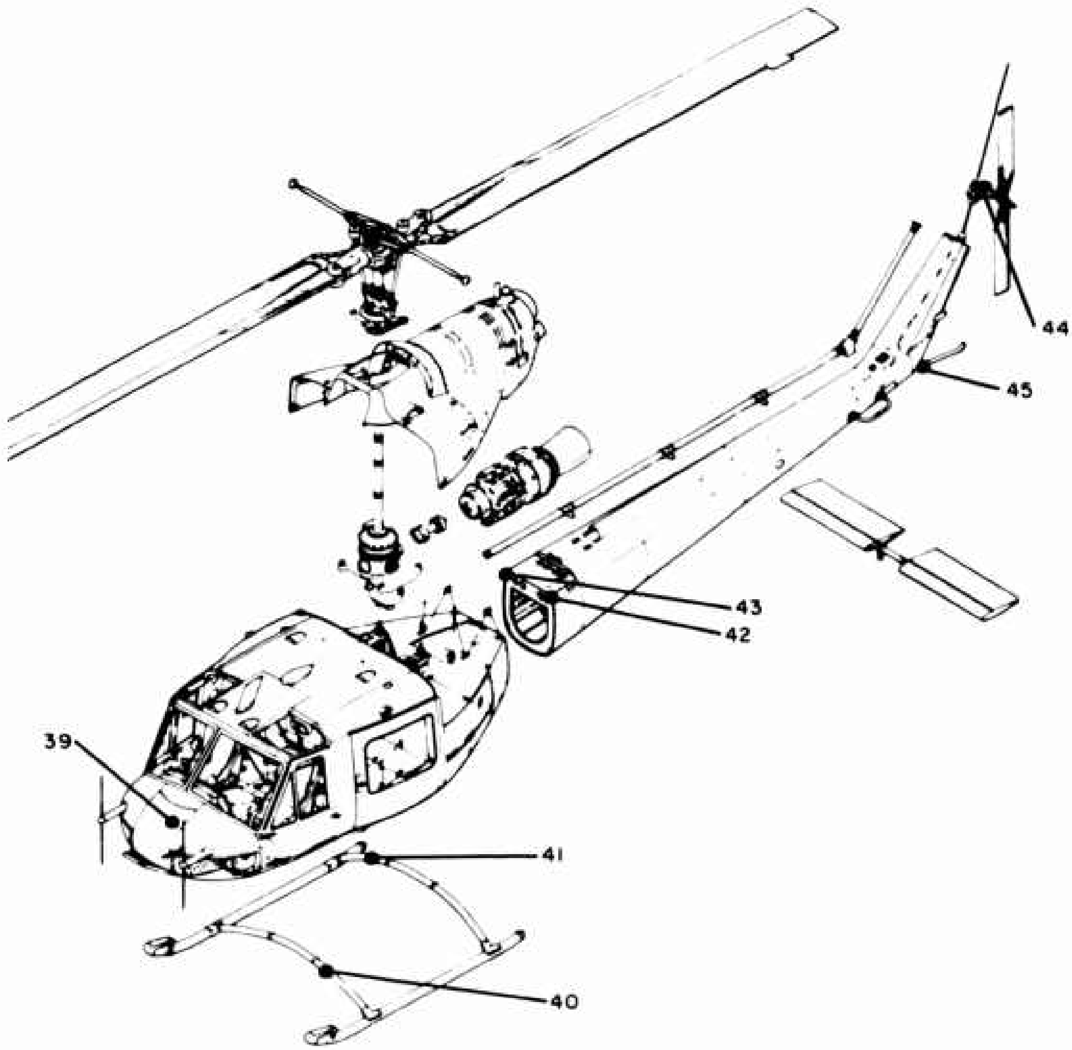
20. Transmission Top Vibration
21. Transmission Base Vibration
22. Transmission Oil Filter Bypass
23. Pressure Relief Valve
24. Transmission Oil Pressure
25. Transmission Oil Temperature
26. Transmission Input Quill Temperature
27. Transmission Generator Output Quill Temperature
28. Transmission Main Mast Bearing Temperature
29. Tail Rotor Drive Quill Temperature
30. Swash Plate Bearing Temperature
31. Forward Shaft Hanger Temperature
32. Mid-Shaft Hanger Temperature
33. Aft Shaft Hanger Temperature
34. 42° Gearbox Temperature
35. Tail Rotor Gearbox Temperature

FIGURE 3. PACER SENSOR LOCATION, DRIVE SYSTEM



36. Sync Elevator
37. Linear Actuator
38. Throttle Control

FIGURE 4. PACER SENSOR LOCATION, CONTROL SYSTEM



39. Low-Frequency Vibration
40. Cross Tube Fwd.
41. Cross Tube Aft
42. Tail Boom Security Left
43. Tail Boom Security Right
44. Tail Vibration
45. Tail Skid Security

FIGURE 5. PACER SENSOR LOCATION, AIR FRAME

TABLE

PACER MONITOR POINTS, HU-1A AIRCRAFT

Monitor Point	Fig. Ref.	Description	Type Sensor	Cable Pin Letter
1	2	Engine Oil Temperature	Thermobulb	J2-P
2	2	Engine Oil Pressure	Pressure Transducer	J2-A&B
3	2	#3 & #4 Bearing Scavenge Outlet	Thermal Ribbon	J2-R
4	2	#2 Bearing Scavenge Outlet	Thermal Ribbon	J2-S
5	2	Engine Oil Filter Bypass	Variable Reluctance	J2-T
6	2	Engine Oil Scavenge Outlet	Flowmeter	J2-NN
7	2	Engine Oil Cooler Fan Drive	Thermal Ribbon	J2-U
8	2	Engine Fuel Filter Bypass	Variable Reluctance	J2-V
9	2	Engine Fuel Pressure	Pressure Transducer	J2-C&D
10	2	Engine Mount Rod Stress	Strain Gage	J2-i
11	2	Engine Mount Rod Stress	Strain Gage	J2-j
12	2	Engine Mount Rod Stress	Strain Gage	J2-k
13	2	Engine Vibration	Accelerometer	J2-y
14	2	Engine Vibration Fwd	Velocity Pickup	J2-CC
15	2	Engine Vibration Aft	Velocity Pickup	J2-DD
16	2	Overspeed Gov. & Tach. Drive Assy Inboard Temperature	Thermal Ribbon	J2-W
17	2	Overspeed Gov. & Tach. Drive Assy Outboard Temperature	Thermal Ribbon	J2-X
18	2	Tailpipe Temperature	Thermocouple	J2-Y

TABLE (Continued)

Monitor Point	Fig. Ref.	Description	Type Sensor	Cable Pin Letter
19	2	Torquemeter Pressure	Pressure Transducer	J1-A&B
20	3	Transmission Top Vibration	Accelerometer	J1-y
21	3	Transmission Base Vibration	Accelerometer	J1-z
22	3	Transmission Oil Filter Bypass	Variable Reluctance	J2-a
23	3	Pressure Relief Valve	Potentiometer	J2-b
24	3	Transmission Oil Pressure	Pressure Transducer	J1-C&D
25	3	Transmission Oil Temperature	Thermobulb	J1-P
26	3	Transmission Input Quill Temperature	Thermal Ribbon	J1-R
27	3	Transmission Generator Output Quill Temperature	Thermal Ribbon	J1-S
28	3	Transmission Main Mast Bearing Temperature	Thermal Ribbon	J1-T
29	3	Tail Rotor Drive Quill Temperature	Thermal Ribbon	J1-U
30	3	Swash Plate Bearing Temperature	Thermal Ribbon	J1-V
31	3	Forward Shaft Hanger Temperature	Thermal Ribbon	J1-W
32	3	Mid-Shaft Hanger Temperature	Thermal Ribbon	J1-X
33	3	Aft-Shaft Hanger Temperature	Thermal Ribbon	J1-Y
34	3	42^{o} Gearbox Temperature	Thermal Ribbon	J1-Z
35	3	Tail Rotor Gearbox	Thermal Ribbon	J1-a
36	4	Sync Elevator	Potentiometer	J2-c

TABLE (Continued)

Monitor Point	Fig. Ref.	Description	Type Sensor	Cable Pin Letter
37	4	Linear Actuator	Potentiometer	J2-d
38	4	Throttle Control	Potentiometer	J2-e
39	5	Low-Frequency Vibration	Velocity Pickup	J1-CC
40	5	Cross Tube Fwd	Strain Gage	J1-i
41	5	Cross Tube Aft	Strain Gage	J1-j
42	5	Tail Boom Security, Left	Strain Gage	J1-k
43	5	Tail Boom Security, Right	Strain Gage	J1-m
44	5	Tail Vibration	Velocity Pickup	J1-DD
45	5	Tail Skid Security	Strain Gage	J1-n
46	-	Essential Bus Voltage	Electrical	J1-b
47	-	Nonessential Bus Voltage	Electrical	J1-c
48	-	Generator Output Voltage	Electrical	J1-d
49	-	Main Inverter	Electrical	J1-e
50	-	Spare Inverter	Electrical	J1-f
51	-	Instrument Transformer	Electrical	J1-g

PACER SENSOR CAPABILITIES

As evolved for the experimental system design of PACER, the sensors are not necessarily the ultimate in capability, sensitivity, weight, etc. They were chosen on the basis of versatility, capability, cost, and availability. With the exception of the filters, all sensors are commercially available, "off the shelf" items. With the exception of the cabinet housing, the "off the shelf" availability is valid for all items in the PACER design as well. No special or exotic designs were undertaken to produce sensors that might resolve a particular anticipated problem area. It has been recognized that in some instances, a specific sensor may have performed a more comprehensive and complete analysis of a particular area, but the cost of development and experimentation to determine the validity was prohibitive. It was also recognized that the use of sensors that were designed to fit physically into a particular area would probably give more reliable and consistent data. However, the limitations of this program precluded the possibility of using sensors that required special design and/or development.

The following detailed list of sensor characteristics contains a brief description of the sensing devices employed in the PACER design. The description includes the manufacturer, model number, range of capability, etc. This list does not exclude consideration of other sensors, however. The capability of the PACER signal conditioners is specified in the PACER Engineering Specification #1129271 and is part of the PACER design. Sensors other than those proposed by the PACER design may be utilized provided that the signal output of the device is compatible with the signal conditioners provided in the PACER System.

NOTE

(All sensor identifications are contained in the preceding table.)

Thermal Ribbon (Monitor Points 3, 4, 7, 16, 17, 26 through 35)

Manufactured by Minco Products Inc.
740 Washington Ave.
North Minneapolis 1, Minn.

Models S8B and S6B

Temp. range - $-60^{\circ}C$ to $+260^{\circ}C$ ($-76^{\circ}F$ to $+500^{\circ}F$)

Temp. gradient - Resistance of 676 ± 1% ohms at $25^{\circ}C$ varies at rate of 3.06 ohms per degree C at $25^{\circ}C$

Time constant - Dependent on installation, usually less than a second.

