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14. ABSTRACT This TOP provides Laboratory Vibration Test Schedules (LVTS) for selected rotary wing aircraft. The LVTS presented in this TOP were developed from field measured data collected on the selected rotary wing platforms. The LVTS are designed to allow for the exposure of a test article to a flight vibration environment of a given rotary wing platform in a laboratory setting.						
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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 01-2-603A
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ROTORCRAFT LABORATORY VIBRATION TEST SCHEDULES

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1. SCOPE.

This Test Operations Procedure (TOP) provides Laboratory Vibration Test Schedules (LVTS) for selected rotary wing aircraft. The LVTS presented in this TOP were developed from field measured data collected on the selected rotary wing platforms. The LVTS are designed to allow for the exposure of a test article to a flight vibration environment of a given rotary wing platform in a laboratory setting.

1.1 Background.

a. The Department of Defense standard for Environmental Testing, which includes vibration testing, is Military Standard (MIL-STD)-810H with Change 1^{1**}. Method 514.8, addresses both secured cargo and installed equipment vibration environments induced by rotary wing aircraft in Categories 9 and 14 respectively.

b. MIL-STD-810H with Change 1 strongly recommends tailoring laboratory vibration tests to the specific environmental interests as anticipated per the life-cycle environmental profile (LCEP). For example, consider the following vibration testing requirement: A component is to be installed on an AH-64E instrument panel and must first undergo vibration testing in a laboratory to demonstrate both structural endurance and functionality while being subjected to flight induced vibration. Ideally, a LVTS would be developed per the LCEP from flight vibration data acquired at the specific location on the AH-64E where the component is to be installed. This would allow for a high-fidelity test in the laboratory. However, this approach, while superior from a technical standpoint, is often cost prohibitive. It is for this reason that MIL-STD-810H provides default, region specific LVTS curves, to be utilized in the absence or inability to collect mission specific field data.

c. Default LVTS curves for rotary wing aircraft vibration exposure are provided in Tables 514.8C-XIV and 514.8D-III of MIL-STD-810H with Change 1. Note that beginning with MIL-STD-810H, the LVTS of this TOP were referenced for the CH-47 and UH-60. The historic default test spectra remaining in MIL-STD-810H are widely used in the Test and Evaluation (T&E) community for laboratory vibration testing of systems that are to be installed in rotary wing aircraft. However, the historic default test curves have significant shortcomings, some of the most notable follow:

(1) The historic default test spectra date back to the early 1980's. The rotary wing aircraft fleet has changed substantially since that time. Consequently, the 30 year old default specifications are not representative of the modern fleet.

(2) LVTS development techniques were not fully mature at the time the original specifications were developed and excessive conservatism and time compression is a major concern.

** Superscript numbers correspond to Appendix F, References.

(3) Metadata associated with the original LVTS development is very limited. The historic default test spectra are not aircraft independent. A single broadband spectra is provided for all rotary wing aircraft platforms. Tonal amplitudes are tabular based solely on engine revolutions per minute (RPM) and blade count.

(4) The historic schedules were designed to be extremely conservative.

(a) The mission scenario was based on 2500 hours of flight at “worst case” flight measurements across the fleet.

(b) The test spectra are axis independent. Each axis of the test article is to be subjected to the same test spectra.

(c) Qualification requirements based on highly conservative reference criteria have the strong potential to force excess design conservatism that may lead to undesired residual effects such as unnecessary weight.

d. Shortcomings in the historic Rotary Wing Aircraft LVTS curves necessitated updates. With this publication, updates have been completed for three aircraft models. Additional updates will be added as opportunities allow.

1.2 Implementation Plan.

a. Flight testing and data collection is an expensive venture that can take months if not years of planning and scheduling. Consequently, it is not feasible to release an all new, 100% complete, set of LVTS for all rotary wing aircraft platforms. The U.S. Army Test and Evaluation Command (ATEC) is the Army’s test authority and current custodian of MIL-STD-810H with Change 1. ATEC’s U.S. Army Redstone Test Center (RTC) is updating the default LVTS for rotary wing aircraft. As funding and aircraft are made available, flight testing will be conducted for the purpose of collecting vibration data on the modern rotary wing aircraft fleet. The vibration data will be utilized to develop LVTS for the aircraft. RTC will file the raw field data and worksheets for each LVTS development effort as they are completed. Each completed set of LVTSs will then be added to this TOP in the form of an Appendix. Due to funding limitations, it may not be possible to gather data from all regions of an aircraft for which LVTS are needed. In those cases, some LVTS will be derived from the data available, and application of the concepts and profiles provided in MIL-STD-810H with Change 1. The derived profiles will be replaced when addition data are acquired.

b. Details such as close up photographs that could be perceived as too sensitive for public release will not be included in the TOP. In the event such detailed information is required, access to the stored files will be considered based on a need to know basis. Each Appendix will document the final LVTS, Vibration Specification Development (VSD) technique details, and all relevant metadata such as mission scenario and instrumentation locations used in the flight test. Formatting of each Appendix will be kept as uniform as possible. The updated LVTS presented in the Appendices of this TOP will supersede the current defaults listed in Tables 514.8C-XIV and 514.8D-III of MIL-STD-810H with Change 1.

2. FACILITIES AND INSTRUMENTATION.

The object of this TOP is to provide default vibration criteria for the current rotary wing fleet in the event item specific field data are not available. Dynamic test facilities and associated test equipment and instrumentation will be used for the test execution phase. The facilities of record for the VSD discussed in this TOP are the actual aircraft. The final LVTSs and associated instrumentation details are provided in the Appendices of this TOP.

3. REQUIRED TEST CONDITIONS.

For the purposes of the flight data acquisition portion of a LVTS development effort, required conditions are an approved airworthiness release and safe operational conditions. Laboratory test conditions such as test durations and temperature for actual implementation may vary based on the mission requirements of the test article. This document provides the actual vibration levels to which testing shall be conducted.

4. ANALYSIS PROCEDURES.

Specialized software tools were employed in the development of the LVTS provided in the Appendices of this TOP. These tools are based on the procedures and are in accordance with (IAW) the guidelines of MIL-STD-810H with Change 1 Method 514.8 Annex F, and North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4370 Allied Environmental Conditions and Test Publication (AECTP) 4370 Leaflet 2410/1².

5. DATA REQUIRED.

LVTS development requires data collection over the full range of aircraft operational flight to characterize the vibration environment. The characterization typically includes a collection of acceleration time histories of all relevant exposure conditions, and an associated table of exposure times or percentages for those conditions per the LCEP.

6. PRESENTATION OF DATA.

a. The final LVTSs and associated instrumentation details are provided in the Appendices of this TOP. The individual vibration schedules are provided in Power Spectral Density (PSD) format with superimposed sinusoidal components that are associated with the rotor speeds and blade count of each aircraft and other sources. Tones associated with the primary and tail rotors are identified as nP and nT, where n is the associated harmonic. Dominant harmonics are not limited to the 3rd harmonic of the blade passage as in MIL-STD-810H with Change 1. Attempts were made to identify and include predominant sinusoidal components associated with aircraft specific rotating subcomponents. Note that the list of tones associated with rotating subcomponents is not all inclusive given the sparse measurement accelerometer placement.

b. All LVTSs provided in the appendices of this TOP are considered to be Endurance specifications. Such lifecycle testing generally involves use of time compression techniques to yield manageable/affordably laboratory test durations. Care was taken to limit the amount of time compression to avoid raising test amplitudes beyond acceptable levels above maximum field measured data per the guidance in MIL-STD-810H with Change 1, Method 514.8, Annex F. Each appendix includes a table of sine tones for which time compression results in levels that exceed MIL-STD-810H with Change 1 guidance.

7. GUIDELINES FOR UTILIZATION OF LVTS.

a. The default test durations and the represented hours of flight are listed with each profile. If the LCEP of the test article is other than the published default, modify the test duration as appropriate (i.e., for a specification published as a 4-hour test representing 2500 hours of flight, a test article expected to have an exposure limited to 1250 hours would yield one-half the published test duration). This linear modification to the default test duration should be limited such that durations are not reduced to less than 30 minutes/axis. If the linear modification would result in durations of less than 30 minutes/axis, further guidance is provided in MIL-STD-810H with Change 1, Method 514.8, Section 9.2.1.2 of Annex F.

b. For test articles where aircraft orientation is unknown or not fixed, it is recommended that each axis of the test article be tested to the envelope of all possible axes of aircraft orientation. For example, for components in which placement relative to the aircraft orientation between x and y are unknown, it is recommended that both x and y axes of the component be tested to the envelope of the longitudinal and transverse LVTS for the zone of interest.

c. For test articles where the aircraft region on a given aircraft is unknown or not fixed, it is recommended that the test article be tested to the worst case of the potential regions. If the test article may be installed in more than one region, it is recommended that the article be tested to the envelope (by axis) of all possible regions of the given aircraft.

d. For test articles that may be installed on more than one aircraft, it is recommended that individual test articles be tested to each candidate aircraft. If this is not feasible, other options should be considered. One option is to test to the envelope of all regions of all aircraft on which the test article may be installed. This could result in a significantly conservative test. Another option is to test to the worst-case exposure. Worst case exposure may be determined by comparison of the test article modes (predicted or measured utilizing the intended mounting) to the candidate aircraft. For example, if the first mode of the test item is near 19 Hertz (Hz) then the AH-64 is likely the worst case. Any selection of worst-case exposure should consider the intended aircraft regions.

e. All LVTS's provided in the appendices of this TOP are considered to be Endurance specifications. In the event Functional testing is to be considered, it is permissible to reduce the test levels provided in the Appendices by an amount which will yield levels representative of maximum measured field levels. The level of reduction to the published endurance specifications will vary based on the amount of time compression employed in deriving the original specification. Refer to Section 6 in each aircraft specific Appendix for guidance on the

amount of reduction to the published Endurance specification for the conduct of a Functional test.

f. For Reliability testing, it is sometimes desired to operate a test article for hundreds of hours in an environment representative of actual exposure (i.e., uncompressed vibration). In the event Reliability testing is to be considered, it is permissible to reduce the test levels provided in the Appendices by an amount which will yield the equivalent fatigue over a longer test duration. Refer to Section 6 in each aircraft specific Appendix for guidance on the amount of reduction to the published Endurance specification for the conduct of a Reliability test.

g. Most LVTs have been developed for the full bandwidth of the available data, up to 2000 Hz. The test bandwidth can be reduced to 500 Hz given proper and thorough justification, to include analysis that demonstrates the test article is not susceptible to damage from higher frequency vibration.

h. In the event a test item is known to be in very close proximity to a rotating subcomponent that is not included in the specification for the region of interest, it is advised that the subcomponent specific RPMs be researched, and the appropriate tone be added to the region specific specification. Select tonal amplitude defaults per the historical guidance provided in Table 1 and Figure 1 (from MIL-STD-810H with Change 1). If the region will be primarily affected by the rotating subcomponent, employ the full spectrum as defined in Table 1.

TABLE 1. ON/NEAR DRIVE SYSTEM DEFAULTS

BROADBAND		TONE FREQUENCY		TONE LEVEL CALCULATION	
Freq (Hz)	PSD (g ² /Hz)	Tone Number	Freq (Hz)	Source Freq (f _x) Range in Hz	Calculation of A _x (g-peak)
10	0.002	f ₁	1S	5 to ≤ 50	0.1 x f _x
100	0.02	f ₂	2 x 1S		
300	0.02	f ₃	3 x 1S	> 50 to 2000	5 + 0.01 x f _x
2000	0.002	f ₄	4 x 1S		
Determine 1S, the frequency of the rotating equipment in Hz, from the specific component.					

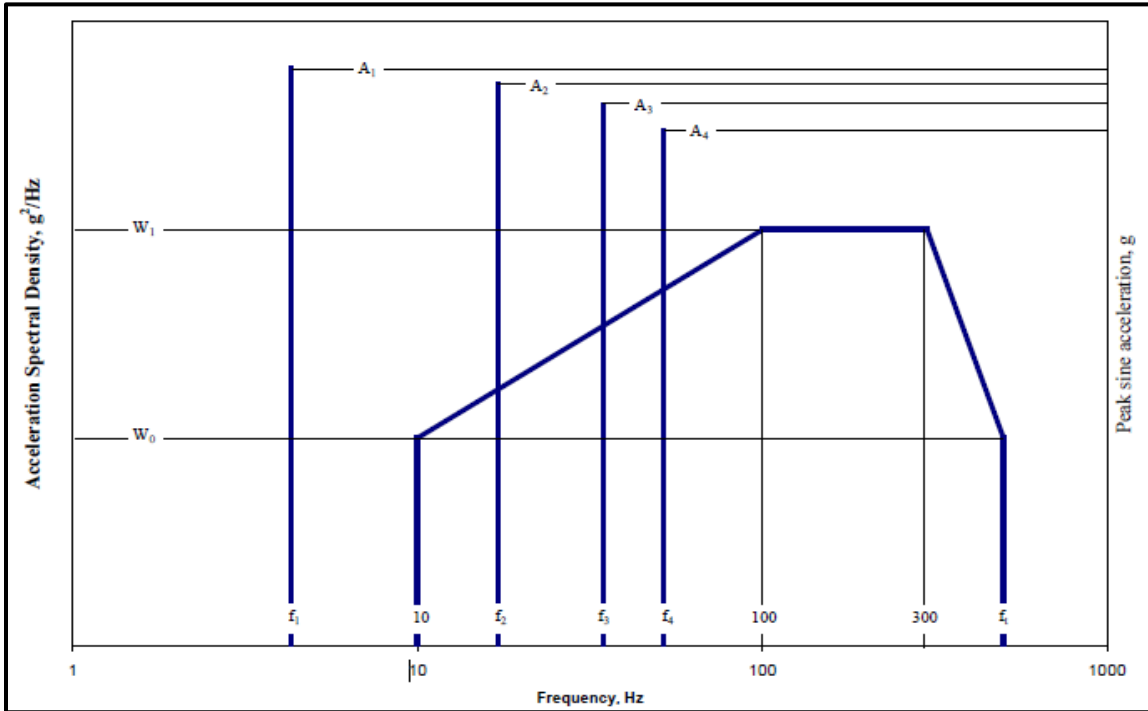


Figure 1. Category 9 - Helicopter vibration exposure.

i. Given significant variance in their structure and vibration exposure, no LVTS are provided for external stores. It is strongly recommended that LVTS be developed per the LCEP from flight vibration data acquired for the specific stores. If system specific LVTS are not yet available, the defaults provided in MIL-STD-810H with Change 1 may be utilized. LCEP duration for external stores is often significantly less than the 2500 flight hours provided by the MIL-STD-810H with Change 1 defaults. The MIL-STD states “it is acceptable to adjust the test durations and test levels per the guidance provided in Section 9.2.1.2 of Annex F, provided the test duration is not less than 30 minutes per axis.” An example LVTS which provides 100 hours of flight for each 0.5 hours of runtime was derived following the MIL-STD-810H with Change 1 Method 514.8 guidance and is proved in Table 2.

TABLE 2. EXTERNAL STORES

BROADBAND		TONE FREQUENCY		TONE LEVEL CALCULATION	
Freq (Hz)	PSD (g²/Hz)	Tone Number	Freq (Hz)	Source Freq (f _x) Range in Hz	Calculation of A _x (g-peak)
10	1.48E-3	f ₁	1P	3 to ≤ 10	0.84 x 0.7 / (10.7 - f _x)
100	1.48E-2	f ₂	n x 1P	> 10 to 25	0.84 x 0.150 x f _x
300	1.48E-2	f ₃	2 x n x 1P	25 to 40	0.84 x 3.75
500	1.48E-3	f ₄	3 x n x 1P	40 to 50	0.84 x (9.75 - 0.15 x f _x)
				50 to 500	0.84 x 2.25

Runtime = 1 hours per 200 hours of flight.
1P = main rotor frequency, n = number of main rotor blades

APPENDIX A. GLOSSARY.

<u>Term</u>	<u>Definition</u>
Laboratory Vibration Test Schedule	Laboratory Vibration Test Schedule (LVTS) – The LVTS is a plot developed from field data depicting the vibration environment for a specific vehicle location or zone. The plot contains information required to perform a laboratory test on a vibration exciter. Typical information includes: a broadband spectra (or profile), sine or narrowband information (if used), test duration and associated field time represented, control methods and tolerances, and any test specific information required. LVTS are designed to produce fatigue equivalency.
Power Spectral Density	The PSD describes how the power of a signal is distributed with respect to frequency. Vibration control systems typically use PSDs as the control reference; therefore, vibration profiles are generally developed in a PSD format. The PSD is also referred to as the auto spectral density (ASD). See MIL-STD-810H with Change 1, Method 514.8, Annex F, Appendix B for a description of ASD/PSD calculation methods often used.

APPENDIX B. ABBREVIATIONS.

ACIP	Airframe Component Improvement Program
AECTP	Allied Environmental Conditions and Test Publication
AOB	angle of bank
ASD	Auto Spectral Density
ASN	Army serial number
ATEC	U.S. Army Test and Evaluation Command
BUTT LINE	Measurement to the right or left of a structure centerline
CAAS	Common Avionics Architecture System
CDU	control display unit
CN	Change Notice
DAFCS	Digital Advanced Flight Control System
dB	decibel
DCU	data concentrator unit
Disp	displacement
DOF	degree of freedom
DP	display processor
EDECU	enhanced digital electronic control unit
ESCG	engine start center of gravity
ESGW	engine start gross weight
Fc	filter cutoff frequency
fpm	feet per minute
frq	frequency
FS	aircraft station; distance forward to aft
hrs	hours
Hz	Hertz
IAW	in accordance with
IGE	in ground effect
ips	inch per second
KCAS	knots calibrated air speed
KGS	knots ground speed
lbs	pounds
LCEP	Life-Cycle Environmental Profile
LVTS	Laboratory Vibration Test Schedule

APPENDIX B. ABBREVIATIONS.

Max Vel	maximum velocity
MFD	multifunctional display
MIL-STD	Military Standard
M-PNVS	modernized-pilot night vision sensor
M-TADS	modernized-target acquisition designation sight
MWO	maintenance work order
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technology
Nr	Rotor Speed
OGE	out of ground effect
P	sinusoid associated with the primary rotor frequency or harmonic
PSD	Power Spectral Density
RPM	revolutions per minute
RTC	U.S. Army Redstone Test Center
SB	service bulletin
SOR	sine-on-random
SP	system processor
SPS	samples per second
STANAG	Standardization Agreement
STATION	measurement from the front to the rear of a structure
T	sinusoid associated with the tail rotor frequency or harmonic
T&E	Test and Evaluation
TOP	Test Operations Procedure
VH	maximum speed in level flight with maximum continuous power
VSD	Vibration Specification Development
WL	waterline; measurement of height on a structure
WP	weapon processor
ZFCG	zero fuel center of gravity

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

C.1 SYSTEM DESCRIPTION.

The CH-47F is a twin turbine engine, tandem-rotor helicopter designed for transportation of cargo, troops, and weapons during day, night, visual and instrument meteorological conditions. The helicopter is equipped with two production Honeywell (formerly AlliedSignal) T55-GA-714A engines. The two engines simultaneously drive tandem, three-bladed, counter-rotating rotors through engine transmissions, a combining transmission, and drive-shafting to the forward and aft transmissions. The engine and transmission data are calculated and transmitted by the data concentrator units (DCUs) and displayed for the pilots to view on any of the five multifunction displays (MFDs). Similarly, the amount of fuel remaining, engine torques, and other aircraft vitals are reported to the MFDs by the DCUs. The aircraft uses a Digital Advanced Flight Control System (DAFCS) that incorporates an optimized consolidation of previously fielded CH-47 Chinook control laws to reduce actuator saturation, improve handling qualities during low-speed flight, and assist pilotage in degraded visual environments. This information is integrated with the communication and navigation functions by the Common Avionics Architecture System (CAAS). Two control display units (CDUs) with alphanumeric keyboards are provided for pilots to input flight, mission, and system data into the CAAS. Each control display unit is capable of both simultaneous and independent operation.



Figure C-1. CH-47 Chinook Helicopter.

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

C.2 ANALYSIS OBJECTIVE.

The objective of the analysis was to develop new LVTS for the CH-47F platform to supersede the legacy vibration test levels presented in MIL-STD-810G CN1. The effort was completed in two phases:

- a. Collected vibration data at locations of interest on the CH-47F during flight testing. Flight testing encompassed maneuvers that provided a good representation of the Mission Scenario.
- b. Utilized flight test data to develop vibration specifications for the CH-47F.

C.3 CALIBRATION.

Calibration of the individual test equipment associated with the data acquisition was performed through the U.S. Army's Test, Measurement, and Diagnostic Equipment Program or via subcontract to accredited calibration laboratories. Calibration was performed IAW the original manufacturer's established standards and procedures for original equipment performance, with standard test equipment and laboratory standards traceable to the National Institute of Standards and Technology (NIST). The validity of equipment calibration was verified prior to test.

C.4 DETAILS OF FLIGHT TEST.

C.4.1 Test Aircraft.

The aircraft utilized for this VSD effort was a CH-47F Chinook, U.S. Army serial number (ASN) 09-088792 (Figure C-1). The aircraft takeoff gross weight was 33,092 pounds (lbs) and the Zero Fuel Center of Gravity (ZFCG) was 332.3 inches. Maintenance Work Orders (MWO) and Service Bulletins (SB) performed on the test aircraft are listed in Table C-1. Flight testing was conducted by RTC on 12 March 2015 and 16 March 2015.

TABLE C-1. CH-47F AIRCRAFT 09-088792 MWO AND SB

MWO OR SB NUMBER	SHORT TITLE
01152024050115	ARMOR SEAT COMPENSATOR (H-47)
01152024050117	AVA TRACKER BRACKET (CH47D/F)
01152027150001	M4 RIFLE MOUNT INSTALLATION (CH-47F)
01152027150002	L/H CREW SEAT SYS INST
01152027150003	AFT PYLON DR UPPER LTCH
01152027150005	STALK LIGHT ADAPTER PLATE
01152027150006	P3 DRAIN LINE INSTALLATION
01152027150007	R/H CRASHWORTHY CREW SEAT
01152027150009	FUEL CROSSFEED BREAKAWAY FITTING

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

TABLE C-1. CONTINUED

MWO OR SB NUMBER	SHORT TITLE
01152027150010	CMWS 5 TH SENSOR (CH-47F)
01152027150011	CH47 IR SUPPRESSION SYS
01152027150012	AN/ARC-231 (V) C
01152027150017	ATIRCM-F
01152027150021	AUDIO PANEL (CAP) KNOB GUARD RAILS
01152027150022	EAWis (CH47F)
01152027150024	CVDR UPGRADE
01152027150025	MFCU COVERS
01152027150026	CARGO PLATFORM HEALTH ENV (CPHE)
01152027150027	CAAS UPGRADE 8.4.6
SB-724-53-1024	C-BOX BEAM REPAIR

C.4.2 Flight Maneuvers.

