NASA CR-145288

RESEARCH REQUIREMENTS TO REDUCE MAINTENANCE COST OF CIVIL HELICOPTERS

By
Daniel J. Million
and Kenneth T. Waters

Prepared under Contract No. NAS1-13624
By
Boeing Vertol Company
Philadelphia, Pennsylvania

for

NASA

National Aeronautics and
Space Administration

February 1978

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ABSTRACT

This report documents the maintenance problems faced by the operators of civil helicopters that result in high costs. Existing technology that can be applied to reduce maintenance costs and research that should be carried out are identified. Good design practice and application of existing technology are identified as having a significant impact on reducing maintenance costs immediately. The research and development that have potential for long-range reduction of maintenance costs are presented.

FOREWORD

This report was prepared by the Boeing Vertol Company for the National Aeronautics and Space Administration, Langley Research Center, under NASA Contract NAS1-13624. William Snyder was NASA Technical Monitor for this work. Kenneth T. Waters was Project Manager for Boeing Vertol.

SUMMARY

The purpose of this study was to identify research and development that can be applied to maintainability problems in the civil helicopter fleets to substantially reduce the costs of maintenance. Solutions to many of the problems that generate high maintenance costs are available and some are in work. Other problems are being solved during design of new helicopters and can be expected to offer much-improved maintainability as these machines reach maturity. Noteworthy items are as follows:

- Vibration troubleshooting of components
- Development of proceduralized troubleshooting aids (PTSA's) and use of new maintenance record-keeping systems
- More application of engine inlet separators for FOD and compressor erosion
- Application of Airline/Manufacturers Maintenance Planning (MSG-2) techniques.

Research and development that should be conducted are identified as follows:

- Reduce helicopter vibration levels
- Demonstrate advanced-technology on-condition transmissions
- Develop airborne maintenance diagnostic equipment for all systems (to be used in conjunction with PTSA's)
- Study computerized maintenance record systems for small operators
- Study cost savings from salvage of high-value components.

The implementation of most of these items will be necessary to effect substantial cost savings and enhance the growth potential of the civil helicopter industry.

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TABLE OF CONTENTS

	Page
ABSTRACT	iii
FOREWORD	iv
SUMMARY	v
LIST OF ILLUSTRATIONS	ix
1.0 INTRODUCTION	1
2.0 BACKGROUND	4
3.0 TECHNOLOGICAL SHORTCOMINGS	6
3.1 Major Elements Impacting Helicopter Maintenance	6
3.2 Factors Impacting Maintenance Costs	11
3.2.1 Vibration	11
3.2.2 Scheduled time between overhauls (TBO's)	13
3.2.3 Foreign-object damage (FOD)	17
3.2.4 Inspection	17
3.2.5 Diagnostics and erroneous maintenance	17
3.2.6 Technical publications and training	22
4.0 RESEARCH RECOMMENDATIONS TO REDUCE MAINTENANCE COST	24
4.1 Vibration Reduction	24
4.2 Demonstration of Advanced-Technology On-Condition Transmissions	24
4.3 Develop Diagnostic Equipment for On-Condition Dynamic Components	24
4.3.1 Develop incipient failure detection (IFD) equipment for field use	24
4.3.2 Develop turbine engine health-monitoring and diagnostic equipment	25
4.4 Develop Airborne Maintenance Diagnostic Equipment for All Systems	25
4.5 Study Computerized Maintenance Record System for Small Operators	26
4.6 Study Cost Savings From Salvaging High-Value Components	26

Page

5.0 IMPACT OF MAINTAINABILITY IMPROVEMENTS ON SIZE, CONFIGURATION, AND MISSION APPLICABILITY 27

6.0 CONCLUDING REMARKS 28

APPENDIXES

A. Helicopter Vibration Analysis Technique 30

B. Fault Isolation Procedure 40

C. Helicopter Maintenance Record-Keeping System 46

REFERENCES 53

LIST OF ILLUSTRATIONS

Figure		Page
1	The relationship of direct maintenance manhours and direct maintenance costs	2
2	Top unscheduled maintenance manhour and cost problems of the operator of civil helicopters	3
3	The relationship of maintainability, maintenance, and cost	5
4	Distribution of operation maintenance manhours	7
5	Causes of unscheduled maintenance	8
6	Mean percentage of scheduled maintenance by aircraft subsystem	9
7	Twenty years of improvement in the maintenance costs of utility transport helicopters	10
8	Comparison of failure rate and maintenance manhours by subsystem with and without vibration absorbers	12
9	The rationale for on-condition maintenance of helicopter gearboxes	15
10	Method of evaluating capability for on-condition maintenance	16
11	Unscheduled engine removal rate for foreign-object damage for various engines and aircraft installations	18
12	Sources of turbine engine damage from foreign objects	19
13	Decision diagram from airline/manufacturer maintenance program	20
14	Distribution of on-aircraft maintenance actions	21

1.0 INTRODUCTION

The maintenance costs associated with operating civil helicopters are, in the eyes of the operators, untenably high. The operator looks to the industry and to governmental agencies to take whatever steps are necessary to make the helicopter more cost-effective.

In this report we identify the costs and maintenance burden associated with civil helicopter operation and maintenance. We deal primarily with those aspects of maintenance costs directly related to the maintainability and maintenance characteristics of the aircraft. Figure 1 illustrates the relationship of direct maintenance manhour expenditures to direct maintenance costs. For example, servicing, inspection, and aircraft fixes make up 88 percent of the direct maintenance manhours (labor) but represent only 49 percent of the direct maintenance costs. The other direct maintenance costs are associated with material costs.

In the reliability report (ref. 1) generated by this study, the major civil helicopter reliability problems are addressed and, where possible, research programs are identified to reduce the maintenance burden and cost generated by component reliability. Figure 2 displays the top 20 civil helicopter maintenance manhour and maintenance cost problems. Each of these problems is addressed in reference 1 and programs are defined for reducing the frequency of occurrence of these problems.

In this document we address the problem of reducing those aspects of direct maintenance costs other than reliability displayed in Figure 1. The elements considered include the following:

1. Time-between-overhaul (TBO) removal costs
2. Erroneous-removal costs
3. Excessive servicing and support requirements
4. Scheduled inspection requirements
5. Troubleshooting difficulties
6. Lengthy maintenance tasks

It should be noted that the FAA helicopter Malfunction or Defect (M or D) report system does not contain data for application to the analysis of the listed maintenance problems. As such, the contents and conclusions of this report are based primarily on discussions with and questionnaires from civil operators and on military helicopter data. However, it should be reiterated that the maintenance costs associated with component reliability have been identified for civil helicopters via an analysis of FAA M or D reports as discussed in reference 1. The reader is encouraged to review that report.

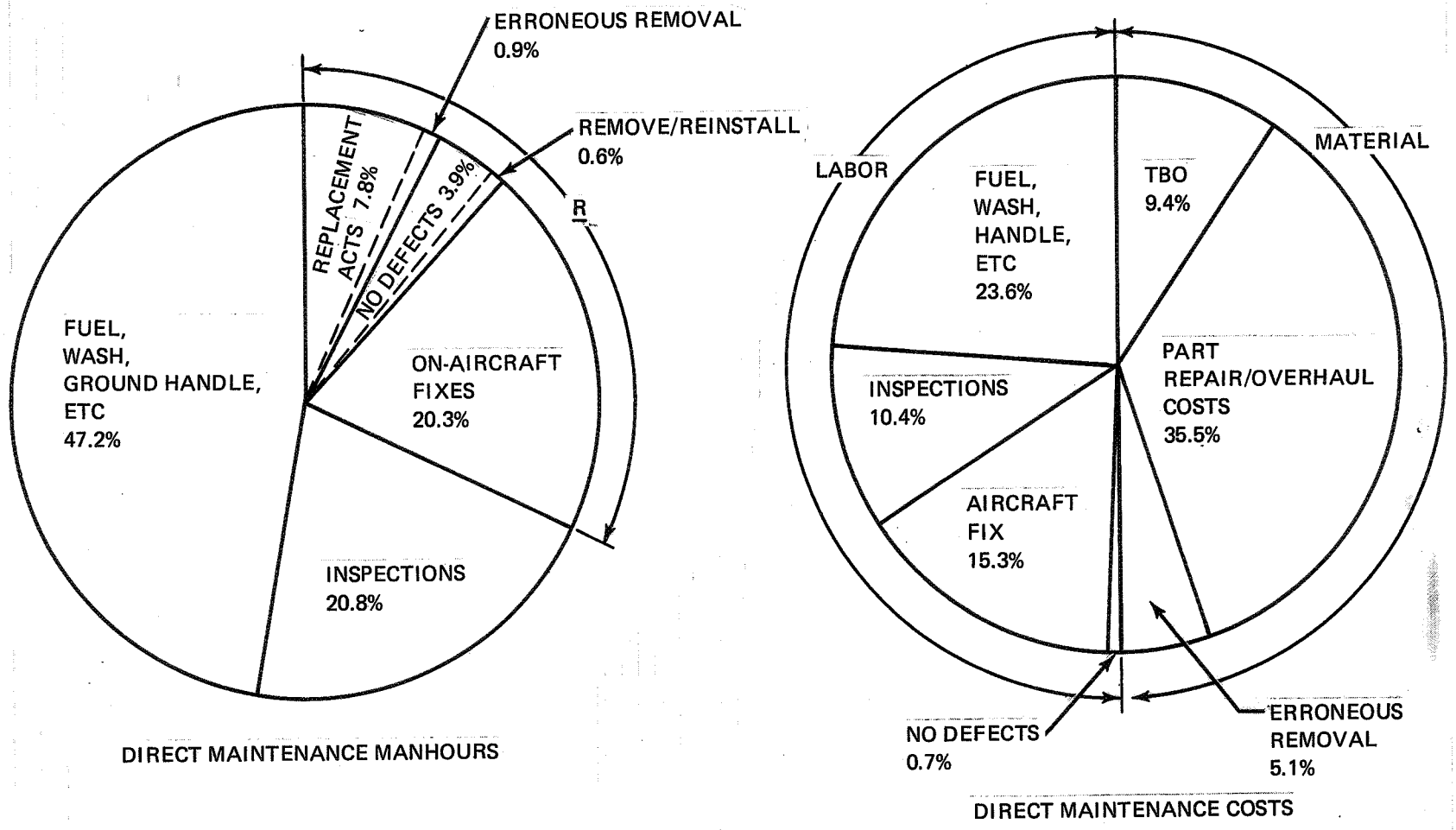

Figure 1. The relationship of direct maintenance manhours and direct maintenance costs

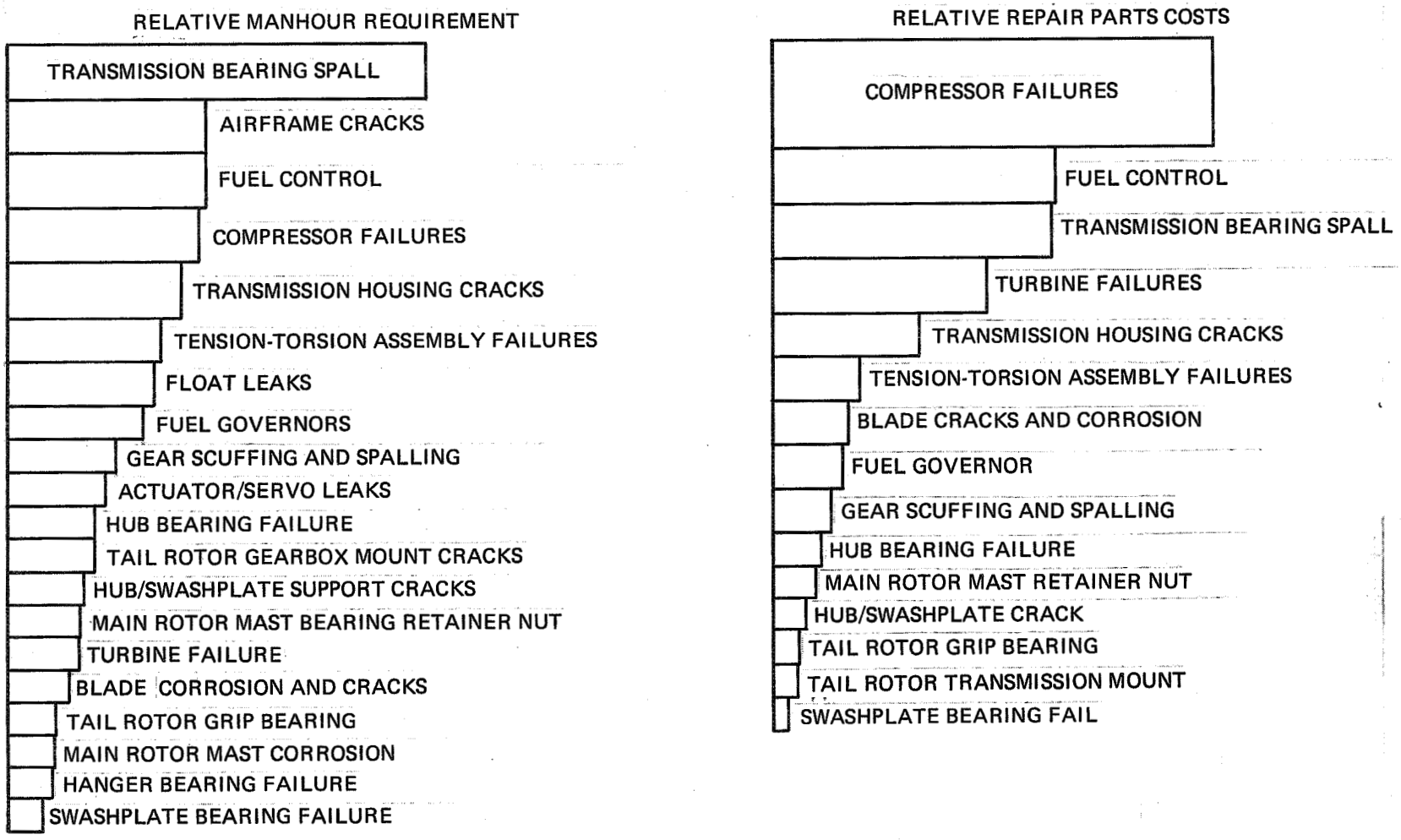

Figure 2. Top unscheduled maintenance manhour and cost problems of the operator of civil helicopters

2965

2.0 BACKGROUND

A prerequisite of research to lower the costs of helicopter maintenance is an understanding of the design discipline directly impacting maintenance and of the existing maintenance penalties paid by the user. Good maintainability engineering techniques and practices introduced in design will result in lower maintenance costs. The relationship of maintainability to maintenance to cost is shown in Figure 3. The figure shows that, in addition to design considerations, two other factors have a direct impact on maintenance and resultant costs. These, the operator/owner plan for use and regulatory agency requirements, are addressed further in section 3.0, TECHNOLOGICAL SHORTCOMINGS. Maintainability as a design discipline is recognized by most helicopter manufacturers as a result of their military sales and government recognition of this parameter as a driver in the life-cycle cost of ownership. Maintainability has been adequately documented in existing reports and will not be expounded upon here. Subsequent paragraphs identify the major elements of the maintenance burden, the factors impacting costs, existing technological and planning shortcomings, and recommendations for additional research to reduce the costs of maintenance support.

