



**AFRL-RH-WP-TR-2020-0074**



**VIBRATION EXPOSURE CHARACTERIZATION  
AND HEALTH RISK ASSESSMENT OF THE  
CH-47F CHINOOK**

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**July 2020  
Interim Report**

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<b>REPORT DOCUMENTATION PAGE</b>			<i>Form Approved</i> <i>OMB No. 0704-0188</i>		
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<b>1. REPORT DATE (DD-MM-YYYY)</b> 01 07 2020		<b>2. REPORT TYPE</b> Interim		<b>3. DATES COVERED (From - To)</b> 1 May 2017 – 30 Jun 2020	
<b>4. TITLE AND SUBTITLE</b> Vibration Exposure Characterization and Health Risk Assessment of the CH-47F CHINOOK			<b>5a. CONTRACT NUMBER</b> FA8650-14-D-6500 0001		
			<b>5b. GRANT NUMBER</b>		
			<b>5c. PROGRAM ELEMENT NUMBER</b> 62202F		
<b>6. AUTHOR(S)</b> Suzanne D. Smith* Steven G. Chervak**			<b>5d. PROJECT NUMBER</b> 5329		
			<b>5e. TASK NUMBER</b> 08		
			<b>5f. WORK UNIT NUMBER</b> H0GW (53290812)		
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Air Force Materiel Command Air Force Research Laboratory 711th Human Performance Wing Airman Systems Directorate Airman Biosciences Division Biomedical Impact of Flight Branch Wright-Patterson AFB OH 45433			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>		
**Army Public Health Center (APHC) 8252 Blackhawk Rd. Aberdeen Proving Ground MD 21010			<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> US ARMY IMCOM AEC		
*Consultant, Infoscitex					
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Secretary of the Army for Installation, Energy, and Environment US Army Environmental Command National Defense Center for Energy and Environment (NDCEE) Pentagon 3D453 Washington, DC 20310			<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b> AFRL-RH-WP-TR-2020-0074		
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b> DISTRIBUTION A. Approved for public release.					
<b>13. SUPPLEMENTARY NOTES</b> 88ABW-2020-2867, cleared 15 September 2020					
<b>14. ABSTRACT</b> This study characterized and assessed aircrew vibration during operation of the CH-47F Chinook owned and operated by the Maryland Army National Guard. The study was part of a collaboration between the Army Public Health Center and the Air Force Research Laboratory, and was funded by the National Defense Center for Energy and Environment. The ISO 2631-1: 1997 was used as the guideline for the assessments. Triaxial accelerations were collected at the floor/seat base, seat pan, and seat back interfaces at the pilot station, crew chief station located behind the pilot, forward and aft aircrew locations, and at the ramp (standing). Data records were collected by aircraft task and the associated flight test conditions. Constant and proportional frequency bandwidth acceleration spectra were generated for each record, as were the unweighted and weighted overall accelerations (1-80 Hz). Most data showed a small spectral peak between 3.5 and 4.0 Hz associated with the propeller rotation frequency (PRF) of the CH-47F. The next higher peak occurred between 11 and 11.5 Hz and was associated with the blade passage frequency (BPF). Additional notable peaks were also observed at multiples of the BPF. Based on the overall vibration total values at each seat station/location, comfort reactions primarily ranged from "a little uncomfortable" to "uncomfortable" (ISO 2631-1). Based on the seat pan point vibration total value for level flight, most stations/locations showed the potential for health risk, and even likely health risk in less than 8 hours depending on the airspeed (ISO 2631-1). Health risk tended to increase with increases in airspeed; the crew chief station and aft aircrew location reached the potential for health risk in 1 to 2 hours of daily flight, and reached health risk likely within 6 hours or less of daily flight (ISO 2631-1), exceeding the exposure criteria set forth in MIL-STD-1472G. The aircrew should be warned that they may be exposed to potential health risk in less than 8 hours of flight, in accordance with MIL-STD-1472G. In summary, these results further support the substantial influence of operational vibration on the discomfort and pain that has been associated with the operation of these aircraft, particularly given the magnitudes of the higher frequency exposures that still result in a potential health risk according to the standards and guidelines.					
<b>15. SUBJECT TERMS</b> Human vibration, helicopters, health risk assessment, discomfort					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>
<b>a. REPORT</b>	<b>b. ABSTRACT</b>	<b>c. THIS PAGE</b>			Donald Harville
Unclassified	Unclassified	Unclassified	SAR	54	<b>19b. TELEPHONE NUMBER (include area code)</b> N/A

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## **PREFACE**

This report summarizes the vibration exposure assessment conducted on the CH-47F Chinook helicopter owned and operated by the Maryland Army National Guard (MD ARNG) in accordance with the ISO 2631-1 (1997) Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements, ISO 2631-1 Amendment 1 (2010), and the MIL-STD-1472G Department of Defense Design Criteria Standard, Human Engineering (2012). The study is the first for the project entitled “Operational Vibration Assessment and Database Project 2: Expanded Flight Test Program. Project 2 was funded by the National Defense Center for Energy and Environment (NDCEE). Three additional platforms were targeted for the expanded test program; the UH-60L Blackhawk, MH-65D Dolphin, and UH-1N Huey helicopters. The test program included the development of a database quantifying operational vibration and active aircrew subjective perceptions, and integrated into the Air Force Collaborative Biomechanics Data Network (CBDN) managed by the 711 HPW/RH. The database will be made available to researchers, equipment designers, and standards developers for establishing effective near- and far-term pain and injury mitigation strategies. A Memorandum of Agreement (MOA) between the APHC and the AFRL 711 HPW/RH was established that set forth the terms and conditions that the two organizations would use to conduct the project with funding from the NDCEE. The AFRL 711 HPW/RH prepared all required documentation including a Flight Test Plan, and conducted all required review boards including the Technical Review Board (TRB) and Safety Review Board (SRB), in accordance with Air Force Research Laboratory Instruction (AFRLI) 61-103, Scientific Research and Development, AFRL Research Test Management (2015).

## **ACKNOWLEDGEMENTS**

The Army Public Health Center (APHC) and Air Force Research Laboratory (AFRL) thank the Maryland Army National Guard (MD ARNG) for their support of flight tests onboard the CH-47F Chinook.

The APHC and the AFRL thank the National Defense Center for Energy and Environment (NDCEE) for their financial support of this project.

## 1.0 SUMMARY

This study characterized and assessed aircrew vibration during operation of the CH-47F Chinook helicopter located at the MD ARNG. The ISO 2631-1: 1997 and MIL-STD-1472G were used as the guideline for the comfort and health risk assessments. The study is part of a larger test program that includes additional aircraft platforms. The specific objectives of this study are:

1. Collect multi-axis acceleration data to characterize the vibration affecting the aircrew and interface equipment onboard the CH-47F Chinook helicopter.
2. Assess the comfort and health risk of the vibration exposures in accordance with existing human vibration standards.
3. Enter acceleration data into the 711 HPW/RH CBDN.

The study was a collaboration between the Army Public Health Center (APHC) and the Air Force Research Laboratory (AFRL), 711 Human Performance Wing (HPW), Airman Systems Directorate (RH), and was funded by the National Defense Center for Energy and Environment (NDCEE).

Four portable battery-powered data acquisition units (DAUs) were used to collect accelerations at the pilot station (left side of cockpit), crew chief station (forward cabin, left side, rearward facing), and two aircrew locations (left side, sideward facing, forward and aft cabin). Triaxial accelerometer packs were attached to the floor or rigid support of each seat. Triaxial acceleration pads were placed on top of the seat pan and seat back cushions at each station location. A helmet mount was attached to the top of the pilot helmet to collect triaxial translational accelerations. Data records were collected by aircraft task and the associated flight test conditions, including pre-departure checks, visual meteorological conditions (VMC), takeoff, hovering flight, VMC flight maneuvers, VMC approach, and simulated sling load operations. The onboard test conductor prompted triggering of the DAUs to collect for 20 second records once the aircraft was on a targeted condition. The acceleration constant and proportional frequency bandwidth acceleration spectra were estimated at each station/location and measurement site. The overall unweighted and weighted (ISO 2631-1) accelerations were calculated between 1 and 80 Hertz (Hz). For assessing the ISO 2631-1 health risks, the point vibration total value ( $pVTV$ ) was calculated as the vector sum of the weighted triaxial seat pan accelerations. For assessing the ISO 2631-1 comfort reactions, the overall vibration total values ( $oVTVs$ ) were calculated as the vector sum of the seat pan and seat back  $pVTVs$ .

Most data showed a small spectral peak between 3.5 and 4.0 Hz associated with the propeller rotation frequency (PRF) of the CH-47F. The next higher peak occurred between 11 and 11.5 Hz and was associated with the blade passage frequency (BPF). Additional notable peaks were also observed at multiples of the BPF. Based on the overall vibration total values at each seat station/location, comfort reactions primarily ranged from “a little uncomfortable” to “uncomfortable” (ISO 2631-1). Based on the seat pan point vibration total value for level flight, most stations/locations showed the potential for health risk, and even likely health risk in less than 8 hours depending on the airspeed (ISO 2631-1). Health risk tended to increase with increases in airspeed; the crew chief station and aft aircrew location reached the potential for health risk in 1 to 2 hours of daily flight, and reached health risk likely within 6 hours or less of daily flight (ISO 2631-1), exceeding the exposure criteria set forth in MIL-STD-1472G. Aircrew should be warned that they may be exposed to potential health risk in less than 8 hours of

operational flight onboard the CH-47F, in accordance with MIL-STD-1472G. In summary, these results further support the substantial influence of operational vibration on the discomfort and pain that has been associated with the operation of these aircraft, particularly given the magnitudes of the higher frequency exposures that still result in a potential health risk according to the standards and guidelines.

## 2.0 INTRODUCTION

Epidemiological surveys have consistently reported that ~85% of the rotary-wing aircrew surveyed has suffered back, leg, or neck pain associated with flying helicopters (Hamon, Healing, Contarino, & Ellenbecker, 2012). Poor posture, inadequate seats, and aircraft vibration have been targeted as contributing factors but their synergies and physiological mechanisms are unknown. The Business Case Analysis (BCA) conducted by R Cubed Consulting for the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD ATL), and Office of the Deputy Under Secretary of Defense Installations and Environment (DUSD I&E) (Hamon et al., 2012) emphasized that musculoskeletal pain and discomfort in these aircrew have a significant negative impact on mission effectiveness and mission readiness with an average yearly avoidable cost of \$239 M. The strong recommendation in the BCA for improved seating systems cannot be effectively addressed without clear guidelines on exposure effects, seat design, and validation testing. Appropriate science- and technology-based guidelines on exposure, seat design, and validation testing are non-existent, perpetuating the health issues.