Operating current - Recommend less than 5 ma but will carry overload of 40 ma continuously.

Weight (including leads) - less than 4 grams

Vibration - When properly installed, will withstand shock and vibration to an extent as great as the surface to which it is attached.

Installation - Self adhering, pressure sensitive tape. May be cemented or held in place mechanically.

Calibration curve - Supplied showing resistance at all temperatures from -60°C to +260°C.

Filters (Monitor Points 5, 8, and 22)

Engine oil, fuel, and transmission oil filters are interchangeable with present equipment. The filters are manufactured by the Air Maze Corporation, Cleveland 28, Ohio.

Engine oil filter part no. 02W10458

Fuel filter part no. R9W459

Transmission filter part no. 02W10457

Specifications remain the same as for the original aircraft equipment. Output from the sensor will be directly proportional to movement of the bypass valve, when the primary coil is energized with 28 volts AC 400 c.p.s.

Flowmeter (Monitor Point 6)

Manufactured by Potter Aeronautical Corporation
Union, New Jersey

Part No. SE(N)5078

Calibration to be furnished on delivery of flowmeter.

Characteristics will vary with each model and unit. General characteristics and range are as follows:

Flow range - 1.5 to 29 g.p.m.

Output frequency - 25 to 500 c.p.s.

Pressure drop - 0.5 p.s.i. @ 7 g.p.m. 20 centistokes

Pressure - to 3000 p.s.i.

Fittings - MS 33656-12

Construction - Stainless steel

Temperature - -430°F to +1000°F

Response Time - 2-5 milliseconds

Engine Velocity Pickup (Monitor Points 14 and 15)

Manufactured by M.B. Manufacturing Co., New Haven 8, Conn.

Model MB Type 11

Frequency range - 30 to 2000 c.p.s.

Temperature range - -85^oF to $+500^oF$

Sensitivity - 96.3 mv/in./sec.

Weight - 2.75 oz.

Max. amplitude - 0.15 in. double amplitude over frequency range

Monitor position - omnidirectional

Natural frequency - 15 c.p.s.

Acceleration output limit - 50g max.

Max. shock without damage - 1000g

Output impedance - 600 ohm nominal d-c coil resistance

Construction - magnesium

Low-Frequency Frame (Monitor Point 39)

Manufactured by M. B. Manufacturing Co., New Haven 8, Connecticut

Model MB type 124

Amplitude range - no practical lower limit. 0.6 inch stroke available between stops

Temperature range - -50^oF to $+250^oF$

Sensitivity - 94.5 mv/in./sec 21.0 mv/0.001 DA/100 c.p.s.

Weight - 11.2 oz.

Natural frequency - 4.75 c.p.s.

Output impedance - 650-ohm nominal, d-c coil resistance

Accelerometers (Monitor Points 13, 20, and 21)

Manufactured by Columbia Research Laboratories Inc., Woodlyn, Pa.

CRL Model 403

Nominal sensitivity - 45 mv/g

Nominal open circuit sensitivity - 55 mv/g

Frequency response - 0.2 c.p.s. to 6 kc

Resonant frequency - 65 kc

Maximum acceleration - 40,000 g

Nominal capacity (with 100 mmfd cable) - 500 mmfd

Output resistance - 5×10^2 ohms

Temp. range - $-100^{\circ}F$ to $+300^{\circ}F$

Construction - aluminum

Weight - 20 grams

Tail Vibration Pickup (Monitor Point 44)

Manufactured by Consolidated Electrodynamics Corp., Pasadena, Calif.

CEC Type 4-118

Sensitivity - 105 mv/in./sec. at 250 c.p.s., $100^{\circ}F$ into a 10,000 ohm load

Frequency response - 50 to 500 c.p.s.

Natural frequency - 30 c.p.s.

Temperature range - $-65^{\circ}F$ to $+ 300^{\circ}F$

Output impedance - 750 ohms, nominal, d-c coil resistance

Construction - aluminum

Weight - 2 oz.

Strain Gages (Monitor Points 10, 11, 12, 40, 41, 42, 43, and 45)

Manufactured by Baldwin-Lima-Hamilton, Waltham, Mass.

Model No. FABX-25-12

Resistance 120 ± 1.5% ohms

Temperature range - $-400^{\circ}F$ to $+350^{\circ}F$

Nominal gage factor - 2, 1

Expansion coefficient compensation - 6 μ in./in./$^{\circ}F$

Elongation limit - 1.5%

Position Indicators (Monitor Points 23, 36, 37, and 38)

Manufactured by Bourns Instrument Division, Riverside, Calif.

Model 155 (10K ohms, 1.5-in. travel)

Resolution - 0.0017 in.

Power rating - 1.0 watt/inch of coil at $40^{\circ}C$

Insul. resistance - 50 megohms at 500 vdc

Nominal temp. coef. of resist. wire - 0.00002/$^{\circ}C$

Dielectric strength 1 minute at room temp. - 900 vac peak

Shaft friction - 4 oz. nominal

Life expectancy - 1,000,000 cycles min.

Temperature range - $-67^{\circ}F$ to $347^{\circ}F$

Vibration W/O electrical discontinuity or error greater than 1/2%; 20-2000 c.p.s--15g

Acceleration W/O electrical discontinuity or error greater than 1/2% - 100g

Shock (per MIL-E-5272A, Procedure 1) - 50g

Approximate weight - 5 oz.

Model 157 (same as above except as noted)

Resolution - 0.0012 in.

Self-aligning actuating shaft

Additional sensors used in the PACER System are sensors that are included in the aircraft instrumentation. These include such items as the pressure and temperature sensors. These items are presently furnished with the aircraft and as such are covered by various military specifications and need not be elaborated upon in this report. The PACER System will use the output signals of these sensors without additional equipment requirements.

The mounting of the PACER sensors into the test-bed aircraft has been covered by appropriate drawings, whenever practical. The sensors that have not been detailed in mounting are those that are or have been affected by changes in the aircraft and those that must be determined by experimentation.

The linear displacement monitors were not detailed since the detail prints made available for our use did not agree with the test-bed aircraft as used in the ALARM program. The strain-gage detailed mountings were not made since no work on actual placement for optimum stress analysis was performed on the aircraft.

The detailed mountings that are presented are made on the basis of the best possible information now available. The actual installation of a PACER System in an aircraft will best determine the optimum placement of all sensors.

The electrical connections for the checkout of the aircraft electrical system are not detailed for the same reason. The test-bed aircraft wiring can best determine the optimum location for each electrical inspection.

FAULT ISOLATION

All aircraft components have an interaction within themselves and with other components as a result of some types of impending failures. This is best illustrated by an example. Vibration from an HU-1 42^{o} gearbox due to a gear failure would be reflected in the 90^{o} gearbox vibration spectrum. The ALARM test data have shown that a tail rotor imbalance has been detected by the aft engine vibration pickup. The normal vibration spectrum, however, would be changed by a pattern recognizable as a deficiency in the tail rotor and not in the engine area.

Because of heat addition, a bearing failure in a transmission affects the transmission oil temperature indication. This indication is limited to the transmission alone and gives no fault isolation. However, if the faulty bearing were monitored for temperature, the bearing temperature indication would indicate a malfunction before the system temperature would indicate a malfunction. The bearing temperature indication provides the fault isolation function.

The engine oil system has numerous sources for heat addition due to malfunctions. With the present military requirements and specifications, oil inlet temperature monitoring is required. With this concept, the result is that the main function of the oil temperature is to indicate proper operation of the oil cooler system and not to detect a malfunction in the engine. The more frequently the engine oil system is monitored, the finer and more accurate the fault isolation becomes. Feasibility of sensor number location will be the limiting factor in fault isolation.

In many instances, fault isolation would be done by different types of sensors. An example of this would be the use of temperature and vibration sensors to determine a malfunction in a gearbox. The vibration sensor may isolate only the gearbox, but the temperature sensor could isolate the bearing from the gear. This type of fault isolation requires that the data be scanned to pinpoint the fault.

If used properly, fault isolation, then, can be a powerful tool in maintenance. The degree to which fault isolation is developed depends on the versatility of equipment and the experience or history with the results of known conditions.

Fault isolation tables would be made up on the same general basis as the present maintenance system. Examples of the present system are in the aircraft -20 and -34 series handbooks. These tables would be based on presently known systems and actual, recorded values from known conditions. As history with the equipment is built up, the fault isolation ability will become more accurate and precise.

As shown by the following example, malfunctions in a complex system can be isolated by a relatively simple procedure:

Assume that the PACER equipment is connected to an HU-1 aircraft and that the following are recorded:

1. Aft engine vibration - high frequency - high

2. Engine oil scavenge flow - low

3. #2 bearing scavenge oil temperature - high

4. All other points - normal

The first isolation points to the engine area. The high vibration frequency indication points to a bearing. The high-temperature indication at the #2 bearing would indicate either a faulty bearing or lack of lubrication at the bearing. The indication that normal oil pressure is available would indicate that lack of lubrication or pump malfunction was not a problem. A significant external leak could cause a drop in pressure. The low output flow would indicate that a leak was either external in the oil scavenge system or internal to the combustion area. The high bearing temperature would be a hint that the leak was probably internal. The #2 bearing has had a history of seal failures. With this background, then, it is now possible to isolate the problem area logically to the #2 bearing seal failure.

The seal loss probably has caused a lack of lubrication which has given the high temperature indication at the #2 bearing scavenge oil outlet. The vibration indication would probably be due to the bearing failure.

The example has shown that a part of a complex system may be logically isolated by a combination of results from test data and past history of aircraft performance.

By means of automatic data processing equipment, it becomes possible to determine problem areas, the indications,thereof, and the possibility of interrelating factors. By careful analysis of the recorded data, it will be possible to determine that preventive maintenance rather than corrective maintenance is required. This type of information can be a very powerful tool in the maintenance program. Without looking at the additional information available and at its possible utilization, it can be seen that fault isolation as presented by the recorded information will lessen the number of premature component removals. This, in turn, reduces man-hour requirements for disassembly, inspection, and reassembly of components. The reduction in maintenance hours produces greater availability and more economical utilization of the aircraft.

COMPARISON OF PRESENT VERSUS PACER METHODS

One of the objectives of the study phase was to make a comparison of skill levels of aircraft maintenance personnel using present Army methods versus those required using PACER equipment. A comparison of this type can at best be an educated estimate, since the PACER equipment has not been built and evaluated. The skill level required to operate PACER will be outlined in the design phase of this report under "Operator Requirements". It is also noted in this report that many of the present aircraft inspections cannot feasibly be performed by automatic electronic equipment. However, the over-all cost of performing Army aircraft maintenance using PACER will be greatly reduced, primarily due to the advantage of not having to remove components according to a TBO schedule, but rather removing them only when they have reached their useful life limit.