The flight maneuvers (test points) were chosen to represent the full flight spectrum of the CH-47 aircraft. The test points flown are provided in the mission scenario discussion below. An effort was made to hold each test point for a minimum of 30 seconds to provide optimal statistical averaging for PSD calculations during the analysis phase.

C.4.3 Instrumentation.

a. Instrumentation locations on the CH-47F were selected in an effort to capture the overall vibration levels on the aircraft. Due to programmatic constraints for this effort, instrumentation was limited to 24 triaxial accelerometers. Particular care was taken to collect sufficient data in the cockpit and cargo area of the aircraft. One trade-off to this was fewer data collection points around the engine and drive train components of the aircraft. A detailed list of instrumentation locations can be found in Table C-2 and Figure C-2. The top diagram of Figure C2 provides the accelerometer station (STA) and waterline. The lower diagram shows accelerometer butt-line. Station is distance forward to aft, waterline is distance up and down, and butt-line is side to side. All measurements are in inches.

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

TABLE C-2. CH-47F INSTRUMENTATION LOCATIONS

Loc	Location Description	Station (inches)	Water Line (inches)	Butt Line (inches)	Aircraft Region
1	Nose – Light Distribution Support Bracket	35	-13	10R	Nose
2	Cockpit Floor Left Support Beam	53	-10	39L	Cockpit Lower
3	Cockpit Floor Right Support Beam	53	-10	39R	
4	Cockpit LHS Instrument Panel	50	5	9L	
5	Cockpit Center Control Panel	75	-12	0	
6	Cockpit Overhead Console	88	38	0	Cockpit Overhead
7	Fwd Cabin, Left Avionics Closet, Lower	120	-23	18L	Avionics Closets (Left and Right)
8	Fwd Cabin, Left Avionics Closet, Upper	120	27	39L	
9	Heater Closet, Avionics Shelf Tie in Point	120	-10	18R	
10	Forward Cabin, Overhead Bulkhead	160	50	1L	General Loc 13, 14 and 15 also used for Cargo Loc 16 Not Used
11	Mid Cabin, Overhead Bulkhead	320	50	1R	
12	Aft Cabin, Right Bulkhead	482	25	47R	
13	Fwd Cargo Floor (Tie Down Point)	182	-30	0	
14	Mid Cargo Floor (Tie Down Point)	300	-30	0	
15	Aft Cargo Floor (Tie Down Point)	480	-30	0	
16	Cargo Hook Support Beam Interface	340	-34	20L	
17	Fwd Right Landing Gear Hardpoint	250	-30	57R	
18	Combining Transmission Fwd Rgt Mount	450	55	11R	Lower Aft and Forward Transmission
19	Aft Transmission Fwd Lft Mount	550	65	13L	
20	Aft Transmission, Transmission Fan	584	50	5L	
21	Right Engine Fwd Outboard Mount	482	60	55R	
22	Right Engine Aft Mount	502	50	50R	Not Used
23	Fwd Pylon Near Vertical Shaft	74	60	0	
24	Aft Pylon Near Vertical Shaft	556	110	10R	Upper Aft Transmission

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

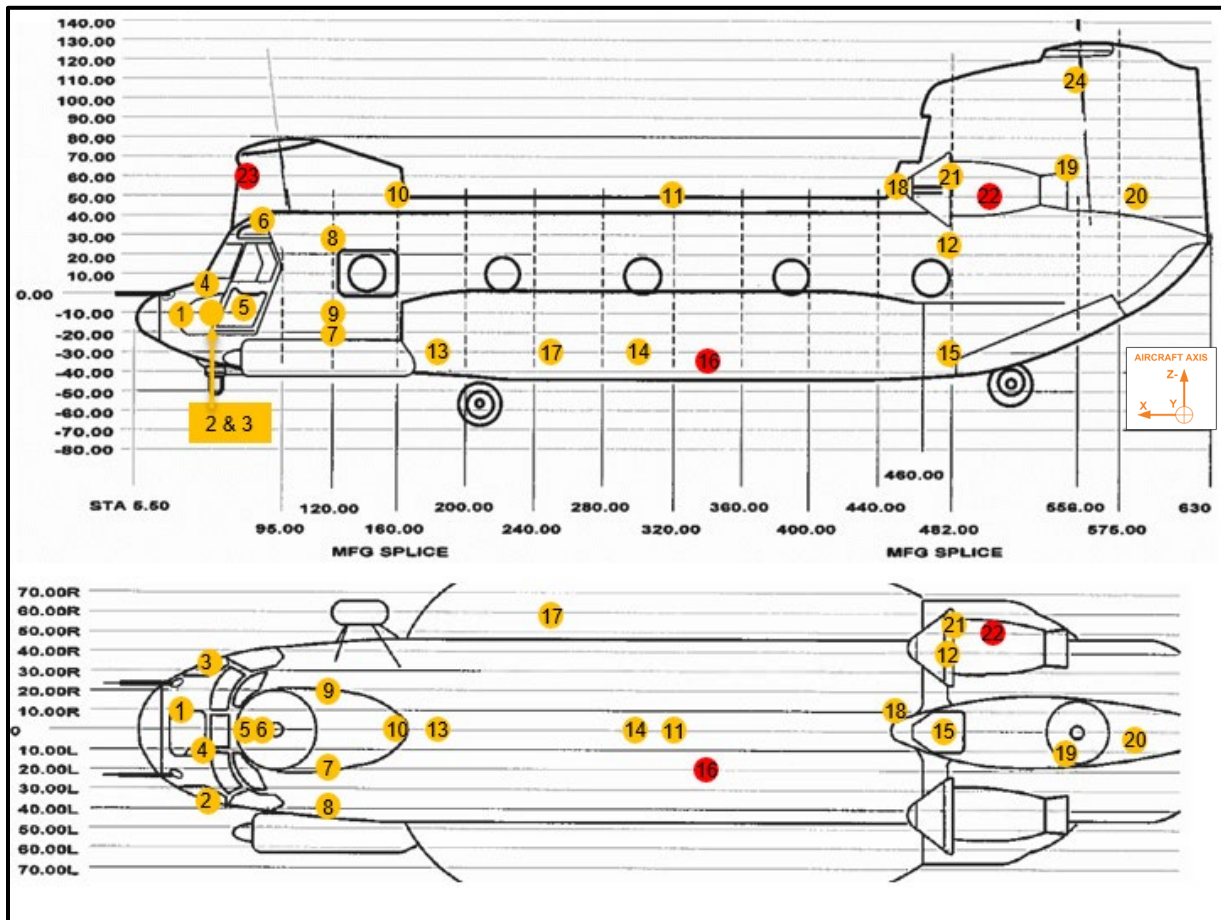


Figure C-2. CH-47F instrumentation locations.

b. All channels were sampled at 7812.5 samples per second. Locations 1 through 17 were filtered at 1302 Hz. Accelerometers locations in the engine and transmission (locations 18 - 24) were filtered at 1953 Hz as higher frequency response was anticipated.

c. A posttest data quality review indicated issues with the data acquired at a few locations, as identified in Table C-2. All three axes were bad or suspect for locations 16, 22 and 23. These locations are identified as red in Figure C-2. Additionally, the longitudinal axis was bad at location 2 and the vertical axis was bad for location 14. These channels were not utilized in the LVTS development.

d. Aircraft regions shown in Table C-2 define how the locations were combined for LVTS development, as discussed in the Locations Groupings section below.

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

e. Multiple aircraft bus parameters were recorded throughout the flight. A list of the subset utilized to identify maneuver start and stop times is provided in Table C-3

TABLE C-3. CH-47F AIRCRAFT BUS PARAMETER LIST

DESCRIPTION	UNITS	DESCRIPTION	UNITS
LATITUDE	Radians	PITCH ANGLE	Degrees
LONGITUDE	Radians	HEADING	Degrees
ALTITUDE	Feet	ROLL RATE	Degrees/Sec
AIRSPEED	Knots	PITCH RATE	Degrees/Sec
ROLL ANGLE	Degrees	YAW RATE	Degrees/Sec

C.5 DETAILS OF VIBRATION SPECIFICATION DEVELOPMENT.

C.5.1 Mission Scenario.

The maneuvers flown during flight testing were chosen to provide a representation of the expected CH-47F usage spectrum. These flight maneuvers were each assigned a percentage value that correlates the flight maneuver to the total expected exposure over the lifecycle of the aircraft (or test article). The LVTs were developed to be equivalent to a total of 2500 flight hours on the CH-47F platform. The Mission Scenario utilized in the VSD process was based off the aircraft usage spectrum provided in Table 1 of Boeing Document Number D125-10011-1, “CH-47 Block II Airframe Component Improvement Program (ACIP) Aircraft Usage Spectrum”³ and discussions with Military Pilots. The Mission Scenario utilized in the VSD can be found in Table C-4. For test points listed as left and right, data was acquired in both directions and the percent of flight was divided equally between them. Factors such as airspeed and angle of bank were verified per the aircraft bus parameters as listed in Table C-3.

TABLE C-4. CH-47F MISSION SCENARIO

MANEUVER DESCRIPTION	TIME	MANEUVER DESCRIPTION	TIME
Ground (Engines: FLY)	2.95%	1500 fpm descent VY	2.28%
Taxi	0.55%	1000 fpm descent VY	2.28%
Take off	0.60%	1500 fpm descent VY	2.28%
Land	0.90%	2000 fpm descent VY	2.28%
IGE Hover	3.93%	45° Turn 80 KCAS Left and Right	1.16%
OGE Hover	3.93%	45° Turn 120 KCAS Left and Right	1.72%
10 KGS Fwd	0.22%	45° Turn VH Left and Right	2.86%
20 KGS Fwd	0.22%	60° Turn 80 KCAS Left and Right	2.00%
30 KGS Fwd	0.22%	60° Turn 120 KCAS Left and Right	1.82%
45 KGS Fwd	2.34%	60 KCAS	25.73%

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

TABLE C-4. CONTINUED

MANEUVER DESCRIPTION	TIME	MANEUVER DESCRIPTION	TIME
20 KGS Left and Right	0.20%	0.6 VH	4.60%
30 KGS Left and Right	0.20%	0.8 VH	8.20%
45 KGS Left and Right	0.20%	VH	14.66%
20 KGS Aft	0.10%	Combat Man. Decelerating Turns	0.50%
30 KGS Aft	0.10%	Combat Man. Break Turn	0.50%
40 KGS Aft	0.10%	Combat Man. Dive	0.50%
500 fpm Climbs VY	1.50%	Combat Man. Recovery	0.50%
1000 fpm Climbs VY	1.50%	Autorotation (10K-2,500 ft AGL)	2.00%
1500 fpm Climbs VY	4.40%	Total	100%
<i>KGS - Knots Ground Speed, VH - Max Speed, fpm - feet per minute, KCAS - Knots Calibrated Air Speed</i>			

C.5.2 LVTS Development Methodology.

The techniques used to compute the subject LVTS are in accordance with the recommendations of MIL-STD-810H with Change 1 Method 514.8, Annex F, with the following clarifications.

a. In order to provide optimal statistical averaging for PSD calculations, an effort was made to hold each test point for a minimum of 30 seconds. Due to the inherent nature of some of the test points, this was not possible for all test maneuvers. Fifty percent overlap was employed to maximize the number of averages. Even so, the number of averages available was less than optimal for a few maneuvers. As the primary concern of helicopter vibration is the sine tones, which are theoretically deterministic with fixed amplitude, the error was considered acceptable.

b. Miner-Palmgern techniques were employed to compress 2500 hours of flight time to a 4.0-hour test duration. The 4-hour test duration was utilized to maintain consistency with previous MIL-STD-810 default helicopter LVTS. The exponent (sometimes referred to as slope or M) utilized was 6.43 for sine tones in g-peak and 7.5 for random profiles in g-rms (3.75 for PSDs).

c. MIL-STD-810H with Change 1 allows conservatism to be added as a standard deviation at two steps in the process, or as a simple multiplier. In this case no standard deviations were added. A multiplier of 1.3 was applied to all sine tone g-peak levels, and 2.0 to all broadband PSD g^2/Hz levels.

d. All locations for a given aircraft region were combined by enveloping (by axis).

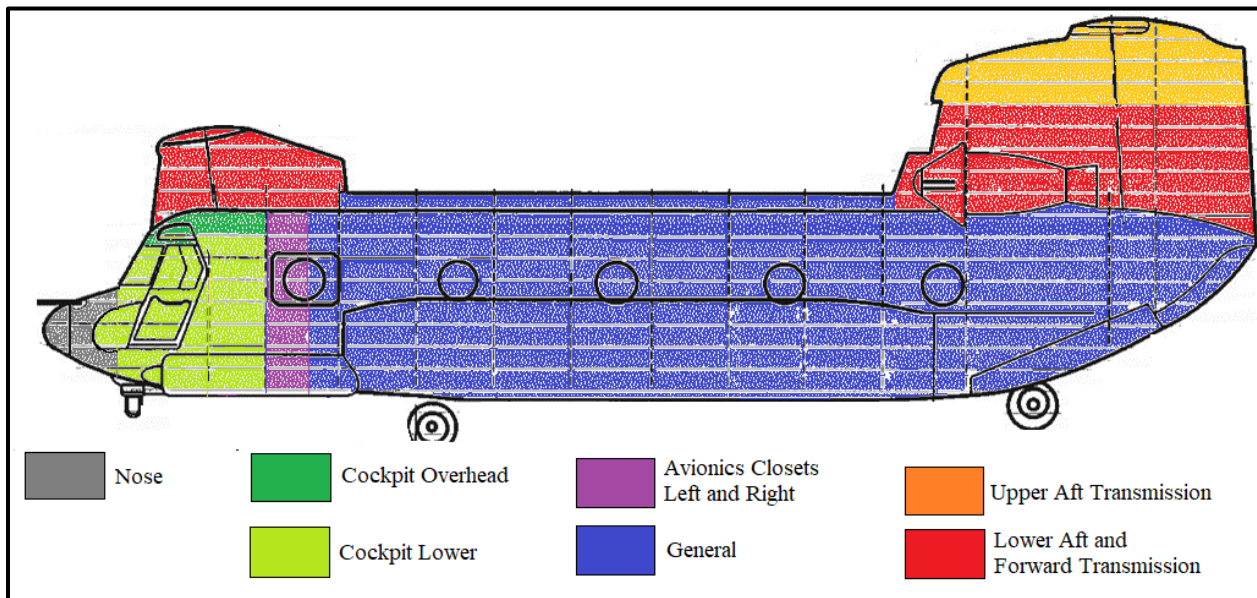
e. All tones that were of significant level for any location were processed for all locations. Tones below the analyst selected thresholds of 0.1 g-peak were left blank in the final LVTS. Additionally, all tones were converted to narrowbands (1 Hz wide) for comparison to the broadband profile. Any tone that was below the broadband profile plus 3 decibel (dB) was left

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

blank in the final LVTS. With the exception of the Cargo LVTS, a minimum threshold for the broadband breakpoints was set at a $1e-4 \text{ g}^2/\text{Hz}$.

C.5.3 Location Groupings.

A determination was made of how to group data locations in producing LVTSs for specific regions of the aircraft. Data collection points were grouped together in the VSD process as shown in Figure C-3 and Table C-2. The final LVTS were established by taking a spectral line by spectral line maxi of the individual LVTS developed within each zone on a per axis basis. In addition to the aircraft regions shown in Figure C-3, Cargo LVTS were developed using the three-accelerometer location on the cargo floor. Rather than the 2500 flight hours in 4-hour test duration, the Cargo LVTS were developed for 20 flight hours in a 0.5-hour test duration. Finally, the locations utilized for the Cockpit Overhead and Cockpit Lower LVTS (locations 2 - 6) were combined to develop Combined Cockpit LVTS.



Note: Regions shown are for general guidance only and are not intended to provide definitive profile selection.

Figure C-3. Aircraft regions.

C.5.4 VSD Results.

a. The spectral content of the vibration energy on the CH-47 was Sine on Random (SOR) in nature. As the rotor speeds have minimal variability, the sine tone frequencies of the LVTS

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

were considered constant. The nature of the vibration data dictated the development of SOR LVTS with stationary sinusoidal tones (dwells).

b. Multiple tones were identified of sufficient level for processing, as listed in Table C-5. The tones are correlated to the main rotor passage frequencies.

TABLE C-5. CH-47 TEST FREQUENCIES

Tone	Freq		Tone	Freq
1P	3.75		9P	33.75
3P	11.25		12P	45.00
6P	22.50		30P	112.50

c. Miner-Palmgern techniques were employed to compress 2500 hours of flight time to a 4.0-hour test duration. The 4-hour test duration was utilized to maintain consistency with previous MIL-STD-810 default helicopter LVTS. All sine tone levels were reviewed to ensure the compression resulted in acceptable exaggeration factors. Exaggeration factor is defined as the ratio of the test reference level (including time compression but before application of conservatism) and the maximum measured level. The exaggeration factor recommended by MIL-STD-810H with Change 1 (Method 514.8, Annex F, Section 9.2.1.2) is 2.0 for g-peak values. The exaggeration factor of all but a few tones was below the recommended 2.0. The exceptions are listed in Table C-6. The exceedance was considered acceptable to maintain historical durations.

TABLE C-6. EXAGGERATION FACTORS EXCEEDING RECOMMENDATION

Aircraft Region	Test Axis	Source	Freq (hz)	Level (g-peak)	Ratio
General	L	30P	112.5	0.41	2.09
Forward and Lower Aft Transmission	T	30P	112.5	2.0	2.19

C.6 GUIDELINES FOR UTILIZATION OF LVTS.

C.6.1 General Considerations.

a. Guidance relevant to all aircraft is provided in Section 7 of the main body of this TOP and should be reviewed. Additional guidance specific to the CH-47F is provided below.

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

b. CH-47F Chinook LVTS were developed for each of the 9 aircraft regions. These are included as Figures C-4 through C-12. Each figure includes LVTS for each of the three mutually orthogonal translational axes with respect to the aircraft (x-axis or longitudinal, y-axis or transverse, and z-axis or vertical). For a complete lifecycle vibration replication, the test article should be subjected to all three LVTS axes.

c. With the exception of Cargo, all LVTS provide the equivalent of 2500 hours of flight in 4 hours of runtime per axis. The Cargo LVTS provides 20 hours of flight in 0.5 hours of runtime per axis. If the LCEP of the test article is other than the published defaults, the test duration may be modified as appropriated. Further guidance is provided in Section 6.

d. LVTS selection should be based on the expected installation location of the test article, utilizing Table C-2 and Figure C-3 as guidance. Care should be taken when selecting an LVTS to ensure it is appropriate for use for the test article. Consider the planned deployment location of the test article on the CH-47 and select the default LVTS for the associated aircraft region.

e. If a test article will be installed exclusively in the cockpit lower or cockpit overhead region, then the article may be tested to the relevant LVTS. However, if the test article may be installed in either cockpit region then it should be tested to the combined cockpit LVTS.

f. The published LVTS are intended to represent the CH-47F. In the event LVTS are required for other variants of the CH-47, the ideal solution would be to develop them based on measured field data. In the absence of such data, the schedules provided in this document may serve as an alternative. Sine tone frequencies may require slight modification if the rotor head frequency of the variant is other than 3.75 main rotor frequency used in this LVTS development.

g. As discussed in paragraph C.5.4, the exaggeration factor of a few tones exceeded the 2.0 maximum recommended by MIL-STD-810H with Change 1. The affected tones are listed in Table C-6. Although the exceedances were considered acceptable, if there is concern for a given test article, the test levels can be reduced (and test duration increased) utilizing Miner-Palmgern techniques. Any reduction should be done with care to prevent reducing other tones to below the measured maximum. Reduction should be less than that provided in the Functional test reduction ratio discussed below. Further guidance on reducing test levels utilizing Miner-Palmgern techniques is provided in MIL-STD-810H with Change 1 Method 514.8, Annex F Section 9.

C.6.2 Functional Test Considerations

a. Functional reference levels should be near the envelope of the maximum measure levels plus conservatism. This is effectively the Endurance reference level reduced by the exaggeration factor. As Miner-Palmgern techniques were employed for time compression, the exaggeration factors varied across the LVTS sine tones, as well as the broadband profile. This

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

eliminated the ability to define a constant reduction level while maintaining a direct fatigue equivalence.

b. To define reduction ratios, a weighted average of the tone exaggeration factors was calculated for each LVTS, with the exaggeration factors weighted by the tone reference levels. The weighted average factors of the three axes were then averaged for each aircraft region. Reduction of the Endurance levels by these resultant factors (sine tones and broadband) will yield Functional reference levels comparable to maximum measured field data with conservatism. The reduction ratios are provided in Table C-7. Functional LVTS can be derived from the published Endurance LVTS by applying the ratios in the table. Alternatively, a control system programmed for the Endurance LVTS can be executed at the dB levels provided.

TABLE C-7. CALCULATION OF FUNCTIONAL REFERENCE LEVEL

Aircraft Region	Functional Level as a Ratio of Endurance Level		
	dB	Ratio for Sine Tones	Ratio for Broadband Breakpoints
Nose	-3.30	0.68	0.47
Cockpit Lower	-2.60	0.74	0.55
Cockpit Overhead	-3.00	0.71	0.50
Combined Cockpit	-2.70	0.73	0.54
Avionics Closets Left and Right	-3.10	0.70	0.49
General	-4.40	0.60	0.36
Cargo	0.00	1.00	1.00
Forward and Lower Aft Transmission	-4.80	0.58	0.33
Upper Aft Transmission	-3.60	0.66	0.44

C.6.3 Reliability Test Considerations.

a. All LVTS's provided in this appendix are considered to be Endurance specifications. For reliability testing it is sometimes desired to operate a test article for hundreds of hours in an environment representative of actual exposure (i.e., uncompressed vibration). Reliability testing at Endurance reference levels would constitute a significant over test and is not appropriate.

b. In the process of establishing reference criteria for a reliability test, while backing out sufficient compression to yield representative field levels, it is desired to maintain a reasonable fatigue equivalency. Dealing with uncompressed 1-degree of freedom (DOF) references, laboratory run time will be 3:1 longer than the actual equivalent flight time. If one applies Miner-Palmgren techniques using the exponent associated with sinusoidal excitation (M=6.43)

APPENDIX C. CH-47F LABORATORY VIBRATION TEST SCHEDULES.

and assuming 1/3 of the 2500 flight hours (833 hours) of laboratory time per axis, the published references would be run at -7.21 dB. The resulting 2500 hours of laboratory run time would then represent 2500 hours of flight. Realizing that the exponent in Miner-Palmgren differs for sine and random signals, and understanding the proposed levels for a reliability test are being defined while maintaining reasonable fatigue equivalency, it is recommended that a 7 dB reduction and a duration of 833 hours per axis (representing 2500 hours) be employed as a basis. Reliability LVTS can be derived from the published Endurance LVTS by applying a factor of 0.447 to each sine tone reference level and 0.200 to each broadband breakpoint. Alternatively, a control system programed for the Endurance LVTS can be executed at -7 dB.

c. Any reliability test to be conducted at an arbitrary number of desired hours may be computed by simply linearly scaling time. For example, if one desired to conduct a reliability test for 1500 hours, the published specs would be executed at -7 dB and the duration per axis would be 500 hrs.

