NASA Contractor Report 159033

Correlation Study Between Vibrational Environment and Failure Rates of Civil Helicopter Components

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BELL HELICOPTER TEXTRON
Fort Worth, Texas 76101

CONTRACT NAS1-15078
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Langley Research Center
Hampton, Virginia 23665
AC 804 827-3966

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LIST OF ABBREVIATIONS

Symbol	Meaning
A/C	Aircraft
ALT	Altitude
CAS	Calibrated Airspeed
CG	Center of gravity
D/S	Drive Shaft
FLT. Hr.	Flight Hours
G, g	Gravity
GW	Gross weight
Hz	Hertz, cycles per second
IAS	Indicated Airspeed
No.	Number
osc G	Oscillatory load in G's
rev	Revolution
RPM	Rotor speed in revolutions per minute
T/R	Tail rotor
UHF	Ultra-high frequency
V_H	Horizontal airspeed
VHF	Very high frequency
$V_{best\ R/C}$	Best airspeed at rate of climb
$V_{cruise\ R/D}$	Cruise airspeed at rate of descent
$V_{min\ R/D}$	Minimum airspeed at rate of descent
V_{NE}	Not to exceed airspeed

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FOREWORD

This study was authorized by the NASA-Langley Research Center, Hampton, Virginia, by issuance of Contract NAS1-15078, "Correlation Study Between Vibrational Environment and Failure Rates of Civil Helicopter Components," conducted under the technical cognizance of Mr. B. L. Lee.

Bell Helicopter Textron personnel involved in the performance or assistance of this study were as listed below in alphabetical order:

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M. L. Grovey - Senior Reliability Engineer

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D. L. Kidd - Senior Technology Project Engineer

G. E. Knudsen - Group Engineer, Reliability

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1. SUMMARY

The rising cost of helicopter maintenance remains a major deterrent to the future use of helicopters in civilian applications. In this regard, vibration has been identified as a major contributor to unscheduled maintenance and has led to this correlation study between the vibrational environment and failure rates of civil helicopter components.

Bell Helicopter Textron, under contract to NASA-Langley Research Center, conducted an investigation of two selected helicopter types; namely, the Models 206A/B and 212. An analysis of the available vibration and reliability data for these two helicopter types resulted in the selection of ten components located in five different areas of the helicopter and consisting primarily of instruments, electrical components, and other noncritical flight hardware.

A data correlation effort was started by attempting to identify failure rates, mean-time-between-failure (MTBF), and failure modes for the selected components in both the Models 206A/B and 212. A task was then undertaken to categorize the failure rates of these components according to the primary use of the helicopter. A comparison of the reliability of the components with the vibratory environment in which they operate was conducted to determine helicopter-component failure rates. This led to an attempt to extrapolate the data analysis to other helicopter types. Finally, the potential for advanced technology in suppressing vibration in helicopters was assessed. This included an analysis of the differences between civil and military applications of similar aircraft.

The results of the correlation effort indicate that there are still several unknowns concerning both the vibration environment and the reliability of helicopter noncritical flight components. Vibration data for the selected components were either insufficient or inappropriate for the purposes of this study. The maintenance data examined for the selected components were likewise found inappropriate due to variations in failure mode identification, inconsistent reporting, or inaccurate information.

During this investigation, it was also found that vendor's component qualification reports contained data which were obtained in compliance with MIL-STD-810B type requirements. In general, these data met minimum acceptance requirements as specified in the Standard but did not yield adequate information to determine cause-and-effect relationships between the vibration environment and the failure rate of components installed in a helicopter.

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2. INTRODUCTION

On August 26, 1977, Bell Helicopter Textron (BHT) and the NASA Langley Research Center (NASA LRC) entered into contract NAS1-15078 entitled Correlation Study Between Vibrational Environment and Failure Rates of Civil Helicopter Components. The intent of this program was to determine if a clear connection can be established between helicopter vibration environment and equipment reliability, and if this connection exists, assess the potential for reducing failure rates and associated maintenance costs by controlling vibration or improving equipment design. Each item of equipment has a damage potential as it responds to the vibration spectrum induced through its mounting points by the numerous sources of fuselage vibration which vary in a complex manner with the mission spectrum of the helicopter. A similar statement can be made for other natural environments such as humidity, temperature, and corrosive (salt-spray) atmospheres as well as the combined effect of these environments. The study reported herein deals only with the vibration environment effects on the helicopter. Therefore, the purpose of this study was to gather and relate helicopter vibration and reliability data to gain insight as to why components fail prematurely and to identify areas where substantial improvements can be made in future designs.

The program was conducted under three tasks which are briefly described as follows.

2.1 TASK I - DATA ACQUISITION

Data acquisition involved the gathering of vibration and reliability data from BHT commercial helicopters, and data as described in service reports from commercial operators. Two helicopter types, Models 206A/B and 212, were chosen based on the availability of vibration and maintenance data.

Ten substantially different components located in separate areas of the airframe were chosen for further evaluation.

2.2 TASK II - DATA CORRELATION

Data correlation encompassed the categorizaton of failure rates according to the primary use of the selected helicopters. This included an assessment of what trends exist between the primary application of the helicopter, its vibration environment, and the failure rates of the selected components.

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2.3 TASK III - DATA ANALYSIS

Data analysis involved taking the results of the first two tasks and extrapolating these results to other helicopter types. This included an assessment of the potential of advanced technology in vibration suppression, and an assessment of the difference between civil and military applications of similar aircraft.

3. TECHNICAL DISCUSSION

3.1 DATA ACQUISITION

3.1.1 Survey of Vibration Data

3.1.1.1 Commercial Data

An examination of available vibration data on BHT's helicopters was conducted by means of a literature survey of BHT flight test reports (reference 1, 2, 3, 4, and 5). These included BHT Models 206, 212 and 214A series helicopters. The survey revealed that not all helicopters were extensively instrumented for vibration during these tests. Both the quality and quantity of vibration data were found to be less than required for determining if there is a cause-and-effect relationship between vibration and equipment reliability. In most cases, it was found that only limited instrumentation was installed in a helicopter to obtain a minimum vibration survey of the helicopter during selected flight conditions. One reason for this is that most of these test programs were conducted under contract to fulfill minimum acceptance requirements specified by the government.

In reference 1, for example, the instrumentation consisted of a cluster of three orthogonal accelerometers (vertical, lateral, and fore-and-aft), on the OH-58A instrument panel, Figure 1. Flight conditions flown that are of interest to this program were hover, and level flight (50 knots IAS) without the gun firing. Figures 2, 3, and 4 are population plots with the points representing the collected peaks from the magnitude frequency spectral plots for the appropriate conditions described in reference 1. These data are directly applicable to the Model 206 because the OH-58A is the military version of the Model 206 which later became available for commercial use.

The Model 212 test helicopter described in reference 2 was monitored for vertical vibration by accelerometers in the nose, center of gravity, right-hand avionics compartment, and right-hand fuselage aft (including other locations not of interest to this study) for various forward speed flight conditions.

Although these tests furnished enough data to meet the minimum flight test requirements of these specific programs, they did not provide adequate definition of the vibration environment in the high density instrument/gauge areas of the helicopter.

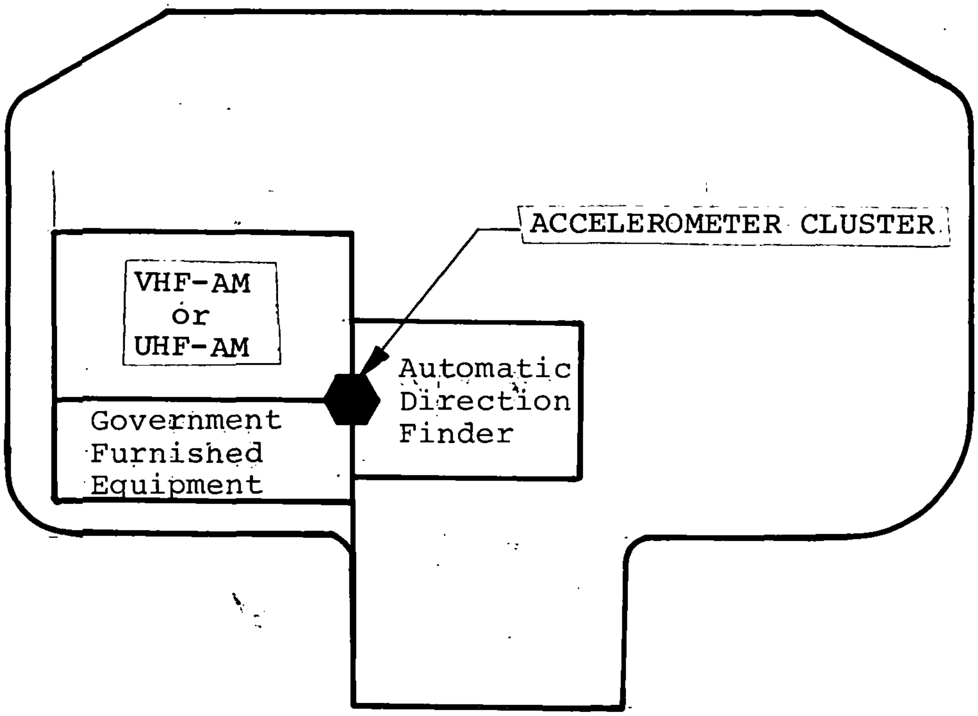

Figure 1. OH-58A (Model 206) instrument panel.

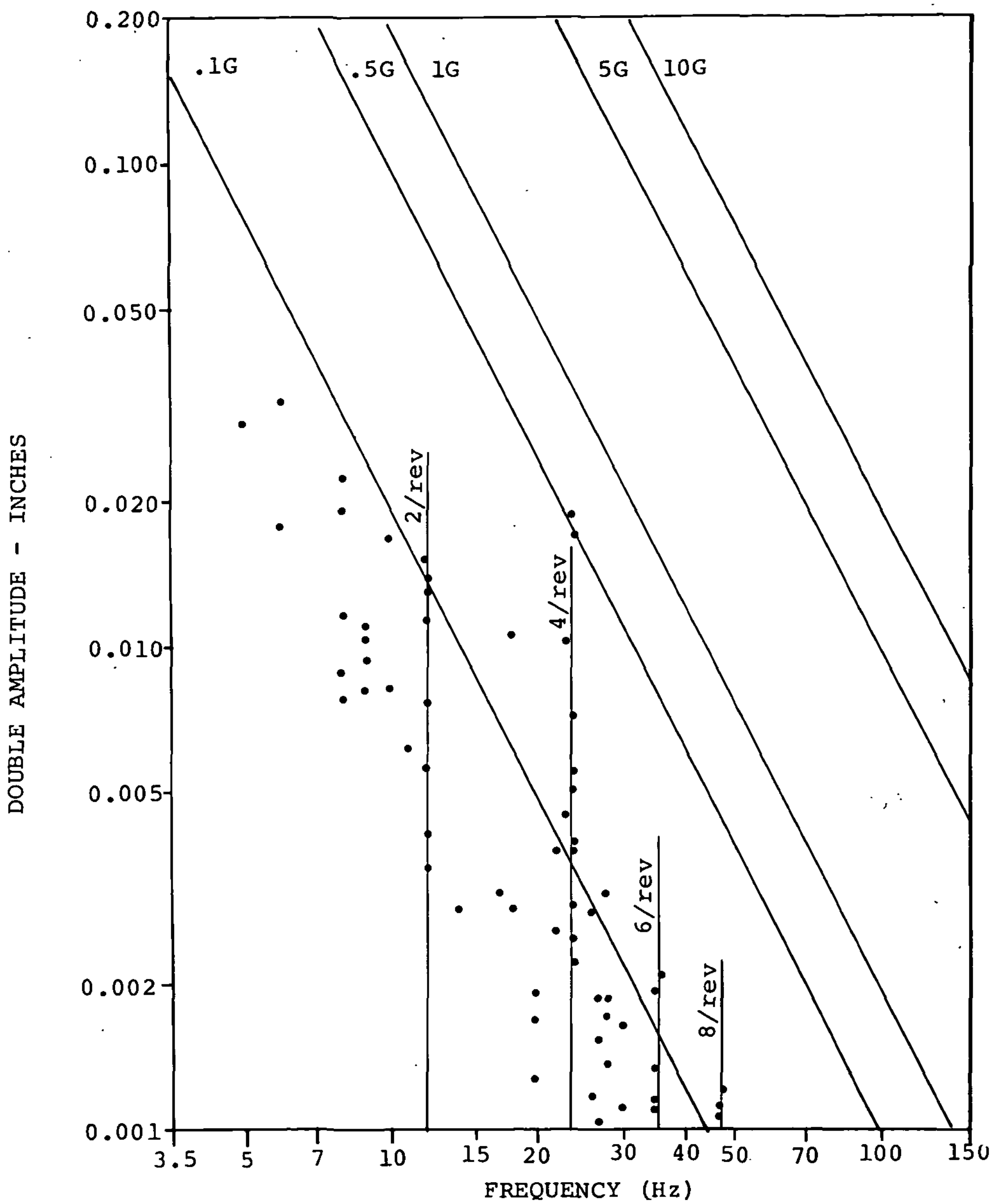

Figure 2. Population plot - left panel lateral.

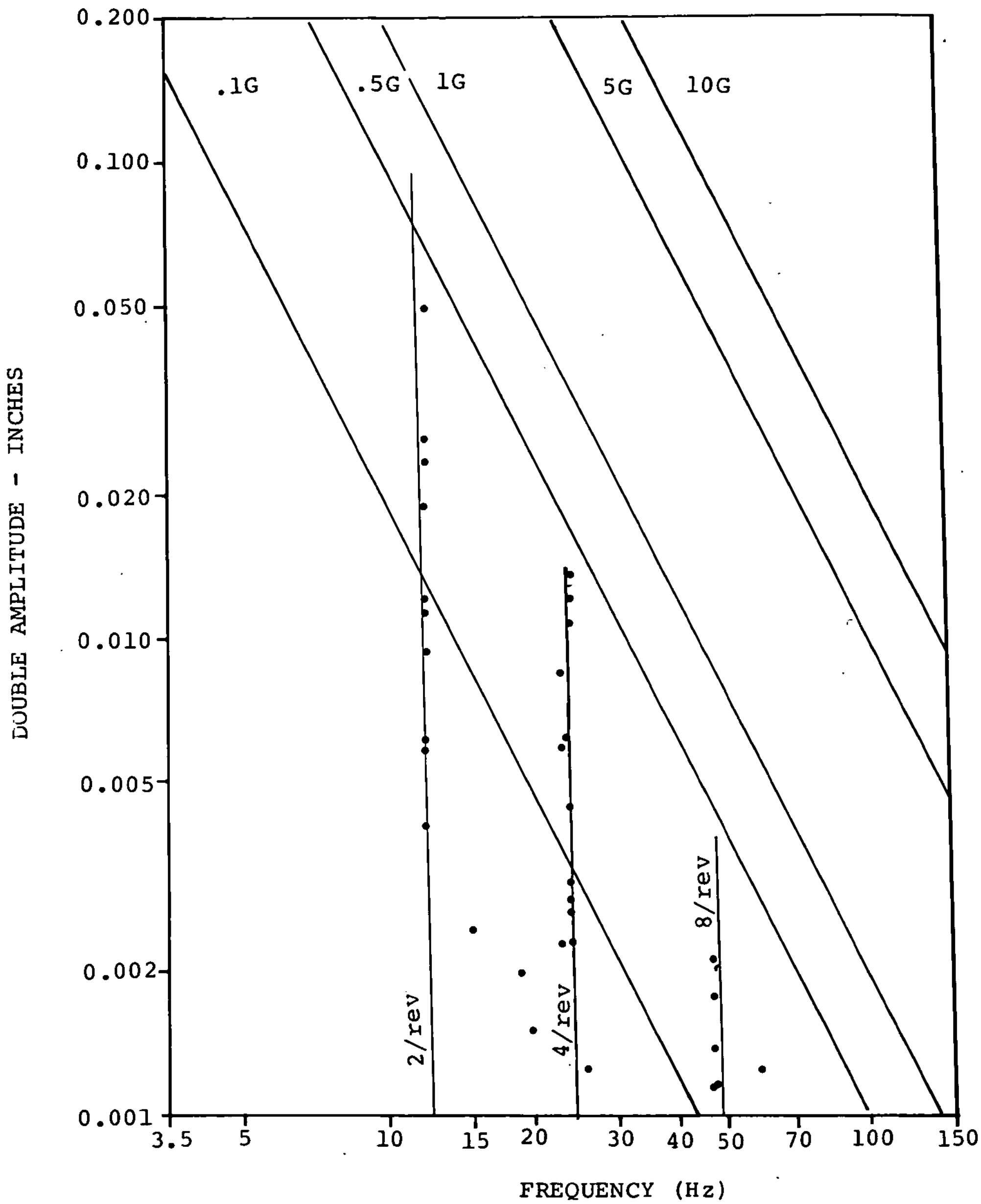

Figure 3. Population plot - left panel fore-aft.

