1979

Accelerated Flight Test Data as a Basis for Forecasting Logistical Requirements of Military Aircraft

Charles James White
University of Central Florida

ACCELERATED FLIGHT TEST DATA AS A BASIS FOR FORECASTING LOGISTICAL REQUIREMENTS OF MILITARY AIRCRAFT

BY

CHARLES JAMES WHITE
B.S.E., Florida Technological University, 1975

RESEARCH REPORT

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Graduate Studies Program of the College of Engineering at the University of Central Florida; Orlando, Florida

Fall Quarter
1979

ABSTRACT

The initial forecasting of logistical support for new types of military aircraft is a perplexing problem. The objective of this research was to investigate the feasibility of using data generated by the accelerated flight tests as a basis for forecasting the logistical field requirements. The data used in the study were obtained from the U.S. Army Aviation Board, Fort Rucker, Alabama, where performance tests are conducted on all new aircraft to determine their suitability for Army use. It was statistically shown that the use of these data could provide more realistic logistical forecasts earlier in the introductory phase of the aircraft. This concept would increase the operational availability of the aircraft and reduce the cost of maintaining the aircraft during its introductory phase.

TABLE OF CONTENTS

CHAPTER I

Introduction

The Forecasting Concept

Logistics is the branch of military science that deals with all aspects of procurement, movement, maintenance, and disposition of supplies, equipment, facilities, and personnel, and the provision of services.

Maintenance and supply of aircraft components and repair parts are the two aspects of logistics that principally affect military aircraft operations. The supply of the required repair parts and replacement components in the required quantities at the required location is a basic problem and one of utmost importance in the day-to-day operation of the military aircraft fleet.

In an attempt to solve this basic supply problem, forecasts, based on the expected usage rates in conjunction with the yearly proposed flying-hour program, are made of the requirements for aircraft repair parts. The effectiveness of the supply system depends to a great extent on the validity of the usage rate factors -- the basis of forecasting.

The forecasting role in military aircraft logistics expanded dramatically during day-to-day operations in

Vietnam. Many excellent techniques in forecasting the requirements for military aircraft replacement parts and dynamic components have been developed or have evolved through the years, but most of these techniques are based on cumulative field data. This is an effective tool and decisive step forward where operational data is available. However, introduction of new military aircraft presents special forecasting problems because adequate operating experience is not yet available to provide a realistic basis for forecasting requirements. As a consequence, there has often been a rather loose assortment of techniques used: lists provided by the manufacturer and military prepared lists based on operating experience gained from similar types of aircraft. Experience has proven this to be an unrealistic approach to reliable forecasting.

The proposed forecasting concept to be explored in this report is an outgrowth of personal experience in the testing and maintenance of military rotary-wing aircraft and is an attempt to provide an accelerated means for more accurate forecasting of replacement components and repair parts during the new aircraft initial operating period.

Background

The acquisition of new aircraft by the U.S. Army can be accomplished in several ways -- from purchase of an existing civilian model to financing the development of a unique model. The introductory phase of a unique model constitutes the greatest challenge to the logistical forecaster. When the Department of Army contracts for the development of aircraft, it specifies a reliability requirement. This requirement may range from a simple statement of system reliability goals to a requirement for contractor demonstration of achievement. Many aircraft dynamic components, however, have time before overhaul (TBO) reliability requirements which encompass an extended period of flight time and are generally never demonstrated prior to the procurement of aircraft in production quantities. This was especially true during the buildup in Army aircraft between 1965 and 1970, when the Army introduced more than 5 new types of aircraft in substantial numbers.

Activities Providing the Data Base for Proposed Forecasting Concept

To determine operational suitability and to establish time between overhaul for the dynamic components of newly introduced aircraft, the U.S. Army Aviation Test Board, Fort Rucker, Alabama conducts accelerated flight test programs. These tests are conducted by flying the aircraft at high gross weights while utilizing flight profiles which represent typical missions the aircraft will experience in field operations. Data derived from these tests are used to establish time before overhaul for dynamic components and to identify those components requiring product improvement programs (PIP) to correct deficiencies. During these tests a monthly flight time averaging 150 to 200 hours per aircraft is accumulated. This is approximately 7 times greater than the normal flight time accumulated by aircraft assigned to field operation.

While these tests provide a relatively small sample, limited to 2 or 3 aircraft, it is hypothesized that the data generated by these flight tests could be used to initially forecast logistical requirements for repair parts, replaceable components, and engine overhauls for the operating fleet, thus establishing a logical basis for a logistical forecasting concept. This would, seemingly, provide a more timely and realistic logistical forecast of the new aircraft system's requirements and alleviate many of the costly supply shortages that generally occur during the introductory phase. Also, it would greatly increase the operating fleet's effectiveness during the introductory period.

The concept of using such a small sample as a basis for a logistical forecasting method is only valid if the sample can be shown to be truly representative of the operating fleet. However, if the concept can be validated, the present practice of waiting for actual field experience to provide a reliable basis for forecasting could be modified to utilize the test data as an interim basis, thereby greatly reducing the time lag in identifying changes in requirements.

A pertinent example of events that sometimes occurs during accelerated flight testing might serve to illustrate the importance of this concept. A major component with a proposed time before overhaul life of 1200 hours contains a design deficiency resulting in its removal for overhaul at only 450 flight hours. A Product Improvement Program (PIP) based on the data generated by the accelerated flight test program is started immediately; however, the logistical supply system continues to procure and stock the component at a rate based on an expected usage factor of 1200 hours before overhaul. Meanwhile, the inadequately designed component continues to be installed in new production aircraft until the PIP provides a way to correct the deficiency and to institute an engineering change in production of the component. However, immediately on discovery of an inadequately designed component, logistical planning needs to be updated in order to prevent serious shortages in the supply system.

Logistical planning for an increase in the usage of most major dynamic components such as engines and transmissions can not be readily achieved due to very long manufacturing lead times, plus any change increasing their production rate will adversely affect program costs. It is ironic, but true, that logistical planning by suppliers often has a greater effect on the introduction and acceptance of a new aircraft by the using units than the ability of the aircraft to perform its assigned mission.

Specific objectives of these accelerated flight test programs for Army helicopters at the Fort Rucker facility were:

a) to determine time between overhaul for dynamic components,

b) to identify design deficiencies which affect reliability,

c) to check adequacy of product improvements, and

d) to determine operating costs (petroleum, oil, lubricants).

During these accelerated flights, the testing was completely controlled by the use of flight profiles which simulated as closely as possible the missions to be flown by the regular fleet. The profiles were scheduled and flown proportionately throughout the test period. Each pilot was briefed prior to each flight on the profile he was to fly and debriefed following the flight to assure that the profile had been flown and to record his comments on the aircraft's performance.