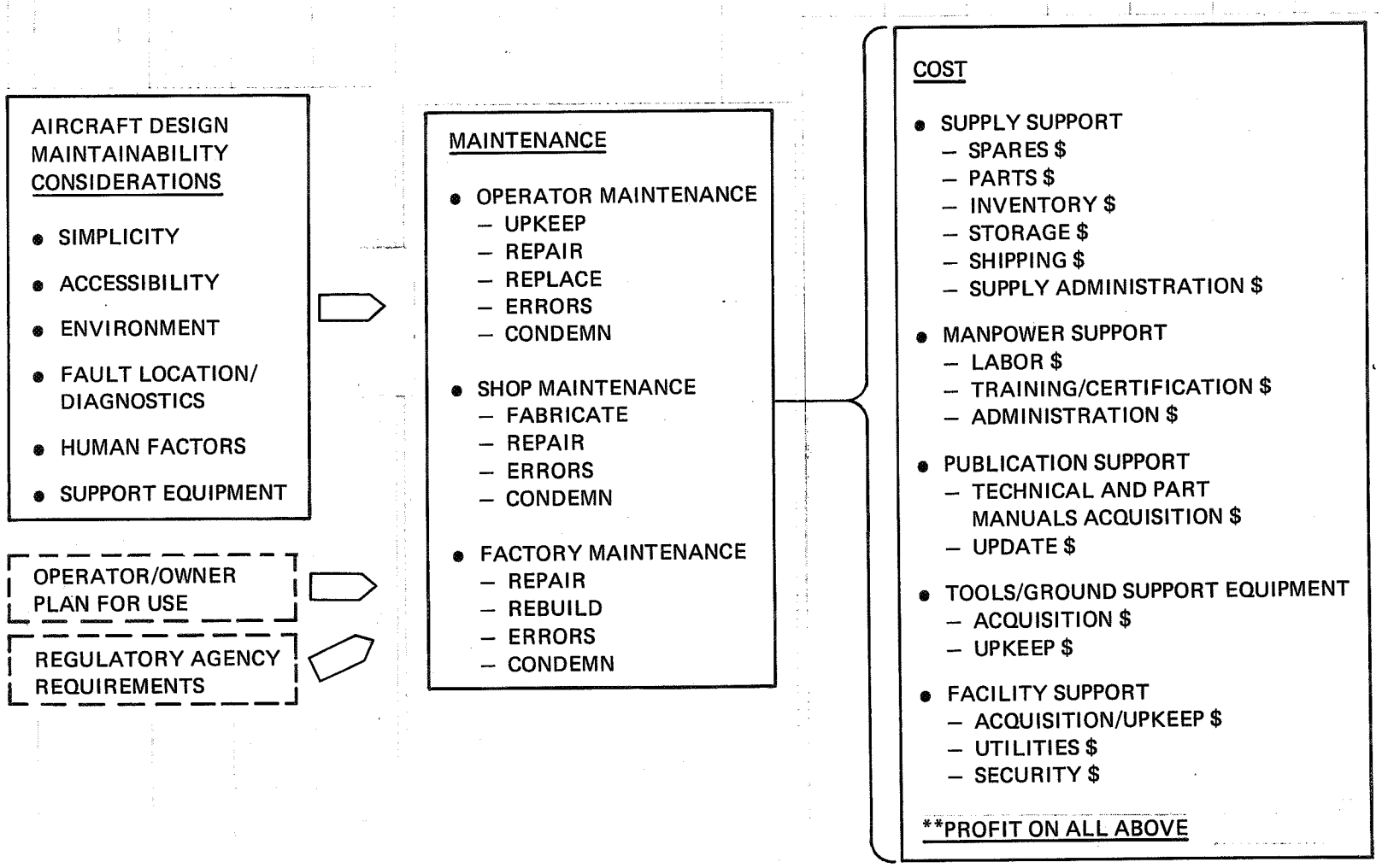

Figure 3. The relationship of maintainability, maintenance, and cost

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3.0 TECHNOLOGICAL SHORTCOMINGS

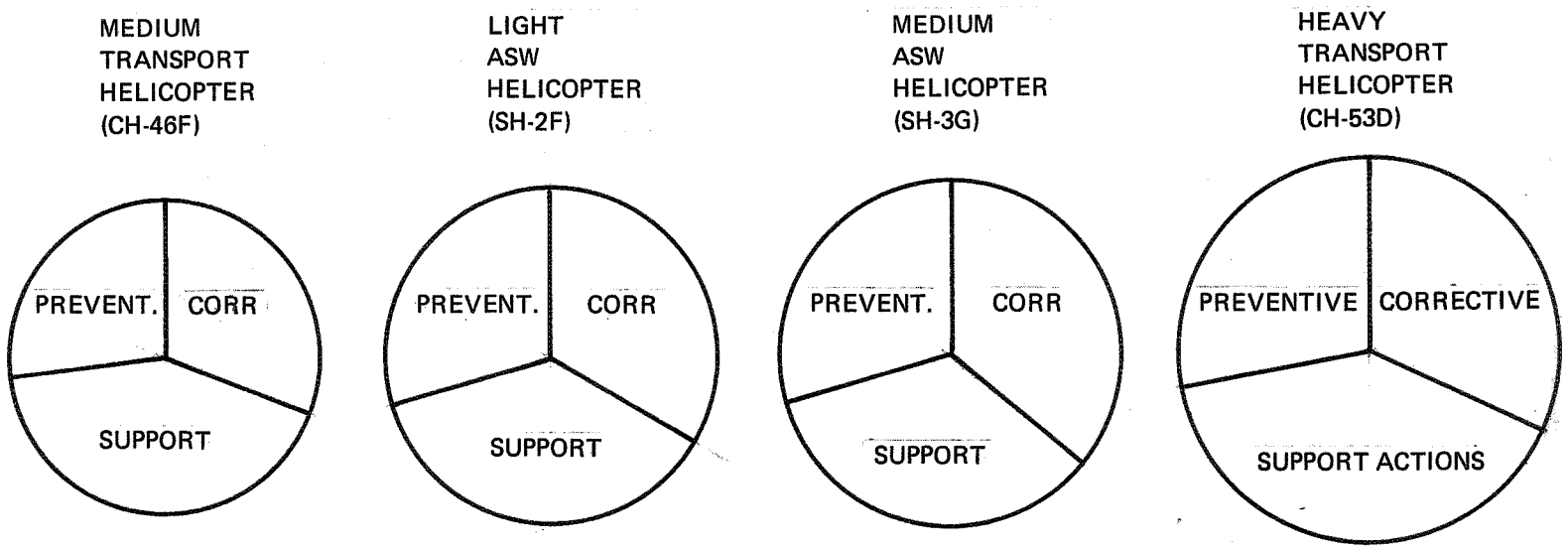
3.1 Major Elements Impacting Helicopter Maintenance

A major deterrent to a study of civil helicopter maintenance and direct maintenance cost is the lack of quantitative historical data. Hence, the quantitative assessments contained herein are based on maintenance data collected on military helicopters which the authors believe to be relevant to civil helicopter operations, on civil operator questionnaires and discussions, and on industry magazine articles (see references 2, 3, and 4).

Figure 4 portrays a distribution of manhour expenditures for operator-performed on-aircraft maintenance and support. Light, medium, and heavy helicopters are shown. It is interesting to note that, although the magnitude of maintenance varies with size or operational employment, the distribution of maintenance and support by type remains relatively constant. Preventive maintenance includes the look phase of aircraft inspections and replacement of TBO components. Support actions relate to aircraft handling, servicing, and those housekeeping-type activities associated with aircraft maintenance. The magnitude of support actions is primarily dependent on operator activity and intentions and does not relate to helicopter design. Support actions are shown here to indicate the amount of this labor expenditure which is beyond design control. However, these activities consume little material and, consequently, are not significant cost drivers.

Results of an operator survey conducted by the University of Virginia (reference 5) are shown in Figures 5 and 6. The unscheduled maintenance estimated by 163 civil helicopter operators averaged approximately 20 percent of total maintenance, with causes as shown in Figure 5. Note that vibration, vehicle design, operational environment, and engine failures were reported to represent over 93 percent of the unscheduled maintenance problems. Figure 6 shows the mean percentages of scheduled maintenance reported by aircraft subsystems.

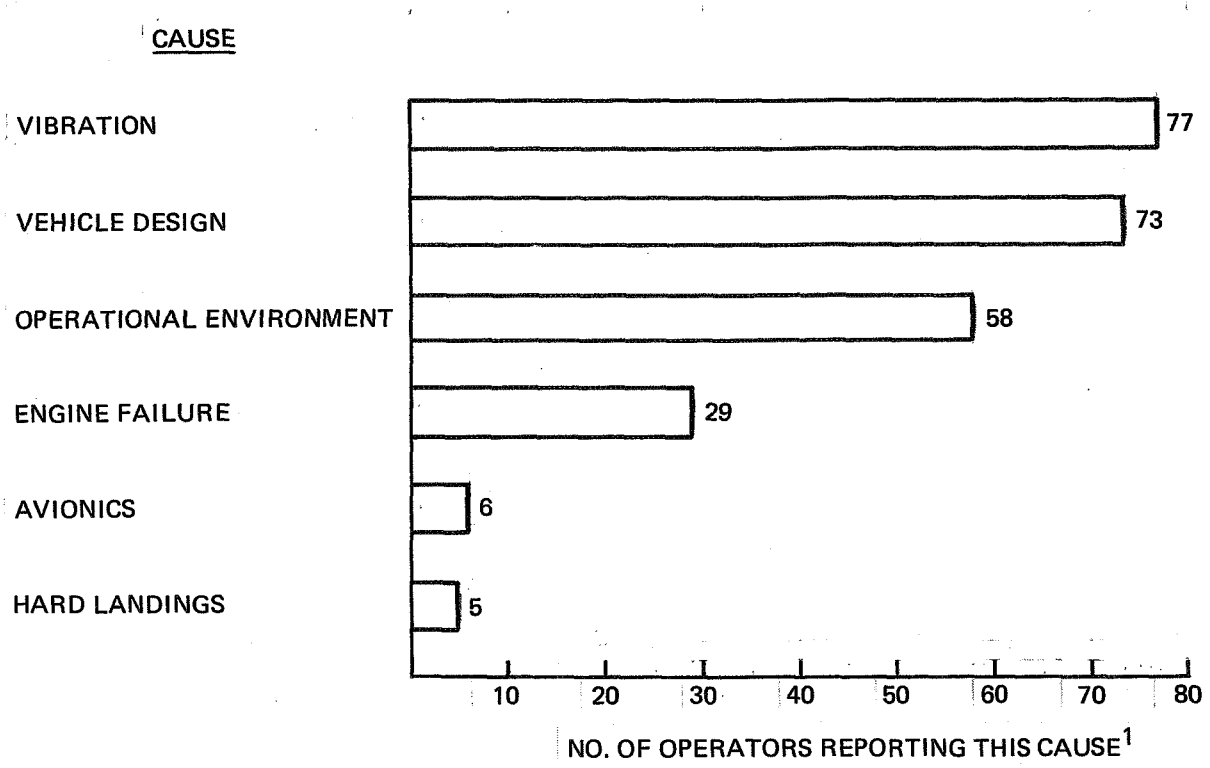
Figure 7 shows the subsystems contributing most to the overall cost of ownership. This figure portrays the results of two studies conducted on similar air vehicles. The chart on the left represents a military study conducted on a 1950-vintage helicopter, while the right chart shows the results of a Boeing Vertol study of a replacement for the 1950-era designs. It is evident that the emphasis placed on reliability and maintainability during the 1960's, coupled with technological advances, have provided significant improvement in the cost-driving subsystems. The overall reduction in powerplant, rotor, and transmission contributions to cost, from 85 to 63 percent, has allowed other subsystems to surface as cost drivers, so that they, too, may receive proper corrective-action attention, with resultant overall reduction in ownership costs. The most significant reduction shown in Figure 7 is in the rotor and transmission system, which is primarily attributed to the composite blades and hingeless rotor system used in the 1970 design. Even with these improvements, the powerplant/rotor/drive subsystems remain as major cost drivers, and – as with all the cost-significant subsystems – require additional improvement.



	MEDIUM TRANSPORT HELICOPTER (CH-46F)	LIGHT ASW HELICOPTER (SH-2F)	MEDIUM ASW HELICOPTER (SH-3G)	HEAVY TRANSPORT HELICOPTER (CH-53D)
PREVENTIVE	4.1 (27.0%)	5.3 (29.1%)	5.4 (28.9%)	6.6 (27.8%)
CORRECTIVE	4.7 (30.9%)	6.0 (33.0%)	6.7 (35.8%)	7.5 (31.6%)
SUPPORT	6.4 (42.1%)	6.9 (37.9%)	6.6 (35.3%)	9.6 (40.5%)
TOTAL	15.2 MMH/FH	18.2 MMH/FH	18.7 MMH/FH	23.7 MMH/FH

SOURCE: NAVY 3-M AVIATION UTILIZATION AND READINESS REPORTS FOR 1975

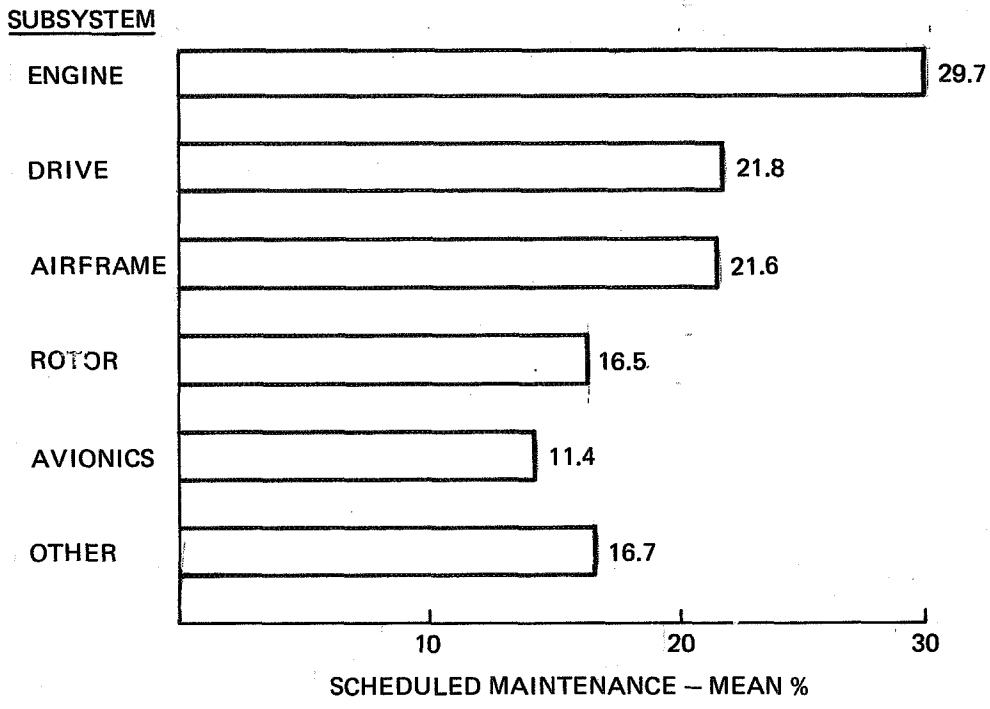
Figure 4. Distribution of operation maintenance manhours



NOTES:

1. SOME GAVE MORE THAN 1 REASON.
2. MEAN UNSCHEDULED MAINTENANCE IS 20% OF TOTAL MAINTENANCE.
3. 163 RESPONDENTS TO OPERATOR SURVEY (REFERENCE 5).

Figure 5. Causes of unscheduled maintenance



NOTES:

1. WILL NOT ADD TO 100% BECAUSE NOT ALL REPORTED EACH ITEM.
2. MEAN SCHEDULED MAINTENANCE IS 80% OF TOTAL MAINTENANCE.
3. 163 RESPONDENTS TO OPERATOR SURVEY (REFERENCE 5).

Figure 6. Mean percentage of scheduled maintenance by aircraft subsystem

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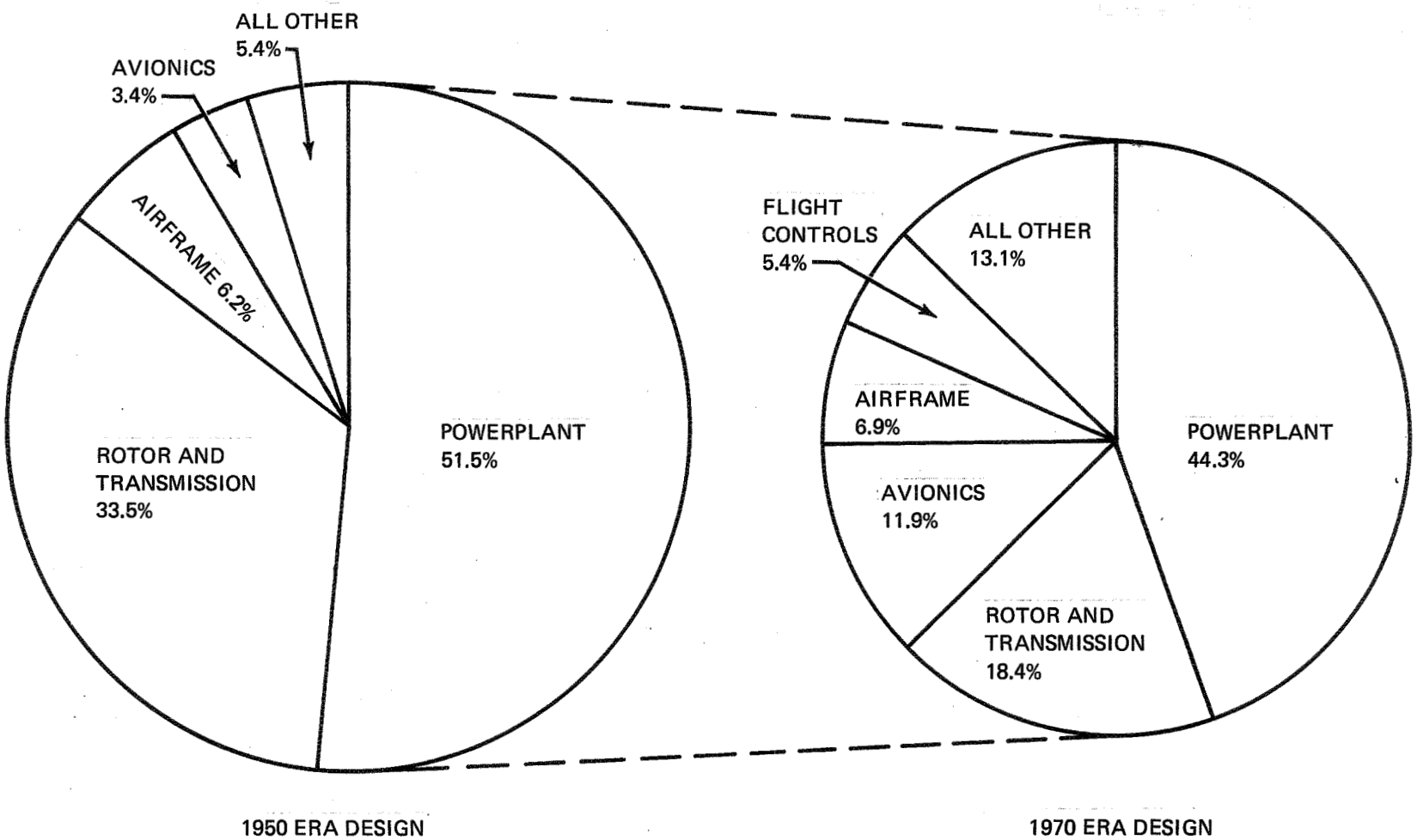


SOURCE:

1. 1950 DESIGN BASED ON ASSESSMENT OF UH-1H CONTAINED IN TR75-3
2. 1970 DESIGN BASED ON BOEING VERTOL YUH-61A DMC STUDY, DECEMBER 1975

Figure 7. Twenty years of improvement in the maintenance costs of utility transport helicopters

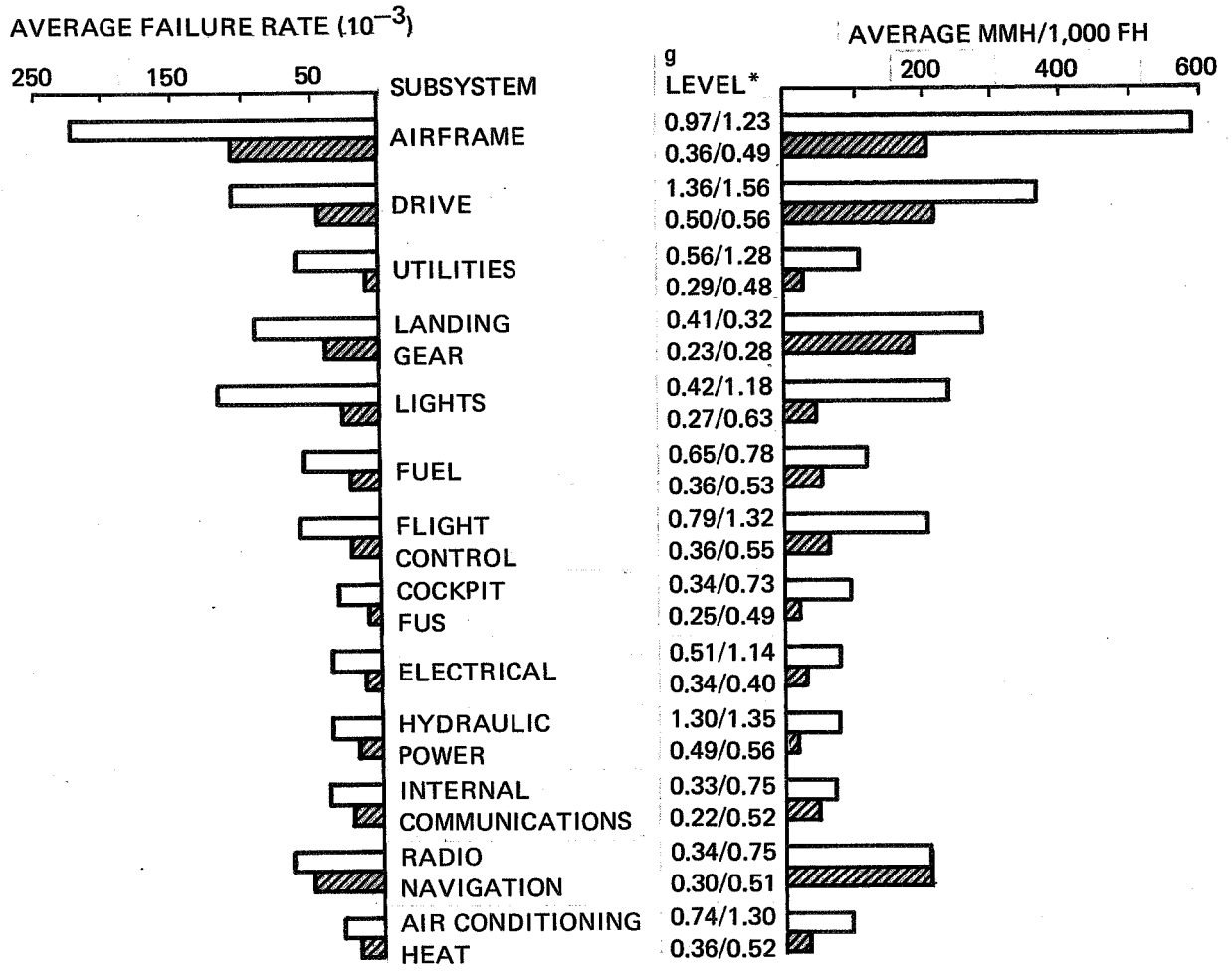
3.2 Factors Impacting Maintenance Costs

Studies have indicated that the most cost-significant maintenance actions are replacement of repairables and preventive maintenance (inspections). This is due to the high material costs associated with repairables, including their attrition, and the relatively high frequency of preventive maintenance. Associated with both these cost drivers and probably the most significant is unnecessary maintenance, which represents wasted dollars. Erroneous removals and repairs, as well as unnecessary inspections, are placed in this category. Controllable factors contributing to these maintenance cost drivers discussed in the following paragraphs are:

- Vibration
- Scheduled time between overhauls (TBO's)
- Foreign-object damage
- Inspection policy
- Diagnostics
- Technical publications and training

Vibration is discussed first since it is a contributor to all the other factors and unique to the helicopter environment. An understanding of the cause, effect, detection, correction and/or compensation of vibration is a prerequisite of the helicopter mechanic. This understanding of vibration is the basic difference between helicopter and fixed-wing aircraft mechanics. All of the other controllable factors addressed relate directly to maintenance costs of component repair, overhaul, and inspection.

3.2.1 Vibration. – Normally, helicopter vibration is thought of in conjunction with reliability studies as a causal factor. Its impact on maintenance is more often thought of as an aftereffect of the reliability failure. This is true to an extent, but it is not the entire story. Figure 8 is an assessment of subsystem failure rate and the resulting maintenance manhour impact for a helicopter with and without vibration absorbers (ref. 6). The chart shows that changes in manhours do not vary directly with changes in failure rate, nor are various subsystem changes comparable. The figure does show that the incorporation of the vibration absorber with resultant reduction in aircraft vibration equates to reduced maintenance expenditures of varying magnitudes. This is expected and can be partially explained by the fact that for some subsystems, the maintenance times for vibration failure fix are greater than the subsystem average failure fix time; for other systems, the time may be shorter. The susceptibility to vibration and subsequent failure varies widely with types of components. Of greater interest to maintenance cost is the vibration failure fix itself, especially that of a high-cost repairable component. By its very nature a vibration failure usually is seen as a functional or visible defect, and the readily apparent failure is fixed and the item returned to service. However, in many cases the vibration that caused the first failure also weakened other components and interface connections. Thus, when the item is returned to service, it fails again in a short interval. When the mean time to failure after repair is much shorter than the mean time to first failure of a component, then the cost-effectiveness



SOURCE: REFERENCE 6

Figure 8. Comparison of failure rate and maintenance manhours by subsystem with and without vibration absorbers

of the repair action is diminished. This condition can be realistically carried to the point where discard upon failure would be more cost-effective than component repair. Until such time when helicopter vibration can be reduced to acceptable levels or components isolated from the vibration, acceptable serviceability standards must be developed and, more importantly, an effective means to test to these standards must be developed for high-cost components.

Existing blade-tracking and vibration-measuring equipment is adequate when used properly. It is estimated that approximately 75 percent of the civil helicopter fleet owns this equipment and the remainder has access to it through rental and loan. It is recommended that more extensive use of vibration-measuring equipment be made. All significant component vibration frequencies should be calculated and listed in each helicopter's maintenance manual, including vibration acceptance limits; this would permit rapid isolation of troublesome components. The procedure for this technique was developed for the YUH-61A helicopter and is included in Appendix A.

3.2.2 Scheduled time between overhauls (TBO's). – It has been found that one of the largest contributors to helicopter operating costs is the policy of scheduled removal and overhaul of components. The concept of a TBO (time between overhaul) interval requires that the component be removed from service at a predetermined time. TBO intervals currently range from 500 to 1,500 hours for most helicopter dynamic components, including the engine. The concept of scheduled removal of a component had its beginnings long before maintainability was a formal aircraft design discipline. It was based on a suspicion that undesired events could be precluded if a time-phased removal philosophy was imposed. The TBO intervals were increased on components until some intuitively acceptable balance was struck between the frequency of unscheduled removals encountered and the TBO duration itself. There is a new era of aircraft procurement upon us characterized by specific numerical objectives and associated contractual requirements. All of the reliability characteristics of a component or system, including the TBO interval, are now being included as requirements. While we are learning how to predict, measure, and demonstrate failure rates, we are not very far along in having a verification method for the proper TBO interval that is accepted by both contractor and customer. Many specifications are now calling for an on-condition removal criterion for components which formerly had TBO intervals. Engines and transmissions for new helicopter programs are included in this category (see references 7, 8, 9, and 10).

The concept of a TBO involves the scheduled removal of a component at a specified operating time for the purpose of avoiding some undesired event. This concept can be approached by considering the traditional bathtub curve. This curve expresses the hazard function of a component with a high infant mortality period of decreasing failure rate, a period of random failures or constant failure rate, and finally, a period of increasing failure rate frequently termed the wear-out period.

A decision to implement an on-condition maintenance philosophy is based on considerations of cost, mission effectiveness, and safety. When compared with operating with a TBO, on-condition will be less expensive, but it must have little or no degradation of mission effectiveness and it cannot compromise safety. The problem is to reduce costs by elimination of the TBO without incurring the mission or safety risks of an increasing hazard rate.

Generally, failure warning and inspection systems reduce the rates of all three hazard functions: maintenance, mission abort, and safety. The maintenance malfunction hazard rate is reduced by eliminating unnecessary removals; the mission abort rate is reduced due to improvements in ground maintenance detection of actual or incipient mission-affecting failures; and the flight safety failure rate is reduced by providing sufficient pilot warning for accident avoidance. When failure warning and inspection systems are combined with sound design practices and adequate service-life testing, the mission abort and safety hazard rates can be reduced to a level where on-condition maintenance is practical. The role of design and testing, specifically for an on-condition objective, is to act in concert with diagnostics to prevent increasing hazard rates.

Figure 9 presents a brief comparison of on-condition versus TBO and summarizes the concepts leading to a decision for on-condition maintenance (ref. 7, 8, 9, and 10).

The evaluation of the potential of any component for on-condition operation requires the application of elements of several mathematical and engineering disciplines.

Basically, the analysis can be summarized into seven steps:

1. Perform failure mode effects and criticality analysis (FMECA).

2. Develop hazard functions by mode and combine into an assembly hazard function.

3. Perform a safety evaluation.

4. Develop limiting cost-effectiveness hazard function.

5. Determine optimum cost-effectiveness TBO or substantiate on-condition potential from cost-effectiveness hazard function.

6. If on-condition operation is not safe and cost-effective, consider impact of redesign, testing, or failure warning and inspection system.

7. Substantiate on-condition or finalize establishment of TBO.

These elements and the manner in which they interact are identified for a transmission in Figure 10.

If the civil helicopter community is to reap the significant cost benefits available through on-condition operation, an analysis of the type described in Figure 10 should be applied to all currently TBO-limited components. Retention of TBO's at their current levels due to industry and government inertia, rather than establishment of rigorous, safety- and cost-effectiveness-related criteria, is totally unacceptable to the civil helicopter operator.

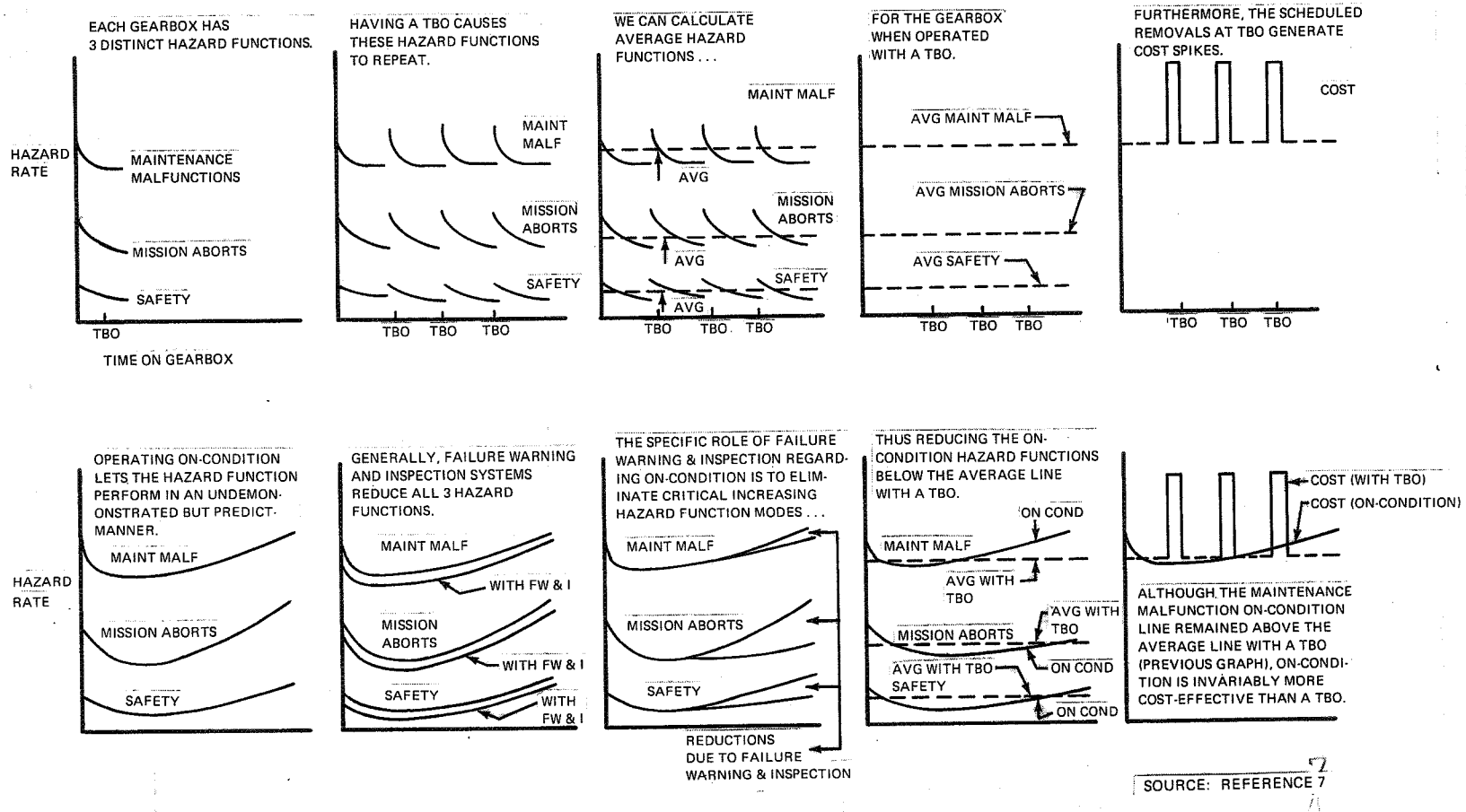
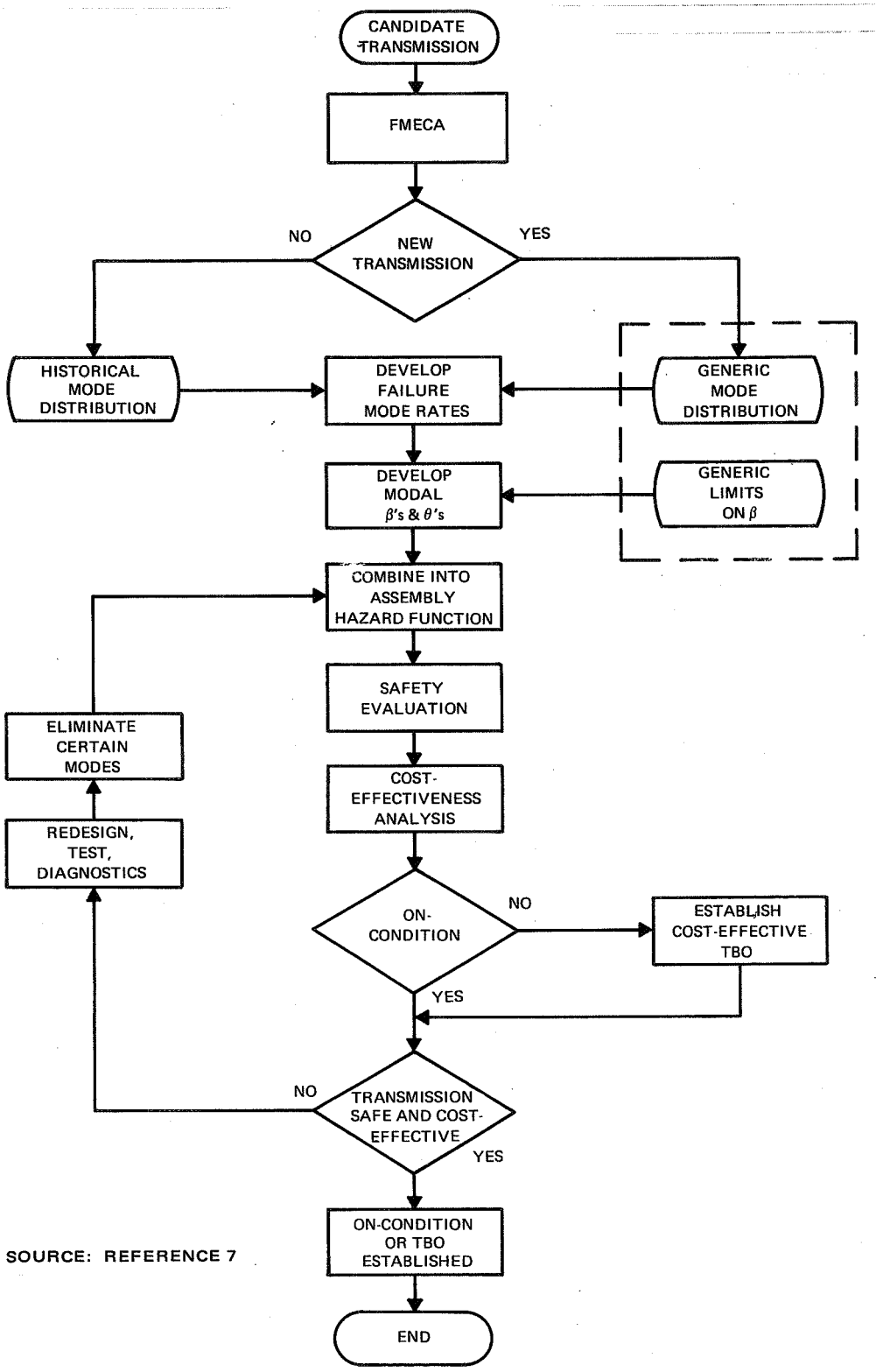


Figure 9. The rationale for on-condition maintenance of helicopter gearboxes



SOURCE: REFERENCE 7

Figure 10. Method of evaluating capability for on-condition maintenance

3.2.3 Foreign-object damage (FOD). – FOD is of major concern to maintenance cost. The highest off-aircraft maintenance cost driver is engine repair and overhaul. A recent analysis of medium transport helicopter maintenance data showed that 11.9 percent of powerplant replacements were caused by FOD. Figure 11 is a quantitative assessment of various engine FOD-caused removals (ref. 11). Figure 12 portrays the primary source of engine FOD. Aircraft design factors related to FOD are addressed in the reliability report (ref. 1). Operational environmental factors must be emphasized and controlled through operator and pilot training programs. Thus, this report is primarily concerned with the 43 percent of engine FOD attributed to maintenance procedures.

