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HELICOPTER DRIVE SYSTEM LOAD ANALYSIS

Raymond B. Johnson, Jr., et al

Technology, Incorporated

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January 1974

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By

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Terry L. Cox

January 1974

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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TECHNOLOGY INCORPORATED
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To study the overtorque conditions of three Army helicopter types - the AH-1G, UH-1H, and OH-6A - and the potential effect of such conditions on the maintenance procedures and design criteria for these helicopters was the prime objective of the reported research. To this end, approximately 755 hours of previously documented multichannel oscillogram data, recorded under combat conditions in the Vietnam theater, were reprocessed and reanalyzed to investigate the extent and significance of engine and transmission operations that exceeded specific torque pressure limits for each helicopter type. With each flight recording separated into five phases - ascent, maneuver, descent, steady state, and hover - the processed data are presented and analyzed according to four primary categories: torque limit exceedances, engine shaft horsepower exceedances, rapid torque excursions, and engine operating spectra. Results indicated that each helicopter type exceeded its transmission limits and probably its engine limits, that each helicopter type likely exceeded its maximum turbine outlet temperature and consequently its engine limits when the altitude and temperature conditions increased over those at sea-level standards, that the UH-1H and AH-1G torque excursions and IRP percentages were similar, and that the OH-6A data were more mission dependent than the UH-1H and AH-1G data.

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landing impact spectra						
transmission torque exceedances						

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DEPARTMENT OF THE ARMY
U.S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

The research described herein was conducted by Technology Incorporated under Contract DAAJ02-73-C-0012. The work was performed under the technical management of Mr. L. T. Burrows, Propulsion Technical Area, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory. PFC P. Haley, also of the Propulsion Technical Area, provided valuable assistance in the preparation of technical data furnished to the contractor.

This program was initiated to define the number and magnitude of transmission torque limit and engine rating limit exceedances typical of Army helicopter operation under combat conditions. This involved the analysis of previously acquired data obtained from 335 flight hours of AH-1G, 216 hours of OH-6A, and 203 hours of UH-1H aircraft while flying combat missions in Southeast Asia. The results of this effort are quite revealing in that it was determined that the AH-1G and UH-1H had more than desired significant exceedances, but the OH-6A tended to operate beyond limits almost continuously during maneuver and subjected its power plant to possible overtemperatures.

Appropriate technical personnel of this directorate have reviewed this report and concur with the data and conclusions contained herein.

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ABSTRACT

To study the overtorque conditions of three Army helicopter types - the AH-1G, UH-1H, and OH-6A - and the potential effect of such conditions on the maintenance procedures and design criteria for these helicopters was the prime objective of the reported research. To this end, approximately 755 hours of previously documented multichannel oscillogram data, recorded under combat conditions in the Vietnam theater, were reprocessed and reanalyzed to investigate the extent and significance of engine and transmission operations that exceeded specific torque pressure limits for each helicopter type. With each flight recording separated into five phases - ascent, maneuver, descent, steady state, and hover - the processed data are presented and analyzed according to four primary categories: torque limit exceedances, engine shaft horsepower exceedances, rapid torque excursions, and engine operating spectra. Results indicated that each helicopter type exceeded its transmission limits and probably its engine limits, that each helicopter type likely exceeded its maximum turbine outlet temperature and consequently its engine limits when the altitude and temperature conditions increased over those at sea-level standards, that the UH-1H and AH-1G torque excursions and IRP percentages were similar, and that the OH-6A data were more mission dependent than the UH-1H and AH-1G data.

FOREWORD

Technology Incorporated, Dayton, Ohio, prepared this report to document a program designed to provide an insight into the typical engine operation of the UH-1H, AH-1G, and OH-6A helicopters performing under combat conditions. The study extended from November 1972 to August 1973. This program was sponsored by the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, under Contract DAAJ02-73-C-0012, Task 1G162204AA7201. The project monitor for the Army was Mr. LeRoy Burrows.

Technology Incorporated personnel responsible for this program were Mr. Ronald I. Rockafellow, who directed the data processing, and Mr. Raymond B. Johnson, Jr., project manager, who directed the data analysis and presentation.

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INTRODUCTION

The operating horsepower environment of Army helicopters is among the major factors to be considered in reviewing and in verifying engine and transmission operating limits, the maintenance procedures, and the design criteria for these helicopters. This environment is particularly significant if overtorque conditions exist, especially under combat operations, since such conditions directly relate to the MTBF (mean-time-between-failures) of the helicopter drive train components. Consequently, in the continual and progressive study of Army helicopter operational data, a program was inaugurated to investigate the extent and significance of engine and transmission operations that exceeded the limits of three helicopter types, namely, the UH-1H, AH-1G, and OH-6A, while they operated in the Vietnam theater. To this end, Technology Incorporated reprocessed and reanalyzed approximately 755 hours of multichannel oscillogram data recorded and processed previously under former contracts. The data consisted of 336 hours from the AH-1G, 203 hours from the UH-1H, and 216 hours from the OH-6A.

As viewed in Figure 1, the AH-1G "Huey Cobra" helicopter is a highly maneuverable, high-speed gun ship. Deployed as a ground-support weapons platform, the AH-1G was equipped, during its operational survey, with a controllable nose turret and two external stores pylons. The nose turret contained a 7.62mm minigun and a 40mm grenade launcher, and each of the pylons carried such armament as the XM-159C, XM-157, XM-18, and XM-159. The crew consisted of a pilot and a copilot/gunner. Table I summarizes the characteristics and limitations of the AH-1G during the operational survey. As listed in Table II, most of the AH-1G flights conducted during the operational survey (Reference 1) were combat assault missions.

As shown in Figure 2, the UH-1H "Huey" is a single-engine helicopter designed for front-line troop and equipment transport. Table I summarizes the characteristics and limitations of the UH-1H helicopter during the operational survey. Table II indicates that during its operational survey (Reference 2), most of the UH-1H flights were combat support operations rather than direct combat assaults.

As viewed in Figure 3, the OH-6A is a highly maneuverable, single-engine helicopter designed for front-line observation. Table I summarizes the characteristics of the OH-6A during the operational survey. As indicated in Table II, the OH-6A flights were almost equally distributed between combat assault and combat support missions during the operational survey

(Reference 3). During the survey, two primary configurations were noted: the "lead ship" and the "wing ship," the former identified by a pilot and two gunners each with an M-60 machine gun, and the latter by a pilot and one gun with an XM-27 minigun mounted on the left side.

In summary, most of the helicopter flights during the respective operational surveys in Vietnam were combat support and direct assault missions.

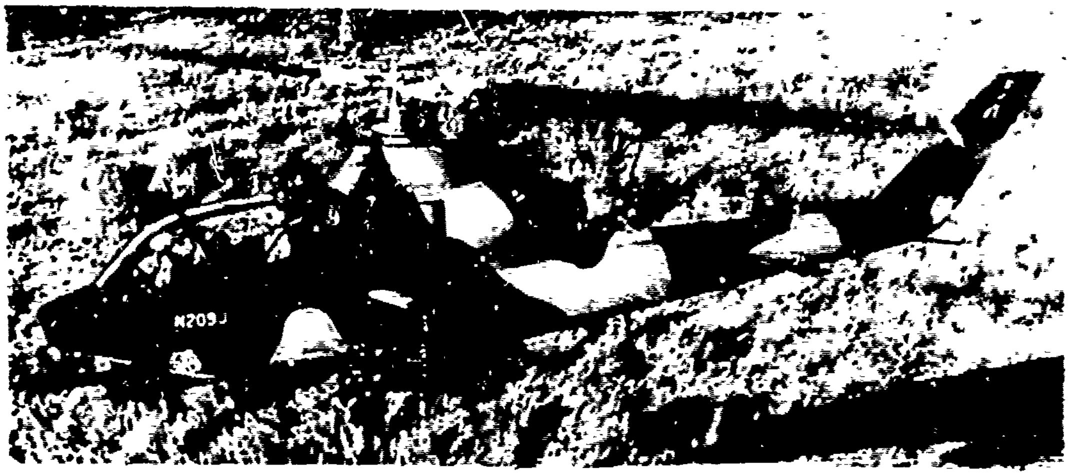


Figure 1. Photograph of AH-1G Helicopter.

Figure 2. Photograph of UH-1H Helicopter.

Figure 3. Photograph of OH-6A Helicopter.

TABLE I. SUMMARY OF AIRCRAFT CHARACTERISTICS AND LIMITATIONS

	UH-1H	UH-1G	OH-6A
Engine	T53-L-13	T53-L-13	T63-A-5A
Max Gros Weight	9500 lb	9500 lb	2163 lb
Max Continuous Power	1250 hp	1250 hp	270 hp 214.5 hp*
Intermediate Rated Power	1400 hp	1400 hp	317 hp 252.5 hp*
Usable Power (transmission torque limit)	1100 hp	1100 hp	214.5 hp

* Derated to these values for OH-6A operation.

TABLE II. SUMMARY OF HELICOPTER MISSION ASSIGNMENT

		Mission Identification			
Helicopter	Number of Missions	Combat Assault (%)	Combat Support (%)	Command Control (%)	Other (%)
AH-1G	321	84.7	2.5	3.7	9.1
UH-1H	249	16.5	71.1	8.4	4.0
OH-6A	217	46.5	53.5	-	-

This report defines the recorded and derived parameters, outlines the data processing and quality control, explains the data computations, and finally presents and analyzes the processed data. The results are presented as cumulative frequency distribution curves and frequency polygons (histograms). The results are also presented in tables that present occurrences, time, and exceedances in ranges. The data presented were divided into five mission segments: (1) ascent, (2) maneuver, (3) descent, (4) steady state, and (5) hover.

The program objectives were accomplished by establishing specific torquemeter limits, by processing each helicopter's operational data to find exceedances of these limits, and by relating these exceedances of torquemeter limits to corresponding values of engine and main rotor shaft horsepower by analytical calculations. The time in excess of the limits and the frequency of the occurrences were recorded and tabulated for further analysis. In addition, the rapid torque excursions were identified as positive or negative values. To develop an insight into the spectrum of engine operation, each helicopter's data base was processed by a specialized computer program. For each instant of recorded data, the computer program produced an instantaneous engine horsepower and an ideal intermediate rated power (IRP) limit. The IRP was derived from tabular data based on density altitude and outside air temperature (OAT). By ratioing the values of instantaneous shaft horsepower and IRP, a spectrum of percent IRP was developed for each helicopter. Finally, in a subsidiary task, the spectrum of the vertical acceleration of each helicopter during landing was developed (see Appendix III).

DATA PRESENTATION AND ANALYSIS

GENERAL

For the continual and progressive review and verification of engine and transmission operating limits, the maintenance procedures, and the design criteria of the AH-1G, UH-1H, and OH-6A helicopters, the previously documented data gathered on these helicopters were reprocessed and reanalyzed to investigate the extent and significance of helicopter operations that exceeded the engine and transmission limits.

In presenting the procedures. equations, and data results and analysis for the current study, this section is divided into four primary areas: transmission torque limit exceedances, engine shaft horsepower exceedances, rapid torque excursions, and engine operating spectrum for each helicopter.

The data processing procedures in the current study followed the general procedures in the original processing as reported in References 1 through 3. One departure from the past procedures was the addition of a hover mission segment to supplement the existing four mission segments of ascent, maneuver, descent, and steady state. This additional segment was to give greater resolution to the horsepower and torque data. The processing procedure includes data editing, data digitizing, quality control, and final acceptance. During the data editing phase, each original oscillogram was re-edited according to new ranges for such parameters as transmission torquemeter pressure limit exceedances and rapid torquemeter pressure excursions. The edited oscillograms were measured on semiautomatic oscillogram readers which transcribed the measurements from oscillogram data onto punched cards. The editing and digitizing procedures were verified by applying standard quality control techniques to a printout of these cards. Based upon random data samples, the mean and variance of the entire data base were established; the three-standard-deviation (σ) values for main rotor speed and torquemeter pressure were ±2.4 rpm and ±0.4 psi, respectively. After the data had been accepted, they were processed through a computer program to convert the data into engineering units and to calculate the engine and main rotor shaft horsepower. A final check of these data was then performed prior to the analysis. All times shown in the computer printout tables are rounded to the nearest tenth of a minute. Since in each table the individual time entries as well as the total time were computed and then rounded, a total may not agree with the sum of the individual times. All printed range values are represented by the lower limits.

TRANSMISSION TORQUE LIMIT EXCEEDANCES

As established by the aircraft manufacturers, each of the three helicopter types has an [illegible] limit for the main rotor transmission. This limit was expressed as a redline or time-limited band on the pilot's torquemeter pressure indicator. As the first phase of the study, exceedances of these limits were identified and examined to determine their frequency of occurrence and the percentage of [illegible] spent above these limits.

In establishing the limits to be used for the operational usage data of each helicopter type, the primary emphasis was placed on existing torquemeter redline limits or other engine/transmission limits; the established limits, taken from References 4 through 6, are presented in Table III.

TABLE III. TRANSMISSION TORQUE LIMITS *

Aircraft	1st Limit	2nd Limit	3rd Limit
UH-1H	45.0	47.5	50.0
AH-1G	45.0	47.5	49.1
OH-6A	63.5	75.0	90.0

* All limits in psi.

For the UH-1H helicopter, the torquemeter pressure limits of 45, 47.5, and 50 psi correspond to an arbitrary lower limit, the usable power (transmission limit), and the maximum allowable transmission torque limit (redline), respectively. Intended to aid the data editing, the lower limit allowed general limits to be used during manual editing without having to adjust for minor variations in the torquemeter transducer and recording system output; these differences were accounted for during the computer processing of the data and allowed all data above 47.5 psi to be included in that data range. Without the lower limit, some of the data above 47.5 psi may have been lost because of minor variations in the day-to-day calibration factor. The same limits were used for the AH-1G helicopter except for the redline limit; as recommended in Reference 4, a redline value of 49.1 psi was used. The OH-6A torque limits of 63.5, 75, and 90 psi correspond to the transmission maximum continuous torque limit, the 5-minute transmission takeoff limit, and the 10-second transmission transient torque limit, respectively.