The first step is to clearly characterize the actual human multi-axis vibration exposure onboard various rotary-wing/tilt-rotor aircraft to identify the frequency components, acceleration magnitudes, and direction of the vibration entering the occupant at the occupant/vehicle interfaces (typically the seating system). In addition, there are guidelines provided in human vibration exposure standards that can be applied to these data for assessing the health risk and discomfort associated with the exposures (ISO 2631-1: 1997; MIL-STD-1472G, 2012). Health risk and comfort assessments have been conducted on a limited number of platforms. With regard to rotary-wing aircraft, a study was conducted in 2013 to collect and assess vibration exposures onboard the HH-60M Medevac and UH-72 Lakota located at the Vermont Army National Guard (VT ARNG) (Smith, Chervak, & Steinhauer, 2014). The APHC, National Guard Bureau (NGB), and the Air Force Research Laboratory, Airmen Systems Directorate (711 HPW/RH) conducted the study. The equipment and methodology established by the AFRL 711 HPW/RH for collecting and analyzing the actual multi-axis measurements at various occupant stations were used to characterize and compare the vibration during different flight conditions, and conduct the comfort and health risk assessments in accordance with the existing standards. An aircrew questionnaire, developed by the APHC and the AFRL 711 HPW/RH, was distributed to aircrew members at the VT ARNG. The health risk assessment suggested that certain aircrew may be subjected to potential health risks in less than three hours for occupational exposures (Smith, 2005; Smith & Gerdus, 2005; Smith, Jurcsisn, & Bowden, 2008; Smith, Chervak, & Steinhauer, 2014). The AFRL 711 HPW/RH has also used these data to recreate the actual stressor environment in controlled laboratory testing for evaluating seat component influences, physiological responses, task performance, and task workload during simulated prolonged exposures.

This test program is an expansion of the previous studies conducted on rotary-wing/tilt-rotor aircraft and was funded by the NDCEE. In addition to the CH-47F, flight tests have been completed on the UH-60L, MH-65D, and UH-1N. Technical reports have been generated summarizing the results of the flight tests conducted onboard the UH-60L (Smith, Chervak, & Clasing, 2019) and MH-65D (Smith & Chervak, 2019), similar to the report generated on the HH-60M and UH-72. The test program includes the development of a database quantifying

operational vibration and active aircrew subjective perceptions, and integrated into the Air Force CBDN managed by the AFRL 711 HPW/RH. The database will be available to researchers, equipment designers, and standards developers for establishing effective near- and far-term pain and injury mitigation strategies.

The specific objectives of this study are:

1. Collect multi-axis acceleration data to characterize the vibration affecting the aircrew and interface equipment onboard the CH-47F Chinook helicopter.
2. Assess the comfort and health risk of the vibration exposures in accordance with existing human vibration standards.
3. Enter acceleration data into the AFRL 711 HPW/RH CBDN.

The primary metric being measured to characterize the vibration is the acceleration generated at the human/equipment interfaces in the three orthogonal axes. This may also include the measurement of triaxial accelerations at the helmet for selected aircrew. The accelerations collected at the interfaces are frequency weighted for estimating the health risk and comfort reactions using guidelines provided in the standards. The survey/questionnaire metrics include subjective ratings and responses on aircrew perception of the vibration, location of symptoms and discomfort, posture, and interface issues.

A Memorandum of Agreement (MOA) between the APHC and the AFRL 711 HPW/RH was established that set forth the terms and conditions that the two organizations would use to conduct the project with funding from the NDCEE. The AFRL 711 HPW/RH prepared all required documentation including a Flight Test Plan, and conducted all required review boards including the TRB and SRB, in accordance with the Air Force Research Laboratory Instruction 61-103 (2015).

This report focuses on the discomfort and health risk assessments conducted on the CH-47F Chinook. The aircrew survey results will be presented in a separate report.

## **3.0 METHODS AND PROCEDURES**

### **3.1 Aircraft and Measurement Locations**

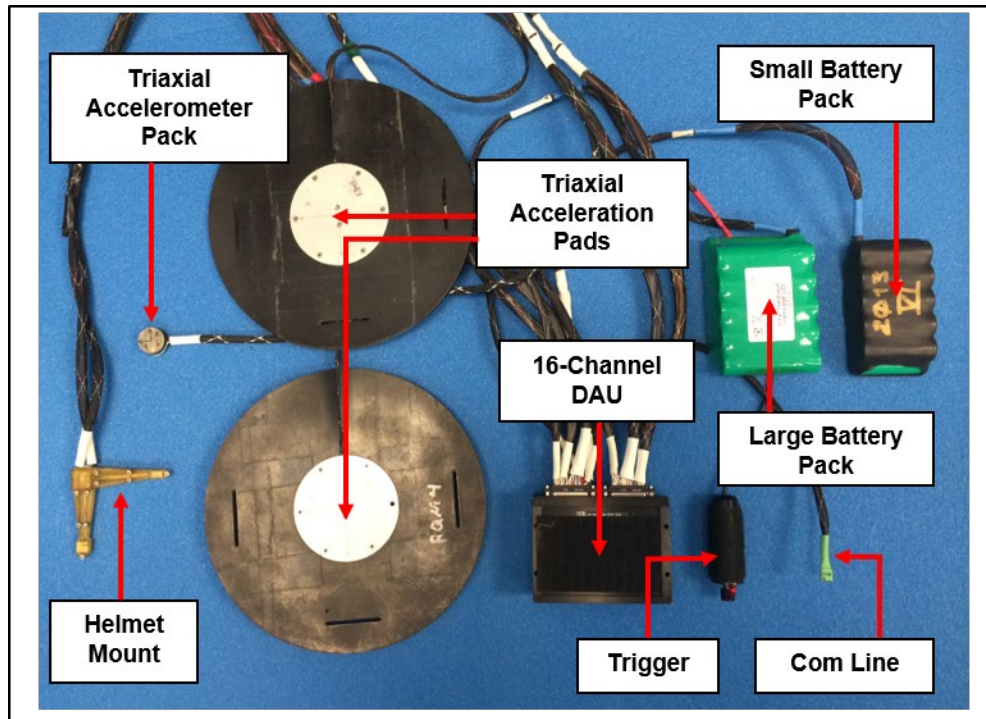
The CH-47F (tail number 12-08875) is owned and operated by the MD ARNG located at Weide Army Heliport, Aberdeen Proving Ground, MD. The measurement locations targeted included the pilot station located on the left side of the cockpit, the crew chief station located on the left side of the forward cabin behind the cockpit and facing rearward, and two aircrew locations on the left side facing sideward in the forward and aft cabin sections. In addition, floor data were also intermittently collected while an occupant was standing on the open rear ramp. All measurement stations or locations were occupied during data collection.

### **3.2 Equipment, Instrumentation, and Measurement Sites**

Four Remote Vibration Environment Recorders (REVERs), developed by the AFRL Airman Systems Directorate (711 HPW/RH), were used to collect multi-axis vibration data at the four aircrew stations or locations. Each REVER, illustrated in Figure 1, consists of the following:

1. A 16-channel data acquisition unit (DAU) (Large or Small)
2. Two battery packs (Large and Small)
3. Triaxial accelerometer pack
4. Triaxial accelerometer seat pads
5. One six-axis helmet mount (Pilot REVER system)
6. One trigger device
7. Connection/extension cables as required
8. Laptop computer

Specifications for the REVER components, including dimensions and weights, are listed in Table A-1.



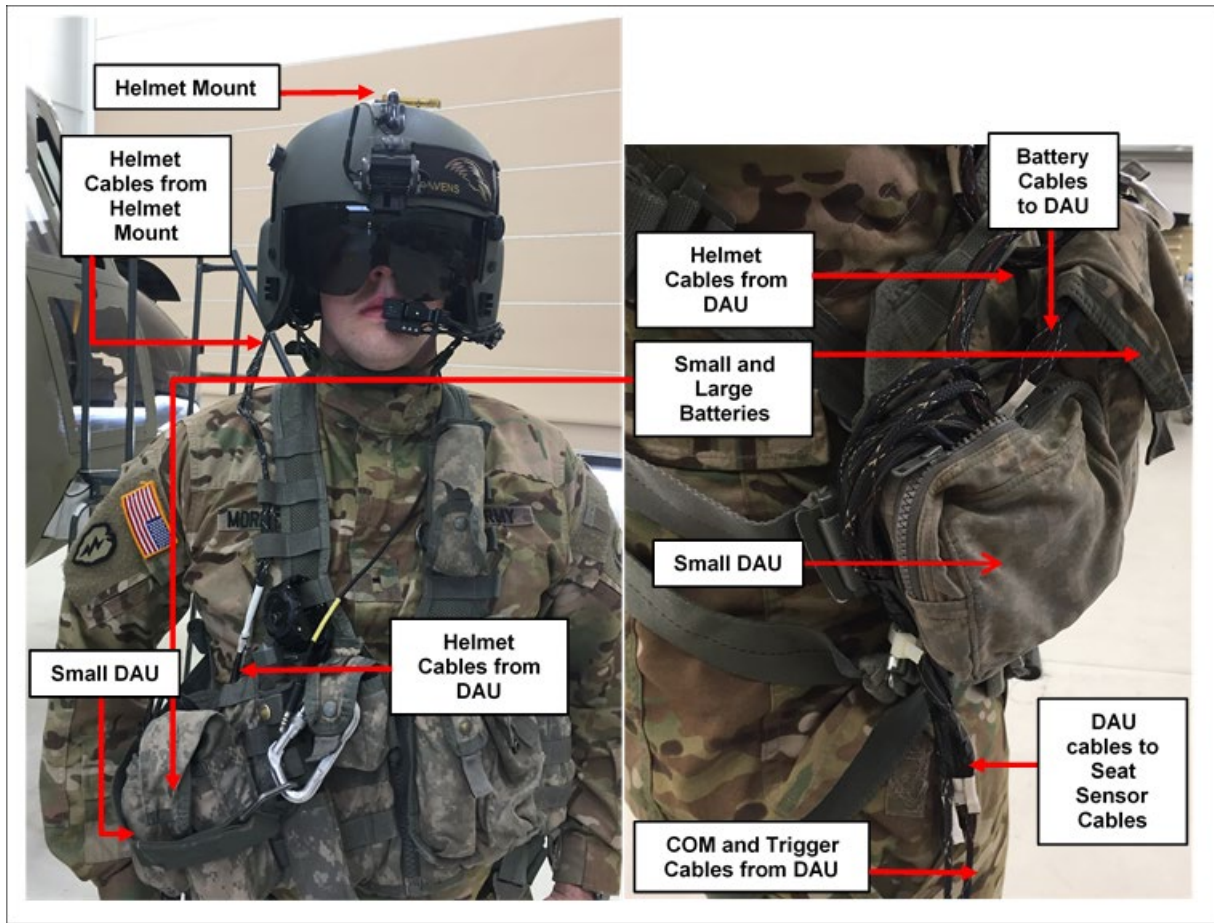
**Figure 1. Remote Vibration Environment Recorder (REVER)**

Table 1 lists the aircrew stations/locations and measurement sites targeted for data collection, including the type of instrumentation. The table also includes the data file designation used in the CBDN.