Another objective was to compare the maintenance man-hours presently required versus those required using PACER. However, the average time to perform the required inspections for each aircraft varied to such a great degree according to the source information that no logical comparison could be made. As an example, the HU-1 intermediate inspection averaged from 8 hours at one installation to 32 hours at another installation. However, it can be stated that elimination of needless component removal, teardown, inspection, and reassembly of good components as determined by the PACER System will measurably reduce the over-all maintenance man-hour requirement.

Mention must also be made of the lead time advantage in spare parts procurement to be gained by the prediction capabilities inherent with this type of equipment. Great reductions in aircraft down-time can be realized by having spare parts available when and where required.

DETERMINATION OF INDICATING LIMITS

The indicating limits now used with the ALARM System were established arbitrarily during the ALARM test program. Sufficient data to determine the limits for PACER are not available. With the exception of certain accomplishments achieved during the ALARM program (TRECOM Technical Report 63-10), the background work necessary to determine limits of component serviceability has not been initiated.

Some limits have been determined by the Army on certain types of monitoring through past experience. These include such indications as the maximum engine oil pressure and maximum transmission oil temperature. These limits are presently monitored by means of visual instruments at the cockpit panel. These limits are usually too broad and may actuate the visual display to indicate that a catastrophic failure is impending or has occurred.

The determination of limits to detect the maximum serviceable life in a component will require considerable data derived through the life history of numerous components on aircraft in field operation. Very little effort has been expended in this type of data accumulation, particularly concerning vibration parameters. Some theoretical work has been accomplished with bearings and gears as components; not, however, as assemblies.

The limits of PACER for any particular channel are variable settings. In this manner, settings can be adjusted as the data dictate.

As the data are accumulated on the various parameters and as the condition of a component is determined, wear-rate curves may be developed. When the wear-rate curve is determined and the limit of serviceability is known, then the ability to predict the remaining life becomes a reality.

DESIGN PHASE

EQUIPMENT OBJECTIVES

The general, over-all equipment objectives are threefold: to evaluate the aircraft, to compare the aircraft condition now with what it was at the time of last evaluation, and to record the present condition of the aircraft.

Equipment design philosophy is centered in the premise that aircraft components deteriorate as a function of use or flying time and that if this deterioration or wear rate can be determined, it is possible to predict component malfunction or failure prior to actual failure. Ruled out from the beginning is the hope of being able to predict erratic catastrophic failures. For these types of failures, there is no known prewarning device Also not considered for inclusion in the PACER equipment are the go /no-go type of warning devices such as chip detectors and interlocks. This was done for two reasons:

1. These devices are used in the ALARM System and thereby warning is already given of failure by this system.

2. The type of failure indicated by these devices is not one of gradual wear, but one of pass or fail. It is therefore not feasible to predict failures with this type of indication.

Evaluation

The evaluation of sensor signals is made by comparing the signal with pre-established limits for that particular point. These limits will represent impending failure levels or no-go conditions; when exceeded, they will indicate that immediate corrective action must be taken.

Comparison

These sensor signals are then compared with what they were at the time of the last PACER evaluation to determine if conditions have changed and, if so, by how much. The intent here is to catch the impending failures prior to their reaching the no-go limit levels as well as to allow for the variations of levels between aircraft in pressures, temperature, vibration, etc.

Recording

Finally, it is desired to store this sensor information on some permanent record. This is to provide the operator with a record from which to evaluate the results of the test and also to be used as raw data for the compilation of the component wear-rate curves, which are discussed later in the report.

EQUIPMENT DESCRIPTION

All components and controls for the portable aircraft condition evaluator/recorder test equipment (PACER) are mounted in an aluminum cabinet-housing measuring approximately 38 inches wide by 49 inches high by 30 inches deep (Figure 6). The anticipated weight is 175 pounds. The complete equipment utilizes aluminum construction throughout for lightness and durability, and is completely waterproofed for use in the field. Large 10-inch wheels provide maximum mobility over any type of terrain. The center of gravity is so positioned that the weight of the device is easily shifted over the wheels when in transport, yet extremely stable when in operation.

A unique feature is the use of pull-out cables for the umbilical cord and calibration cables. The reel-mounted cables are retracted when not in use. Flat ribbon cable will be utilized which reduces weight and size. This feature will simplify the storage of relatively large quantities of cable in a compact area.

As illustrated in Figure 6, the control panel, voltmeter, and printer are mounted in a recess at the top portion of the cabinet. The punch readers are mounted immediately beneath the control section, and the signal conditioners, programmer, and power supply are contained in separate horizontal drawers adjacent to the cable storage bin. Means are provided to enclose the control section and component drawers when not in use.

The following advantages are obtained by packaging the electronic circuits in the horizontal drawer configuration:

1. Modular construction
2. Standard size circuit-card assemblies
3. Easy to maintain and isolate troubles within the test system
4. Permits excellent air flow around components for stable operating temperature
5. Provides maximum utilization of all available space
6. Provides excellent capabilities for withstanding shock and vibration.

The over-all equipment may be subdivided into three basic sections:

1. Input Section
2. Programmer Section
3. Evaluator/Recorder Section.

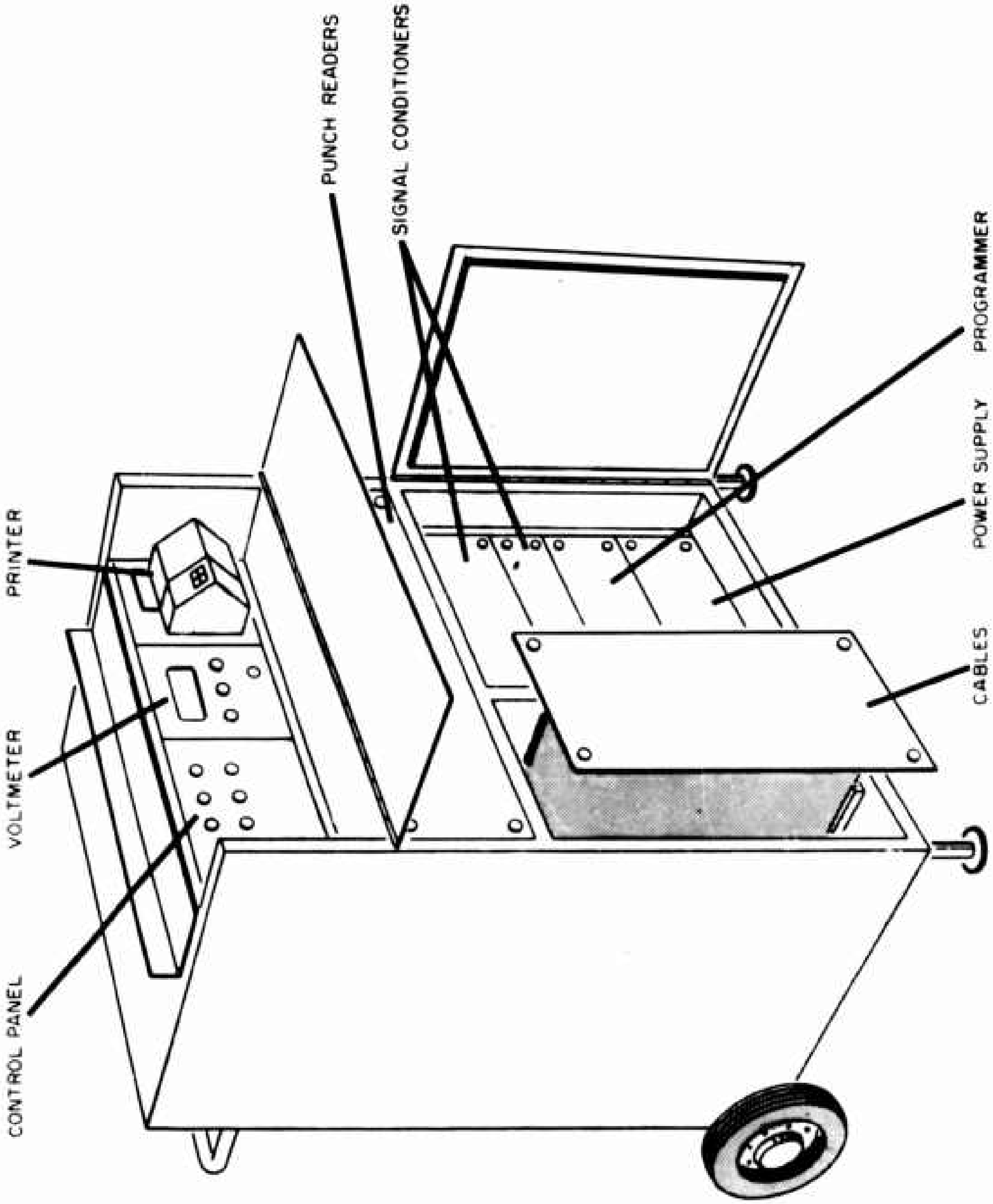


FIGURE 6. PACER CABINET

Input Section

The Input Section contains the vibration, pressure, and temperature signal conditioners, together with an ambient temperature generator. The electrical outputs of the various aircraft sensors are applied to appropriate circuitry within PACER to provide proper impedance transformation, and are electronically processed to convert all signals into proportional d-c voltages. Thus, all subsequent operations are performed on a common electrical quantity, enabling utilization of standard techniques in the conversion and evaluating processes.

An ambient temperature generator is employed in conjunction with the temperature data signal conditioner. This permits the measurement of temperature differences to be evaluated rather than absolute temperature; thereby compensating for ambient air temperature effects on the absolute temperature.

Programmer Section

The Programmer Section contains the input selector, timer, and precision limit level generator. The input selector is a switching network, which, upon command, connects a conditioned signal to the Evaluator/Recorder Section. Inasmuch as considerably more detailed analysis and evaluation of sensor outputs is accomplished by PACER than provided by the ALARM System, it is desirable to utilize an evaluator/recorder unit. Time-sharing sequence can be employed since evaluations are made at a comparatively rapid rate and over-all test time is not sacrificed. A rotating switch is employed for this operation inasmuch as high-speed selection is not required, and the complexity of solid-state switching networks is not justified.

The timer's function is basically to coordinate all sections of PACER and provide a time base for sequencing the equipment. The timer outputs are several trains of pulses to the various sections. Verification of program information is provided in such a manner that, should a malfunction of the test set occur, the timer interrupts the continuation of the test sequence.

Self-test of PACER is performed prior to testing the aircraft. The timer sequences this operation and the results are printed on the permanent record. Upon successful completion of the self-test, the timer holds PACER in a READY status, and properly displays this indication to the operator. In the event of self-test failure, the record indicates which replaceable subassembly is at fault.

Evaluator/Recorder Section

The Evaluator/Recorder Section contains a digital evaluator, display printer, tape punch, tape, an analog-to-digital converter (ADC), and data/time - data input. The digital evaluation system employs an analog-to-digital converter which converts the voltage produced by the equipment under test into a form compatible to the digital evaluator. The input voltage is converted into a three-digit, binary-coded, decimal number presented in time parallel. The ADC unit performs the digital conversion by comparing the input voltage with an accurately generated linear ramp voltage. Gated clock cycles are counted and presented through control gates to the digital evaluator as a binary coded decimal. This information is fed directly to the display/printer and the tape punch.