CH-47F LVTS
Aircraft Region: Cockpit Overhead

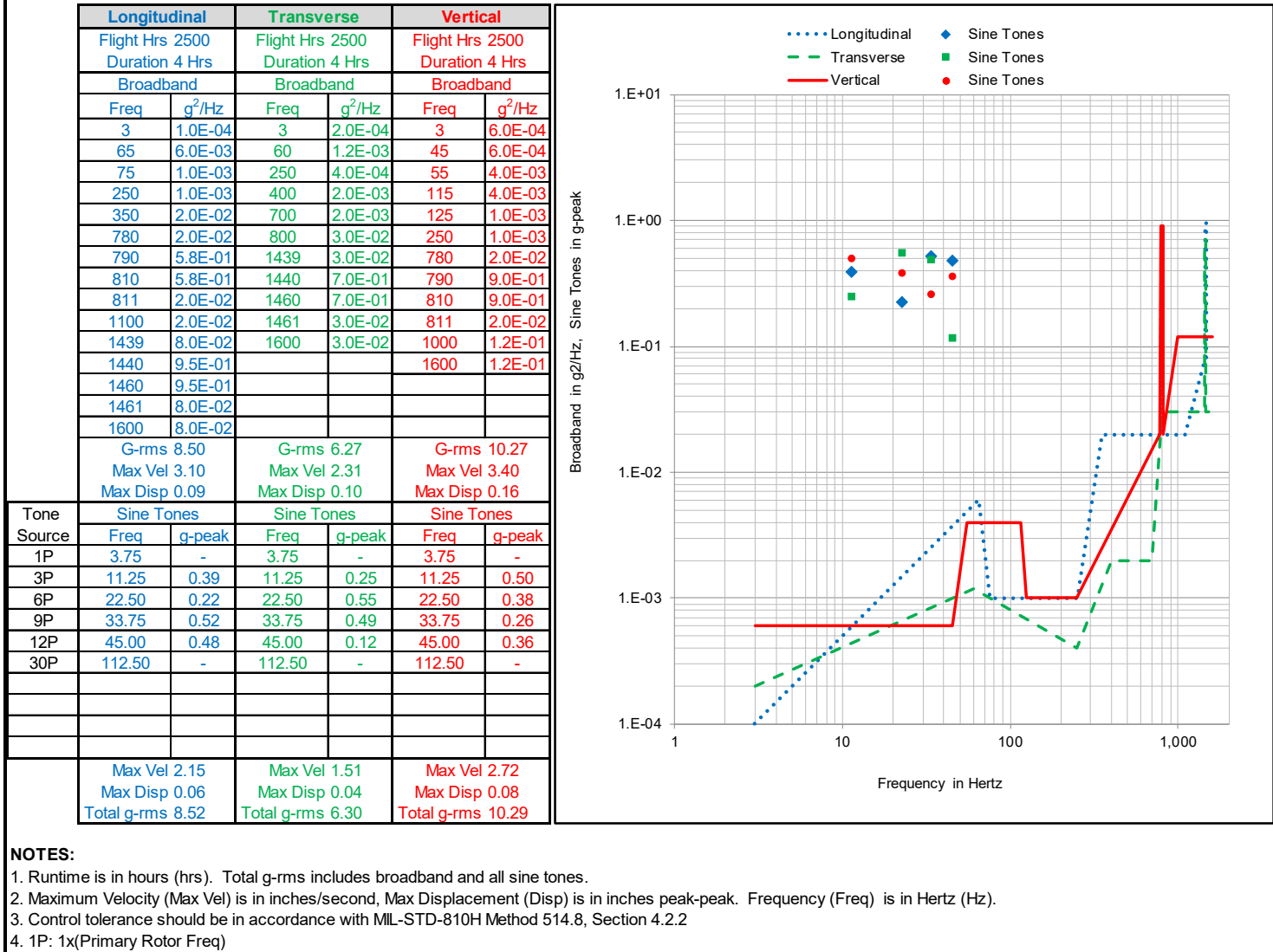


Figure C-6. CH-47F LVTS, Region: Cockpit Overhead.

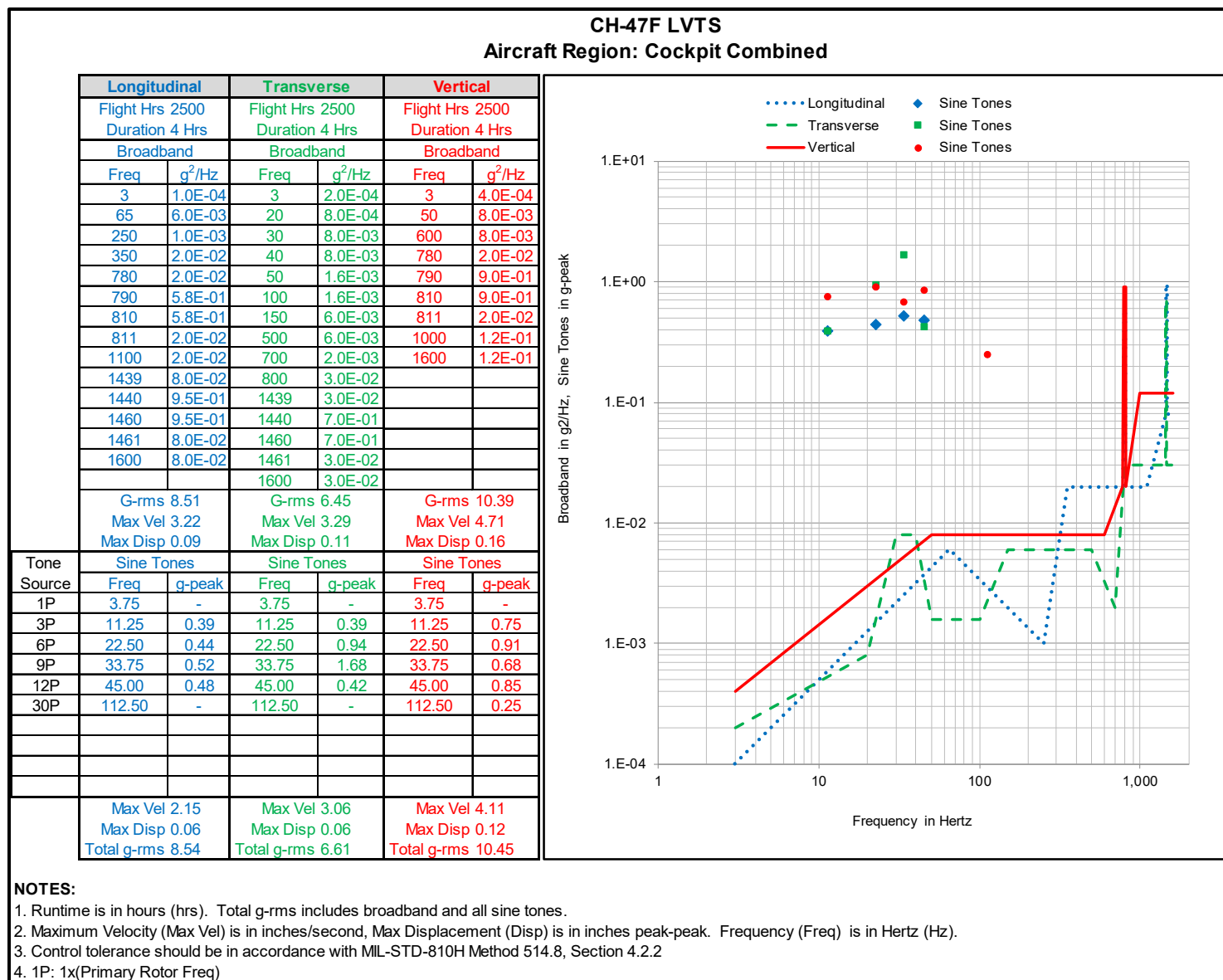


Figure C-7. CH-47F LVTS, Region: Cockpit Combined.

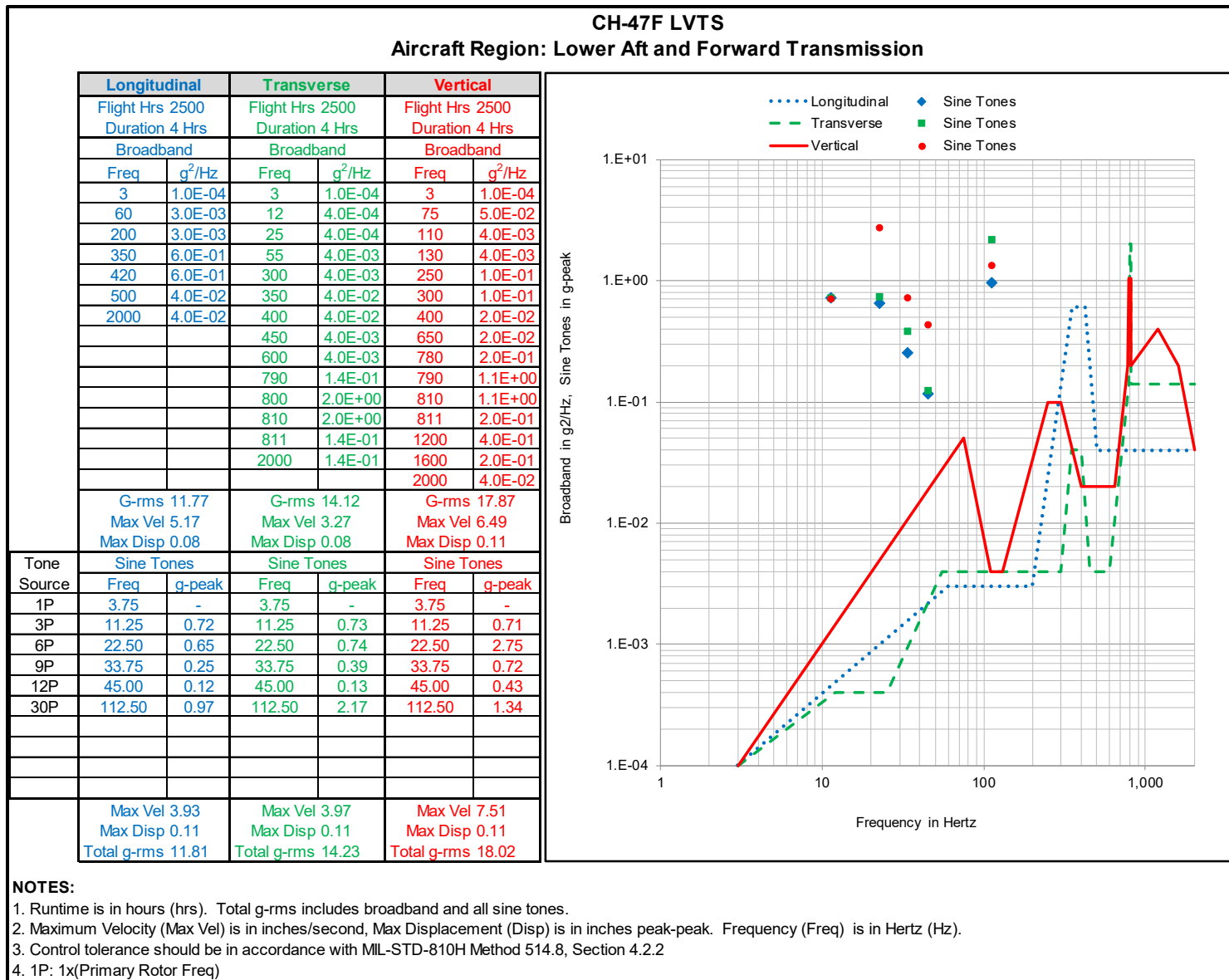


Figure C-10. CH-47F LVTS, Region: Lower Aft and Forward Transmission.

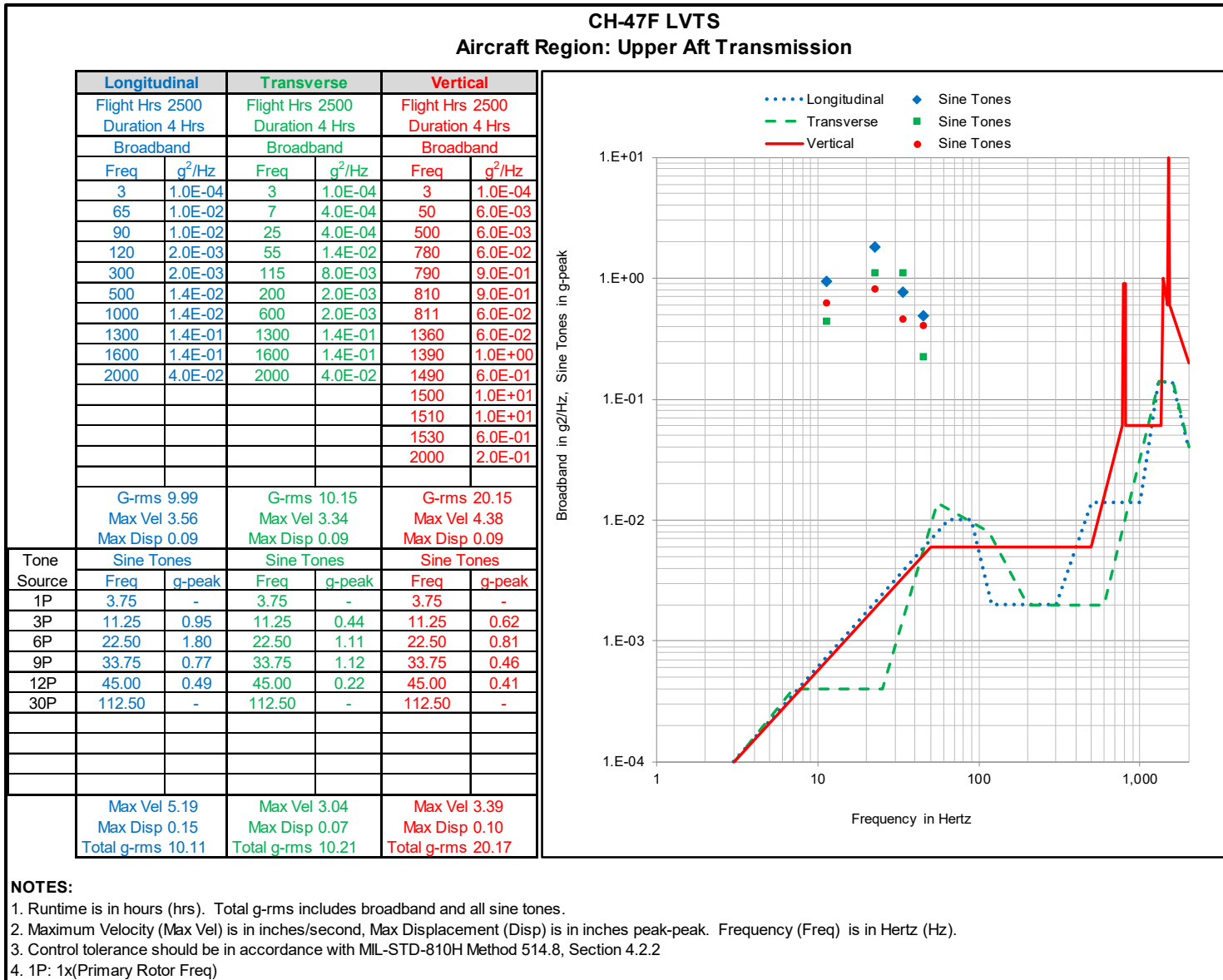


Figure C-11. CH-47F LVTS, Region: Upper Aft Transmission.

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

D.1 SYSTEM DESCRIPTION.

The UH-60M (Figure D-1) is a twin turbine engine, single rotor four blade, semi-monocoque fuselage helicopter. The primary mission of the UH-60M is tactical transport of troops, supplies, and equipment. Secondary missions include training, mobilization, development of new and improved concepts, support of disaster relief, and command and control. The UH-60M is equipped with composite spar wide-cord main rotor blades that provide 500 pounds more lift than the current UH-60L blades. Additionally, the new General Electric T700-GE-701D engines produce slightly more shaft horsepower, allowing 500 pounds of additional payload. The UH-60M features a Rockwell Collins glass cockpit with a narrower instrument panel to improve chin window visibility. The UH-60M new cabin and transition section use high-speed machine frames, reducing the cost and complexity of the cabin. Dual digital flight controls and fully-coupled flight directors are installed to reduce pilot workload. Altitude and hover hold help to avoid “white-out” and “brown-out” mishaps, while active vibration control reduces pilot fatigue encountered in lengthy missions. On-board diagnostics isolate problems and allow precise system diagnosis, and an Improved Hover Infrared Suppression System provides superior battlefield protection from infrared weapons.



Figure D-1. UH-60M Blackhawk Helicopter.

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

D.2 ANALYSIS OBJECTIVE.

The objective of the analysis was to develop new LVTS for the UH-60M platform to replace outdated vibration test levels presented in MIL-STD-810G CN1. The testing effort was completed in two phases.

a. Collected vibration data at locations of interest on the UH-60M during flight testing. Flight testing encompassed maneuvers that provided a good representation of the Mission Scenario.

b. Utilized flight test data to develop vibration specifications for the UH-60M.

D.3 CALIBRATION.

Calibration of the individual test equipment associated with the data acquisition was performed through the U.S. Army's Test, Measurement, and Diagnostic Equipment Program or via subcontract to accredited calibration laboratories. Calibration was performed IAW the original manufacturer's established standards and procedures for original equipment performance, with standard test equipment and laboratory standards traceable to NIST. The validity of equipment calibration was verified prior to test.

D.4 DETAILS OF FLIGHT TEST.

D.4.1 Test Aircraft.

Two datasets were utilized for this VSD effort. The primary was a from UH-60M, Aircraft 11-20541. The vehicle Engine Start Gross Weight (ESGW) was 16,385 lbs and the Engine Start Center of Gravity (ESCG) was 386.8 inches. Maintenance Work Orders (MWO) and Service Bulletins (SB) performed on the test aircraft are listed in Table D-1. Flight testing was conducted by RTC on 23-24 June 2014. An alternate dataset was utilized only for the Vertical Tail Pylon aircraft region. This second aircraft was a UH-60A with army serial number (ASN) 85 25511. Testing was conducted the first quarter of calendar year 2006. For additional details see Test Plan, UH-60 Dual Common Missile Warning System Software Test Bed Fiscal Year 2006⁴.

TABLE D-1. UH-60M AIRCRAFT 11-20541 MWO AND SB

MWO OR SB NUMBER	SHORT TITLE
1-1520-237-50-90	ENGINE INLET BARRIER FILTER AND APU INLET FILTER

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

D.4.2 Flight Maneuvers.

The flight maneuvers (test points) were chosen to represent the full flight spectrum of the UH-60 aircraft. The test points flown for the primary dataset are provided in the mission scenario discussion below. An effort was made to hold each test point for a minimum of 30 seconds to provide optimal statistical averaging for PSD calculations during the analysis phase. No maneuver list was provided to the analyst for the alternate dataset.

D.4.3 Instrumentation.

Instrumentation locations on the UH-60M were selected in an effort to capture the overall vibration levels on the aircraft. Due to programmatic constraints for this effort, instrumentation was limited to 20 triaxial accelerometers. A detailed list of instrumentation locations can be found in Table D-2 and Figure D-2. Observe that the filter cutoff frequency (Fc) was raised to 2170 Hz for accelerometer locations in the engine and transmission locations as higher frequency response was anticipated. A posttest review of the data showed issues with the data taken at the Tail Rotor Gear Box location. The instrumentation issues resulted in insufficient data to develop LVTS for the Vertical Tail Pylon region. An alternate dataset was identified with sufficient data and was utilized for this purpose. Instrumentation descriptions for the alternate dataset are identified as A-1 and A-2 in Table D-2 and the approximate locations are provided in Figure D-2. A list of aircraft parameters measured on the UH-60M is provided in Table D-3. No aircraft parameter data were available for the UH-60A dataset.