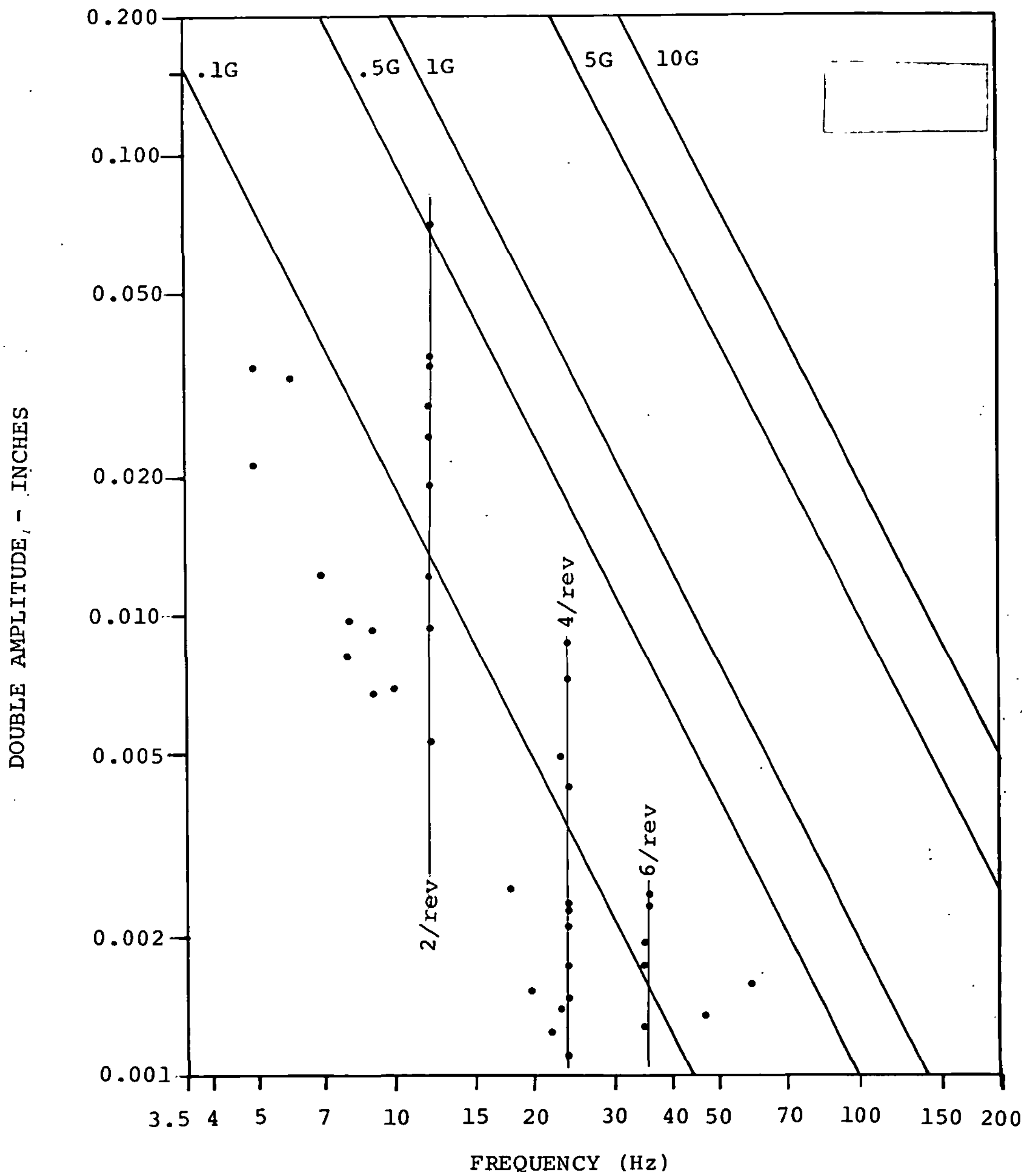

Figure 4. Population plot - left panel vertical.

3.1.1.2 Military Data

The remaining commercial reports surveyed during Task I did not provide data for the areas of the helicopter that would be meaningful to this program. Therefore, an examination of available military data was included in the literature survey to supplement the commercial vibration data base. It was found that references 6 and 7 which involve tests conducted at Edwards Air Force Base, California contained the most comprehensive set of vibration data available on the military's OH-58A and UH-1H models which for the purpose of this study are similar to the commercial Models 206 and 212, respectively.

This necessarily entailed a study to determine the applicability or relevancy of military data with respect to that of the Model 212. An examination of Bell's production history shows that all the UH-1 series helicopters and Bell Models 204, 205, 212, and 214 are basically derivatives of the UH-1A (Bell Model 204) which was BHT's first production turbine powered series helicopter. The main difference between the UH-1H and UH-1N is that the former is configured with a single engine and the latter with a twin engine. The Model 212 is basically the UH-1N (twin-engine) and so the data from each are readily comparable. However, the UH-1H and UH-1D (both single engine) data are still comparable to the Model 212 in the sense that the error associated with this assumption is no greater than the errors inherent in the normal practice of MIL-STD-810.

Of particular interest, as reported in reference 6, is that 21 accelerometers were mounted triaxially at five locations on the instrument panel and two locations in the avionics compartment for the OH-58A. The flight conditions for the OH-58A are shown in Table 1 which is obtained from reference 6. Similarly, the instrumentation for the UH-1H as described in reference 7 consisted of 43 triaxial accelerometer locations, 5 biaxial accelerometer locations, and 1 uniaxial accelerometer location. The flight conditions for the UH-1H are shown in Table 2 as obtained from reference 7.

It is noteworthy to mention that in references 6 and 7, a statement was made with regard to data relevancy. In both cases it was mentioned that qualitative pilot evaluations indicated that there were wide variations in the vibration level of different helicopters of the same model due to differences in the mechanical condition of each helicopter. The authors in references 6 and 7 go on to state that, as a result, if vibration levels are to be measured which are representative of those encountered in a particular model of helicopter, then a sample of several helicopters of the same model helicopter should be tested. This leaves open the possibility that there

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SOURCE: REFERENCE 6

TABLE 1. OH-58A VIBRATION TEST CONDITIONS[1]

Test	Conditions	Average Gross Weight (lb)	Configuration	Average Density Altitude (ft)
Hover	In ground effect, out of ground effect	2500	Clean (doors on)	5000
Level flight	V_{loiter} (60 KCAS[2]), $0.7V_H$ (72 KCAS), $0.8V_H$ (85 KCAS), $0.9V_H$ (95 KCAS), V_H (108 KCAS)	2500	Clean (doors on)	5000
Dive (maximum power)	V_{NE} (120 KCAS)	2500	Clean (doors on)	5000
Climb (maximum power)	$V_{min\ power}$ (60 KCAS), V_{cruise} (80 KCAS)	2500	Clean (doors on)	5000
Descent (minimum power)	$V_{min\ R/D}$ (60 KCAS), $V_{cruise\ R/D}$ (80 KCAS)	2500	Clean (doors on)	5000
Autorotation	$V_{min\ R/D}$ (60 KCAS), $V_{max\ range}$ (80 KCAS)	2500	Clean (doors on)	5000
Maneuvering flight	Maneuver A, 80 to 100 KCAS, low-level reconnaissance[3]	2500	Clean (doors on)	4500
Maneuvering flight	Maneuver B, 80 to 100 KCAS, return to target[3]	2500	Clean (doors on)	4500
Maneuvering flight	Maneuver C, pullout at 120 KCAS, simulated gun runs[4]	2500	Clean (doors on)	4500
Weapons firing	2000 and 400 shots per minute; full-up, horizontal, and full-down gun positions	2800	Armed[5] (doors on and off[6])	5000

[1]All testing was conducted at a mid center of gravity and a main rotor speed of 354 rpm.
[2]Knots calibrated airspeed.
[3]1.5 to 2.0g, left and right turns, 75-degree maximum bank angle.
[4]1.5 to 2.0g, left and right turns, 75-degree maximum bank angle, initiated at 500, 1000, and 1500 feet above ground level.
[5]Armed with XM27E1 armament subsystem.
[6]All doors except the copilot door were removed for the doors-off weapons firing.

SOURCE: REFERENCE 7

TABLE 2. UH-1H VIBRATION TEST CONDITIONS[1]

Test	Conditions	Average Gross Weight (lb)	Configuration	Average Density Altitude (ft)	Average Temperature (~ °C)
Hover	In ground effect, out of ground effect	7000 and 9000	Clean (doors closed)	3300	18
Level flight	V_H (122 KCAS)[2], $0.9V_H$, $0.8V_H$, $0.7V_H$, V_{loiter} (60 KCAS); 7000-lb GW			5000	11
	V_H (102 KCAS), $0.9V_H$, $0.8V_H$, $0.7V_H$, V_{loiter} (60 KCAS); 9000-lb GW				
Climb	$V_{best\ R/C}$ (55 KCAS), 7000-lb GW; $V_{best\ R/C}$ (60 KCAS), 9000-lb GW; maximum power			5000	11
	$V_{cruise\ R/C}$ (80 KCAS), 7000-lb and 9000-lb GW, maximum power				
Descent	$V_{min\ R/D}$ (49 KCAS), 7000-lb GW; $V_{min\ R/D}$ (55 KCAS), 9000-lb GW; minimum power			5000	11
	$V_{cruise\ R/D}$ (80 KCAS), 500 ft/min				
Takeoff (T/O)	Normal (A), level acceleration (B); from 3-ft hover			3300	15
Landing (LDG)	Normal (A), steep (B), shallow (C); to 3-ft hover			3300	15
Maneuvering flight	90° turns at constant altitude; 15°, 30°, and 45° bank angle, right and left; 100 KCAS entry airspeed			5000	12
Ground run	Flight idle (324 rpm), ground idle (220 rpm), wind speed 15 to 20 knots			2700	14
Weapons firing	Right gun fwd, mid, aft; left gun fwd, mid, aft; both guns fwd, mid, aft; 80 KCAS	8100	Armed (doors open) M23 armament subsystem	4700	17

[1]Coordinated flight maintained at level flight, climb, descent, and maneuvering flight test conditions.
[2]Knots calibrated airspeed.

are other helicopters of the same model which may be in operation and having higher vibration levels than the two helicopters tested.

Nevertheless, in spite of these shortcomings in the available data files, trends were sought to relate the vibration envionment of the Models 206 and 212 to their respective maintenance records. Therefore, it became necessary to determine if adequate maintenance data were available to support the use of the Models 206 and 212 as the two selected helicopter models for further analysis under this program.

3.1.2 Survey of Maintenance Data

Three sources of failure data files were used for the survey of components whose failure may be attributable to vibration. These are the BHT Discrepancy/Malfunction Report (DMR), Navy Maintenance and Material Management Data (3-M), and the OH-58 Reliability and Maintainability (R&M) Demonstration Failure and Maintenance Action Report Data.

3.1.2.1 Discrepancy/Malfunction Report (DMR). These reports are submitted to BHT by its technical representatives and commercial customers on forms as shown in Figure 5. These forms contain information which described discrepancies or failures of components installed in the customer's helicopter. These reports include records of the helicopter model and serial number, part name and number, helicopter hours, part hours, etc. The DMR data are put into a computer file when they are received at BHT where computer programs sort, select, and list the DMR data, as required. Problem investigation results and corrective action summaries are added to the file as they become available. Special study tapes of selected records are created from which sample aircraft and selected time intervals may receive more detailed analysis. Figure 6 shows an example of the type of output that can be obtained from the DMR data.

3.1.2.2 Navy Maintenance and Material Management (3-M) Data

BHT periodically receives these maintenance and failure data from the Navy on magnetic tape. These data are added to a master 3-M computer file when they are received at BHT. Computer programs calculate the maintenance and failure rates and mean-time-between-failure (MTBF) values from the raw data, and sort, select and list the output as required. Figure 7 shows a sample of output that can be obtained from the 3-M data files. This is considered one of the most complete and reliable sources of data available on BHT helicopters that are in Navy operation.

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Bell Helicopter TEXTRON
Division of Textron Inc.

MAIL TO: BELL HELICOPTER TEXTRON
ATTN: SERVICE MANAGER
P.O. BOX 482
FORT WORTH, TEXAS 76101

DISCREPANCY/MALFUNCTION REPORT

FOR WARRANTY-FORM MUST BE FULLY COMPLETED

9 [1] USE PENCIL OR BLACK INK 11 MO DA YR 16

REPORT DATE

CONTROL NO. 1 8

BELL USE ONLY

SUBMITTED BY	17 CODE NO. 20	ADDRESS

21 OCCURANCE DATE	27 HELICOPTER MODEL	34 SERIAL NUMBER	41 TOTAL HOURS	46 PART NUMBER	60 PART SERIAL NUMBER 68	9 [2]

11 PART NAME (CATALOGUE)	28 PART HOURS	33 HOURS SINCE LAST INSP.	VENDOR NAME (IF APPLICABLE)	QUANTITY THIS REPORT 37 38

PARTS REPLACEMENT CONSIDERATION ONLY ISSUED UPON PROOF OF REPLACEMENT PART HAVING BEEN PURCHASED FROM BELL HELICOPTER TEXTRON, OR ITS AUTHORIZED REPRESENTATIVES OR AGENCIES

EXHIBIT AVAILABLE 39 YES NO

WARRANTY CONSIDERATION 40 YES NO

HELICOPTER SALE		SPARE PART SALE				
FACTORY DELIVERY DATE	DEALER DELIVERY DATE	DATE SPARE INSTALLED	BELL INVOICE NO.	INVOICE DATE	REPL. PART INVOICE NO.	LIST PRICE

DESCRIPTION OF DIFFICULTY: ....

ACTION TAKEN: ....

PROPERTY OF COMPANY ____________ 41 CODE NO.

ADDRESS ____________ SIGNED ____________

MAIL ORIGINAL COPY TO ABOVE ADDRESS FOR AUTHORIZATION TO RETURN PART(S) REMOVED FOR INVESTIGATION, OVERHAUL OR RECONDITION. YOU WILL RECEIVE BY RETURN MAIL A COPY WITH COMMENTS OR AUTHORIZATION TO RETURN THE PART(S) DESCRIBED ON THIS FORM.

45 BELL USE ONLY

ENG	LOG	P.A.	S.B.

SPACE BELOW RESERVED FOR BELL HELICOPTER TEXTRON

REMARKS

7871 57985 REV 277

MAIL WHITE COPY TO SERVICE DEPARTMENT

Figure 5. Sample form - discrepancy/malfunction report (DMR).

```
        P/N ORDER DMRS OF 2068, ETC.. ADDED AFTER 01/01/77. 06/22/78
A CARD:   ..PART NUMBER...##.....PART NAME.....--PT SN--PTHRS.LI.EM-MODEL--AC SN.ACHRS.CC.RMRDRYDMODDY--BY--PROB.FILE.COE   PAGE 19


RM7275X0A206-070-399-001 01TORQUE METER       271         00355     Y206A        518 036060     061070     0
                                                     --->  NSERVICE                             760825<---
        B   TORQUE METER READING TOO HIGH
        C   * UNKNOWN
        D          RETURN INDICATOR FOR WARRNTY CONSIDR

RM7321X0A206-070-399-001 0 TORQUEMETER        427         00100     Y206A        410 079595     111170     0
                                                     --->  NSERVICE                             760825<---
        B   TORQUEMETER QUIT
        C   * TORQUEMETER FAILED
        D          RETURN UNIT FOR WARRANTY CONSIDERATN

RM7694X0A206-070-399-001 01TORQUEMETER.IN     171         00162     Y206B        761 018282     081172     0
                                                     --->  NSERVICE                             760825<---
        B   TORQUEMETER INDICATES LOW FLUCTUATES
        C   * UNKNOWN
        D          TO WARRANTY SECTION

RM7218X0A206-070-399-001 01TORQUEMETER         79         00135     Y206A        432 013535     051170     0
                                                     --->  NSERVICE                             760825<---
        B   INACCURATE READINGS FLUXUATES
        C   * UNKNOWN
        D          RETURN FOR WARRANTY CONSIDERATION

RM7622X0A206-070-399-001 01TORQUEMETER        467         00057     Y206A        607 005757     091471     0
                                                     --->  NSERVICE                             760825<---
        B   NEEDLE FAILED TO INDICATE IN FLIGHT
        C   * INSTRUMENT FAILURE
        D          RETURN FOR WARRANTY CONSIDERATION

RM7335X0A206-070-399-001 01INDICATOR          184         00175     Y205A        562      0 0   121470     0
                                                     --->  NSERVICE                             760825<---
        B   INDICATOR IS INOPERATIVE
        C   * UNKNOWN
        D          RETURN EXHIBIT FOR WARRANTY

RM7296X0A206-070-399-001 01TORQUEMETER IN     370          0    0   Y206A        526      0 0   091470     0
                                                     --->  NSERVICE                             760825<---
        B   NO INDICATION ON GAGE
        C   * UNKNOWN
        D          RETURN UNIT FOR WARRANTY CONSIDERATN

RM7053X0A206-070-399-001 01INDICATOR.TORQ     676         00035     Y206A        705 003535     051572     0
                                                     --->  NSERVICE                             760825<---
        B   TORQUEMETER READS 0 WHEN GEN SWTH OF
        C   * SUSPECT MALFUNCTN OF INTERNL COMPNTS
        D          SERVICE DEPT REQUESTED VENDR REVIEW

RM7656X0A206-070-399-001 01INDICATOR TORQ     464         00040     Y206A        704 004040     061572     0
                                                     --->  NSERVICE                             760825<---
        B   TORQUEMETER READS 0 ON START UP
        C   * MALFUNCTION OF TORQUEMETER INDICATOR
        D          UPON RECEIPT,RETURN TO VENDOR

RM7428X0A206-070-399-001 01TORQ METER IND     111         00128     Y206A        515 012828     101670     0
                                                     --->  NSERVICE                             760825<---
        B   DURING FLIGHT ENG TORQUE FLUCTUATES
        C   * NEW TORQUE METER GAGE INSTALLED
        D          UPON RECEIPT OF INDICATOR WILL TEST

RM7408X0A206-070-399-001 01TORQUE METER       198         00145     Y206A        527 014444     121670     0
                                                     --->  NSERVICE                             760825<---
        B   TORQUE READINGS HIGHER THAN NORMAL
        C   * UNKNOWN
        D          RETURN UNIT FOR WARRANTY CONSIDERATN

RM6746X0A206-070-399-001 01TORQUEMETER        151         00034     Y206A        454 003434     031670     0
                                                     --->  NSERVICE                             750825<---
        B   UNIT FAIL TO FUNCTION IN FLIGHT
        C   * UNKNOWN
        D          RETURN UNIT TO VENDOR FOR EVALUATION

RM7338X0A206-070-399-001 01INDICATOR          221          0    0   Y206A        562 018080     121670     0
                                                     --->  NSERVICE                             760825<---
        B   INDICATOR NEEDLE READS INACCURATE
```

Figure 6. Sample computer output of DMR data.