A problem frequently attributed to maintenance procedures concerns the captive hardware devices for retention of frequently handled components; design attention to these devices would reduce the hardware FOD problem. More easily inventoried tool kits, combined with rigid supervision of tool kits and consumable maintenance material, would also help. Helipad area cleaning and policing, coupled with area inspection, should be made standard procedure before engine start. However, foreign objects will always be present to some extent and the most positive approach to elimination of FOD is through the development and application of adequate engine protection devices. An example of this type of device is the integral inlet particle separator built into the GE T700 engine. Inlet screens, engine air inlet swirl devices, and full barrier filters are all in use on older engines.

3.2.4 Inspection. – As in the case with TBO's, many inspection requirements were based on a suspicion that undesired events could be precluded if a time-phased inspection philosophy was imposed. To compound matters, it seems that once an inspection requirement is levied, it is never rescinded; but conversely, additional requirements are imposed, escalating the cost of inspection. As was shown in Figure 1, this cost is substantial and accounts for about 10 percent of the direct maintenance cost. A vigorous application of the techniques of the "Airline/Manufacturer Maintenance Program Planning Document, MSG-2" (ref. 12), as expressed by the logic of Figure 13, should be used for establishing all inspection requirements. Perhaps of more importance, the governing regulatory agency should advocate this process alone and not impose additional requirements.

Review of Figure 13 shows that if reduction in failure resistance is detectable by routine flight crew monitoring, then an inspection is not required for that mode of failure. Thus, the benefits of failure warning and prognostic aids can also be applied to a reduction of inspection time and cost. Continued development of diagnostic and prognostic techniques should be pursued until reliable failure warning levels are attained.

3.2.5 Diagnostics and erroneous maintenance. – Figure 14 shows the distribution of on-aircraft maintenance actions. The crosshatched area contains erroneous removals, no defect, and remove and install actions. These may all be grouped and called unnecessary maintenance which, in addition to wasting time and contributing to aircraft unavailability, induce other maintenance through removal, installation, and handling errors. These actions can also be related to diagnostics, as can lengthy and/or repetitive maintenance.

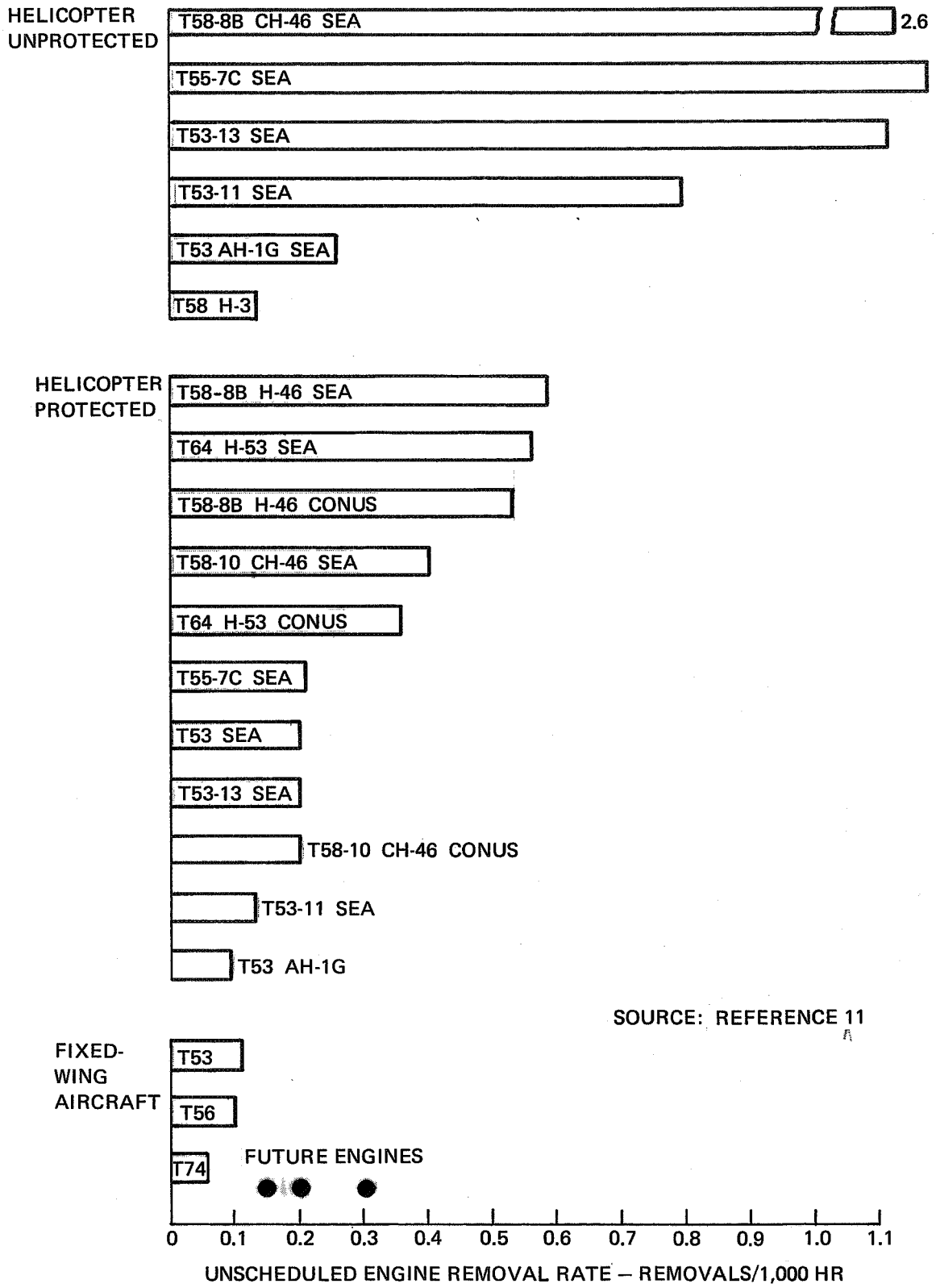


Figure 11. Unscheduled engine removal rate for foreign-object damage for various engines and aircraft installations

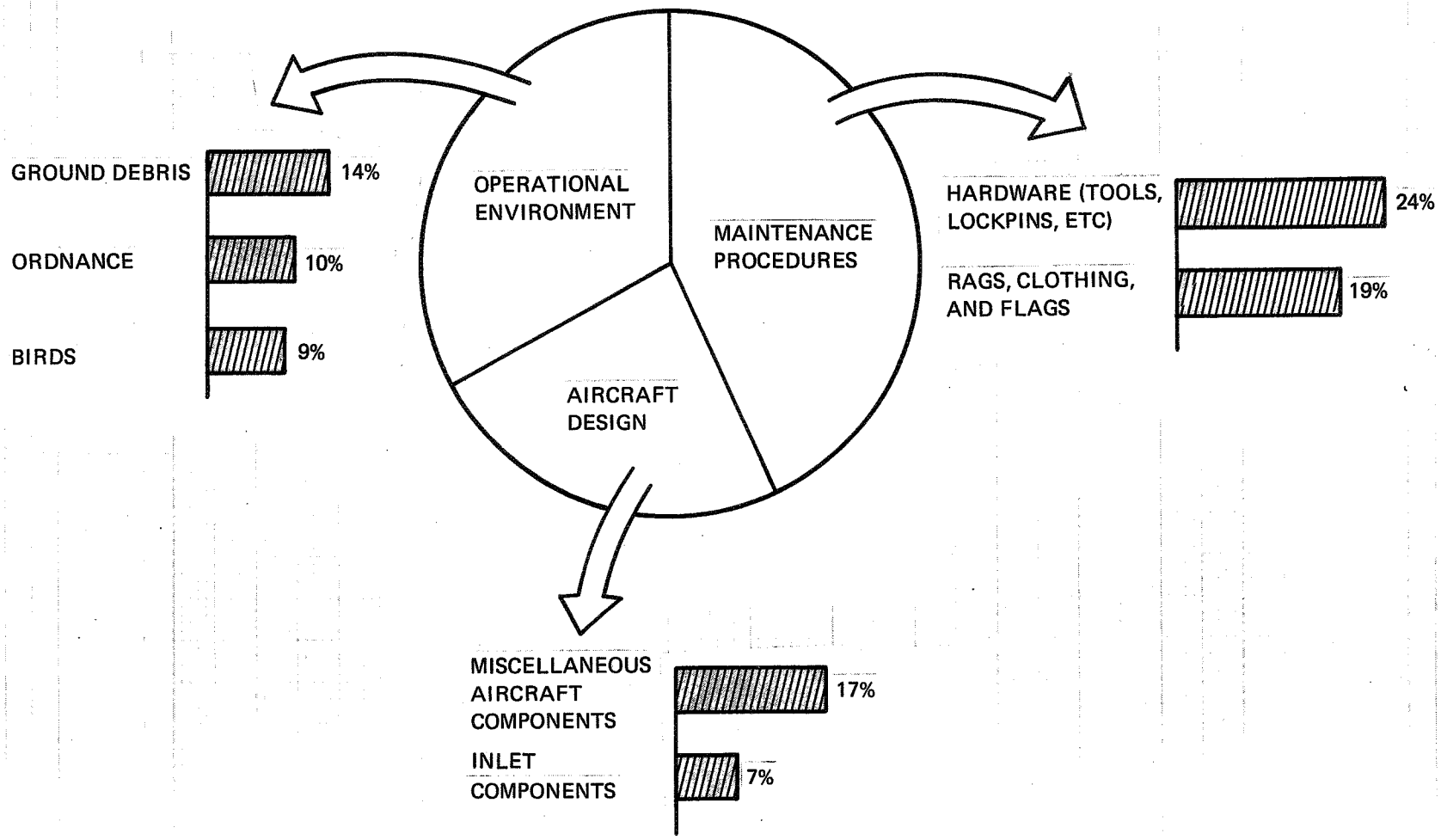


Figure 12. Sources of turbine engine damage from foreign objects

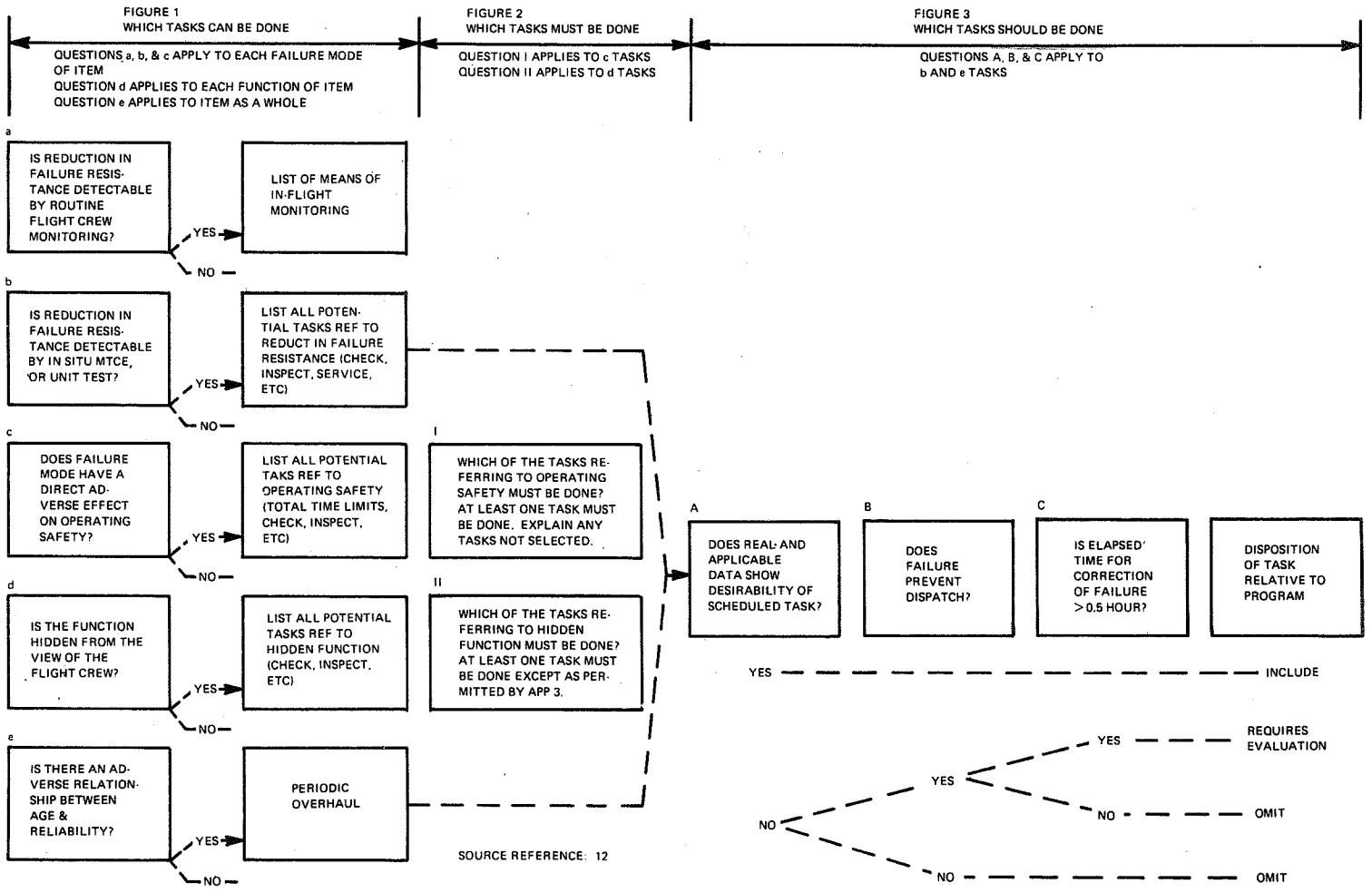
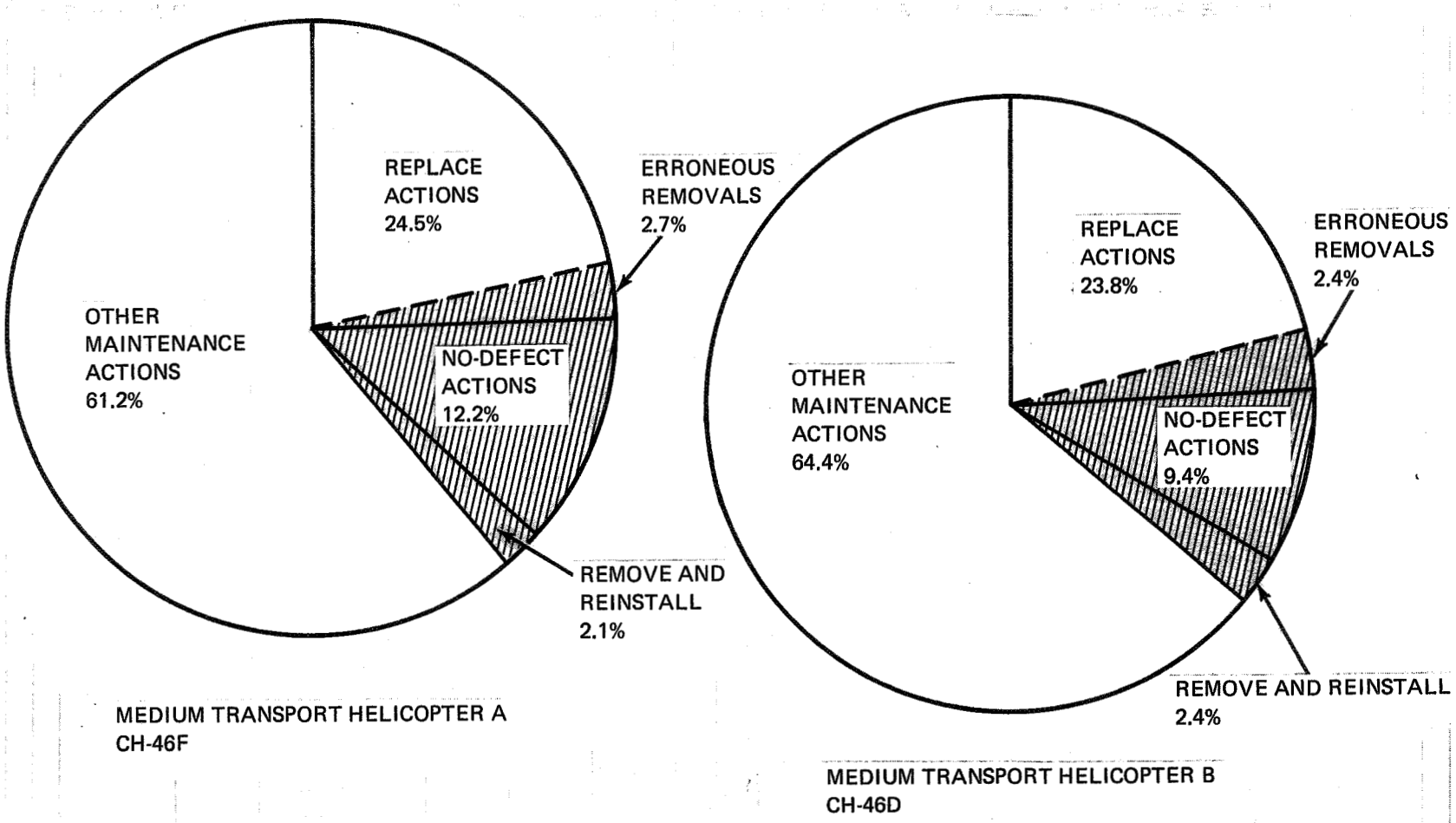


Figure 13. Decision diagram from airline/manufacturer maintenance program



SOURCE: NAVY 3-M AVIATION DATA COLLECTED DURING 1974
REPRESENTING 72,968 FLIGHT HOURS

Figure 14. Distribution of on-aircraft maintenance actions

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Erroneous removals were confirmed by functional tests in repair shops where the components were found to be operating satisfactorily. They can be attributed to improper diagnosis of a reported discrepancy by a maintenance mechanic. In addition to the penalties of unnecessary transportation and handling with the probability of resultant damage, and the cost incurred for check and test, other consequences of this action are that the fault is still on the helicopter and will reveal itself on the next flight or that the fault has been subsequently corrected with the expenditure of additional resources.