A typical flight profile for a light cargo, rotary-wing aircraft was:

PROFILE #-- Tactical Transport Mission: The aircraft will takeoff at maximum allowable gross weight. Each flight is scheduled for a three-hour period. Aircraft will be refuled every hour to bring it back up to the maximum allowable gross weight. Cruising flight throughout each period will be at an indicated altitude of 800 feet and at 90 knots indicated air speed. Four consecutive normal to steep approaches to a hover are to be performed each hour utilizing barriers. Each approach will begin at an altitude of 800 feet, and two of these approaches will be made down wind when surface winds are less than 15 knots. This profile shall account for 50 percent of this accelerated flight test program.

Research Objective

The objective of this research is to determine the validity of using accelerated flight test data to calculate usage rates for aircraft repair parts, replaceable components, and engines in order to establish a basis for forecasting future requirements for these items.

Significance Tests and Level of Confidence

In order to determine the validity of the proposed forecasting concept, a series of comparison and statistical inference tests will be made utilizing data generated by the accelerated flight test of two different aircraft types and data generated over an extended period of time by the same types of aircraft during fleet operations. The validity of using accelerated flight data to calculate usage rates will be considered substantiated if all valid test samples can be shown to have met the following statistical requirements:

a) the mean time between failures (MTBF) achieved during accelerated testing is an unbiased estimator of the MTBF experienced by the same component during fleet operation.

b) the use of the MTBF achieved during the tests to predict fleet MTBF would not underestimate by more than 0.10 (a figure derived during discussions with Army Aviation logisticians), with a statistical confidence of 0.90.

The null hypothesis H_O: $\overline{X}_F - \overline{X}_T < 0.1\ \overline{X}_F$ will be tested on a suitable t statistic which signifies the level of confidence and is based on the following assumptions. The failure rate is assumed constant even though the sample size is small for each type component tested during the accelerated test. The distribution of failure times is an exponential distribution for both the accelerated flight test and the fleet operation based on theory developed in the article by B. Epstein listed in the bibliography. In performing this test, it was assumed that the exponential model of failures holds for each component, and the variance for each sample is equal to the sample mean. It is also assumed that the sample distribution in both cases would be normal with mean equal to variance. This should be conservative in the field data case since it represents such a large sample, $n_F > 1000$, and the variance would be very small. Due to the vast differences in sample size between accelerated test data and fleet operation data, tests of the hypothesis that accelerated test usage rates would not overestimate fleet usage rates by more than 0.10 were based on a one-sided test of the modified t statistic

$$t = \frac{(\bar{X}_F - \bar{X}_T) - 0.1\bar{X}_F}{S_{\bar{X}_F - \bar{X}_T}}$$

with degrees of freedom limited to n_T to reduce the influence of fleet operation sample size.

where:

$\bar{X}_F$ = mean operating time experienced during fleet operations.

$\bar{X}_T$ = mean operating time experienced during accelerated flight test.

n_F = number of samples in fleet operations data.

n_T = number of samples in accelerated test data.

$$S_{\bar{X}_F - \bar{X}_T} = \sqrt{\frac{(n_F-1)S_F{}^2 + (n_T-1)S_T{}^2}{(n_F+n_T-2)}}$$

modified to reduce the effect of the large sample size of fleet operations.

c) The degree of correlation between accelerated test data and fleet operations data can be measured by a nonparametric sum ratio test of the components respective means. A value of unity would represent perfect correlation; deviation from one, either plus or minus, reduces the degree of correlation. The sum ratio is expressed by the following equation:

$$r = \frac{\sum_{n=1}^{n} \frac{\bar{X}_T}{\bar{X}_F}}{n}$$

where:
n = total number of component types sampled.

In accordance with sign test theory, a correlation interval of plus or minus 0.05 will signify a statistical confidence of 0.90 that the accelerated tests produced representative samples.[1]

---

[1]Irwin Miller and John E. Freund, Probability and Statistics for Engineers (Englewood Cliffs, N.J.: Prentice-Hall, 1965), p. 212.

CHAPTER II

Data Comparison for UH-1 Aircraft

UH-1 Aircraft Accelerated Flight Test Programs

During the period June 11, 1962 to November 2, 1963, the U.S. Army Aviation Test Board, Fort Rucker, Alabama conducted a 1000-hour test of the proto-type YUH-1D to determine and evaluate the UH-1D helicopter, with special emphasis directed toward increasing service life of major dynamic components. After this evaluation was completed, Department of the Army determined that a second set of dynamic components should be evaluated "to provide a broader base of data until such time as information on dynamic components is available from aircraft in the operating fleet." A second test of 1000 hours was conducted between February, 1963 and December, 1964, during which many product improvement program components were tested. Both of these tests were based on flight profiles involving a high percentage of flights at normal takeoff gross weights (6,600 - 7,800 pounds) and a very low percentage of flights at the maximum gross weight (8,600).

In the meantime, the UH-1D helicopters assigned to the operating fleet were being operated continuously at or near the maximum takeoff gross weight, and these operations were providing examples that showed continuous operation at high gross weights increased stress on airframes and decreased life on all dynamic components. In addition, a new 48-foot main-rotor system which would increase the maximum takeoff gross weight to 9,500 pounds was programmed to replace the 44-foot rotor system. Since procurement of UH-1D dynamic components and spare parts was based on a component fatigue life calculated for an aircraft operating at a design takeoff gross weight of 6,600 pounds and an 1100-hour time between overhaul of components, a third accelerated flight test of the UH-1 was directed which would utilize an aircraft with 48-foot rotor system, operate at high gross weights, and maintain profiles which truly represented fleet operations. This test was conducted between February 10, 1965 and October 18, 1965 and consisted of an 1100-hour flight program.

Flight Test Results

In addition to the engine, detailed data was compiled for 12 airframe dynamic components which were subject to overhaul and had an assigned time before overhaul life of 1100 hours. The following compiled