As a result of editing each helicopter's operational data, the number and duration of torque limits were identified and categorized. These data are presented in Figures 4 through 8 and in Tables VIII through XIII of Appendix I. In these presentations, the data are normalized to a common base of 100 flight hours.

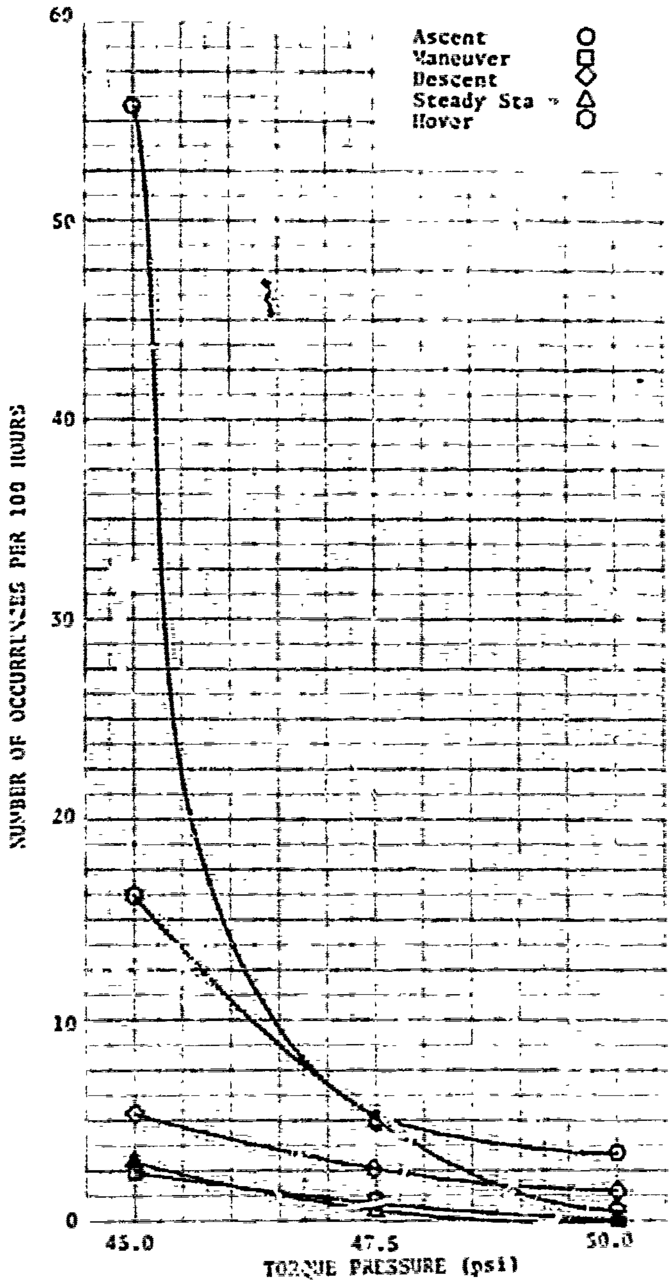


Figure 4. Torque Limit Exceedances per Mission Segment for the UH-1H.

The torque limit exceedances per 100 hours by mission segment for the AH-1G, UH-1H, and OH-6A helicopters are presented i.. Figures 4 through 6, respectively. For all three helicopters, the torque limit exceedances tended to diminish quite rapidly as the higher torque limits were approached. Whereas both the UH-1H's and OH-6A's had most of their excursions in single mission segments (ascent and maneuver, respectively), the AH-1G's had most of their excursions in three segments (maneuver, hover, and ascent). As evident in Figure 7, which shows the total number of torque limit exceedances for each helicopter type, the curves for the AH-1G and UH-1H are quite similar, but that for the OH-6A has about 40 times as many exceedances as the other two helicopter types. The OH-6A data tend to follow a straight line, whereas the AH-1G and UH-1H data follow a parabolic pattern.

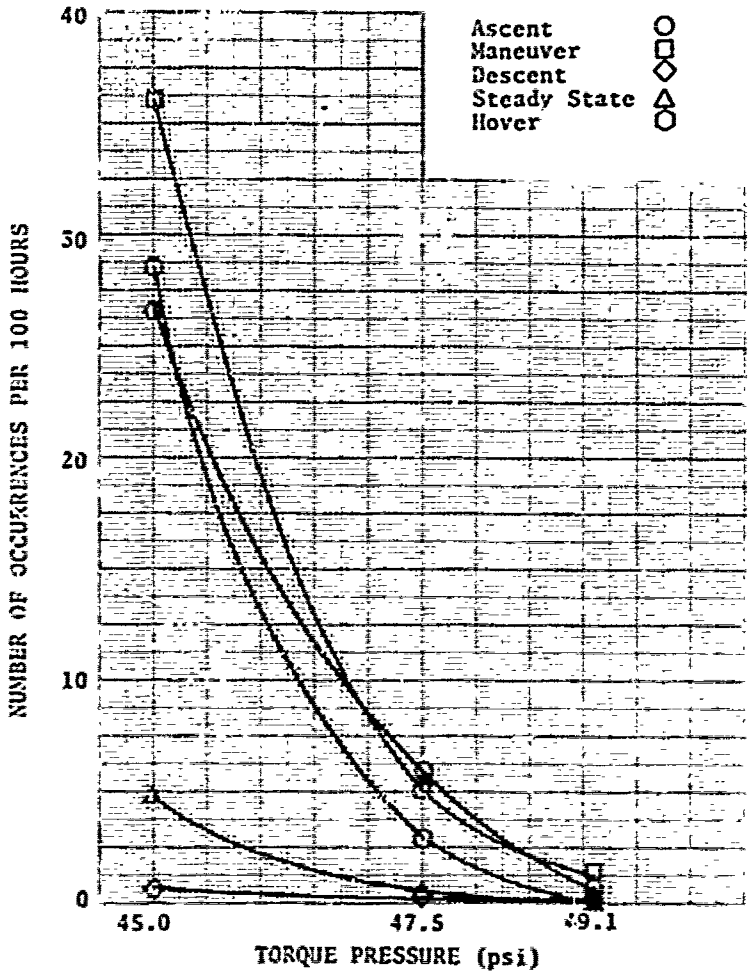


Figure 5. Torque Limit Exceedances per Mission Segment for the AH-1G.

From Tables VIII through XIII of Appendix I, the number of upper limit exceedances for the AH-1G, UH-1H, and OH-6A helicopters are 8, 11, and 48, respectively, and the times above the limit are 47.8, 36.6, and 154.8 seconds, respectively. While the amount of time spent above the upper limit is insignificant when compared with the total flight time of any of the helicopters (36.6 to 154.8 seconds vs. 203 (3600) to 336 (3600) seconds), the actual exceedances represent damage of some extent to the main rotor transmission and are, therefore, important in assessing the usage of any of the helicopters.

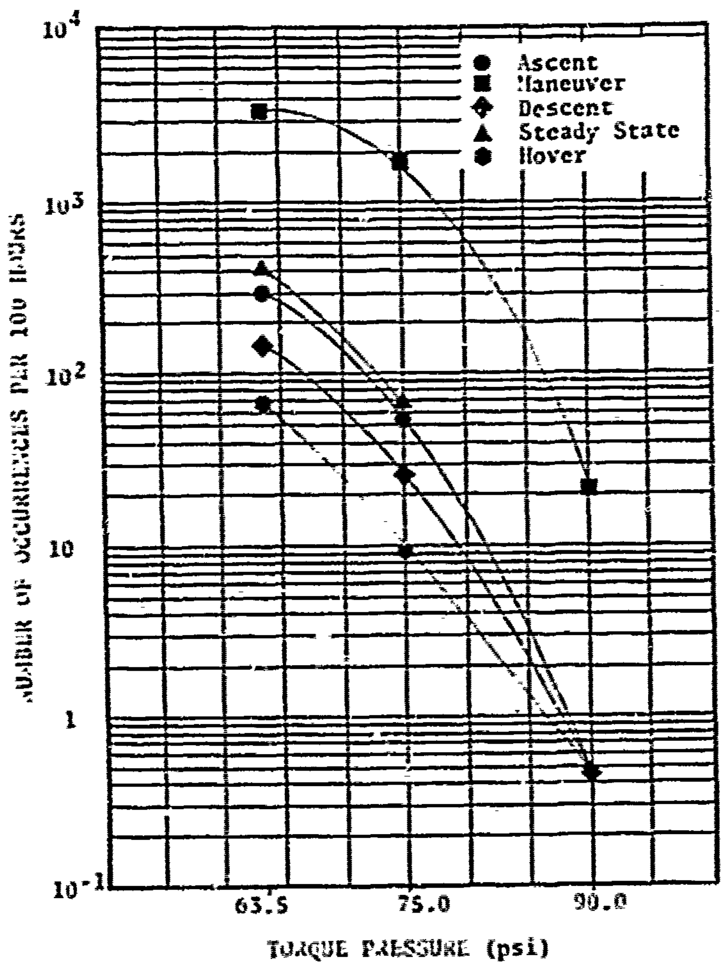
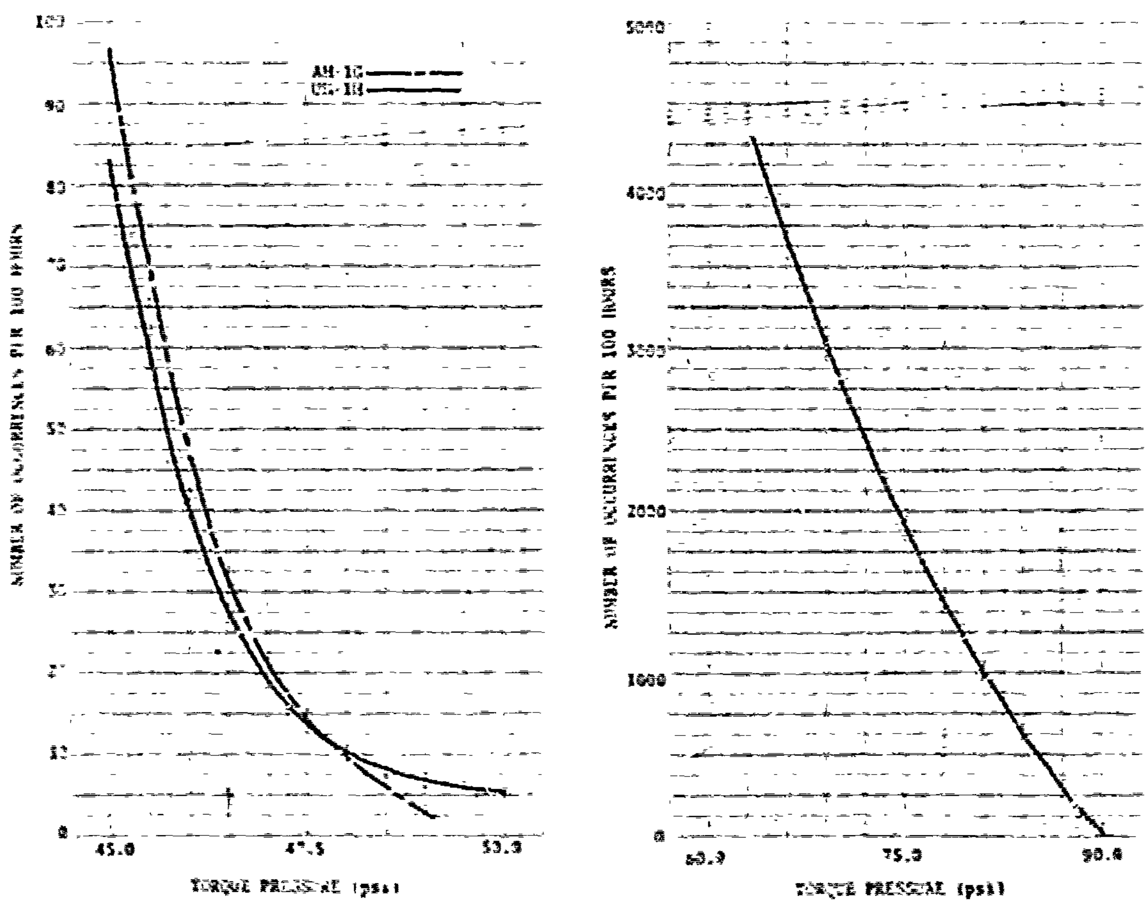


Figure 6. Torque Limit Exceedances per Mission Segment for the OH-6A.

Because of the wide variation in exceedances per limit by mission segment, Figure 8 presents a data band for all data of the UH-1H and AH-1G and for all but the maneuver segment of the OH-6A. The data band represents the range of collected data bounded by the highest and lowest number of torque excursions tabulated at the torque pressure limits. The OH-6A maneuver segment is shown as a separate curve. As apparent, the OH-6A data band falls between the limits of the other band, and the OH-6A maneuver segment curve generally exceeds the uppermost limit. Since the OH-6A had 40 times as many exceedances as the other two helicopter types and its maneuver segment curve is generally higher than the other data, the OH-6A drive system was subjected to more demanding conditions characteristic of an observation helicopter.



a) UH-1H and AH-1G b) OH-6A

Figure 7. Torque Limit Exceedances per Totals of Mission Segments for the UH-1H, AH-1G, and OH-6A.