TABLE D-2. UH-60M INSTRUMENTATION LOCATIONS

ACCEL NUMBER	LOCATION DESCRIPTION	RANGE (g)	SAMPLE RATE (SPS)	Fc (Hz)
1	Nose mount	±20	8680	1085
2	Floor (pedals) Left	±20	8680	1085
3	Floor (pedals) Right	±20	8680	1085
4	Pedal Adjust Left	±20	8680	1085
5	Center Console	±20	8680	1085
6	Cockpit 250 beam left	±20	8680	1085
7	Cockpit 250 beam Right	±20	8680	1085
8	Aft ESSS mount high left	±20	8680	1085
9	Aft ESSS mount high right	±20	8680	1085
10	ESSS mount low right	±20	8680	1085
11	Main Transmission Mount front	±50	8680	2170
12	Main Transmission Mount aft	±50	8680	2170
13	398 Beam Right mid	±20	8680	1085
14	ALQ-144 Mount	±50	8680	2170
15	Aft AVX Comp Bulkhead	±20	8680	1085
16	Aft Stringer	±20	8680	1085
17	Aft AVX rack mid	±20	8680	1085

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

TABLE D-2. CONTINUED

ACCEL NUMBER	LOCATION DESCRIPTION	RANGE (g)	SAMPLE RATE (SPS)	Fc (Hz)
18	Drive Shaft Damper	±50	8680	2170
19	Intermediate G/B	±50	8680	2170
20	Tail Rotor G/B	±50	8680	2170
A-1	Aft Tail – Upper (Alternate Data Set)	±20	3086	771
A-2	Aft Tail – Lower (Alternate Data Set)	±20	3086	771

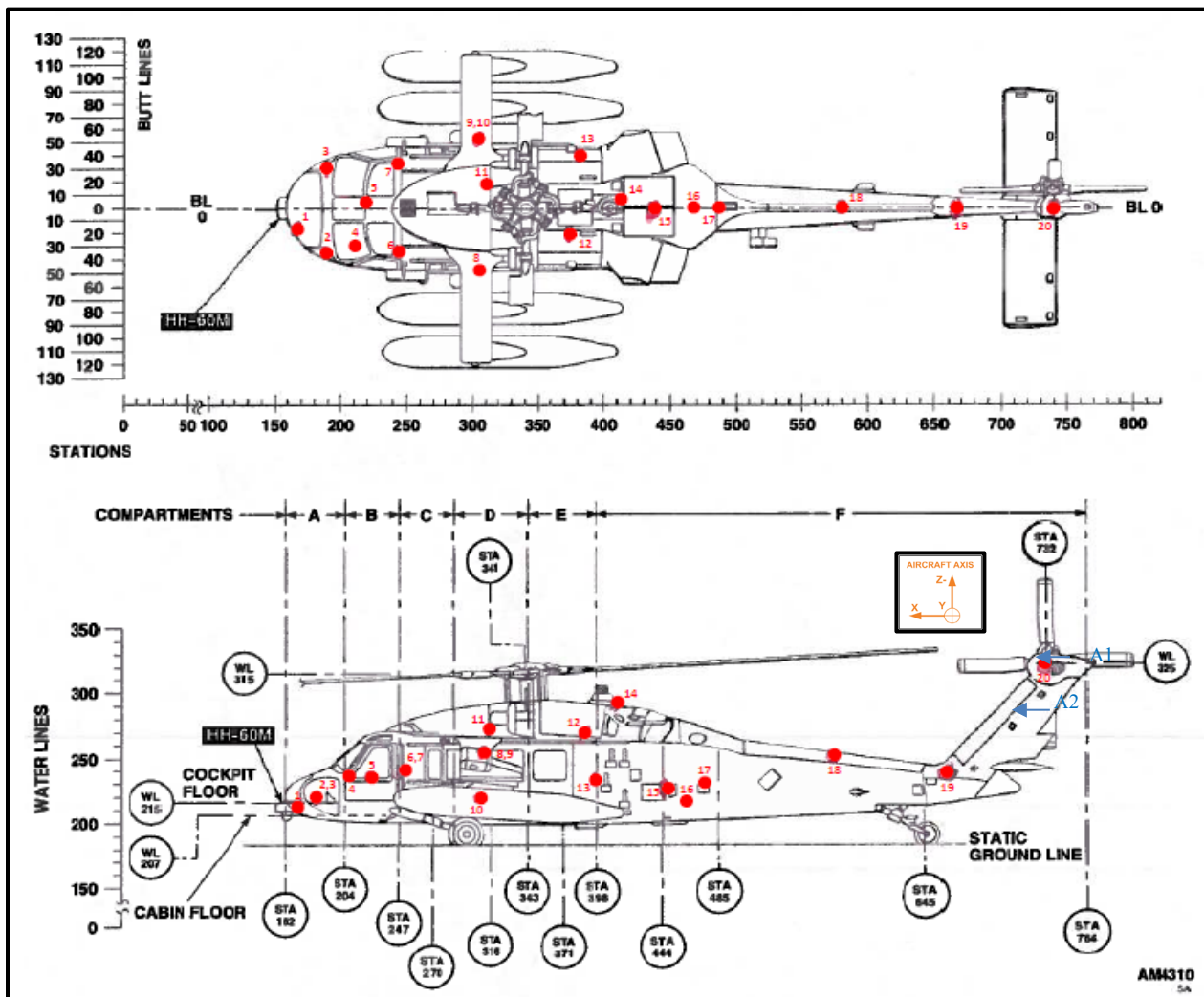


Figure D-2. Accelerometer locations.

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

TABLE D-3. UH-60M BUS PARAMETER LIST

DESCRIPTION	UNITS	DESCRIPTION	UNITS
LATITUDE	Radians	PITCH ANGLE	Degrees
LONGITUDE	Radians	HEADING	Degrees
ALTITUDE	Feet	ROLL RATE	Degrees/Sec
AIRSPEED	Knots	PITCH RATE	Degrees/Sec
ROLL ANGLE	Degrees	YAW RATE	Degrees/Sec

D.5 DETAILS OF VIBRATION SPECIFIC DEVELOPMENT.

D.5.1 Mission Scenario.

a. The flight maneuvers flown for the primary dataset were chosen to provide a representation of the expected UH-60M usage spectrum. These flight maneuvers were each assigned a percentage value that correlates the flight maneuver to the total expected exposure over the lifecycle of the test article. The LVTSs were developed to be equivalent to a total of 2500 flight hours on the UH- 60M platform. The lifecycle scenario was developed from the UH-60M Flight Usage Spectrum detailed in Table D-3 of AVNS-PRF-10002H, Performance Specification System Specification for the UH-60M Black Hawk Utility Helicopter⁵ and discussions with Military Pilots. The lifecycle scenario utilized in the LVTS development can be found in Table D-4. For test points listed as left and right, data was acquired in both directions and the percent of flight was divided equally between them. Factors such as airspeed and angle of bank were verified per the aircraft bus parameters as listed in Table D-3.

b. Limited meta data was available for the UH-60A dataset utilized for the Vertical Tail Pylon LVTS. Acceleration data for 51 flight events were available, however no maneuver descriptions were available. Based on discussions with test engineers involved with the test, the maneuvers list was believed to be similar to that of the UH-60M dataset. The scenario was defined as follows. The 18 maneuvers with the highest vibration levels were selected for processing, and it was assumed that these maneuvers represented 25 percent of 2500 hours of flight time. Vibration for two of the maneuvers was significantly higher than the others. Based on the utilization of the UH-60M scenario, 0.2 percent of the flight time was associated with those two maneuvers. The remaining 25 percent of the scenario was distributed evenly among the remaining 18 processed events. Although less than ideal, this approach was believed sufficient to provide LVTS for the Vertical Tail Pylon.

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

TABLE D-4. UH-60M MISSION SCENARIO

MANEUVER DESCRIPTION	TIME	MANEUVER DESCRIPTION	TIME
VMC Take Off	5.81%	OGE Hover at 100'	0.98%
VMC Approach	2.85%	AGL 20ft 10 Kts Rel. Azi 0 Deg .06Vh	1.28%
Level Flight 80 Kts .5Vh	6.84%	AGL 20ft 20 Kts Rel. Azi 0 Deg .12 Vh	1.28%
Level Flight 100 Kts .6Vh	4.70%	AGL 20ft 30 Kts Rel. Azi 0 Deg .19Vh	0.86%
Level Flight 120 Kts .8Vh	22.23%	AGL 20ft 40 Kts Rel. Azi 0 Deg 0.25Vh	0.86%
Level Flight Vh (approx 158 Kts)	38.49%	AGL 20ft 10 Kts Rel. Azi 90 Deg	0.14%
Turn 78 Kts 30 Deg AOB, Lft & Rgt	1.32%	AGL 20ft 20 Kts Rel. Azi 90 Deg	0.14%
Turn 78 Kts 60 Deg AOB, Lft & Rgt	0.42%	AGL 20ft 30 Kts Rel. Azi 90 Deg	0.14%
Turn 100 Kts 30 Deg AOB, Lft & Rgt	1.32%	AGL 20ft 40 Kts Rel. Azi 90 Deg	0.14%
Turn 100 Kts 60 Deg AOB, Lft & Rgt	0.42%	AGL 20ft 10 Kts Rel. Azi 180 Deg	0.14%
Turn 120 Kts 30 Deg AOB, Lft & Rgt	1.32%	AGL 20ft 20 Kts Rel. Azi 180 Deg	0.14%
Turn 120 Kts 60 Deg AOB, Lft & Rgt	0.42%	AGL 20ft 30 Kts Rel. Azi 180 Deg	0.14%
Climb Turn 80 Kts, 30 Deg AOB, Lft & Rgt	1.32%	AGL 20ft 40 Kts Rel. Azi 180 Deg	0.14%
Climb Turn 100 Kts, 30 Deg AOB, Lft & Rgt	1.32%	AGL 20ft 10 Kts Rel. Azi 270 Deg	0.14%
Climb Turn 120 Kts, 30 Deg AOB, Lft & Rgt	1.32%	AGL 20ft 20 Kts Rel. Azi 270 Deg	0.14%
Autorotation 80 Kts	1.49%	AGL 20ft 30 Kts Rel. Azi 270 Deg	0.14%
Ground Run 100%Nr	0.50%	AGL 20ft 40 Kts Rel. Azi 270 Deg	0.14%
I GE Hover at 10'	0.98%	Total	100%

D.5.2 LVTS Development Methodology.

The techniques used to compute the subject LVTS are in accordance with the recommendations of MIL-STD-810H with Change 1 Method 514.8, Annex F, with the following clarifications.

a. In order to provide optimal statistical averaging for PSD calculations, an effort was made to hold each test point for a minimum of 30 seconds. Due to the inherent nature of some of the test points, this was not possible for all test maneuvers. Fifty percent overlap was employed to maximize the number of averages. Even so, the number of averages available was less than optimal for a few maneuvers. As the primary concern of helicopter vibration is the sine tones, which are theoretically deterministic with fixed amplitude, the error was considered acceptable.

b. Miner-Palmgern techniques were employed to compress 2500 hours of flight time to a 4.0-hour test duration. The 4-hour test duration was utilized to maintain consistency with previous MIL-STD-810 default helicopter LVTS. The exponent (sometimes referred to as slope or M) utilized was 6.48 for sine tones in g-peak and 7.5 for random profiles in g-rms (3.75 for PSDs).

c. MIL-STD-810H with Change 1 allows conservatism to be added as a standard deviation at two steps in the process, or as a simple multiplier. In this case no standard

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

deviations were added. A multiplier of 1.3 was applied to all sine tone g-peak levels, and 2.0 to all broadband PSD g^2/Hz levels.

d. All locations for a given aircraft region were combined by enveloping (by axis).

e. All tones that were of significant level for any location were processed for all locations. Tones below the analyst selected thresholds of 0.1 g-peak (below 100 Hz) or 0.5 g-peak (above 100 Hz) were left blank in the final LVTS. Additionally, all tones were converted to narrowbands (1 Hz wide) for comparison to the broadband profile. Any tone that was below the broadband profile plus 3 decibel (dB) was left blank in the final LVTS.

f. As no aircraft parameters were available for the UH-60A dataset, data for the full event was used to calculate PSDs for each maneuver. As with the maneuver scenario discussed above, this approach was believed sufficient to provide LVTS for the Vertical Tail Pylon based on measured data as opposed to the MIL-STD-810H with Change 1 defaults.

D.5.3 Location Groupings.

A determination was made of how to group data locations in producing LVTSs for specific regions of the aircraft. Data collection points were grouped together in the VSD process as shown in Figure D-3 and Table D-5. The final vibration specification was developed by taking a spectral line by spectral line maxi of the test levels for each group on a per axis basis.

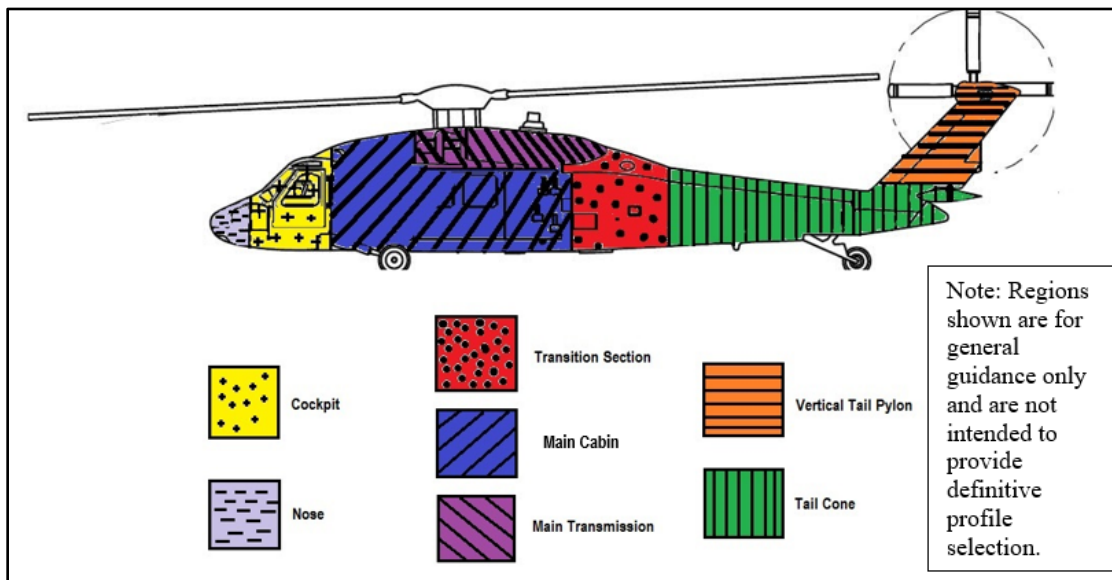


Figure D-3. Aircraft regions.

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

TABLE D-5. ACCELEROMETER VSD GROUPINGS

AIRCRAFT REGION	ACCEL NUMBER	DATA POINT LOCATION	STATION (INCHES)	WATER LINE (INCHES)	BUTT LINE (INCHES)
Nose	1	Nose Mount	168	212	-10
	2	Floor (Pedals) Left	186	215	-29
	3	Floor (Pedals) Right	186	215	+29
Cockpit	4	Pedal Adjust Left	198	240	-25
	5	Center Console	231	229	+4
	6	Cockpit 250 Beam Left	247	240	-40
	7	Cockpit 250 Beam Right	247	240	+40
Main Cabin	6	Cockpit 250 Beam Left	247	240	-40
	7	Cockpit 250 Beam Right	247	240	+40
	8	Aft ESSS Mount High Left	307	260	-51
	9	Aft ESSS Mount High Right	307	260	+51
	10	ESSS Mount Low Right	308	217	+48
Transition Section	13	398 Beam Right Mid	398	248	+42
	15	Aft AVX Comp Bulkhead	444	203	-6
	16	Aft Stringer	455	203	-11
Main Transmission	17	Aft AVX Rack Mid	485	230	+15
	11	Main Transmission Mount Front	327	265	+10
	12	Main Transmission Mount Aft	357	267	-9
Tail Cone	14	ALQ-144 Mount	412	276	+9
	18	Drive Shaft Damper	575	250	0
Vertical Tail Pylon	A-1	Aft Tail – Upper	Not Available		
	A-2	Aft Tail – Lower	Not Available		

D.5.4 VSD Results.

a. The spectral content of the vibration energy for the locations of interest on the UH-60M was SOR in nature. The sine portion of the vibration energy was primarily driven by the main rotors of the UH-60M. The frequency of the dominant sinusoidal content was constant and driven by harmonics of the main rotor frequency (4.3 Hz) or the tail rotor frequency (19.8 Hz). The nature of the vibration data dictated the development of a SOR laboratory vibration test with stationary sinusoidal tones.

b. Miner-Palmgern techniques were employed to compress 2500 hours of flight time to a 4.0-hour test duration. The 4-hour test duration was utilized to maintain consistency with previous MIL-STD-810 default helicopter LVTS. All sine tone levels were reviewed to ensure the compression resulted in acceptable exaggeration factors. Exaggeration factor is defined as the ratio of the test reference level (including time compression but before application of conservatism) and the maximum measured level. The exaggeration factor recommended by MIL-STD-810H with Change 1 (Method 514.8, Annex F Section 9.2.1.2) is 2.0 for g-peak values. Numerous tones exceed the 2.0 ratio. However, in all but a few cases the tone levels

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

were too low to be of concern. All tones with a velocity above 1.0 inch/second (ips) are listed in Table D-6. None have a displacement above 0.1 inches peak-peak. In all cases, the exceedance was considered acceptable to maintain historical durations.

TABLE D-6. EXAGGERATION FACTORS EXCEEDING RECOMMENDATION

Region	Axis	Freq (Hz)	Level (g-peak)	Velocity (ips)	Displacement (inch pk-pk)	Ratio
Tail Cone	T	17.2	0.50	1.80	0.03	2.34
Tail Cone	V	17.2	0.81	2.89	0.05	2.34
Tail Cone	V	79.2	3.44	2.67	0.01	2.35
Main Transmission	L	17.2	1.04	3.69	0.07	2.14
Main Transmission	T	34.4	0.75	1.35	0.01	2.33
Main Transmission	V	17.2	1.53	5.45	0.10	2.34
Main Transmission	V	34.4	0.70	1.25	0.01	2.01
Transition Section	V	17.2	1.04	3.69	0.07	2.14
Main Cabin	T	34.4	0.86	1.54	0.01	2.33
Main Cabin	V	34.4	0.75	1.34	0.01	2.30
Cockpit	L	34.4	0.69	1.23	0.01	2.33
Cockpit	T	34.4	1.33	2.38	0.02	2.33
Cockpit	V	34.4	0.86	1.54	0.01	2.33
Nose	T	34.4	0.59	1.06	0.01	2.34
Nose	V	34.4	0.58	1.04	0.01	2.34

D.6 GUIDELINES FOR UTILIZATION OF LVTS.

D.6.1 General Considerations.

a. Guidance relevant to all aircraft is provided in Section 7 of the main body of this TOP and should be reviewed. Additional guidance specific to the UH-60M is provided below.

b. UH-60M Blackhawk LVTS were developed for each of the seven aircraft regions. These are included as Figures D-4 through D-10. Each figure includes LVTS for each of the three mutually orthogonal translational axes with respect to the aircraft (x-axis or longitudinal, y-axis or transverse, and z-axis or vertical). For a complete lifecycle vibration replication, the test article should be subjected to all three LVTS axes.

c. All LVTS provide the equivalent of 2500 hours of flight in 4 hours of runtime per axis. If the LCEP of the test article is other than the published defaults, the test duration may be modified as appropriated. Further guidance is provided in Section 6.

d. LVTS selection should be based on the expected installation location of the test article, utilizing Table D-2 and Figure D-5 as guidance. Care should be taken when selecting an LVTS

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

to ensure it is appropriate for use for the test article. Consider the planned deployment location of the test article on the UH-60 and select the default LVTS for the associated aircraft region.

e. The published LVTS are intended to represent the UH-60M. In the event LVTS are required for other variants of the UH-60, the ideal solution would be to develop them based on measured field data. In the absence of such data, the schedules provided in this document may serve as an alternative. Sine tone frequencies may require slight modification if the main rotor or tail rotor frequency differ from the frequencies used in this LVTS development.

f. As discussed in paragraph D.5.4, the exaggeration factor of a few tones exceeded the 2.0 maximum recommended by MIL-STD-810H with Change 1. The affected tones are listed in Table D-6. Although the exceedances were considered acceptable, if there is concern for a given test article, the test levels can be reduced (and test duration increased) utilizing Miner-Palmgern techniques. Any reduction should be done with care to prevent reducing other tones to below the measured maximum. Reduction should be less than that provided in the Functional test reduction discussed below. Further guidance on reducing test levels utilizing Miner-Palmgern techniques is provided in MIL-STD-810H with Change 1 Method 514.8, Annex F Section 9.

D.6.1 Functional Test Considerations.

a. Functional reference levels should be near the envelope of the maximum measure levels plus conservatism. This is effectively the Endurance reference level reduced by the exaggeration factor. As Miner-Palmgern techniques were employed for time compression, the exaggeration factors varied across the LVTS sine tones, as well as the broadband profile. This eliminated the ability to define a constant reduction level while maintaining a direct fatigue equivalence.

b. To define reduction ratios, a weighted average of the tone exaggeration factors was calculated for each LVTS, with the exaggeration factors weighted by the tone reference levels. The weighted average factors of the three axes were then averaged for each aircraft region. Reduction of the Endurance levels by these resultant factors (sine tones and broadband) will yield Functional reference levels comparable to maximum measured field data with conservatism. The reduction ratios are provided in Table D-7. Functional LVTS can be derived from the published Endurance LVTS by applying the ratios in the table. Alternatively, a control system programed for the Endurance LVTS can be executed at the dB levels provided.

APPENDIX D. UH-60M LABORATORY VIBRATION TEST SCHEDULES.

TABLE D-7. CALCULATION OF FUNCTIONAL REFERENCE LEVEL

Aircraft Region	Functional Level as a Ratio of Endurance Level		
	dB	Ratio for Sine Tones	Ratio for Broadband Breakpoints
Nose	-5.0	0.56	0.31
Cockpit	-5.1	0.55	0.31
Main Cabin	-5.0	0.56	0.32
Transition Section	-5.3	0.54	0.29
Main Transmission	-6.1	0.50	0.25
Tail Cone	-5.8	0.51	0.26
Vertical Tail Pylon	-2.0	0.79	0.63

D.6.3 Reliability Test Considerations.