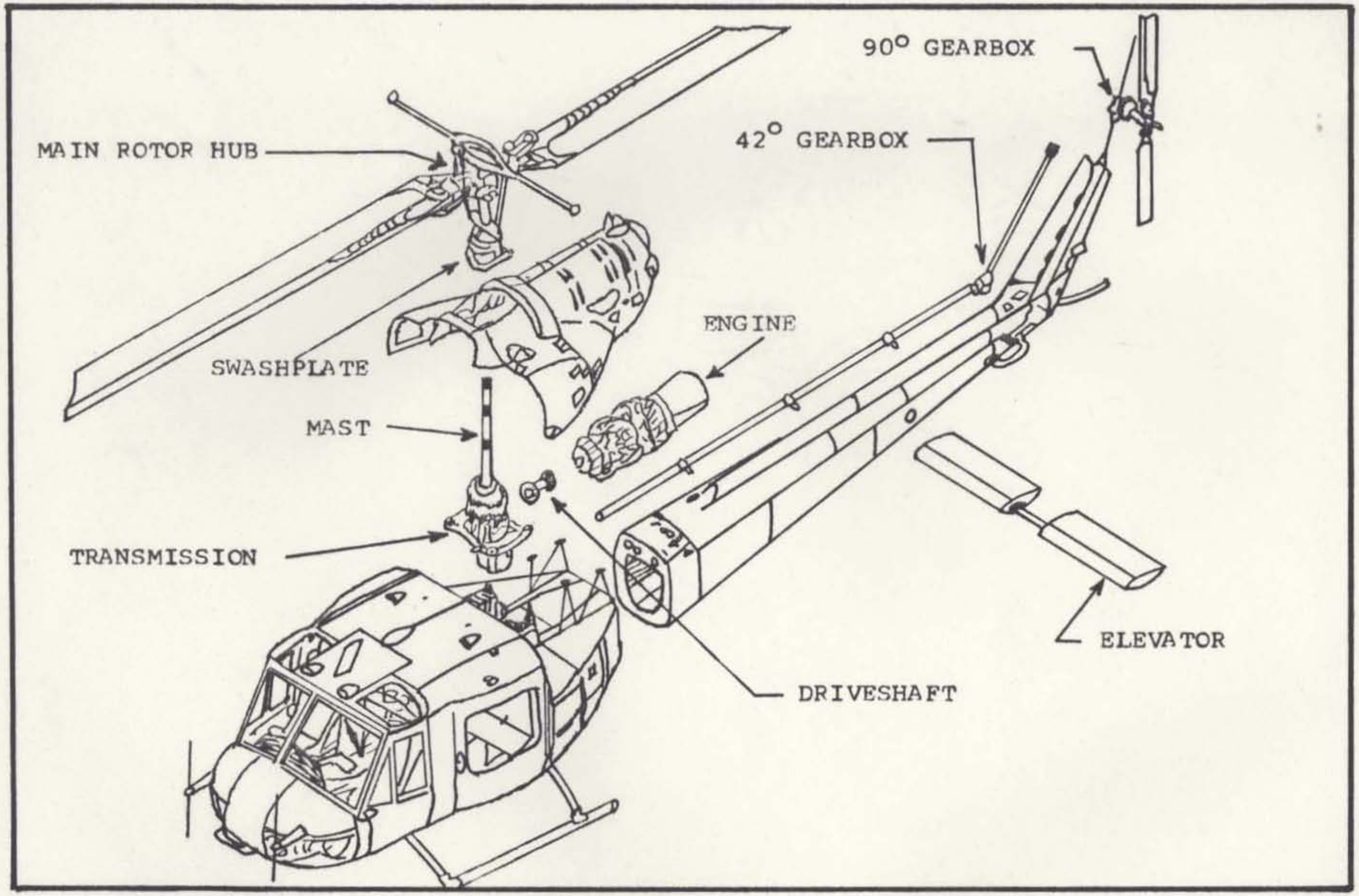

Fig. 1. Exploded View of UH-1 Aircraft

information is an analysis of the engine and the airframe dynamic components used during the third accelerated flight test of the UH-1 type aircraft which will be used as a basis for forecasting usage data.

a) Engine Assembly, T52-1-11, TBO life 1200 hours. Three engines were used during the test. The first engine was removed at 253.1 hours. The second engine failed at 20.9 hours, and engine number three had accumulated 826.0 hours by the end of the test and was still serviceable. Mean operating time was 366.67 hours, with a standard deviation of 19.15 hours.

b) Transmission Assembly, TBO life 1100 hours. Two transmission assemblies were used during test. The first transmission assembly was replaced at 598.9 hours. The second transmission had accumulated 501.1 hours at the end of test. Mean operating time was 550.0 hours, with a standard deviation of 23.45 hours.

c) Ninety-Degree Gearbox Assembly, TBO life 1100 hours. A total of five 90-degree gearboxes were utilized during this test. Flight time per gearbox was: #1 - 274 hours, #2 - 18.5 hours, #3 - 14.8 hours, #4 - 70.3 hours, #5 - 722.5 hours. Cause of failures was accumulation of metal particles in the oil. Mean operating time during test was 220.0 hours, with a standard deviation of 14.83 hours.

d) Forty-two-Degree Gearbox Assembly, TBO life 1100 hours. Two 42-degree gearboxes were utilized during test. Gearbox #1 accumulated 292.2 hours and was damaged by engine surge during engine failure. Gearbox #2 had accumulated 807.8 hours by the end of test and was still operating satisfactorily. Mean operating time was 550.0 hours, with standard deviation of 23.45 hours.

e) Main-Rotor Hub Assembly, TBO life 1100 hours. Two main-rotor hubs were used during the test. Hub #1 had flown 674.5 hours when an inspection revealed damaged retainer straps and corrosion inside the hub yokes. The second hub was installed and had operated 185.6 hours when product improvement parts were incorporated. It then operated another 239.9 hours before the test ended. Considering the introduction of PIP parts as a minor overhaul, mean operating time for this component was 366.67 hours, with standard deviation of 19.15 hours.

f) Main-Rotor Mast Assembly, TBO life 1100 hours. The same main-rotor mast assembly was used throughout the test and final inspection revealed no unsatisfactory condition. As the main thrust bearing is retirement-life limited to 1100 hours, mean operating time for this one example was 1100 hours.

g) Scissors and Sleeve Assembly, TBO life 1100 hours. Two sleeve assemblies were operated during the test. The first was removed after 253.1 hours because of loose bearings. The second sleeve assembly had accumulated 59.1 hours prior to being installed on the test aircraft. After being installed on the test aircraft, it accumulated an additional 846.9 hours for a total of 906 hours. Mean operating time for sleeve assemblies was 579.55 hours, with standard deviation of 24.07 hours.