The PACER equipment is automatically controlled by punched paper tape. In order to maintain flexibility, all of the prime functions of the equipment require command information. Since this command information is on the program tape, the program can be changed, at will, by merely changing the program tape. This technique eliminates the requirement to rewire or redesign the equipment as new requirements develop.

Paper tape was chosen over other methods of programming, such as punched cards, because of its many advantages for this portable field-type usage. Reduced storage space required and the elimination of problems such as lost or out-of-order cards were among the items considered.

PACER USE IN ARMY SYSTEM

The intended use of the PACER equipment is in the third and fourth echelons of Army maintenance. The function of the third-echelon maintenance organization is to repair components and assemblies and to perform repairs for lower echelons within the limits imposed by specific authorization of tools, parts, and test equipment.

The principal function of fourth-echelon maintenance is to repair assemblies, components, and end items for return to using organizations or to maintenance float stock. As evolved, the PACER equipment will not be applicable to the fourth echelon of maintenance in performing its principal function, but it will be of value in performing its auxiliary function of assisting in the repair or modification of overflow work from third-echelon maintenance organizations.

Upon receipt of an aircraft by the field maintenance unit from the using organization, it must first be established if the aircraft can be ground run. If inoperative, the aircraft must be repaired by a "quick fix" to the extent that it can safely be ground run but not necessarily flyable. The PACER is then connected and an aircraft evaluation performed. The necessary repairs as determined by PACER are made, and a subsequent PACER evaluation is performed. If successful repairs have been made, the aircraft is given a flight test and then returned to the using organization. These automatic tests will be supplemented with manual tests and inspection of items which cannot be feasibly monitored automatically.

Operator Requirements

The PACER equipment is designed to be operated by one man. It is recommended that troubleshooting charts similar to the type now provided for the mechanic in the series -20 and -34 handbooks be included in the instruction manual. These charts would be used to aid in fault isolation of the more complex malfunctions.

Anyone authorized to ground run the aircraft will possess a sufficient skill level to operate and interpret the result of the PACER evaluations. Maintenance of the equipment will require persons trained in the repair of similar electronic devices. Personnel trained for MOS 295.2, Electronic Instrument Repairman would be capable of making the necessary repairs and adjustment.

Aircraft Pretest Requirements

In order to perform a PACER evaluation successfully, there are several pretest requirements which must be met. The aircraft to be evaluated must be in an operable condition so that it can be run up on the ground. It need not be in flyable condition.

If aircraft condition is such that it cannot be ground run, it must be repaired so that it can be ground run. This is necessary since the aircraft tests are dynamic in nature and cannot be performed on a static aircraft.

Another pretest requirement is that the aircraft must be located on a relatively flat and level area. This is to hold changes in the vibration characteristics of the aircraft to a minimum.

Any cowlings which are on the aircraft must be in their in-flight positions and secured. This, again, is to maintain controlled conditions for each test.

In the further evaluation and development of the PACER System, it may become necessary to perform some of the tests with collective pitch applied in order to simulate more closely actual operating conditions. If this is deemed necessary, the aircraft must be tied down to prevent it from becoming airborne. This, then, would become another pretest requirement.

As designed, the system is equipped with two umbilical cords for connection to the aircraft. The cables are similar in their signal-handling capacity, and each can be used for 5 pressure signals, 29 single line inputs (10 of which are shielded), 4 accelerometer inputs, 10 velocity coils and several wires for miscellaneous functions. Whether or not both cables are used for any particular aircraft depends upon the type and quantity of sensor instrumentation employed. It is envisioned that on smaller aircraft, only one of the cables will be required; on larger aircraft, both cables will be used.

The punched paper tapes necessary for operating PACER will be stored in the aircraft. These two tapes are the program tape and the history tape. It was first envisioned that the program tape would be stored in PACER, one program tape for each type of aircraft. This possibility was eliminated because all aircraft of the same type do not necessarily have the same type of equipment or even the same type of engine. Therefore, it is conceivable that similar-type aircraft may require different PACER instrumentation and different test programs. To accomplish a different program, a separate tape is required.

For the HU-1, the length of the program tape will be approximately 22 feet; the history tape will be about 5 feet long. Both tapes will be of the fan-folded type for ease of storage. The tapes will be of different colors to distinguish between program and history tapes.

The two tapes must be placed in the appropriate tape readers in the PACER equipment.

After the pretest requirements have been met, an evaluation can begin.

Equipment Self-Check and Calibration

In order to insure that the PACER equipment itself is operating properly, a self-check is required prior to performing an aircraft evaluation. The program for this self-check is contained in the program tape. The equipment as designed will perform nine individual self-check tests designed to give a reasonable assurance that it is operating satisfactorily. These tests require proper operation of a maximum number of dynamic sections within the equipment.

After the self-check portion of the program is successfully completed, the calibration of aircraft vibration sensors is begun. Vibration sensors are the only sensors that are calibrated. This type of device has a known deterioration factor, thereby requiring verification as to its condition. In the area of accelerometers, the state of the art is such that self-calibrating types are available and are being used for the aircraft instrumentation.

These self-calibrating units have a calibrating crystal which can be electrically excited and which, in turn, mechanically excites the sensor crystal. All of the accelerometers on the aircraft will be checked in sequence to verify that they are within acceptable limits. The velocity coils on the aircraft will likewise be evaluated to determine their conditions. The active coil will be electrically excited by a low-frequency oscillator, and the sensor output will be evaluated to determine if the sensor is functioning properly.

The remainder of the aircraft sensors are sufficiently reliable that no calibration will be performed during the evaluation of the aircraft by the PACER equipment.

Aircraft Test

Upon successful completion of the self-check and calibration, the PACER equipment will be ready to perform the aircraft evaluation, beginning with the static checks.

The static checks, for the most part, require operator participation. These include manual movement of the aircraft flight controls through their end limits and pushing a button signalling PACER to record the measurement. The static tests for the HU-1 include the elevator, linear actuator, and the droop compensator cam box assembly.

To perform these checks the operator will take the remote control box into the aircraft. Appropriate lights on the remote control box will indicate to the operator what manual functions he is to perform and in what sequence to perform them.

After completion of the static tests, the operator will be directed to run up the aircraft to a given r.p.m. (and, in the case of the HU-1, to hold this r.p.m. for 20 minutes before proceeding with the evaluation).

There are several factors which require this stabilization time. The two prime considerations concern temperature measurements and vibration measurements. Reference is made to Final Report, Project Alarm Subtask #1, Bell Helicopter, 25 August 1960, in which it is stated that rate of change of temperature is more significant as warning data than absolute temperature. This statement is true. However, in diagnostic type equipment with intended usage such as PACER, it is unlikely that rate of change of temperature can be measured. There are no controlling forces over such things as length of time the aircraft is down prior to PACER evaluation, length of run-up time prior to evaluations, etc.; therefore, there can be no time reference base. In order to insure stable reference temperatures by which to compare deteriorations, we have established that the normal component operating temperature under controlled run-up conditions will be used. This method will allow for repeated measurement of any given point for verification if desired.

The other consideration requiring this stabilization time is the aircraft vibration. The possibility exists of having abnormal vibration in the aircraft when it is first run up after sitting idle for some time. These vibrations then return to normal as moisture, etc., is removed by running. Obviously, a PACER evaluation performed during the presence of these abnormal vibrations would not reflect the true condition of the stabilized aircraft and, therefore, would be invalid.

The length of time required for temperature and vibration stabilization will vary for each type of aircraft. From data reported in the above referenced Bell report, a 20-minute run-up is indicated for the HU-1. Smaller aircraft would require less time due to the smaller mass of the dynamic components.

After the required stabilization time, the operator will push a button directing PACER to proceed with the dynamic tests.

Upon completion of all aircraft tests, PACER will stop and will indicate the end of the test to the operator. Following shutdown of the aircraft, the operator will evaluate the results of the test. A typical HU-1 PACER test will take about 7.5 minutes; this time includes 10 seconds each for the operator to perform the manual aircraft control manipulations, but it obviously does not include the 20-minute stabilization time.

EVALUATION OF AIRCRAFT TESTS

To evaluate the results of the test, the operator will examine the printed sheet for any red-printed data. If there have been no red prints, the aircraft has no detectable impending faults; the necessary visual inspection can be performed, and the aircraft returned to the using organization.

Print-Red Conclusions

In the case where red prints have occurred, it is first necessary for the operator to determine the cause of the print-red. As explained in the next section of this report, a red print can occur as a result of either the monitored point being out of limits or the monitored point value having changed since the last previous PACER evaluation.

A print-red caused by a deviation limit's being exceeded may not indicate a fault but a possible impending fault; it calls the operator's attention to the fact that a given point has changed beyond a set percentage since the last evaluation and that investigation of the cause is warranted. A print-red condition due to a deviation limit may be indicated by an asterisk or another symbol if so desired.

A print-red caused by an out-of-limit signal indicates a no-go condition and requires immediate attention and repair. Multiple print-reds may require analysis in accordance with the fault isolation techniques described elsewhere in this report.

Duplicate Tape

After a satisfactory PACER evaluation is made, the operator will remove the new history tape from the history-tape reader and insert it into the program reader to make a duplicate history tape. One of the new history tapes is stored in the aircraft along with the program tape and will be used for the subsequent PACER evaluation of this aircraft.

The purpose of the duplicate history tape is to provide recorded, coded information for processing at any convenient Army data reduction center. One product of this processing would be the establishment of wear-rate curves on dynamic components of the aircraft. Once these wear-rate curves are established it becomes an easy task to predict, based upon these curves, component failure prior to actual failure. The ability to do this will have a tremendous economic effect on the Army supply system as well as substantially increasing the flight availability of aircraft. Down time of aircraft can be greatly reduced due to the lead time advantage made possible with this technique.

The coded information on this history tape is in such a format that it is compatible with the present Army data processing equipment.

DETAILED OPERATIONAL DESCRIPTION

PROGRAMMER AND CONTROL

With PACER mated to the aircraft by the two connecting cables, signals from the aircraft are applied to the input side of the three selection relay trees as illustrated in Figure 7, PACER, Simplified Block Diagram.

By commanding various relays in the appropriate input tree, the aircraft signal is applied to the input of the signal conditioner selector tree which, when commanded, will apply the aircraft signal to the input of the desired signal conditioner. Following any adjustment to the signal by the conditioner, the signal is extracted from the conditioner by the output tree in the form of a d-c voltage with a level that may range from 0.01 volt to 9.99 volts.

Once the signal is in this condition, it is ready to be evaluated. Several tests of this voltage, which we will now call the data voltage, are made by PACER. It will be compared with a low-limit voltage representing the minimum acceptable level which the data voltage can reach without being considered too low in value for acceptance. This is done by the relative voltage detector. If the data are found to be less than this limit, the color control circuit will be actuated and a print-red command will be sent to the printer.