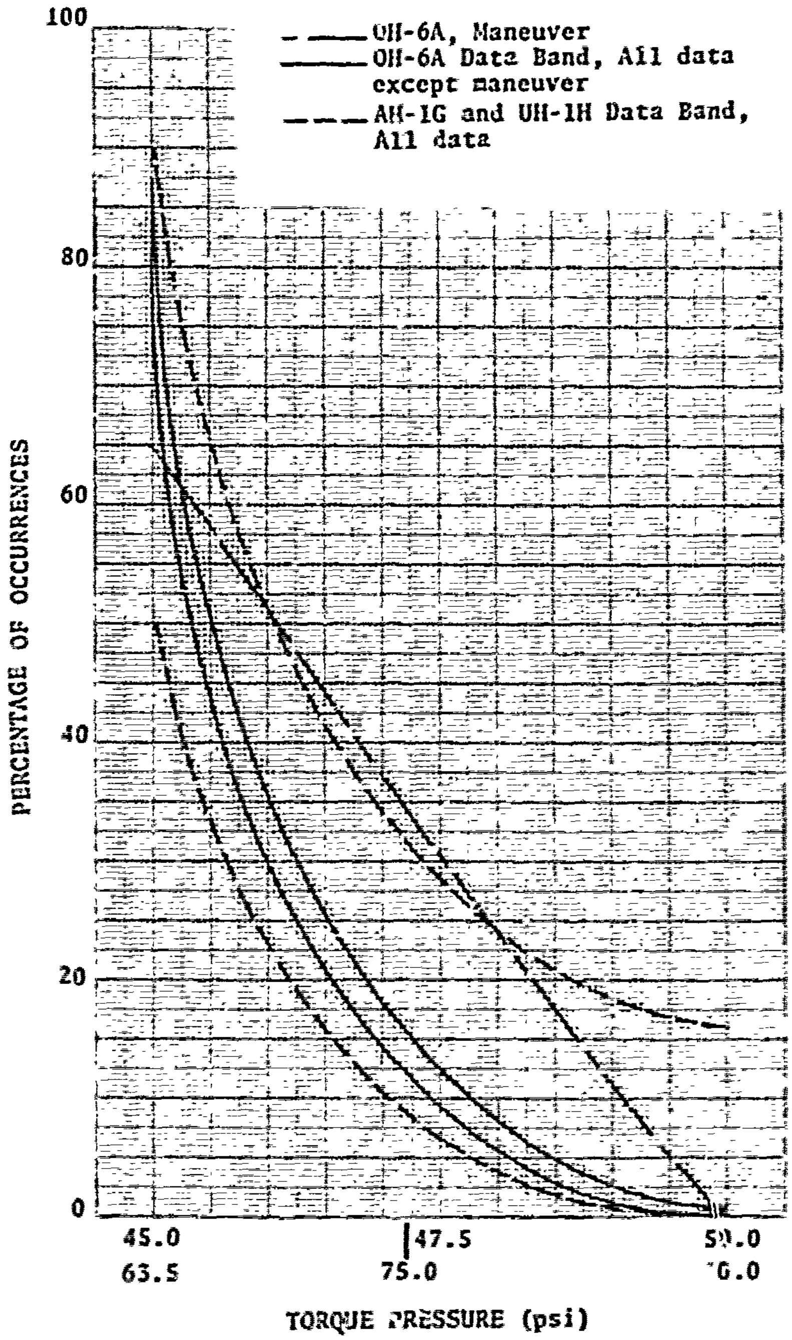


Figure 8. Data Bands for the UH-1H, AH-1G, and OH-6A.

ENGINE SHAFT HORSEPOWER EXCEEDANCES

The assumption that exceedances of engine shaft horsepower are directly related to exceedances of the torquemeter pressure limits is not realistic, since horsepower depends on the torque and rotor speed of either the main rotor or the engine. Certain combinations of rotor speed and torquemeter pressure could yield an engine shaft horsepower in excess of its limits, even though the torquemeter pressure is below its upper limit. Such a situation may exist because of the type of mission flown by the helicopter. Therefore, to determine whether this is happening, the engine shaft horsepower was calculated on the basis of torque limit excursions and coincident main rotor speed. These data are presented in terms of frequency distributions of both occurrences and time in various ranges of engine and main rotor shaft horsepower.

A relationship between shaft horsepower and torque is needed to determine the transmission torque limit exceedances in terms of engine shaft horsepower. Shaft horsepower is a function of the transmitted torque and the coincident engine output speed, as shown in Equation (1):

$$SHP_E = \left(\frac{2\pi}{33000}\right) N_E Q \tag{1}$$

where SHP_E = engine shaft horsepower
N_E = engine output speed (rpm)
Q = engine output torque (ft-lb)

On the basis of this general equation, the shaft horsepower related to specific torquemeter pressure readings was calculated by using relationships of engine speed versus main rotor speed and engine output torque versus torquemeter pressure. The resulting equations used during this study were

$$SHP_E = 3.88 \times 10^{-3} N_R (17.76\ Qp + 53.53) \tag{2}$$

for the AH-1G and UH-1H helicopters, and

$$SHP_E = 2.438 \times 10^{-3} N_R (2.89\ Qp + 4.28) \tag{3}$$

for the OH-6A helicopter,

where N_R = main rotor speed (rpm)
Qp = torquemeter pressure (psi)

These equations are derived in Appendix II.

Based on the equations for calculating engine shaft horsepower using torquemeter pressure and main rotor speed data, equations for calculating main rotor shaft horsepower were derived to account for various factors such as transmission efficiency and the varying horsepower required by the tail rotor during hover and other flight conditions. The derived equations are based on the propulsion system performance data presented in Table IV; these data were supplied by the airframe manufacturers. To compute the main rotor shaft horsepower for each helicopter type, one equation was derived for hover and another equation for all other flight conditions. The equations for the AH-1G and UH-1H helicopters are

$$SHP_{MR} = 0.90(0.95\ SHP_E) \text{ for hovering flight} \quad (4)$$

and

$$SHP_{MR} = 0.95(0.95\ SHP_E) \text{ for all other flight} \quad (5)$$

conditions. For the OH-6A helicopter, Equations (4) and (5) may be expressed as

$$SHP_{MR} = 0.875(0.98\ SHP_E - 5.2) \text{ for hovering} \quad (6)$$

flight and

$$SHP_{MR} = 0.94(0.98\ SHP_E - 5.2) \text{ for} \quad (7)$$

all other flight conditions.

As stated before, it is possible to have shaft horsepower limit excursions and not torquemeter pressure limit exceedances for a specific set of conditions. Therefore, to provide insight into the correlation of torque limit exceedances and horsepower excursions, the data of Tables XIV through XXV will be plotted several ways and discussed.

TABLE IV. HELICOPTER PROPULSION SYSTEM PERFORMANCE FACTORS

Helicopter	% SHP to Main Rotor Hover	Flight	Efficiency	Transmission Horsepower Ext.
AH-1G/UH-1H	0.90	0.95	0.95	
OH-6A	0.875	0.94	0.98	5.2

Figures 9 and 10 present the frequency distribution of occurrences in ranges of engine shaft horsepower per 100 hours of flight. Superimposed over the curves of Figure 9 are the limits for usable power and the maximum transmission torque limits for the AH-1G and UH-1H; over the curve of Figure 10 are the 5-minute transmission takeoff limit, the 10-second transmission transient limit, and the IRP. Figure 9 shows that the AH-1G and UH-1H curves are quite similar and that the UH-1H curve has more occurrences at higher horsepower ranges. While the AH-1G curve has relatively few exceedances of the usable power and maximum transmission torque limit horsepower values, the UH-1H curve has a substantial number of exceedances for both parameters. In marked contrast, the OH-6A curve has approximately 100 times as many exceedances of the 10-second transmission transient limit and the IRP limit. Since the engine rating of this helicopter is reduced in this application, it is not surprising that a large number of exceedances of the transmission limits would occur during the combat operation of an observation helicopter.

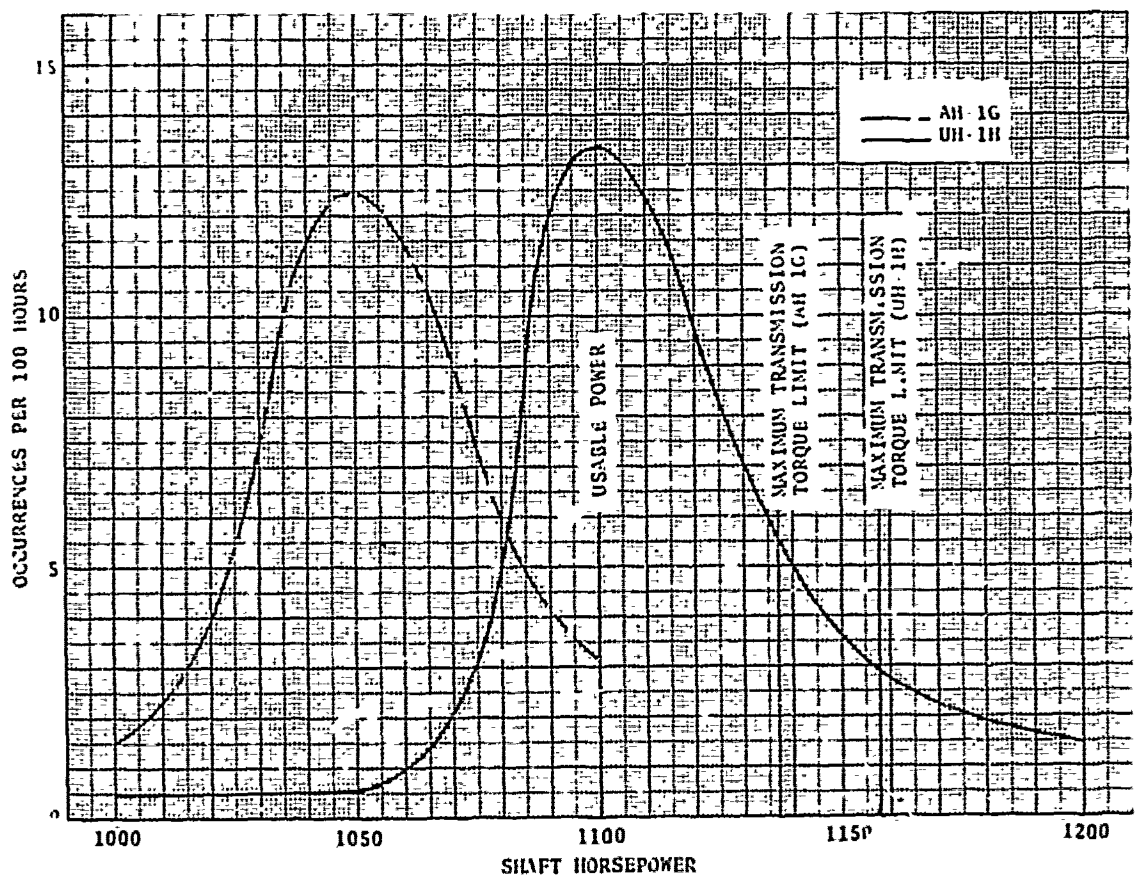


Figure 9. Total Number of Occurrences in Engine Shaft Horsepower Ranges for the UH-1H and AH-1G.

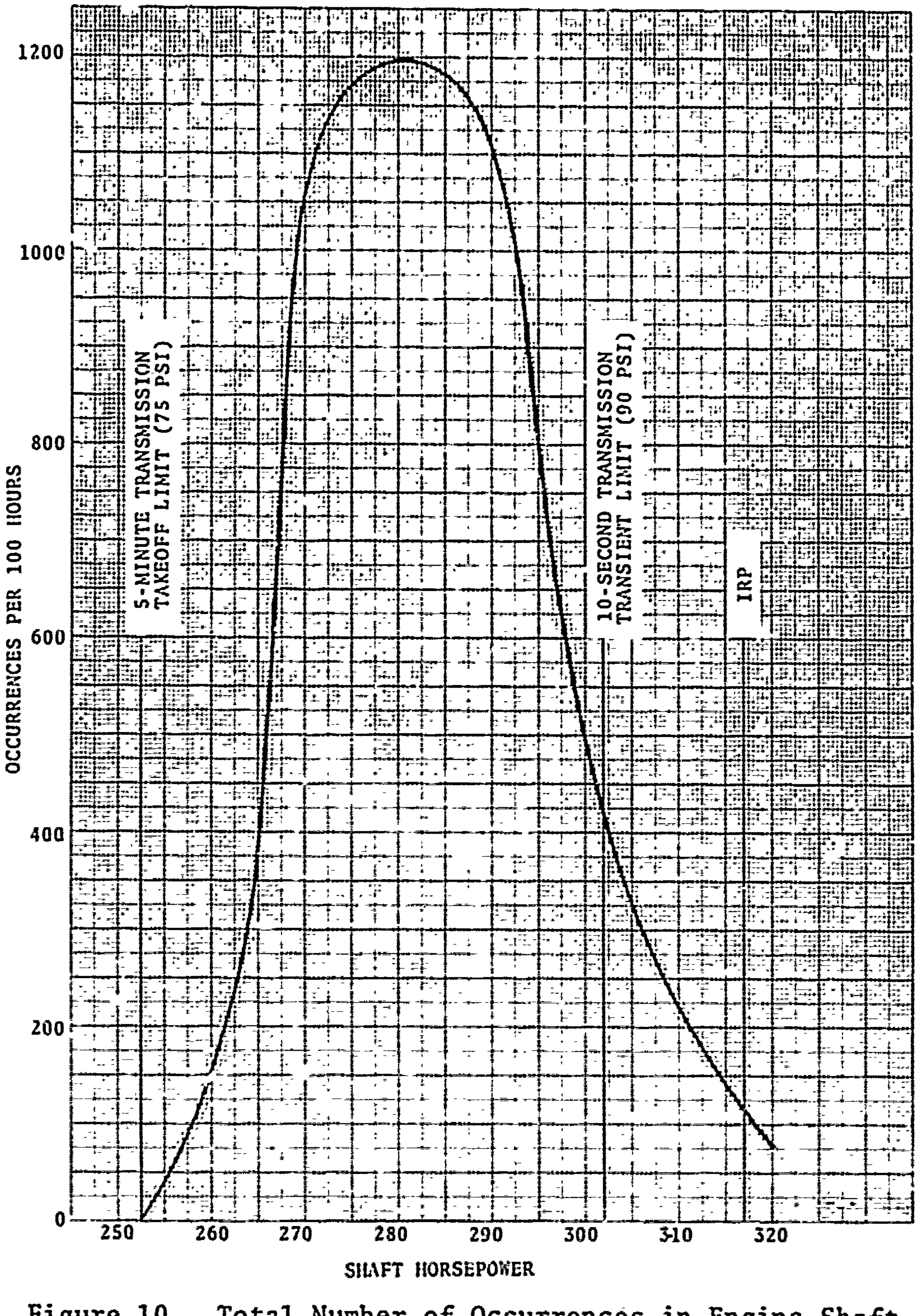


Figure 10. Total Number of Occurrences in Engine Shaft Horsepower Ranges for the OH-6A.