Several sets of scissors were utilized during this test to check out product improvement program ideas. Since scissors bearing problems can be detected and replacement made at operating level, mean operating time for scissors and sleeve assemblies is dependent only upon the life of the sleeve assembly, which was 579.55 hours.

h) Swashplate and Support Assembly, TBO life 1100 hours. One swashplate and support assembly was operated during this test and accumulated 1100 hours. Upon test completion, overhaul of the swashplate revealed one of four bearings in the swashplate and support ring had what appeared to be corrosion on one of the balls. The bearing was replaced. Swashplate has a calculated fatigue life of 3300 hours. Mean operating time for tested swashplate and support was 1100 hours.

i) Stabilizer Bar Assembly, TBO life 1100 hours. The stabilizer bar assembly assumulated 1100 hours during the test. Inspection at the end of test disclosed that the bearing in the end of the lever assembly was rough and interfered with the smoothness of the lever's movement. The mean operating time for stabilizer bar assembly was 1100 hours.

j) Drive Shaft Assembly, TBO life 1100 hours. Four drive shaft assemblies were utilized during this test. The first assembly accumulated 204.9 hours and was removed because of excessively worn teeth. The second accumulated 48.2 hours and was removed because of damage sustained when the helicopter struck tree limbs. The third accumulated 699 hours during the test and, with 405 hours previous operating time, had a total accumulated time of 1104 hours at the time of removal. The fourth assembly had accumulated 147.9 hours by the end of testing. The mean operating time for drive shaft assembly was 376.25 hours, with a standard deviation of 19.40 hours.

k) Tail-Rotor Hanger Assemblies, TBO life 1100 hours. One set of tail-rotor hanger assemblies was operated 1100 hours during this test. The mean operating time for this item was 1100 hours.

l) Tail-Rotor Control Quill, Condition Change Item. The quill accumulated 1100 hours during the test. The mean operating time for tail-rotor control quill was 1100 hours.

m) Tail-Rotor Pitch-Change Tube, Condition Change Item. The tube accumulated 1100 hours during the test. Mean operating time was 1100 hours.

Table 1 is a summary of the results achieved in the third accelerated flight test of UH-1 aircraft:

TABLE 1

UH-1 MAJOR COMPONENTS - FLIGHT TEST DATA

Component	TBO	Average Operating Hours
Engine	1200 hours	366.7 hours
Transmission	1100 hours	550.0 hours
90-degree Gearbox	1100 hours	220.0 hours
42-degree Gearbox	1100 hours	550.0 hours
Hub, Main-Rotor	1100 hours	366.7 hours
Mast, Main-Rotor	1100 hours	1100.0 hours
Scissors and Sleeve	1100 hours	579.6 hours
Swashplate	1100 hours	1100.0 hours
Stabilizer Bar	1100 hours	1100.0 hours
Drive Shaft	1100 hours	376.3 hours
Hangers, Tail Rotor	1100 hours	1100.0 hours
Quill, Tail Rotor	CCI*	1100.0 hours
Tube, Tail Rotor	CCI*	1100.0 hours

*Has been changed from TBO to condition change item.

Factors for Forecasting Usage of UH-1 Aircraft Major Dynamic Components

The test results discussed above showed that in addition to the engine, six of the major dynamic components experienced a mean operating time which would tend to indicate that the usage rate of these items was higher than planned. The requirements for overhaul of components and repair parts result directly from the operating fleet. Knowing how many flight hours the fleet will be operated and the usage of components per flight hour will allow the logistician to forecast requirements. A new usage factor for engines and each of the six components was based on the mean operating time and is shown in Table 2.

TABLE 2

UH-1 MAJOR COMPONENTS - FLIGHT TEST USAGE RATE

Component	Average Operating Hours	Usage Factor/ Flight Hour
Engine	366.7 hours	0.002727
Transmission	550.0 hours	0.001818
90-degree Gearbox	220.0 hours	0.004545
42-degree Gearbox	550.0 hours	0.001818
Hub, Main-Rotor	366.7 hours	0.002727
Scissors and Sleeve	579.6 hours	0.001725
Drive Shaft	376.3 hours	0.002658

Fleet Operations Data, UH-1H Helicopter

The fleet operating data contained in the U.S. Army Aviation System Command Technical Report 75-3, titled "Executive Summary Report, UH-1H Assessment and Comparative Fleet Evaluation," dated April, 1975 was used as a basis for determining the usage factors actually experienced in operating UH-1 type aircraft. This report contains information on the use of TBO items by UH-1 type aircraft from October 1, 1969 to May 21, 1974, a period of 4 years, 8 months. The average number of UH-1 type aircraft assigned to the U.S. Army fleet during this period varied, but the average for the period covered by fiscal years 72, 73, 74, and 75 was 3805 aircraft. The average age of the UH-1 fleet on December 31, 1974 was 5 years, 8 months, with approximately 140 aircraft less than 7 months old and with 5 aircraft more than 11 years, 3 months old. The average aircraft in the fleet on December 31, 1974 had accumulated 2308 flight hours. This included 250 aircraft with less than 300 flight hours and 5 aircraft with over 5700 flight hours.

UH-1H Fleet Logistical Requirements

An analysis of field operating costs showed that during the period April, 1971 through March, 1972, the cost per flight hour to operate a UH-1H helicopter was $194.72. Parts consumption accounted for $149.64 of the total cost. The average number of flight hours per aircraft per month during this period was 36.3 hours. The approximate cost for parts for one year was $65,185 per aircraft. Usage factors based on fleet experience was well established by this time. The average operating hours at removal for parts that failed had stabilized and fluctuations, if any, were very small. Utilizing the average operating hours at removal as a basis, a usage factor for engines and each of the six previously identified components was calculated and is shown in Table 3.

TABLE 3

UH-1 MAJOR COMPONENTS - FLEET USAGE RATE

Component	Frequency of Replacement	Usage Factor/ Flight Hour
Engine	360.5 hours	0.002774
Transmission	647.7 hours	0.001544
90-degree Gearbox	471.1 hours	0.002123
42-degree Gearbox	568.2 hours	0.001760
Hub, Main-Rotor	371.4 hours	0.002693
Scissors and Sleeve	649.8 hours	0.001539
Drive Shaft	274.2 hours	0.003647

Comparison of Usage Rates Based on Accelerated Test Data with Fleet Usage Experience

Most of the methods of estimation and of testing hypotheses are based on the assumption that the observations are taken from normal populations. These methods extract all the information that is available in a sample, and they usually attain reliable results. The assumption that the samples provided by the accelerated flight tests were truly representative of the fleet will be confirmed by showing through comparison of the usage rates that they gave reasonably accurate answers.

a) Engine Assembly, T53-L-11. The usage rate for engines during the accelerated test was 0.002727, and the usage rate experienced by the fleet stabilized at 0.002774, with n_F = 24,360. The rate experienced by fleet operation is only a 1.7 percent increase in the rate predicted by the data from the accelerated flight test. To test the hypothesis that component's mean operating time was valid predictor of fleet usage rate, a t statistic was calculated and found to be -2.22, with 3 degrees of freedom, which indicates a confidence level of 0.94 (well above minimum of 0.90).

b) Transmission Assembly. The usage rate for main transmissions during the accelerated test was 0.001818, whereas the usage rate for the fleet reached a steady 0.001544, with n_F = 13,560. The fleet rate represents a 15 percent reduction in the rate that was achieved during the accelerated test. Investigation showed there had been more than 10 separate product improvements made in the transmission since the accelerated test, and these improvements probably account for at least two-thirds of the reduction in the usage rate experienced by the fleet. The accelerated test data may have over-estimated the usage rate by 5 percent at the most. A t statistic of

+1.28 with 2 degrees of freedom indicates a confidence level of 0.17, far below minimum of 0.9. This is not a valid sample due to changes in transmission design.