**Table 1. CH-47F Stations/Locations, Measurement Sites and Type of Sensors**

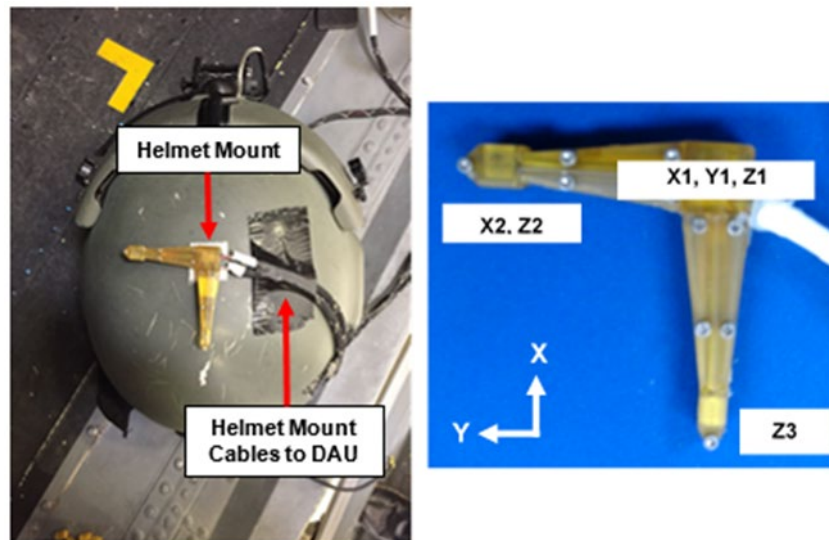
Station	Measurement Site	Instrumentation
Pilot Station (Left Side Cockpit) CBDN Test: CH47FPILOT	Rigid X-Bar Behind Seat	Triaxial Accelerometer Pack
	Seat Pan	Triaxial Acceleration Pad
	Seat Back	Triaxial Acceleration Pad
	Helmet	Six-Axis Helmet Mount
Crew Chief Station (Forward Cabin, Left Side, Rearward Facing) CBDN Tests: CH47FCCLEFT	Floor beneath seat	Triaxial Accelerometer Pack
	Seat Pan	Triaxial Acceleration Pad
	Seat Back	Triaxial Acceleration Pad
Aircrew Locations (Forward and Aft Cabin, Left Side, Sideward Facing) CBDN Test: CH47FACLEFTFORE CH47FACLEFTAFT (note: Ramp data are included with the AFT data)	Floor beneath each seat	Triaxial Accelerometer Pack
	Seat Pan	Triaxial Acceleration Pad
	Seat Back	Triaxial Acceleration Pad
	Ramp	Triaxial Accelerometer Pack

At the pilot station, the small DAU and batteries were carried in pockets attached on the outside of a survival vest. Figure 2 illustrates the vest configuration.



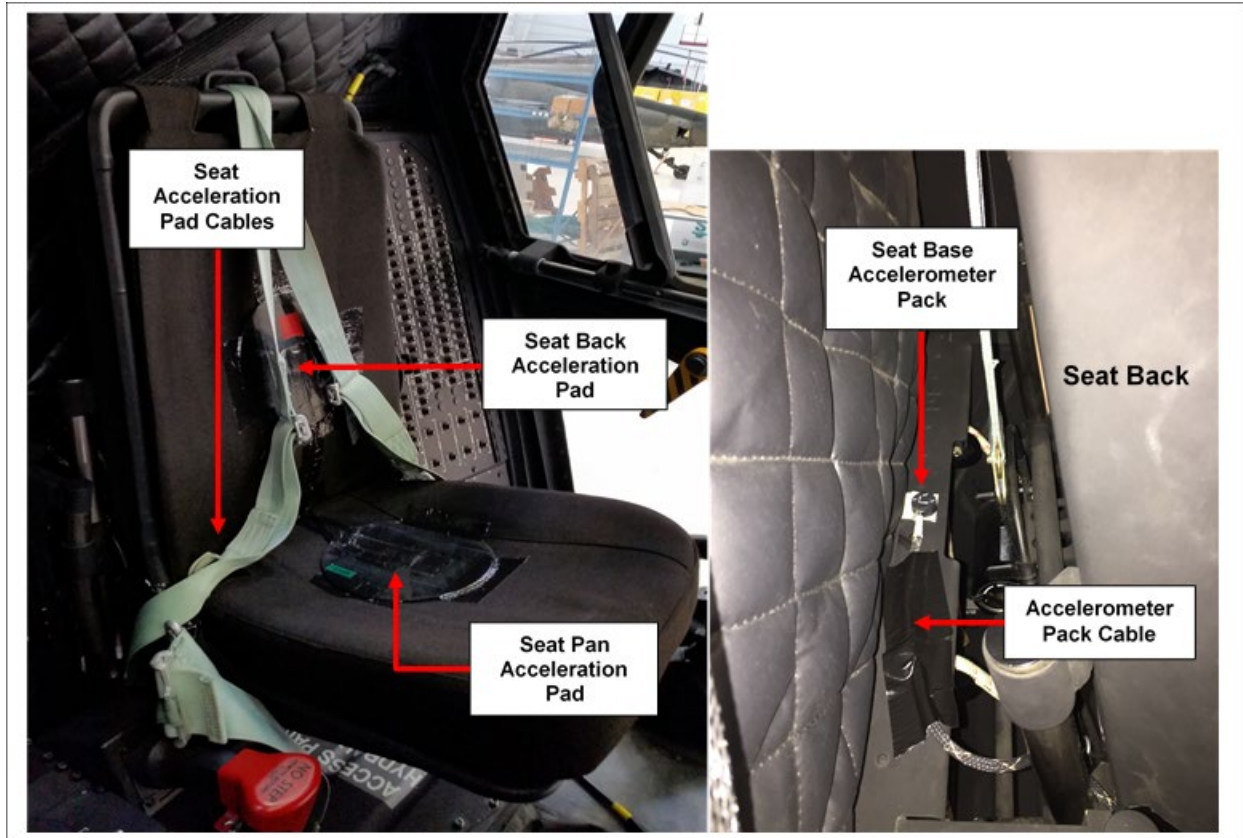
**Figure 2. Pilot Survival Vest Configuration**

A helmet mount was attached onto the top of the pilot helmet using double-sided mounting tape. The helmet mount consisted of six miniature accelerometers strategically arranged to estimate helmet translations in the three orthogonal axes (fore-and-aft or X, lateral or Y, and vertical or Z) and, if desirable, helmet roll, pitch, and yaw. Figure 3 illustrates the helmet mount attached to the helmet. Figure 2 shows the routing and connection of the helmet cables to the respective DAU cables. The helmet mount was further secured with duct tape to prevent any snags.



**Figure 3. Helmet Mount**

At each station or location, a triaxial accelerometer pack was used to measure the input acceleration either on a rigid seat component or on the floor beneath the seat (Figure 1, Table 1; Table A-1) in the fore-and-aft (X), lateral (Y), and vertical (Z) axes, relative to the seat/occupant orientation. Each pack consisted of three orthogonally-arranged miniature accelerometers embedded in a Delrin® cylinder. Double-sided mounting tape was used to secure the pack to the appropriate site. Triaxial accelerometer pads were used to measure the vibration transmitted to the occupant via the seat pan and seat back (pilot station, crew chief station only) and feet (ramp) in accordance with the International Standards Organization, ISO-2631-1: 1997 Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part I: General Requirements (ISO 2631-1: 1997). The pad consisted of a flat rubber disk with a triaxial accelerometer pack embedded in the center (Figure 1; Table A-1). Double-sided adhesive tape and duct tape were used to secure the pads to the seat cushions or seat cloth and ramp floor. Figure 4 illustrates the location of the seat acceleration pads and the triaxial accelerometer pack (on rigid X-bar behind seat) at the pilot station. Figure 5 illustrates the location of the seat acceleration pads and floor accelerometer pack and acceleration pads at the crew chief station. Figure 6 illustrates the location of the seat pan acceleration pad and the floor accelerometer pack at the aircrew locations. No seat back pads were installed at the aircrew locations. Figure 7 illustrates the location of the acceleration pad for the standing occupant on the CH-47F ramp.



**Figure 4. Pilot Station Instrumentation**

When using the survival vest, the seat accelerometer cables were connected to the DAU cables at the lower back edge of the vest on the pilot's right side as illustrated in Figure 2. The cables were run beneath the lap belt to ensure no interference with the safety features of the aircraft or the occupant's task. The cables from the helmet were secured at the back of the helmet and run over the right shoulder to the DAU connection at the front of the vest as shown in Figure 2. All cable connections between the seat and helmet accelerometers and the DAU were made via break-away connectors. Each cable requires less than 21.8 Newtons (4.9 pounds) of static weight to separate. The three-cable bundle shown in Figure 2 takes a peak force of 40 to 45 Newtons (9 – 10 pounds) to separate when the occupant stands up (demonstrated in laboratory setting).

A triggering device (Figure 1) was run from each DAU via cable to two designated individuals responsible for initiating data collection (see Section 3.3). Once triggered, the DAU would collect data for a pre-specified amount of time. Prior to flight, a laptop computer was used to conduct sensor balance, calibration checks, and arming of each DAU. The computer was used to assign a specific sensor associated with a measurement site and direction to a channel in the DAU. Once armed, the computer was disconnected from the DAU.