These exceedances and their duration tend to shorten the service life of various other system components. Therefore, time in ranges of engine shaft horsepower for all three helicopters is plotted in Figures 11 and 12. Once again, various limits are superimposed over each of the figures. While the AH-1G and UH-1H engines have shaft horsepower exceedances, the time above the limits are very short, ranging from 0.1 to 0.4 minute per 100 hours of flight. In marked contrast, the OH-6A spent approximately 30 minutes every 100 hours at the 10-second transmission transient limit and approximately 9 minutes at IRP.

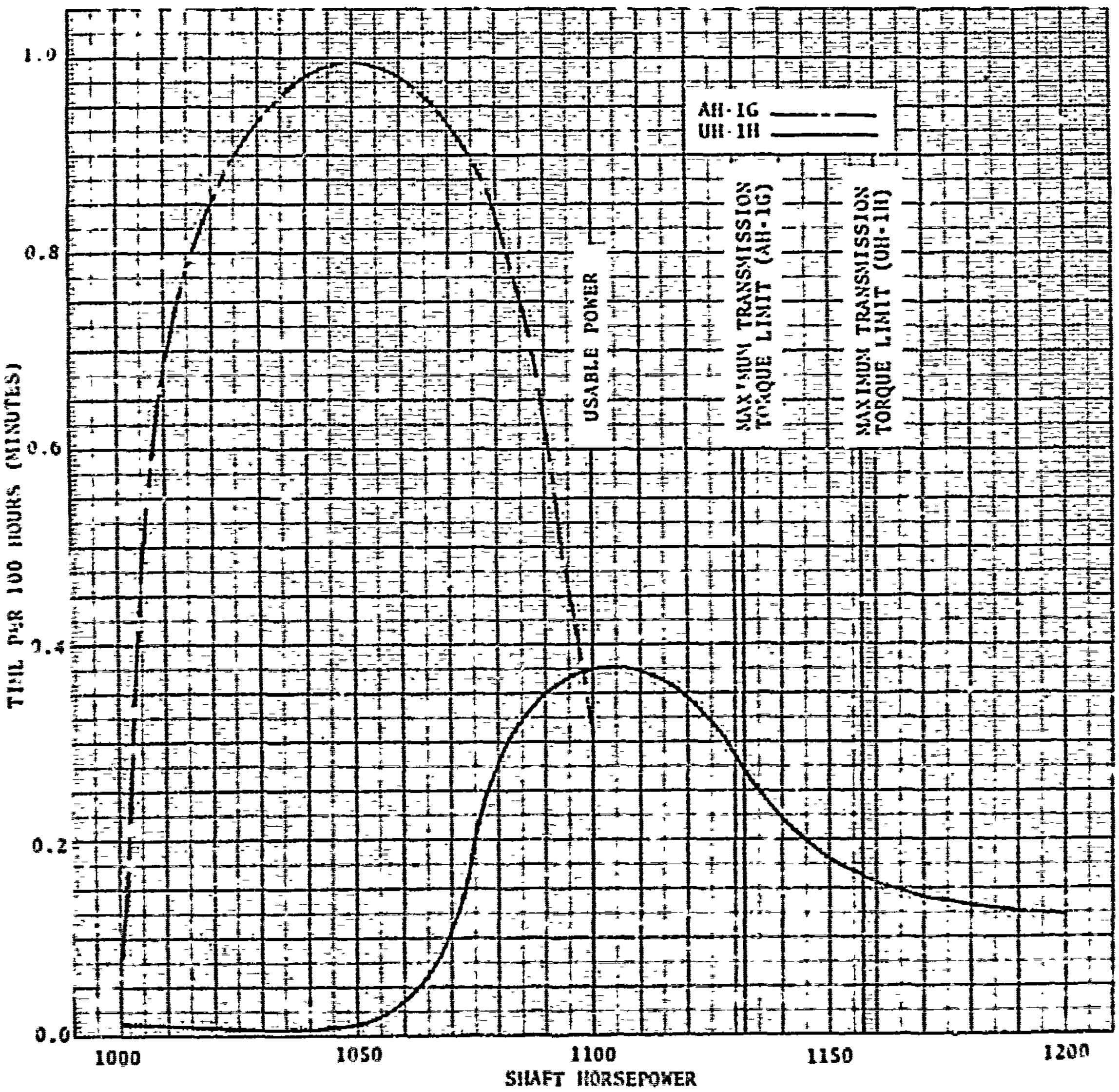


Figure 11. Total Time in Ranges of Engine Shaft Horsepower per 100 Hours for the UH-1H and AH-1G.

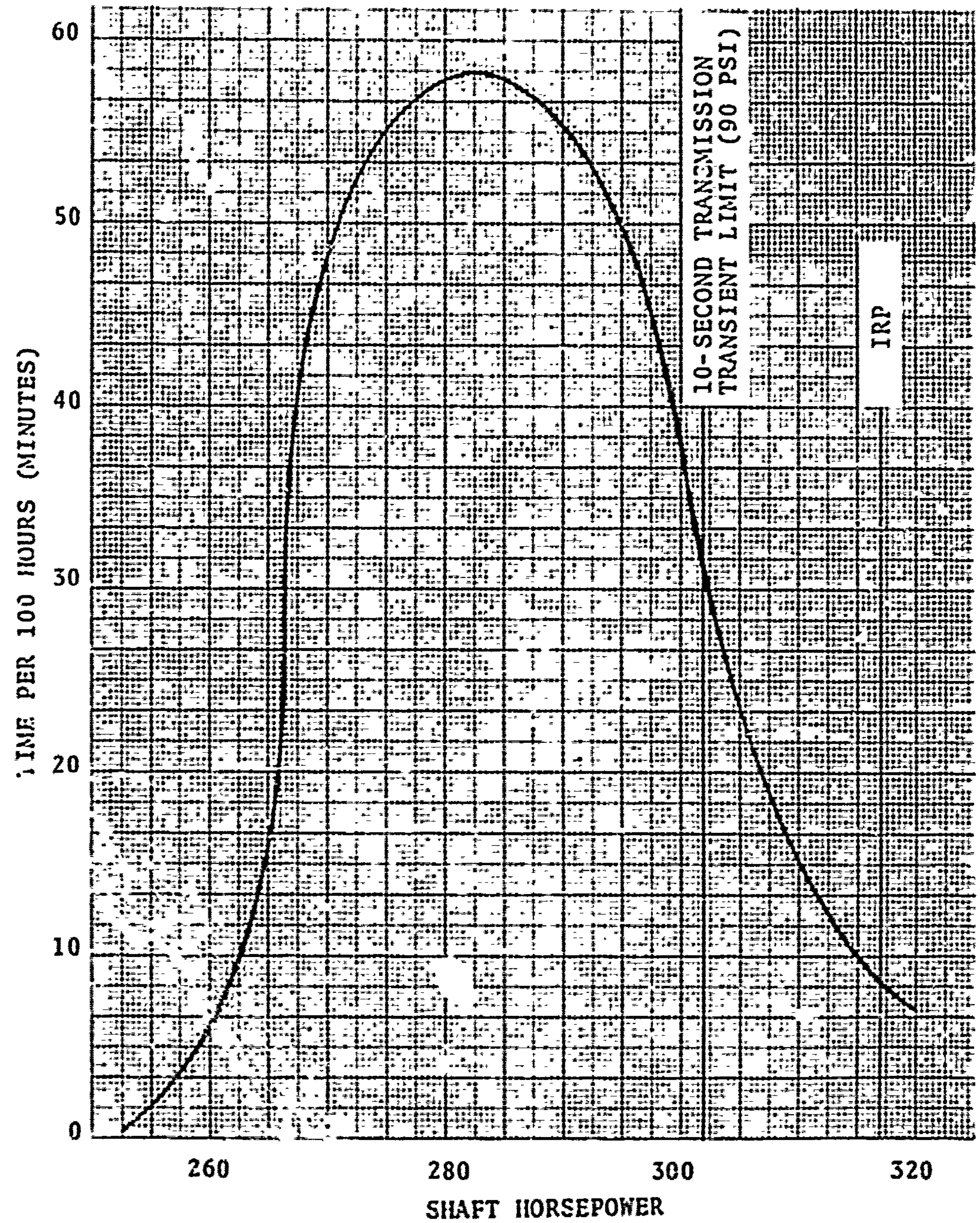


Figure 12. Total Time in Ranges of Engine Shaft Horsepower per 100 Hours for the OH-6A.

With the equations derived for calculating main rotor shaft horsepower, the torquemeter exceedance and coincident main rotor speed were used to calculate equivalent main rotor shaft horsepower. The data are presented in Tables XV through XXV of Appendix I.

RAPID TORQUE EXCURSIONS

There are specific requirements for the acceleration or deceleration rate of the engine rotor speed during throttle bursts or chops. These requirements are established so that an engine, during its design and test phase, may be substantiated with respect to the thermal cycles that these bursts or chops create; these cycles affect the engine life because of the associated thermal fatigue and low-cycle fatigue.

Since throttle bursts and chops may be directly related to shaft horsepower variations and engine thermal cycles, the requirements of the engine specification concerning acceleration and deceleration rates were translated into various ranges of torquemeter pressure for various spans of time. These ranges and spans are shown in Table V.

TABLE V. RAPID TORQUE EXCURSION RANGES

Time (sec)	UH-1H & AH-1G (psi)	OH-6A (psi)
3	20 to 29	25 to 39
6	30 to 39	40 to 59
9	40 to 59	60 to 90

The original data from the AH-1G, UH-1H, and OH-6A operational surveys were scanned to identify rapid torquemeter pressure changes, either increasing or decreasing, within the appropriate time span. In Table XXVI of Appendix I, these excursions are categorized as having occurred during flight or during a takeoff or landing. In addition, for each helicopter, the number of engine starts, the number of flights with and without excursions, and the average altitude and outside air temperature (OAT) during the excursions are listed in Table VI.

TABLE VI. RAPID TORQUE EXCURSION PARAMETERS

	AH-1G	UH-1H	OH-6A
Total Engine Starts	342	242	242
Total Flights	259	249	218
Total Flights with Excursions	142	146	214
Total Flight Time (hr)	335	203	216
Average Altitude (ft)	2000	1780	2400
Average OAT (°F)	85	84	92

These rapid torque excursions are not the same as the torque excursions discussed earlier. Rapid torque excursions are based on a specific pressure change, either increasing or decreasing, within a certain time span. These excursions may or may not exceed the torque pressure limits. However, each rapid excursion could affect the engine because of the resultant thermal cycle.

These rapid torque excursions are plotted in Figure 13 as the number of occurrences in 100 hours of flight for the various ratios of torque excursions shown in Table VII.

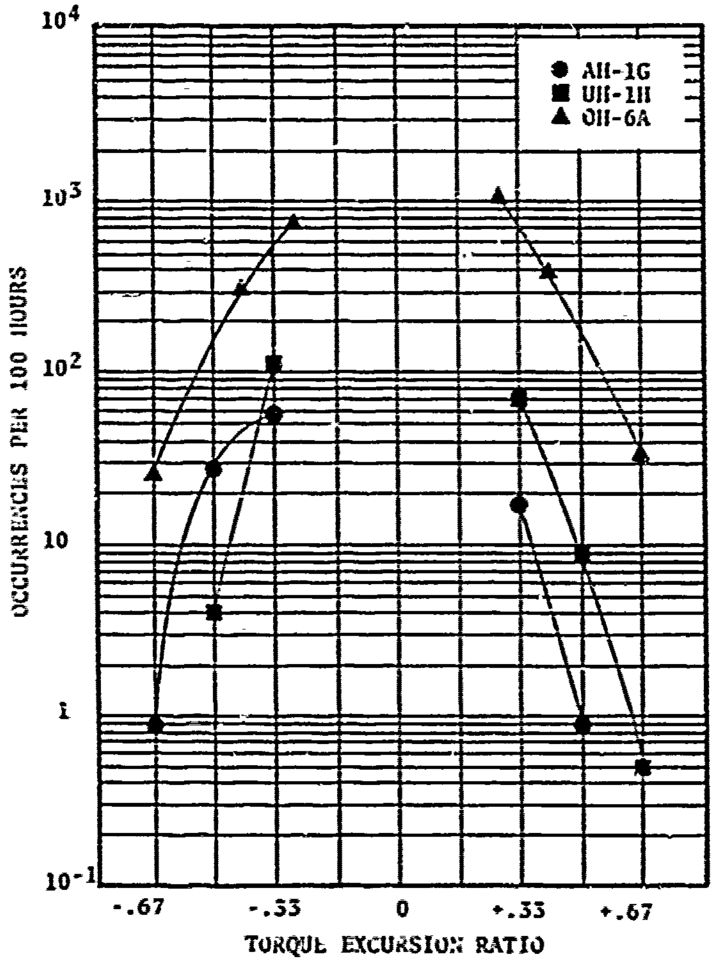


Figure 13. Rapid Torque Excursions for the AH-1G, UH-1H, and OH-6A.

This ratio of torque excursions is the lower pressure value of each range divided by 60 psi for the AH-1G and UH-1H and by 90 psi for the OH-6A. This nondimensional ratio permits the direct comparison of the three helicopters. Figure 13 shows that the AH-1G and UH-1H experienced twice as many rapid decreases as rapid increases. Conversely, the OH-6A had twice as many rapid increases as rapid decreases. This figure also shows that the number of torque excursions for the OH-6A is about 10 times greater than those for the AH-1G and UH-1H. Within the maximum decreasing range, the AH-1G had three excursions and the UH-1H only one. In contrast, the OH-6A experienced 77 maximum increasing excursions and 57 maximum decreasing excursions.

TABLE VII. RAPID TORQUE EXCURSION RATIOS

Helicopter	Pressure Change (psi)	Ratio
AH-1G/UH-1H	20-29	.33
	30-39	.50
	40-59	.67
OH-6A	25-39	.28
	40-59	.44
	60-90	.67

ENGINE OPERATING SPECTRUM

Using the operational usage data gathered on each helicopter, an operating spectrum was developed to better understand how each engine operated. For each engine, the operating spectra are represented as time spent in ranges of engine shaft horsepower and IRP percentages. These spectra were developed by surveying master magnetic tapes containing the digitized oscillogram data for coincident values of altitude, outside air temperature, torquemeter pressure, rotor speed, and time spent at these values; by calculating engine shaft horsepower based on torquemeter pressure and main rotor speed; by adjusting IRP based on ambient altitude and temperature conditions; and by ratioing the calculated engine shaft horsepower to the adjusted IRP value.