c) Ninety-degree Gearbox Assembly. The 90-degree gearbox had the highest usage rate of all dynamic components during the accelerated test - 0.004545. The 90-degree gearbox had a product improvement program under way while the accelerated flight test was being conducted, and the fifth gearbox to be installed during the test was a product of that program. It had accumulated 722.5 hours by the end of the test. A total of 6 engineering changes have been incorporated in the 90-degree gearbox, and the field usage rate has been reduced to 0.002123, with n_F = 18,640 indicating a better than 50 percent reduction from accelerated flight test data. However, a careful analysis of the test data indicates one replacement was precautionary and another was probably due to infant mortality, caused by improper run-in. Utilizing the remaining accelerated test samples as a basis of data, the usage rate would have been 0.002812. The actual usage rate is 25 percent below what the accelerated test data would have forecast it to be. Using only the samples considered valid, a t statistic of +3.18 with 3 degrees of freedom indicates a confidence level of 0.025. Sample is not considered valid due to changes in design of 90-degree gearbox.

d) Forty-two-degree Gearbox Assembly. During the accelerated test, the 42-degree gearbox had a usage rate of 0.001818 per flight hour. The fleet experienced a usage rate of 0.001760 per flight hour, with n_F = 15,456. The usage rate experienced by the fleet is a mere 3 percent less than that predicted by the accelerated flight test data. T statistic for 42-degree gearbox is -1.63 with two degrees of freedom, which indicates a confidence level of 0.88. Hypothesis is rejected.

e) Main-Rotor Hub Assembly. The usage rate for main-rotor hubs during the accelerated test was 0.002727 per flight hour. Fleet operation has produced a usage rate of 0.002693 per flight hour, with n_F = 23,645. The usage rate experienced in fleet operations is only one percent lower than that experienced during the test. Calculations produced a t statistic for the main-rotor hub assembly of -1.68 with 3 degrees of freedom, signifying a confidence level of 0.90.

f) Scissors and Sleeve Assembly. During the accelerated test the scissors and sleeve assemblies had a usage rate of 0.001725 per flight hour. There were 4 engineering changes in the sleeve assembly resulting from the product improvement program. Utilizing assemblies with these changes, the fleet established a usage rate for scissors and sleeve assemblies of 0.001639 per flight hour, with n_F = 13,515. The fleet rate is nearly eleven percent less than predicted by the accelerated test data. If only 50 percent of the reduction in usage was the result of product improvement, the accelerated test data would still have overestimated fleet usage by 5 percent. Calculated t statistic for scissors and sleeve assembly is +0.20 with two degrees of freedom, giving a confidence level of 0.35, which is well below the minimum of 0.90. Hypothesis is not validated at acceptable level.

q) Drive Shaft Assembly. The engine to transmission drive shafts utilized during the accelerated test included one shaft which had 405 hours of previously accumulated flight time, and this time was utilized in arriving at the mean operating time of 367.25 flight hours. The operating conditions under which these prior hours were accumulated is unknown, but an inspection made prior to installation on the test aircraft showed this drive shaft to be serviceable. An inspection conducted on this particular drive shaft upon its reaching TBO life revealed that several parts were severely damaged, and the assembly had damaged the engine inner coupling internal spline. If only the time data accumulated during the accelerated flight test is used, the mean operating time would be 275 flight hours, and the usage rate would be 0.003636 per flight hour. The operating fleet has established a usage rate for drive shaft assemblies of 0.003647 per flight hour, which is only .3 percent greater than that predicted by the test data. Calculations for drive shaft assembly produced a t statistic of -1.71 with 4 degrees of freedom, signifying a confidence level of 0.91; therefore, test data is considered valid.

The comparison of select dynamic components' usage rates during the fleet operations and the accelerated test are shown in Table 4.

TABLE 4

UH-1 MAJOR COMPONENTS -- USAGE RATE COMPARISON

Component	Test Usage Rate	Fleet Usage Rate	Difference
Engine	0.002727	0.002774	+1.7%
Transmission	0.001818	0.001544	-15%*
90-degree Gearbox	0.002812	0.002123	-25%*
42-degree Gearbox	0.001818	0.001760	-3%
Main-Rotor Hub	0.002727	0.002693	-1%
Scissors and Sleeve	0.001725	0.001539	-10.8%*
Drive Shaft Assembly	0.003636	0.003647	+0.3%

*Reductions due primarily to PIP program.

Tests confirmed the null hypothesis for all components which remain essentially unchanged, except for one which had confidence level of 0.88. These tests of the null hypothesis have the accelerated test data falling above the 0.90 confidence level for 75 percent of the items.

CHAPTER III

Data Comparison for OH-58 Aircraft

OH-58A Aircraft Accelerated Flight Test Programs

The OH-58A light observation helicopter was flight tested by the U.S. Army Aviation Test Board, Fort Rucker, Alabama during the period June, 1969 through April, 1970 to determine reliability and maintainability. Three OH-58A aircraft were used for the test. During the test, aircraft #1 accumulated 1200 hours of controlled flight time, using profiles which had been developed by the U.S. Army Combat Developments Command Aviation Agency as being representative of fleet operations. Aircraft #2 accumulated 410 flight hours of operational suitability testing. Aircraft #3 accumulated 217 flight hours while being evaluated by the Board for Aviation Accident Research and by the Laboratory for Aeromedical Research.

Flight Test Results

A detailed Automated Data Process (ADP) record was kept throughout the test on all operational and maintainability data generated by the three aircraft. All parts