BELL RELIABILITY GROUP 3-M WUC FAILURE MODE SUMMARY LISTING DATE 11/05/77

JULIAN DATES ALL
COMMAND CODES ALL
ACFT S/N(S) ALL
ACFT MODEL AHAP (MODEL UH-1N)

TOTAL ACFT TIME 134157.0
NO.A/C W/FLT.HRS 182
AVG.HOURS/FLIGHT 1.3
RATES=QTY/1000000 A/C HRS.
MFHBMA.ETC..IN ACFT HOURS

WUC	MALF CODE		MAINTENANCE QTY	MAINTENANCE RATE	ACTION MFHBMA	MATERIAL QTY	MATERIAL RATE	FAILURES MFHBF	ACFT MISSION ABORTS QTY	RATE	MFHBA	MAINTENANCE MAN-HOURS/FH ORG	IMA	ALL
5111H00	020	WORN.CHAFED.FRAYED OR STRIPPED	1-	7	134157	1-	7	134157	0-	0	*********	0.000015	0.0	0.000015
5111H00	037	FLUCTUATES. UNSTABLE. ERRATIC	12-	89	11179	11-	81	12196	0-	0	*********	0.000713	0.000027	0.000739
5111H00	080	DEF.LT.BULB.CIRC.BRKR.FUSE BLN	18-	134	7453	17-	126	7891	0-	0	*********	0.000136	0.000081	0.000217
5111H00	105	LOOSE OR DAMAGED HARDWARE	15-	111	8943	15-	111	8943	0-	0	*********	0.000160	0.0	0.000160
5111H00	135	BINDING. STUCK. JAMMED	7-	52	19165	7-	52	19165	0-	0	*********	0.000107	0.000007	0.000114
5111H00	160	CONTACT/CONNECTION DEFECTIVE	33-	245	4065	32-	238	4192	0-	0	*********	0.000734	0.000004	0.000738
5111H00	169	INCORRECT VOLTAGE	1-	7	134157	1-	7	134157	0-	0	*********	0.0	0.000007	0.000007
5111H00	242	INOPERATIVE-REASON UNKNOWN	58-	432	2313	56-	417	2395	0-	0	*********	0.000902	0.000215	0.001117
5111H00	306	NON-METAL CONTAMINATION/DIRTY	2-	14	67078	2-	14	67078	0-	0	*********	0.000011	0.0	0.000011
5111H00	314	SLOW ACCELERATION OR CYCLE	1-	7	134157	1-	7	134157	0-	0	*********	0.000030	0.0	0.000030
5111H00	374	INTERNAL FAILURE	152-	1133	882	133-	991	1008	2-	14	67078	0.002412	0.000733	0.003146
5111H00	381	LEAKING	1-	7	134157	1-	7	134157	0-	0	*********	0.000002	0.0	0.000002
5111H00	450	OPEN	2-	14	67078	2-	14	67078	0-	0	*********	0.000060	0.0	0.000060
5111H00	457	OSCILLATING	1-	7	134157	1-	7	134157	0-	0	*********	0.000011	0.0	0.000011
5111H00	458	OUT OF BALANCE	2-	14	67078	2-	14	67078	0-	0	*********	0.000019	0.000006	0.000025
5111H00	561	UNABLE TO ADJUST TO LIMITS	2-	14	67078	2-	14	67078	0-	0	*********	0.000052	0.000004	0.000056
5111H00	615	SHORTED	3-	22	44719	3-	22	44719	0-	0	*********	0.000037	0.000004	0.000041
5111H00	690	VIBRATION EXCESSIVE	2-	14	67078	2-	14	67078	0-	0	*********	0.000022	0.000026	0.000048
5111H00	710	BEARING FAILURE	1-	7	134157	1-	7	134157	0-	0	*********	0.000002	0.0	0.000002
5111H00	730	LOOSE	33-	245	4065	33-	245	4065	2-	14	67078	0.000294	0.0	0.000294
5111H00	782	TIRE TREAD AREA DEFECTIVE	1-	7	134157	1-	7	134157	0-	0	*********	0.000015	0.0	0.000015
5111H00	932	WONT LOCK/UNLOCK CORRECTLY	1-	7	134157	1-	7	134157	0-	0	*********	0.000016	0.000002	0.000018
5111H00	957	NO DISPLAY	1-	7	134157	1-	7	134157	0-	0	*********	0.000007	0.0	0.000007
5111H00	958	INCORRECT DISPLAY	28-	208	4791	26-	193	5159	1-	7	134157	0.000534	0.000087	0.000621
5111H00	***		378-	2817	354	352-	2623	381	5-	37	26831	0.006292	0.001203	0.007495
5111J00	080	DEF.LT.BULB.CIRC.BRKR.FUSE BLN	3-	22	44719	3-	22	44719	0-	0	*********	0.000109	0.000015	0.000124
5111J00	135	BINDING. STUCK. JAMMED	12-	89	11179	12-	89	11179	0-	0	*********	0.000185	0.000081	0.000265
5111J00	160	CONTACT/CONNECTION DEFECTIVE	2-	14	67078	2-	14	67078	0-	0	*********	0.000089	0.0	0.000089
5111J00	242	INOPERATIVE-REASON UNKNOWN	10-	74	13415	10-	74	13415	0-	0	*********	0.000178	0.000059	0.000237
5111J00	374	INTERNAL FAILURE	18-	134	7453	16-	119	8384	0-	0	*********	0.000537	0.000075	0.000612
5111J00	561	UNABLE TO ADJUST TO LIMITS	1-	7	134157	1-	7	134157	0-	0	*********	0.000014	0.000007	0.000022
5111J00	615	SHORTED	1-	7	134157	1-	7	134157	0-	0	*********	0.000010	0.0	0.000010
5111J00	730	LOOSE	1-	7	134157	1-	7	134157	0-	0	*********	0.000007	0.0	0.000007
5111J00	958	INCORRECT DISPLAY	9-	67	14906	8-	59	16769	0-	0	*********	0.000183	0.000037	0.000220
5111J00	***		57-	424	2353	54-	402	2484	0-	0	*********	0.001313	0.000274	0.001587
5111K00	037	FLUCTUATES. UNSTABLE. ERRATIC	2-	14	67078	2-	14	67078	0-	0	*********	0.000044	0.000007	0.000051
5111K00	105	LOOSE OR DAMAGED HARDWARE	3-	22	44719	3-	22	44719	0-	0	*********	0.000006	0.000004	0.000010
5111K00	135	BINDING. STUCK. JAMMED	1-	7	134157	1-	7	134157	0-	0	*********	0.000007	0.000002	0.000010
5111K00	242	INOPERATIVE-REASON UNKNOWN	3-	22	44719	3-	22	44719	0-	0	*********	0.000030	0.000004	0.000034
5111K00	374	INTERNAL FAILURE	14-	104	9582	13-	96	10319	0-	0	*********	0.000184	0.000157	0.000341
5111K00	450	OPEN	1-	7	134157	1-	7	134157	0-	0	*********	0.000009	0.0	0.000009
5111K00	730	LOOSE	2-	14	67078	2-	14	67078	0-	0	*********	0.000041	0.0	0.000041
5111K00	958	INCORRECT DISPLAY	2-	14	67078	2-	14	67078	0-	0	*********	0.000015	0.0	0.000015
5111K00	***		28-	208	4791	27-	201	4968	0-	0	*********	0.000336	0.000174	0.000510
5111L00	080	DEF.LT.BULB.CIRC.BRKR.FUSE BLN	1-	7	134157	1-	7	134157	0-	0	*********	0.000015	0.0	0.000015
5111L00	374	INTERNAL FAILURE	1-	7	134157	1-	7	134157	0-	0	*********	0.000007	0.0	0.000007
5111L00	***		2-	14	67078	2-	14	67078	0-	0	*********	0.000022	0.0	0.000022
5111M00	105	LOOSE OR DAMAGED HARDWARE	1-	7	134157	1-	7	134157	0-	0	*********	0.000037	0.0	0.000037
5111M00	730	LOOSE	1-	7	134157	1-	7	134157	0-	0	*********	0.000004	0.0	0.000004
5111M00	***		2-	14	67078	2-	14	67078	0-	0	*********	0.000041	0.0	0.000041
5111N00	105	LOOSE OR DAMAGED HARDWARE	1-	7	134157	1-	7	134157	0-	0	*********	0.000015	0.0	0.000015
5111N00	170	CORRODED	1-	7	134157	1-	7	134157	0-	0	*********	0.000004	0.0	0.000004
5111N00	374	INTERNAL FAILURE	5-	37	26831	5-	37	26831	0-	0	*********	0.000054	0.000004	0.000057
5111N00	730	LOOSE	2-	14	67078	2-	14	67078	0-	0	*********	0.000034	0.0	0.000034
5111N00	958	INCORRECT DISPLAY	1-	7	134157	1-	7	134157	0-	0	*********	0.000007	0.0	0.000007

Figure 7. Sample computer output of 3-M data.

3.1.2.3 OH-58A R&M Demonstration Failure and Maintenance Action Report Data

These data were collected under an Army contract to monitor an Army test program that was conducted to determine that the OH-58A would meet specified R&M contract requirements. The data were collected by two BHT R&M engineers who were stationed at Fort Rucker to monitor two OH-58A helicopters for 2400 flight hours. The recorded data included the action date, number of flight hours, failure details, parts replaced, unscheduled maintenance performed, and mission abort information.

3.1.2.4 Use of Military Data

The sources containing military data described in sections 3.1.2.2 and 3.1.2.3 were included in this survey to supplement the limited commercial DMR data. The reason for this limitation is that BHT requires that all customer requests for warranty service and/or repair be accompanied by a DMR form. However, as these helicopters go out of warranty (500 flight hours or 6 months), the operators do not necessarily request service or repair work from BHT. AS a result, BHT's DMR file is handicapped by inconsistent reporting on the part of commercial operators who either perform their own maintenance or go directly to approved vendor supply houses for the needed parts or repair work without reporting these maintenance actions to BHT.

3.1.3 Selection of Helicopter and Components

3.1.3.1 Helicopter Selection Based on Vibration Data

As discussed in section 3.1.1, the survey of available commercial and military vibration data indicated that the Models 206 and 212 were potentially the best candidates to select as the two basic helicopter types for examination under this program. Figures 8 and 9 for the Model 206, and Figures 10 through 14 for the Model 212 are flight enveloped plots of the vibration spectrum taken for the various components reported in BHT references 1 through 5. As can be seen, these are rather limited in scope and do not provide ample data to make determinations as to the vibration environment of those areas of interest in the respective helicopters. Figures 15 through 19 provide compressed summary data that was collected by the military during their flight test programs. Compressed data or data compressions are a means of presenting the results of numerous narrow-band spectral analyses plots by using a statistical method of summarizing the data on a digital computer. In particular, Figures 15, 16, and 17 contain maximum, upper 3-Sigma, and mean vibration accelerations for the OH-58A. These plots contain compressed data for all nonfiring flights

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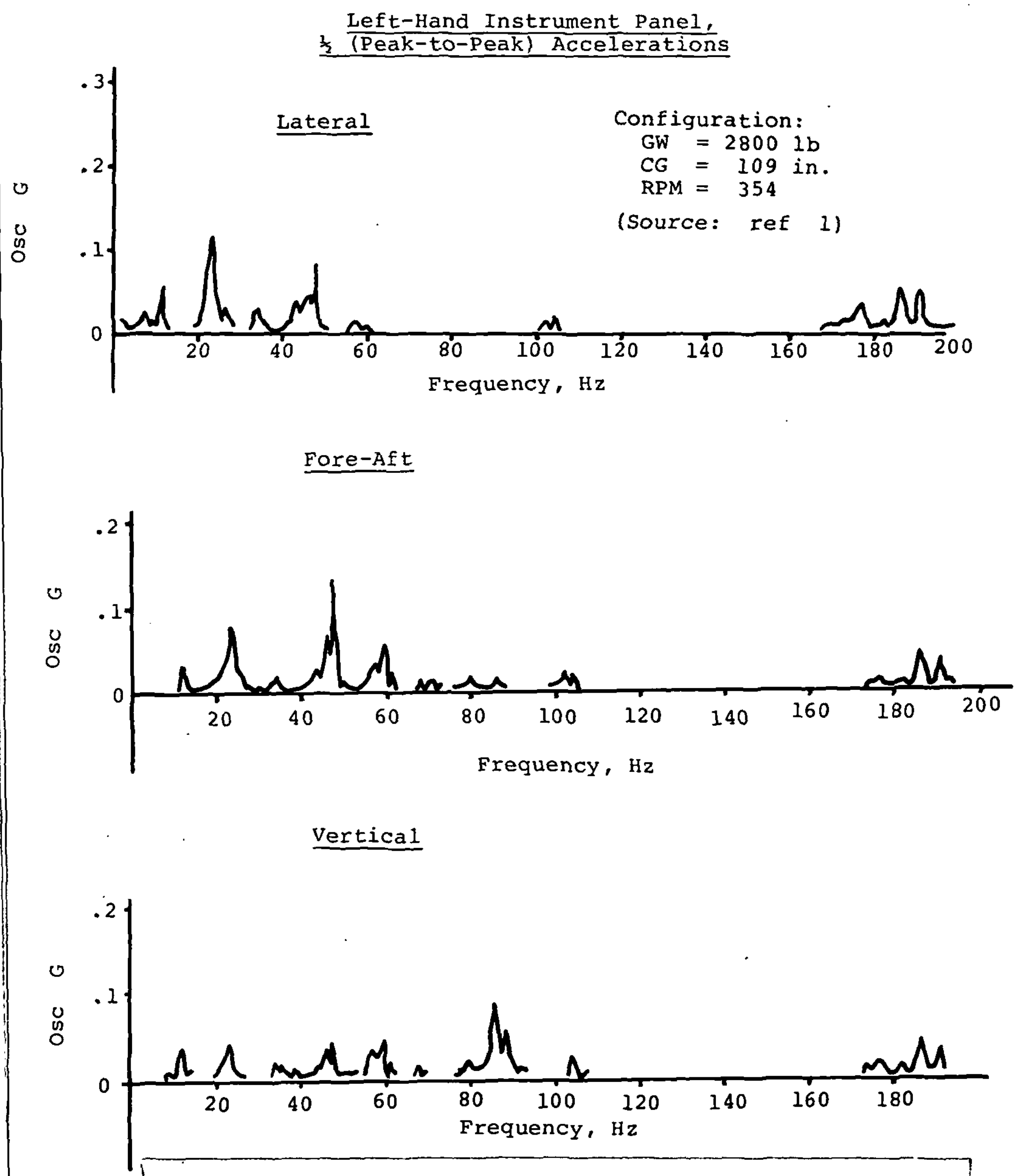

Figure 8. Model 206 vibration envelope in hover flight.

Left-Hand Instrument Panel,
½ (Peak-to-Peak) Accelerations

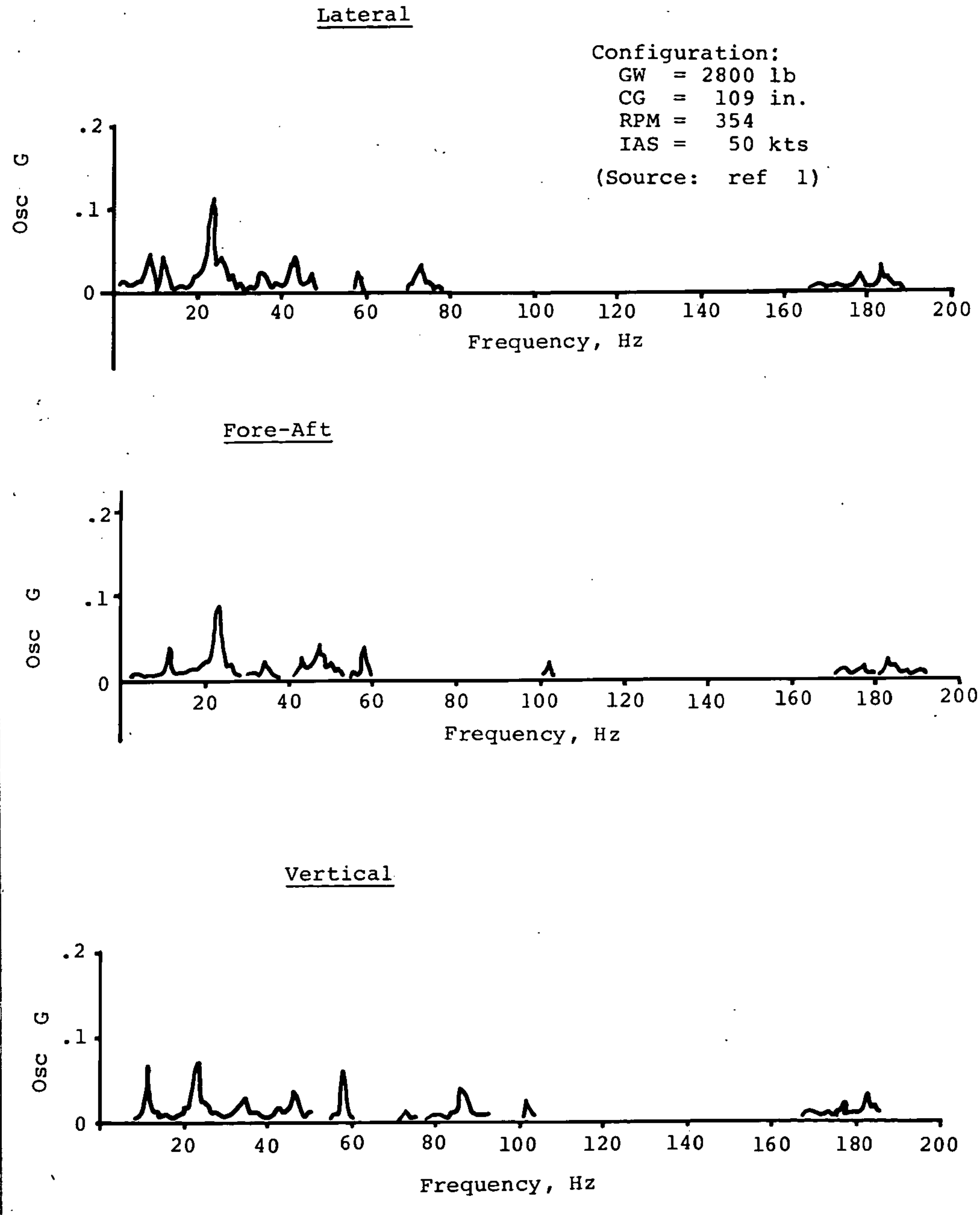

Figure 9. Model 206 vibration envelope in level flight.