Engine shaft horsepower for each coincident reading was calculated by using the equations derived in Appendix II. Values for installed IRP were obtained for the T53-L-13 (UH-1H/AH-1G) and T63-A-5A (OH-6A) engines by correcting the engine specification performance for altitude and ambient temperature readings and for engine installation losses. The installation losses, obtained from the airframe manufacturers, were 54, 54, and 3 shaft horsepower at IRP for the AH-1G, UH-1H, and OH-6A helicopters, respectively. The ratio of each coincident calculated engine shaft horsepower to adjusted IRP was determined, and the coincident time was assigned to this ratio of IRP percentage. These coincident times, accumulated at their respective IRP percent levels, represent the operating spectrum for each engine installation, and are presented in Table XXVII of Appendix I. In addition, the cumulated time spent in ranges of engine shaft horsepower is presented in XXVIII.

For each of the three helicopters, the engine operating spectrum as represented by percentage of IRP is presented in Figure 14. The UH-1H, AH-1G, and OH-6A operated mostly at 70%, 60%, and 80% IRP, respectively. The operating load curve for the UH-1H helicopter is nearly symmetrical about 70% IRP. The curve for the AH-1G is skewed to the right of 60% IRP. However, the net result as depicted by the cumulative curves shows a difference of less than 5% in the time spent above 70% IRP.

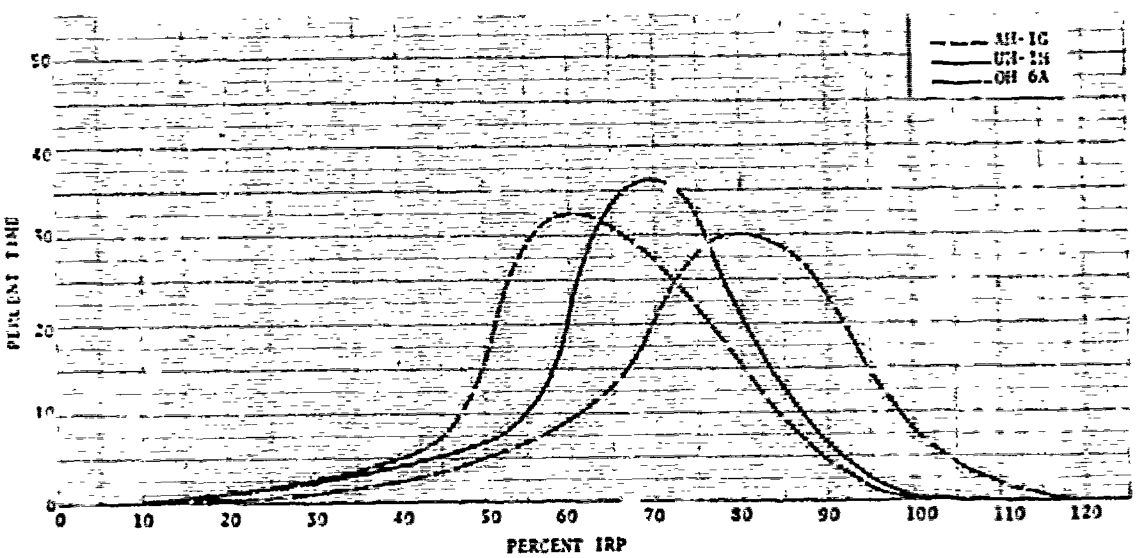


Figure 14. Frequency Distributions of Percentage Time versus Percentage IRP for the UH-1H, AH-1G, and OH-6A.

Since the AH-1G and UH-1H helicopters share a common engine, the engine operating curves presented in Figure 14 need to be examined in greater detail to identify the factor(s) causing the apparent difference. Reviewing the cumulative frequency distribution curves of torquemeter pressure and rotor speed presented in Reference 2, it can be seen that the distribution of torquemeter pressure in Figure 15 is nearly identical for each helicopter; however, the distribution for rotor speed, as shown in Figure 16, shows that the UH-1H operates at a higher average rotor speed. This higher rotor speed requires higher shaft horsepower, and, consequently, the percentage of IRP will be higher, as shown in Figure 14 or in the comparison of the cumulative curves in Figures 18 and 20. Both the AH-1G and UH-1H helicopters operated in approximately the same environment, as shown in Table VI.

Finally, cumulative curves of shaft horsepower and percent IRP are presented in order to have a qualitative feel of shaft horsepower as compared with percent IRP. In Figures 17 through 22, graphs of the cumulative percentage of time versus shaft horsepower and the cumulative percentage of time versus the percentage of IRP are paired for each helicopter type. In addition, a histogram of percentage of time in ranges of percentage of IRP is presented for each helicopter type. These data are tabulated in Tables XXVII and XXVIII of Appendix I. Since IRP is a function of shaft horsepower and ambient conditions, the shaft horsepower curve would be identical to the percentage of IRP if the ambient conditions were held constant. The engine shaft horsepower curves for the UH-1H and AH-1G are almost identical, as are the IRP curves. In Figures 21 and 22, the OH-6A curves are quite similar to the AH-1G and UH-1H curves, although the curve scales are different because of the different engines. The one major difference is that the curves for the AH-1G and UH-1H rise more quickly than the OH-6A curve, thereby indicating that the OH-6A spends a greater percentage of its operating time at higher percentages of IRP. These data are substantiated by the OH-6A nap-of-the-earth, slow-speed flight which requires more power than normal flight operations. On the basis of the data presented in Reference 3, approximately 50% of the OH-6A operation was spent at airspeeds below 75 knots.

Since turbine outlet temperature (TOT) was not measured, this study assumed a specification engine which in reality is a minimum engine. An exception would be an engine which has deteriorated in performance because of age or environmental effects. Therefore, when using specification performance as a baseline, engine temperature limit exceedances cannot be readily ascertained; only transmission limits can be determined. Accordingly, the data presented above probably represent the worst case.

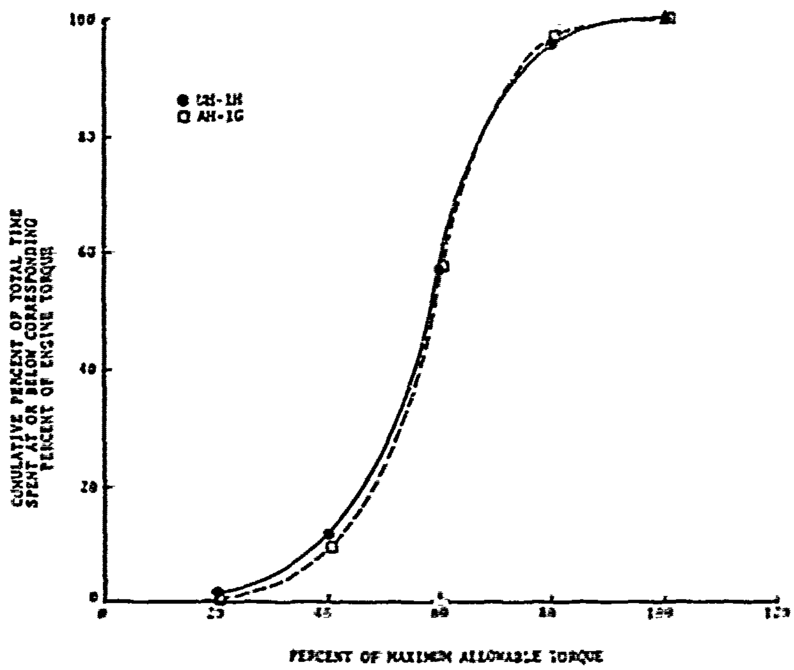


Figure 15. Comparison of Cumulative Engine Torque Frequency Distribution for the AH-1G and UH-1H.

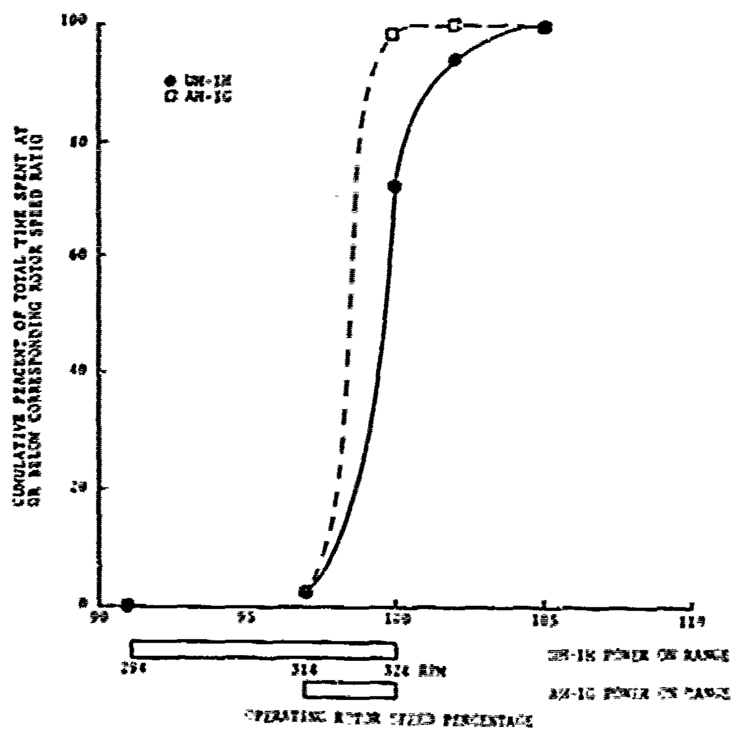


Figure 16. Comparison of Cumulative Rotor Speed Frequency Distribution for the AH-1G and UH-1H .

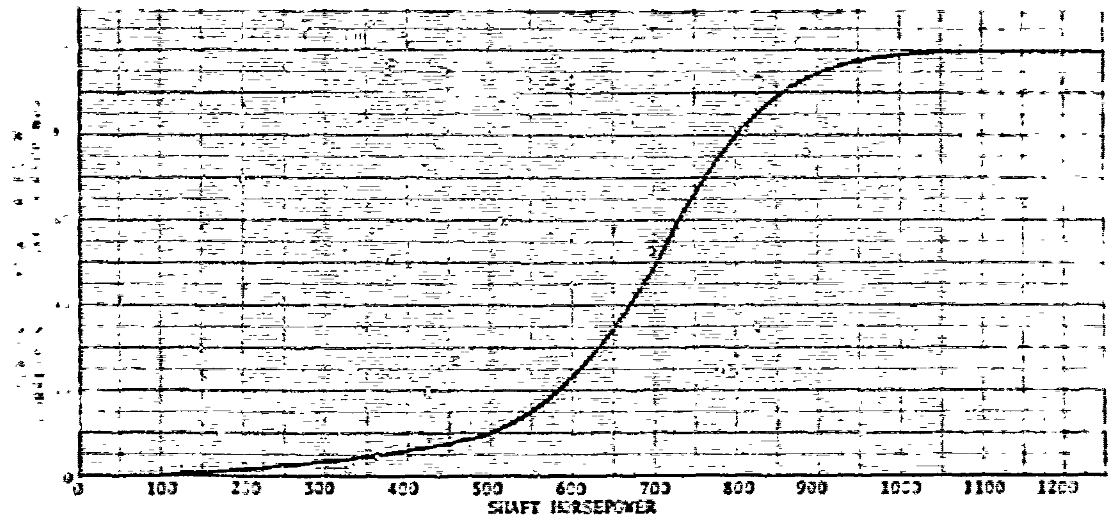


Figure 17. Cumulative Frequency Distribution of Percent Time in Shaft Horsepower Ranges for the UH-1H .

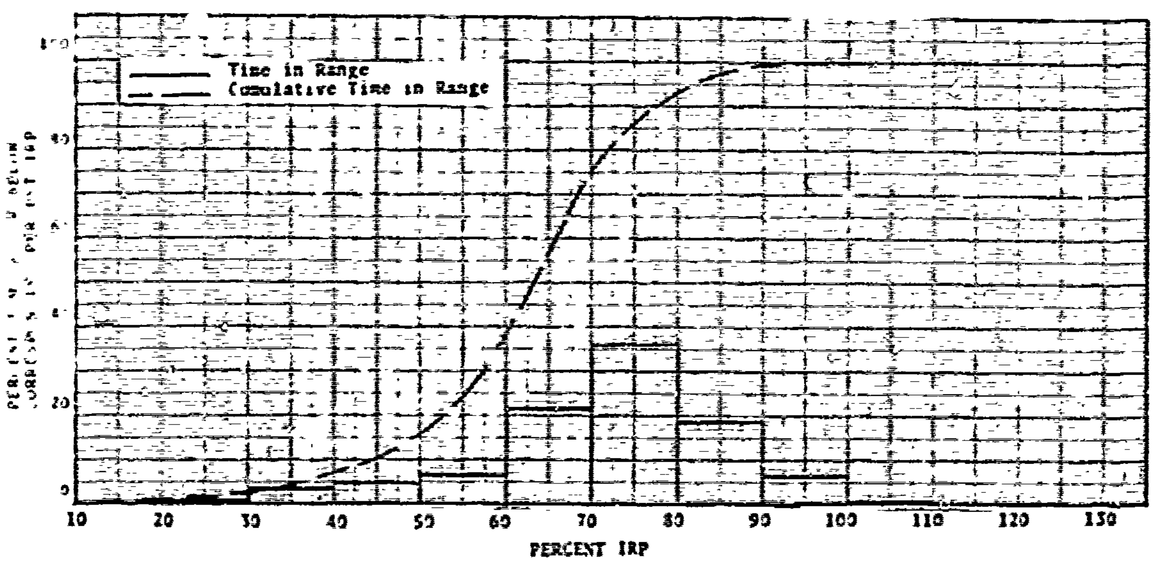


Figure 18. Engine Operating Load Spectrum for the UH-1H.