No-defect actions are those taken as a result of a reported discrepancy in which the mechanic could find nothing wrong. Again, this is a diagnostic problem, either by the operator in misinterpreting his symptoms or by the mechanic in checking the reported failure. Although both represent wasted maintenance, the latter is more serious for the discrepancy still exists undetected by maintenance. No-defect reports also occur when both operator and mechanic are correct in their assessment. These result from intermittent failures that are present only during certain flight regimes.

Repetitive maintenance results from both no-defect actions in which a defect is in fact present, and from incomplete or incorrect failure fixes. The first cause dictates a need for better diagnostic equipment, while the second calls for prognostic equipment. Unnecessary (repetitive) maintenance increases the frequency of maintenance and reduces the availability of helicopters, with increased cost and reduced revenue.

In all cases except for large dynamic components, lengthy maintenance tasks can be attributed to two task elements: troubleshooting and system checkout. Again, the resolution of the problem lies with the development of effective diagnostic and prognostic equipment.

As used herein, diagnostics refers to built-in test (BIT) provisions of aircraft components and systems, as well as the ground support equipment (GSE) used on the flight line and in the repair shop for fault location, alignment, adjustment, and checkout.

BIT provisions are now required for all military electronic and avionic system design and MIL-STD-415 provides general guidance. The impact of diagnostic aids on military avionics maintenance has been great. Now over 95 percent of avionics discrepancies can be rapidly corrected by a quick visual inspection and easy replacement task by a mechanic with no special electronic training. The applicability of this philosophy to other complex aircraft system components should be researched, especially in the light of the increased system modularity expected of new designs.

3.2.6 Technical publications and training. – The best design, supported by the most effective support equipment or system, can be an economic failure without an effective man-machine interface. This interface is affected by the training the mechanic receives, coupled with the technical publications used in day-to-day maintenance. Unlike military operations, where training is an in-house function and in peacetime a prime function, civil operators must rely on individuals to possess basic skills and licenses prior to hire, and on helicopter manufacturers for special training as a part of new purchases.

Normally, the quality and cost of a manufacturer's training are directly related to the number of vehicles he sells. Training as such has no bearing on civil helicopter research. However, it is mentioned here since it can be a significant factor in direct maintenance costs and is one of the considerations in warranty and contract maintenance decisions.

Technical publications are used daily. Although there is no known feedback on the quality of technical manuals from civil operators, it is assumed that conditions similar to military use exist. The usability of existing military manuals has been so poor that it has gained the attention of top-level DOD planners who now recognize this deficiency as a prime factor in military manning and its resultant cost. Much effort is currently being expended in this area to develop new and better techniques of maintenance information presentations. Programs such as Proceduralized Troubleshooting Aids (PTSA's) (see Appendix B) and Job Performance Aids (JPA's), which are logically sequenced and illustrated, should be used for guidance in developing civil helicopter maintenance publications.

Reference 15 reported on a new aircraft maintenance record-keeping system for owners and operators of civil aircraft applicable to fixed-wing aircraft and helicopters. Details of this system are discussed in Appendix C.

4.0 RESEARCH RECOMMENDATIONS TO REDUCE MAINTENANCE COST

The state of the art in maintainability technology is discussed in section 3. Gaps in technology, and the research and development needed to fill those gaps, are discussed in this section.

4.1 Vibration Reduction

A recommended research and development program to reduce helicopter vibration is outlined in reference 13. This program covers analysis, wind tunnel testing, bench testing, and flight testing of an aeroelastically adaptive rotor (AAR).

- AAR development $6.3 million 5 years

4.2 Demonstration of Advanced-Technology On-Condition Transmissions

Recommended research to achieve advanced-technology helicopter transmissions with an objective of 6,000 hours mean time between removal (MTBR) is outlined in reference 14. This provides for an on-condition removal basis and will result in substantial savings in maintenance and overhaul costs. The development program recommended in reference 14 outlines design, bench testing, ground testing, and flight testing of drive system improvements leading to transmissions capable of on-condition removal.

- Advanced-technology transmissions $10 million 7.5 years

4.3 Develop Diagnostic Equipment for On-Condition Dynamic Components

In conjunction with paragraph 4.2 preceding, there exists a need for improved diagnostic equipment.

4.3.1 Develop incipient failure detection (IFD) equipment for field use. – As discussed in reference 14, advanced incipient failure detection (IFD) equipment will reduce overhaul costs by identifying incorrect removals prior to transmission teardown. IFD shows promise for reducing the need for time- and material-consuming teardown inspection of gear and bearing assemblies and for reducing infant mortality due to assembly-induced failure modes. Research to demonstrate the many uses of IFD for field maintenance and for use at overhaul depots is required. Several versions of IFD are being proposed and the final solution may be a combination of existing laboratory equipment.

- Develop IFD for field and depot use $500,000 2 years

4.3.2 Develop turbine engine health-monitoring and diagnostic equipment. – Develop lightweight, low-cost health-monitoring systems that will diagnose impending failures in time to prevent occurrence in flight. The newer turbine engines, such as the GE T700, have health-monitoring diagnostic systems, but there is still a need for refinement and adaptation to the other turbine engines used in civil helicopters. The most practical solution is to provide an on-board minicomputer with multiplexing and memory storage for trending of critical parameters, such as oil debris, chip indications, vibration, pressures, temperatures, torque, etc. The engine health parameters would only be a portion of the data input, and therefore costs for the on-board computer would be shared with sensor inputs from the dynamic system, flight controls, and stability augmentation systems. Preliminary estimates indicate that a user cost of $10,000 per aircraft for a complete system should be achievable with a weight penalty of 10-20 pounds. Such a system would enhance on-condition maintenance capability, greatly reduce accident potential, and offer substantial savings in maintenance fault analysis and reduced repetitive maintenance throughout the aircraft. It is recommended that the concept be demonstrated with engine parameters and extended later to other systems.

• Lightweight on-board diagnostics package (engine portion only)	$250,000	18 months

4.4 Develop Airborne Maintenance Diagnostic Equipment for All Systems

A large amount of time is now wasted in incorrect troubleshooting. This results in removal and replacement of good parts, unnecessary overhaul costs, and excessive downtime. Since these problems occur frequently at remote sites or where small operators are poorly equipped for troubleshooting, a critical need exists for improvement. It is proposed that a lightweight, low-cost, on-board diagnostic system be developed. Such a black box would be capable of health diagnosis and fault isolation of engines, transmissions, drive shaft hanger bearings, swashplate bearings, vibration levels and isolation, shaft balancing, rotor blade balancing, in-flight tracking, hydraulics, electrical system, and avionics.

The technology for a box of this type is available through the use of multiplexing, micro-processors, and other hybrid circuit technology. The development of such a box would involve the identification of critical troubleshooting parameters, combination of new techniques for fault isolation, vibration reduction, and main and tail rotor blade tracking, and provision of appropriate controls and readouts for either maintenance personnel or pilot use. The engine health system discussed in paragraph 4.3.2 would be developed by engine manufacturers separately for integration into the system described here.

• Develop a prototype airborne maintenance diagnostic system	$500,000	3 years

4.5 Study Computerized Maintenance Record System for Small Operators

The larger civil operators use computers for record-keeping on a large number of helicopters to assist in scheduling maintenance activities so as to provide for maximum availability and utilization. Availability in helicopter operations is critical because the majority of the flying is during daylight hours and customers' demands are frequently on short notice. The smaller operators also have critical availability requirements but cannot afford expensive computer equipment. It is recommended that this problem be studied to determine what could be done to achieve the benefits of computerized record-keeping at lower cost.

• Study low-cost record-keeping for small operators	$35,000	6 months

4.6 Study Cost Savings From Salvaging High-Value Components

Salvage of components is subject to the capabilities of operators and overhaul shops. It is believed that this may be a significant cost-saving area and it should be studied further. A survey of scrap and salvage practices is therefore recommended.

• Study scrap and salvage practices	$20,000	6 months

5.0 IMPACT OF MAINTAINABILITY IMPROVEMENTS ON SIZE, CONFIGURATION, AND MISSION APPLICABILITY

Table 1 is a summary of the research and development recommended to reduce maintenance costs, including an estimation of the impact on size, configuration, and mission applicability.

TABLE 1. SUMMARY OF RECOMMENDED R&D FOR IMPROVED MAINTAINABILITY

Research Item or Area	Priority	Size/ Applicability	Payoff
Reduce helicopter vibration levels	High	All	High
Demonstration of advanced-technology on-condition transmissions	High	All	High
Develop diagnostic equipment for on-condition dynamic components	High	All	High
a. Develop incipient failure detection (IFD) equipment for field use	High	All	High
b. Develop turbine engine health-monitoring and diagnostic equipment	High	All	High
Develop airborne maintenance diagnostic equipment for all systems	High	All	High
Study computerized maintenance record system for small operators	Medium	All	Medium
Study cost savings from salvaging high-value components	Medium	All	Medium

6.0 CONCLUDING REMARKS

This study has focused attention on civil helicopter maintenance and identified the causes of high maintenance costs. Existing technology that can be applied and research needed to further reduce maintenance costs are listed below. In general, it is believed that good design practices with increasing attention to maintenance problems and adaptation of existing technology will be most effective in reducing costs immediately. R&D offers further potential for cost savings in certain areas. Eight areas that are within the scope of existing technology are listed below:

1. More extensive use of blade-tracking and vibration-measuring equipment to reduce vibration levels and component failures.

2. Calculation of component vibration frequencies and vibration acceptance limits for all maintenance manuals (see Appendix A).

3. Continuous attention to increasing TBO intervals based on civil experience. Levels set on military counterparts are usually lower than those which are acceptable for civil versions.

4. Design for reduced servicing requirements, ease of inspection, and ease of component replacement.

5. Develop Proceduralized Troubleshooting Aids (PTSA's) for all civil helicopters (see Appendix B).

6. More extensive use of a new maintenance logging system (see Appendix C).

7. Use more engine inlet separators and observe good FOD protection practices in maintaining and servicing of aircraft.

8. Apply the Airline/Manufacturer Maintenance Programs Planning Document (MSG-2) techniques to civil helicopter maintenance planning.

Six areas for research and development to reduce maintenance costs should be initiated as follows:

1. Reduce vibration levels to reduce component failures.

2. Demonstrate advanced-technology on-condition transmissions.

3. Develop diagnostic equipment for on-condition dynamic components.

4. Develop airborne maintenance diagnostic equipment for all systems.

5. Study computerized maintenance record systems for small operators.

6. Study cost savings from salvaging high-value components.

NOTE

(Refer to research and development areas 3, 4, and 5 above and to paragraphs 4.3, 4.4, and 4.5.)

As this report went to press an article was published in the January 1978 issue of Rotor and Wing International (ref. 16) concerning development of airborne computers that may eventually be used for on-condition maintenance. The computers would have multiple uses, such as recording engine health history; displaying engine power margins; providing flight-manual performance data computations; measuring and recording external loads carried; recording on-condition maintenance data; and providing diagnostic information for trouble-shooting. Other uses for this airborne computer will surely develop when operators find they can save time and money by having more information at their fingertips in the field and in the air.

APPENDIX A

HELICOPTER VIBRATION ANALYSIS TECHNIQUE

Excerpted here are the details for use of the vibration analyzer on the YUH-61A as presented in DTM 55-1520-XXX-24.

4-7A. HELICOPTER VIBRATION ANALYSIS. Vibrations generated by malfunctioning, out-of-balance, or worn components on the helicopter can be amplified thru the airframe. Such vibrations can cause discomfort to personnel, damage to cargo, and, in some cases, damage to the helicopter. The two types of vibration are airframe vibration and component vibration.

a. Airframe Vibrations. Most airframe vibrations are produced by operation of the rotary-wing system. During flight, malfunctioning, out-of-balance, or worn components can cause excessive vibration. These occur primarily as one cycle of vibration for each revolution of the rotor shafts (one-per-rev) or four cycles of vibration for each revolution (four-per-rev).

b. Component Vibrations. Component vibrations are produced by out-of-balance or wear conditions on any of the rotating components. These vibrations occur at the rotating speeds of the components and can be detected in the airframe adjacent to the affected component during ground or flight operation.

4-7B. Vibration Troubleshooting.

a. To identify and locate a reported vibration, the 177M-6 balancer is used. (See fig. 4-3A.) Connect the balancer as shown in fig. 4-3B. Operate the helicopter as required to duplicate the vibration condition. Hold the accelerometer firmly against the surface on which the vibration was felt. Maintain as close to a 90 degree angle to that surface as possible.

b. Tune the rpm to each of the speeds listed in fig. 4-3C. When the meter indicates a disturbance at a given RPM, go to the procedure listed to the right of that RPM. Check the items listed in that procedure.

NOTE

Disturbance at 286 and 1144 are main rotor induced and the helicopter will normally respond up and down or side to side. Therefore at each of these rpm's, the accelerometer should be held firmly against the structure in both directions.

c. For those rpm's which occur at more than one location in the aircraft, take readings at each of the locations. Investigate that area which produces the highest IPS reading.

NOTE

The 4177A accelerometer must always be held on rigid structure, not on fairing or skin. Also, it must be as close to the structural mounting of the rotating component as possible.

d. If, when a specific location is checked and the measured IPS of vibration does not exceed the value in the applicable procedure, no corrective action is required and the helicopter should be released for flight.