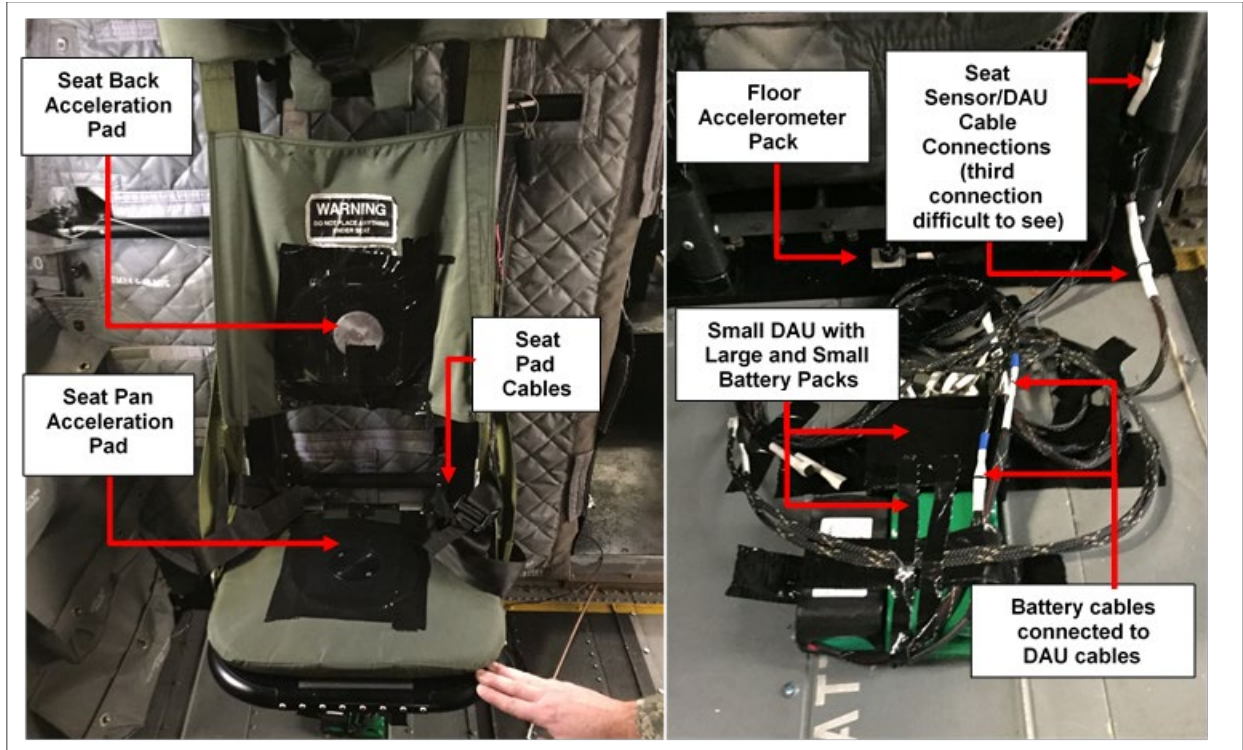


Figure 5. Right Crew Chief/Flight Engineer Station Instrumentation

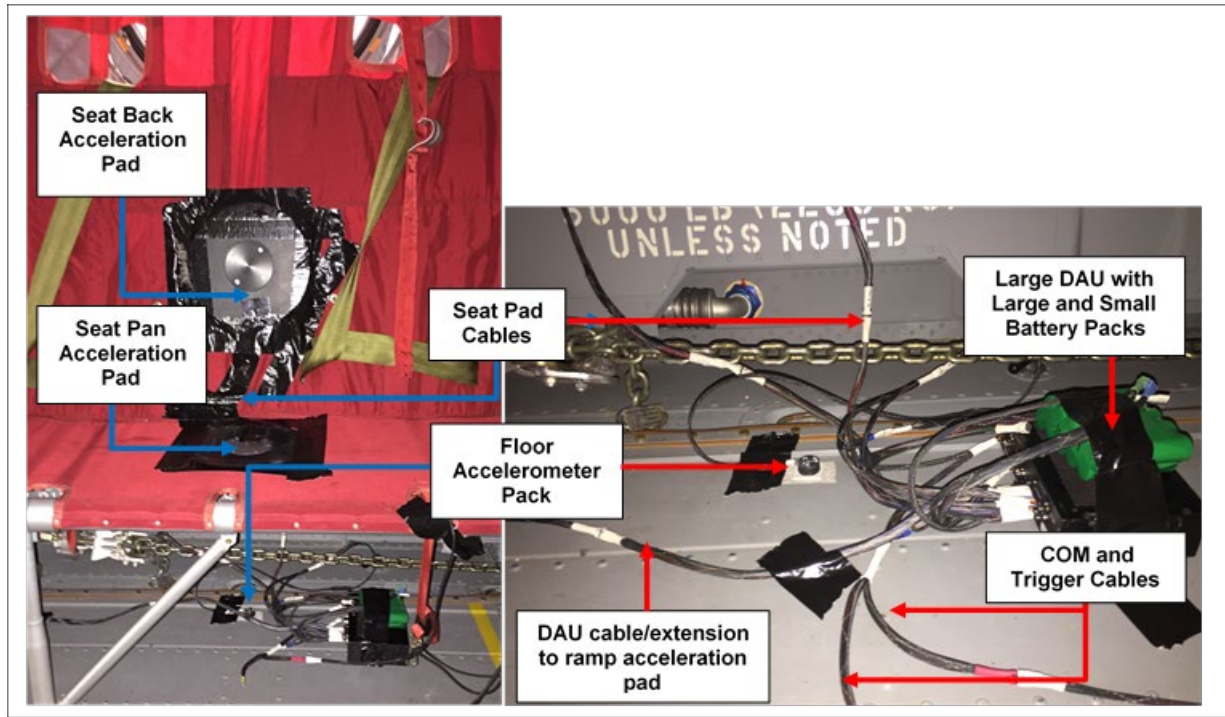
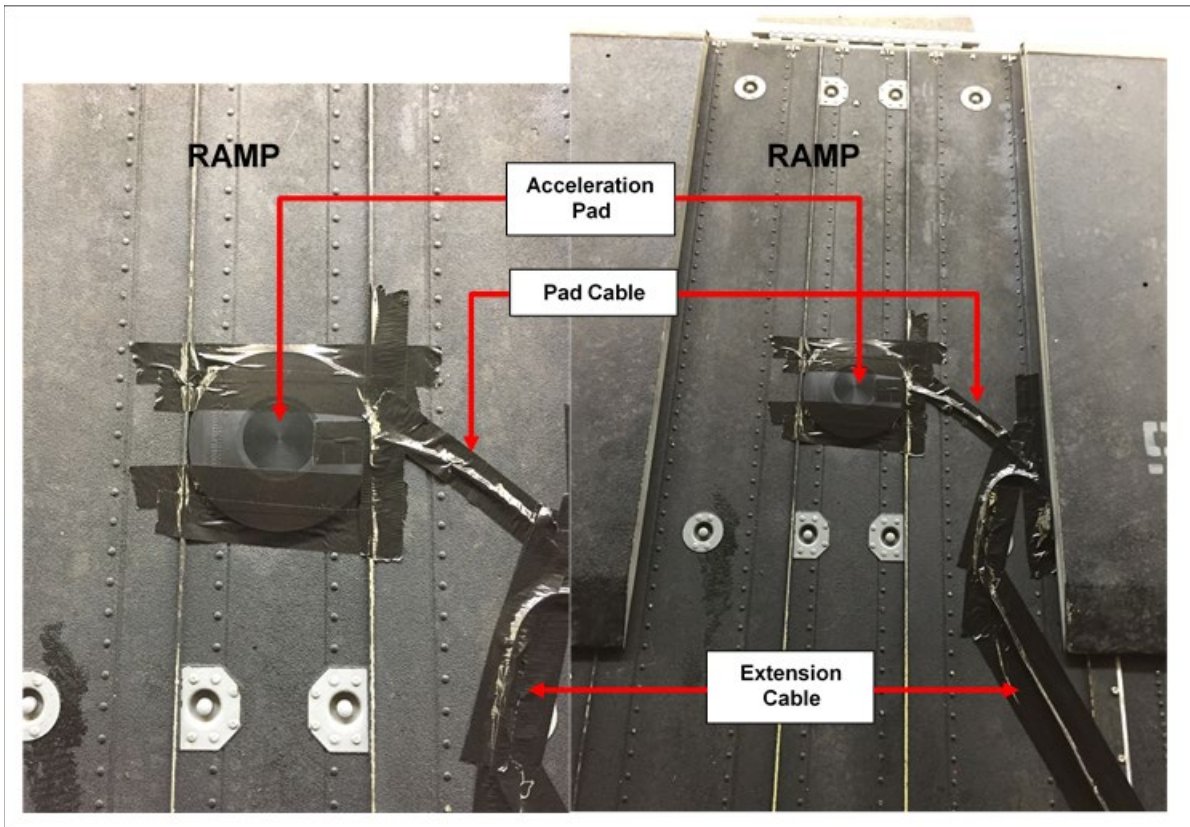


Figure 6. Left Side Forward and Aft Aircrew Instrumentation



**Figure 7. Triaxial Acceleration Pad attached to CH-47F Ramp Floor**

### **3.3 Data Collection, Processing, and Analysis**

#### **3.3.1. Data Collection**

Acceleration data were collected at the aircrew stations/locations and measurement sites for the flight test conditions listed in Table A-2 Flight Test Records. The flight test conditions were organized relative to the specific flight tasks that were identified by the aircrew. For the CH-47F, the flight test tasks and conditions were similar to those used onboard the UH-60L, which was also located at MD ARNG. One individual was designated as the test conductor, who prompted other individuals to trigger data collection once the pilot or copilot indicated that the aircraft was on the flight test condition. Multiple data records were collected for several of the conditions. Data records were collected throughout the flight and not necessarily collected in the order presented in Table A-2. The designated test conductor assured that the data records were numbered consecutively in the order they were collected.

Once triggered, data were automatically collected for 20 seconds, filtered at 250 Hz, and digitized at 1024 samples per second. Upon return of the aircraft, the laptop was reconnected to each DAU and the time histories for each channel downloaded to the computer for processing. All data were collected during one flight test. Table A-2 lists the number of records collected for each flight test condition.

### 3.3.2. Data Processing and Analysis

A computer program developed by the AFRL 711 HPW/RH was used to separate the 20-second records for each channel and assemble all channels for a particular record into a table of time histories. For each record, the time histories were processed using the MATLAB<sup>®</sup> Signal Processing Toolbox (The MathWorks, Inc., Natick, MA) to estimate the constant bandwidth spectral content. Using Welch's Method (Welch, 1967), each 20-second time history was divided into two-second sub-segments with a 50% overlap. A Hamming window was applied to each sub-segment and the resultant power spectral densities averaged over the 20-second period. The root-mean-square (rms) acceleration,  $a_{rms}$ , was calculated from the power spectral densities in 0.5 Hz intervals. The constant bandwidth rms acceleration spectra were used to locate the peak accelerations.

Each acceleration time history was also processed in one-third octave proportional frequency bands using a software program developed for MATLAB<sup>®</sup> (Couvreur, 1997). The accelerations were reported at the center frequency of each respective one-third octave band. These data were used to assess the exposures in accordance with current standards.

The overall unweighted acceleration level,  $a_{uw}$ , between 1 and 80 Hz was calculated for each station at the floor or seat base, seat pan, seat back, helmet (pilot only), and ramp:

$$a_{uw} = [\sum_i a_{rmsi}^2]^{1/2} \quad (1)$$

where  $a_{rmsi}$  is the rms acceleration associated with the  $i$ th frequency component (in 0.5 Hz increments for constant bandwidth analysis, and at the center frequency of the one-third octave band for proportional bandwidth analysis).