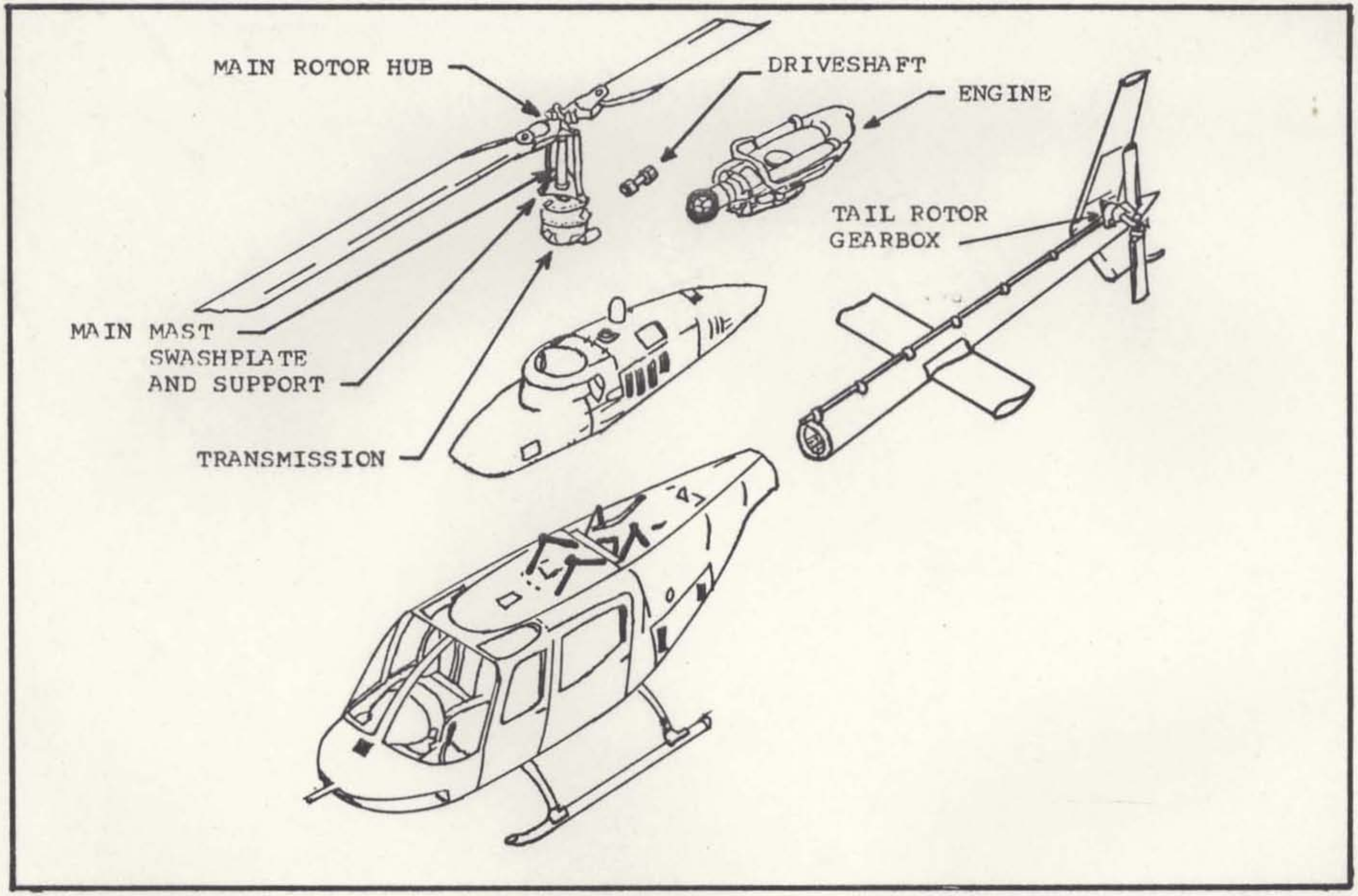

Fig. 2. Exploded View of OH-58A Aircraft

and components, by subsystem (Aircraft, Armament or Avionics), replaced during the test were recorded. Cause of failure of items replaced was analyzed to identify those parts, components, and component accessories requiring a product improvement program.

There are 19 major items on an OH-58A aircraft that require historical data be kept on them. From these 19 items, the five having the highest cost of overhaul were selected as a basis for checking out the validity of the proposed forecasting theory. They are:

a) Turbine Engine, T63-A-700, FSN 2840-179-5536. Six engines were used during the test. On the aircraft which accumulated 1200 flight hours: Engine #1 was removed at 302.4 hours, Engine #2 failed at 450 hours, Engine #3 failed at 95.7 hours, Engine #4 accumulated 351.9 hours by the end of the test and was still operating. Aircraft #2 and #3 completed their tests with the installed engines. Mean operating time was 304.5 hours, with a standard deviation of 17.45 hours.

b) Transmission Assembly, P/N 206-040-003-5, FSN 1615-121-6543. Four transmissions were used during the test. One transmission failed during test at 1159.6 hours. By the end of test, the three remaining transmissions had accumulated 40.4, 410, and 217 hours. Mean operating time was 456.75 hours, with a standard deviation of 21.37 hours.

c) Axial Compressor, P/N 687439, FSN 2840-179-7023. One axial compressor accumulated 1200 hours during the test. One compressor failed at 269.0 hours and was removed because of excessive vibration. The two compressors on the aircraft at test's end had accumulated 141.0 and 217.1 hours. Mean operating time was 456.75 hours, with a standard deviation of 21.37 hours.

d) Main-Rotor Hub, P/N 206-011-100-1, FSN 1615-125-4061. One main-rotor hub attained TBO life of 1200 hours during the test. The two main-rotor hubs still installed at the end of test had 410 and 217 hours. Mean operating time was 609 hours, with a standard deviation of 24.68 hours.

e) Swashplate and Support P/N 206-010-450-5, FSN 1615-120-0482. One swashplate and support accumulated 1200 hours during the test and was removed for having attained TBO life. The two assemblies still installed at end of test had accumulated 410 and 217 hours. Mean operating time was 609 hours, with a standard deviation of 24.68 hours.

Table 5 is a summary of the results derived from the service test of the OH-58A type aircraft.

TABLE 5

OH-58A MAJOR COMPONENTS -- FLIGHT TEST DATA

Component	TBO	Average Operating Hours
Engine	1200 hours	304.5 hours
Transmission	1200 hours	456.75 hours
Axial Compressor	1200 hours	456.75 hours
Main-Rotor Hub	1200 hours	609.00 hours
Swashplate and Support	1200 hours	609.00 hours

Forecasting Factors for OH-58A Aircraft Major Dynamic Components

Based on the data generated during the service test, factors were derived which can be used to forecast the requirements for the replacement of certain OH-58A type aircraft dynamic components. The results of the service test discussed in Table 5 indicated that the five dynamic components selected experienced a mean operating time which points out the probability that the usage rate of these items may be relatively high. Using the mean operating time as a basis, a usage factor for the engine and the four major dynamic components was calculated and is shown in Table 6.

TABLE 6

OH-58A MAJOR COMPONENTS -- FLIGHT TEST USAGE RATE

Component	Average Operating Hours	Usage Factor/ Flight Hour
Engine	304.5 hours	0.003284
Transmission	456.75 hours	0.002189
Axial Compressor	456.75 hours	0.002189
Main-Rotor Hub	609.00 hours	0.001642
Swashplate and Support	609.00 hours	0.001642

Fleet Operation Data -- OH-58A Helicopter

The fleet operations data contained in U.S. Army Aviation Systems Command Technical Report 75-34, titled "Executive Summary Report, OH-58A Fleet Assessment," dated September, 1975, was used as a basis for determining the usage factors actually experienced in operating OH-58A aircraft. This report contains information on the support requirements of the OH-58A fleet from October 1, 1969 to May 31, 1974. The size of the fleet at the end of the data period was 2082 aircraft. The average age of the OH-58A fleet on June 20, 1975 was 3 years, 8 months, with approximately 50 aircraft less than 2 years old and with 10 aircraft more than 6 years old. The average aircraft in the fleet on June 20, 1975 had accumulated 760 flight hours; this included 220 aircraft with less than 300 hours and an aircraft with 4200 hours.