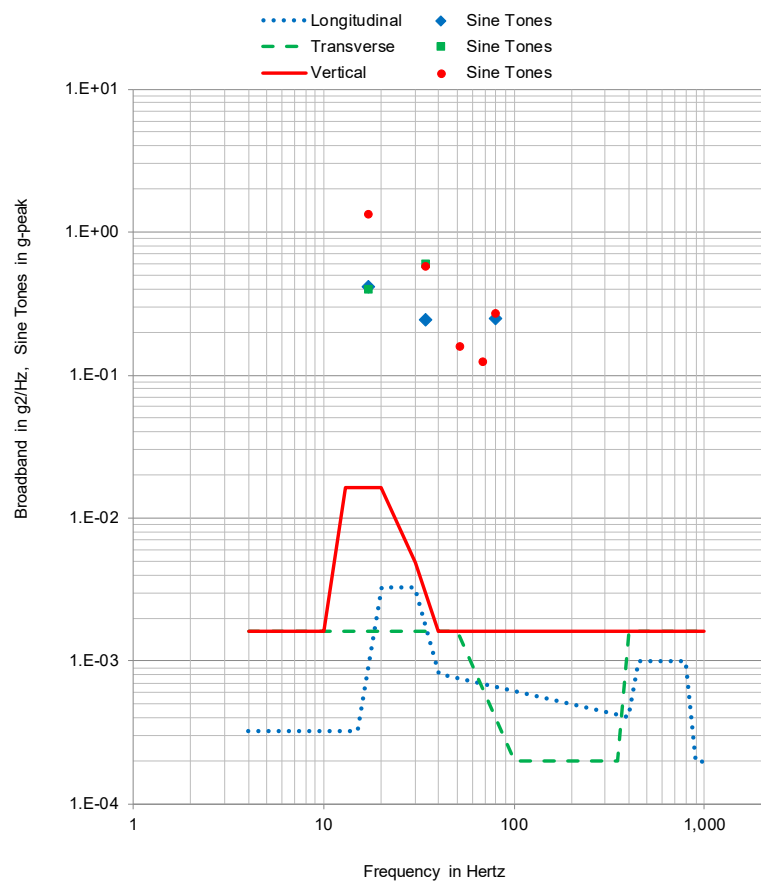
a. All LVTS's provided in this appendix are considered to be Endurance specifications. For reliability testing it is sometimes desired to operate a test article for hundreds of hours in an environment representative of actual exposure (i.e., uncompressed vibration). Reliability testing at Endurance reference levels would constitute a significant over test and is not appropriate

b. In the process of establishing reference criteria for a reliability test, while backing out sufficient compression to yield representative field levels, it is desired to maintain a reasonable fatigue equivalency. Dealing with uncompressed 1-DOF references, laboratory run time will be 3:1 longer than the actual equivalent flight time. If one applies Miner-Palmgren techniques using the exponent associated with sinusoidal excitation ($M=6.43$) and assuming 1/3 of the 2500 flight hours (833 hours) of laboratory time per axis, the published references would be run at -7.21 dB. The resulting 2500 hours of laboratory run time would then represent 2500 hours of flight. Realizing that the exponent in Miner-Palmgren differs for sine and random signals, and understanding the proposed levels for a reliability test are being defined while maintaining reasonable fatigue equivalency, it is recommended that a 7 dB reduction and a duration of 833 hours per axis (representing 2500 hours) be employed as a basis. Reliability LVTS can be derived from the published Endurance LVTS by applying a factor of 0.447 to each sine tone reference level and 0.200 to each broadband breakpoint. Alternatively, a control system programed for the Endurance LVTS can be executed at -7 dB.

c. Any reliability test to be conducted at an arbitrary number of desired hours may be computed by simply linearly scaling time. For example, if one desired to conduct a reliability test for 1500 hours, the published specs would be executed at -7 dB and the duration per axis would be 500 hrs.

UH-60M LVTS
Aircraft Region: Nose

Longitudinal		Transverse		Vertical		
Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		
Broadband		Broadband		Broadband		
Freq	g ² /Hz	Freq	g ² /Hz	Freq	g ² /Hz	
4	3.3E-04	4	1.6E-03	4	1.6E-03	
15	3.3E-04	50	1.6E-03	10	1.6E-03	
20	3.3E-03	100	2.0E-04	13	1.6E-02	
30	3.3E-03	350	2.0E-04	20	1.6E-02	
40	8.2E-04	400	1.6E-03	30	4.9E-03	
400	4.1E-04	1000	1.6E-03	40	1.6E-03	
450	1.0E-03			1000	1.6E-03	
800	1.0E-03					
900	2.0E-04					
1000	2.0E-04					
G-rms 0.84 Max Vel 2.37 Max Disp 0.08		G-rms 1.08 Max Vel 3.62 Max Disp 0.17		G-rms 1.35 Max Vel 5.98 Max Disp 0.20		
Tone Source	Sine Tones		Sine Tones		Sine Tones	
	Freq	g-peak	Freq	g-peak	Freq	g-peak
1P	4.30	-	4.30	-	4.30	-
4P	17.20	0.42	17.20	0.40	17.20	1.33
8P	34.40	0.24	34.40	0.59	34.40	0.58
12P	51.60	-	51.60	-	51.60	0.16
16P	68.80	-	68.80	-	68.80	0.13
4T	79.20	0.25	79.20	-	79.20	0.27
8T	158.40	-	158.40	-	158.40	-
MGBx1	218.00	-	218.00	-	218.00	-
HSS	348.00	-	348.00	-	348.00	-
MGBx2	436.00	-	436.00	-	436.00	-
	Max Vel 1.48 Max Disp 0.03 Total g-rms 0.92		Max Vel 1.42 Max Disp 0.03 Total g-rms 1.19		Max Vel 4.73 Max Disp 0.09 Total g-rms 1.71	

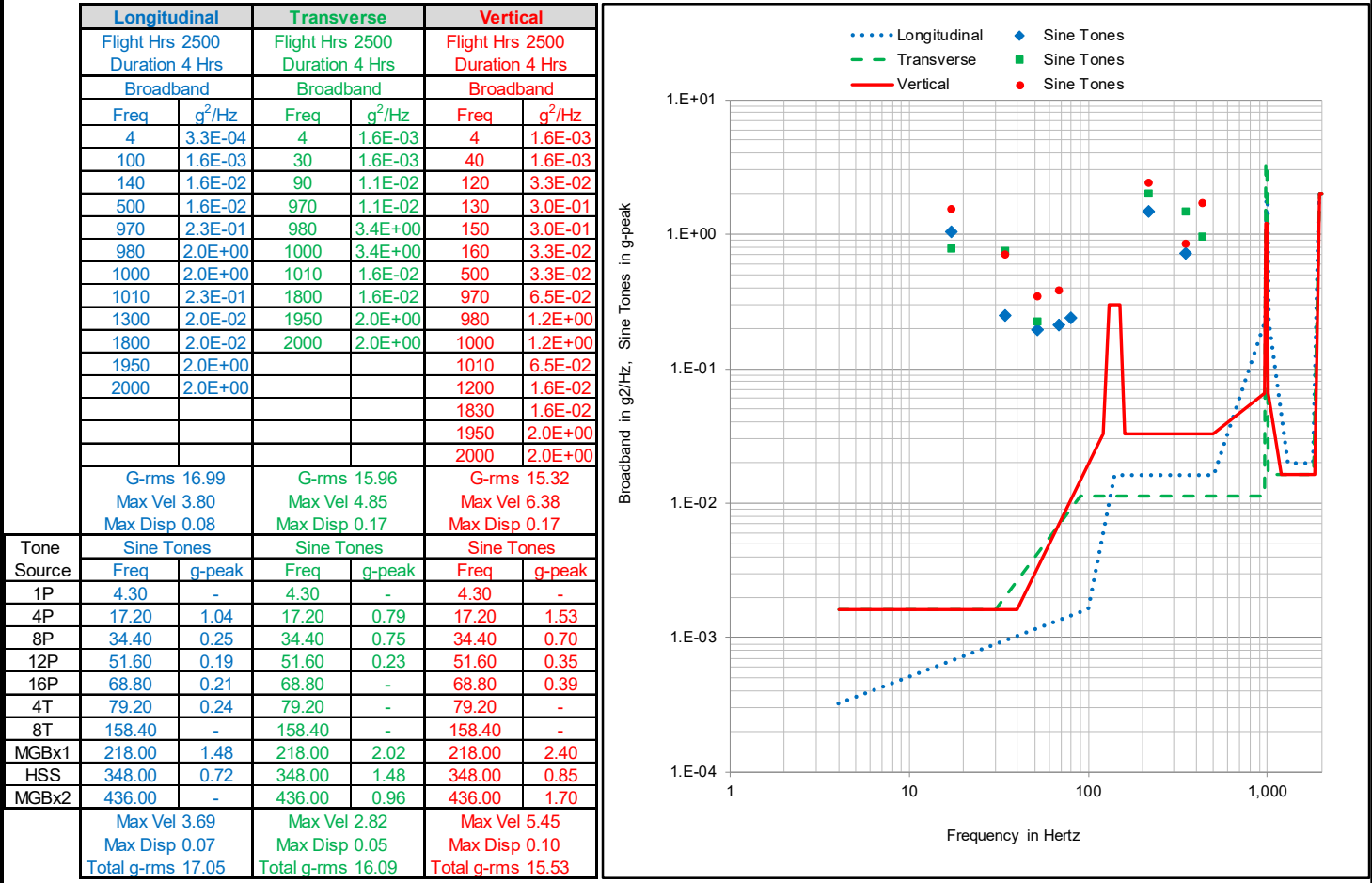


NOTES:

1. Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
2. Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
3. Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
4. 1P: 1x(Primary Rotor Freq), 4T: 4x(Tail Rotor Freq), HSS: High Speed Shaft, MGB: Main Gearbox Lube Pump

Figure D-4. UH-60M LVTS, Region: Nose.

UH-60M LVTS
Aircraft Region: Main Transmission



NOTES:

1. Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
2. Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
3. Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
4. 1P: 1x(Primary Rotor Freq), 4T: 4X(Tail Rotor Freq), HSS: High Speed Shaft, MGB: Main Gearbok Lube Pump

Figure D-8. UH-60M LVTS, Region: Main Transmission.

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

E.1 SYSTEM DESCRIPTION.

The AH-64D/E Apache Attack Helicopter (Figure E-1) is a twin-engine, tandem seat, aerial weapons platform built by The Boeing Company. The aircraft has an irreversible flight control system with a fully articulated, four-bladed main rotor system equipped with elastomeric lead-lag dampers. The four-bladed tail rotor is of a semi-rigid design. Two T700 GE-701D (-701D) turboshaft engines transmit power to the main transmission through engine-mounted nose gearboxes. Engine control functions are provided by the common enhanced digital electronic control unit (EDECUC) on -701D engines. The main transmission drives the main and tail rotors and accessory gearbox. The flight control system consists of conventional cyclic, collective, and pedal cockpit controls connected mechanically to hydromechanical actuators for the main and tail rotors, a limited authority automatic stabilization system, and an electrically driven stabilator. As an aerial weapons platform, the AH-64E has a modernized-target acquisition designation sight (M-TADS) and a modernized-pilot night vision sensor (M-PNVIS) mounted to the nose of the aircraft. Left and right wings, attached to the center fuselage, provide four hard-points for mounting up to four M-299 Hellfire missile launchers, four M-261 rocket pods, or two external auxiliary fuel tanks (inboard stations only). A fire control radar or manned-unmanned teaming system may be installed or removed, based on mission requirements. The AH-64D is equipped with display processors (DPs), system processors (SPs), and weapons processors (WPs). The two DPs provide display information to two multipurpose displays in each cockpit, the TADS display and control, and the integrated helmet and display sight system. The AH-64D uses two SPs, one as primary and the other as a secondary designed to automatically assume control if the primary fails. The primary SP commands all subsystem-initiated tests, monitors system status and fault information, and processes the information for display. The AH-64D incorporates two WPs, which command portions of the weapon subsystems and provide system status and fault information to the SPs. The AH-64E has two mission processors that command all system initiated tests, monitor system status and default data, and process the data for display.

D-1



Figure E-1. AH-64E Apache Helicopter.

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

E.2 ANALYSIS OBJECTIVE.

The objective of the analysis was to develop new LVTS for the AH-64D and AH-64E platforms to replace outdated vibration test reference levels presented in MIL-STD-810H with Change 1. The effort was completed in two phases:

- a. Collected vibration data at locations of interest on the AH-64 during flight testing. Flight testing encompassed maneuvers that provided a good representation of the Mission Scenario.
- b. Utilizing flight tests data to develop LVTS for the AH-64.

E.3 CALIBRATION.

Calibration of the individual test equipment associated with the data acquisition was performed through the U.S. Army’s Test, Measurement, and Diagnostic Equipment Program or via subcontract to accredited calibration laboratories. Calibration was performed IAW the original manufacturer’s established standards and procedures for original equipment performance, with standard test equipment and laboratory standards traceable to the NIST. The validity of equipment calibration was verified prior to test.

E.4 DETAILS OF FLIGHT TEST.

E.4.1 Test Aircraft.

Three datasets from three AH-64 helicopters flight programs were used to derive the LVTS in this document. In all cases, instrumentation was added to support this effort to flight tests primarily intended to support other test programs. The three datasets are detailed in Table E.1

TABLE E-1. AH-64 DATASET UTILIZED

	Dataset A	Dataset B	Dataset C
Test Dates	2010	October 2016	2019
Aircraft	AH-64D ASN99-05132	AH-64D ASN08-07050	AH-64E ASN 14-01001
Accelerometer Locations	avionics bays cockpit	avionics bays tail boom tail rotor.	avionics bays, cockpit, nose, main rotor gearbox, engine mount locations
Sample rate	5896 samples/second (sps)	11,235 sps	6,579 sps
Cutoff Filter	983 Hz	~ 2500 Hz	~ 2000 Hz
Reference Document	RTC-12-E5076-0116 ⁶	RTC-16-G2921-0946 ⁷	RTC-18-H0456-1111 ⁸

Notes:

1. ASN99-05132 was equipped with previous version General Electric T700-GE-701C engines

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

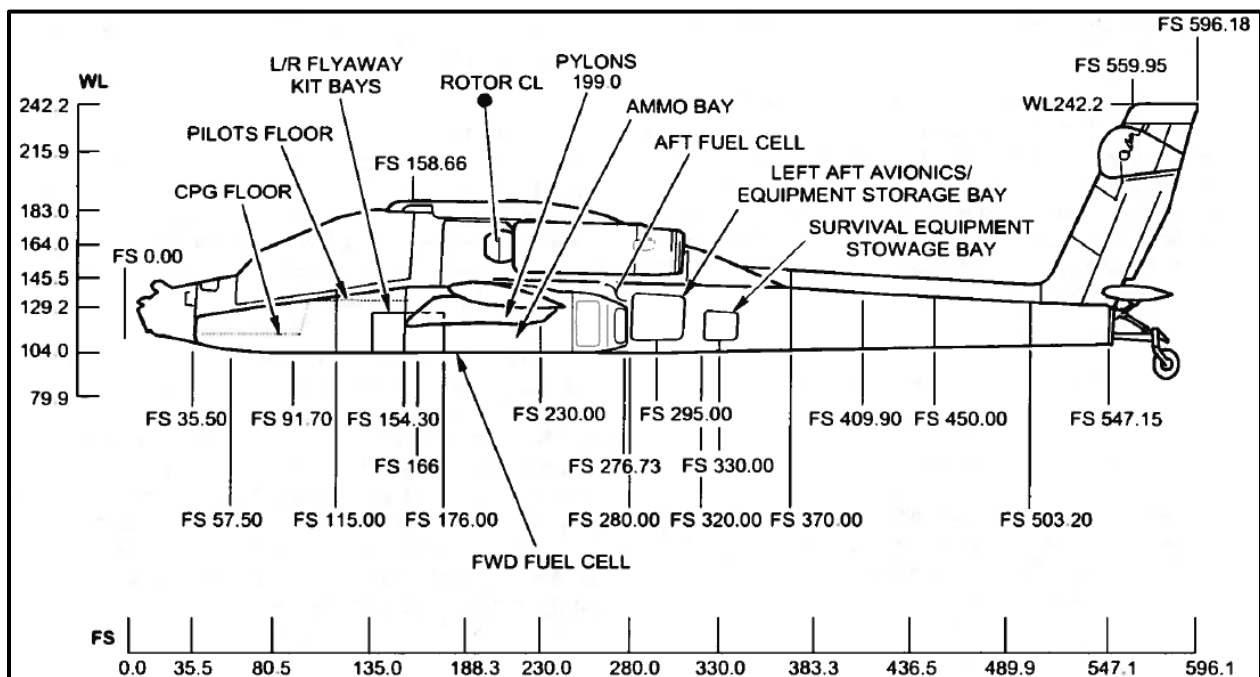
E.4.2 Flight Maneuvers.

The flight maneuvers (test points) varied among the three test programs. In all cases, the maneuvers were chosen to represent the full flight spectrum of the AH-64 aircraft. The test points flown are provided in the mission scenario discussion below. An effort was made to hold each test point for a minimum of 30 seconds to provide optimal statistical averaging for PSD calculations during the analysis phase.

E.4.3 Instrumentation.

a. Collectively, the three datasets provided vibration data over the full AH-64 aircraft. Dataset A flights were intended to capture data for all needed locations. However, due to programmatic constraints and instrumentation issues, the dataset was limited to 6 triaxial accelerometer locations. Additionally, a posttest review of the data found accelerometer orientation issues. Discussions with the original test engineer revealed that proper identification of orientations was not possible. Therefore, the dataset was determined insufficient for LVTS development. Accelerometers were included during the Dataset B flights to replicate two of the Dataset A locations to allow validation of the previous data orientation, and to provide locations in the tail. Dataset C was for an AH-64E and provided replication of some Dataset A and B locations, as well as additional locations. Figure E-2 provides the aircraft station (FS) and waterline (WL) of the AH-64E (AH-64D is similar). The aircraft station (FS) is distance forward to aft, and waterline (WL) is distance up and down. All measurements are in inches. A detailed list of instrumentation locations can be found in Table E-2, to include approximate aircraft stations and waterlines.

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APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

Figure E-2. AH-64E aircraft stations.
TABLE E-2. AH-64 INSTRUMENTATION LOCATIONS

Data Set / Accel Number	Location Description	Aircraft Station (inches)	Aircraft Waterline (inches)	Aircraft Region	Note
A1	Eyebrow - Sta40, Left	40		Nose	1
A2	Fwd FAB - Sta86, Left	86		Fwd Avionics Bays	2
A3	Av Bay - Station 160, Left	160		Fwd Avionics Bays	1
A4	Aft FAB - Station 225, Left	225		Aft Avionics Bay	1
A5	Aft Av Bay - Station 295, Left	295		Aft Avionics Bays	2
A6	Aft Cockpit, Left			Cockpit	1
B1	Avionics Bay - Station 86, Left	86		Fwd Avionics Bays	
B2	Avionics Bay - Station 295, Left	295		Aft Avionics Bays	
B3	Shaft Horizontal Bearing - Station 385	385		Tail Boom	
B4	Tail Gearbox Mount - Station 499	499		Tail Boom	
B5	Upper Tail Rotor - Station 565	565		Tail Rotor	3
B6	Upper Tail Rotor - Station 569	569		Tail Rotor	
C1	Sensor Turret, Left, Upper Panel	33	130	Nose	
C2	Sensor Turret, Right, Upper Panel	33	130	Nose	
C3	Sensor Turret, Center, Under Camera	18	114	Nose	
C4	Pilots Seat	150		Cockpit	5
C5	TDAC	80		Cockpit	3
C6	Fwd FAB, Left, Mid Shelf Center	87	115	Fwd Avionics Bays	
C7	Fwd FAB, Right, Mid Shelf Center	72	115	Fwd Avionics Bays	4
C8	Mid Ammo Bay, Left, Mid Shelf Center	221	113	Fwd Avionics Bays	
C9	Mid Ammo Bay, Right, Mid Shelf Center	206	115	Fwd Avionics Bays	3
C10	Aft Avionics Bay, Left, Mid Upper Shelf	295	126	Aft Avionics Bays	
C11	Aft Avionics Bay, Left, Mid Lower Shelf	295	117	Aft Avionics Bays	
C12	Aft Avionics Bay, Right, Mid Upper Shelf	297	129	Aft Avionics Bays	4
C13	Aft Avionics Bay, Right, Mid Lower Shelf	289	116	Aft Avionics Bays	4
C14	MRGB, Lower Deck, Fwd Lft	180	145.5	MRGB	
C15	MRGB, Lower Deck, Fwd Rgt	180	145.5	MRGB	
C16	MRGB, Lower Deck, Aft Rgt	226	145.5	MRGB	
C17	MRGB, Lower Deck, Aft, Lft	226	145.5	MRGB	
C18	MRGB, Upper Mast Base, Left	200		MRGB	
C19	MRGB, Upper Mast Base, Right	200		MRGB	3
C20	Engine 1 Mount, Left, Lower Center			Engine Mount	
C21	Engine 2 Mount, Right, Mid Inboard	255		Engine Mount	

1. Accelerometer orientation was suspect and could not be verified.
2. Data not used as equivalent location of Dataset B was from a more representative aircraft.
3. Data was suspect and not used for LVTS.
4. Right side avionics bay had vertical accelerometer only.
5. Location above pilot seat isolation so not used.

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

b. Multiple aircraft bus parameters were available for all three datasets. A list of the subset utilized to identify maneuver start and stop times is provided in Table E-3.

TABLE E-3. AH-64 BUS PARAMETER LIST

DESCRIPTION	UNITS	DESCRIPTION	UNITS
LATITUDE	Radians	PITCH ANGLE	Degrees
LONGITUDE	Radians	HEADING	Degrees
ALTITUDE	Feet	ROLL RATE	Degrees/Sec
AIRSPEED	Knots	PITCH RATE	Degrees/Sec
ROLL ANGLE	Degrees	YAW RATE	Degrees/Sec

D-5

E.5 DETAILS OF VIBRATION SPECIFIC DEVELOPMENT.

E.5.1 Mission Scenario.

The flight maneuvers (test points) flown during each of the flight test programs were chosen to provide a representation of the expected AH-64 usage spectrum. The maneuver lists were developed over a period of several years and varied based on the knowledge available at the time and the needs of the individual test programs. These flight maneuvers were each assigned a percentage value that correlates the flight maneuver to the total expected exposure over the lifecycle of the aircraft (or test article). The lifecycle scenarios were developed from the AH64D Apache Usage Spectrum of 1999 (Boeing Document MDHS Report Number STN 99-008⁹), the usage spectrum of 1993 (McDonald Douglas Document AH64D-STN-93-024¹⁰) and discussions with military pilots. As with the maneuver lists, the scenarios differ between the three programs, although the percent of flight by test point category are very similar. Note in a few cases the scenario included test points for which no data was acquired (e.g., Level Flight less than 0.4 Vh for Data Set A). These are identified with “(No Data)” in the test point description. All missing test points were expected to be low vibration conditions that would have little impact on the final LVTS. All LVTSs were developed to be equivalent to 2500 flight hours on the AH-64 platform. The lifecycle scenario utilized can be found in Tables E-4a through E-4c. For test points listed as left and right, data was acquired in both directions and the percent of flight was divided equally between them.