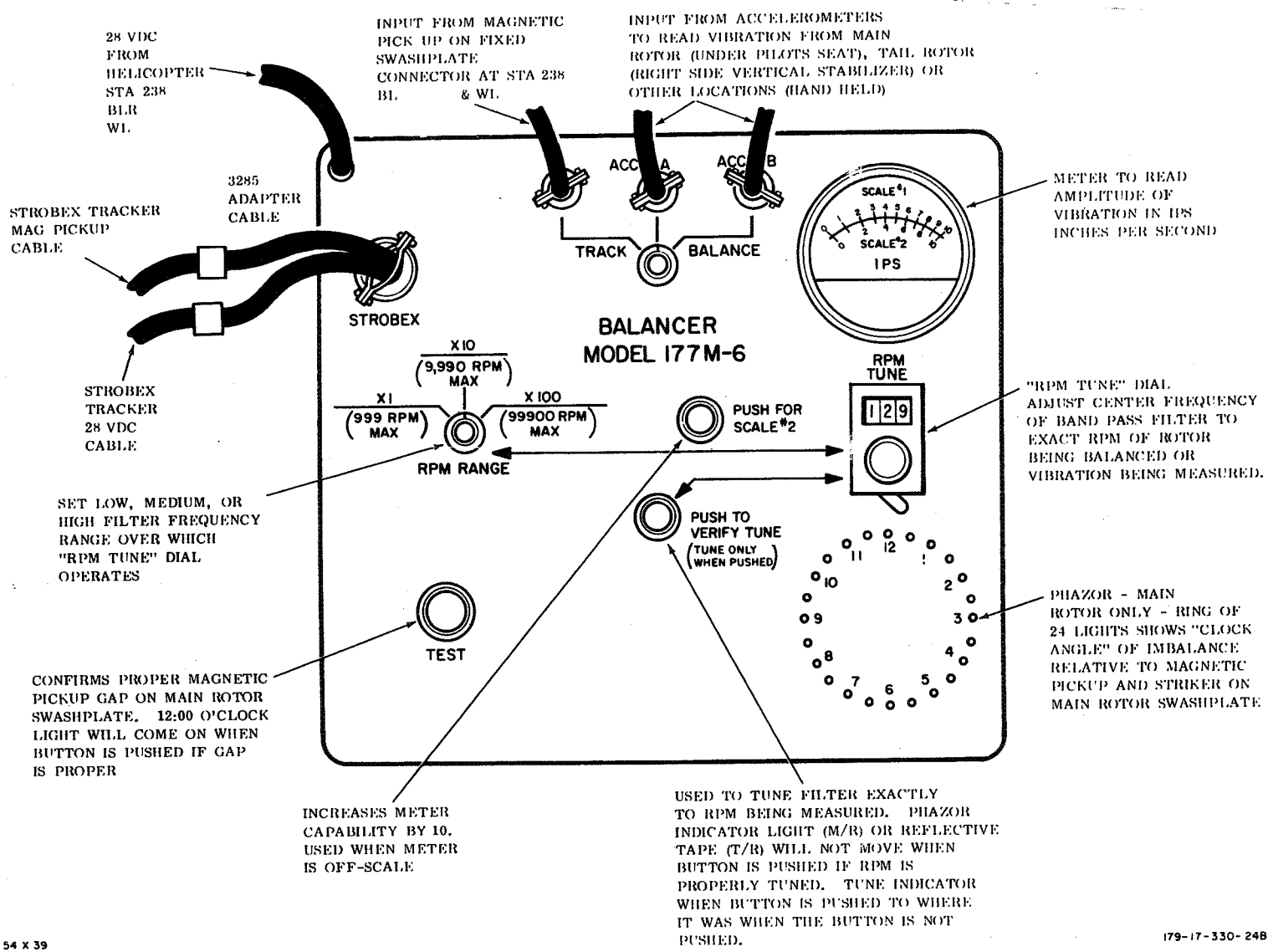


Figure 4-3A. Vibration Tester — Balancer Model 177M-6

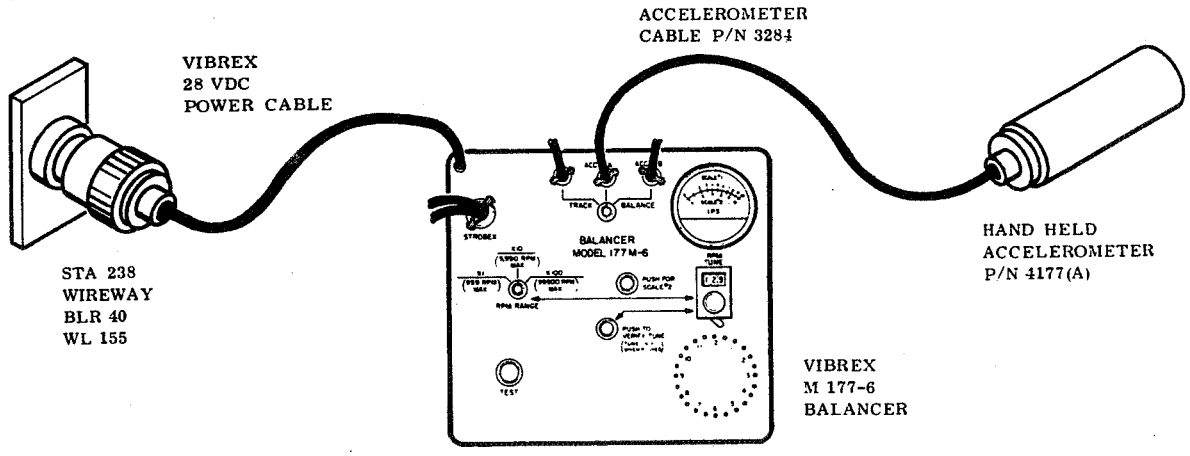


Figure 4-3B. Vibration Troubleshooting Test Setup

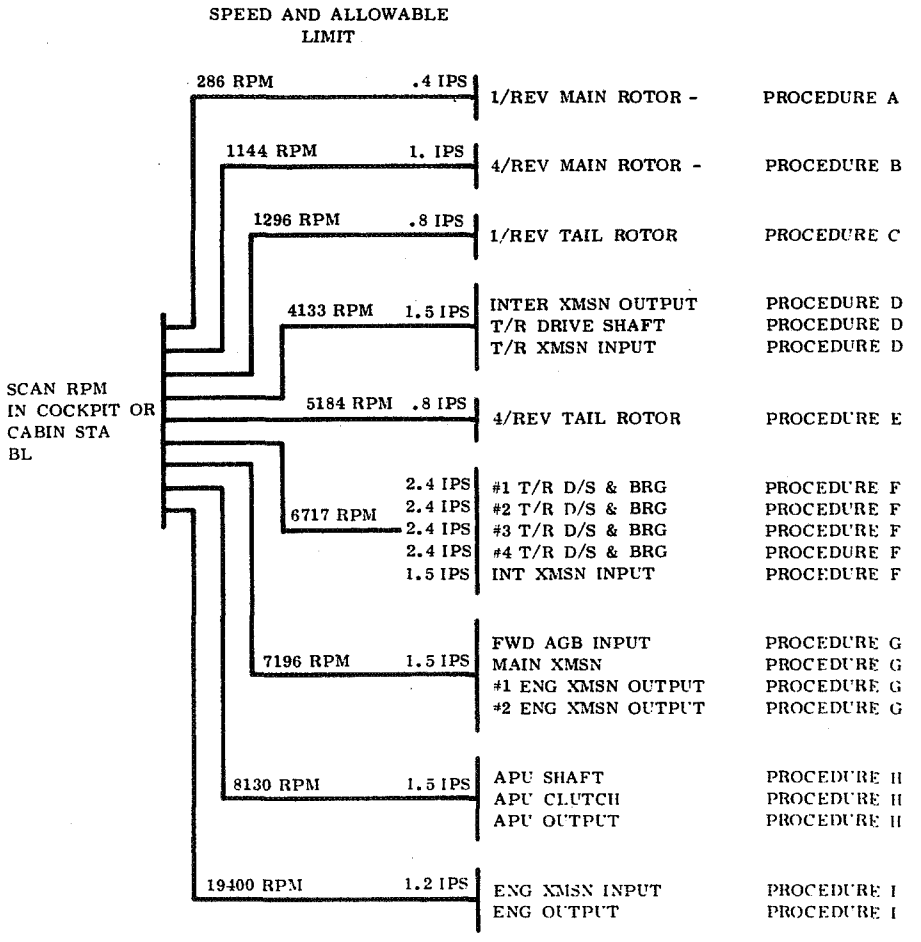


Figure 4-3C. Vibration Troubleshooting RPM

Table 4-1. Vibration Troubleshooting

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION
			PROCEDURE A	
When investigating vibrations at this speed, mount the accelerometer to the structure rather than holding it by hand. To measure lateral vibration at 286 rpm, locate the accelerometer in the cockpit as described in the main rotor balance procedure. (Refer to para 8-55.) For vertical vibration locate the accelerometer in the same location mounted vertically so that the cable is on top. Make sure the main rotor is operating at 100% and the aircraft is at a stable hover. Set the Vibrex RPM TUNE at 286 and the RPM RANGE at X1. When the main rotor has stabilized, slowly adjust the RPM TUNE to achieve the highest IPS indication with the PUSH TO VERIFY TUNE button depressed.				
1/Rev Main Rotor	286	.4	Blade	Check for damage to blade and condition and security of pendabs
			Blade Pins	Check blade pin indicator
				Check blade pins for proper latching
			Pitch Arm	Check pitch arm hardware for security and indications of fretting
				Check elastomer for indication of deterioration (checked, rubber dust, and bond separations)
			Pitch Link	Check turnbuckle handware for security, indications of fretting and proper torque
				Check upper and lower bolts for clamp up torque
				Check bearings for wear. .015 max radial play
Swashplate	286	.4	Rotating Scissors	Check security and presence of hardware
				Check deterioration of elastomer. (Checked surface, rubber dust, and bond separations)
If the above checks do not identify the problem, track and balance main rotor.				
			PROCEDURE B	
When investigating vibrations at this rpm, mount the accelerometer as described in PROCEDURE A. Make sure the main rotor is operating at 100% and the aircraft is at stable hover. Set the Vibrex RPM TUNE at 114 and the RPM RANGE at X10. When the main rotor has stabilized, slowly adjust the RPM TUNE to achieve the highest IPS indication with the PUSH TO VERIFY TUNE button depressed.				
4/Rev Main Rotor	1144	.1	Main Rotor Actuator	Upper and lower bearing wear. Max allowable 0.015 radial play
				Security and proper torque on actuator support hardware
				Cracks in leg of actuator support
				Looseness in actuator linkage
				Clamp up of actuator mount bolts. Indications of bolt dye

Table 4-1. Vibration Troubleshooting (Continued)

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION
				Lubricate pendabs and check for freedom of movement
			Main XMSN	Mount bolts for torque and indications of fretting
				Support arms for cracks
			XMSN Mount Structure	For cracks and failed, missing or loose fasteners

PROCEDURE C

To confirm an excessive vibration at this rpm, observe the displacement of the tip of the Troop Commanders FM antenna mounted on top of the vertical stabilizer. Check with the main rotor operating at 100%, and full down collective so that the helicopter is resting firmly on the ground. If the displacement is over 1 foot, shut down the helicopter and perform the defined checks. Mount the accelerometer as described in the Tail Rotor Balance procedure and check the tail rotor balance. (Refer to para 9-22.) If the FM antenna is not installed, mount the accelerometer to confirm the discrepancy. Set the Vibrex RPM TUNE at 129 and the RPM RANGE at X10. When the main rotor has stabilized, slowly adjust the RPM TUNE to achieve the highest IPS indication with the PUSH TO VERIFY TUNE button depressed.

Tail Rotor	1296	.8	Tail rotor Blade	Check for damaged blade or flex strap. Presence and security of mounting hardware
				Check pitch link bearings for .015 max radial play
				Check track and balance of tail rotor. If out of track , replace blade and balance assy
				Balance assembly

PROCEDURE D

Operate the main rotor at a stabilized 100% with full down collective so that the helicopter is resting firmly on the ground. Set the Vibrex RPM TUNE at 413 and the RPM RANGE at X10. Stand on the right side of the tailboom and hold the accelerometer firmly against the side of the intermediate transmission support structure. Adjust the RPM TUNE to achieve the highest IPS indications with the PUSH TO VERIFY TUNE button depressed. Reach high up the vertical stabilizer to get as close to the tail rotor transmission mounting as possible. Hold the accelerometer on the forward vertical stabilizer spar at a 90 degree angle to the surface. If either of the IPS readings exceed the limit , perform the defined checks.

Inter. XMSN Output	4133	1.5	Pinion Adapter	Check for correct hardware
				Check hardware torque
				Lubricate adapter
			XMSN Pinion	Adapter diameter on each side of seal
			Drive Shaft	Loose or missing balance weights
				Excessive damage
				Foreign material on or inside of shaft

Table 4-1. Vibration Troubleshooting (Continued)

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION
Tail Rotor XMSN Input	4133	1.5	Pinion Adapter	Check for correct hardware Check hardware torque Lubricate adapter

PROCEDURE E

Mount the accelerometer as defined in the tail rotor balance procedure. (Refer to para 9-22.) Operate the main rotor at a stabilized 100% rpm. Hold the collective full down so that the helicopter is resting firmly on the ground. Set the Vibrex RPM TUNE at 518 and the RPM RANGE at X10. Adjust the RPM TUNE to achieve the highest IPS indications with the PUSH TO VERIFY TUNE button depressed. If the IPS reading exceeds the limits, perform the defined checks.

4/Rev of the Tail Rotor	5184	0.8	T/R Hub	Check for looseness, security and torque of flex strap and load alleviator mounting hardware Check for damage to T/R support structure and security of mounting hardware Check for looseness in tail rotor controls from T/R XMSN to output of T/R actuator, total allowable Max per bearing .003 Check mounting of tail rotor boost actuator Check tail boom structure and mounting hardware

PROCEDURE F

Operate the main rotor at a stabilized 100%. Hold the collective fulldown so that the helicopter is resting firmly on the ground. Set the Vibrex RPM TUNE at 672 and the RPM RANGE at X10. Stand on the right side of the tailboom and hold the accelerometer firmly against the intermediate transmission support structure at a 90 degree angle to the surface. Adjust the RPM TUNE to achieve the highest IPS indications with the PUSH TO VERIFY TUNE button depressed. Make similar measurements at each of the tail rotor drive shaft bearing mounts and on the bottom of the main transmission accessory section inline with the tail rotor shaft output. (Open access panel 6-1 .) If any of the IPS readings exceed the limits, perform the defined checks.

Tail Rotor Drive Shaft and Coupling (Measure at Brg. Mount Structure)	6717	2.4	Mount	Unbonded Damaged
			Mount Bushing	Excessive wear 0.030 Loose Binding
			Mount Structure	Cracked Loose Damaged

Table 4-1. Vibration Troubleshooting (Continued)

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION
			Bearing	Lubricate Overheating Bearing or bearing cage material in grease
			Coupling Plates and Adapter	Check correct hardware Check hardware torque
Main XMSN	6717	1.5	T/R Drive Pinion Adapter	Check for correct hardware and proper torque Check for longitudinal movement and proper torque Lubricate
	6717	1.5	T/R Drive Pinion	
Intermediate XMSN	6717	1.5	Input Pinion Adapter	Check for correct hardware and proper torque Lubricate adapter Check diameter of adapter at both sides of seal

PROCEDURE G

Open access panels 6-5, 6-1, 3-10, and 2-2. Operate the main rotor at a stabilized 100%. Hold the collective full down so that the helicopter is resting firmly on the ground. Set the Vibrex RPM TUNE at 720 and the RPM RANGE at X10. Through access panel 6-5, hold the accelerometer firmly against the bottom of the forward agb at a 90 degree angle to the surface. Adjust the RPM TUNE to achieve the highest IPS indications with the PUSH TO VERIFY TUNE button depressed. Make similar measurements on the main transmission agb output through access panel 6-1, on the main transmission NO. 1 and NO. 2 engine inputs through access panel 6-1, on the underside of No. 1 engine at the forward mount through access panel 3-10, and on the underside of No. 2 engine at the forward mount through access panel 2-2. If any of the IPS readings exceed the limits, perform the defined checks.

Fwd AGB	7196	1.5	Pinion Adapter	Check for correct hardware Check hardware torque Lubricate adapter
Main XMSN (Output To AGB)	7196	1.5	Pinion Adapter	Check for correct hardware Check hardware torque Lubricate Adapter
			Drive Shaft	Damage Loss of balance weights Loose rivets
Eng. XMSN	7196	1.5	Pinion Adapter	Check for correct hardware Check hardware torque Check adapter retention nut Lubricate adapter

Table 4-1. Vibration Troubleshooting (Continued)

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION
			Drive Shaft	Check for damage Loss of balance weights Loose rivets
Main XMSN Eng. Input	7196	1.5	Pinion Adapter	Check for correct hardware Check hardware torque Lubricate adapter

PROCEDURE H

a. With apu not operating. Open access panel 6-1. Operate the main rotor at a stabilized 100%. Hold the collective full down so that the helicopter is resting firmly on the ground. Set the Vibrex RPM TUNE at 813 and the RPM RANGE at X10. Through access panel 6-1, hold the accelerometer firmly against the bottom of the main transmission accessory gear box at a 90 degree angle to the surface. Adjust the RPM TUNE to achieve the highest IPS indications with the PUSH TO VERIFY TUNE button depressed. If the IPS reading exceeds the limit, perform the defined checks.

b. With apu operating and engines not operating. Open access panel 6-1, 5-1, and 5-2. Set the Vibrex RPM TUNE at 820 and the RPM RANGE at X10. Through access panel 6-1, hold the accelerometer against the bottom of the main transmission accessory gear box at a 90 degree angle to the surface. Adjust the RPM TUNE to achieve the highest IPS indication with the PUSH TO VERIFY TUNE button depressed. Make a similar measurement through access panel 5-2 at the apu output. If any of the IPS readings exceed the limits, perform the defined checks.

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION
APU Inst (Vibration Present With Rotor Turning) and APU in ON	8130	1.5	APU Shaft	Obvious damage Loose rivets Foreign material on or inside of shaft
			Pinion Adapters (Both Ends)	Check for correct hardware Check hardware torque Lubricate forward adapter
			C.F. Clutch	Check torque on C.F. clutch mount torque
Vibration Present With APU Operating	8130	1.5	C.F. Clutch	Replace the clutch
			APU	Check hardware torque Check shaft Check diameter of adapter going into transmission

COMPONENT	RPM	IPS	PROBABLE CAUSE	CORRECTIVE ACTION

PROCEDURE I

Open access panels 2-2 and 3-10. Operate the main rotor at a stabilized 100%. Hold the collective full down so that the helicopter is resting firmly on the ground. Set the Vibrex RPM TUNE at 194 and the RPM RANGE at X100. Through access panels 2-2 and 3-10, hold the accelerometer firmly against the bottom of each engine just forward of the mount, at a 90 degree angle to the surface. Adjust the RPM TUNE to achieve the highest IPS indication with the PUSH TO VERIFY TUNE button depressed. If the IPS reading exceeds the limit, perform the defined checks.