The assessment of discomfort (comfort reaction) and health risk followed the guidelines provided in ISO 2631-1 and the MIL-STD-1472G. The frequency weightings and multiplying factors listed in Table 2, based on human sensitivity to the location, frequency, and direction of vibration, were used to assess comfort reaction and health risk. Figure 8 illustrates the frequency weightings  $W_d$ ,  $W_k$ , and  $W_c$ . The frequency weightings and multiplying factors for comfort are the same for the seated surface (seat pan) and standing surface (ramp).

**Table 2. ISO 2631 Frequency Weightings and Multiplying Factors (ISO 2631-1: 1997)**

Direction	HEALTH RISK		COMFORT REACTION			
	Seat Pan		Seat Pan/Ramp		Seat Back	
	Frequency Weighting	Multiply Factor	Frequency Weighting	Multiply Factor	Frequency Weighting	Multiply Factor
X	$W_d$	$k = 1.4$	$W_d$	$k = 1.0$	$W_c$	$k = 0.8$
Y	$W_d$	$k = 1.4$	$W_d$	$k = 1.0$	$W_d$	$k = 0.5$
Z	$W_k$	$k = 1.0$	$W_k$	$k = 1.0$	$W_d$	$k = 0.4$

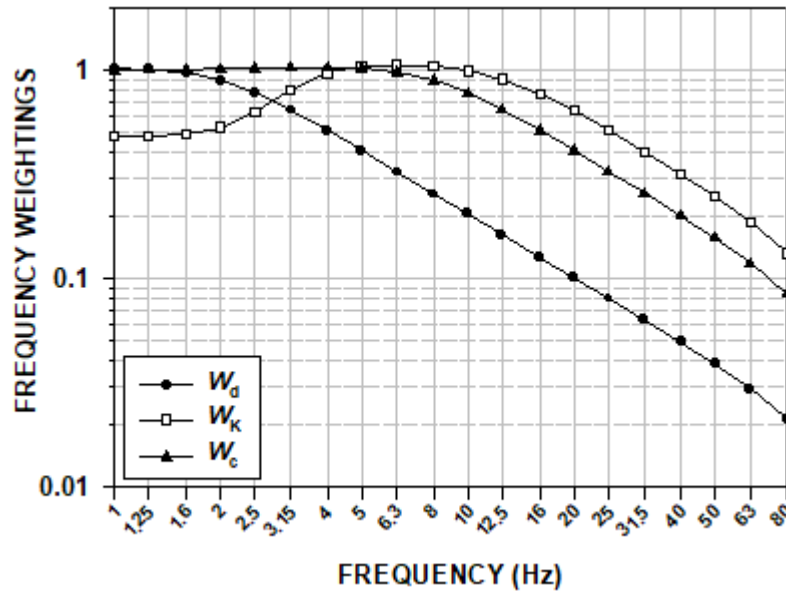


Figure 8. ISO 2631 Frequency Weightings  $W_d$ ,  $W_k$ , and  $W_c$  (ISO 2631-1: 1997)

The overall weighted rms acceleration level,  $a_w$ , was calculated between 1 and 80 Hz in each axis (X, Y, and Z) relative to the coordinate system of the seated occupant using the one-third octave rms accelerations:

$$a_w = \left[ \sum W_{ij}^2 a_{rmsi}^2 \right]^{1/2} \quad (2)$$

where  $W_{ij}$  is the frequency weighting associated with a particular direction and measurement site  $j$ , for the  $i$ th one-third octave center frequency component. For assessing comfort reaction, the  $pVTV$  was calculated at the seat pan, seat back, and ramp as the vector sum of the weighted fore-and-aft, lateral, and vertical accelerations, respectively, after applying the appropriate multiplying factors for the measurement location (seat pan, seat back, or ramp):

$$pVTV = \left[ k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2 \right]^{1/2} \quad (3)$$

The  $oVTV$  was calculated as the vector sum of the seat pan and seat back  $pVTVs$ . The  $oVTVs$  were compared to the weighted accelerations associated with the comfort reactions given in ISO 2631-1: 1997, Annex C. The  $pVTVs$  at the ramp were also compared to weighted accelerations associated with the comfort reactions. The comfort reactions include “Not Uncomfortable”, “A Little Uncomfortable”, “Fairly Uncomfortable”, “Uncomfortable”, “Very Uncomfortable”, and “Extremely Uncomfortable”.

For assessing health risk, the highest weighted seat pan acceleration in any axis (fore-and-aft, lateral, or vertical) was used after applying the appropriate multiplying factors given in Table 3. The weighted data were compared to the ISO Health Guidance Caution Zones (HGCZs) illustrated in Figure 9 (ISO 2631-1: 1997, Annex B). The ISO 2631-1: 1997 also states that the

vector sum of the weighted accelerations at the seat pan ( $pVTV$ ), after applying the appropriate multiplying factors for health risk, can be used when vibration in two or more axes are similar. The ISO 2631-1 does not provide health risk guidance for the standing individual. For weighted accelerations falling below the lower boundary of the ISO HGCZs for the expected duration, health risks are unlikely. For those levels falling between the two boundaries, caution is given with respect to health risk, or there is a potential for health risk. For those levels falling above the upper boundary, health risks are likely for repeated occupational exposures. The current MIL-STD-1472G states the following:

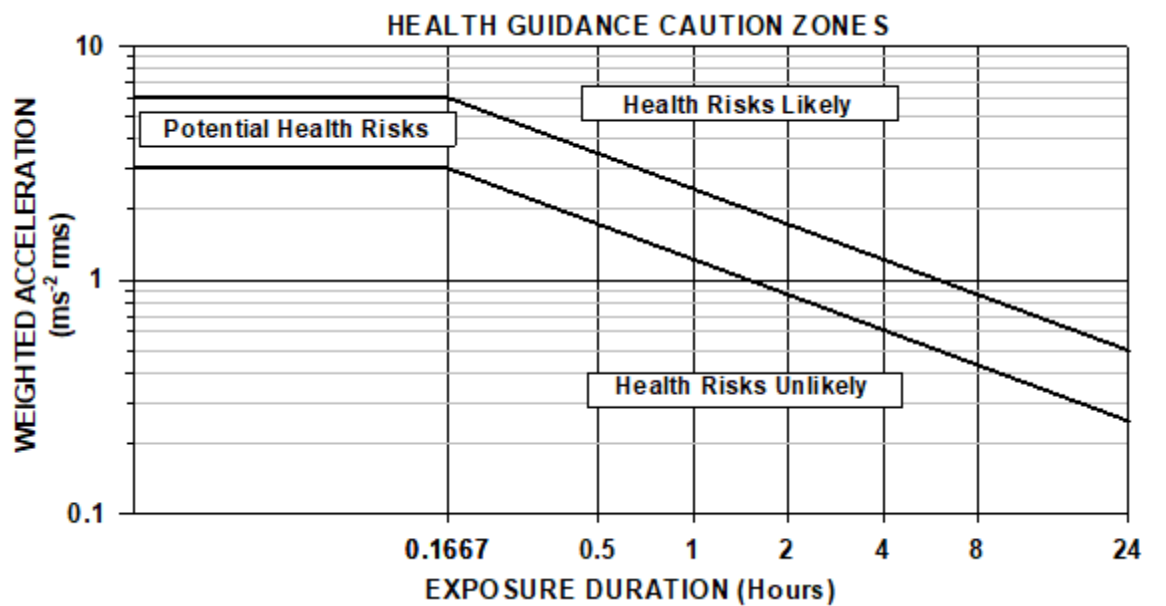


Figure 9. ISO 2631-1 Health Guidance Caution Zones (HGCZs)

*“For exposures lasting 8.0 hours or less, the seat pan frequency weighted triaxial RMS accelerations in any orthogonal direction for any occupied space shall not fall within the zone labeled “Health Risks are LIKELY”. Preferably the weighted accelerations shall fall within the “Minimal Risk to Health” zone. For exposures lasting greater than 8.0 hours, the seat pan frequency weighted triaxial RMS accelerations shall not exceed 0.315 m/s<sup>2</sup>. If the weighted accelerations fall within the “Caution Zone”, a warning to occupants shall be provided indicating the potential health risk”*

A revision of the MIL-STD-1472 (version H) is scheduled for release in 2020 that may include modifications to these exposure criteria.

## 4.0 RESULTS

All Figures and Tables referred to in this section are located in the Appendix. A total of 90 – 95 records were collected for the flight test conditions listed in Table A-2, depending on the aircrew station/location. It is noted that the ramp was not lowered during all flight test conditions, nor did the aircrew member stand on the ramp for all flight test conditions. It was noted that the member did stand on the ramp for all level flight conditions, but may have only had one foot on the acceleration pad. This can certainly affect the level of vibration transmitted at the interface. In addition, a detailed review of the raw time history data collected at the ramp indicated that the member was in contact with the acceleration pad during all flight test conditions associated with Task 1052 Perform VMC Flight Maneuvers (Table A-2). All other flight conditions showed excessively high vertical (Z) vibration at the ramp. The results at the ramp should be viewed with caution.

### 4.1 Characteristics of the Multi-Axis Accelerations Onboard the CH-47F

#### 4.1.1. CH-47F Acceleration Spectra

Typically, with helicopters, a peak in the acceleration spectra is expected to occur in the vicinity of the main rotor speed of the aircraft. The frequency associated with the rotor speed is referred to as the propeller rotation frequency or PRF in this document. A peak is also expected to occur at the blade passage frequency or BPF, which is predicted as the number of blades multiplied by the PRF. This peak tends to be the highest in magnitude but does depend on the flight condition and aircraft. Both the PRF and BPF may vary slightly depending on the flight maneuver and whether the aircraft is operated at 100% power. Additional peaks are also expected at multiples of the BPF. The direction of the highest acceleration associated with the BPF was unknown prior to the analysis of these data.