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

TABLE E-4a. MISSION SCENARIO FOR DATA SET A

Category Total Percent of Flight	Test Points	Percent of Flight for Test Point
Takeoff / Landing 5.0%	Takeoff to 5ft Hover	0.18%
	Normal VMC Takeoff	4.25%
	Rolling Takeoff	0.18%
	Rollon Landing	0.40%
Hover / Low Speed Flight 18.0%	IGE Hover	8.30%
	OGE Hover	4.18%
	Lowspeed Left Sideward	1.00%
	Lowspeed Right Sideward	1.00%
	Lowspeed Rearward	1.26%
	Lowspeed FWD	1.26%
	Left Pedal Turn	0.50%
	Right Pedal Turn	0.50%
Accel / Decel	Accel from 60 TO VH	3.00%
Climb / Decend 4.0%	Normal VMC Approach	0.17%
	Steep VMC Approach	0.17%
	Diving Flight NORMAL 110 KT	0.33%
	Diving Flight STEEP 60 KT	0.33%
Turns 4.9%	30 Deg AOB Level Turn 100KT Lft & Rgt	2.86%
	45 Deg AOB Level Turn 100KT Lft & Rgt	1.26%
	60 Deg AOB Level Turn 100KT Lft & Rgt	0.18%
	30 Deg AOB Level Turn 120KT Lft & Rgt	0.60%
Fwd Level Flight 50.4%	Level Flight less than 0.4 Vh - (No Data)	4.28%
	Level Flight at 0.4 VH	7.05%
	Level Flight at 0.6 VH	16.37%
	Level Flight at 0.8 VH	18.13%
	Level Flight at 1.0 VH	4.53%
Maneuver Flight 2.1%	Decel Turn Lft & Rgt	0.54%
	Break Turn Lft & Rgt	0.52%
	CCPB Lft & Rgt	0.46%
	Pitch Back Turn Lft & Rgt	0.56%
Nap of Earth 10.0%	Terrain Flight, 50-100 ft AHO, 80 KCAS	10.00%

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

TABLE E-4b. MISSION SCENARIO FOR DATA SET B

Category	Test Points	Percent
Takeoff / Landing 5.0%	Takeoff to a Hover; A/C Light on Wheels (30 sec)	0.40%
	Takeoff to a Hover	0.40%
	VMC Takeoff from the Ground using 5-ft hover Q + 10%	0.75%
	VMC Level Acceleration Takeoff using 5-ft hover Q + 10%	0.75%
	VMC Approach, Termination to the Ground	1.05%
	Rolling Takeoff using no more than 5-ft hover Q - 10%	0.20%
	Roll-on Landing	0.40%
	Land from a Hover	1.05%
Hover /	Hovering Flight	4.50%
Low Speed Flight 18%	Hovering Turn, 15 deg/sec (left and right)	4.50%
	Hovering Turn, 30 deg/sec (left and right)	4.50%
	Hovering Turn, 45 deg/sec (left and right)	4.50%
Accel / Decel	VMC Takeoff from a Hover using 5-ft hover Q + 10%	1.55%
Climb / Decend 6.7%	VMC Approach, Termination to a Hover	1.55%
	Normal Dive	1.19%
	Steep Dive to Right Recovery (90-deg heading change)	1.19%
	Steep Dive to Left Recovery (90-deg heading change)	1.19%
	Transient Torque, Left and Right	1.38%
Turns 4.9%	Rotor Coning	0.69%
	Pitch Down Tendency, Left and Right	1.38%
	Weight vs. Lift Correlation, Left and Right turns	1.26%
	Airspeed & Attitude Trade Off, Left and Right	0.18%
	Level Flight less than 60 Knots - (No Data)	4.53%
Fwd Level Flight 50.3%	Level Flight 60 Knots (.4 Vh)	6.04%
	Level Flight 80 Knots (.6 Vh)	10.57%
	Level Flight 100 Knots (.7 Vh)	11.58%
	Level Flight 120 Knots (.85 Vh)	13.09%
	Level Flight 140 Knots (.95Vh)	4.53%
	Left Decelerating Turn, Target 90-deg AOB	0.27%
Maneuver Flight 2.1%	Right Decelerating Turn, Target 90-deg AOB	0.27%
	Left Break Turn, Target 90-deg AOB	0.26%
	Right Break Turn, Target 90-deg AOB	0.26%
	CCPOB Left, Target 90-deg AOB	0.23%
	CCPOB Right, Target 90-deg AOB	0.23%
	Left Pitch Back Turn, Target 120-deg AOB & 60-deg Pitch	0.28%
	Right Pitch Back Turn, Target 120-deg AOB & 60-deg Pitch	0.28%
	Terrain Flight	5.71%
Nap of Earth 10.0%	Masking in Flight	0.41%
	Unmasking in Flight	0.41%
	Unmasking at a Hover (Vertically),	0.82%
	Unmasking at a Hover (Laterally), Left & Right	0.82%
	Terrain Flight, Approach	0.63%
	Terrain Flight, Deceleration	0.41%
	Terrain Flight, Takeoff	0.79%

TABLE E-4c. MISSION SCENARIO FOR DATA SET C

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

Category	Test Points	Percent
Takeoff / Landing	Rolling Takeoff	2.50%
5.0%	Rolling Lanfing	2.50%
Hover /	Low Airspeed - 20kts 035 deg	1.00%
Low Speed Flight	Low Airspeed - 25kts 035 deg	1.00%
18%	Low Airspeed - 30kts 035 deg	1.00%
	Low Airspeed - 35 kts 125 deg	1.00%
	Low Airspeed - 40kts 030 deg	1.00%
	Hover - (No Data)	13.00%
Accel / Decel	Accel Decel - low	0.75%
Climb / Decend	Accel Decel - med	0.75%
6.7%	Accel Decel - fast	0.17%
	Quick Stops - low	0.50%
	Quick Stops - med	0.50%
	Quick Stops - fast	0.04%
	Decel to Dash - slow	0.50%
	Decel to Dash - fast lower deck right fwd x, y &	0.04%
	VMC Approach Normal	0.08%
	Climb - 60 kt	0.21%
	Climb - VBE 75 kt	0.41%
	Climb - 100 kt	0.67%
	Climb -120 kt	0.37%
	Descent - 60 kt	0.21%
	Descent - VBE 75 kt	0.41%
	Descent - 100 kt	0.67%
	Descent - 120 kt	0.37%
Turns	Turns - 15 left and right	3.43%
4.9%	Turns - 30 left and right	0.86%
	Turns - 45 left and right	0.26%
	Turns - 60 left and right	0.13%
	Turn - 90kts - 40degAOB - left and right	0.26%
Fwd Level Flight	30kts and below - (No Data)	2.52%
50.4%	Level Flight - 40 kts	3.53%
	Level Flight - 60 kts	5.29%
	Level Flight - 80 kts	10.32%
	Level Flight - 100 kts	17.00%
	Level Flight - 120 kts	9.44%
	Level Flight - VH	2.27%
Maneuver Flight	Decelerating Turns - modirate - left and right	0.41%
2.1%	Decelerating Turns - fast - left and right	0.12%
	Break Turns - moderate - left and right	0.41%
	Break Turns - fast - left and right	0.12%
	CCPB - left and right	0.12%
	Pitch Back Turns - left and right	0.12%
	Dive Recoveries (Normal) - left and right	0.41%
	Dive Recoveries (Steep) - left and right	0.12%
	Lateral Right Unmask - fast	0.21%
Nap of Earth 10.0%	Nap of Earth - (No Data)	10%

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

E.5.2 LVTS Development Methodology.

The techniques used to compute the subject LVTS are in accordance with the recommendations of MIL-STD-810H with Change 1 Method 514.8, Annex F, with the following clarifications.

a. In order to provide optimal statistical averaging for PSD calculations, an effort was made to hold each test point for a minimum of 30 seconds. Due to the inherent nature of some of the test points, this was not possible for all test maneuvers. Fifty percent overlap was employed to maximize the number of averages. Even so, the number of averages available was less than optimal for a few maneuvers. As the primary concern of helicopter vibration is the sine tones, which are theoretically deterministic with fixed amplitude, the error was considered acceptable.

b. Miner-Palmgern techniques were employed to compress 2500 hours of flight time to a 4.0-hour test duration. The 4-hour test duration was utilized to maintain consistency with previous MIL-STD-810 default helicopter LVTS. The exponent (sometimes referred to as slope or M) utilized was 6.43 for sine tones in g-peak and 7.5 for random profiles in g-rms (3.75 for PSDs).

c. MIL-STD-810H with Change 1 allows conservatism to be added as a standard deviation at two steps in the process, or as a simple multiplier. In this case no standard deviations were added. A multiplier of 1.2 was applied to all sine tone g-peak levels, and 2.0 to all broadband PSD g^2/Hz levels.

d. All locations for a given aircraft region were combined by enveloping (by axis).

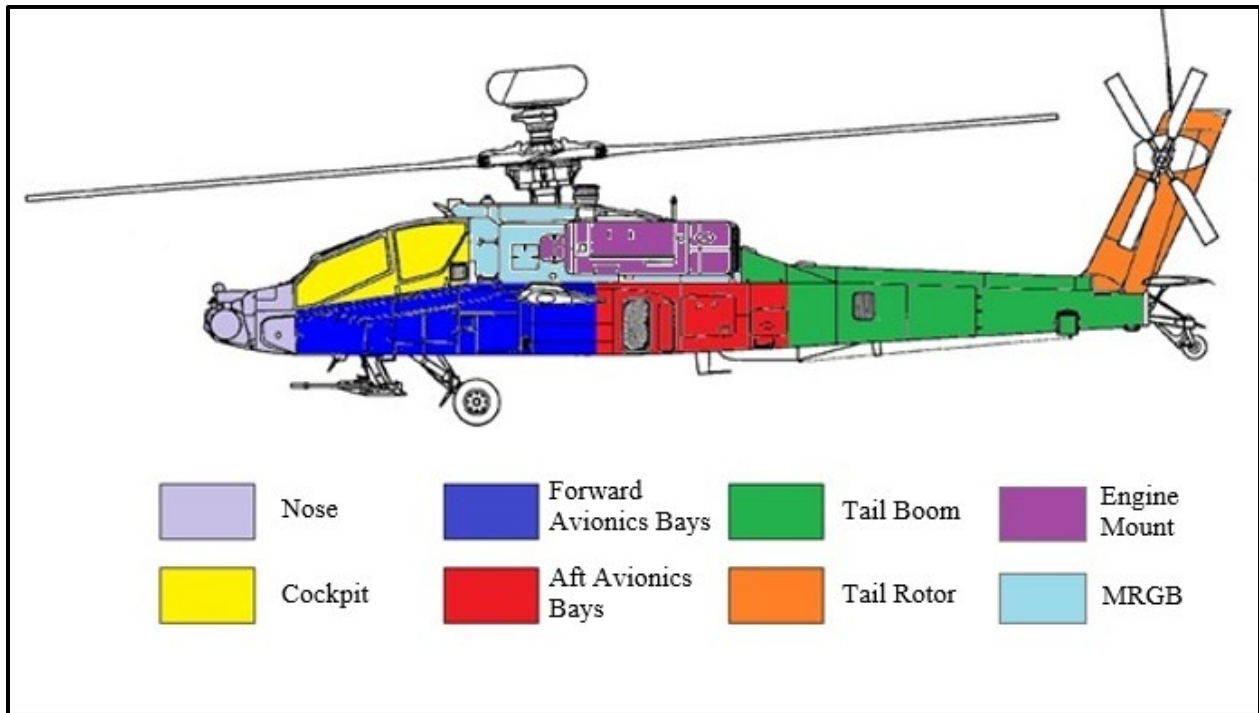
e. As previously discussed, accelerometer orientations for Dataset A were suspect. Comparison with similar locations of Dataset B allowed orientation identification for some locations/axes but not all. Given the difficulty in obtaining substitute data, rather than excluding the data fully, the following compromises were made. Both the transverse (T) and vertical (V) axes of location A1 were used for the T and V LVTS for the Nose region. Both the longitudinal (L) and T axis of location A3 were used for L and T LVTS for the Forward Avionics Bay region. All three axis of location A6 were used for all three LVTS for the Cockpit region. As with any enveloping of multiple channels, this introduced some unquantified level of conservatism. However, a review of the overlays found the conservatism to be acceptable.

f. All tones that were of significant level for any location were processed for all locations. Those below 200 Hz were removed from the broadband and processed as tones in accordance with MIL-STD-810H with Change 1. Those above 300 Hz were processed along with the broadband and converted to tones during the final stages of development. Tones below the analyst selected thresholds of 0.1 g-peak (below 300 Hz) or 1.0 g-peak (above 300 Hz) were left blank in the final LVTS. Additionally, all tones were converted to narrowbands (1 Hz wide) for comparison to the broadband profile. Any tone that was below the broadband profile plus 3 dB was left blank in the final LVTS. A minimum threshold for the broadband breakpoints were set at a $1e-4 g^2/Hz$.

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

E.5.3 Location Groupings.

A determination was made of how to group data locations in producing LVTSS for specific regions of the aircraft. Data collection points were grouped together in the VSD process as shown in Figure E-3 and Table E-2. Each final LVTSS was developed by taking a spectral line maxi of the reference levels for each region on a per axis basis.



Note: Regions shown are for general guidance only and are not intended to provide definitive LVTSS selection.

Figure E-3. Aircraft regions.

E.5.4 VSD Results.

a. The spectral content of the vibration energy on the AH-64 was Sine on Random (SOR) in nature. As the rotor speeds have minimal variability, the sine tone frequencies of the LVTSS were considered constant. The nature of the vibration data dictated the development of SOR LVTSS with stationary sinusoidal tones (dwells).

b. Multiple tones were identified of sufficient level for processing, as listed in Table E-5. Tones that could be correlated to the main and tail rotor passage frequencies are identified in the table. The variance in rotor frequencies of the two aircraft was considered insignificant from a

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

test perspective and were averaged in the final LVTS. This allows vibration testing to either aircraft with acceptable frequency error. However, if testing to precise frequencies is desired, the aircraft specific rotor frequencies of Table E-5 can be utilized in place of the frequencies listed on the individual LVTS. The source of other tones could not be positively identified, and in some cases were restricted to the aircraft regions for which only one dataset was available. The test frequencies provided for those tones are the same for both aircraft variants.

TABLE E-5. AIRCRAFT SPECIFIC TEST FREQUENCIES

Source	Test Frequency		
	Average	AH-64D	AH-64E
1P	4.80	4.87	4.77
4P	19.20	19.48	19.08
8P	38.40	38.96	38.16
2T	47.20	46.80	47.20
12P	57.60	58.44	57.24
	66.30	66.30	66.30
	80.30	80.30	80.30
4T	94.40	93.60	94.40
6T	141.60	140.40	141.60
8T	188.80	187.20	188.80
	353	353	353
	787	787	787
	1618	1618	1618
<i>1P: 1 x (Primary Rotor Freq), 2T: 2 x (Tail Rotor Freq)</i>			

c. Miner-Palmgern techniques were employed to compress 2500 hours of flight time to a 4.0-hour test duration. The 4-hour test duration was utilized to maintain consistency with previous MIL-STD-810 default helicopter LVTS. All sine tone levels were reviewed to ensure the compression resulted in acceptable exaggeration factors. Exaggeration factor is defined as the ratio of the test reference level (including time compression but before application of conservatism) and the maximum measured level. The exaggeration factor recommended by MIL-STD-810H with Change 1 (Method 514.8, Annex F Section 9.2.1.2) is 2.0 for g-peak values. The exaggeration factor of all but a few tones was below the recommended 2.0. The exceptions are listed in Table E-6. The exceedance was considered acceptable to maintain historical durations.

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

TABLE E-6. EXAGGERATION FACTORS

Aircraft	Aircraft Region	Axis	Source	Freq (hz)	Level (g-peak)	Ratio
Combined	Nose	Long		80.3	0.17	2.27
Combined	Forward Avionics Bay	Vert	6T	141.6	0.41	2.06
Combined	Aft Avionics Bay	Tran		80.3	0.3	2.08
Combined	Tail Boom	Long	6T	141.6	0.24	2.01
Combined	Tail Boom	Vert		80.3	0.52	2.30
Combined	Tail Boom	Vert	6T	141.6	0.66	2.07
Combined	Tail Rotor	Tran	4P	19.2	1.21	2.08
AH-64D	Forward Avionics Bay	Vert	6T	141.6	0.41	2.06
AH-64E	Aft Avionics Bay	Long	6T	141.6	0.21	2.07
AH-64E	Aft Avionics Bay	Tran		80.3	0.30	2.08
AH-64E	Aft Avionics Bay	Vert	6T	141.6	0.41	2.09

E.6 GUIDELINES FOR UTILIZATION OF LVTS.

E.6.1 General Considerations.

a. Guidance relevant to all aircraft is provided in Section 7 of the main body of this TOP and should be reviewed. Additional guidance specific to the AH-64 is provided below.

b. Combined AH-64D/E LVTS were developed for each of the 8 aircraft regions. These are included as Figures E-4 through E-11. Each figure includes LVTS for each of the three mutually orthogonal translational axes with respect to the aircraft (x-axis or long, y-axis or transverse, and z-axis or vertical). For a complete lifecycle vibration replication, the test article should be subjected to all three LVTS axes.

c. For the Forward and Aft Avionics Bay regions, LVTS were also developed independently for the two aircraft platforms. These are included as Figures E-12 through E-17. Each figure includes LVTS for the two individual aircraft, as well as the combined. The individual aircraft LVTS should be utilized only if it is known that a test article will only be exposed to one platform.

d. LVTS selection should be based on the expected installation location of the test article, utilizing Table E-2 and Figure E-3 as guidance. Care should be taken when selecting an LVTS to ensure it is appropriate for use for the test article. Consider the planned deployment location of the test article on the AH-64 and select the default LVTS in the associated zone of interest.

e. The published LVTS are intended to represent either of the two platforms AH-64D or AH-64E. In the event LVTS are required for other variants of the AH-64, the ideal solution would be to develop them based on measured field data. In the absence of such data, the schedules provided in this document may serve as an alternative. Sine tone frequencies may

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES

require modification if the rotor head frequency of the variant differs significantly from the 4.82 Hz main rotor and 23.5 Hz tail rotor frequencies used in this LVTS development.

f. The variance in rotor frequencies of the two aircraft was considered insignificant from a test perspective and were averaged in the final LVTS. Therefore, a test article qualified to the published LVTS can be installed on either aircraft. If the test article will be carried on only one platform, and testing to precise frequencies is desired, the aircraft specific rotor frequencies of Table E-5 can be utilized in place of the frequencies listed on the individual LVTS.

g. As discussed in paragraph E.5.4 c, the exaggeration factor of a few tones exceeded the 2.0 maximum recommended by MIL-STD-810H with Change 1. The affected tones are listed in Table E-6. Although the exceedances were considered acceptable, if there is concern for a given test article, the test levels can be reduced (and test duration increased) utilizing Miner-Palmgern techniques. Any reduction should be done with care to prevent reducing other tones to below the measured maximum. Reduction should be less than that provided in the Functional test reduction ratio of Table E-7. Further guidance on reducing test levels utilizing Miner-Palmgern techniques is provided in MIL-STD-810H with Change 1 Method 514.8, Annex F Section 9.

E.6.2 Functional Test Considerations.

a. Functional reference levels should be near the envelope of the maximum measure levels plus conservatism. This is effectively the Endurance reference level reduced by the exaggeration factor. As Miner-Palmgern techniques were employed for time compression, the exaggeration factors varied across the LVTS sine tones, as well as the broadband profile. This eliminated the ability to define a constant reduction level while maintaining a direct fatigue equivalence.

b. To define reduction ratios, a weighted average of the tone exaggeration factors was calculated for each LVTS, with the exaggeration factors weighted by the tone reference levels. The weighted average factors of the three axes were then averaged for each aircraft region. Reduction of the Endurance levels by these resultant factors (sine tones and broadband) will yield Functional reference levels comparable to maximum measured field data with conservatism. The reduction ratios are provided in Table E-7. Functional LVTS can be derived from the published Endurance LVTS by applying the ratios in the table. Alternatively, a control system programed for the Endurance LVTS can be executed at the dB levels provided.

TABLE E-7. CALCULATION OF FUNCTIONAL REFERENCE LEVEL

APPENDIX E. AH-64 LABORATORY VIBRATION TEST SCHEDULES.

Aircraft Region	Functional Level as a Ratio of Endurance Level		
	dB	Ratio for Sine Tones	Ratio for Broadband Breakpoints
Nose	-3.1	0.70	0.49
Cockpit	-2.4	0.76	0.58
Forward Avionics Bay	-4.0	0.63	0.40
Aft Avionics Bay	-3.3	0.68	0.47
Tail Boom	-4.5	0.60	0.35
Tail Rotor	-4.5	0.60	0.35
Main Rotor Gearbox	-4.4	0.60	0.36
Engine Mount	-2.9	0.72	0.51

E.6.3 Reliability Test Considerations.

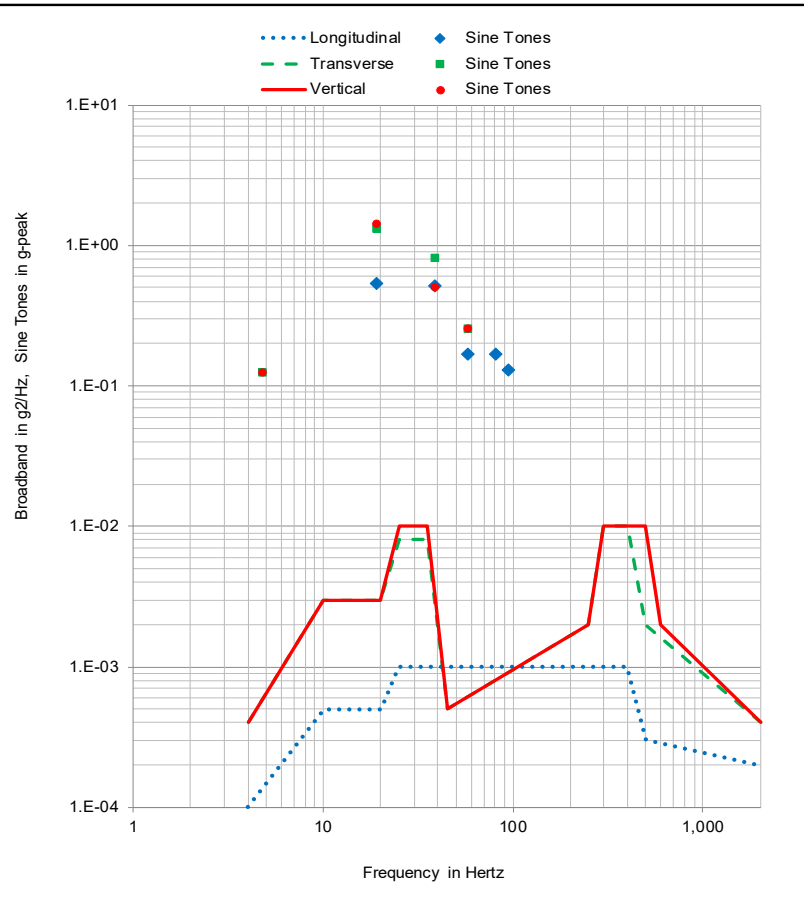
a. All LVTS's provided in this appendix are considered to be Endurance specifications. For reliability testing it is sometimes desired to operate a test article for hundreds of hours in an environment representative of actual exposure (i.e., uncompressed vibration). Reliability testing at endurance reference levels would constitute a significant over test and is not appropriate.

b. In the process of establishing reference criteria for a reliability test, while backing out sufficient compression to yield representative field levels, it is desired to maintain a reasonable fatigue equivalency. Dealing with uncompressed 1-DOF references, laboratory run time will be 3:1 longer than the actual equivalent flight time. If one applies Miner-Palmgren techniques using the exponent associated with sinusoidal excitation ($m=6.43$) and assuming 1/3 of the 2500 flight hours (833 hours) of laboratory time per axis, the published references would be run at -7.21 dB. The resulting 2500 hours of laboratory run time would then represent 2500 hours of flight. Realizing that the exponent in Miner-Palmgren differs for sine and random signals, and understanding the proposed levels for a reliability test are being defined while maintaining reasonable fatigue equivalency, it is recommended that a 7 dB reduction and a duration of 833 hours per axis (representing 2500 hours) be employed as a basis. Reliability LVTS can be derived from the published Endurance LVTS by applying a factor of 0.447 to each sine tone reference level and 0.200 to each broadband breakpoint. Alternatively, a control system programmed for the Endurance LVTS can be executed at -7 dB.

c. Any reliability test to be conducted at an arbitrary number of desired hours may be computed by simply linearly scaling time. For example, if one desired to conduct a reliability test for 1500 hours, the published specs would be executed at -7 dB and the duration per axis would be 500 hrs.