The data are similarly compared with a high-limit voltage representing the maximum acceptable level which the data voltage can reach without indicating a failure. During the time the high and low evaluations are being made, the digital voltmeter is reading the data voltage, and, when stabilized, it will provide an output to the storage scanner and printer storage unit for later printing. Available on the front panel of the voltmeter is a display of the voltage read by the meter. Normally during automatic operation of the equipment, this display does not remain long enough to be observed; however, during single-step operation, it is useful.

The ratio of the data voltage and the history information (transformed into a d-c voltage in the digital/analog converter, equal to the binary coded decimal value from the history tape) is obtained in the ratiometer section of the digital voltmeter. The ratio of the two voltages appears on the output of the ratiometer and enters the percent deviation circuit, where it is converted into a plus or minus percentage figure representative of the amount that the present data have deviated from the history information.

As mentioned before, the print-red circuit may be actuated by a failure either on a fail high-limit test or on a low-limit test or on both. It is also possible to obtain a print-red if the percent deviation exceeds either of two preselected limits, ±20 percent or ±50 percent limit is always applicable; and if the deviation ever exceeds this value, a print-red is generated. If it is desirable to obtain a print-red at the 20 percent limit, a special code is placed in the program tape for that particular test.

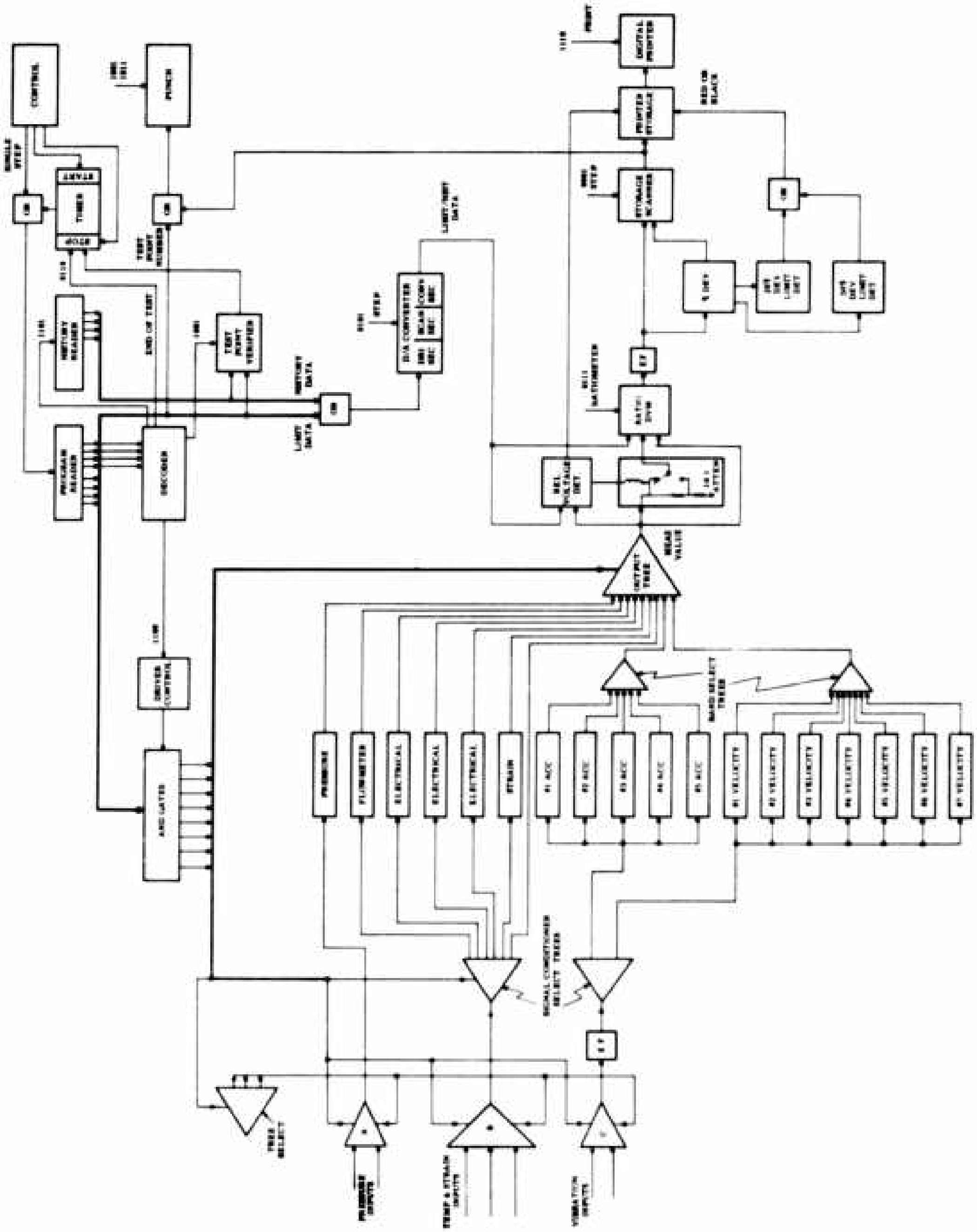


FIGURE 7. PACER, SIMPLIFIED BLOCK DIAGRAM

The percent variation limit may be changed by an alternation in the circuitry of the deviation circuit. The 20 percent and 50 percent figures are arbitrary figures and should not be construed as being absolute.

Two types of recording methods are provided in PACER for the checkout of each aircraft. A Beckman Model 1453 automatic printer provides a permanent, printed record of the test point number, high and low limits, data voltage, and percentage by which the present data have changed from that of the past history data. These are all 3-digit numbers appearing in 3 columns on 2 rows, per test. Any out-of-tolerance information is indicated in red by the printer on the second line.

An Invac Model P-100-8 paper tape punch is provided to record on punched paper tape the test point and data information obtained during the checkout of the aircraft (Figure 8). Only four channels (bits) of the eight channels available are used. Information in the tape will be test point number and data value only. No special programming information is provided. Any special programming required for the particular data processing system in which the tape will be used may be inserted at the time of use.

PROGRAM CONTROL

The program tape reader supplies the program commands to the various circuits throughout PACER. Usually four bits in the program tape are program information and four bits are numerical information. The exceptions to this are commands sent to the input selector sections where all eight bits in two tape positions are required for complete input selection.

Three general types of signals are present in the programmer section:

1. The aircraft data signal is the d-c voltage to be evaluated. This voltage is read by the digital voltmeter, compared with the high and low limits for the go/no-go test, and compared with the history information for the percent deviation test as three separate functions.

2. The -12 volts and ground signals are used to operate all the various transistor circuits. These signals, usually originating in the program tape reader, will either drive circuits directly or operate relay driver circuits which will operate relay trees or stepping switches.

3. The 28-volts d-c is used throughout the programmer to actuate relays and stepping switches.

The sequence of operation of PACER is as follows:

The appropriate cables of PACER are attached to the aircraft, the primary power cable is connected to a 115-volt, 60-cycle line source, and the pilot's manual control box is placed in the aircraft for remote operation.

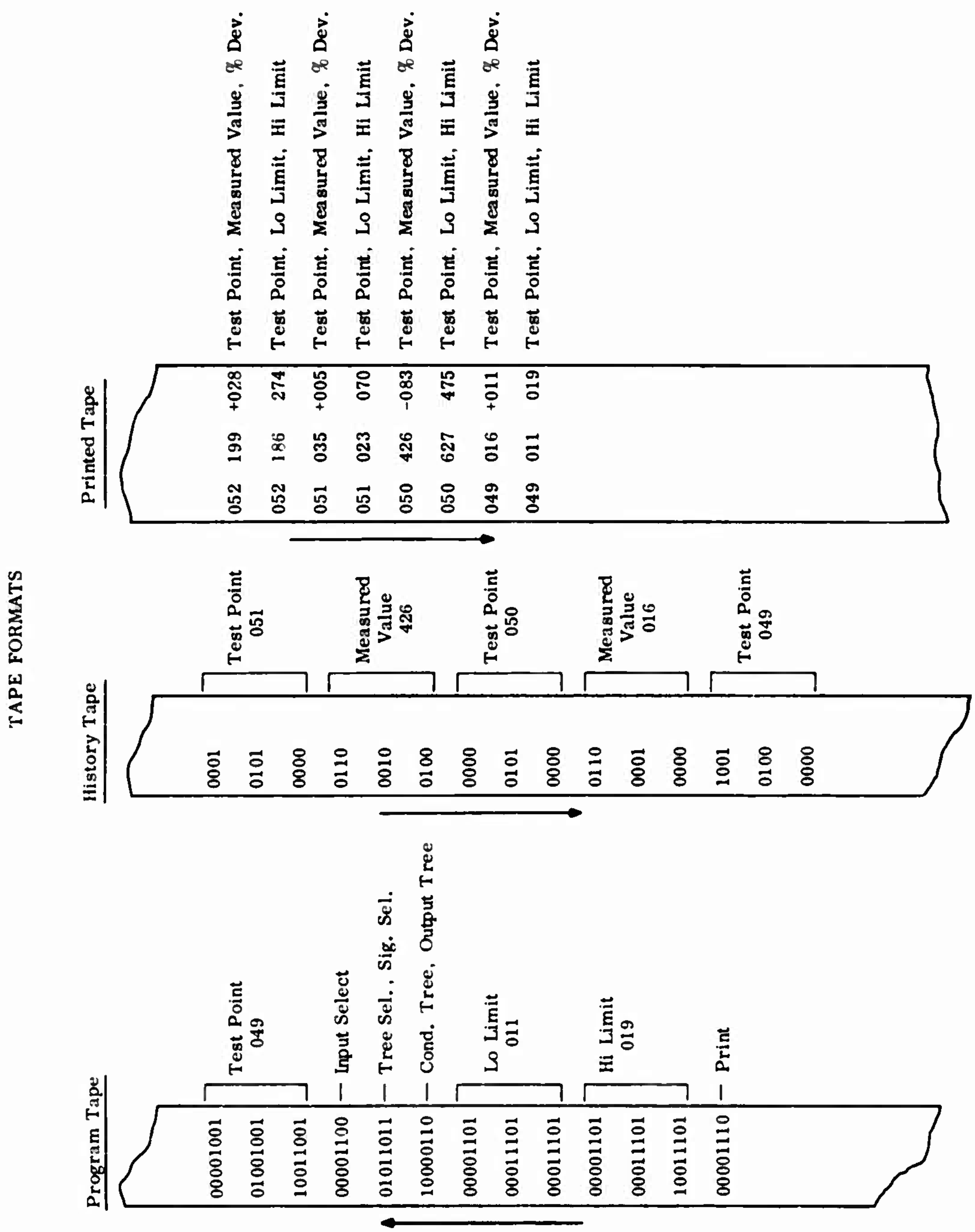


FIGURE 8. TAPE FORMAT

PACER power is turned on; and during warm-up of equipment, the two tapes are inserted in the tape readers and the tape punch is checked for a sufficient supply of blank tape.