Figures A-1 through A-4 illustrate sample acceleration spectra for the CH-47F at the rigid X-bar or floor, seat pan, seat back, and helmet (pilot only) in the fore-and-aft (X), lateral (Y), and vertical (Z) directions for a selected data record collected during level flight (120 KCAS) at the pilot, left crew chief, and left fore and aft aircrew station/locations. Figure A-4 also includes the level flight spectra at the ramp. It is noted that the orientation of the sensors were with respect to the seated (or standing) occupant. Therefore, the accelerations in the X, Y, and Z directions at the pilot, crew chief, and ramp stations/locations aligned with the coordinate system of the aircraft. (The fore-and-aft (X) direction of the aircraft is sometimes considered the longitudinal axis of the aircraft.) The accelerations in the X direction at the two sideward-facing aircrew locations were associated with the lateral (Y) direction of the aircraft, while the aircrew Y accelerations were associated with the longitudinal (X) axis of the aircraft. Data from the vertical (Z) sensor located on the rigid X-bar at the pilot station was corrupted and was not included in the analysis. Most data showed a small peak between 3.5 and 4.0 Hz. Given that the main rotor speed of the CH-47F is 225 revolutions/min, the actual PRF was 3.75 Hz. The next higher peak occurred between 11 and 11.5 Hz and was associated with the BPF. Based on the actual PRF and with three main rotor blades, the actual BPF was  $3 \times 3.75$  Hz or 11.25 Hz. All measurement locations showed additional notables peaks at multiples of the BPF (for example, ~22.5 Hz, ~33.75 Hz, ~45 Hz, etc.). Interestingly, as shown in Figures A-1 through A-4, the highest peak did not always occur at the BPF, but at a multiple of the BPF depending on the

occupant station/location, measurement site, and direction (note highest peak occurring at ~22.5 Hz in fore-and-aft (X) direction at left aft aircrew location (lateral direction of aircraft), and highest peak occurring at ~22.5 Hz in lateral (Y) direction at the ramp). In addition, while the low peak at the PRF was highest in the vertical (Z) direction at the seat/occupant interfaces, this was not necessarily the case at subsequent peaks observed at the BPF and multiples of the BPF (also see Section 4.1.2 regarding the overall unweighted accelerations during level flight). It was noted that the floor data at the aircrew forward and aft stations/locations appeared fairly noisy, with substantial peaks occurring at multiples of the BPF.

#### 4.1.2. Overall Unweighted Accelerations

Figures A-5 through A-9 illustrate the mean unweighted overall accelerations  $\pm$  one standard deviation at the pilot, crew chief, forward aircrew aft aircrew, and ramp, respectively, at the seat base or floor, seat pan, and seat back measurement sites, in each direction, for each flight test condition. Tables A-4 through A-7 include the unweighted overall seat pan accelerations for each level flight record at each of the four aircrew stations/locations (excluding ramp). As mentioned previously, the vertical (Z) pilot seat base sensor data was corrupted and not included in the analysis. In general, all stations showed overall accelerations for level flight that tended to be similar to the overall accelerations observed for the other flight test conditions, with a few exceptions.

The Repeated Measures Analysis of Variance and Bonferroni Comparison Test were applied to evaluate the significance of direction on the overall unweighted accelerations at the floor, seat pan, seat back, and ramp during level flight. Significant differences were associated for  $P < 0.05$ . At the pilot station, located on the left side of the cockpit, the overall unweighted fore-and-aft (X) accelerations at the seat X-bar were significantly higher than the overall lateral (Y) accelerations at all three airspeeds (Figure A-5, Table A-7) (noting that vertical (Z) accelerations were not available for comparison). Although not statistically evaluated, Figure A-5 shows that higher fore-and-aft (X) overall accelerations at the seat X-bar were also observed for most of the other flight test conditions. The overall unweighted fore-and-aft (X) accelerations at the pilot seat pan were also significantly higher as compare to the other directions, with the vertical (Z) overall accelerations being the lowest at all three airspeeds (Table A-7). In contrast, the overall unweighted vertical (Z) accelerations at the pilot seat back were significantly higher as compared to the other directions, with the fore-and-aft (X) overall accelerations being the lowest at all three airspeeds. These trends were also observed for most of the other flight test conditions.

At the crew chief station, located on the left side of the cabin immediately behind the cockpit and facing rearward, the overall unweighted floor vertical (Z) accelerations were significantly and notably higher at all airspeeds. (Figure A-6, Table A-7). Higher overall floor vertical (X) accelerations were also observed for most flight test conditions (Figure A-6). The overall unweighted seat pan lateral (Y) accelerations were significantly the highest at 100 KCAS, while the overall unweighted seat pan fore-and-aft (X) accelerations were significantly the highest at 120 and 135 KCAS. The overall unweighted seat back lateral (Y) accelerations were also significantly the highest at 100 KCAS, while the overall unweighted seat back vertical (Z) accelerations were significantly the highest at 120 and 135 KCAS. The overall unweighted fore-and-aft (X) accelerations were significantly the lowest at the seat back and quite notable for all flight test conditions associated with Task 1052. In addition, the higher overall accelerations

were most notable at the highest airspeed (135 KCAS) at both the crew chief seat pan and seat back (Figure A-6).

At both sideward-facing aircrew locations, the overall unweighted vertical (Z) accelerations at the floor were notably higher for all flight test conditions (note vertical axis scale for floor accelerations in Figures A-7 and A-8) (Table A-7). The overall unweighted seat pan fore-and-aft (X) accelerations at both aircrew locations (lateral direction of aircraft) were significantly the highest at all three airspeeds and consistently observed to be higher for all flight test conditions associated with Task 1052. The overall unweighted seat back vertical (Z) accelerations at both aircrew locations were significantly the highest at all three airspeeds and consistently observed to be higher for all flight test conditions associated with Task 1052. The directional tendencies at the aircrew seat pan and seat back were also observed at for other flight test conditions but appeared to be influenced by the occupant location (forward or aft cabin).

At the ramp interface, the overall unweighted lateral (Y) accelerations were statistically the highest at 100 and 120 KCAS, but equal to the vertical (Z) acceleration at 135 KCAS.

It was noted that at most stations/locations, even though the overall unweighted accelerations showed statistically significant differences as a function of direction, these differences appeared to be small (see Figures A-5 through A-8 and Tables A-4 through A-7). This was particularly evidenced at the lower airspeeds of 100 and 120 KCAS.

The effect of airspeed was not statistically evaluated but there was a tendency for increased in overall acceleration levels with increasing airspeed, particularly for the highest accelerations and the highest airspeed.

## 4.2 Assessment of the CH-47F Aircrew Comfort and Health Risks

### 4.2.1 Overall Weighted Accelerations

It is cautioned that the summary provided below on the weighted overall accelerations are observations and have not been statistically evaluated for significant effects of measurement site and direction.

Summary plots of the overall unweighted accelerations at the seat base, seat pan, and seat back, and the overall weighted accelerations at the seat pan and seat back at the four seated aircrew stations/locations are provided in Figure A-13 for comparison. The figure also includes plots of the  $pVTV$ s and  $oVTV$  for the comfort assessment, and the  $pVTV$ s for health assessment. All plots include the mean overall unweighted or weighted accelerations combined for level flight at the three airspeeds. The figure shows the higher overall unweighted fore-and-aft (X) accelerations measured at the seat pan for all aircrew stations/locations (blue bars) as described in Figures A-5 through A-8 and Table A-7. However, the highest overall weighted seat pan accelerations occurred in the vertical (Z) direction for all aircrew stations/locations (Figure A-13, yellow bars). This difference was dramatic for most stations/locations even with the 1.4 multiplying factor applied to the horizontal directions in accordance with Table 2 for assessing health risk. It is noteworthy that the frequency weighting,  $W_d$ , for the horizontal directions reduce the higher frequency contributing accelerations to a much greater extent than in the vertical direction ( $W_k$ )

(Figure 8). Likewise, Figure A-13 shows a tendency for higher overall unweighted vertical (Z) accelerations measured at the seat back for all stations (blue bars) as illustrated in Figures A-5 through A-8 and for most airspeeds as listed in Table A-7. However, the highest overall weighted seat back accelerations occurred in the fore-and-aft (X) direction for all aircrew stations/locations (Figure A-13, yellow bars). The multiply factors and frequency weightings also affected the contributions at the seat back (Table 2, Figure 8).

#### **4.2.2. Aircrew Vibration Comfort Assessment (ISO 2631-1 Comfort Reactions)**

The guidelines in ISO 2631-1 were used to assess the comfort reactions of the aircrew. At the four seated aircrew stations/locations, the assessment was based on the  $oVTV$  calculated as the vector sum of the  $pVTVs$  estimated at the seat pan and seat back in accordance with Eq. (3) and using the frequency weightings and multiplying factors in Table 3. At the ramp location, the comfort reactions were assessed using the aircrew/ramp interface  $pVTV$ . The Comfort Reactions are independent of time.

Figures A-10 through A-12 illustrate the  $oVTVs$  for assessing comfort reaction for all flight test conditions at the pilot, crew chief, and two aircrew stations/locations. The  $oVTVs$  for the forward and aft aircrew locations are plotted in the same figure (Figure A-12). Figure A-12 also includes the  $pVTVs$  at the ramp location. All figures include illustration of the ISO 2631-1 Comfort Reactions. Figure A-10 shows that the pilot  $oVTVs$  were primarily considered “a little uncomfortable” to “fairly uncomfortable”. Figure A-11 shows that the comfort reactions at the crew chief station were considered “fairly uncomfortable” to “uncomfortable”. Figure A-12 shows a broad range of comfort reactions associated with the two aircrew locations. Comfort reactions ranged from “a little uncomfortable” to “uncomfortable”. There was a tendency for higher discomfort at the aft location relative to the comfort reactions. Figure A-12 shows that the  $pVTVs$  calculated for the standing aircrew at the ramp were primarily associated with being “fairly uncomfortable” (Task 1052 only), with the exception of the steep rate turn (“uncomfortable”) and level flight at 135 KCAS (“very uncomfortable”). As mentioned previously, these results should be viewed with caution, since the crew member at the ramp may only have had one foot on the acceleration pad, and not both feet with his full body weight. It is speculated that the measured levels may be an overestimation of the comfort reactions.

#### **4.2.3. Aircrew Vibration Health Risk Assessment (ISO 2631-1)**

The guidelines in the ISO 2631-1 were also used to assess health risk, using the level flight seat pan data. It was assumed that the aircrew would spend most of the daily mission in level flight. The health risk assessment is dependent on the daily exposure duration. It was assumed that the range of accelerations collected at level flight were representative of the expected acceleration levels occurring for various missions. This is based on the assumption of no adverse weather (such as high wind) or evasive maneuvering (such as may occur when under live fire).

Tables A-3 through A-6 list the weighted overall seat pan accelerations and seat pan  $pVTVs$  for assessing health risk for each level flight record at each of the four aircrew stations/locations. The tables also list the minimum exposure duration for each listed record, in hours, for potential health risk (lower boundary of HGCZs) and minimum exposure duration for likely health risks (upper boundary of HGCZs) (Figure 9) (ISO 2631-1 boundaries only)). These exposure durations were based on the highest overall seat pan acceleration in any direction, as well as the

seat pan  $pVTV$  for health risk. The highest weighted acceleration at the seat pan always occurred in the vertical (Z) direction, regardless of the station/location, as noted in the summary plots illustrated in Figure A-13 and Tables A-3 through A-6. Any exposure duration below the lower boundary would be associated with minimal health risk. Any exposure duration between the lower and upper boundaries would be associated with the potential for health risk, and any exposure at or above the upper boundary would be associated with a likely health risk. The durations were calculated based on the square root time dependency. The durations and associated acceleration levels are color-coded (orange for lower boundary and red for upper boundary) to easily identify which maneuvers and records would reach the two boundaries in less than 8 hours.