Eng. XMSN (Input)	19400	1.2	Quill Shaft	Check security of mounting hardware Check for cracks in engine transmission mounting flange Check quill shaft coating

APPENDIX B

FAULT ISOLATION PROCEDURE

The contractor's previous and on-going activities in fault isolation technology have enabled the development of guidelines for preparation of fault isolation procedures. These guidelines were successfully used to prepare a complete set of Proceduralized Troubleshooting Aids (PTSA) for all systems of the Army YUH-61A UTTAS helicopter. These PTSA's were used to train Army technicians to maintain the three prototype YUH-61A's during the government competitive test in 1976. The Source Selection Evaluation Board reported favorable results in the application of these manuals. The contractor believes that these guidelines form a substantive base upon which to project the activities required by this study, and that an optimized analytical technique will result.

Guidelines for Preparation of Fault Isolation Procedures

For information purposes, the contractor presents herewith a condensed definition of the guidelines used to develop the above-mentioned Army PTSA's.

Step 1. Develop a system diagram. – This is a composite schematic of an entire system and is constructed from wiring diagrams, schematic diagrams, and component and installation drawings. For most systems, the diagram should include all electrical, fluid, or mechanical circuits, internal circuits of all components, and complete interconnection information. Input-output criteria for all components are placed on the diagram.

NOTE: The contractor has abandoned the use of functional analysis block diagrams in favor of the system diagram.

Step 2. Develop the operational check. – Using the engineering/factory acceptance test document(s) for the system and its components, develop a series of steps, in correct sequence, for placing the system in operation. For each step, describe fully every event or action which results from performing that step.

Step 3. Validate the operational check. – Using hardware, if available, perform the operational check. Update the check with normal conditions, rates, durations, sequences, and unpredicted events.

Step 4. Make a list of failure modes. – Make a list of all components in the system and, using the failure modes and effects analysis for the system and components, list all predicted failure modes.

Step 5. Develop a list of symptoms. – From the operational check, develop a symptom list. For each normal event that does not occur as defined in the operational check, a trouble symptom exists. Record the symptom and beside it list the names and the failure modes of the components (from the failure modes list) which can cause it.

Step 6. Develop logic diagrams and procedures. – Work the symptoms in order as they appear in the operational check. Identify the symptom on a copy of the system diagram; then mark in red every component and interconnection which could have caused the symptom at that point in the operational check. Now examine the marked area of the system diagram to determine the easiest and simplest kind of observation or test that will exonerate any part or will narrow the fault to approximately half of the suspected circuit. Use built-in test features or other maintenance conveniences to best advantage; use test equipment only after all other techniques are exhausted. Work within these assumptions:

a. Assume system is connected correctly.

b. Assume only one failure or one unsatisfactory condition unless you know that a particular failure causes a secondary failure.

c. Assume a component failure before a connection failure.

Begin troubleshooting in the system where the symptom is evident. Continue within a fluid, mechanical, or electrical circuit as long as the circuit is part of the system. If logical homing on a fault is not practical, try schematic homing. First, list all possible components and failure modes. Next, use tests or checks to eliminate as many components or conditions as possible. Then, develop a course of economical action based on failure probabilities and ease of access or replacement.

NOTE: Since this process is not systematic, those performing validation or verification of the schematic homing procedure must be informed by notes.

Step 7. Document the troubleshooting strategy. – Using preprinted logic diagram form, record the troubleshooting strategy as a logic diagram. Present requirements for tests or observations as questions as though you are directing the operation by remote control.

Step 8. Maintain traceability. – Retain copies of the marked-up system diagram and the completed logic diagram to provide a record of the logic used in developing the final strategy. Otherwise, no one, including you as the author, will be able to reconstruct the logic in the same sequence, and development of strategies for additional related symptoms will take longer.

FINAL NOTE: At this point the basic logic diagram is expanded into detailed procedures and system illustrations for incorporation into the Proceduralized Troubleshooting Aid (PTSA).

All of the steps in the guidelines presented above are not appropriate for establishing the symptom-to-failed component relationships for generic components. However, the logic development guidelines are quite appropriate in those areas where it is difficult to relate the symptom to a single component, and they help us quickly identify those areas where additional symptoms, GSE, or BITE may be required to positively isolate the troublesome component.

The following charts, Figures B-1, B-2, B-3, and B-4, illustrate how the PTSA for the YUH-61A is broken down to a subsystem operational check.

UTTAS PUBLICATIONS

- **MANUALS IN USE AT GCT SITES**

-10, CL	LIMITS CONTENT TO DATA PILOTS NEED FOR COMPETITIVE TEST
-10FICL	PILOT'S FAULT ISOLATION CHECKLIST
-24	COMBINES ALL MAINTENANCE (AIR VEHICLE, AVIONICS, GSE) INTO ONE MANUAL
-24TS	MECHANIC'S PROCEDURALIZED TROUBLESHOOTING AIDS (PTSA)

PTSA IS BROKEN DOWN TO THE FOLLOWING BOOKS

TM 55-1520-XXX-24TS	Index
TM 55-1520-XXX-24TS1	Airframe and Landing Gear
TM 55-1520-XXX-24TS2-1	Engine Starting Procedure
TM 55-1520-XXX-24TS2-2	Fuel System
TM 55-1520-XXX-24TS2-3	Bleed Air and Anti-Ice Systems
TM 55-1520-XXX-24TS3	Hydraulic and Pneumatic Systems
TM 55-1520-XXX-24TS4	Transmission Monitoring System
TM 55-1520-XXX-24TS5	Rotor Systems
TM 55-1520-XXX-24TS6	Flight Controls
TM 55-1520-XXX-24TS7-1	Engine and Transmission Instruments
TM 55-1520-XXX-24TS7-2	Flight and Navigation Instruments
TM 55-1520-XXX-24TS7-3	AC and DC Systems
TM 55-1520-XXX-24TS7-4	Lighting Systems
TM 55-1520-XXX-24TS8-1	Utility Systems
TM 55-1520-XXX-24TS8-2	APU and Cargo Hook
TM 55-1520-XXX-24TS9-1	Communications
TM 55-1520-XXX-24TS9-2	Navigation
TM 55-1520-XXX-24TS9-3	SCAS

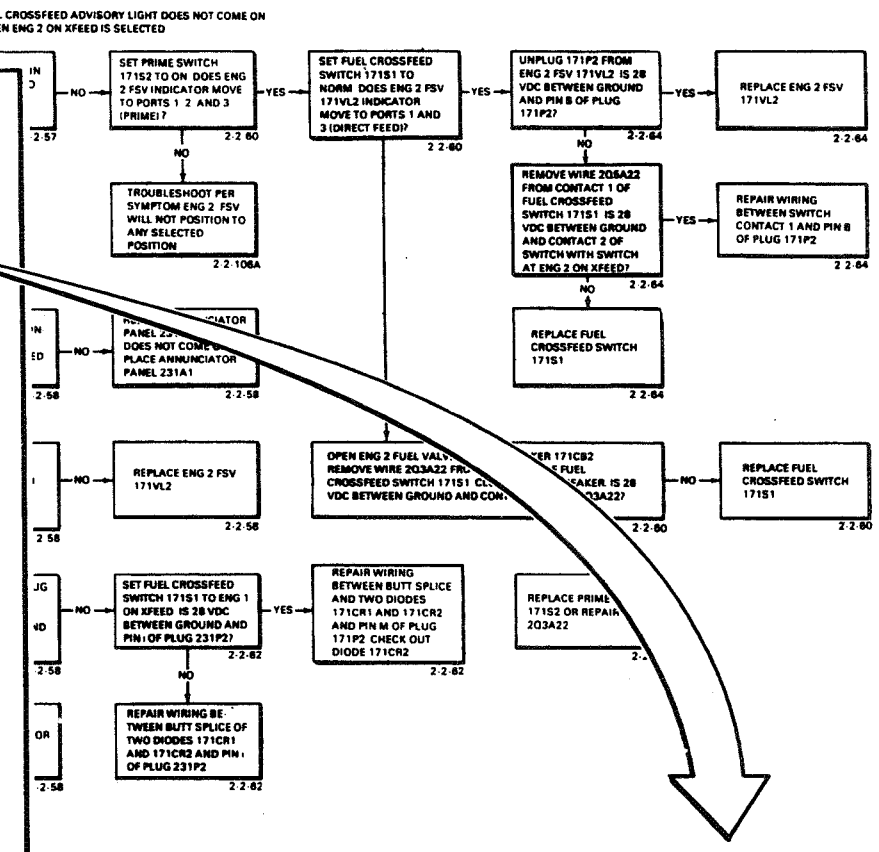
EACH PTSA BOOK CONTAINS

1. SYSTEM OPERATIONAL CHECK
2. OPERATIONAL CHECK INPUT CONDITIONS
3. PICTORIAL COMPONENT LOCATION
4. TESTPOINT IDENTIFICATION AND LOCATION SUCH AS:
   - CONNECTOR PLUGS AND RECEPTACLES
   - TERMINAL BOARDS
   - RELAY SOCKETS
   - GROUND STUDS
5. LOGIC DIAGRAMS
6. DETAILED PROCEDURES

AIRFRAME FUEL SYSTEM OPERATIONAL CHECK

TM55-1520-XXX-24TS2-2

Procedure	Result or Action
i. Set FUEL CROSSFEED switch to NO. 2 ENG ON XFEED.	Fuel CROSSFEED advisory light will come on. If not,go to page 2-2-55.
	ENG 2 FUEL VALVE indicator will point to ports 1 and 2 (CROSSFEED). If not, go to page 2-2-55.
	If ENG 2 FUEL OFF light comes on, go to page 2-2-67.
j. Set FUEL CROSSFEED switch to NORM.	Fuel CROSSFEED advisory light will go out. If not,go to page 2-2-71.
k. Push ENG 1 FIRE switch.	ENG 1 FIRE SW FUEL off light will come on. If not,go to page 2-2-79.
	ENG 1 FUEL VALVE indicator will point to ports 2 and 3 (OFF). If not, go to page 2-2-79.



2-2-55/2-2-56 blank

THERE ARE THREE WAYS TO ISOLATION PROCEDURE FOR SPECIFIC FAULT:

1. PILOT USES FAULT ISOLATION CHECKLIST
2. MECHANIC USES SYSTEM OPERATIONAL CHECK
3. MECHANIC USES TROUBLE SYMPTOM INDEX

(1) IF RESPONSE ON CONVENTIONAL CHECKLIST IS NEGATIVE . . . . .

CONVENTIONAL CHECKLIST

DTM55-1520-XXX-CL

		FICL
	POST START CHECK	
*	1. Engine condition levers—FLT.	F-32
*	2. Annunciator panel—Check.	F-33
*	3. Engine and transmission instruments—Check normal.	F-38
(O) *	4. Engine beep trim system—Set.	F-41
*	5. APU switch—STOP.	F-41
*	6. Ground power (if used)—Disconnected.	
	GROUND OPERATION CHECK	
	1. NO. 2 primary hydraulic system—Check operation.	F-42
	2. (First flight of day) Fuel crossfeed—Check operation.	F-45
	PRE TAXI CHECK	
*	1. Radios—Check for operation.	F-46
*	2. Cabin doors—Secured.	
*	3. Crew—Ready to taxi.	
*	4. Nose wheel lock—As required	
*	5. Chocks—Removed.	
*	6. Area—Check clear.	
*	7. PARKING BRAKE—Release.	F-53
*	8. BRAKES—Check.	F-53
	TAXIING	
	1. Wheel brakes—Check released.	F-54
	2. Cruise guide indicator—Check	

N-9

(2) . . . THEN PILOT GOES TO

FAULT ISOLATION CHECKLIST

DTM55-1520-XXX-CL

Procedure	Result or Action
4 [illegible]el crossfeed system c[illegible] as follows:	
a [illegible]UEL CROSSFEED s[illegible]ch—NO. 1 ENG ON X[illegible]ED.	FUEL CROSSFEED advisory light comes on. If not, report: *FUEL CROSSFEED advisory light does not come on when NO. 1 ENG ON XFEED is selected.*
	Fuel quantity indicatio[illegible] decreases approxima[illegible] 200 pounds. If not, [illegible]rt: *Fuel quantity indic[illegible]n does not decrease whe[illegible]el crossfeed switch [illegible]t to NO. 1 ENG or NO. 2 [illegible]G ON XFEED.*
b. FUEL CROSSFEED switch—NO. 2 ENG ON XFEED.	FUEL CROSSF[illegible]ED advisory light comes on. If not, report: *FUEL CROSSFEED advisory light does not come on when NO. 2 ENG ON XFEED is selected.*
c. FUEL CROSSFEED switch—NORM.	FUEL CROSSFEED advisory light out. If not, report: *FUEL CROSSFEED advisory light on when crossfeed switch set to NORM.*

F-45

(3) a. HELP PILOT TO CORRECT APPARENT MALFUNCTION OR b. TELL PILOT EXACTLY WHAT TO REPORT.

FICL WILL:

(4) THE REPORT IS KEYED TO REPAIRMAN PTSA INDEX OF TROUBLE SYMPTOMS

REPAIRMAN'S PTSA

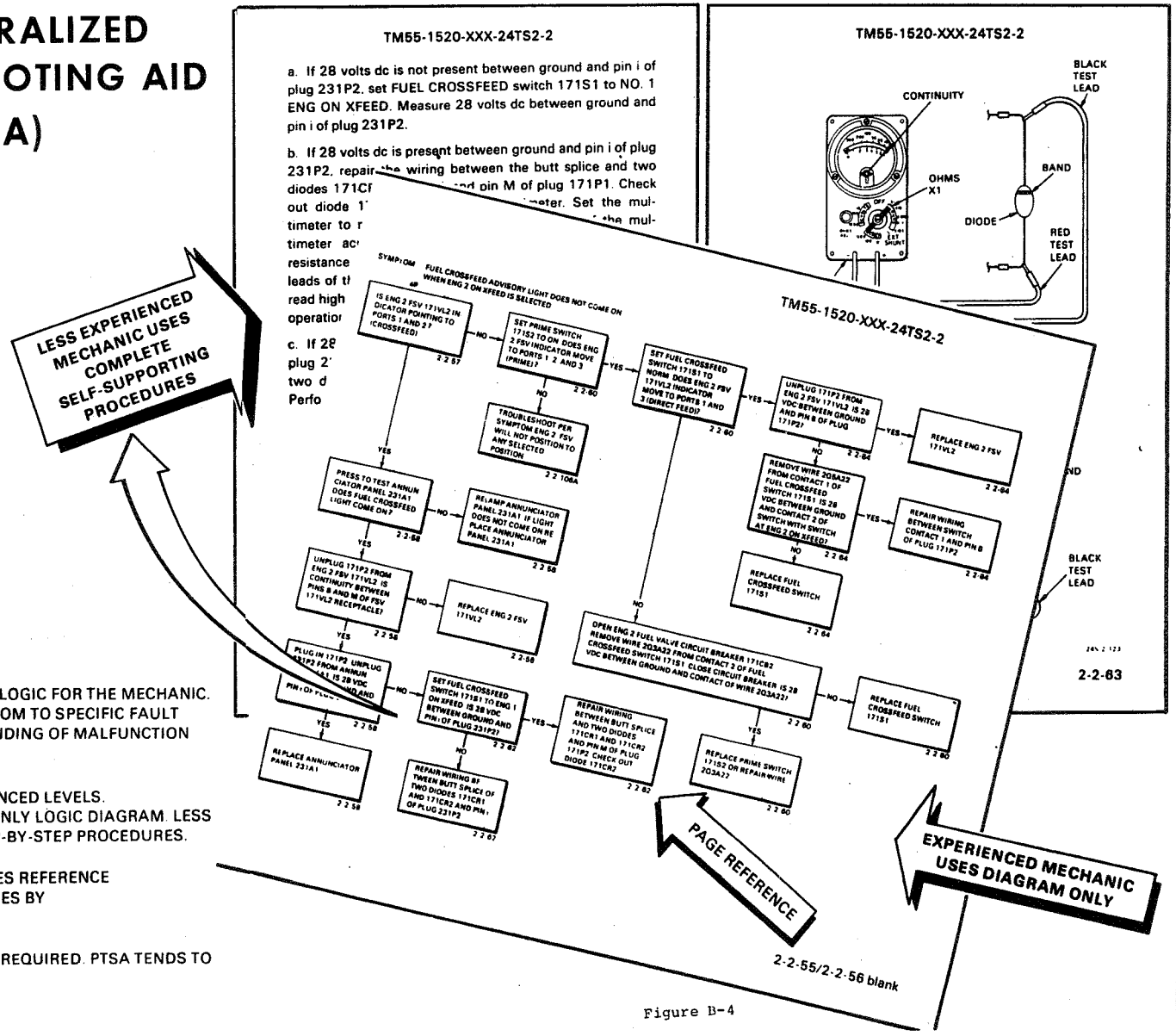
INDEX OF TROUBLESHOOTING SYMPTOMS

[illegible] Advisory [illegible]
Not Come On When Engine 1 On XFEED Is Selected 2-2-45
FUEL CROSSFEED Advisory Light Does Not Come On When Engine 2 On XFEED Is Selected 2-2-55
FUEL CROSSFEED Advisory Light On When Fuel XFEED Switch Set At NORM 2-2-71
Fuel Quantity Indication Does Not Decrease When FUEL CROSSFEED Switch Set To NO. 1 ENG On Or NO. 2 ENG On XFEED 2-2-233
Fuel Quantity Indication Does Not Decrease When FUEL QTY TEST Switch Depressed 2-2-231

INDEX 20

Figure B-3

PROCEDURALIZED TROUBLESHOOTING AID (PTSA)



PROVIDES PREDETERMINED LOGIC FOR THE MECHANIC. HE CAN TRACE FROM SYMPTOM TO SPECIFIC FAULT WITH MINIMUM UNDERSTANDING OF MALFUNCTION CAUSE AND EFFECT.