OH-58A Fleet Logistical Requirements

An analysis of field operating costs showed that during the period July, 1970 through June, 1972, the cost per flight hour to operate an OH-58A helicopter was $98.91. Parts consumption accounted for $74.53 of the total cost. The average number of flight hours per aircraft per month during the period July, 1974 to June, 1975 was 14.0 hours. The approximate cost for parts for one year was $12,525.00 per aircraft. The total cost per flight hour for the five components listed in Table 6 was $46.30. Usage factors based on fleet experience were well established at the time of the report. The mean time to removal because of failure had stabilized, and any major changes in the future would be investigated to determine exact cause, or causes. Utilizing the average operating hours at removal as a basis, a usage factor for each of the five OH-58A components previously listed was calculated and is shown in Table 7.

TABLE 7

OH-58A MAJOR COMPONENTS -- FLEET USAGE RATE

Component	Frequency of Replacement	Usage Factor/ Flight Hour
Engine	318.1 hours	0.003144
Transmission	571.0 hours	0.001751
Axial Compressor	491.4 hours	0.002035
Main-Rotor Hub	365.7 hours	0.002734
Swashplate and Support	637.1 hours	0.001570

Comparison of Usage Rates and Check of Test Data Validity

The usage rates based on the accelerated service test data was compared with the actual usage rate experienced during prolong fleet operation. The results of that comparison were as follows:

a) Engine T63-A-700, FSN 2840-179-5536. The usage rate for engines during the accelerated test was 0.003284 and the usage rate established by fleet operation had stabilized at 0.003144 per flight hour, with $n_F = 4975$. The rate experienced during fleet operations was only reduced by 4.3 percent from the usage rate predicted by the data from the accelerated flight test. A t statistic for the engine was calculated to be -1.03 with 6 degrees of freedom indicating a confidence level of 0.83; therefore the null hypothesis that accelerated test data is representative of fleet operating experience is not valid.

b) Transmission Assembly, P/N 206-040-003, FSN 1615-121-6543. The main transmission during the accelerated test had a usage rate of 0.002189 per flight hour. The fleet experienced a usage rate of 0.001760 per flight hour with $n_F = 2771$. The usage rate experienced by the fleet is almost a 20 percent reduction from that achieved during the accelerated test. An analysis of the accelerated test data indicated that one transmission accumulated only 40 hours when the test was completed and was not overhauled as a test sample. If this transmission's data were removed from the accelerated test data, the mean operating time for transmissions during the accelerated tests becomes 595.5 hours and the usage rate for the test becomes 0.001679 per flight hour, which is only 4.6 percent less than that experienced by the fleet. Using data list above, calculations produced a t statistic for the transmission of -3.41 with 4 degrees of freedom, which gives a confidence level of 0.98; therefore, test data is considered verified.

c) Axial Compressor, P/N 688439, FSN 2340-179-7023. The usage rate for axial compressors during the accelerated tests was 0.002189 per flight hour, whereas the usage rate experienced by the fleet stabilized at 0.002035, with $n_F = 3220$. The fleet usage rate is a 7 percent reduction from the rate that was achieved during the accelerated test. Calculations of a t statistic for the axial compressor produced t = -0.65 with 4 degrees of freedom, indicating a confidence level of 0.73, which is below the minimum acceptable of 0.90. Null hypothesis is rejected.

d) Main-Rotor Hub, P/N 206-011-100-1, FSN 1615-125-4051. The usage rate for main-rotor hubs experienced by the operating fleet stabilized at 0.002734 per flight hour, with n_F = 4327. The usage rate predicted by the accelerated flight test was 0.001642 per flight hour. A careful analysis of the maintenance record for the main-rotor hub which reached its TBO life of 1200 hours flight time reveals that maintenance to correct leaking seals was accomplished 10 times during the 1200-hour test. Operating fleet data reveals the primary cause for replacement of main-rotor hubs prior to reaching TBO life is leaking seals. It appears that the accelerated test data was an accurate predictor of the leaking seal problem, but not a very good predictor of maintenance unit's acceptance of a continuous maintenance problem. Test was not an adequate basis for usage forecasting due to the inability to determine how many times an item will be repaired before it is returned for overhaul. Data not considered valid.

e) Swashplate and Support P/N 206-010-450-5, FSN 1615-120-0482. The usage rate for swashplate and support during accelerated test was 0.001642 per flight hour, whereas during operations by the fleet, the usage rate decreased to 0.001570, with $n_F = 2484$. There is a reduction of 4.4 percent from that predicted by the accelerated test data. A confidence level for swashplate and support was calculated to be 0.87, with t statistic of -1.42 with 3 degrees of freedom. Null hypothesis is accepted.

A summary of the comparison of selected OH-58A dynamic components' usage rates during fleet operations and the accelerated tests are shown in Table 8.

TABLE 8

OH-58A MAJOR COMPONENTS -- USAGE RATE COMPARISON

Component	Test Usage Rate	Fleet Usage Rate	Difference
Engine	0.003284	0.003144	-4.3%
Transmission	0.001679	0.001760	+4.8%
Axial Compressor	0.002189	0.002035	-7.9%
Main-Rotor Hub	0.001642	0.002734	+66.5%*
Swashplate and Support	0.001642	0.001570	-4.4%

*Comparison is not valid for reasons discussed above.

The comparison of accelerated test data with fleet operation data shows a high degree of correlation; however, only one valid sample attained the 0.90 confidence level. Confidence levels of three other valid samples were 0.87, 0.83, and 0.73 respectively.

CHAPTER IV

Discussion, Conclusions, and Recommendations

Discussion

As noted earlier, the objective of this research was to determine the validity of using accelerated flight test data as a basis for forecasting requirements of aircraft components during the time interval between introduction of a new military aircraft and the time when fleet operations have stabilized. Logistical forecasts for new aircraft are initially very difficult to make and, since few new aircraft are truly original, such forecasts in the past have been based on experience with a similar product. This approach has been plagued with errors, especially with the advancement of technology, creating a detrimental effect on the new aircraft's initial operational capability.

For new aircraft, an estimate of the forecasting error is essential. Within this context the proposal to base initial forecasting requirements of repair parts for new military aircraft on accelerated flight test data was evaluated. These evaluations were made by determining the forecasting error that would have existed had the accelerated flight data been used. The items selected for this comparison were the high cost, overhaulable components; their selection was based on two factors: (1) usage data was readily available, both from the accelerated flight tests and from fleet operations, and (2) the components selected typically represented approximately 60 percent of the cost of repair parts for each of the aircraft systems.