The start button is then depressed; PACER automatically performs a self check and calibrates aircraft sensors.

In the event of a failure during any of the above operations, PACER will stop following the calibration tests and indicate a failure to the operator.

Should all tests be satisfactory, PACER will continue into the static tests of the aircraft. During this portion of the checkout, the operator in the aircraft will command PACER from the remote control box. During the static tests, PACER will stop periodically to permit the operator to manipulate certain flight controls of the aircraft. As the operator completes each step, he will then depress a button on the control box which will command PACER to resume operation. PACER will automatically stop as programmed for the various static tests until the operator signals completion of that particular step. PACER will stop automatically upon completion of the static check and will signal to the operator to proceed with the inspection.

A light on the control box will indicate to the operator to run up the aircraft. After waiting approximately 20 minutes for the aircraft to stabilize, the operator will then depress the PACER start button, and the equipment will automatically perform the dynamic aircraft tests. The electrical tests will be performed during this stabilizing time.

Twenty-five tape positions in the program tape are required to complete the evaluation of one aircraft data point. The tape stops automatically from time to time to allow stabilization of PACER circuits. These conditions, then, do not utilize the maximum speed of the tape reader.

The following information is recorded by the printer: The data point number, the low-limit, and the high-limit are printed on the first line; and the data point, the present data, and the percent deviation are printed on the second line. Two cycles of operation occur for each test: the printing of line 1 and the printing of line 2.

Because it is necessary to have all the information in the printer at the time when the print command occurs and because the information being printed is obtained from various parts of PACER, it is necessary to store this information somewhere until the time to print. A printer storage unit is provided for this purpose.

Each test on the aircraft will be performed in a similar manner so that a description of one of the dynamic tests of the aircraft will be adequate.

As the program tape is stepping through the reader, the following sequence of operations will occur:

The 1st, 2nd, and 3rd tape positions contain the three-digit test-point number in binary coded decimal forms. This information is sent to the printer storage unit and the history tape punch.

The 4th tape position contains a special command that will enable the relay drivers for the signal selection relay section.

The 5th and 6th positions select the appropriate input tree, the desired input line in the tree, the proper signal conditioner, and, finally, the output of the signal conditioner to the digital voltmeter and relative voltage detector input lines.

The 7th tape position activates the digital/analog converter, and contains the 1st digit of the low limit which is sent to the printer storage and digital/analog converter.

The 8th and 9th positions contain the 2nd and 3rd low-limit digits which are fed into the digital/analog converter for limit evaluation and into the printer storage unit for later print-out.

At this time the evaluation of the data and the low limit is performed. The output of the digital/analog converter and the test data is fed into the relative voltage circuit. If the data voltage is larger than the low limit, no further action will occur in the detector. If the data voltage is smaller than the low limit, it is a "failure" and a "print-red" color command will be generated for the printer. Following this command, the digital/analog converter is reset. The 10th, 11th, and 12th tape positions contain the high-limit information which is placed in the digital/analog converter and printer storage.

At this time the evaluation of the data and the high limit is performed. This operation is the same as that for the low limit. If the data exceed the limit, a "print-red" command will be generated in the detector.

Tape position 13 contains the "print command" for the recorder. This initiates one printing cycle, and all information in the storage unit will be recorded as the first line of the information for the test. Note that the first line will never be printed in red. If there has been a "print-red" command generated, it will affect only the second line.

The 14th, 15th, and 16th tape positions contain the binary coded decimal test point information that will go to the storage unit. The history reader is stepped, and the digital/analog converter is activated to provide readout of the binary coded decimal history information from the history reader into the digital/analog converter for the history data evaluations.

Tape position 17 steps the storage scanner switch to position 13 where PACER is held until the digital voltmeter has stabilized on the data voltages.

The 18th, 19th and 20th tape positions contain a command to connect the output of the digital voltmeter to the printer storage unit which will provide storage of the data information for print-out in the second line. This command will also cause the information to be punched in the history tape and step the tape punch. At the completion of these functions, the digital voltmeter and tape punch are deactivated. The 21st tape position contains a command to activate the percent deviation circuit and the ratiometer part of the digital voltmeter. The data signal is removed from the input of the digital voltmeter and applied to the input of the ratiometer.

Positions 22, 23, and 24 step the storage scanner switch and enter the percent deviation into storage. During position 22, the 20 percent tolerance on the percentage deviation is selected if desired.

Tape position 25 contains the second print command. Following the printing of line two, all sections of PACER will be reset by a "print-complete" command from the printer and the equipment is ready for the next data point evaluation.

Upon the completion of the dynamic tests, PACER will stop and an indicator will tell the operator that all aircraft testing has been completed.

Automatic and manual modes of operation are provided in PACER. In the automatic mode, the program tape reader steps automatically. In the manual mode, it will be possible to single step the program tape reader. This will provide the operator with an opportunity to stop testing at any time for trouble shooting or making adjustments to the aircraft.

SELECTION RELAY SECTION

The selection relay section is controlled by predetermined codes in the program tape. Two tape positions are required to select completely the various inputs and conditioners and to provide a single-line d-c output to the digital voltmeter. (See Figure 9)

The first of the two tape positions contains coded information for the selection of 1 and 3 input selection trees and selects the appropriate line within the tree.

The second tape position contains coded information that selects the appropriate signal conditioners for the signal and the appropriate signal conditioner for the digital voltmeter.

The three input trees are:

1. Pressure Transmitters Selection Tree - This tree contains 12 dual-line inputs. Four bits (codes) in the tape are required to select any 1 of 12 inputs.

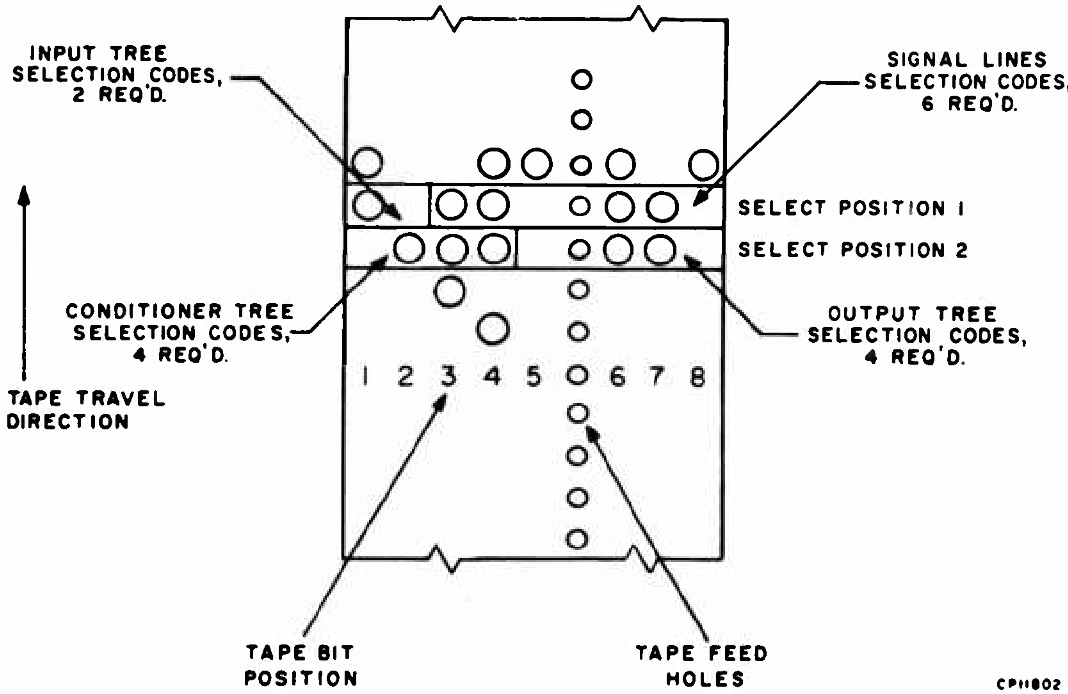


FIGURE 9. PROGRAM TAPE CODING, SIGNAL SELECTION RELAY SECTION

2. Temperature, Electrical and Strain Test Point Selection Tree - This tree contains up to 58 single-line inputs. Six bits in the tape are required to select any one of these lines.

3. Vibration Sensors Selection Tree - This tree contains up to 29 single-line inputs. Five bits in the tape are required to select any one of these lines.

A small relay tree operated by two bits from the program tape activates one of the three input trees by applying +28 volts d-c to the relay coils.

NOTE: Small subminiature and microminiature latching-type relays are used in the trees. The microminiature 2-pole type is used for small quantity switching functions, while the 6-pole subminiature relays are used for large-quantity switching functions.

The set of relay trees commanded by the second tape position are:

1. Temperature and Electrical Signal Conditioners Tree - This tree contains up to 16 lines for the selection of as many as 16 conditioners and is commanded by 4 bits on the program tape.

2. Vibration (Accelerometer Filter/Amplifier and Velocity Filter/Amplifier), Conditioner Bus Selector - This is a double-pole, double-throw relay using one pole section to select the appropriate bus and the other pole section to apply +28 volts d-c to the appropriate filter output tree.

3. Accelerometer Filter/Amplifier Output Tree - This tree provides the selection of up to 8 different filter outputs and is commanded by 3 bits from the tape.

4. Velocity Coil Filter/Amplifier Output Tree - This tree provides the selection of up to 8 different filter outputs. It is a duplicate of the accelerometer filter/amplifier tree. Both are commanded by 3 bits of tape information; however either one or the other is enabled (28 volts d-c applied), depending on which vibration filter/amplifier bus has been selected.

5. Output Selector Tree - This tree contains up to 16 lines used in the selection of the various conditioner outputs and couples the conditioner to the digital voltmeter. Commands for this tree are obtained from 4 bits of information in the tape.

As mentioned before, supply voltage (enabling) for the input trees comes from the input tree selector tree. However, supply for the signal conditioner trees comes from the associated input tree; that is, the temperature and electrical test point selector tree activates the temperature and electrical signal conditioner tree, and the vibration sensors selection tree enables the vibration conditioner bus tree.

With the selector system described, it is possible to select an input line on one tree and hold it if stabilization is required, go to another input selector tree, perform evaluations, and return to the original signal. To hold information for stabilization, the last four bits in the second tape position would be omitted. This would leave the information in the conditioner until it is suitable for evaluation.

Normally, at the end of each test cycle following the recording of the test information, a "clear all relays" command is generated. If there is a signal being held in a conditioner, a command is generated preventing the clearing of that particular conditioner tree. Note that only one signal can be stored at one time from each input selector tree.

Program Tape Reader

The entire operation of PACER is controlled by an eight-channel, paper-tape reader. The purpose of this unit is the sequencing of evaluations of the data information and the providing of binary coded decimal information used in these evaluations as limits or test-point numbers.