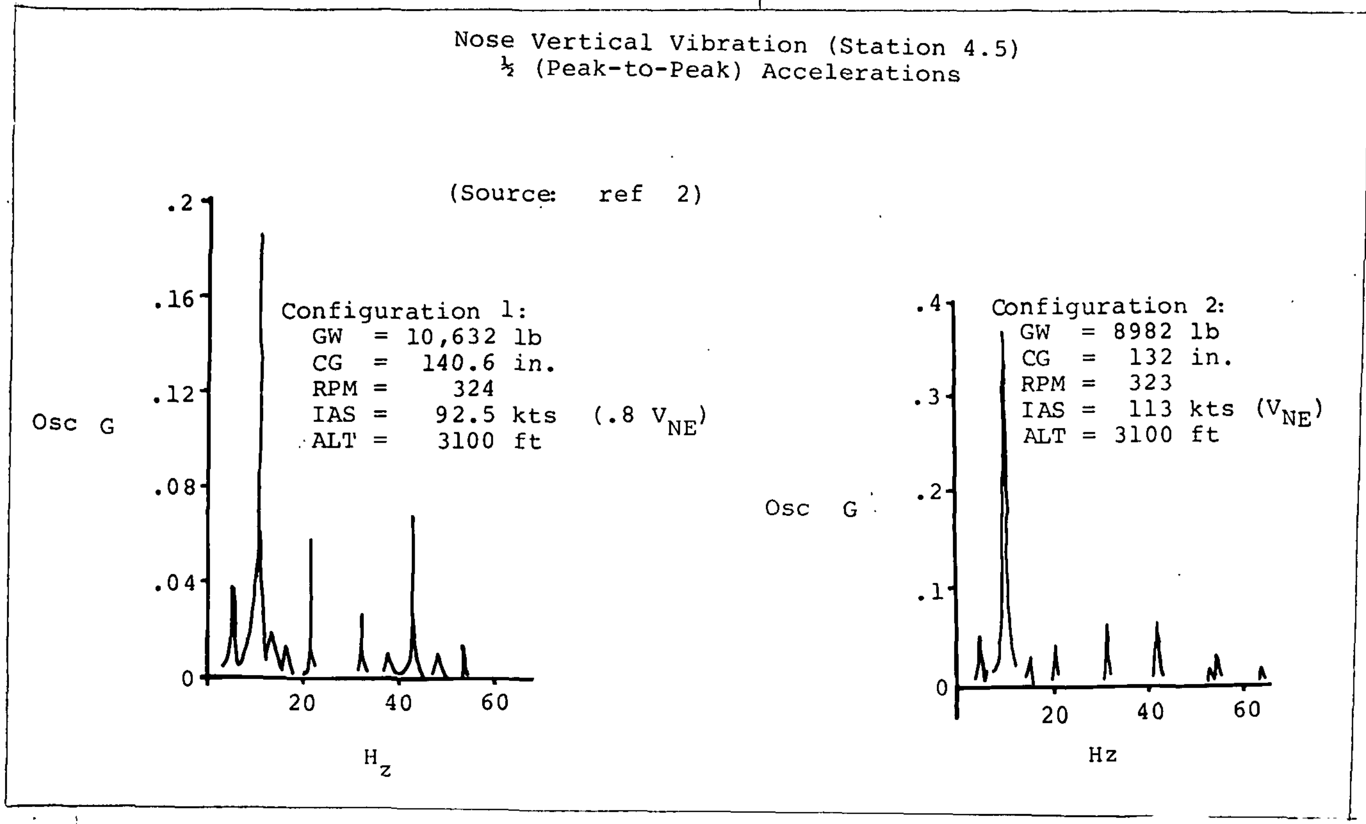

Figure 10. Model 212 magnitude-frequency spectral, nose-station 4.5.

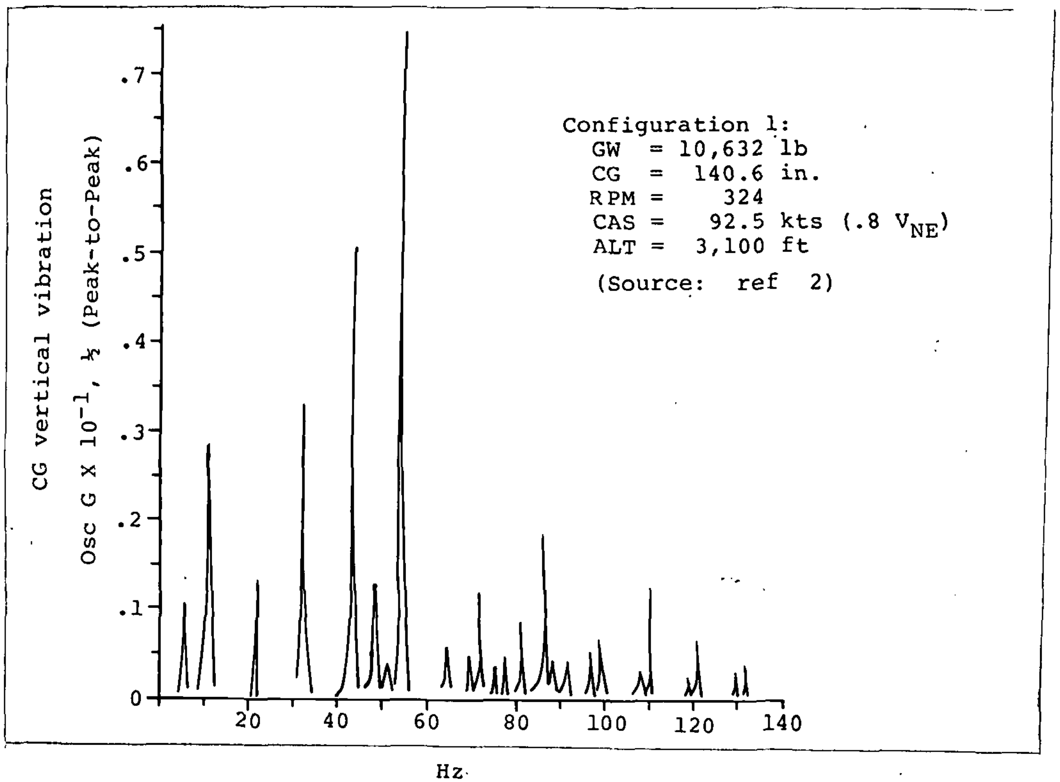

Figure 11. Model 212 magnitude - frequency spectral, C.G., Configuration 1.

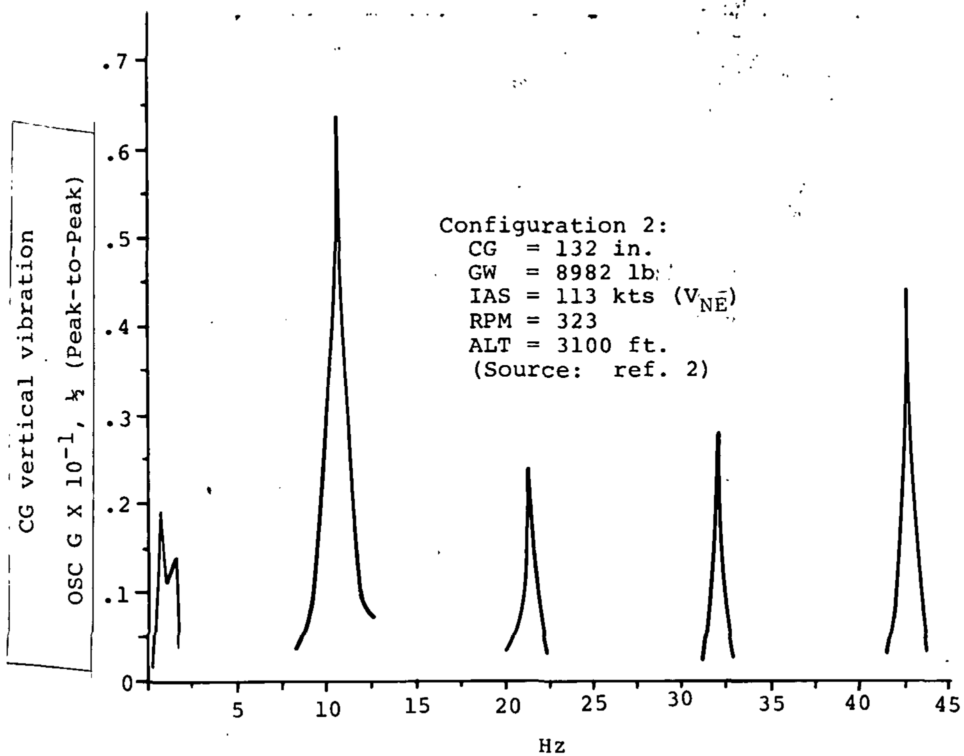

Figure 12. Model 212 magnitude - frequency spectral, C.G., Configuration 2.

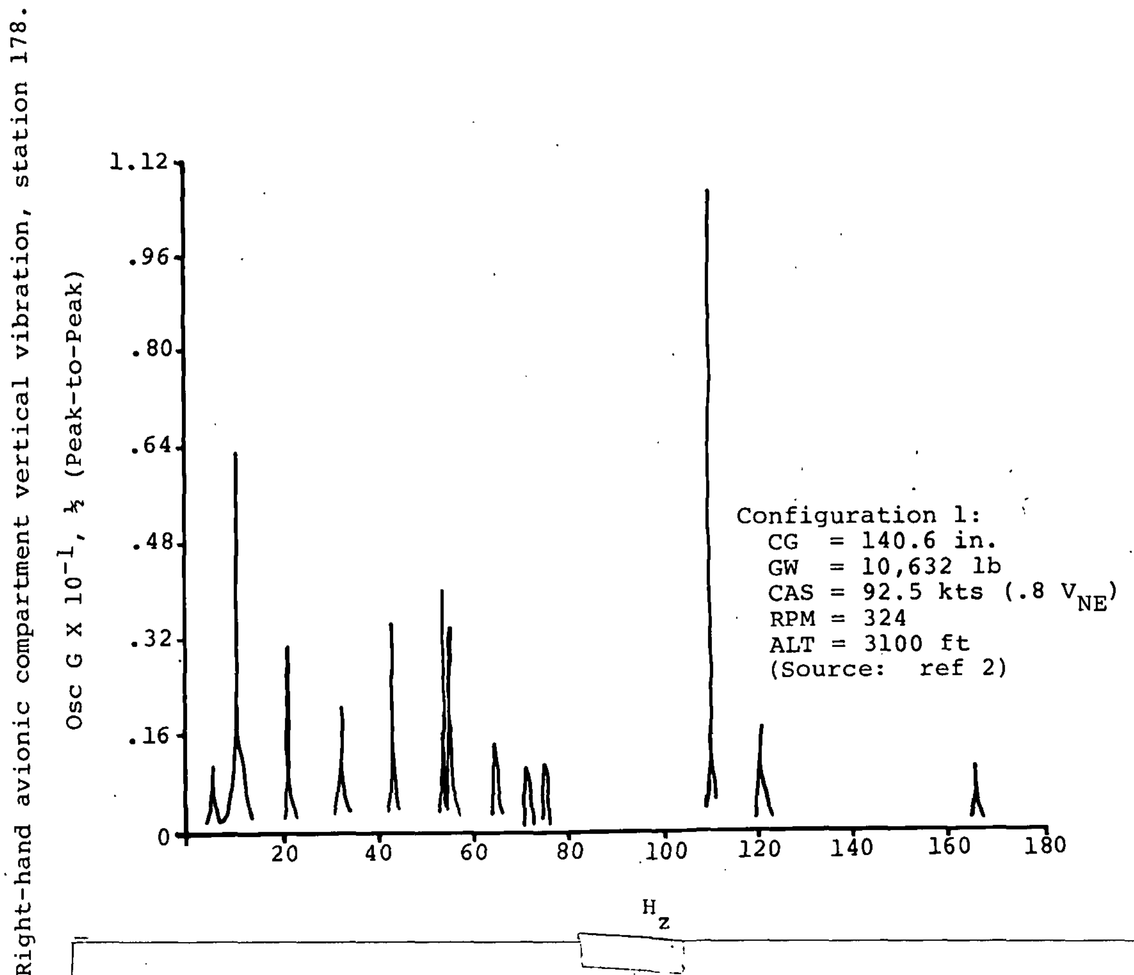

Figure 13. Model 212 magnitude - frequency spectral, R/H avionic compartment, Configuration 1.

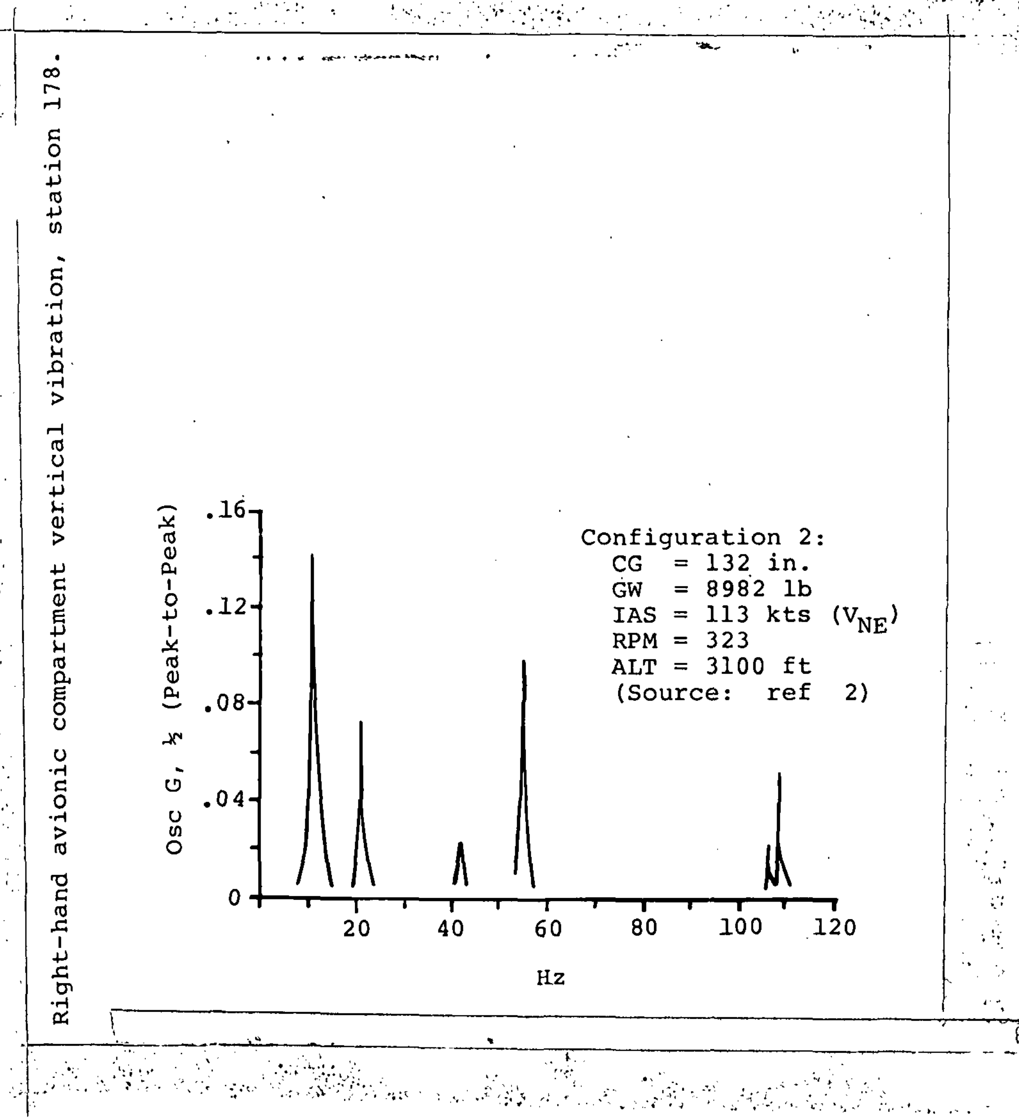

Figure 14. Model 212 magnitude - frequency spectral, right-hand avionic compartment, Configuration 2.

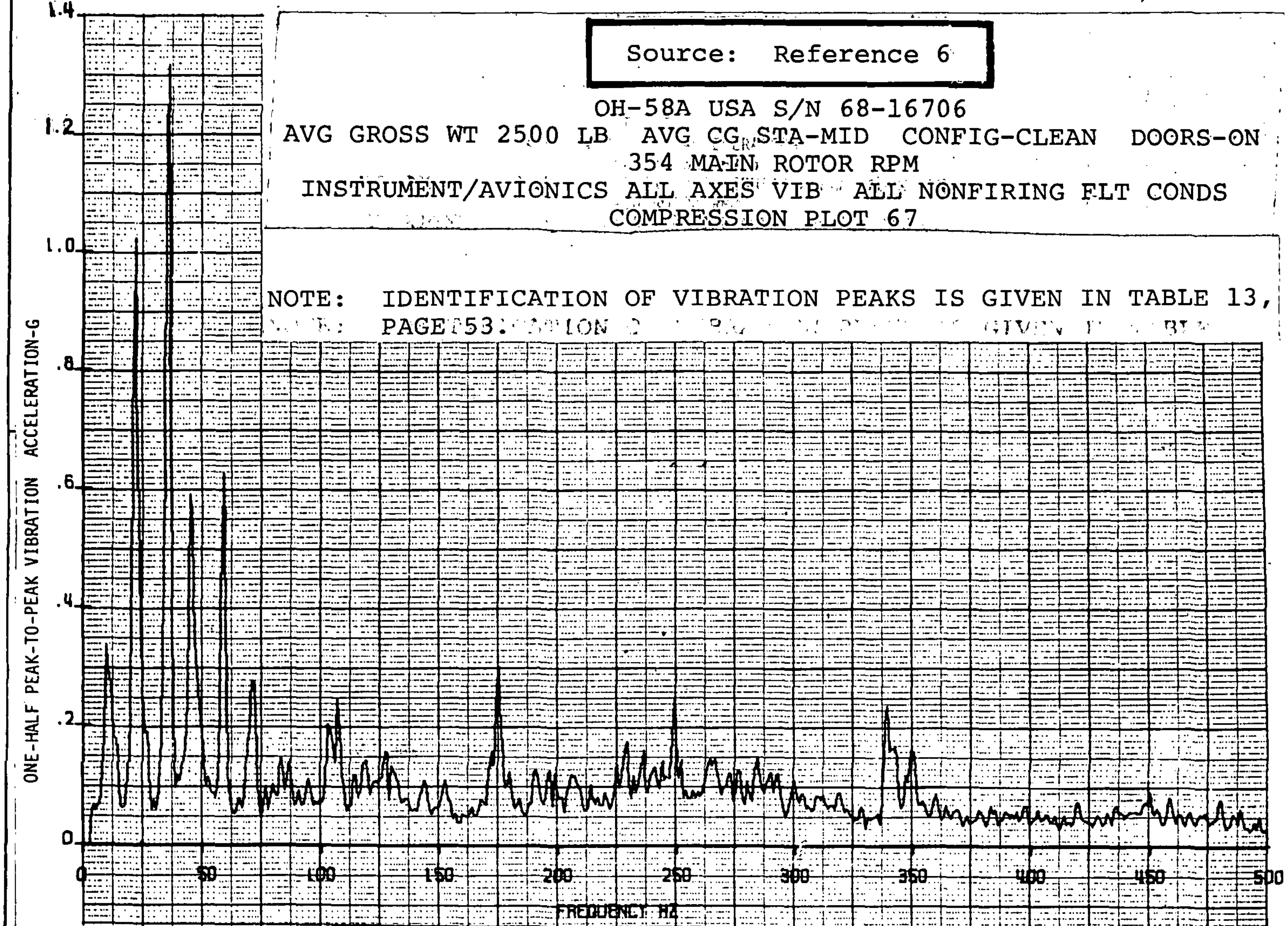

Figure 15. OH-58A maximum vibration acceleration.