Figure A-14 illustrates the minimum exposure durations associated with the potential for health risk at all four stations/locations at each airspeed based on the seat pan  $pVTV$ s. Figure A-15 illustrates the minimum exposure durations associated with likely health risks. The figures indicate that lower durations occurred at the higher airspeeds for the seated aircrew. These durations were associated with the tendency for higher seat pan  $pVTV$ s at higher airspeeds. As shown in Figure A-14, the majority of exposures associated with level flight were restricted to durations of less than 8 hours to assure minimal health risk and avoid the potential for health risk. The one exception was at the aft aircrew location during level flight at 100 KCAS, where higher durations above 10 hours were observed. Several records at 120 KCAS also indicated allowable durations of greater than 8 hours for minimal health risk. As shown in Figure 15, the majority of exposures associated with level flight at 100 and 120 KCAS were only associated with likely health risks for daily exposures lasting 10 hour or more. With the exception of the pilot, at the higher airspeed of 135 KCAS, likely health risks existed for daily exposures lasting less than 8 hours and in as little as around 4 hours (Aft Aircrew). These findings are detailed in the color coding presented in Tables A-3 through A-6.

In summary, the pilot was exposed to the potential for health risk in less than eight hours for the majority of measured acceleration levels (based on seat pan  $pVTV$ ) (Figure A-14, Table A-3). At 135 KCAS, the pilot potential for health risk existed in as little as 3 hours. Likely health risks for the pilot were associated with daily durations of greater than 10 hours.

Regardless of the assessment method (weighted seat pan Z or seat pan  $pVTV$ ), the crew chief was exposed to the potential for health risk in less than 8 hours at all airspeeds (Figure A-14, Table A-4). At the higher airspeeds, the crew chief was exposed to potential health risk in about 4 hours or less of daily flight at 120 KCAS, and between 1 and 2 hours of daily flight at 135 KCAS. Likely health risks for the crew chief were associated with daily durations lasting less than about 6 hours at 135 KCAS (Figure A-15, Table A-4).

The forward aircrew was exposed to potential health risk in less than 8 hours for the majority of measured acceleration levels (Figure A-14, Table A-5). At the highest airspeed of 135 KCAS, the potential for health risk existed in as little as 2 to 3 hours of flight. Likely health risks for the forward aircrew were associated with daily durations of greater than 10 hours at 100 and 120 KCAS, but between about 8 and 10 hours at 135 KCAS.

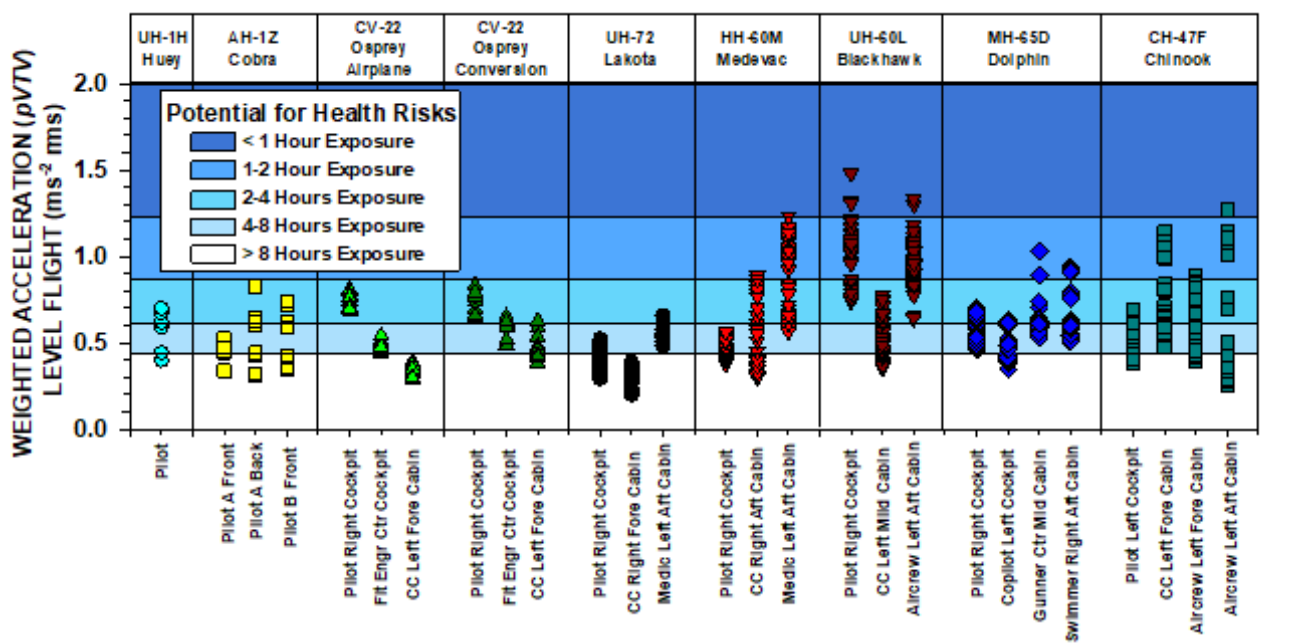
The aft aircrew was exposed to the potential for health risk in less than 8 hours for several records at 120 KCAS and all measured acceleration levels at 135 KCAS (Figure A-14, Table A-6). At 135 KCAS, the potential for health risk existed for exposure durations as low as about 1 to 2 hours, similar to the results for the crew chief. Likely health risks required exposures lasting 10 hours or greater at 100 and 120 KCAS, while likely health risks could occurred in less than 8 hours and in as little as about 4 to 5 hours of flight at 135 KCAS (Figure A-15, Table A-6).

## 5.0 DISCUSSION AND CONCLUSIONS

This document provides a summary of the vibration exposure characterization and assessment conducted onboard the CH-47F Chinook helicopter. Included is a synopsis of the seat pan and seat back acceleration spectra generated by the aircraft. The characteristics of the spectra generated by the CH-47F were similar to that observed during other investigations conducted on rotary-wing and tilt-rotor aircraft, where the highest accelerations were associated with the propulsion system and occurred at relatively distinct frequencies (Smith, 2005; Smith & Gerdus, 2005; Smith, Jurcsisn, & Bowden, 2008; Smith, Chervak, & Steinhauer, 2014; Smith, Chervak, & Clasing, 2019; Smith & Chervak, 2019). A relatively smaller peak associated with the propeller rotation frequency or PRF was observed below 10 Hz (3.75 Hz). A peak in the spectra was also observed between 11 and 11.5 Hz and associated with the blade passage frequency or BPF. Additional and substantial peaks were observed at harmonics of the BPF for the CH-47F. Peak magnitudes were observed in the fore-and-aft (X), lateral (Y), and vertical (Z) directions, depending on the flight test condition, station, and measurement site. The CH-47F platform operates at a lower PRF than other platforms referenced in this report, including the three-bladed CV-22 (Smith, Jurcsisn, & Bowden, 2008). Given the three blade configuration as compared to the four blade configuration common to other rotary-wing aircraft, the BPF is also lower.

As shown in Figure A-13, the higher frequencies associated with the CH-47F, as with other rotary-wing/tilt-rotor aircraft, can be substantially weighted once the ISO 2631-1 frequency weightings and multiplying factors are applied for calculating the overall weighted accelerations,  $pVTVs$ , and  $oVTVs$ . This is particularly true for the horizontal vibration measured at the seat pan, and the lateral and vertical vibration measured at the seat back. This can dramatically reduce the contribution of the vibration to the comfort reaction and health risk assessments defined in the standards. Regardless, as with other rotary-wing/tilt-rotor aircraft, the CH-47F did show that certain flight test conditions were associated with seated comfort reactions ranging from being considered ‘a little uncomfortable’ to ‘uncomfortable’, particularly at the crew chief station and aft aircrew location, as illustrated in Figures A-10 through A-12. The aircraft also showed level flight exposures associated with the potential for health risk, and even likely health risks, in less than 8 hours, as illustrated in Figures A-14 and A-15 and Tables A-3 through A-6. As with other platforms that have been assessed for health risk using level flight data, the CH-47F showed that higher airspeeds reduced the allowable exposures for potential health risk, as well as likely health risk. In particular, the crew chief station, located in the forward cabin, and the aircrew location in the aft cabin showed the potential for health risk in approximately 1 to 2 hours and likely health risks in 6 or less hours of daily flight at 135 KCAS. Interestingly, at the aft aircrew location, no health risk was evidenced below 10 hours of daily flight at the lowest airspeed (100 KCAS). It is not known how long or under what type of operation or mission the CH-47F would fly at the higher airspeed. Based on the results of this study, daily flight at a constant airspeed of 135 KCAS should conservatively be minimized to a duration not to exceed 1 hours. This duration will be further reduced if the daily mission includes exposure to other flight conditions.

Figure 10 compares the seat pan  $pVTVs$  from other aircraft that have been previously assessed for health risk in accordance with ISO 2631-1. As with the HH-60M medic located in the aft cabin, and the UH-60L pilot and aft aircrew, the potential for health risk could occur for daily flights of 1 to 2 hours duration onboard the CH-47F at the crew chief station and aft aircrew location. At these locations, and at the higher airspeed of 135 KCAS, these exposures exceed the health risk criteria given in MIL-STD-1472G Section 5.5.5.



**Figure 10. Comparison of Health Risk  $pVTVs$  Among Rotary-Wing/Tilt-Rotor Aircraft (Flt Engr = Flight Engineer, CC = Crew Chief)**

As described in previous reports on other rotary-wing/tilt/rotor aircraft included in the project to characterize and assess aircrew operational vibration exposure, the assessment guidelines provided in the standards are based on human physical and psychophysical (perceptual) responses to the frequency, magnitude, and direction of the vibration exposure. These response characteristics are expressed by the frequency weightings and multiplying factors that are applied during the assessment process. Humans are the most sensitive to vibration occurring below 10 Hz, particularly in the vertical (Z) direction. Vibration at these lower frequencies can produce relative motions between body regions (vertical motion) and cause postural instabilities (when combined with low frequency horizontal motion) that are readily perceived as being uncomfortable and even painful. Whole-body resonance has been identified during vertical vibration in the range of 4 and 8 Hz, where the large relative motions between the upper and lower torso transmit easily to the head. The comfort reactions defined in Appendix C of ISO 2631-1 are based on passenger expectations in public transportation, where exposures are expected to occur at lower frequencies and shorter durations than in military operations. Caution should be taken in applying these reactions to military environments, where longer durations and higher frequency exposures could affect aircrew perception. Likewise, the ISO 2631-1 health

risks of vibration have primarily been associated with the lumbar spine and connected nervous system. It is logical to conclude that higher magnitude lower frequency vibration could contribute to these symptoms due to the relative upper and lower torso motions and postural instability that can dynamically and repeatedly stress the spinal column. Vibration transmission to the upper torso and head dramatically decreases at frequencies beyond 10 Hz, unless there are substantial amplitudes or the upper torso/head is in direct contact with a vibrating surface. Humans primarily perceive higher frequency vibration at the interfaces where the body is in contact with the vibrating surface. The mechanisms by which higher frequency vibration generates spinal musculoskeletal stresses that contribute to discomfort and pain may be physiologically different than the mechanisms associated with low frequency vibration. This suggests there could be a substantial impact on the most appropriate criteria to apply for assessing discomfort and health risk in military air vehicles.