AH-64D/E LVTS
Aircraft Region: Nose

Longitudinal		Transverse		Vertical		
Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		
Broadband		Broadband		Broadband		
Freq	g ² /Hz	Freq	g ² /Hz	Freq	g ² /Hz	
4	1.0E-04	4	4.0E-04	4	4.0E-04	
10	5.0E-04	10	3.0E-03	10	3.0E-03	
20	5.0E-04	20	3.0E-03	20	3.0E-03	
25	1.0E-03	25	8.0E-03	25	1.0E-02	
400	1.0E-03	35	8.0E-03	35	1.0E-02	
500	3.0E-04	45	5.0E-04	45	5.0E-04	
2000	2.0E-04	250	2.0E-03	250	2.0E-03	
		300	1.0E-02	300	1.0E-02	
		400	1.0E-02	500	1.0E-02	
		500	2.0E-03	600	2.0E-03	
		2000	4.0E-04	2000	4.0E-04	
G-rms 0.89 Max Vel 1.87 Max Disp 0.06		G-rms 1.85 Max Vel 4.16 Max Disp 0.13		G-rms 2.10 Max Vel 4.30 Max Disp 0.13		
Tone Source	Sine Tones		Sine Tones		Sine Tones	
	Freq	g-peak	Freq	g-peak	Freq	g-peak
1P	4.80	-	4.80	0.12	4.80	0.12
4P	19.20	0.53	19.20	1.33	19.20	1.42
8P	38.40	0.52	38.40	0.81	38.40	0.51
2T	47.20	-	47.20	-	47.20	-
12P	57.60	0.17	57.60	0.26	57.60	0.26
	66.30	-	66.30	-	66.30	-
	80.30	0.17	80.30	-	80.30	-
4T	94.40	0.13	94.40	-	94.40	-
6T	141.60	-	141.60	-	141.60	-
8T	188.80	-	188.80	-	188.80	-
	353.00	-	353.00	-	353.00	-
	787.00	-	787.00	-	787.00	-
	1618.00	-	1618.00	-	1618.00	-
	Max Vel 1.71 Max Disp 0.03 Total g-rms 1.05	Max Vel 4.25 Max Disp 0.11 Total g-rms 2.16	Max Vel 4.55 Max Disp 0.11 Total g-rms 2.36			



NOTES:

- Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
- Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
- Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
- 1P: 1x(Primary Rotor Freq), 2T: 2x(Tail Rotor Freq)

Figure E-4. AH64 Combined LVTS, Region: Nose.

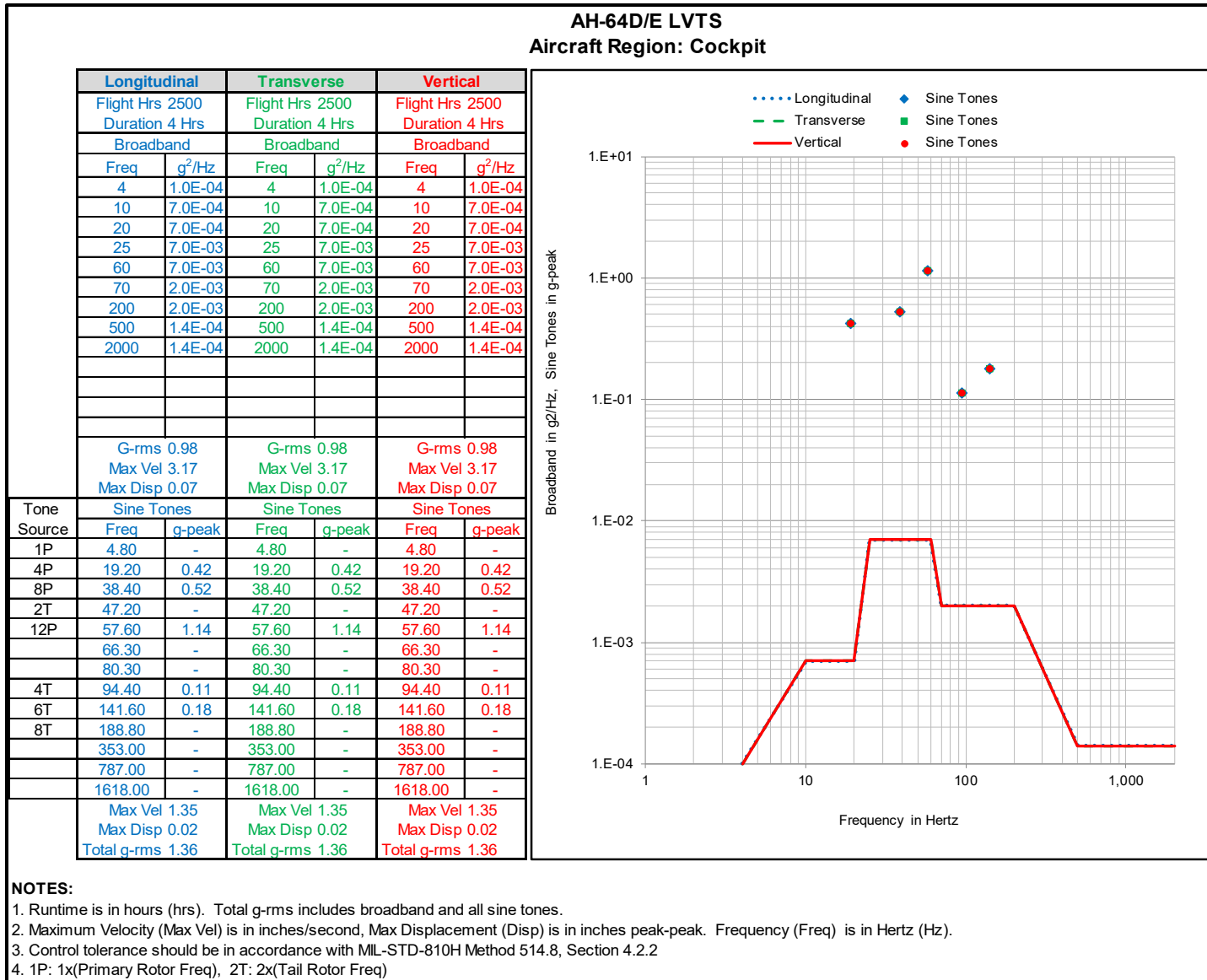


Figure E-5. AH64 Combined LVTS, Region: Cockpit.

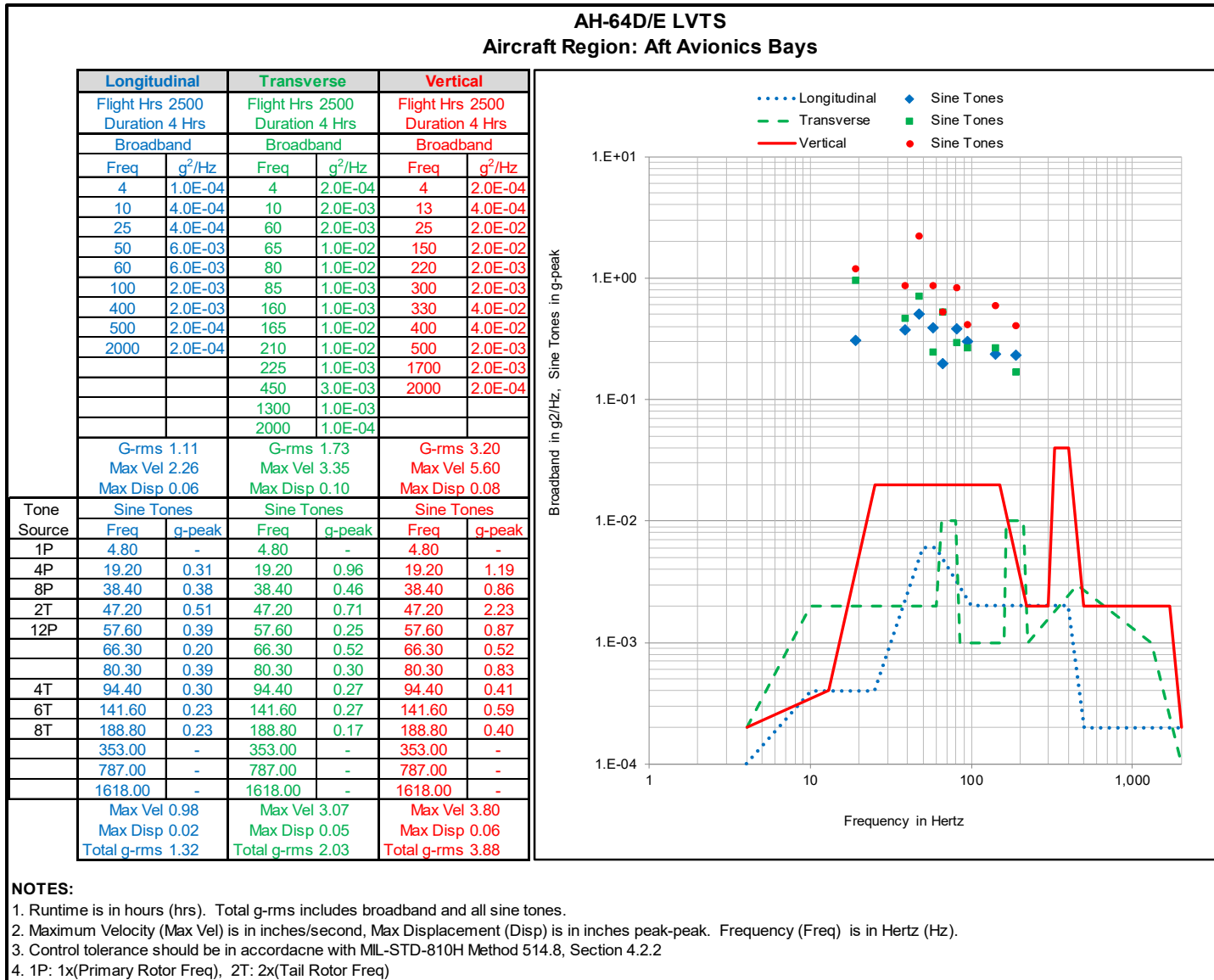
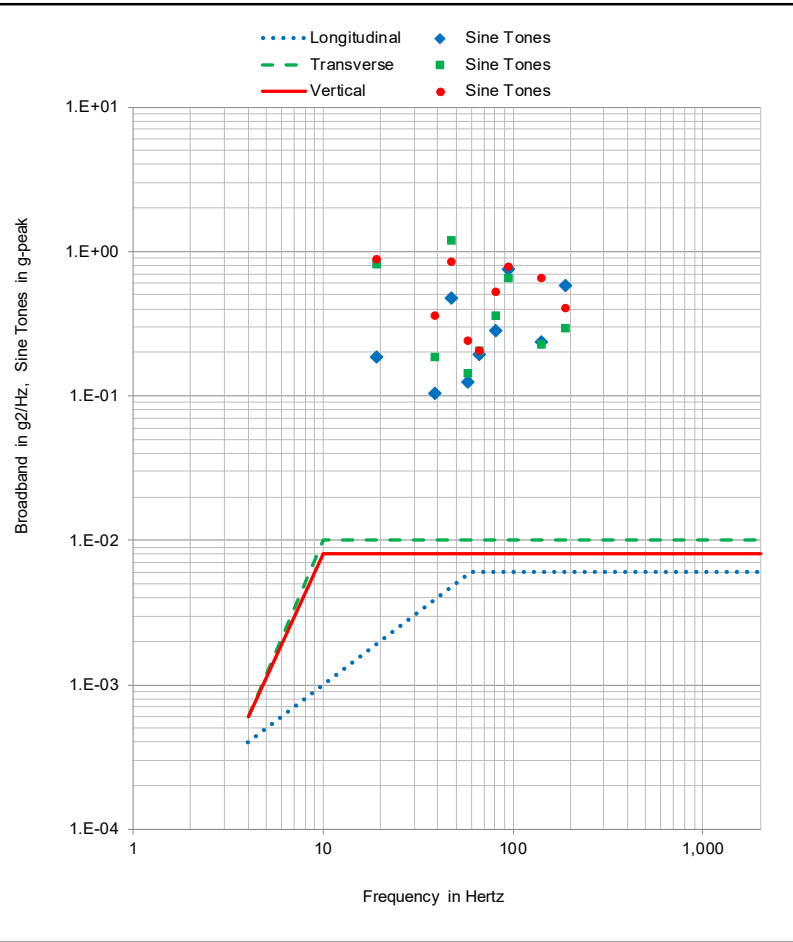


Figure E-7. AH64 Combined LVTS, Region: Aft Avionics Bays.

AH-64D/E LVTS
Aircraft Region: Tail Boom

Longitudinal		Transverse		Vertical	
Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs	
Broadband		Broadband		Broadband	
Freq	g ² /Hz	Freq	g ² /Hz	Freq	g ² /Hz
4	4.0E-04	4	6.0E-04	4	6.0E-04
60	6.0E-03	10	1.0E-02	10	8.0E-03
2000	6.0E-03	2000	1.0E-02	2000	8.0E-03
G-rms 3.44 Max Vel 2.70 Max Disp 0.10		G-rms 4.46 Max Vel 6.91 Max Disp 0.20		G-rms 3.99 Max Vel 6.25 Max Disp 0.19	
Tone Source		Sine Tones		Sine Tones	
Freq	g-peak	Freq	g-peak	Freq	g-peak
1P	-	4.80	-	4.80	-
4P	0.19	19.20	0.82	19.20	0.89
8P	0.10	38.40	0.18	38.40	0.36
2T	0.48	47.20	1.18	47.20	0.85
12P	0.13	57.60	0.14	57.60	0.24
	0.19	66.30	0.21	66.30	0.21
	0.28	80.30	0.36	80.30	0.52
4T	0.76	94.40	0.66	94.40	0.79
6T	0.24	141.60	0.23	141.60	0.66
8T	0.58	188.80	0.30	188.80	0.40
	-	353.00	-	353.00	-
	-	787.00	-	787.00	-
	-	1618.00	-	1618.00	-
Max Vel 0.62 Max Disp 0.01 Total g-rms 3.54		Max Vel 2.61 Max Disp 0.04 Total g-rms 4.62		Max Vel 2.84 Max Disp 0.05 Total g-rms 4.19	



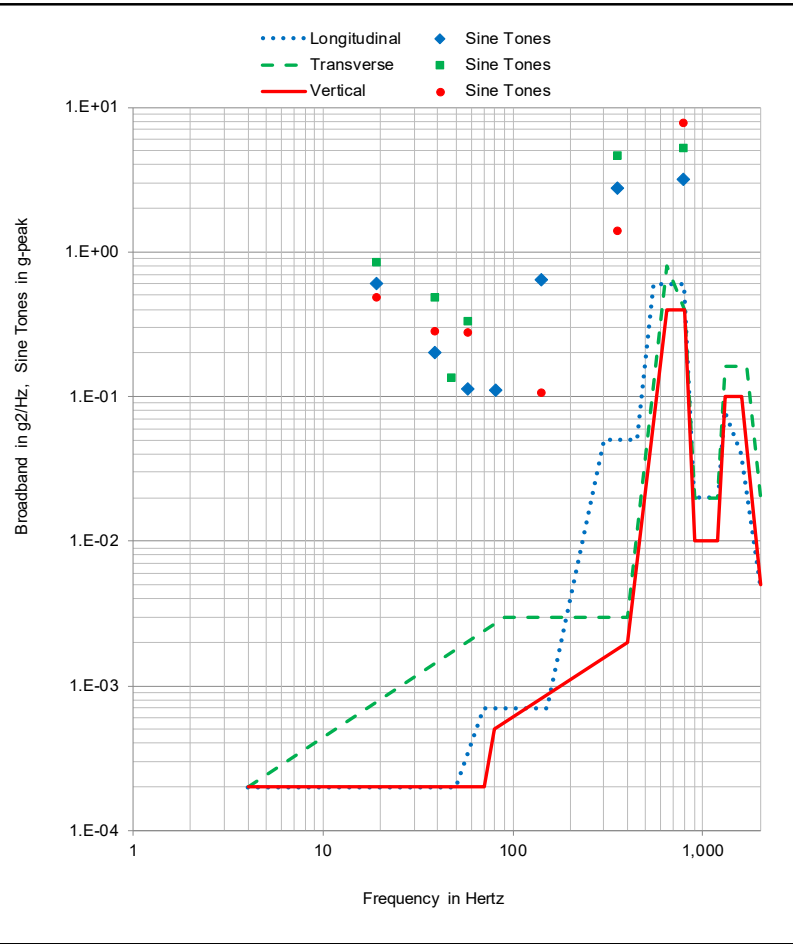
NOTES:

1. Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
2. Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
3. Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
4. 1P: 1x(Primary Rotor Freq), 2T: 2x(Tail Rotor Freq)

Figure E-8. AH64 Combined LVTS, Region: Tail Boom.

AH-64D/E LVTS
Aircraft Region: Engine Mount

Longitudinal		Transverse		Vertical		
Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		
Broadband		Broadband		Broadband		
Freq	g ² /Hz	Freq	g ² /Hz	Freq	g ² /Hz	
4	2.0E-04	4	2.0E-04	4	2.0E-04	
50	2.0E-04	90	3.0E-03	70	2.0E-04	
70	7.0E-04	400	3.0E-03	80	5.0E-04	
150	7.0E-04	650	8.0E-01	400	2.0E-03	
300	5.0E-02	800	4.0E-01	650	4.0E-01	
450	5.0E-02	900	2.0E-02	800	4.0E-01	
550	6.0E-01	1200	2.0E-02	900	1.0E-02	
800	6.0E-01	1300	1.6E-01	1200	1.0E-02	
900	2.0E-02	1700	1.6E-01	1300	1.0E-01	
1200	2.0E-02	2000	2.0E-02	1600	1.0E-01	
1300	8.0E-02			2000	5.0E-03	
1600	4.0E-02					
2000	5.0E-03					
G-rms 15.27 Max Vel 4.55 Max Disp 0.06		G-rms 15.39 Max Vel 4.13 Max Disp 0.07		G-rms 11.89 Max Vel 3.04 Max Disp 0.06		
Sine Tones		Sine Tones		Sine Tones		
Tone Source	Freq	g-peak	Freq	g-peak	Freq	g-peak
1P	4.80	-	4.80	-	4.80	-
4P	19.20	0.61	19.20	0.85	19.20	0.48
8P	38.40	0.20	38.40	0.48	38.40	0.29
2T	47.20	-	47.20	0.13	47.20	-
12P	57.60	0.11	57.60	0.33	57.60	0.28
	66.30	-	66.30	-	66.30	-
	80.30	0.11	80.30	-	80.30	-
4T	94.40	-	94.40	-	94.40	-
6T	141.60	0.64	141.60	-	141.60	0.11
8T	188.80	-	188.80	-	188.80	-
	353.00	2.74	353.00	4.63	353.00	1.40
	787.00	3.18	787.00	5.26	787.00	7.78
	1618.00	-	1618.00	-	1618.00	-
Max Vel 1.94 Max Disp 0.03 Total g-rms 15.57		Max Vel 2.73 Max Disp 0.05 Total g-rms 16.19		Max Vel 1.54 Max Disp 0.03 Total g-rms 13.15		



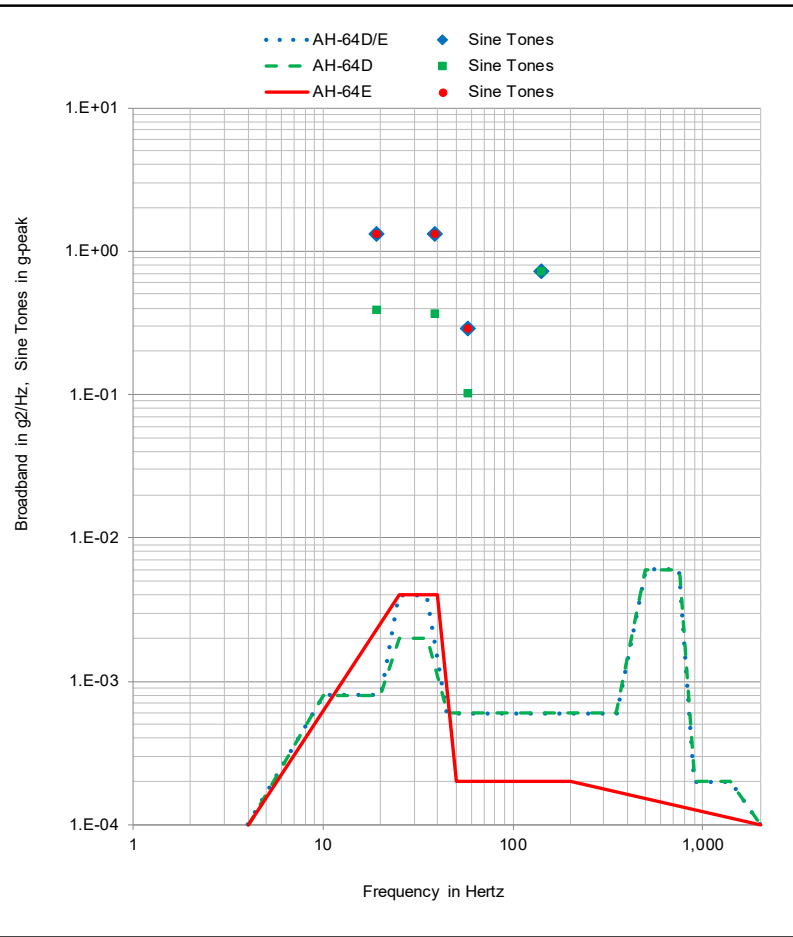
NOTES:

1. Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
2. Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
3. Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
4. 1P: 1x(Primary Rotor Freq), 2T: 2x(Tail Rotor Freq)

Figure E-11. AH64 Combined LVTS, Region: Engine Mount.