Source: Reference 6

OH-58A USA S/N 68-16706
AVG GROSS WT 2500 LB AVG CG STA-MID CONFIG-CLEAN DOORS-ON
354 MAIN ROTOR RPM
INSTRUMENT/AVIONICS ALL AXES VIB ALL NONFIRING FLT CONDS
COMPRESSION PLOT 67

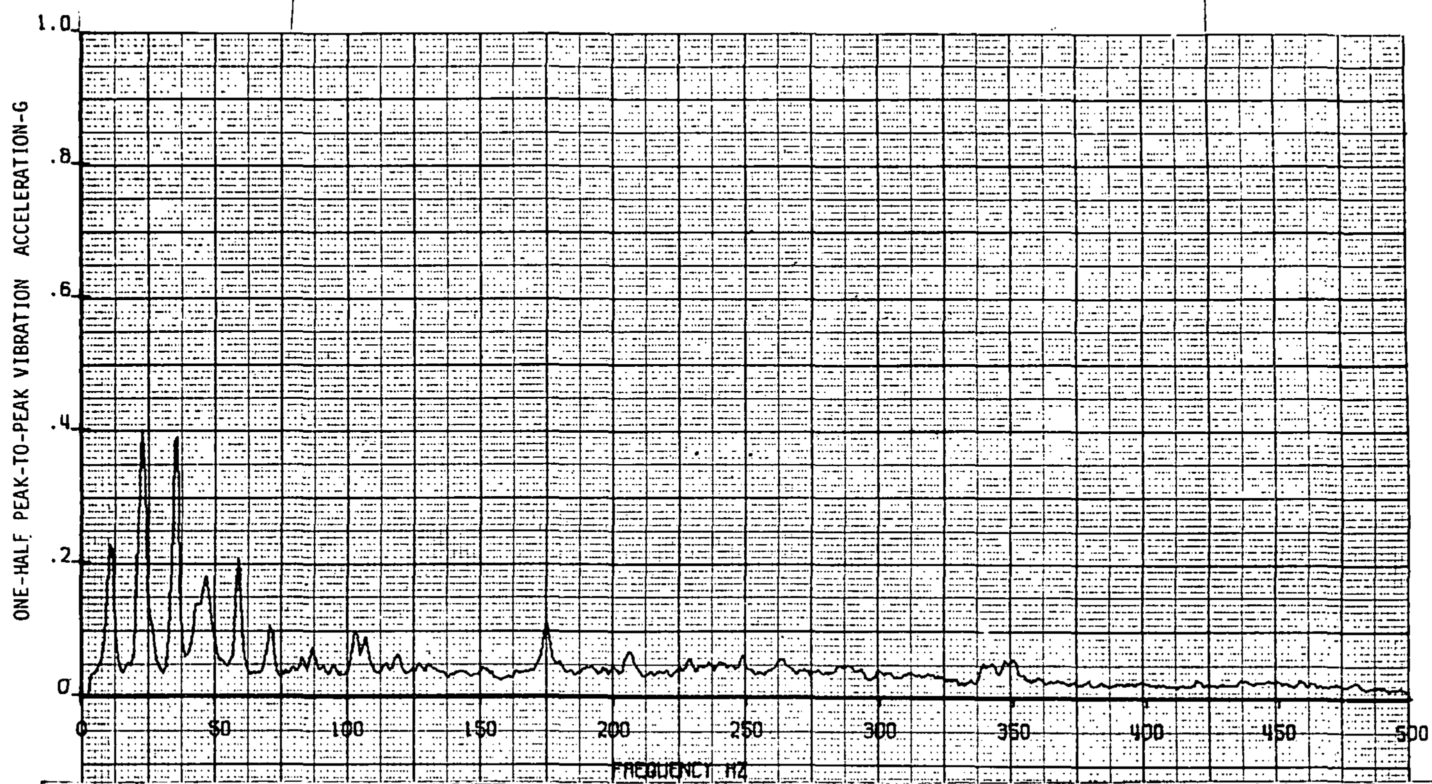

Figure 16. OH-58A upper 3-sigma vibration acceleration limits.

Source: Reference 6

OH-58A USA S/N 68-16706
AVG GROSS WT 2500 LB AVG CG STA-MID CCONFIG-CLEAN DOORS-ON
354 MAIN ROTOR RPM
INSTRUMENT/AVIONICS ALL AXES VIB ALL NONFIRING FLT CONDS
COMPRESSION PLOT 67

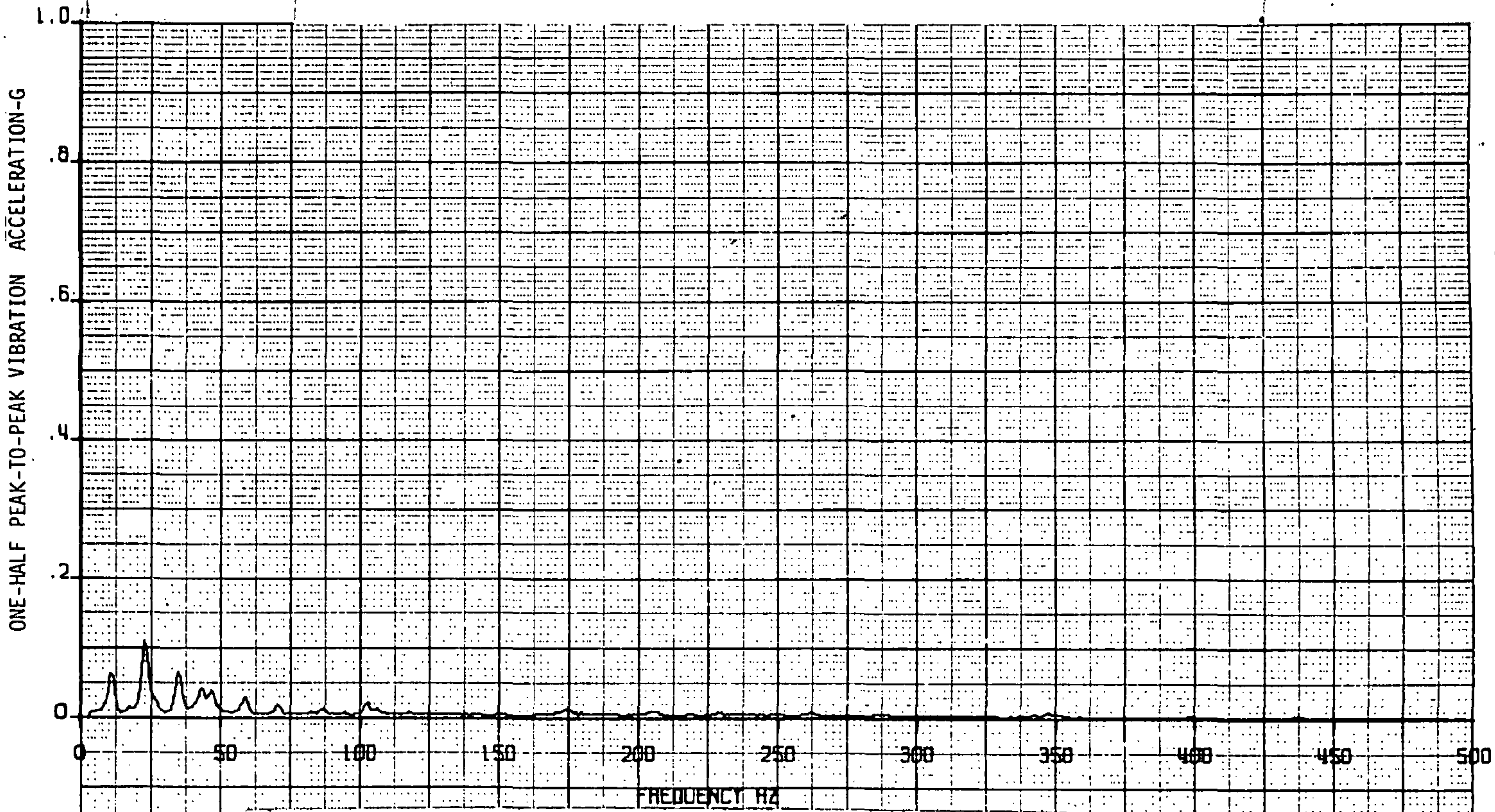

Figure 17. OH-58A mean vibration acceleration.

Source: Reference 7

UH-1H USA S/N 67-17145
GROSS WT 7000 AND 9000 LB AVG CG STA-MID CMBD CONFIG
ALL FLT CONDS INSTR PANEL AND AVIONICS COMPT CMBD AXIS VIB COMPRESSION 436
324 MAIN ROTOR RPM

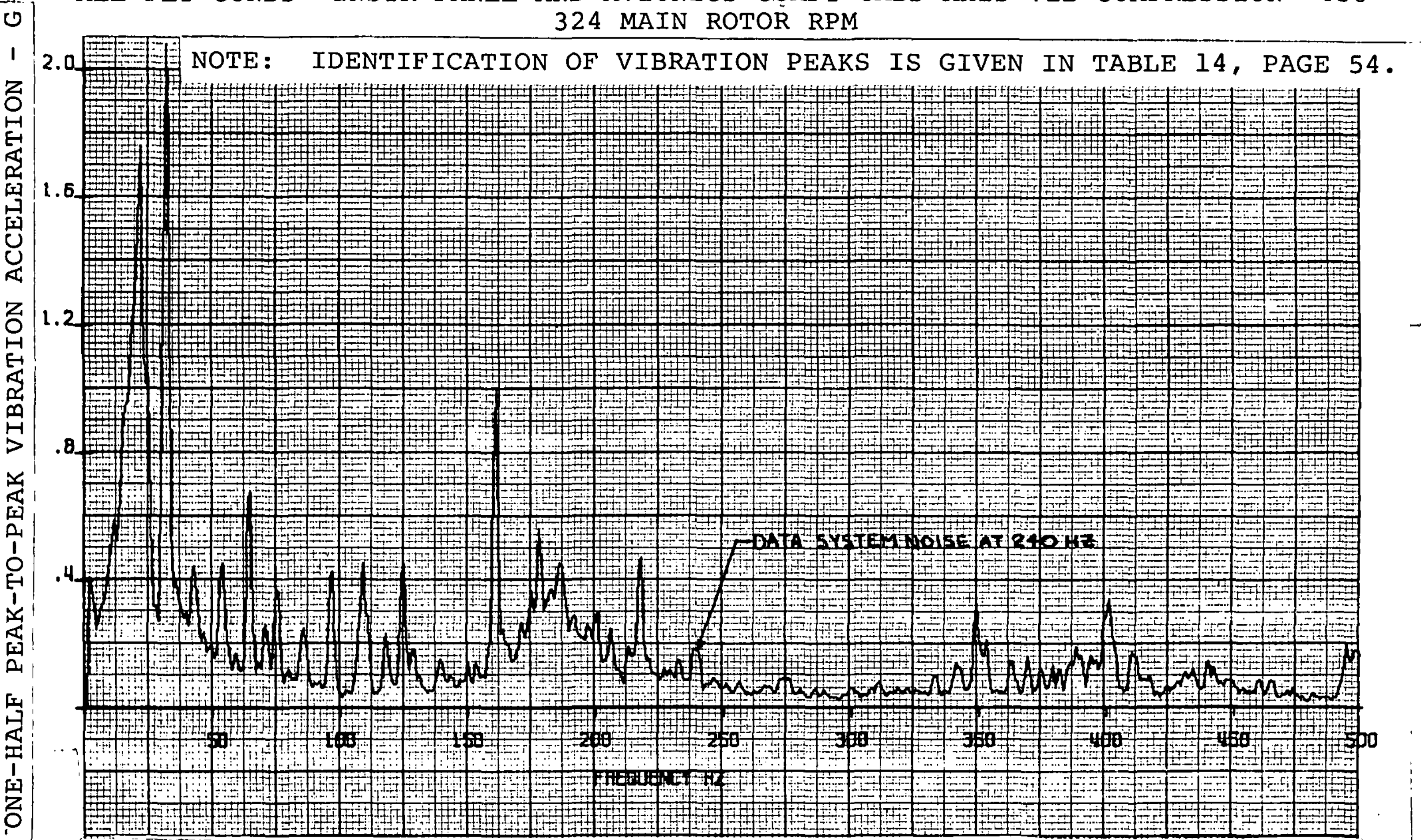

Figure 18. UH-1H compressed vibration data - maximum acceleration.

Source: Reference 7

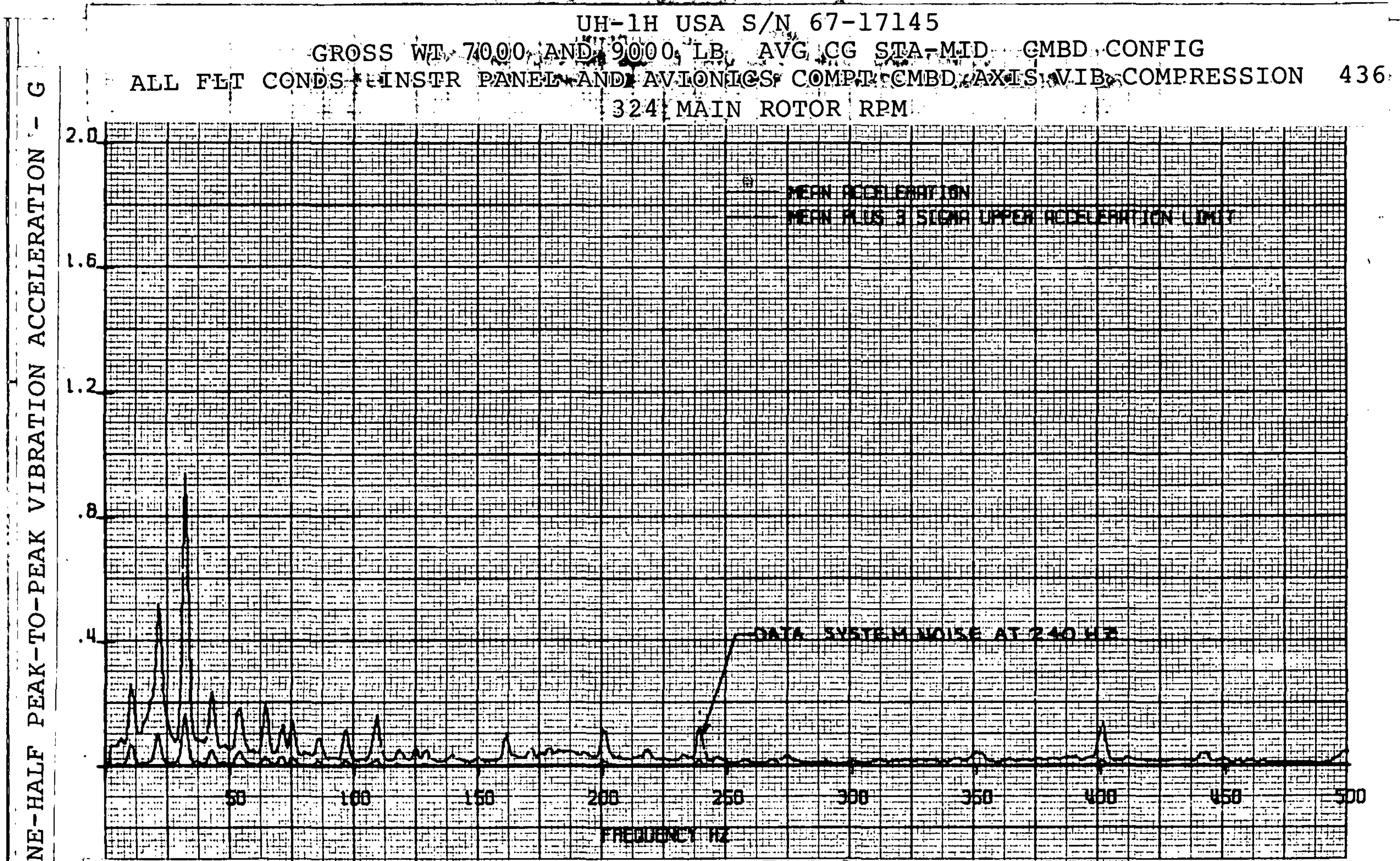

Figure 19. UH-1H compressed vibration data.

conducted during the test program. These figures were taken directly from reference 6. Similarly, Figures 18 and 19 which were taken from reference 7 also contain maximum, and mean plus 3-Sigma upper acceleration limit, respectively. Again, these plots present compressed data taken from all flights conducted during the UH-1H test program.

3.1.3.2 Helicopter Selection Based on Maintenance Data

An investigation of the available commercial data in the DMR files was conducted in an attempt to select the two helicopter types from the standpoint of maintenance data. Since most of the available commercial data were recorded against the Model 205A, 206A/B, 206L, 212, and 214B series helicopters, the investigation was limited to these models. As a primary step in determining which models had the most vibration-related failures, an analysis of the number of vibration occurrences reported for each of the selected helicopter models was accomplished. From a total of 496 failures attributed to vibration reported on the commercial models, 59 precent were recorded against the Model 206A/B and 21 percent against the Model 212. The remaining 20 percent of the occurrences were distributed among the Model 205A, 206L, and 214B helicopters. Therefore, an analysis of the maintenance and failure data also led to the conclusion that the correlation study should be based on the Models 206A/B and 212 helicopters due to the availability of commercial data in the DMR files.

Similarly, an investigation of data for military models was limited to the OH-58A R&M demonstration data, and the UH-1N and UH-1D/H 3-M data. The distribution of the 334 apparent vibration occurrences reported on military aircraft was 38 percent, 36 percent, and 26 percent for the UH-1D/H, UH-1N, and OH-58A, respectively.

These selections are further supported by BHT's production records. These records show that BHT has manufactured 2196 Model 206A/B and 427 Model 212 commercial helicopters, respectively. In addition, BHT has produced over 2400 OH-58, and 7400 UH-1 series helicopters for the military. Consequently, the large number of helicopters in these two fleets (both commercial and military) was also a strong consideration during the helicopter selection process.