A comparison of field and test data showed the initial forecasting error for the selected repair components for UH-1 type aircraft would have varied from a low of less than 4 percent for 4 items to a high of 25 percent for one item; however, no error greater than 10 percent was experienced by those components that remained essentially as tested during the accelerated flight test. While data is not available on the expected initial usage rates furnished by the manufacturer for all of these components, the expected initial usage rate furnished for the engine underestimated the actual usage rate by more than 66 percent. Three components which experienced 11, 15, and 25 percent decreases in usage rates since the accelerated flight tests were redesigned during PIP and are, therefore, no longer the same parts that were originally tested. Evaluation of valid UH-1 samples reveals that 75 percent have justified a conclusion to accept the null hypothesis.

The initial forecasting error for components of the OH-58A was similarly evaluated, and the error was found to be less than 5 percent for 4 samples, with a confidence level of above 0.90 for only one. Three components did not satisfy the hypothesis test. Sample with lowest level of confidence (0.72) had a forecasting error of 7 percent.

Accordingly, analysis of accelerated flight test data indicates that as few as three samples would provide a reasonable basis for calculating field usage. Also, in order to assure that accelerated flight tests provide a minimum of three samples of any component which fails, the tests should be conducted on two aircraft through a complete TBO cycle. To do this would generate many more samples of those components which experience high usage rates. For example, consider the two aircraft analyzed in this study. If two aircraft of each type had been tested through a complete engine TBO cycle, the tests would have produced 7 or 8 engine samples for each type aircraft. This would have increased the level of confidence.

Further justification of the use of accelerated flight test data as a basis for forecasting fleet requirements of aircraft components was established by a test which evaluated that the MTBF of the components in the tests was an unbiased estimator of those experienced in the fleet. Results of this test are shown in Table 9.

TABLE 9

$\overline{X}_T$ as Unbiased Example of $\overline{X}_F$

Test Results

Component	$\overline{X}_F$	$\overline{X}_T$	$\overline{X}_T$ / $\overline{X}_F$
Engine	360.5	366.7	1.02
Transmission	647.6	550.0	0.85*
90-degree Gearbox	471.1	355.0	0.75*
42-degree Gearbox	568.2	550.0	0.97
Rotor Hub	371.4	366.7	0.99
Scissors and Sleeve	649.8	579.6	0.89*
Drive Shaft	274.2	275.0	1.00
Engine	318.1	304.5	0.96
Transmission	571.0	595.5	1.04
Axial Compressor	491.4	456.75	0.93
Rotor Hub	365.7	609.0	1.67*
Swashplate and Support	637.1	609.0	0.96
			7.87

*Not valid.

$$r = \frac{\sum \overline{X}_T / \overline{X}_F}{n} = \frac{7.87}{8} = 0.98$$

Results of bias test (r) fall well within the established range of 0.95 -- 1.05, for a confidence level of 0.90 that the accelerated tests did not produce biased results.

Conclusions and Recommendations

The failure data generated during accelerated flight tests can be used to forecast the field logistical requirements for new aircraft within statistically acceptable levels of confidence. This hypothesis was statistically validated at the 0.20 level of significance.

The evaluation analysis also supports the conclusion that the forecasting error associated with the use of military aircraft accelerated flight test data as a basis for logistical forecasting should be 10 percent or less.

A minimum of 2 aircraft should be subjected to accelerated flight testing through one complete TBO cycle in order to generate an adequate basis for logistical planning. Due to the high level of quality control exercised during the manufacture of aircraft components, as few as three samples are adequate to indicate failure trends.

The implementation of the proposed forecasting method would provide logistical planners with more accurate data upon which to base procurement of repair parts and the scheduling of overhaul facilities as much as 9 months earlier than the current system, thereby eliminating many costly program changes. With an improved supply program, the fleet will attain a high operational readiness level much earlier than can be achieved using the present method of forecasting logistical support requirements.

It is recommended that future accelerated flight testing of military aircraft to determine operational reliability and maintainability characteristics be conducted on a minimum of two aircraft under highly controlled conditions.

It is also recommended that following completion of accelerated flight tests, immediate action be taken to base logistical requirements on test data until modified by fleet experience.

Bibliography

Amstadter, Bertram L. Reliability Mathematics. New York: McGraw-Hill, 1971.

Bethea, Robert M.; Duran, Benjamin S.; and Boullion, Thomas L. Statistical Methods for Engineers and Scientists. New York: Marcel Dekker, Inc., 1975.

Carnley, Lewis V. Logistical Evaluation (Phase F) of UH-1B Helicopter Equipped with the Model 540 Rotor System. Final Report, USATECOM Project No. 4-4-0108-05. Fort Rucker, Alabama: U.S. Army Aviation Test Board, September 1966.

Directorate for Product Assurance. UH-1H Assessment and Comparative Fleet Evaluation. Executive Summary Report 75-3. St. Louis, Missouri: U.S. Army Aviation Systems Command, April 1975.

Directorate for Product Assurance. OH-58A Fleet Assessment. Executive Summary Report 75-3. St. Louis, Missouri: U.S. Army Aviation Systems Command, September 1975.

Epstein, Benjamin. "Estimation from Life Test Data." Technometrics 2 (November 1960): 447-54.

Feigenbaum, A. V. Quality Control: Principles, Practice, and Administration. New York: McGraw-Hill, 1951.

Hansen, Bertrand L. Quality Control: Theory and Applications. Englewood Cliffs, N.J.: Prentice-Hall, 1963.

Hatton, Richard R., and Followill, Richard J. Evaluation of Alternate Engine Installation in the UH-1D Helicopter. Final Report, USATECOM Project No. 4-3-0150-10. Fort Rucker, Alabama: U.S. Army Aviation Test Board, August 1966.

Hill, Jack D., and Stork, Vernon R. Service Test (Reliability) of the OH-58A Helicopter. Final Report, USATECOM Project No. 4-A1-130-58A-003. Fort Rucker, Alabama: U.S. Army Aviation Test Board, May 1970.

Key, James C., and McCrory, F. J. Logistical Evaluation (Phase F) of UH-1D Helicopter at High Gross Weight. Final Report, USATECOM Project No. 4-3-0150-15. Fort Rucker, Alabama: U.S. Army Aviation Test Board, August 1966.

Miller, Irwin, and Freund, John E. Probability and Statistics for Engineers. Englewood Cliffs, N.J.: Prentice-Hall, 1965.

Peterson, Rein, and Silver, Edward A. Decision Systems for Inventory Management and Production Planning. New York: John Wiley and Sons, 1979.

Plossl, G. W., and Wight, O. W. Production and Inventory Control. Englewood Cliffs, N.J.: Prentice-Hall, 1967.

Wadsworth, George P., and Bryan, Joseph G. Applications of Probability and Random Variables. New York: McGraw-Hill, 1974.