DESIGNED FOR ALL EXPERIENCED LEVELS. EXPERIENCED MAN NEEDS ONLY LOGIC DIAGRAM. LESS SKILLED MAN CAN USE STEP-BY-STEP PROCEDURES.

EACH LOGIC BLOCK PROVIDES REFERENCE TO STEP BY STEP PROCEDURES BY PAGE NUMBER.

MINIMUM TRAINING IN USE REQUIRED. PTSA TENDS TO BE SELF-GUIDING.

Figure B-4

APPENDIX C

HELICOPTER MAINTENANCE RECORD-KEEPING SYSTEM

Reprinted from PrivatePilot March 1977

A.D. Logs: A Better Idea

Paperwork Eased with Organization

WHEN MARVIN STERN acquired a Piper Comanche 250, he also acquired a gross load of frustration. A methodical, orderly person, as many in the printing and publishing business are, Stern found the paperwork for his new pride-and-joy was a mess.

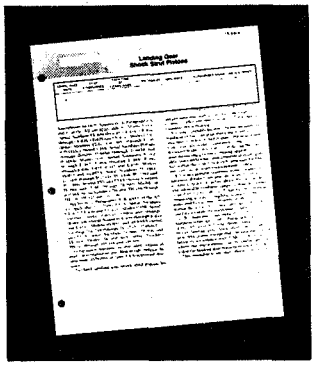
The Piper PA-24 series are fine airplanes, but they have a list of Airworthiness Directives on them that is nearly of wingspan length. Trying to sort out what had and hadn't been done proved an overwhelming task as Stern sifted through batches of those tiny, cheap paper logbooks the manufacturer supplied with the airplane. Stern knew there had to be a better way.

As he poked and noted, he developed a system, and being a printer, he knew that he could reproduce this system on forms that would be attractive and helpful for other aircraft owners. Thus, Stern's "adLog" system was born and first marketed. Response was immediately favorable, but the desire for a better maintenance record-keeping system also was revealed, so Stern went to work again. This time, he evolved a complete system for maintenance records, along with permanent Airworthiness Directive files, that fulfilled all FAA requirements for aircraft record-keeping.

Stern's company, AeroTech Publications, recently moved to new quarters because the growing demand for his adLog and maintenance record systems.

The maintenance record portion consists of a standard sized three-ring looseleaf binder into which are inserted prebound, punched logbooks for airframe, engine (two if multi aircraft), propeller (again, two if multi) and avionics. These are 8-3/8 by 10-7/8 inches in size and neatly columned and ruled for all the appropriate service entries. The first inside page of each logbook section has blanks for serial numbers, registration numbers, ownership records, etc. — all those items an owner and his mechanic need immediately available at inspection time. The Airframe and Engine books each have 32 pages for entries, while the Propeller and Avionics books each have 12 pages; probably enough for the lifetime of any general aviation airplane.

The large format of these books makes them at least three times the size and five times as useful as those small logs left over from the days when airframe/engine logbooks had to be carried in the aircraft whenever it was flown. Now that aircraft logs can be filed at home, office or hangar, and not carried along on every flight, there's no reason to put up with their limited space and cramped columns.



The record system is neatly contained in a standard sized three-ring binder, indexed for content; front portion is the maintenance logs, rear portion the AD pages.

Sample Airworthiness Directive page from the adLog System. Along with name, number and wording of the AD, it provides space for accurate notation of compliance.

The collection of AD notes is broken down into repetitive and permanent compliance sections. The permanently complied with ADs have green coding, the repetitive ADs have red color identification for instant location. Each directive occupies one full sheet and gives the full number, name and wording of the directive as well as its application, and provides adequate space for signing-off the AD at its compliance.

When the customer orders his Maintenance Record and adLog System, he receives all the Airworthiness Directives for his model airplane issued since the model was first certificated. That means he can receive many out-dated, non-applicable ADs along with all those with which he has complied. However, it is better to have too many and sort out and throw away those not applicable than to have too few. In the case of my Mooney, I saved the non-applicable ADs, logged their numbers in the index just to avoid the hassle of trying to look them up again. Same thing with current, non-applicable ADs; they're logged as N/A and saved to prove to the inspecting A&P at next annual time that no action on them was needed.

AeroTech's system includes a full-year's update and revision service for the AD portion to insure the plane owner that he sees all the notes applicable. Extensions of that service are available at one-third the initial purchase price, Stern says.

The system can reduce paperwork to a matter of minutes instead of hours, which can effect considerable savings in shop time charges during inspections and annuals. All the needed information, with appropriate signatures and dates, are right there in one place for the AI to peruse.

The initial investment is little more than two hour's charges at the current shop rates and will repay itself completely on the first annual. The Maintenance Record costs $13 for a single and $16 for a twin; adLogs for individual aircraft have differing prices because of the numbers of ADs for each. An adLog for Stern's Comanche, for instance, would be $25; for my Mooney it was $24 . . . an adLog for a Twin Beech, which probably has the most ADs of any airplane, goes for $49, AeroTech's highest price. Thus, if one wanted the complete system for his Cessna 210, it would cost $23 for the adLog, $13 for the Maintenance Record, and $2.50 for shipping charges. At $38.50, its the best investment in aircraft record-keeping an owner can make.

In addition to all the general aviation fixed wing planes, Stern's company has files for virtually all helicopters. Because of choppers' inherently frequent inspections and maintenance, an AeroTech record system must be as necessary as a set of box-end wrenches.

For a price list on various other airplanes, contact AeroTech Inc., P.O. Box 99, Morganville, NJ 07751; or call Marvin Stern at (201) 591-9314 — he's got a better idea. —*Dennis Shattuck*

How the adLog works . . .

AD NUMBERS

The *adLog* contains the complete text (no illustrations) of *every AD that was issued for your series of aircraft*, and are in numerical order. The FAA numbers AD's by the year, bi-weekly period during that year, and by the number of AD's issued during that bi-weekly period.
For example:

76-16-2

Year of issuance — Bi-Weekly Period — AD number issued during bi-weekly period

Fig. 1

The first 2 digits indicate the year of issuance, the second grouping of 1 or 2 digits indicates the bi-weekly period during that year and the third group of 1 or 2 digits indicates the AD number issued during the 2 week period. In the case of the above example, the number indicates that this was the second AD issued by the FAA during the 16th bi-weekly period of 1976.

COLOR-CODING

The *adNote* pages are *color-coded green to indicate* non-repetitive AD's and red for repetitive or recurring AD's. This makes it possible to locate repetitive ADs in a matter of seconds.

For example:

The maintenance log forms on the repetitive ADs are set up so that the interval for future compliance can be determined *instantly*.

Total Time At time of Compliance — *Tach or recording meter time at Time of Compliance*

DATE	TT AT COMP.	TACH TIME AT COMP.	METHOD OF COMPLIANCE	NEXT COMP. DUE AT		AUTHORIZED SIGNATURE & NUMBER
				TT	TACH TIME	
1-26-76	1147	324	Per 1a,b,c below	1247	424	Jonathan Mech 12345
6-4-76	1157	424	Per 1a,b,c below	1347	524	Jonathan Mech 12345678

Fig. 2

In Fig. 2 above, you will note that on January 26 the AD was complied with at 1147 hours of total time on the aircraft. The Tachometer indicated 324 hours. If, for example the AD requires compliance every hundred hours, the time for the next compliance is extended in the "Compliance Due" column which indicates that the next compliance is due at Total Time of 1247 hours or 424 hours on the tachometer.

This example shows a tach time that differs from the total time. This is frequently common in that many airplanes have had tachometers *changed during the life of the aircraft* and consequently both tach and total time entries must be made in all maintenance logs. The *adLog* format eliminates the problem of juggling numbers.

"METHOD OF COMPLIANCE" ENTRIES

The FARs require that the method of compliance *be spelled out in its entirety* when making log entries. The *adNote* page *simplifies and facilitates* these entries as the AD itself is spelled out word for word on the same page as its associated maintenance log form, therefore, it is only necessary when making entries to refer to the appropriate paragraph in the AD as illustrated in Fig. 2.

MULTI-ENGINE AIRCRAFT

For multi-engine aircraft, 2 sets of *adNotes* are supplied, one for each engine, propeller, and engine related accessory, such as magneto's, vacuum pumps, generators, etc.

These individual *adNote* pages provide the owner/operator with a comprehensive picture of AD compliance requirements *for each engine, propeller, etc.—instantly!*

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AD INDEX & TYPE OF AD

In the upper right hand corner of each *adNote* page there is a letter or combination of letters. The Letter **N** indicates a non-repetitive AD or an AD requiring one-time compliance.

The letters **N/M** indicate a non-recurring AD that requires more than one type of compliance. (The use of the **N/M** category on *adNote* pages will be effective December 1, 1976)

The letter **R** indicates a repetitive or recurring AD.

The letters **N/R** indicate an AD that requires repetitive or recurring compliance which becomes non-recurring when some type of modification or parts replacement is made.

The type of AD codes are entered on the index page as illustrated in Fig. 3.

AD INDEX

AD NUMBER	TITLE	Revised or Superseded by AD Number	N/A	TYPE*
	AIRFRAME			
63-10-3	AILERON COUNTERWEIGHT		✓	
63-27-3	LANDING GEAR RETRACTION CIRCUIT			N
64-22-3	LANDING GEAR SAFETY SWITCH			N
65-11-4	STABILATOR CONTROL SYSTEM		✓	
65-25-3	NOSE LANDING GEAR DRAG LINK CLEVIS			N/R
66-18-4	BAGGAGE DOOR LATCH		✓	
66-30-7	FUEL PURGE VALVE HOSE ASSEMBLY		✓	
68-13-3	FUEL CELL COLLAPSE			N/R
71-13-5	ELECTRIC TRIM SWITCH			N
72-22-5	OPERATION LIMITATION PLACARD			N
74-13-1	STABILATOR TORQUE TUBE			N/R
74-13-3	STABILATOR ATTACH BOLTS		✓	
75-5-2	AIR-OIL FILTRATOR			R
75-12-6	FIN FORWARD SPAR			N
75-27-8	STABILATOR BEARING BLOCK RIVETS			

Fig. 3

When an AD coded **N/R** has been complied with in such manner as to become non-recurring, it is only necessary to cross off the letter **R**. With respect to AD's coded with an **N/M**, when the multiple compliance feature has been completed, cross off the letter **M**, thus it is possible to spot AD's that require additional compliance in the time it takes to run your finger down the column, looking for either **R**'s or **M**'s that have not been crossed off.

To further simplify keeping track of recurring AD's, those users of the complete *adLog System* will find color-coded indexed sections in the Maintenance Record Log for AD's fully complied with and those requiring additional compliance.

DOT Advisory Circular AC 43-9 which pertains to General Aviation Maintenance Records states:

"...The important thing is to have a system that will provide the necessary information. There is also no requirement that the records be bound; they may be loose leaf type if this better serves the purpose. Also, many airworthiness directives require repetitive inspections after a specified time in service or in cycles. This alone could create the need for a separate record. In addition, engines, propellers, rotors, and appliances can be and are changed from one aircraft to another, making separate records a necessity...."

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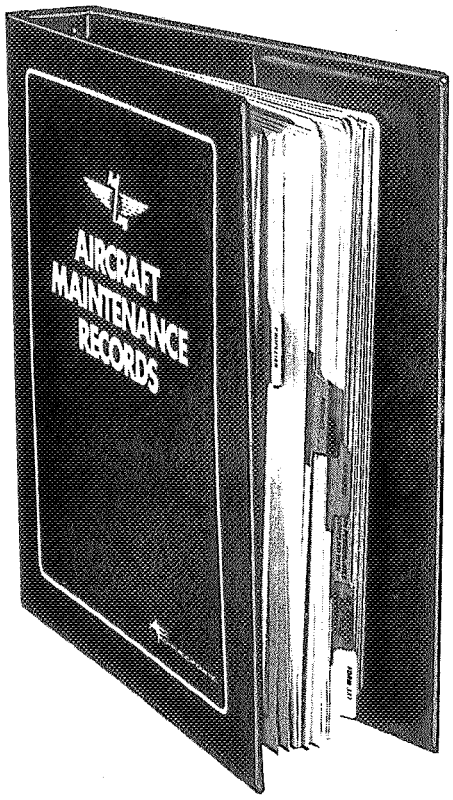
This is the adlog® SYSTEM . . .



A complete system for maintenance records, combined with permanent Airworthiness Directive files, that fulfills all FAA requirements for aircraft maintenance recordkeeping.

MEETS ALL FAA RECORD KEEPING REGULATIONS

The best investment in aircraft maintenance record-keeping an owner/operator can make.

- Contains all the Airworthiness Directives for your series aircraft since it was certificated
- All needed maintenance records with appropriate signatures and dates are in one place for convenient reference
- Reduces paperwork & research to a matter of minutes instead of hours
- Make sure your aircraft is legally airworthy — prove Airworthiness Directive compliance in just minutes (instead of hours)
- Tells you instantly when your repetitive ADs are due & what compliance is necessary

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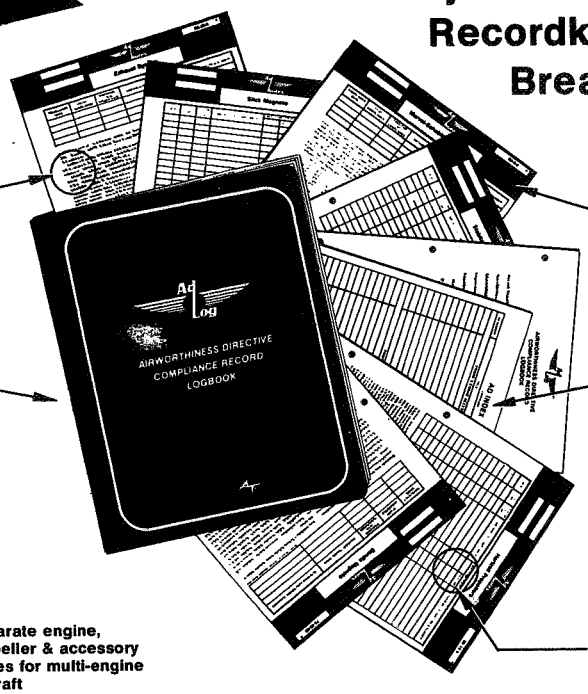


Complete AD on same page as maintenance record form

Color-coded to easily identify repetitive & non-repetitive ADs

Poly Binder

Quick-reference index separates airframe, engine and accessory ADs

Loose-leaf construction makes it possible to transfer all AD records if component is removed from aircraft

Log form conveniently presents tach & total time at compliance & when repetitive compliance is due

Separate engine, propeller & accessory pages for multi-engine aircraft

Each **adLog®** consists of every word of all applicable and current ADs that have been issued for each *series* of aircraft, its engine(s), propeller(s) and accessories. Every page is an individual AD combined with its associated maintenance record form. (Included is a full years update & revision service).

- **Reduce AD research time from hours to minutes**
- **Customized to include all your optional equipment — ELT, Strobes, Autopilots, Avionics, STC'd equipment, etc.**
- **Subscribers receive ADs not always sent to owners of record**
- **Exclusive index & color-coded pages spot repetitive & non-repetitive ADs instantly**
- **Maintenance Personnel — Make "Method of Compliance" entries in just a few short words... Eliminates detailed written descriptions**

UNIQUE adLog® SUBSCRIPTION SERVICE

Yearly revision service cost will be approximately 1/3 the initial purchase price of the **adLog® service,** for which a minimum of four (4) updates or revisions will be guaranteed. The yearly revision subscription period will be automatically extended until this requirement is met.

adlog®
maintenance records

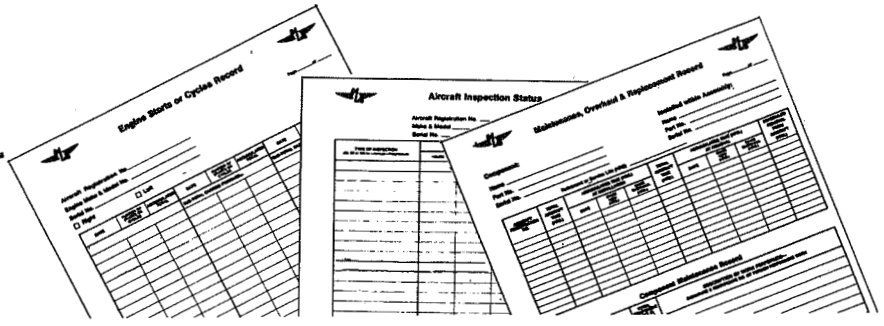
FIXED WING AIRCRAFT

- Greater space means clearer presentation of all entries
- Separate color-coded & bound logs for airframe, engine, propeller & avionics
- Separate indexed sections for ADs fully complied with & ADs requiring additional compliance
- For multi-engine aircraft—individual logs for each engine & propeller
- Clear vinyl carrier page to hold and protect your Form 337s
- Room for storing service notes & bulletins

HELICOPTERS & TURBINE-POWERED FIXED WING AIRCRAFT

For Turbine-powered aircraft & all Helicopters . . . a special section containing a separate index and individual maintenance record forms for Service or Life Limited Components. Also included are forms for recording Inspection Status and Start-Stop cycles etc.

NEW 8½ x 11" FORMAT



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