3.1.3.3 Component Selection Based on DMR Data

Upon selection of the Models 206A/B and 212 as the two helicopter types for this study, it was possible to begin sorting through the DMR data to identify components that were reported most frequently. This effort resulted in a list of 34 components (see Table 3) that was submitted to the contracting

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TABLE 3. MOST FREQUENTLY REPORTED COMPONENTS

Part Name	Failure Quantities 206A/B	Failure Quantities 212	Location
Pressure (Press.) Transducer	756		Engine (Eng.) compartments
Press. Transmitter		5	Forward (Fwd.) Eng. Firewall
Turbine Outlet Temperature (Temp.) Indicator	425		Instrument panel
Inlet Turbine Temp. Indicator		25	Instrument panel
Fuel Boost Pump	289	56	Fuel cells below and aft of passenger seat
Torque Indicator	207		Instrument panel
Dual Torque Indicator		60	Instrument panel
Dual Tachometer Indicator	138		Instrument panel
Triple Tachometer Indicator		28	Instrument panel
Static Inverter	2	105	Nose compartment (Comp.)
Attitude Indicator	100	28	Instrument panel
Gas Producer Tachometer Indicator	96	14	Instrument panel
Voltage Requlator	20	87	206A/B-below instrument panel or aft of hat box - electrical (elec.) comp. 212 - Nose comp.
Transmission (Xmsn.) Oil Temp./ Press. Indicator	83	27	Instrument panel
Hydraulic Pump	8	77	Near transmission
Hydraulic Pump + Reservior Assy.	63		Near transmission
Directional Gyro	76		Instrument panel
3-Axis Gyro (Tarsyn)		49	Aft of passenger door
Eng. Oil Temp./Press. Indicator	68	22	Instrument panel
Power Supply	51	65	Fwd. Section Elec. Installation
Turn & Slip Indicator	63	4	Instrument panel

TABLE 3. MOST FREQUENTLY REPORTED COMPONENTS (Concluded)

Part Name	Failure Quantities 206A/B	212	Location
Hydraulic Actuator Assy. (3 per helicopter)	144	50	206A/B - fwd. pylon
Torque Transmitter	-	50	Engine
Relay Inverter	-	48	Nose, Lower
RPM Warning Box RPM Sensor	 57	42	Nose, Upper Nose Compartment
Headset	2	31	Upper cockpit
Tail Rotor (T/R) Driveshaft (D/S) Hanger Bearings	140	34	Tail Rotor Driveshaft
Starter Generator	110	23	Engine
Isolation Mount	57	-	Fuselage - Upper
Tail Rotor Hanger	23	13	Tail Rotor Driveshaft
Directional Actuator	13	21	206A/B - fuselage - above aft of baggage compartment 212 - fuselage - under eng. deck fwd. of tail-boom
Navigation Lights	9	0	206A/B - stabilizer assy. top of fin 212 - fwd. half of tail-boom
Tail Lights	2	3	206A/B - end of tail 212 - tailboom - lower aft

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officer at NASA Langley. A list of ten components that are substantially different and located in separate areas of the airframe were then mutually chosen by the BHT and NASA Langley Project Engineers with verbal concurrence from the Contracting Officer. Table 4 presents a list of the ten components selected for analysis under this program.

The selection was based primarily on the location of the equipment items in the airframe and their proximity to accelerometers used during the vibration surveys discussed in Section 3.1.1. Figure 20 and 21 illustrate the locations of the selected components from both side and top views of each of the two helicopters. A further consideration was to identify those components whose failure modes and failure rates could be obtained and correlated with the available vibration data. However, the discovery of voids in the data with respect to failure modes led to difficulties in establishing the primary cause of component failure that would be typical of both of the selected helicopter systems. The problem is that DMR reports submitted to BHT by the helicopter operators may or may not describe the reason for the failure and/or replacement of the components. Also, these reports usually are highly subjective, making it extremely difficult or impossible to ascertain the results of the data. Nevertheless, the selected components seem to fail or need replacement more often than expected and therefore were investigated with the assumption that vibration is the primary cause of reported failures.

x 10

TABLE 4. SELECTION OF FAILED COMPONENTS

Helicopter Area	Component	Baseline Helicopter Model	
		206A/B	212
Instrument Panel	Torque Indicator	√	√
	Attitude Indicator	√	√
	Oil Temp./Press.	√	√
Nose	RPM Sensor (Warning Box)	√	√
	Voltage Regulator	√	√
	Power Supply	-	√
Transmission	Power Supply	√	-
Engine	Starter Generator	√	√
	Torque Transmitter	-	√
	Fuel Transducer	√	-
Driveshaft	Driveshaft Hangers	√	√

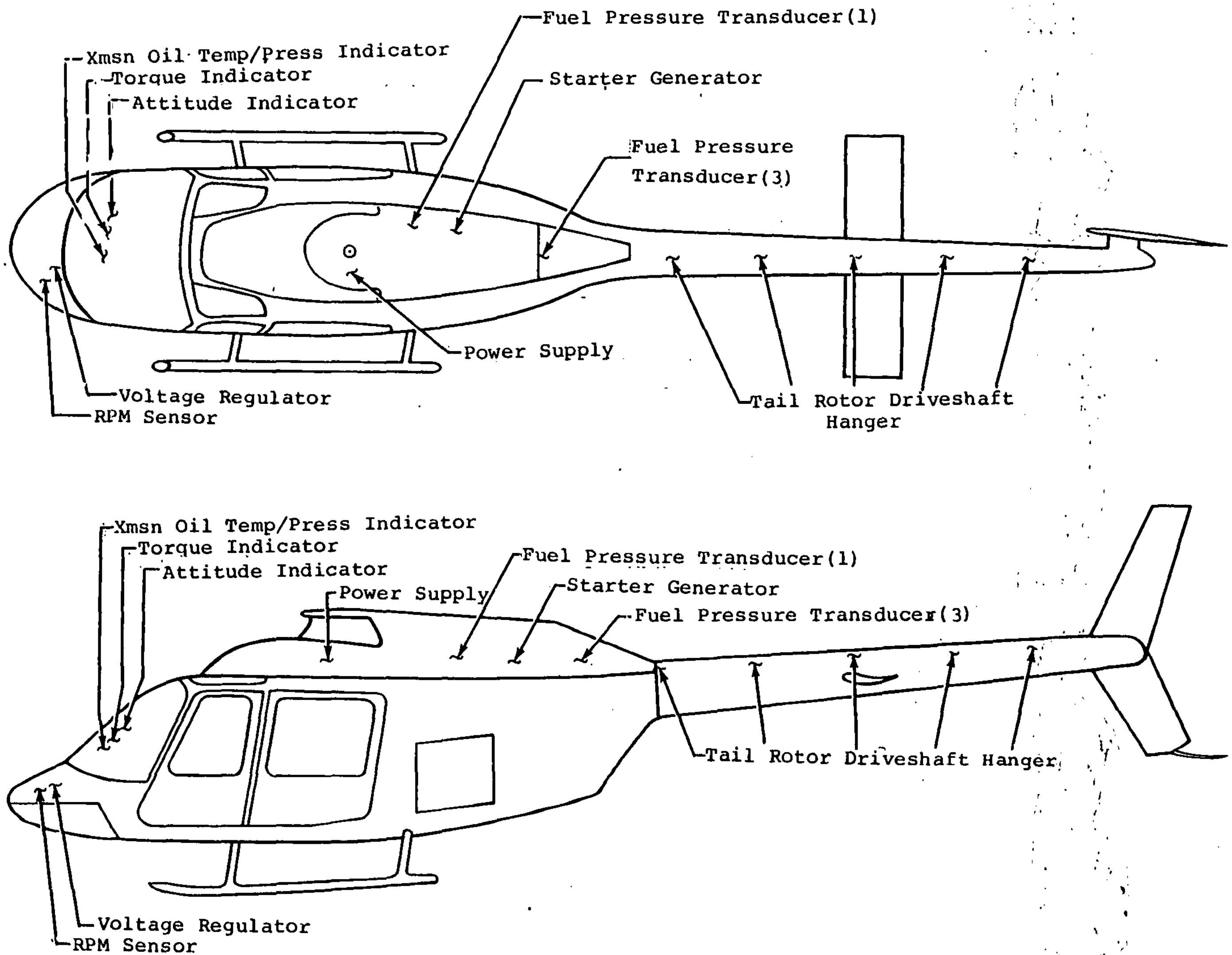

Figure 20. Model 206A/B selected component locations.

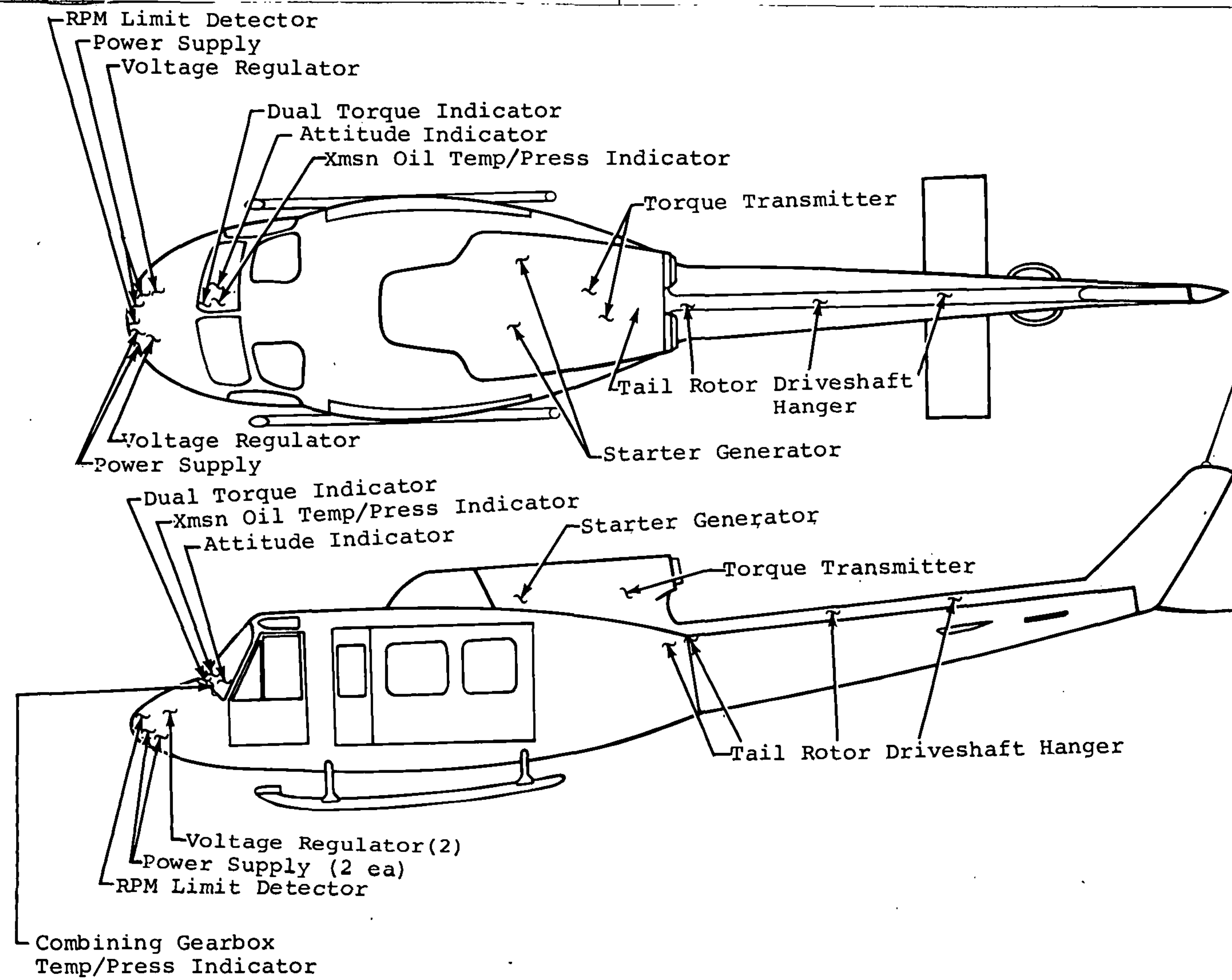

Figure 21. Model 212 selected component locations.

3.2 DATA CORRELATION

3.2.1 Helicopter Mission Profiles

As specified in Task II of the contract statement of work, an attempt was made to categorize the failure rates of the selected components according to the primary use of the selected helicopters. To accomplish this, BHT conducted a statistical sampling by contacting ten different operators and obtaining data from them (as shown in Table 5 for the Model 206A/B and Table 6 for the Model 212). The operator's identities and the number of aircraft and flight hours flown per aircraft per year for each operator have been excluded from Tables 5 and 6 to preserve information that is proprietary to each of the individual operators. However, the total number of aircraft and the total number of flight hours per year have been included at the bottom of Tables 5 and 6, respectively. From these data, a weighted average was calculated for each mission profile by the following relationship:

$$(WA)_{ik} = \frac{\sum_{j=1}^{10} (FH)_{ij}(A/C)_{ij}(PMT)_{ikj}}{\sum_{j=1}^{10} (FH)_{ij}(A/C)_{ij}}$$

where

$(WA)_{ik}$ = weighted average for each of the two helicopter types and for each of the three missions (hover, cruise, maneuver)

$(FH)_{ij}$ = flight hours per helicopter type per year per operator

$(A/C)_{ij}$ = number of each type of helicopter per operator

$(PMT)_{ikj}$ = percent of time in each mission per helicopter type per operator

i = counter for helicopter types (i = 1,2)

j = counter for surveyed operators (j=1,...,10)

k = counter for missions (k = 1,2,3)

The analysis resulted in weighted averages which provide percent of time values of mission profiles for both the Model

TABLE 5. MODEL 206A/B STATISTICAL SAMPLE OF COMMERCIAL OPERATORS' MISSION PROFILES

Operator No.	% Hover	% Cruise	% Maneuver
1	5	70	25
2	5	70	25
3	10	75	15
4	5	80 (35)*	15 (60)*
5	20	40	40
6	5	85	10
7	2	96	2
8	15	30	55
9	10	90	-
10	5	90	5

Total Number of Aircraft in Sample: 327
Total Flight Hours per year: 335,400

*Aerial Applications Mission

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TABLE 6. MODEL 212 STATISTICAL SAMPLE OF COMMERCIAL OPERATOR'S MISSION PROFILES

Operator No.	% Hover	% Cruise	% Maneuver
1	90*	10	-
2	90*	10	-
3	10	60	30
4	-	-	-
5	-	-	-
6	5	85	10
7	2	96	2
8	-	-	-
9	-	-	-
10	8	87	5

Total Number of Aircraft in Sample: 50; 18*
Total Number of Flight Hours per Year: 71,200; 19,000*

*Sling and Logging/Heavy Lift Mission

206A/B and 212 fleets, Table 7. These weighted averages are reasonable and fairly representative in light of the fact that they represent a 14.9 percent sample for the Model 206A/B and 15.9 percent for the Model 212. Note that these were obtained by taking a ratio of the 327 Model 206A/Bs with the 2196 aircraft in the field as mentioned in Section 3.1.3.2; and similarly taking a ratio of the 68 Model 212s with the 427 aircraft also mentioned in Section 3.1.3.2. Using this sample of aircraft, an average of 1025 flight hours per aircraft per year was determined for the Model 206A/B. Similarly, for the Model 212 averages of 1424 and 1055 flight hours per aircraft per year were obtained for normal, and sling-and-logging operations, respectively.

It is interesting to note from Table 7 that the operators fly the Models 206 and 212 in cruise 87.6 and 92.4 percent of the time, respectively. That is, the prime area of concern in providing a service to customers is moving people and/or equipment over a substantial distance requiring longer periods in the cruise mode of the helicopter mission.

BHT design criteria for the OH-58A and UH-1H were also studied to determine the breakdown of missions which the military anticipated for utilization of their fleet. The results of this investigation are shown in Table 8 where percentages of time for hover, cruise, and maneuver are included.

An examination of the data in Tables 7 and 8 shows that commercial operators are utilizing their aircraft differently than the military. Civilian helicopters are used in cruise flight approximately 12 percent more than are the military helicopters. This shows that the civilian machines are subjected to a different vibration spectrum due to the dissimilar mission profile. This is further complicated by the various gross weight configurations flown by the civilian operator as a result of increased payload, required mission equipment, and other FAA considerations.

3.2.2 Component Failure-Rate Categorization

3.2.2.1 Component MTBFs

During this task, efforts were directed toward categorization of the failure rate of the identified components with the associated helicopter vibration environment. In order to accomplish this, the mean-time-between-failure for each selected component was calculated. The MTBF of a component was derived by dividing the total number of flight hours for each aircraft type by the total number of failures of the particular component. That is: MTBF = t/n

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TABLE 7. SUMMARY OF MISSION PROFILE SURVEY FOR COMMERCIAL OPERATORS

Ship Model	No. A/C	Flt. Hr. per Year	Percent of time (Weight averages)		
			Hover	Cruise	Maneuver
206A/B	320	332,600	4.2	87.6	8.2
212	50	71,200	3.2	92.4	4.4
212*	18*	19,000*	90.0*	10.0*	-

*Sling and Logging/Heavy Lift Mission

TABLE 8. MILITARY MISSION PROFILES

Ship Model	Percent of Time		
	Hover	Cruise	Maneuver
OH-58	15	75	10
UH-1H	10	80	10

where

t = total flight hours per aircraft model

n = total number of failures of a component (from Table 3)

Two approaches were used in determining the total number of flight hours for each aircraft model. These were:

- Flight hours were summed for helicopters for which operators submitted DMRs documenting the failures of the selected component only, (t_1), and
- Flight hours were summed for all helicopters for which operators submitted DMRs to document failures of any component, (t_2), not necessarily on the selected list of components for this study.

The two sets of MTBF were calculated for each component using t_1, and t_2 values. Tables 9 and 10 present the results of this exercise.

3.2.2.2 <u>Component MTBFs - Upper and Lower 80 Percent Confidence Limit</u>

A lower 80 percent confidence limit ($MTBF_L$) was calculated for each component. Simply expressed this is two times the total flight hours divided by a chi-square factor.

$$MTBF_L = \frac{2T}{\chi^2_{2(r+1),.2}}$$

where

T = the total flight hours

χ^2 = chi-square factor obtained from tables at $2(r+1)$ degrees of freedom and 20th percentile

r = number of failures of the component

$MTBF_L$ values were calculated for each component using the values of t_1 and t_2 for the flight hours and are included in Tables 9 and 10.