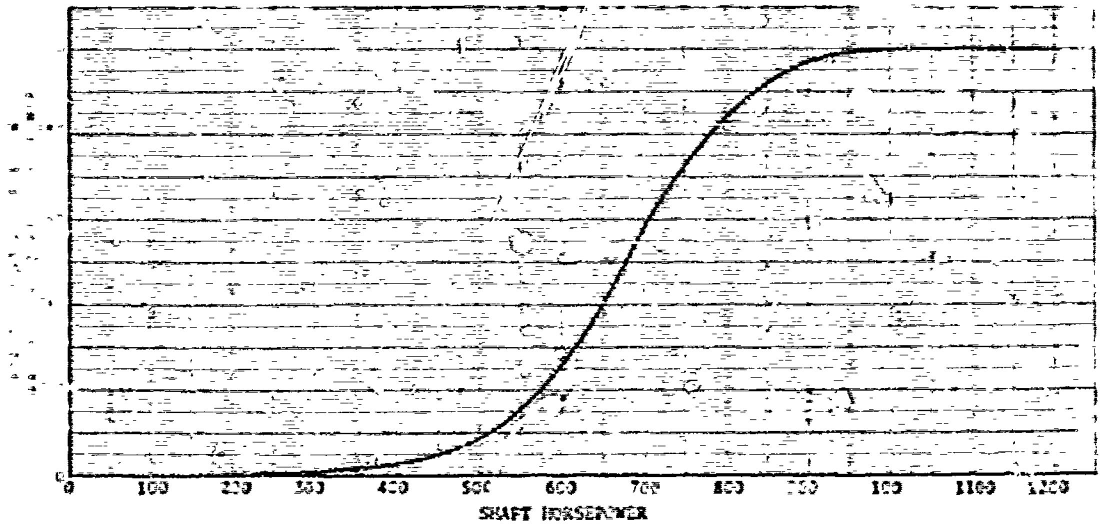


Figure 19. Cumulative Frequency Distribution of Percent Time in Shaft Horsepower Ranges for the AH-1G.

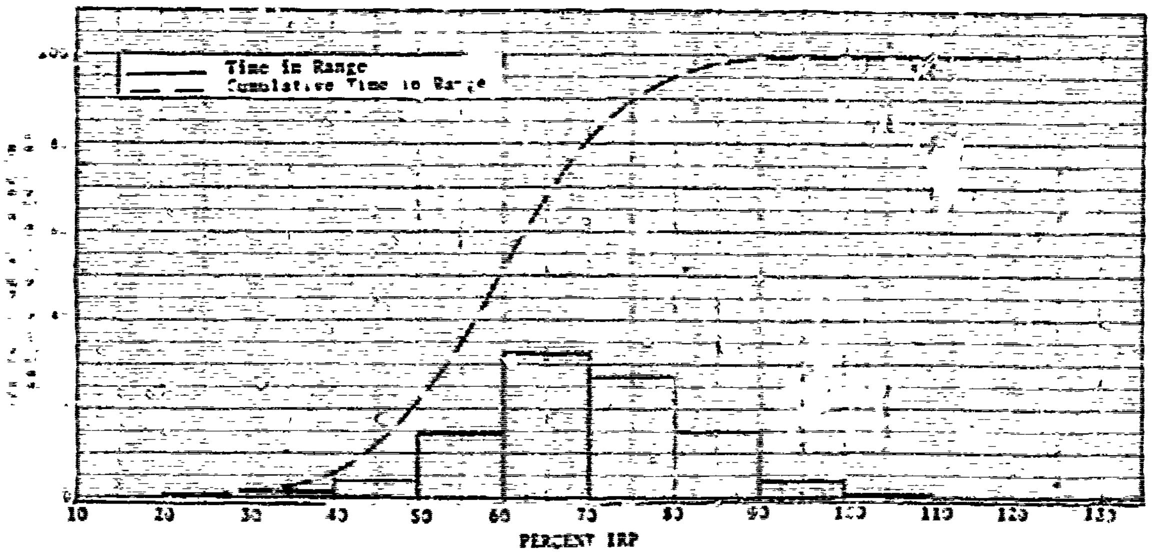


Figure 20. Engine Operating Load Spectrum for the AH-1G.

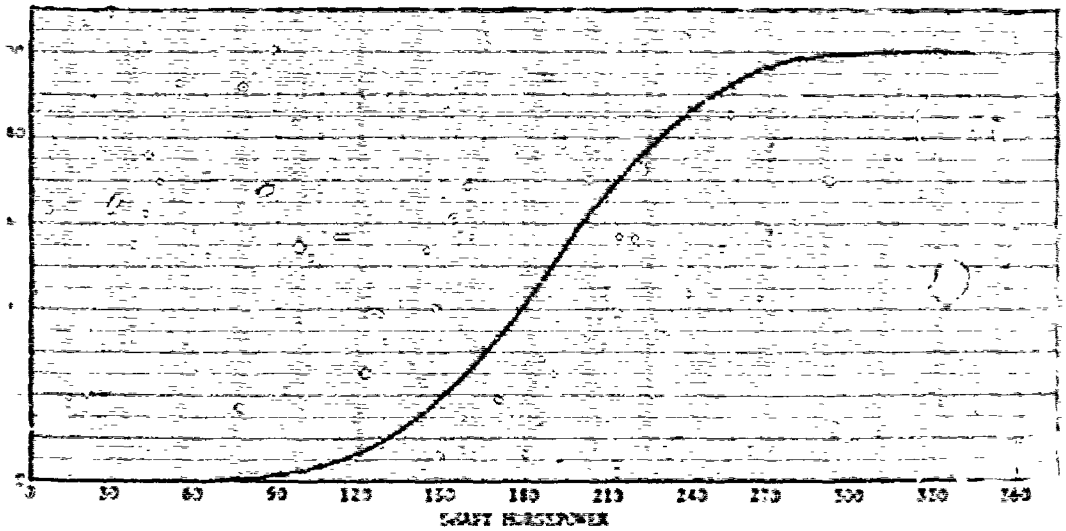


Figure 21. Cumulative Frequency Distribution of Percent Time in Shaft Horsepower Ranges for the OH-6A.

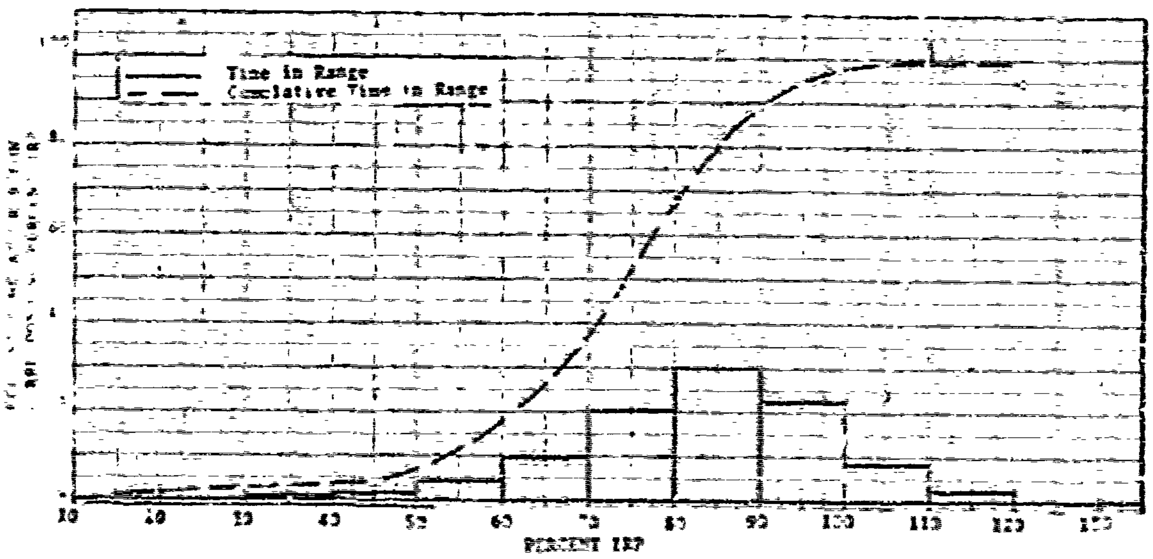


Figure 22. Engine Operating Load Spectrum for the OH-6A.

CONCLUSIONS

On the basis of the data reprocessed and analyzed during this program and the comparisons drawn between these data, it is concluded that:

(1) Since the upper transmission limit for each of the three helicopter types was exceeded a significant number of times, the reliability and life of the main rotor transmission was reduced.

(2) For all aircraft, the engine shaft horsepower occurrences exceeded the maximum transmission input limit. The OH-6A exceeded the 10-second transmission limit and the IRP limit many times.

(3) The OH-6A had approximately ten times as many rapid torque excursions as the AH-1G and UH-1H helicopters.

(4) The engine operating SHP spectrum for the OH-6A was considerably more severe than those for the AH-1G or UH-1H.

(5) The operation of the OH-6A was more demanding of its engine and drive system as evidenced by the relatively large number of engine shaft horsepower exceedances and rapid torque excursions, and the higher IRP spectrum.

(6) Since the turbine outlet temperature (TOT) was not measured, this study assumed a specification engine which in reality is a minimum engine. Therefore, when the specification performance is used as a baseline, the engine temperature limit exceedances cannot be readily ascertained; only transmission limits can be determined. Accordingly, the data presented probably represent the worst case.

RECOMMENDATION

During future operational surveys of Army helicopters, the turbine outlet temperature should be monitored to permit a complete assessment of engine operations at or near engine or transmission limits.

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APPENDIX I
TORQUE AND HORSEPOWER TABULAR DATA

Tables VIII through XXVIII present the torque and horsepower data extracted from the reprocessed AH-1G, UH-1H, and OH-6A oscillogram data for the current overtorque study. The two types of tables used consist of flight time distributed among the coincident ranges of various parameters and frequency of exceedances of limits per mission segment. The data presented in these tables are not normalized to a 100-hour data base. Also, all printed range values are the lower limits.

TABLE VIII. TORQUE LIMIT EXCEEDANCES FOR THE UH-1H

Mission Segment	45	47.5	50	TOTAL
ASCENT	113	10	7	130
MANEUVER	5	2		7
DESCENT	11	5	3	19
STEADY STATE	6	1		7
HOVER	33	10	1	44
TOTAL	168	28	11	207

TABLE IX. TIME IN EXCESS OF TORQUE LIMITS FOR THE UH-1H*

Mission Segment	47.5	50	TOTAL
ASCENT	14.5	32.1	46.6
MANEUVER	11.5		11.5
DESCENT	7.6	4.3	11.9
STEADY STATE	1.4		1.4
HOVER	13.8	.2	14.0
TOTAL	48.8	36.6	85.4

* Time in seconds

Total Flight Time - 203 hours

TABLE X. TORQUE LIMIT EXCEEDANCES FOR THE AH-1G				
Mission Segment	45	47.5	49.1	TOTAL
ASCENT	89	20	2	111
MANEUVER	121	17	5	143
DESCENT	2	1		3
STEADY STATE	16	2		18
HOVER	96	10	1	107
TOTAL	324	50	8	382

TABLE XI. TIME IN EXCESS OF TORQUE LIMITS FOR THE AH-1G*			
Mission Segment	47.5	49.1	TOTAL
ASCENT	104.3	12.2	116.5
MANEUVER	90.9	33.6	124.5
DESCENT	2.8		2.8
STEADY STATE	5.9		5.9
HOVER	26.7	7.0	28.7
TOTAL	230.6	47.8	278.4

* Time in seconds

Total flight time - 336 hours

TABLE XII. TORQUE LIMIT EXCEEDANCES FOR THE OH-6A

Mission Segment	63.5	75.0	90.0	TOTAL
ASCENT	652	115	1	768
MANEUVER	7323	3829	45	11197
DESCENT	291	52	1	345
STEADY STATE	862	144		1006
HOVER	143	20	1	164
TOTAL	9271	4160	48	13479

TABLE XIII. TIME IN EXCESS OF TORQUE LIMITS FOR THE OH-6A*

Mission Segment	75.0	90.0	TOTAL
ASCENT	482.7	.6	483.3
MANEUVER	13280.4	143.0	13423.4
DESCENT	137.0	2.6	139.6
STEADY STATE	364.6		364.6
HOVER	41.7	8.6	50.3
TOTAL	14306.4	154.8	14461.2

* Time in seconds

Total flight time - 216 hours

TABLE XIV. OCCURRENCES IN RANGES OF ENGINE SHAFT HORSEPOWER FOR THE UH-1H

Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT					1	9	4	3	17
MANEUVER						2			2
DESCENT				1		5	2		8
STEADY STATE						1			1
HOVER						10	1		11
TOTAL				1	1	27	7	3	39

TABLE XV. OCCURRENCES IN RANGES OF MAIN ROTOR SHAFT HORSEPOWER FOR THE UH-1H

Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT			2	10	3	2			17
MANEUVER				2					2
DESCENT		1	1	6					8
STEADY STATE				1					1
HOVER		1	9	1					11
TOTAL		2	12	20	3	2			39

TABLE XVI. OCCURRENCES IN RANGES OF ENGINE SHAFT HORSEPOWER FOR THE AH-1G

Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT					17	5			22
MANEUVER				3	14	5			22
DESCENT					1				1
STEADY STATE					2				2
HOVER				2	8	1			11
TOTAL				5	42	11			58

TABLE XVII. OCCURRENCES IN RANGES OF MAIN ROTOR SHAFT HORSEPOWER FOR THE AH-1G

Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT		1	20	1					22
MANEUVER		4	15	3					22
DESCENT			1						1
STEADY STATE			2						2
HOVER	3	8							11
TOTAL	3	13	38	4					58

TABLE XVIII. OCCURRENCES IN RANGES OF ENGINE SHAFT HORSEPOWER FOR THE OH-6A							
Mission Segment	240	252.5	260	280	300	320	TOTAL
ASCENT			93	21	2	167	116
MANEUVER			63	2534	1110		3874
DESCENT		3	41	8	1		53
STEADY STATE		9	113	22			144
HOVER		2	15	4			21
TOTAL		14	325	2589	1113	167	4808

TABLE XIX. OCCURRENCES IN RANGES OF MAIN ROTOR SHAFT HORSEPOWER FOR THE OH-6A							
Mission Segment	210	230	252.5	270	290	310	TOTAL
ASCENT		74	40	2			116
MANEUVER	1	2275	1374	224			3874
DESCENT		38	13	2			53
STEADY STATE		115	29				144
HOVER	15	6					21
TOTAL	16	2508	1456	228			4208

TABLE XX. TIME IN RANGES OF ENGINE SHAFT HORSEPOWER FOR THE UH-1H*									
Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT					1.2	12.1	19.0	15.3	46.6
MANEUVER						11.5			
DESCENT				1.6		7.0	3.3		11.9
STEADY STATE						1.4			1.4
HOVER						13.8	.2		14.0
TOTAL				1.6	1.2	45.8	21.5	15.3	85.4

* Time in seconds

Total flight time - 203 hours

TABLE XXI. TIME IN RANGES OF MAIN ROTOR SHAFT HORSEPOWER FOR THE UH-1H*									
Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT			3.5	11.2	27.9	4.0			46.6
MANEUVER				11.5					11.5
DESCENT		1.6	1.4	8.9					11.9
STEADY STATE				1.4					1.4
HOVER		.9	12.9	.2					14.0
TOTAL		2.5	17.8	33.2	27.9	4.0			85.4

* Time in seconds

Total flight time - 203 hours

TABLE XXII. TIME IN RANGES OF ENGINE SHAFT HORSEPOWER FOR THE AH-1G*

Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT					94.0	22.5			116.5
MANEUVER				13.1	73.4	38.0			124.5
DESCENT					2.8				2.8
STEADY STATE					5.9				5.9
HOVER				3.4	24.2	1.1			28.7
TOTAL				16.5	200.3	61.6			278.4

* Time in seconds.