The tape itself is paper, 1 inch wide, fan folded for ease of storing, and having a maximum capacity of eight perforations (bits) to the row. (See Figure 9)

The program tape provides two functions per row. The first four bits represent binary coded decimal information which is either a digit of a test point or a digit of the high or low limit used during data evaluations. The last four bits generate program commands required in the controlling of all sections of PACER.

The only exception to this dual function breakdown of the tape is the code required during the operation of signal selection section of PACER, when all eight bits are used to actuate the appropriate relays in the trees.

History Tape Reader

The function of this reader is to extract information from a tape made during a previous test of the aircraft and to utilize this information in determining the percentage by which the present data have changed from the past data.

Four channels (bits) are used in this reader. They are the binary coded decimal test point and history data information. There is no requirement for programming information in this tape.

This reader is controlled by the program reader and operates at the same speed.

Reader Operation

The tape reader used for program control and the reader used for the history tape are identical, and the explanation of operation is applicable for both units.

The tape readers used in PACER are Invac Model R-100-8. This model is a low cost, compact, all-solid-state unit capable of reading an 8-hole tape at 20 characters per second. It uses a photoelectric reading technique and contains all-solid-state circuits.

Other features of the R-100 include: self-cleaning; up to 60-percent light transmission; and a long-life, low-temperature light source that does not offset the photo cells. The mechanical construction of the reader is extremely compact, and the tape transport is driven by two special long-life solenoids.

The output from the amplifiers for a logical 1 (hole) is 0 volts, and the logical output for a O (no hole) is -12 volts. These outputs operate the solid-state circuitry in PACER directly and without any modification.

Tape Punch

Tape generated in the history data tape punch provides a permanent record of the data obtained during the checkout of an aircraft by PACER. In addition, it records the number of each data point.

A history tape is made during an aircraft test for two purposes. It will be used during the following aircraft test as history data for determining the present data/history percentage deviation. It will also be available for use at an automatic data processing center, where the information will be reduced by a computer and the wear-rate curves will be generated for the dynamic components.

Because there is no need for any program information in this tape when it is run through the history reader, only four of the eight channels available in the punch will be used.

The tape punch used in PACER is an Invac Model P-100-8, which is a motorless, direct-drive unit that perforates the history tape at a rate of 20 characters per second. The punches are actuated directly by solenoids, and a restoring bail assures positive return. Solid-state drivers are used to drive the solenoids.

Decoder

The decoder unit is an all-solid-state drive that converts the coded program information from the program tape reader to special command lines used throughout PACER for the control of various circuits.

The major parts of the unit are: transistor matrix drivers, a diode matrix, and transistor output inverters.

Basically, eight matrix drivers are used to provide gain enough to operate the diode matrix and inverters. The diode matrix provides the decoding action in that each code is converted into one of 15 single-line outputs. The inverters provide gain to drive the various sections of PACER.

CONTROL PANEL

The control panel located in the upper left-hand corner of PACER contains the various switches and lights required to operate the unit.

Power Switch and Light, S1 and L1

This switch is used to turn PACER "on" and "off" and is connected in series with the 115-volts a-c, 60-cycle line. When in the "on" condition, all power supplies and equipment within PACER will be activated. A fuse is provided for protection in the event of equipment failure. The indicator lamp is connected to the +28-volt d-c supply and will be illuminated if this supply is "on".

Reset (button), Switch, S2

This switch, when depressed, resets all circuits in PACER to a condition suitable to start an aircraft test.

Start Switch, S3

When depressed this switch starts the program tape reader, and PACER is placed in an automatic mode of operation.

Stop Switch, S4

This switch stops PACER by inhibiting the automatic stepping of the program tape reader.

SC/Cal Fail Light, L2

This light is illuminated when there has been a failure in one or more of the self-check and calibration tests. If this light is lighted, PACER will be in a stopped condition.

Step (button) Switch, S5

If PACER has been previously stopped by the stop switch, this switch shall be used to step the program tape reader one step at a time. This is considered the manual mode of operation.

Test Complete Light, L3

This light is lighted at the completion of the checkout of the aircraft. PACER will be in a stopped condition.

Tape Duplicate Switch

This switch is used when it is desired to duplicate a history tape. The tape to be duplicated should be placed in the program tape reader prior to actuating this switch.

NOTE: All switches should be in the "off" condition prior to connecting or disconnecting any cables going to PACER

Digital to Analog Converter

The Digital/Analog Converter receives 3-digit binary coded decimal information and converts it into a d-c voltage. The magnitude of the d-c voltage output is equal to 1/100 of the digital representation (i.e. 376 = 3.76 volts; 035 = 0.35 volts, etc.).

A series of resistors is switched in or out across a 12-volt d-c source by relays that are latched by the binary coded decimal information appearing at the four input terminals of the unit. Any voltage from 0.01 to 9.99 volts can be set up in 10 mv steps.

Four input lines to relay drivers latch the relays. Another relay driver operates a stepping switch that switches each (binary coded decimal) digit into the appropriate relay in the voltage string.

A Clare, type 211, 11-position, 5-level stepping switch is used for this function. The additional positions on the switch enable the unit to handle the high limit, low limit, and history evaluations of a test in one rotation of the switch rather than in three.

RELATIVE VOLTAGE DETECTOR AND PERCENT DEVIATION CIRCUIT

The Beckman 4011P Digital Voltmeter is used as a ratiometer to provide the ratio of the history voltage and the present data voltage in binary coded decimal form. The output is fed into a complimenting circuit when the deviation is minus (-) or into a direct circuit when the deviation is plus (+) to yield the deviation directly for the printer.

The complete process for printing the deviation is as follows:

The history data, stored in a punched paper tape (binary code) from a previous test, are fed into a digital/analog converter which provides a d-c output equivalent to the original d-c voltage obtained from the signal conditioner during the previous test.

The conditions that are met prior to entering the two voltages into the ratiometer are:

1. The history voltage must be greater than the data voltage.

2. The history voltage is always in the denominator.

3. Both voltages must be of the same polarity.

It is possible that an input signal may either increase or decrease as a function of time. As such, the deviation will be plus for an increase and minus for a decrease.

To satisfy these conditions, a relative voltage detector and 10:1 attenuator are used. The relative voltage detector compares the amplitude of the data voltage with the amplitude of the history voltage. If the history voltage is greater than the data voltage, no adjustment is made to the data voltage.

NOTE: The history voltage is never adjusted.

When both voltages satisfy the input conditions of the ratiometer, they are not altered. In addition, the relative voltage detector generates a "print minus" command to the printer. If the history voltage is less than the data voltage, the data voltage is automatically reduced in order to satisfy condition one. The

10:1 voltage attenuator performs the function of reducing the data voltage, and a "print plus" command is generated.

The ratiometer can now evaluate both conditions of voltages and will provide the ratio output.

In the case of a positive deviation, the ratio output is not the true deviation. It is necessary to subtract one (1) from the highest order digit. A subtractor in the percent deviation circuit performs this function. In other words, 3000 as the ratio would actually be +200 percent (disregard the last digit). Maximum range for a plus (+) deviation is 999 percent with print-out accurate to the nearest lower whole percent.

In the case of a negative deviation, the ratio output is the reciprocal of the deviation and must be complemented prior to recording. This is accomplished by complementing the two highest order digits (disregard the last two digits) in the percent deviation circuit. In other words, 3333 as the ratio would actually be -66 percent. Maximum range for a minus (-) deviation is 99 percent with print-out accurate to the nearest lower whole percent.

Also provided in the percentage deviation circuit is a digit shifting relay (K-6) for positioning of the deviation value in the correct column of the printer.

The digital voltmeter that is used in PACER is a Beckman Model 4011P. This unit serves a dual purpose in the evaluation of the aircraft data points. During an evaluation, its first function is to provide an electrical read-out of the data voltage in the form of a 1-2-4-8 binary code to operate the printer. The second function of the digital voltmeter is to provide an electrical output which represents the ratio of history data to present data. This output will be fed to the percentage deviation circuit. It is also possible to use the digital voltmeter as a separate instrument available to the operator for trouble-shooting purposes.

The voltmeter automatically measures the data voltage and takes comparison measurements with a resolution of plus or minus one digit and a balance time for most measurements of one second.

PRINTER STORAGE AND SCANNER

The printer storage unit provides storage of the digital test information. In this unit, all digits that will appear in one row of the printer are retained until the printing of the row is complete. Thirty-six solid-state, bi-stable storage units are used for the storing of the digits. Four units are required to supply the binary coded decimal information for each digit.

The plus/minus commands and color-control commands are stored separately in one bi-stable unit for each command.

Following the printing of each line, the digit storage units are cleared. A command from the printer (inhibit reset) clears the digit storage; and a command from the storage scanner switch, when in the last position, along with the inhibit reset command, clears all storage units.

A line-1/line-2 bi-stable is provided in the storage unit to inhibit the printing of the plus or minus sign during the first line of print and to prevent the line from being printed in red. This unit is pulsed with each inhibit reset command from the printer and every other pulse causes the line 1/line 2 circuit bi-stable to provide the above action.

The storage scanner selects information from the program reader during the storage and printing of the first line of a test and from the program reader, digital voltmeter, and percent deviation circuit during the second line printing. By using a switch such as the Clare type 20, only one rotation of the switch is required to insert the information in storage for both lines of printing. The switch assures, through fixed sequencing, that all information will be placed correctly in the storage unit.

DIGITAL PRINTER

The Beckman Printer Model 1453 is used in PACER to provide immediate visual read-out of all information associated with the aircraft test. Ten digits are printed per line and two lines are printed per test point evaluated.

It is operated automatically from commands within PACER and provides printed information at a rate of two lines every 4 seconds. Each digit column is controlled by an individual solid-state, plug-in module connected independently to the data storage unit. All columns are digits with the exception of column 4, which is either a ± sign or a blank. Space is provided in the 5th and 9th column positions to provide separation between the three rows of three-digit numbers. Black or red print-out of line 2 is controlled by the color control circuit. When line 2 prints red, it indicates the presence of failure information. Paper for the unit is standard commercial roll type, 2-1/4 inches wide.

REMOTE CONTROL

A remote control box is provided with PACER for the operator's convenience for control of certain static tests from inside the aircraft. Several tests are performed on the aircraft that require the operator to make some minor adjustment to the controls prior to the evaluation of the data by PACER.

Thirteen lights, four of which are spare, and one push button switch are provided on the control box. The 12 lights located in the center of the box indicate to the operator what operation he should perform. Upon completing the indicated operation, the "Push to Acknowledge" switch is depressed and the evaluation is performed.

Located at the top center of the box is the "Test in Progress" indicator. This indicates to the operator that an evaluation is being performed and that no adjustments are required or should be made at this time.

At the completion of the aircraft static tests, the remote control box is deactivated and only the "Test in Progress" light remains illuminated through the remainder of the tests. At the end of all tests, this light is extinguished.