AH-64, Aircraft Region: Forward Avionics Bays
Test Axis: Longitudinal

AH-64D/E		AH-64D		AH-64E		
Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		
Broadband		Broadband		Broadband		
Freq	g ² /Hz	Freq	g ² /Hz	Freq	g ² /Hz	
4	1.0E-04	4	1.0E-04	4	1.0E-04	
10	8.0E-04	10	8.0E-04	25	4.0E-03	
20	8.0E-04	20	8.0E-04	40	4.0E-03	
25	4.0E-03	25	2.0E-03	50	2.0E-04	
35	4.0E-03	35	2.0E-03	200	2.0E-04	
45	6.0E-04	45	6.0E-04	2000	1.0E-04	
350	6.0E-04	350	6.0E-04			
500	6.0E-03	500	6.0E-03			
750	6.0E-03	750	6.0E-03			
900	2.0E-04	900	2.0E-04			
1400	2.0E-04	1400	2.0E-04			
2000	1.0E-04	2000	1.0E-04			
G-rms 1.60 Max Vel 2.46 Max Disp 0.07		G-rms 1.59 Max Vel 2.22 Max Disp 0.07		G-rms 0.60 Max Vel 2.63 Max Disp 0.07		
Tone Source	Sine Tones		Sine Tones		Sine Tones	
	Freq	g-peak	Freq	g-peak	Freq	g-peak
1P	4.80	-	4.80	-	4.80	-
4P	19.20	1.32	19.20	0.39	19.20	1.32
8P	38.40	1.32	38.40	0.37	38.40	1.32
2T	47.20	-	47.20	-	47.20	-
12P	57.60	0.29	57.60	0.10	57.60	0.29
	66.30	-	66.30	-	66.30	-
	80.30	-	80.30	-	80.30	-
4T	94.40	-	94.40	-	94.40	-
6T	141.60	0.72	141.60	0.72	141.60	-
8T	188.80	-	188.80	-	188.80	-
	353.00	-	353.00	-	353.00	-
	787.00	-	787.00	-	787.00	-
	1618.00	-	1618.00	-	1618.00	-
	Max Vel 4.23 Max Disp 0.07 Total g-rms 2.15		Max Vel 1.25 Max Disp 0.02 Total g-rms 1.71		Max Vel 4.23 Max Disp 0.07 Total g-rms 1.47	



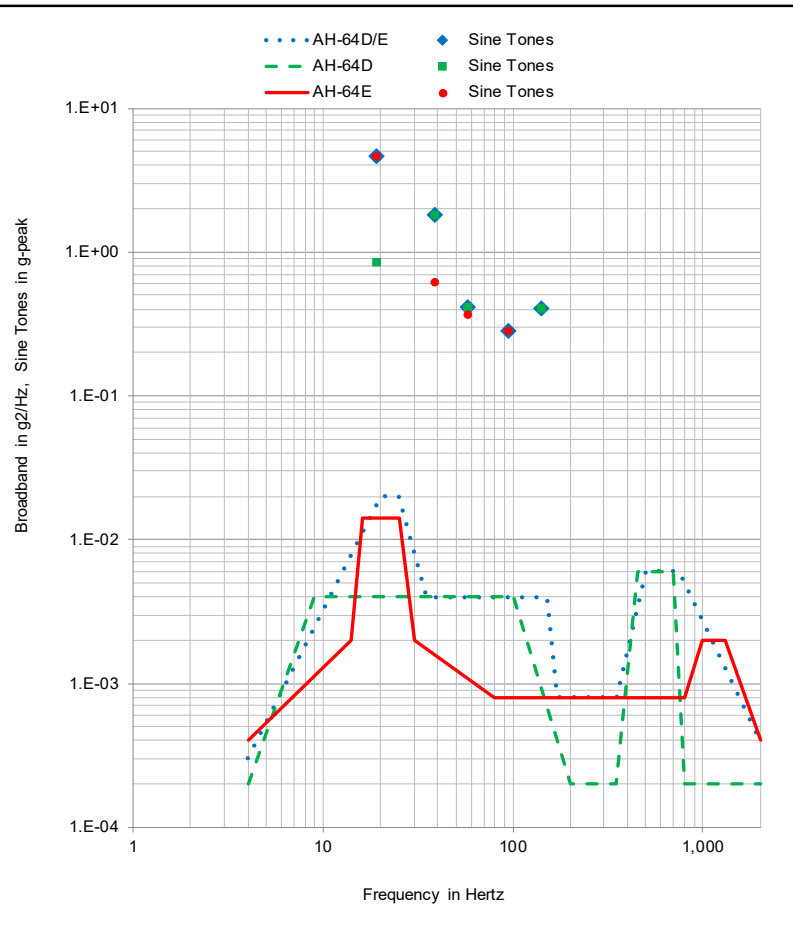
NOTES:

1. Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
2. Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
3. Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
4. 1P: 1x(Primary Rotor Freq), 2T: 2x(Tail Rotor Freq)

Figure E-12. AH64 Individual Aircraft LVTS, Region: Forward Avionics Bays, Axis: Longitudinal.

AH-64, Aircraft Region: Forward Avionics Bays
Test Axis: Vertical

AH-64D/E		AH-64D		AH-64E		
Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		Flight Hrs 2500 Duration 4 Hrs		
Broadband		Broadband		Broadband		
Freq	g ² /Hz	Freq	g ² /Hz	Freq	g ² /Hz	
4	3.0E-04	4	2.0E-04	4	4.0E-04	
20	2.0E-02	9	4.0E-03	14	2.0E-03	
25	2.0E-02	100	4.0E-03	16	1.4E-02	
35	4.0E-03	200	2.0E-04	25	1.4E-02	
150	4.0E-03	350	2.0E-04	30	2.0E-03	
170	8.0E-04	450	6.0E-03	80	8.0E-04	
350	8.0E-04	700	6.0E-03	800	8.0E-04	
500	6.0E-03	800	2.0E-04	1000	2.0E-03	
750	6.0E-03	2000	2.0E-04	1300	2.0E-03	
2000	4.0E-04			2000	4.0E-04	
G-rms 2.23 Max Vel 5.81 Max Disp 0.15		G-rms 1.61 Max Vel 4.38 Max Disp 0.13		G-rms 1.53 Max Vel 4.52 Max Disp 0.12		
Tone Source		Sine Tones		Sine Tones		
	Freq	g _{peak}	Freq	g _{peak}	Freq	g _{peak}
1P	4.80	-	4.80	-	4.80	-
4P	19.20	4.59	19.20	0.86	19.20	4.59
8P	38.40	1.80	38.40	1.80	38.40	0.62
2T	47.20	-	47.20	-	47.20	-
12P	57.60	0.41	57.60	0.41	57.60	0.37
	66.30	-	66.30	-	66.30	-
	80.30	-	80.30	-	80.30	-
4T	94.40	0.28	94.40	-	94.40	0.28
6T	141.60	0.41	141.60	0.41	141.60	-
8T	188.80	-	188.80	-	188.80	-
	353.00	-	353.00	-	353.00	-
	787.00	-	787.00	-	787.00	-
	1618.00	-	1618.00	-	1618.00	-
	Max Vel 14.68 Max Disp 0.24 Total g-rms 4.16		Max Vel 2.88 Max Disp 0.05 Total g-rms 2.18		Max Vel 14.68 Max Disp 0.24 Total g-rms 3.63	



NOTES:

1. Runtime is in hours (hrs). Total g-rms includes broadband and all sine tones.
2. Maximum Velocity (Max Vel) is in inches/second, Max Displacement (Disp) is in inches peak-peak. Frequency (Freq) is in Hertz (Hz).
3. Control tolerance should be in accordance with MIL-STD-810H Method 514.8, Section 4.2.2
4. 1P: 1x(Primary Rotor Freq), 2T: 2x(Tail Rotor Freq)

Figure E-14. AH64 Individual Aircraft LVTS, Region: Forward Avionics Bays, Axis: Vertical.

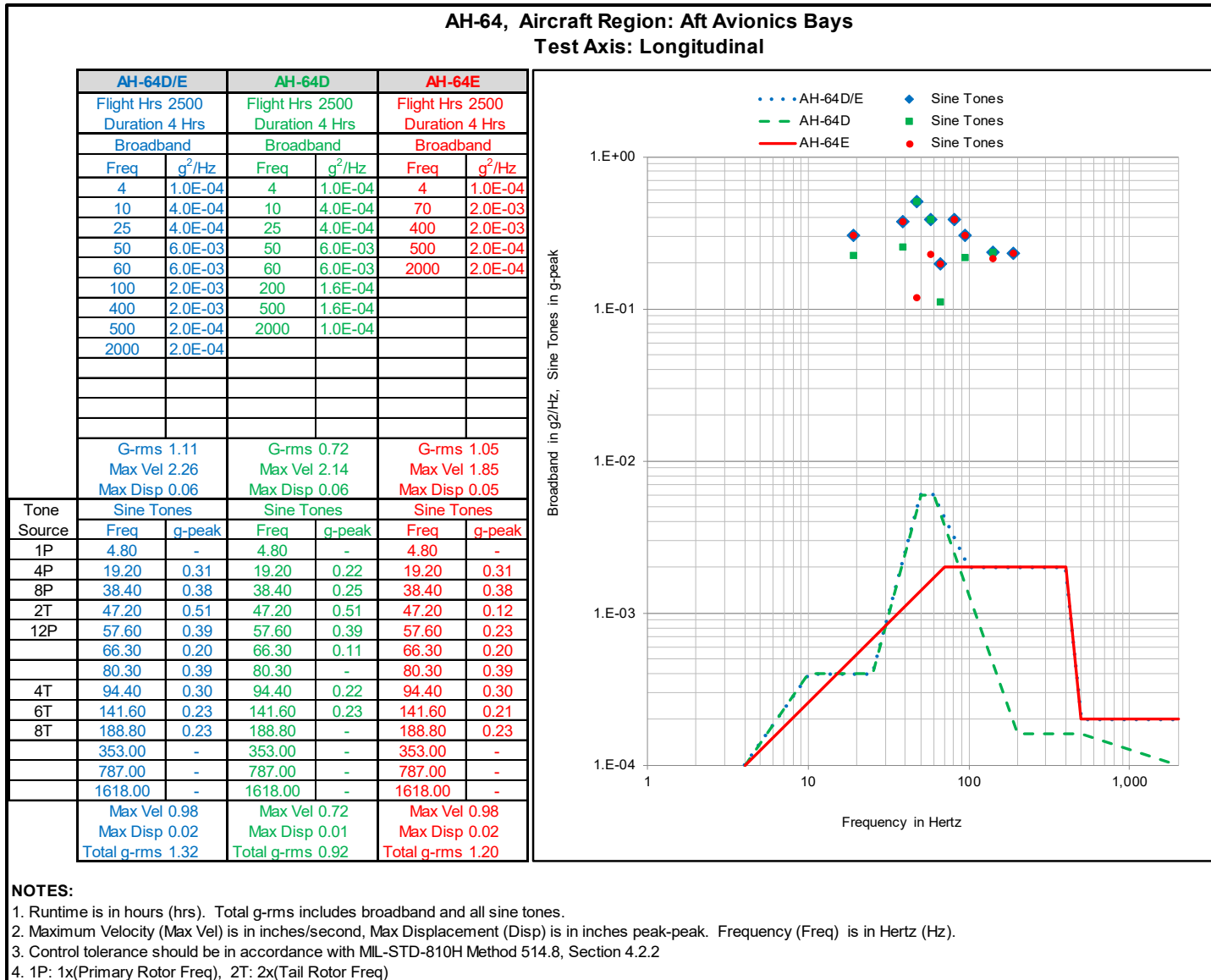


Figure E-15. AH64 Individual Aircraft LVTS, Region: Aft Avionics Bays, Axis: Longitudinal.

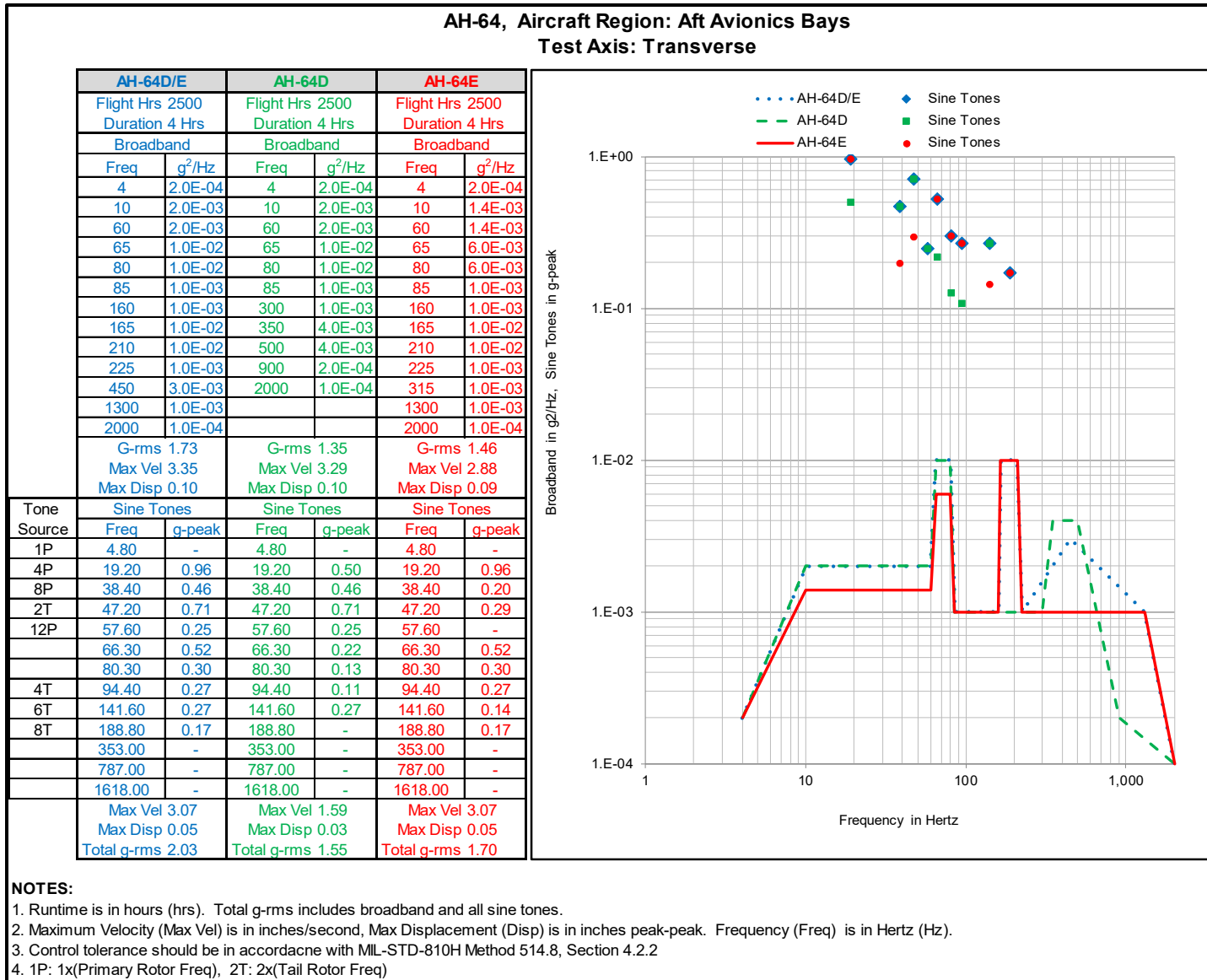


Figure E-16. AH64 Individual Aircraft LVTS, Region: Aft Avionics Bays, Axis: Transverse.

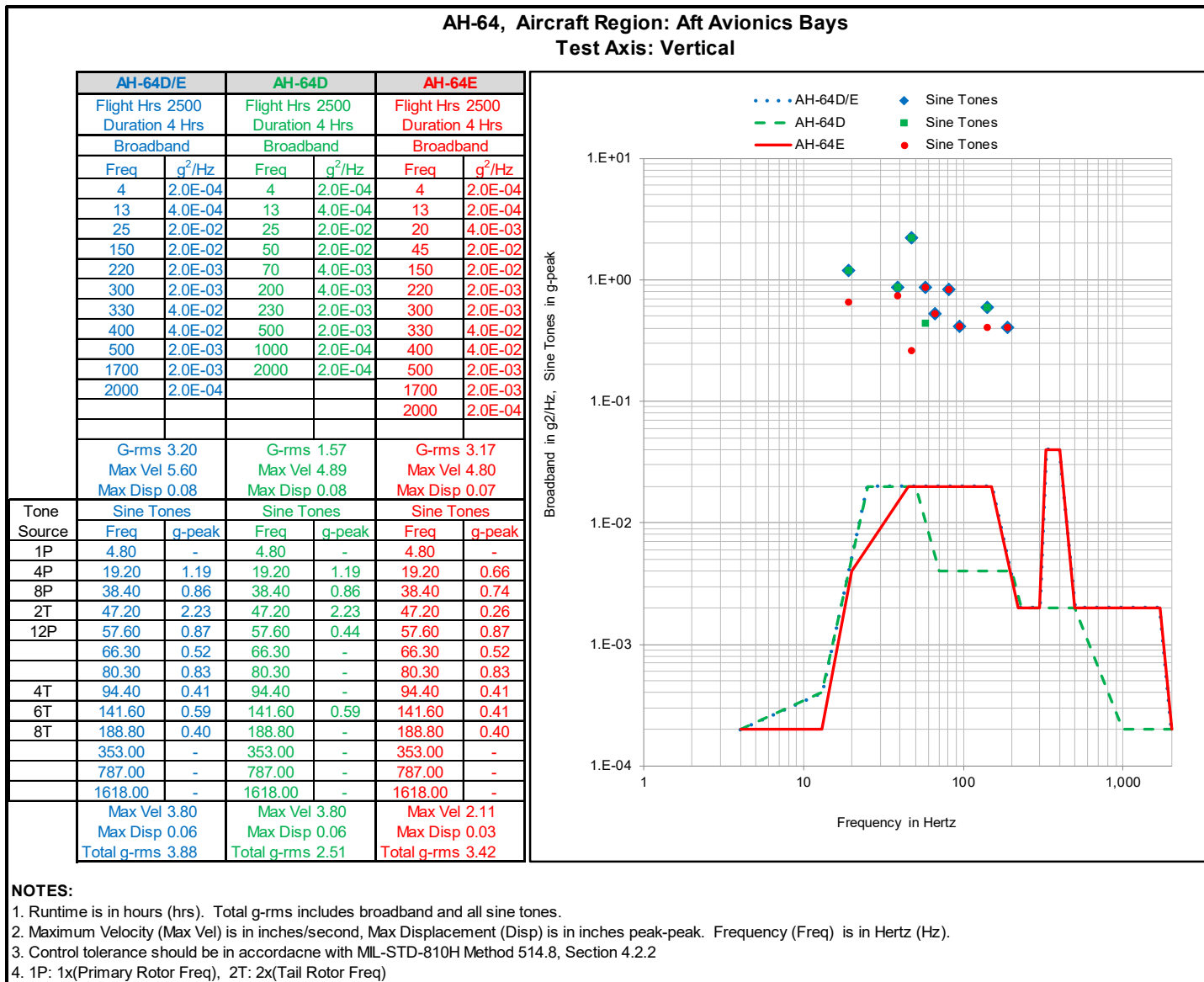


Figure E-17. AH64 Individual Aircraft LVTS, Region: Aft Avionics Bays, Axis: Vertical.

APPENDIX F. REFERENCES.

1. MIL-STD-810H with Change 1, Department of Defense Test Method Standard, Environmental Engineering Considerations and Laboratory Tests, 18 May 2022.
2. AECTP 240 Mechanical Conditions, Leaflet 2410/1 Development of Laboratory Vibration Test Schedules, Edition 3, June 2009.
3. Boeing Document Number D125-10011-1, CH-47 Block II Airframe Component Improvement Program (ACIP) Aircraft Usage Spectrum, 2 April 2014.
4. CSTE-DTC-AC-FT-I (70-10r2) MEMORANDUM, SUBJECT: Test Plan, UH-60 Dual Common Missile Warning System Software Test Bed Fiscal Year 2006, ATEC Project No. 2007-DT-ATTC-CMWSR-D2732.
5. AVNS-PRF-10002H, Performance Specification System Specification for the UH-60M Black Hawk Utility Helicopter, 3 March 2009.
6. ATEC Project No. 2011-DT-RTC-LBHMS-E5076 RTC, Document No. RTC-12-E5076-0116 "Test Record for the Captive Carry Vibration Characterization of the Quad-Rail Modernized Hellfire Launcher (M299A1) on the Apache Helicopter (AH-64D)", December 2011.
7. RTC Document No. RTC-16-G2921-0946, "System Performance Evaluation of the AN/APR-39D(V)2 Radar Signal Detecting Set, Tail Rotor Vibration Survey and Developmental Test 2", dated September 2016
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9. Boeing Document MDHS Report Number STN 99-008, "AH64D Apache Usage Spectrum," dated May 1999
10. McDonald Douglas Document AH64D-STN-93-024, "AH64D Longbow Apache Usage Spectrum," 14 July 1993.

APPENDIX G. APPROVAL AUTHORITY.

CSTE-CIP (73-1jj)

06 February 2023

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Test Operations Procedure 01-2-603A Laboratory Vibration Schedules for Rotary Wing Aircraft

1. Test Operations Procedure (TOP) 01-2-603A, Laboratory Vibration Schedules for Rotary Wing Aircraft has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency.
2. Scope of the document: This TOP provides Laboratory Vibration Test Schedules (LVTS) for selected rotary wing aircraft. The LVTS presented in this TOP were developed from field measured data collected on the selected rotary wing platforms. The LVTS are designed to allow for the exposure of a test article to a flight vibration environment of a given rotary wing platform in a laboratory setting.
3. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at <https://vdls.atec.army.mil/otcs/cs.exe>.
4. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-CI), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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