Total flight time - 336 hours

TABLE XXIII. TIME IN RANGES OF MAIN ROTOR SHAFT HORSEPOWER FOR THE AH-1G*

Mission Segment	850	900	950	1000	1050	1100	1150	1200	TOTAL
ASCENT		10.0	97.5	9.0					116.5
MANEUVER		13.9	79.2	31.4					124.5
DESCENT				2.8					2.8
STEADY STATE				5.9					5.9
HOVER	14.7	14.0							28.7
TOTAL	14.7	37.9	185.4	40.4					278.4

* Time in seconds

Total flight time - 336 hours

TABLE XXIV. TIME IN RANGES OF ENGINE SHAFT HORSEPOWER FOR THE OH-6A*

Mission Segment	240	252.5	260	280	300	320	TOTAL
ASCENT			347.6	122.4	13.3		483.3
MANEUVER			103.2	7311.8	5114.2	894.2	13423.4
DESCENT		2.4	104.4	30.2	2.6		139.6
STEADY STATE		20.1	274.8	69.7			364.6
HOVER		9.9	25.8	14.6			50.3
TOTAL		32.4	855.8	7548.7	5130.1	894.2	14461.2

* Time in seconds

Total flight time - 216 hours

TABLE XXV. TIME IN RANGES OF MAIN ROTOR SHAFT HORSEPOWER FOR THE OH-6A*

Mission Segment	200	210	230	252.5	270	290	TOTAL
ASCENT			237.2	232.8	13.3		483.3
MANEUVER		.5	6065.7	6154.6	1202.6		13423.4
DESCENT			85.7	49.3	4.6		139.6
STEADY STATE			275.6	89.0			364.6
HOVER		32.6	17.7				50.3
TOTAL		33.1	6681.9	6525.7	1220.5		14461.2

* Time in seconds

Total flight time - 216 hours

TABLE XXVI. RAPID TORQUE EXCURSIONS					
		INCREASING		DECREASING	
HELICOPTER	TIME (SEC) PRESSURE (PSI)	TOTAL	T/O OR LANDING	TOTAL	T/O OR LANDING
OH-6A	3 25-39	2358	151	1637	146
	6 40-59	1054	338	671	331
	9 60-90	77	32	57	45
UH-1H	3 20-29	146	7	242	206
	6 30-39	18	0	8	6
	9 40-59	1	0	0	0
AH-1G	3 20-29	58	24	193	120
	6 30-39	3	1	91	47
	9 40-59	0	0	3	0

TABLE XXVII. TIME IN RANGES OF PERCENT IRP						
	UH-1H		AH-1G		OH-6A	
% IRP	TIME (MIN)	CUMULATIVE TIME (MIN)	TIME (MIN)	CUMULATIVE TIME (MIN)	TIME (MIN)	CUMULATIVE TIME (MIN)
10	16.6	16.6	41.4	41.4	15.0	15.0
20	127.5	144.1	52.9	94.2	31.0	45.9
30	413.4	557.5	271.9	366.2	101.6	147.5
40	610.3	1167.7	812.5	1178.7	217.4	364.9
50	797.8	1695.6	2917.3	4095.9	508.7	873.6
60	2654.4	4619.9	6553.7	10649.7	1258.8	2132.4
70	4392.7	9012.6	5522.4	16172.1	2605.1	4737.6
80	2302.9	11315.6	3047.9	19220.0	3864.4	8602.0
90	763.0	12078.6	808.0	20027.9	2950.3	11552.3
100	80.0	12158.5	124.5	20152.4	1058.7	12611.0
110	3.5	12162.1	3.9	20156.4	308.4	12919.4
120	0.0	12162.1	0.0	20156.4	56.9	12976.3

TABLE XXVIII. TIME IN RANGES OF SHAFT HORSEPOWER			
	UH-1H	AH-1G	OH-6A
SHP	CUMULATIVE TIME (MIN)	CUMULATIVE TIME (MIN)	CUMULATIVE TIME (MIN)
100	12.9	37.7	323.9
200	87.6	65.5	7816.7
300	349.0	221.3	12977.8
400	842.5	647.2	12983.5
500	1453.4	1734.4	12983.5
600	2408.3	5079.4	12983.5
700	6004.6	11564.3	12983.5
800	9554.1	16561.4	12983.5
900	11327.2	19281.6	12983.5
1000	12072.3	20058.8	12983.5
1100	12158.8	20154.8	12983.5
1200	12161.8	20156.3	12983.5
1300	12162.1	20156.3	12983.5

APPENDIX II
SHAFT HORSEPOWER DERIVATION

A relationship between shaft horsepower and torque is needed to determine transmission torque limit exceedances in terms of shaft horsepower. Shaft horsepower is a function of the transmitted torque and coincident engine output speed as shown in Equation (8).

$$SHP_E = \left(\frac{2\pi}{33000}\right) N_E Q \qquad (8)$$

where SHP_E = engine output shaft horsepower
N_E = engine output (rpm)
Q = engine output torque (ft-lb)

On the basis of this general equation, equations for the AH-1G, OH-6A, and UH-1H helicopters were derived to calculate engine output shaft horsepower based on specific torquemeter pressure and main rotor speed data. The derivations of these equations are presented below.

UH-1H and AH-1G Equation Derivation

From Reference 4, the fixed transmission ratio relating the engine output speed and main rotor speed is given as

$$N_E = 20.383 N_R \qquad (9)$$

where

N_R = rotor speed (rpm).

The derivation of an equation that relates torquemeter pressure (psi) to shaft horsepower for the UH-1H and AH-1G is basically a problem of finding a relationship between torquemeter pressure and torque. This relationship can be found by preparing a least-squares-fit curve based on the T53-L-13 engine characteristics presented in Reference 4 or by deriving an equation that fits the nomograph in Figure I of Reference 6. However, after both methods were reviewed, it was decided to use the former procedure based upon the Engineering Flight Test data of Reference 4, since it was assumed that these data were more accurate and representative of the engine characteristics.

From the engine curve presented in Reference 4, a straight line of the presented data points was obtained by the method of least squares, as represented by the following equation:

$$Q = 17.27Q_p + 62.18 \qquad (10)$$

where

Q = engine output torque (ft-lb)
Q_p = torquemeter pressure (psi)

This equation is based only on the data between 60 and 120 inches of mercury, since only this range of torque pressure is relative to this study.

Combining equations (8), (9), and (10) and rearranging terms yields the following equation:

$$SHP_E = 3.88 \times 10^{-3} N_R(17.27Q_p + 62.18) \qquad (11)$$

Table XXIX shows calculated shaft horsepower versus actual shaft horsepower. In order to obtain more accurate results, Equation (11) was modified by adjusting the equation-based curve at the torque pressure of 25 psi. This adjustment was based on the variances of data at 50.896 inches of mercury (25 psi) as presented in Reference 4. By using a calculated mean of 600 hp at this pressure for the lower bound of the desired equation and 1158 hp as an intermediate condition, a set of simultaneous equations of the form

$$SHP_E = 3.88 \times 10^{-3} N_R(\beta Q_p + \alpha) \qquad (12)$$

may be set up and values for α and β may be calculated. Equation (12) then becomes

$$SHP_E = 3.88 \times 10^{-3} N_R(17.76Q_p + 33.33) \qquad (13)$$

TABLE XXIX. SHAFT HORSEPOWER VERSUS TORQUE PRESSURE FOR THE AH-1G/UH-1H*

Q_p(psi)	N_R(rpm)	SHP_{cal}(hp)	SHP_{act}(hp)	Δerror(hp)
47.5	324	1109.4	1100	9.4
49.1	324	1144.2	1137	7.2
50.0	324	1163.7	1158	5.7
25.0	324	620.9	-	-

* Initial SHP Equation.

Table XXX shows calculated shaft horsepower versus actual shaft horsepower. Because of the close agreement, Equation (13) was used in this program. The error of 2.3 hp at 1100 hp is smaller than the error which would result from a torquemeter or instrumentation inaccuracy.

TABLE XXX. REVISED EQUATION PARAMETERS FOR THE AH-1G/UH-1H*

Q_p(psi)	N_R(rpm)	SHP_{cal}(hp)	SHP_{act}(hp)	Δerror(hp)
47.5	324	1102.3	1100	2.3
49.1	324	1138.0	1137	1.0
50.0	324	1158.1	1158	0.1
25.0	324	600.0	600 (assumed)	0.0

* Final SHP Equation.

OH-6A Equation Derivation

The derivation of the shaft horsepower equation for the OH-6A is based on the transmission limits for the T63-A-5A engine. Taken from the OH-6A flight manual (Reference 5), these limits are listed in Table XXXI.

TABLE XXXI. OH-6A TRANSMISSION LIMITS*

	Normal Power	Takeoff Power
Engine Speed (rpm)	6000	6000
Torque Pressure (psi)	63.5	75.0
Shaft Horsepower (hp)	214.5	252.5

* See OH-6A Flight Manual.

Knowing that

$$SHP = \left(\frac{2\pi}{33000}\right) N_E Q$$

and that

$$N_E = 12.806 N_R \qquad (14)$$

Equations (8) and (14) were combined to yield

$$SHP = 2.438 \times 10^{-3} N_R Q. \qquad (15)$$

The assumption that a linear relationship exists between torque, Q, and torque pressure, Q_p, yielded the following equation:

$$SHP = 2.438 \times 10^{-3} N_R(\alpha + \beta Q_p) \qquad (16)$$

If the torque pressures and shaft horsepowers in Table XXXI are substituted in a set of simultaneous equations of the form given by Equation (16), α and β may be calculated; consequently, Equation (17) assumes the form of

$$SHP = 2.438 \times 10^{-3} N_R(2.89 Q_p + 4.28) \qquad (17)$$

APPENDIX III
VERTICAL ACCELERATIONS DURING LANDING

As a subsidiary task of this contract, a spectrum of vertical accelerations of each of the helicopters during landings was derived from the original operational usage data. The data were acquired from a linear accelerometer mounted at the appropriate centerline of the main rotor shaft of each helicopter. These spectra were developed because very severe landings can shorten the lives of the engine, main transmission, and other dynamic components.

During the editing of the oscillograms for torque exceedances, each vertical accelerometer peak which occurred during a landing was identified and measured; the peaks were categorized as having occurred after a descent or a hover. The vertical acceleration peak was converted to normal load factor, n_z, by using the following relationships:

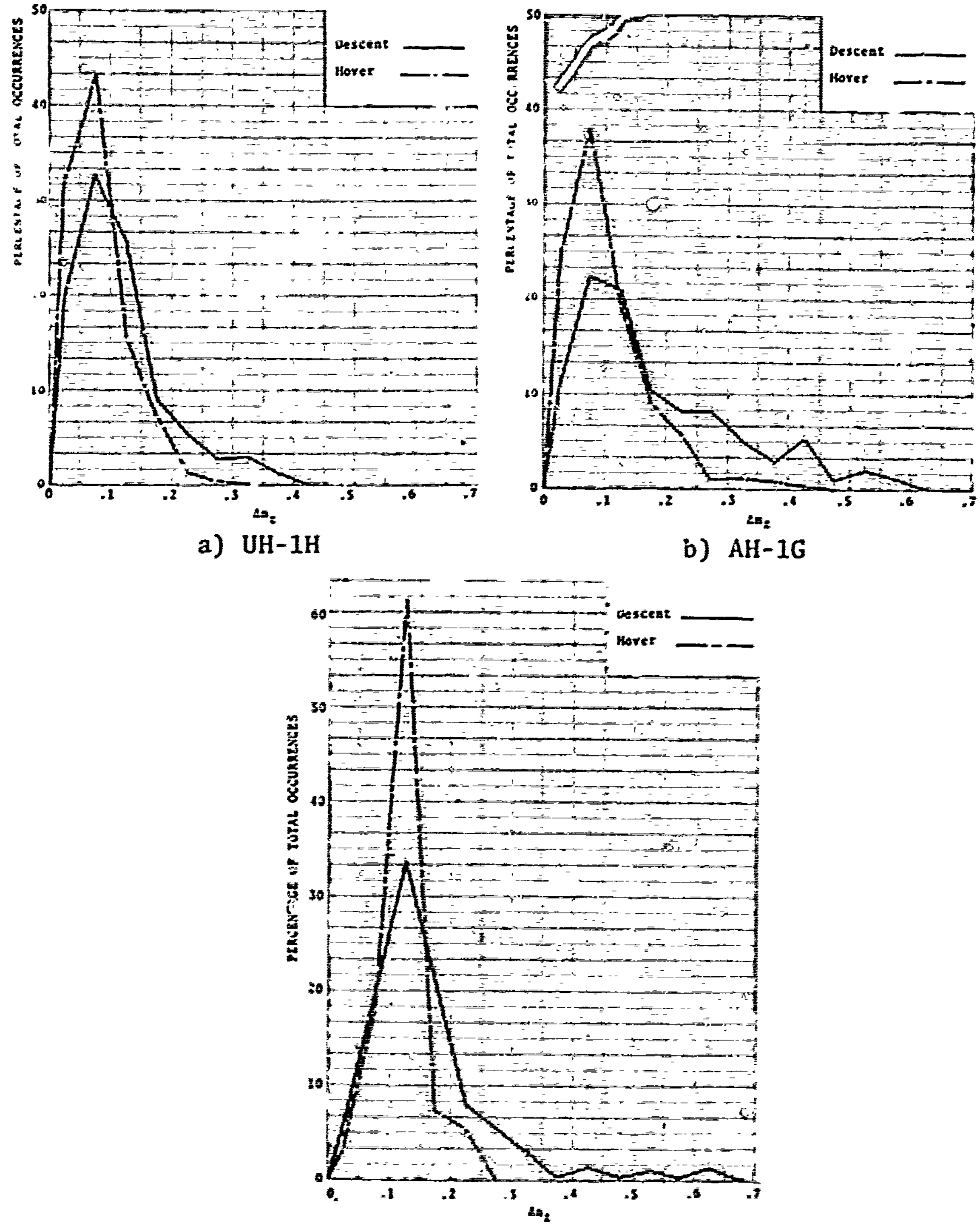
$$n_z = \Delta n_z + 1.0 \quad (18)$$

$$\Delta n_z = az/g \quad (19)$$

where n_z = normal load factor
a_z = center-of-gravity vertical acceleration
g = acceleration due to gravity

In order to group the derived Δn_z impact peaks by helicopter gross weight, an instantaneous gross weight was computed from fuel, cargo, and passenger weights at takeoff and landing, as logged in supplementary data sheets, and from an assumed fuel consumption rate.

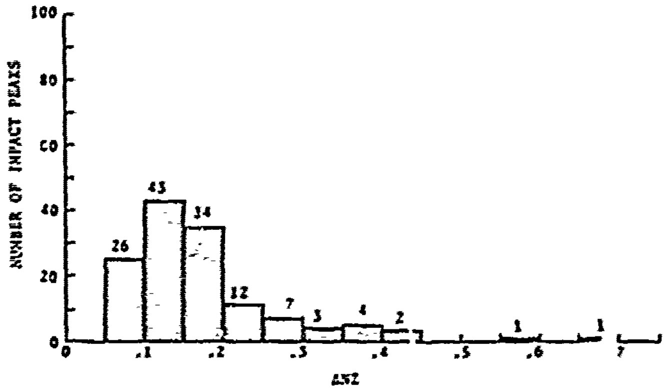
The frequency distributions of landing impact peaks are presented in curve form in Figure 23 for each of the three helicopter types and in histogram form in Figures 24, 25, and 26 for the UH-1H, AH-1G, and OH-6A, respectively; these figures are based on the data presented in Tables XXXII through XXXVII where the data are not normalized to a 100-hour data base. In each figure, the peaks are separated into landings from hover and landings from descent. The OH-6A and AH-1G helicopters landing from descent tend to have impact peaks of greater magnitude than the UH-1H's. When the aircraft land from hover, the peaks tend to be of lesser magnitude. As indicated in these figures, the curves for the UH-1H and AH-1G have the same basic shape and represent approximately the same percentage of total number of occurrences; the AH-1G landed twice as often from a hover as it did from a descent; most of the impact peaks occurred within the 8000-pound gross weight range; and the UH-1H landed approximately five times as often from a hover as from a descent. Whereas the impact peaks after landing from descent were fairly evenly distributed among the gross weight ranges, most of the peaks after landing from hover occurred in the 7000-pound gross weight range. In marked contrast, the OH-6A landed from a descent approximately 6 times as often as it did from a hover. Since the number of impact peaks after landing from a descent is so high for the OH-6A, the OH-6A possibly landed at higher velocities than the UH-1H and AH-1G.



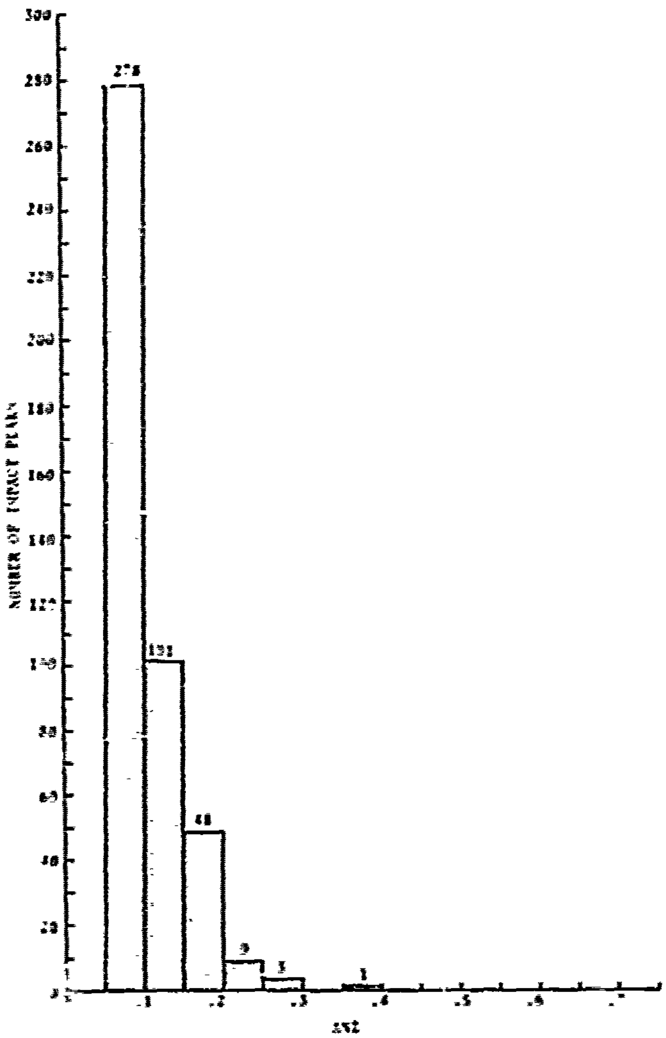
a) UH-1H b) AH-1G

c) OH-6A

Figure 23. Percentage of Impact Peaks per Δn_z Level for the UH-1H, AH-1G, and OH-6A.

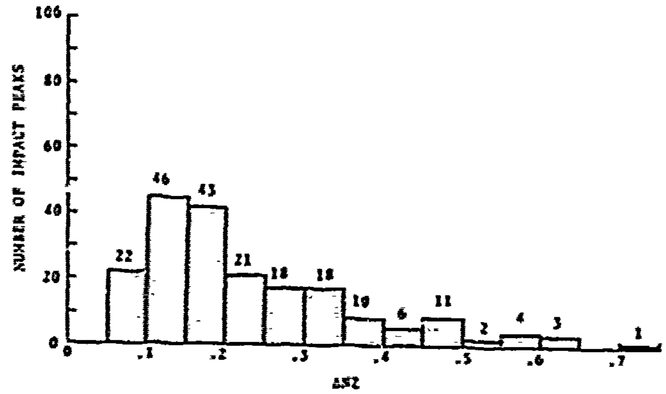


a) Descent

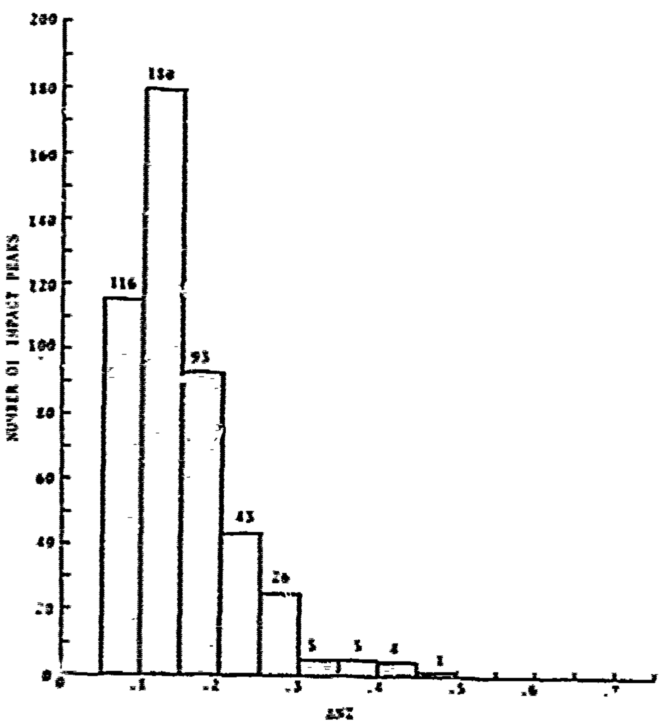


b) Hover

Figure 24. UH-1H Landing Impact Peaks.

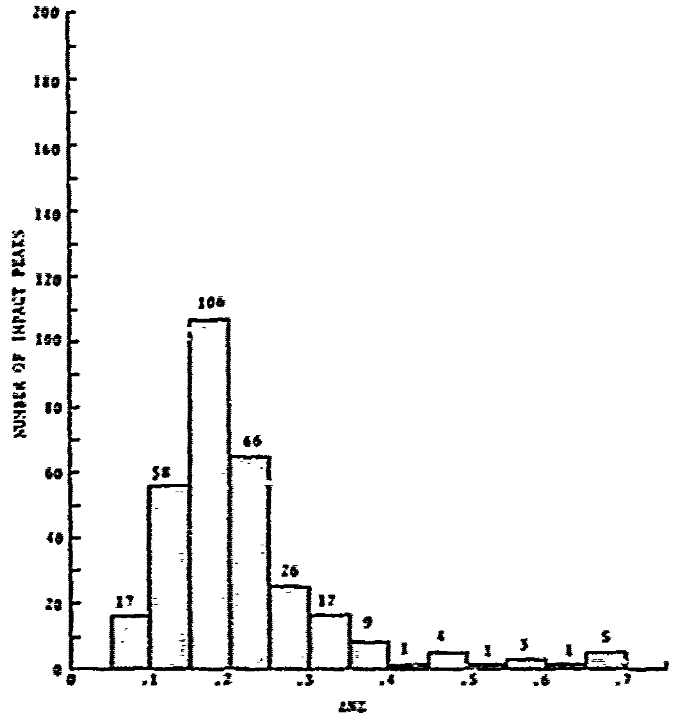


a) Descent

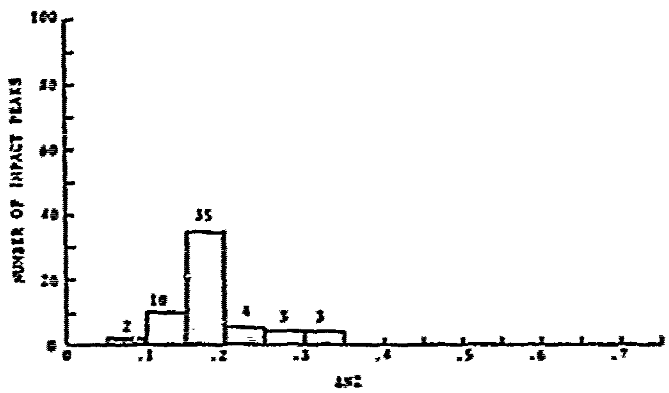


b) Hover

Figure 25. AH-1G Landing Impact Peaks.



a) Descent



b) Hover

Figure 26. OH-6A Landing Impact Peaks.

TABLE XXXII. UH-1H IMPACT PEAKS FROM DESCENT																
WEIGHT RANGE	.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	TOTAL
6000	2	6	7	8	4		3	2			1		1			34
7000	13	17	9	1	2		1									43
8000	9	15	16	2	1	3										46
9000	2	5	2	1												10
TOTAL	26	43	34	12	7	3	4	2			1		1			133

TABLE XXXIII. UH-1H IMPACT PEAKS FROM HOVER																
WEIGHT RANGE	.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	TOTAL
6000	14	38	15	6	1	1		1								76
7000	109	138	66	28	5	2										348
8000	67	92	20	9	3											191
9000	13	10		5												28
TOTAL	203	278	101	48	9	3		1								643

TABLE XXXIV. AH-1G IMPACT PEAKS FROM DESCENT																
WEIGHT RANGE	.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	TOTAL
6000				1												1
7000	2	6	3	1		1		1	1	1						16
8000	14	30	34	19	14	17	7	5	10	1	4	3			1	159
9000	6	10	6		4		3									29
TOTAL	22	46	43	21	18	18	10	6	11	2	4	3			1	205

TABLE XXXV. AH-1G IMPACT PEAKS FROM HOVER																
WEIGHT RANGE	.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	TOTAL
6000		1	1													2
7000	5	8	3	5	3											24
8000	79	127	61	26	17	4	4	2								[illegible]
9000	32	44	28	12	6	1	1	2	1							127
TOTAL	116	180	93	43	26	5	5	4	1							473

TABLE XXXVI. OH-6A IMPACT PEAKS FROM DESCENT														
Weight Range	.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	Total
Less	1	5	13	9	5	4	2	1	2					42
2000	4	12	30	14	7	6	2		1		1			77
2200	9	31	46	33	11	5	2		1	1	2	1	5	[illegible]
2400	3	10	16	10	3	2	3							47
2600			1											1
Total	17	58	105	66	26	17	9	1	4	1	3	1	5	314

TABLE XXXVII. OH-6A IMPACT PEAKS FROM HOVER														
Weight Range	.00	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	Total
Less		1	5		1									7
2000		1	7											8
2200	2	7	14	4	2	3								32
2400		1	9											10
2600														
Total	2	10	35	4	3	3								57