SIGNAL CONDITIONER OPERATION

General

The general function of all signal conditioners in the PACER equipment is to transform the sensor output signals into d-c voltages between 0.01 and 9.99 volts. Signals of this amplitude and form are conveniently handled by the PACER evaluating circuitry. A qualitative explanation of signal conditioner functioning is given in the following paragraphs. Individual sensors and signal conditioners are selected by input and output relay trees. The operation of these trees is discussed under "Selection Relay Section" in this report.

Vibration Signal Conditioners

The desired sensor output is connected to the vibration conditioner bank through an emitter follower. This emitter follower isolates the sensor so that its output characteristics are not degraded and provides sufficient gain to drive the entire bank of signal conditioners.

Each segment of the vibration conditioner bank contains a filter to permit a one octave analysis of the vibration spectrum, an amplifier to compensate for filter insertion loss, a detector to convert from peak to peak a-c to an equivalent d-c voltage for evaluation, and an integrator to provide immunity from signal transients caused by wind gusts and other abnormal conditions.

The conditioners are arranged in banks because of the 10 second integrator stabilization time. This arrangement requires only one stabilization delay per sensor, which can be followed by rapid and sequential evaluation of each octave segment of the total spectrum. The single octave segments will permit good fault isolation capability and evaluation sensitivity with a minimum of circuitry.

The velocity and acceleration conditioners are identical configurations except for the frequency segments. Velocity transducers are most useful in low frequency applications and accelerometers are more suitable for high frequency analysis. The sensitivity of all vibration sensors will be normalized to a standard value.

The signal conditioners are exclusively solid-state circuitry and are temperature-stabilized for operation from $-20^{\circ}F$ to $+130^{\circ}F$. Solid state devices provide long operating life, low maintenance requirements, and high immunity to shock, vibration, and humidity.

Strain Signal Conditioner

The strain sensor standards installed on the aircraft consist of two strain gages mounted in a temperature compensating half-bridge configuration. The desired strain monitor point is connected to a high-gain, transistorized, differential amplifier through a low pass filter. The low pass filter reduces the effect of spurious signal pickup on the low-level strain signal.

This strain signal d-c voltage represents one input to the high-gain differential amplifier. The other input to this amplifier is connected to the high-precision reference leg of the strain-gage bridge. The strain signal, or difference between the two input voltages, is then amplified to a level suitable for PACER evaluation circuitry.

A balance control is provided for each strain monitor point to compensate for gage manufacturing tolerances. The balance control will be set to a preselected residual level consistent with the normal strain present, and the strain limits will be indicated by a fixed percentage above or below this residual.

Electrical Signal Conditioners

The electrical signal conditioners will monitor only a-c and d-c voltages. With a d-c voltage input, the conditioner will consist only of a precision voltage divider to put the data voltage within the operating range of the PACER evaluating circuitry. With an a-c voltage input, the precision divider will be preceded by a rectifier assembly to convert a-c to d-c.

Attenuation will be required only when the electrical system monitor points provide signals above the range required by PACER.

Temperature Signal Conditioners

Low-Level Signals (Thermocouples) - Thermocouple outputs, normally in the millivolt range, will be amplified by the strain signal differential amplifier before processing by the evaluation circuitry. The precision reference voltage will be placed on both differential amplifier inputs to cancel its effect, and the resultant amplifier output voltage will represent only the thermocouple output signal.

High-Level Signals (Thermal Ribbons and Thermal Bulbs) - The temperature signals from these devices are within the range of the PACER evaluating circuitry. No intermediate signal conditioner will be required.

Flowmeter Signal Conditioner

The flowmeter output signal is an alternating voltage varying in frequency and amplitude proportional to the liquid flow through the device. The frequency change is the characteristic that will be monitored by PACER.

The flowmeter output is connected to a series of amplifiers and clippers to provide a uniform signal amplitude at all frequencies. The resulting square wave characteristic is then differentiated and integrated to provide a d-c voltage proportional to the flowmeter output frequency. This d-c voltage output will then be processed by the PACER evaluating circuitry.

The circuit configurations used in this signal conditioner have a high degree of inherent temperature stability. Proper signal conditioner operation from $-20^{\circ}F$ to $+130^{\circ}F$ will be obtained without external compensating circuits.

Pressure Signal Conditioners

The pressure signal conditioners use a system analogous to the one installed for the HU-1 aircraft pressure monitor.

The aircraft synchro transmitter drives the PACER synchro receiver in parallel with the aircraft synchro receiver. A d-c voltage proportional to synchro angular position (pressure signal) is obtained from a precision potentiometer coupled to the PACER synchro receiver. This resultant d-c voltage is used by the PACER evaluating circuitry.

The error introduced by the additional receiver is expected to be only about one percent. The redundancy of this method will also provide a reliable check on the aircraft pressure indicators operation.

PACER SELF-CHECK MECHANISM

General

The purpose of the self-check feature of the PACER equipment is to verify proper functioning of internal circuits before applying any external signals for evaluation. In the event of a failure on any self check test, the equipment will not proceed with the automatic evaluation sequence. It is possible, however, for the operator to force a continuation of tests.

The equipment employs nine different self-check tests. These tests force the operation of a maximum number of internal functions with a minimum amount of added self-check circuitry. The self-check tests are discussed in the following paragraphs. In these discussions, "proper operation" refers to the functioning of all section circuit elements associated with the self-check test in progress.

A simulated sensor output is connected to the input side of the appropriate selector tree. Each of the following conditions must then be fulfilled before the evaluation of the self-check signal can produce a test "GO". The performance of these items represents proper functioning of the PACER circuitry from input connector to final data print out.

1. Proper operation of command circuits from tape reader (origin) to tree selector command lines.

2. Proper operation of input selector and signal conditioner selector relays on command.

3. Proper operation of the associated signal conditioner.

4. Proper operation of the output selector relays on command.

5. Proper operation of the relative voltage detector, digital to analog converter, high and low limit fail circuits, digital voltmeter, printer storage and scanner unit, and data printer.

Conditions unique to each self-check test are discussed in subsequent paragraphs.

Pressure Input

This test uses a d-c voltage at a normal input signal amplitude. This signal checks the items listed in the General section that are associated with the pressure input lines. A special requirement in this self-check test is that all pressure input tree relays have positive operation. The pressure signal conditioner is bypassed, however, because its functioning requires an operating aircraft, which is not compatible with the self-check philosophy.

Temperature Input (High-Level Signal)

This test uses a d-c voltage at a normal input signal amplitude. In addition to the items of the General section, this test requires positive operation of all relays in the temperature input tree. These are high level temperature signals and do not require a signal conditioner. They are connected directly from the input to output selector relay sections.

Electrical System D-C Input

This test uses a d-c voltage at a normal input signal amplitude. In addition to the items of the self-check General section, this test requires positive operation of all relays in the electrical sensor input tree.

Electrical System A-C Inputs

Two tests are performed on the electrical system a-c channels. A-C test voltages are used, and the items of the General section apply. Multiple tests are performed to check out both signal conditioners in this system.

Flowmeter Input

This test uses an a-c voltage at a normal input signal amplitude and frequency. This test requires performance of the items of the General section.

Strain and Low-Level Temperature Inputs

This test uses a d-c voltage at a normal input signal amplitude. In addition to the items of the General section, this test requires positive operation of all relays in the strain input and conditioner selector trees. This test verifies operation of both the strain and low-level temperature processing circuits because a common signal conditioner is used.

Vibration Inputs

Acceleration Signal Input - This test uses an a-c voltage from the 1.2-kc. calibration oscillator at a normal input signal amplitude and frequency. In addition to the items of the General section, this test requires positive operation of all relays in the input selector and conditioner selector relay trees.

Velocity Signal Input - This test uses an a-c voltage from the 1.2-kc. calibration oscillator at a normal input signal amplitude and frequency. In addition to the items of the General section, this test requires positive operation of all relays in the input selector tree.

CALIBRATION MECHANISM

General

Vibration sensor checks represent a calibration of all active devices installed on the aircraft, with the exception of the flowmeter. A method is not feasible to calibrate the flowmeter devices. A calibration for passive sensors such as thermal ribbons, strain gages, etc., will not be performed due to the inherent stability of these devices. A passive sensor malfunction is obvious on data read-out and will always result in a fail indication.

Accelerometer Calibration

PACER instrumentation employs dual-element accelerometers specially designed for "in place" calibration. A temperature-stabilized calibration oscillator excites the accelerometer calibrating element. The resultant sensing element output is processed as a conventional vibration signal.

The calibration sequence is performed at a frequency of 1200 c.p.s. This frequency is in the lowest frequency band of the accelerometer output spectrum. Any long term degradation of device performance appears first in this low frequency region.

Velocity Transducer Integrity

The response checks performed on velocity sensors are not true calibration operations. They are, however, a better indication of device integrity than a simple continuity check.

The velocity sensor coil is the output element of a precision voltage divider excited by a temperature stabilized calibration oscillator. The effective impedance of the divider output element is then a function of the sensor magnetic field, the coil inductance and resistance, and the freedom of coil motion to generate a counter.

Response tests have indicated that a considerable impedance change results when the coil motion is restricted. This effect is most pronounced (up to 175 percent change) at the device natural frequency, where maximum coil motion exists.

The velocity sensor checks are performed at a frequency of 17.5 c.p.s. This frequency is the optimum point to achieve an equal impedance change effect (approximately 25 percent) on each of the two types of velocity sensors used.

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Air Proving Ground Center, Eglin AFB	1
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Air Force Systems Command, Wright-Patterson AFB	3
Chief of Naval Operations	1
Bureau of Naval Weapons	1
U. S. Naval Postgraduate School	1
David Taylor Model Basin	1
U. S. Marine Corps	1
Marine Corps Schools	2
Marine Corps Liaison Officer, U. S. Army Transportation School	1
U. S. Coast Guard	1

U. S. Army Standardization Group, Canada	1
Canadian Army Liaison Officer, U. S. Army Transportation School	3
British Army Staff, British Embassy	4
U. S. Army Standardization Group, U. K.	1
National Aviation Facilities Experimental Center	3
NASA-LRC, Langley Station	2
George C. Marshall Space Flight Center, NASA	1
Manned Spacecraft Center, NASA	1
Ames Research Center, NASA	2
Lewis Research Center, NASA	1
Scientific and Technical Information Facility	1
U. S. Government Printing Office	1
Defense Documentation Center	10
Human Resources Research Office	2
U. S. Patent Office	1
U. S. Army Transportation Engineering Agency	1
U. S. Strike Command	1
Air Force Flight Test Center, Edwards AFB	1
U. S. Army Mobility Command	3
U. S. Army Materiel Command	4

York Division of The Bendix Corp., York, Pa.
PORTABLE AUTOMATIC CONDITION EVALUATOR/RECORDER STUDY & DESIGN PROGRAM
TRECOM Technical Report 63-48, Dec. 1963 74 pp.
(Contract DA 44-177-TC-750) USATRECOM Proj 9R89-02-015-16

Unclassified Report

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