Similarly, the upper 80 percent confidence limits ($MTBF_U$) were calculated for each component by using the expression

$\int \cdot / \ell \ell$

TABLE 9. SELECTED COMPONENT MTBF VALUES BASED ON SELECTED AIRCRAFT*

Part Name	Aircraft Model	Qty. per Aircraft	Failure Qty. per Aircraft	Location on Aircraft	MTBF	MTBF[1]	MTBF[2]
Torque Indicator	206 A/B	1	207	Instrument Panel	4579	4308	4865
Dual Torque Indicator	212	1	60	Instrument Panel	4076	3625	4579
Attitude Indicator	206 A/B	1	100	Instrument Panel	9478	8668	10358
	212	1	28	Instrument Panel	8734	7321	10415
Xmsn Oil Temp/Press Indicator	206 A/B	1	83	Instrument Panel	11419	10347	12595
	212	2	27	Instrument Panel	18115	15130	21679
RPM Sensor	206 A/B	2	57	Nose	33256	29484	37486
RPM Limit Detector	212	1	42	Nose	5823	5053	6705
Voltage Regulator	206 A/B	1	20	Nose	47390	38334	58595
	212	2	87	Nose	5622	5106	6186
Starter Generator	206 A/B	1	110	Engine	8616	7914	9376
	212	2	23	Engine	21266	17472	25878
Pressure Transducer (Engine)	206 A/B	4	742	Engine	5015	4860	5174
Pressure Transducer (Xmsn)	206 A/B	1	14	Xmsn			
Torque Transmitter	212	2	50	Engine	9782	8597	11123
T/R D/S Hangers	206 A/B	5	23	Tail Rotor Driveshaft	206045	169291	250736
	212	4	13	Tail Rotor Driveshaft	75247	57496	98710
Power Supply	206 A/B	1	51	Pylon	18584	16335	21102
	212	4	65	Nose	15049	13452	16826

*Total Flight Hours - Selected A/C on DMR File for Models: 206 A/B = 947,807 on 634 A/C
212 = 244,554 on 147 A/C

[1]Lower 80% Confidence Limit

[2]Upper 80% Confidence Limit

TABLE 10. SELECTED COMPONENT MTBF VALUES BASED ON ALL AIRCRAFT*

Part Name	Aircraft Model	Qty. per Aircraft	Failure Qty. per Aircraft	Location on Aircraft	MTBF	MTBF[1]	MTBF[2]
Torque Indicator	206 A/B	1	207	Instrument Panel	12865	12103	13670
Dual Torque Indicator	212	1	60	Instrument Panel	6709	5968	7538
Attitude Indicator	206 A/B	1	100	Instrument Panel	26630	24354	29103
	212	1	28	Instrument Panel	14377	12051	17145
Xmsn Oil Temp/Press Indicator	206 A/B	1	83	Instrument Panel	32084	29072	35388
	212	2	27	Instrument Panel	29819	24906	35686
RPM Sensor	206 A/B		57	Nose	93438	82840	105320
RPM Limit Detector	212	1	42	Nose	9585	8318	11037
Voltage Regulator	206 A/B	1	20	Nose	133150	107705	164632
	212	2	87	Nose	9254	8406	10182
Starter Generator	206 A/B	1	110	Engine	24209	22237	26343
	212	2	23	Engine	35005	28761	42598
Pressure Transducer (Engine)	206 A/B	3	742	Engine	{ 14090	13656	14536
Pressure Transducer (Xmsn)	206 A/B	1	14	Xmsn			
Torque Transmitter	212	2	50	Engine	16102	14152	18309
T/R D/S Hangers	206 A/B	5	23	Tail Rotor Driveshaft	578912	475646	704478
	212	4	13	Tail Rotor Driveshaft	123865	94645	162486
Power Supply	206 A/B	1	51	Pylon	52216	45953	59290
	212	4	65	Nose	24773	22143	27698

*Total Flight Hours - All A/C on DMR File for Models: 206 A/B = 2,662,997
212 = 402,560

[1]Lower 80% Confidence Limit

[2]Upper 80% Confidence Limit

$$MTBF_U = \frac{2T}{\chi^2_{2r,.8}}$$

These values are also shown in Tables 9 and 10.

3.2.2.3 <u>3-M Data MTBFs</u>

The 3-M data for the Navy versions of the Model 206A/B and 212, TH-57A and UH-1N, respectively, were examined by sorting the data according to Work Unit Code (WUC). The MTBFs for each component were calculated for comparison to DMR MTBF data. This was done to provide a basis for determining if similar trends exist between civil and military applications of similar aircraft. Also, this trend analysis may provide enough information to determine if additional data collection on commercial helicopters is justified. The MTBF values derived from 3-M data are shown in Table 11.

3.2.2.4 <u>Component Dynamic Characteristics</u>

Prior to comparison studies of the reliability data, BHT conducted an examination of vendor's component qualification test reports to determine if dynamic characteristics of the components are readily available. These reports were researched in microfiche form and reproduced for further data analysis. The results of the component dynamic characteristics data analysis are shown in Table 12.

Practically all component qualification vibration tests were based on MIL-STD-810 or other appropriate military specifications. Once the criteria of the test specification were met, a component was considered to have passed qualification testing. Nevertheless, it can also be seen that not all dynamic characteristics were reported. Some components were tested but the results were not available in the respective qualification reports. This was the case for items such as the attitude indicator, transmission oil temperature/pressure indicator, voltage regulator, etc. Furthermore, dynamic response data were not readily available for the tail rotor driveshaft hangers and therefore not included in the table listing. The data shown in Table 12 are not sufficient to make judgements concerning the interrelationship between the vibration environment of the helicopter and the dynamic characteristics of the selected components.

TABLE 11. 3-M DATA MTBF VALUES

Part Name	Model	MTBF
Torque Indicator	206A/B	1319
Dual Torque Indicator	212	340
Attitude Indicator	206A/B	-
Attitude Indicator	212	381
Xmsn Oil Temp/Press Indicator	206A/B	4130 (Temp) 2242 (Press)
Xmsn Oil Temp/Press Indicator	212	3534
RPM Sensor	206A/B	-
RPM Limit Detector	212	1788
Voltage Regulator	206A/B	2616
Voltage Regulator	212	452
Starter Generator	206A/B	262
Starter Generator	212	821
Pressure Transducer (Engine + Xmsn)	206A/B	4647
Torque Transmitter	212	8969
T/R Driveshaft Hangers	206A/B	4757
T/R Driveshaft Hangers	212	1024
Power Supply	206A/B	-
Power Supply	212	-

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TABLE 12. SELECTED COMPONENTS' DYNAMIC CHARACTERISTICS

Part Name	Model	Freq. ~ Hz	Acceleration	Axis	Time	Resonance	Remarks
Instrument Panel							
Torque Indicator	206 A/B	5-50	1.5g	X,Y,Z		No	No natural frequency.
		50		X,Y,Z	1 hr.	No	
Dual Torque Indicator	212	100	12g*	X	30 min	Yes	Varied frequency and range Vib. freq. | Vib. Amplitude 3.75 to 10 Hz | 0.4 in. D.A.** 10 to 250 Hz | ±2g 250 to 400 Hz | 0.0006 in. D.A. 400 to 500 Hz | ±5g
		103	15g*	X	30 min	Yes	
		105	19g*	X	30 min	Yes	
		109	9g*	X	30 min	Yes	
		90	6g*	Y	30 min	Yes	
		100	9g*	Y	30 min	Yes	
		105	15g*	Y	30 min	Yes	
		-	-	Z		No	
Attitude Indicator	206 A/B						Must be subjected to a vibration of 0.002 to 0.005 in. D.A. at 25-33.3 Hz. Must not be adversely affected when subjected to vib. of the following characteristics: Inst. Loc. | Hz | DA(in) | Max Acc. Power Plant | 5-150 | 0.100 | 20g Wings (Emp) | 5-500 | 0.036 | 10g Fuselage | 5-500 | 0.036 | 5g Panel or Rack (with shock-mounts) | 5-50 | 0.020 | 1.5g
Attitude Indicator	212						Per MIL-I-53034 and MIL-STD-810 2g input from 5-500 Hz, D.A. ≤.1 in.
Transmission Oil Temp/ Press Indicator	206 A/B						TSO Vib. test; .1 in. D.A. at 20 Hz to .00001 in. D.A. at 2000 Hz. Max. wt. = 1 lb.
Transmission Oil Temp/ Press Indicator	212						

* Peak Output
** Double Amplitude

TABLE 12. (Continued)

Part Name	Model	Freq. Hz	Accelera-ation	Axis	Time	Reso-nance	Remarks
Nose							
RPM Sensor	206 A/B	5-10	2g			No	
		410	±6g*			Yes	
RPM Limit Detector	212	135		X		Yes	5-500-5 Hz frequency range with
		182		X		Yes	sweep rate of 15 min. and
		219		X		Yes	5-10 Hz - .40 in. D.A.**
		258		X		Yes	10-33 Hz - 2g. Unit failed.
		139		X		Yes	33-53 Hz - .036 in. D.A.
		185		X		Yes	53-500 Hz - 5g. Unit failed.
		270		X		Yes	
		440		X		Yes	
		225		X		Yes	Unit failed.
		280		X		Yes	
		315		X		Yes	
		250		X	2 hr 15 min	Yes	Unit failed.
		360		X	2 hr 15 min	Yes	Unit failed.
		218		X		Yes	Unit failed.
		395		X		Yes	
		275		X		Yes	
		400		X		Yes	
		105		X		Yes	
		135		X		Yes	
		187		X		Yes	
		385		X		Yes	
		120		Y,Z		Yes	
		120		X		Yes	Unit failed.
		150		Y,Z		Yes	
		195		Y,Z		Yes	
		200		Y,Z		Yes	
		360		X		Yes	Unit failed.
		420		X		Yes	Unit failed.
		220		X		Yes	
		395		X		Yes	
		445		X		Yes	
		360		Y,Z		Yes	
		420		Y,Z		Yes	
		370				Yes	Unit failed.

* Peak Output
** Double Amplitude

TABLE 12. (Continued)

Part Name	Model	Freq. Hz	Acceleration	Axis	Time	Resonance	Remarks
Nose							
RPM Limit Detector (Continued)		495				Yes	Unit failed.
		275				Yes	
		445				Yes	
		360		Z		Yes	
		405		Y		Yes	
		320		X		Yes	
Voltage Regulator	206 A/B						Units should not be damaged by 0.1g at 6.67 Hz 0.3g at 13.3 Hz 10g at 100 Hz Frequencies within 10% of above shall not produce resonance of unit or parts of the unit.
Voltage Regulator	212						MIL-STD-810
Engine							
Starter Generator	206 A/B	243	10g	X	28 min	Yes	Do not exceed .001 in D.A.
		248	5g	X		Yes	Support broke.
		248	5g	Y		Yes	
		251	5g	Z		Yes	
		193	5g	Z		Yes	
		255	7g	X		Yes	
		235	7g	X		Yes	
		263	7g	Y		Yes	Brush support bracket failed.
		308	7g	Z		Yes	Unit did not meet requirements, as specified, but did successfully complete vib. tests at a reduced input of 5g's. At the 5g level, the resonant freq. in Z axis was less than the required 200 Hz.

TABLE 12. (Concluded)

Part Name	Model	Freq. Hz	Acceleration (Peak Output)	Axis	Time	Resonance	Remarks
Engine							
Starter Generator	212						MIL-E-5272C The resonant freq. shall not be less than 200 Hz. Immediately following this test, the starter generator shall operate as generator at full rated load for a period of 2 hrs.
Fuel Pressure Transducer	206 A/B	10-35 35-1000 10-20 20-1000	±30g ±10g	X,Y,Z X,Y,Z X,Y,Z X,Y,Z	3 hr 20 min 3 hr 20 min		10 min - 30g - 10-1000 Hz (High level vib.) 10 hr - 10g - 10-1000 Hz with max. allowed error = ±2.0% (Low level vib.) Max. weight = 6 oz.
Torque Transmitter	212	150-2000 5-169	40g	X,Y,Z	20 min		MIL-STD-810B, 514.1 Curve E MIL-STD-810B, 514 Curve H 166.9-2000 Hz at ±40g D.A. did not exceed .036 in. For low temp (-54c) high temp (+177c). Shall follow curve 1 - MIL-STD-810 (514)
Transmission							
Power Supply (Strobe light)	206 A/B						MIL-STD-810 - Curve Z Qualified for 5g in X,Y,Z.
Power Supply	212						MIL-T-5422 except 0.4 in. D.A. 5-23 Hz, ±10g 23-500 Hz

3.2.3 Helicopter Component Vibration/Failure Rate Trends

3.2.3.1 Task Analysis

After considerable effort to relate failure rates of components to the primary application of the helicopter and its associated vibration environment, it became clear that the effort could not show a meaningful cause-and-effect relation. At this point, a selective survey of related literature was made to trace the history and assess the state of the art of the study problem. A discussion of these findings is presented in the following paragraphs.

First, it is instructive to consider an ideal pattern which possibly would yield a verifiable trend and then to compare this to the pattern which unfolded during the study. Consider if the following were true for a particular commercial model:

- That a stable mission spectrum could be defined.

- That the triaxial acceleration spectra associated with the mission spectrum were known over the range 5 to 500 Hz in three mutually perpendicular directions at the mounting points of each equipment item of interest.

- That the dynamic characteristics of the equipment were known in enough detail to design a laboratory shake test which would serve as a meaningful fatigue test of the equipment with respect to the mission vibration spectrum.

- That the lab-induced times to failure and the failure modes resulting from application of the vibration spectra were known.

It would then be expected that detailed field reliability data would tend to exhibit the failure rates and modes predicted by the laboratory tests except as modified by synergistic effects produced by combined environments, maintenance-induced failures, deviations in use spectrum, etc.

The nonideal pattern revealed by the subject study is that there are major voids in all of the important areas of consideration outlined in the ideal pattern:

- Some type of mission spectrum can be defined, but its accuracy with respect to the problem is unknown.

- Vibration data with the required accuracy are not usually measured.

- Relatively little is known about the dynamic characteristics of equipment items.

- Laboratory fatigue tests using actual measured vibration spectra are not conducted.

- Reliability bookkeeping in the field seldom contains the detail required. In particular, statements of the type "failure due to vibration" are almost always anecdotal and seldom the result of an investigation in a failure mode laboratory.

This picture was recognizable at least as early as 1950, and it gave rise to a great deal of effort, the results of which were brought together and published as a synthesis of the state of the art in 1961 (Reference 8). This synthesis provided the foundation for the vibration tests of MIL-STD-810 which was issued in 1963.

The dialog surrounding the vibration tests of MIL-STD-810 consists of a large number of papers and reports which helped provide the basis for the Standard plus a large amount of literature written since its adoption, commenting on all aspects of the tests and judging their efficacy. This dialog is important here because it treats the same problem as in this study and shows why the desired results cannot be produced. That is, MIL-STD-810 propagates the previously mentioned nonideal pattern. This is not, however, a derogation of the standard. The ideal pattern was initially sought; but, for practical reasons the nonideal pattern, which does not yield a traceable cause-and-effect relation, had to be adopted.

3.2.3.2 Vibration Data

Despite the aforementioned problem, an analysis of the vibration data was conducted to determine if there were any possible traces of correlation with the failure rates of the selected components. One reason that can be given for lack of sufficient data is that the magnitude of the required instrumentation package and helicopter configurations possible for all flight conditions can lead to a very elaborate and costly correlation program. In other words, time histories are needed for each component along with the flight conditions and helicopter gross weight and cg configuration in order to make reasonable assessments of the type of vibration environment in which these components operate. The data presented in Figures 8 through 14 provided only a small part of the total spectrum of the vibration environment of a helicopter. Figures 15 through 19 present a more comprehensive set of vibration data for the OH-58A and UH-1H, respectively. Tables 13 and 14 identify maximum accelerations taken from Figures 15 and 18,

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TABLE 13. NONWEAPONS-FIRING MAXIMUM ACCELERATIONS FOR FIGURE 15

Frequency (Hz)	Axis	Maximum Acceleration (g)	Vibration Source	Flight Condition[2]	Location
11	Vertical	.34	Main rotor, 2/rev	120 KCAS	AN/ARC-51BX radio mount
22	Lateral	1.03	Main rotor, 4/rev	120 KCAS	Instrument panel, attitude indicator
36	Vertical	1.32	Main rotor, 6/rev	Maneuver B	AN/ARC-51BX radio
45	Longitudinal	.59	Main rotor, 8/rev	120 KCAS	Instrument panel, center front
59	Lateral	.63	Main rotor, 10/rev	Maneuver B	Instrument panel, AN/ARC-115 radio
71	Longitudinal	.28	Main rotor, 12/rev	Maneuver A	Instrument panel, attitude indicator
87	Longitudinal	.15	Tail rotor, 2/rev	Climb, 80 KCAS	Instrument panel, center front
103	Longitudinal	.25	Note[1]	Maneuver A	Instrument panel, attitude indicator
175	Longitudinal	.30	Tail rotor, 4/rev	IGE hover	AN/ARC-51BX radio mount
250	Longitudinal	.25	Unknown	Maneuver B	Instrument panel, top right panel back
337	Lateral	.24	Unknown	Maneuver A	AN/ARC-51BX radio
350	Lateral	.16	Tail rotor, 8/rev	Maneuver A	AN/ARC-51BX radio

[1]Engine shaft and tail rotor drive shaft fundamental.

[2]Flight condition abbreviations defined in Table 1.

TABLE 14. INSTRUMENTS AND AVIONICS MAXIMUM ACCELERATIONS FOR FIGURE 18 (NONFIRING)

Frequency (Hz)	Flight Condition[1]	Gross Weight (lb)	Axis[2]	Location Number	Amplitude (~ g)	Source
12	LDG B	7000	V	4	0.59	Main rotor 2/rev
22	LDG B	7000	V	5	1.76	Main rotor 4/rev
32	LT 45°	7000	H	2	2.08	Main rotor 6/rev
43	LDG C	7000	V	6	0.45	Main rotor 8/rev
54	LF (V_H)	7000	H	5	0.46	Main rotor 10/rev Tail rotor 2/rev
65	LDG C	7000	H	2	0.68	Main rotor 12/rev
72	LDG B	9000	H	4	0.26	Tail rotor drive shaft
76	LDG C	7000	H	5	0.38	Main rotor 14/rev
86	LDG A	7000	H	5	0.25	Main rotor 16/rev
97	LT 45°	7000	H	2	0.43	Main rotor 18/rev
109	T/O B	9000	V	8	0.46	Main rotor 20 rev Tail rotor 4/rev Engine shaft
125	V_{min} R/D	7000	V	7	0.45	--
161	V_{cruise} R/D	7000	V	7	1.00	--
178	V_{min} R/D	7000	V	7	0.56	--
186	V_{cruise} R/D	7000	V	7	0.45	--
218	V_{min} R/D	7000	V	7	0.47	--
349	V_{min} R/D	9000	V	8	0.33	Power turbine
401	OGE Hover	7000	V	7	0.34	Gas producer

[1]Flight condition abbreviations defined in table 2.
[2]V: vertical.
H: longitudinal.

respectively. However, as mentioned in the results of References 6 and 7, a qualitative pilot evaluation indicates the presence of large variations in the vibration level of different helicopters of the same model due to differences in the mechanical condition of each helicopter. Consequently, for a particular helicopter model, representative vibration levels should be measured by testing several helicopters of the same model. The mechanical condition of the selected test helicopters should also be considered since this can also have significant impact on the respective vibration levels. The instrument and avionics vibration levels, as measured during these programs in References 6 and 7 were reported as being well below the laboratory qualification vibration levels of MIL-STD-810B.

3.2.3.3 Component Data

The data presented in Table 12 gives some idea of the vibration characteristics of the selected components. However, these data are based on test criteria specified by a military standard such as MIL-STD-810B. As a result, there is only enough data to meet the specifications and thereby qualify the component. The fallacy of this test procedure is that it does not identify the failure modes of the component. In other words, acceptance testing is not the same as a failure-modes-and-effects analysis which is necessary in attempting to identify the cause of failure. At this point, a few comments should be made about the qualification standard.

MIL-STD-810 is a component qualification method consisting of a series of compromises that do not necessarily conform to physical cause-and-effect relationships. Its bookkeeping practices have been highly variable and the data preserved tends toward the minimum required for the immediate purpose of qualifying the equipment at hand. In this regard, the standard has evolved into a pragmatic engineering method that is somewhat lacking in scientific content or methodology. It does not lend itself to an after-the-fact definition of any cause-and-effect relationships that influence the component's reliability.

Some of the problems encountered in studying data such as those presented in Table 12 are:

- The vibration test procedure and environment in the laboratory are simulations and therefore may not completely reflect the field environment.

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- The method relies heavily on "exaggeration" or "amplification" factors as applied to resonances observed in the laboratory simulation. These observed resonances may not be related to those encountered in the helicopter vibration environment.

- It is impractical to provide sufficient internal instrumentation to define all or even most of the important dynamic characteristics.

- Insufficient information is recorded on failure modes.

- No prediction of field life is made or can be made.

Another look at Table 12 reveals the numerous voids in the data. As the survey of component qualification reports was conducted, it was often found that a component's test data were not published but the results were provided. These results were usually provided in summary form in which it was stated that the component had satisfactorily passed all qualification tests. Detail data sheets were not provided in the vendor qualification reports but were available for review by the cognizant committee at Bell. As a result, these data were not readily available for this program.

3.2.3.4 Data Relevancy

The data shown in Tables 9 and 10 indicate that the MTBF values found for most of the components were very high. This is certainly inappropriate in light of the fact that commercial operators are constantly citing these components as being a large share of nagging unscheduled maintenance programs. The reason these MTBFs are high is suspected to be an inherent problem with the way DMR records are obtained. That is, all BHT customers are given a warranty of 500 flight hours or six months during which time all claims for repair or service are accompanied by a DMR as shown in Figure 5. There are two deficiencies that can be cited with this reporting system--both of which fall within the responsibility of the operator.

The first deficiency deals with the warranty period. Operators will faithfully submit this report during the warranty period. This is done primarily in compliance with BHT policy. However, operators have also found that their claims will be processed faster if they will submit their request for service using a DMR that has been properly filled out. As a result, operators will comply with this system and submit their DMRs as requested by BHT. After the warranty period has expired, however, operators will no longer submit these reports because they will either buy enough spare parts for their own inventory and replace the components themselves, and/or they will

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send their components directly to a vendor for repair or replacement. BHT is usually not informed of these maintenance actions and as such the DMR data bank is deprived of this information. The reason commercial operators do not report through BHT is strictly a matter of economics and schedule.

The operators are constantly trying to minimize down-time and will consequently seek the most expeditious and inexpensive methods to keep their fleet availability as high as possible. Also, the operators must necessarily devote their efforts to the conduct of their business (usually 24-hour service). As a result, the process of sending a DMR file to BHT for components usually ends up being a tedious paperwork operation that is quite often eliminated. At this point it should be re-emphasized that this argument is presented only with regard to the types of components analyzed under this contract. That is, instruments and otherwise nonprimary flight hardware are the only components that are included in this discussion. Flight hardware or critical components (actuators, gearbox, etc.) are not included in any discussions in this report.

The second deficiency deals with the DMR files. Usually, these reports are completed by maintenance personnel such as mechanics who work directly with the aircraft in performing all necessary maintenance actions. The problem is that members of the maintenance crew are often too pressed for time or lack enough information to make an accurate assessment of the component's cause of failure or malfunction.

As a result, the reasons for failure given on DMRs are often based on speculation on the part of the mechanic, or the pilot who sometimes makes recommendations to the crew chief when requesting maintenance work on his aircraft. There is some merit to these speculations however, since these are educated guesses made by qualified pilots and/or mechanics. But the fact remains that a well-founded, qualitative, quantitative, and thorough evaluation of the failed or malfunctioning component is normally not available for further analysis.

The relevancy of the MTBF data is therefore questionable for the purpose of this effort. Any efforts to obtain more meaningful data of this type from the operators' maintenance records was well beyond the scope of this program. However, this is a worthwhile consideration in the formulation of future similarly related programs.

3.3 DATA ANALYSIS

3.3.1 Data Extrapolation to Other Helicopter Types

An analysis was made of the DMR files to determine if any trends could be extrapolated to other helicopter types.

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Tables 15 and 16 contain MTBF data obtained from the DMR files for the Model 206L and 214B, respectively. The components chosen were the same as those analyzed for Models 206A/B and 212. Again it can be seen that the MTBF values are somewhat high although the number of failures are low. This is due to the low number of flight hours logged on the Models 206L and 214B which are relatively new aircraft. Also, the same arguments that were pointed out concerning the Models 206A/B and 212 with respect to DMR data can be reiterated here. That is, customers will respond to BHT policy by submitting DMRs during the life of the warranty period. Once the warranty period has expired, however, the frequency of submittal of DMRs drops considerably. It is interesting to note the similarites in the MTBF values when comparing Tables 9, 10, and 15. MTBF data from Table 9 and the $MTBF^1$ values in Table 15 are both based on the total flight hours for those helicopters reporting on the selected components only. Furthermore, the MTBF values in Table 10 and the $MTBF^2$ values of Table 15 are based on total flight hours for all helicopters reporting on any type of component. These two comparisons show how the related MTBFs are of the same order of magnitude. That is, there are indications of a trend in the MTBF data. Of course, this is not conclusive evidence that any trends exist but the point can be made that a more in-depth analysis may yield more substantive data that can be used to establish the presence of a trend.

3.3.2 Advanced Technology Impact on Vibration Suppression

At the present time, it is impossible to predict during the design cycle the broad band (5-500 or 5-1000 Hz) vibration environment that a helicopter component will encounter during its service life. However, predicting and controlling the 0- to 40-Hz vibration environment for the helicopter's crew, passengers, and cargo has been the subject of considerable effort over the past decade. As a result of this effort, the occupant's vibration level has been substantially reduced as shown in Figure 22 from Reference 9.

Programs such as those described in References 10 and 11 involved the use of rotating system dynamic absorbers (specifically, rotor-mounted bifilar vibration absorber) and a rotor isolation system such as the Dynamic Antiresonant Vibration Isolator (DAVI), respectively.

The results indicate that these systems were fairly successful in effectively attenuating specific harmonics of rotor-induced vibrations. Other vibration-isolation systems such as nodal beams, improved rotors, improved structural dynamic tuning, and other means of rotor isolation by conventional or active devices have contributed significantly to the reduction of

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TABLE 15. MTBF VALUES FOR MODEL 206L COMPONENTS

206L — DMR REPORTS THRU 6-14-78 — (Selected components)

Part Name	Part Number	Qty. per Aircraft	Qty. of Failures	MTBF[1]	MTBF[2]
Torquemeter	206-075-185-003	1	1	36548	87621
Altitude Indicator (kit)	102-0017-01 206-706-323-017	1 1	5 -	7310	17524
Xmsn Oil Temp/Press Indicator	206-075-188-005 206-075-187-001 206-075-187-003	1	- 1 2	12183	29207
RPM Sensor (Eng) (Rotor)	206-075-545-001 206-075-545-005	1 1	- 4	18274	43811
~~Voltage Regulator~~	~~206-075-447-007~~	~~1~~	~~15~~	~~2437~~	~~5841~~
Starter Generator	23032-010	1	4	9137	21905
Fuel Pressure Transducer	206-061-535-007	1	20	1827	4868
Torque Transmitter					
T/R D/S Hangers	206-040-344-009 206-040-346-021 206-040-355-003	2 2 1	1 1 -	91370	219053
Power Supply	AH12A28V	1	2	18274	43811

[1]Flight hours of helicopters reporting DMRs on selected components only = 36548

[2]Flight hours of all helicopters reporting DMRs = 87621

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TABLE 16 MTBF VALUES FOR MODEL 214B COMPONENTS

214B — DMR REPORTS THRU 6-14-78

Part Name	Part Number	Qty. per Aircraft	Qty. of Failures	MTBF[1]	MTBF[2]
Torquemeter	214-075-239-011	1	3	3654	8060
Altitude Indicator	214-075-243-003	1	14	783	1727
Xmsn Oil Temp/Press Indicator	212-070-116-025	1	2	5482	12090
RPM	205-075-388-015	1	4	2741	6045
Voltage Regulator	214-075-187-001 or 214-075-187-003	1	19	577	1273
~~Starter-Generator~~	~~204-060-200-019~~	~~1~~	~~5~~	~~2193~~	~~4836~~
Fuel Pressure Transducer	209-062-608-001	1			
Torque Transmitter					
T/R D/S Hangers	214-040-600-002 214-040-600-005	1 3	1	43852	96716
Power Supply	209-075-387-001 or 212-075-962-001 or 214-075-234-003	3	10	3289	7254

[1]Flight hours of helicopters reporting DMRs on selected components only = 10963

[2]Flight hours of all helicopters reporting DMRs = 24179

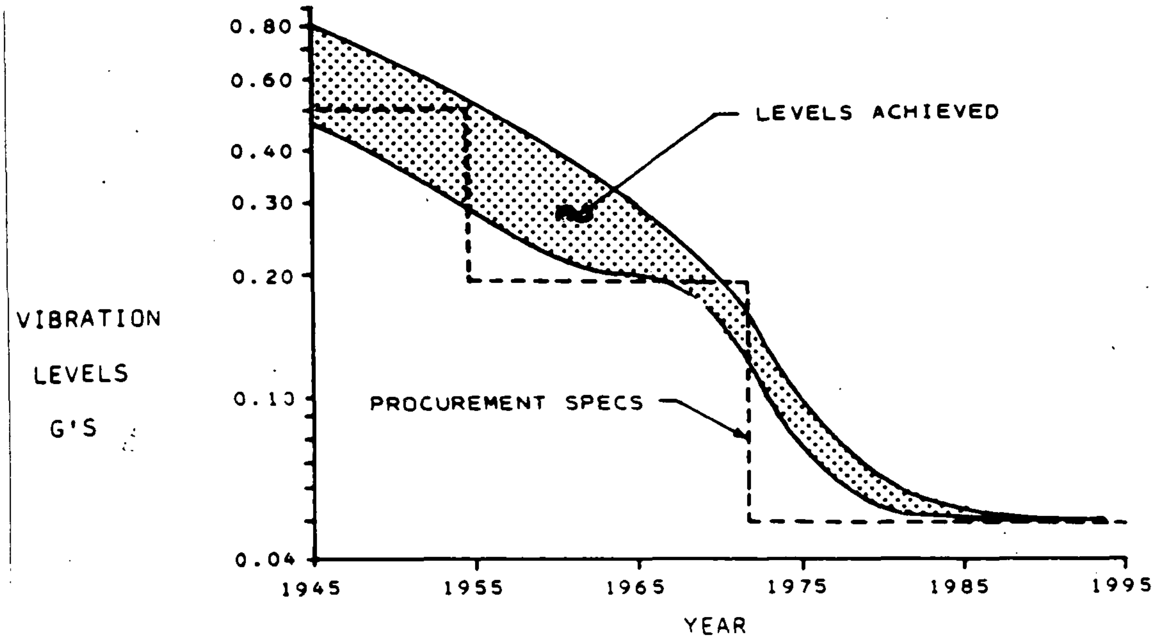

Figure 22. Progress in helicopter vibration control.

helicopter rotor-induced vibrations. The historical trend is shown in Figure 22. The merits of these devices can be defended from the standpoint of occupant comfort alone; the reliability benefits for primary load-carrying structure is a bonus. These same reliability benefits unfortunately do not accrue to a significant degree for avionic, electronic, and electrical equipment because the main rotor harmonics are not usually the damaging frequencies for such equipment whose natural frequencies are grouped toward the high end of the scale (above 150 Hz).

It is a desirable goal to seek to predict analytically during the design cycle the actual broad range vibration environment that the helicopter components will encounter in flight. However, achieving this goal will require a quantum jump in the basic understanding of helicopter unsteady aerodynamics, nonlinear structural dynamics, and also vastly improved computer hardware.

3.3.3 Comparison of Military and Commercial Helicopter Applications

One point of comparison between military and commercial helicopter applications can be made by reviewing Tables 7 and 8 and evaluating the respective mission profile surveys. The data show how commercially operated helicopters are flown somewhat differently from their military counterparts. This is particularly true of the cruise profile for which a higher percentage of time was found for the commercial aircraft. Furthermore, the larger percentage of time spent in cruise is accompanied by a rather substantial reduction in hover time. This is to be expected since the majority of work involved in commercial flight is dedicated to moving people, equipment, or other payload from point A to point B, etc. This is generally the type of service most frequently requested by the customers who desire helicopter transportation. Helicopter services that require hover or maneuvers are not in high demand except when engaged in sling-load, heavy lift, logging, or agricultural spray applications. The larger block of time at high power and high speed is an important difference in that all of the vibration-generating components are operating under greater stress and there is more energy in the broad-band excitation.

Helicopter configurations are also different when one considers military versus commercial requirements. That is, the Model 206A/B and OH-58 helicopters are similar but have significant differences. The OH-58 has armament, different rotational speeds of components, loadings, and equipment packages. These differences may cause substantial differences in the excitation and dynamic response of the aircraft and equipment

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components. Similar statements apply when comparing the UH-1H, UH-1N, and the Model 212. However, within the texture of the practices of MIL-STD-810, it is common to assume that the excitation of all derivatives of a given model are similar except for armament firing.

4. OVERVIEW

The main thrust of this contracted effort was to perform a correlation study between installed helicopter components and the vibration environment in which they operate. This was to be accomplished by using existing data files such as those obtained from component qualification tests, flight test programs, and field service data for civilian helicopter applications. The results were that correlation could not be obtained due to the insensitivity of the data.

Numerous studies of this type have been conducted during the course of the last ten to fifteen years. As mentioned in Section 3.2.3.1. A brief review of a few of these studies such as those cited in references 12 and 13 indicate that good correlation was unattainable. The reasons given for this range from a lack of a statistically meaningful data base, to a misapplication of military standards in the area of component reliability testing. To go one step further, the conclusions in reference 10 also point out inadequacies that were found in the various vibration design and test criteria specifications. However, it is believed that a thorough literature survey of all these programs would enable further investigators to determine what results are actually available from other research efforts and also what direction should be taken as a next step.

F2-1?

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The results of this program have shown that there still remain several unknowns regarding both the vibration environment and the reliability of non-flight-critical helicopter components. Vibration data for Models 206A/B and 212 helicopters were either insufficient in content or were not in a readily usable form for this type of study program. Thus, a thorough understanding of the dynamic characteristics of components such as those selected for analysis under this program was not possible. It is doubtful that an appropriate collection of vibration and maintenance data, which would be useful in establishing correlation with the failure rate of secondary components, are readily available on any type of helicopter. This statement is based on the supposition that all or most components are predominantly qualified in accordance with acceptance test criteria of the type found in MIL-STD-810B specifications. This is not intended to criticize or degrade the Standard but rather to point out that the resultant data obtained during component acceptance testing are not necessarily suitable for establishing cause-and-effect relationships for these components due to the established testing techniques. Instead, the data from these test programs yield information describing the ability of a component to withstand stresses from expected dynamic, thermal, and other environmental factors.

Similarly, vibration data obtained during qualification flight test programs are not suitable for substantiating the failure cause-and-effect investigation of the same components. Again, this is due to the test criteria and economics concerning these programs. The majority of qualification flight test programs are conducted to obtain data for performance and structural substantiation of primary components which carry flight loads. Consequently, aircraft instrumentation for these programs is often limited to that which is necessary to obtain the desired data. The high cost of flight test prohibits the expanded scope of effort to obtain the appropriate data for this type of correlation study related to secondary components. Only a very comprehensive and complex flight test program could yield data that could be useful in establishing a correlation for the selected components.

A few of the problems involved in attempting to gather enough data to adequately describe the vibration environment of the selected helicopter components are shown below.

- Which components should be instrumented
- How do you instrument the components
- What type of instrumentation should be used
- Which and how many aircraft should be tested
- How much flight time and what flight profiles should be selected
- Under what range of environments should the tests be conducted

5.2 RECOMMENDATIONS

The following recommendations are presented for NASA Langely's consideration of future efforts regarding the subject program.

- Conduct a literature survey of all study programs conducted within the last 10 years and cite the major issues and state-of-the-art thinking. A determination needs to be made as to what questions have and have not been answered.
- Investigate the potential for MIL-STD-810 to accomplish its task. Determine its effect on total aircraft system reliability.
- Establish methodology for a well-designed laboratory test that will yield useful data for relating component reliability with the vibratory environment in which they operate.

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