In summary, the results of the assessments on the CH-47F Chinook further support the substantial influence of operational vibration on the discomfort and pain that has been associated with the operation of these aircraft, particularly given the magnitudes of the higher frequency exposures that still result in a potential health risk according to the standards and guidelines. The higher frequency characteristics of the vibration do warrant investigation of the mechanisms by which the vibration can cause pain and injury, leading to the development of more robust discomfort and pain mitigation strategies.

## 6.0 RECOMMENDATIONS

1. Conduct periodic monitoring of the aircrew by occupational health specialists, particularly documenting reports of discomfort, pain, tingling, and numbness in the back, buttocks, and lower extremities. This could be accomplished using the aircrew surveys developed for this study or some modification. Per MIL-STD-1472G, the aircrew should be warned that the potential for health risk exists during CH-47F flight operations.
2. Consider adding seat pan and seat back cushion support that may improve posture and also mitigate some of the higher frequency vibration entering the occupant at interfaces, particularly for aircrew occupying the back of the aircraft. Attention should be paid to the multi-axis characteristics of the exposures.
3. Consider the use of passive, semi-active, and active vibration mitigation technologies either added to the existing CH-47F seats or via new seat design concepts. The data collected during this project on four different rotary-wing platforms, as well as the data from past studies on rotary-wing/tilt-rotor aircraft, should be leveraged in the development of appropriate equipment design criteria and testing strategies of equipment concepts for improving the safety and health of military aircrew.

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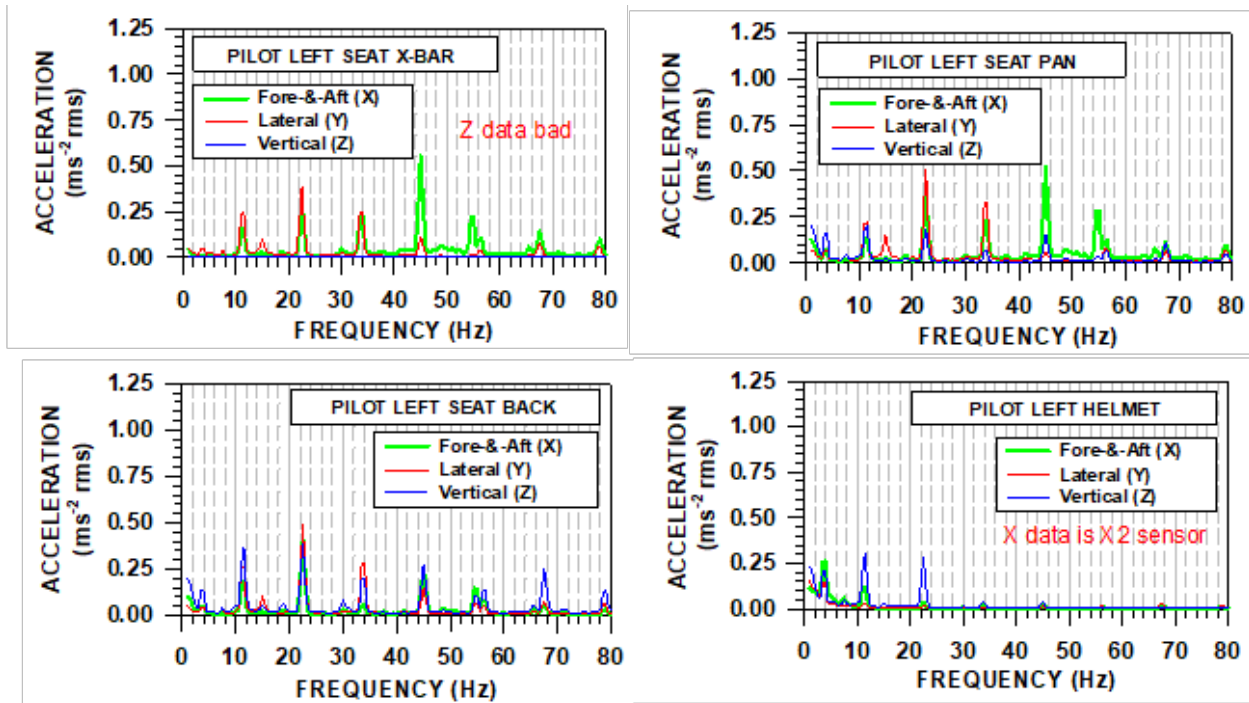
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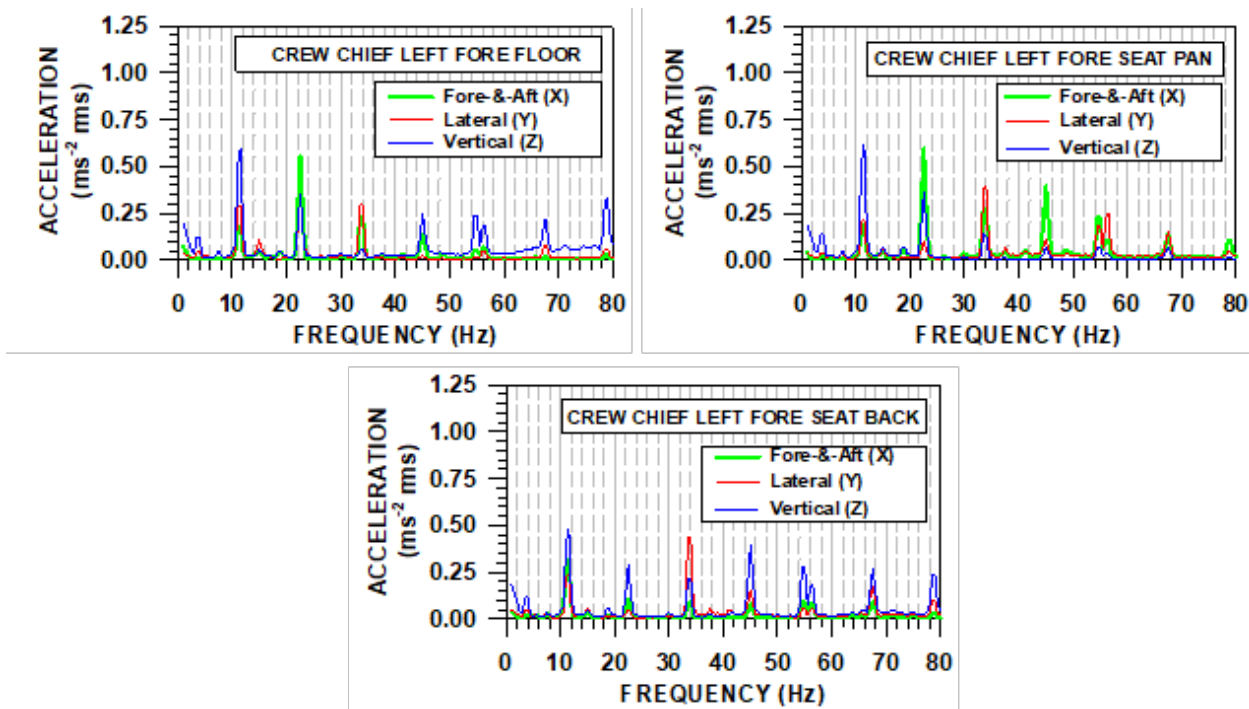
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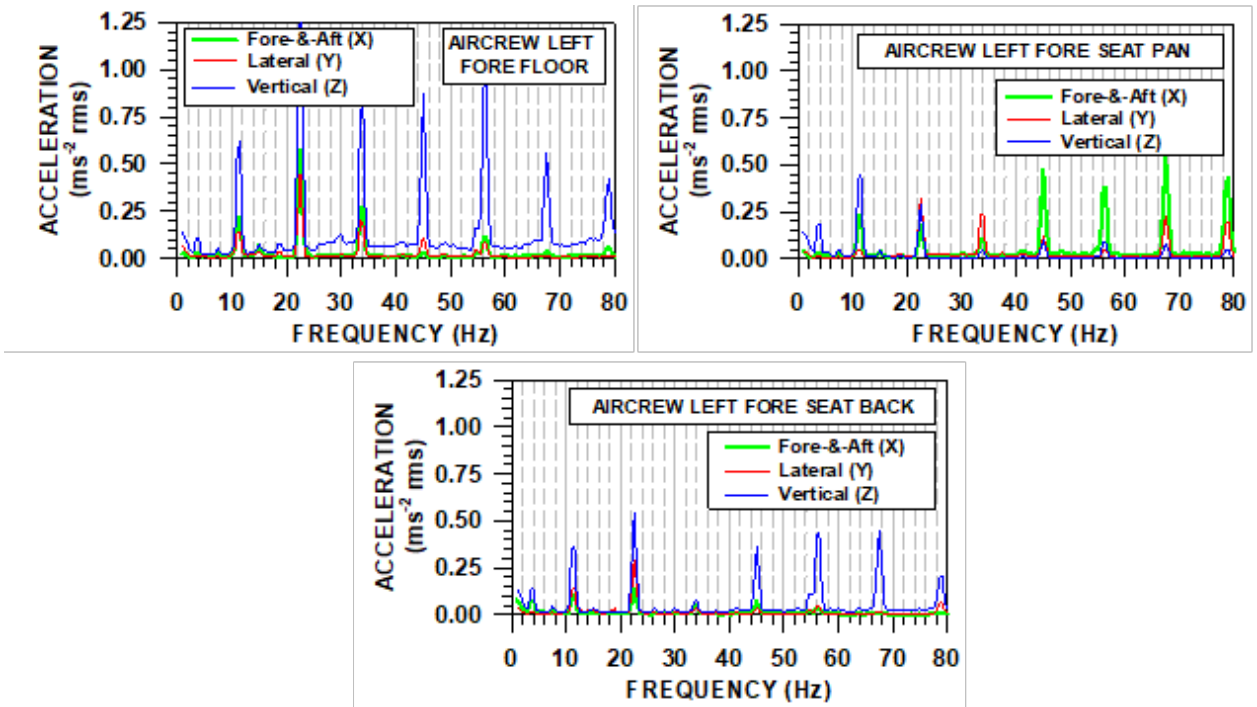


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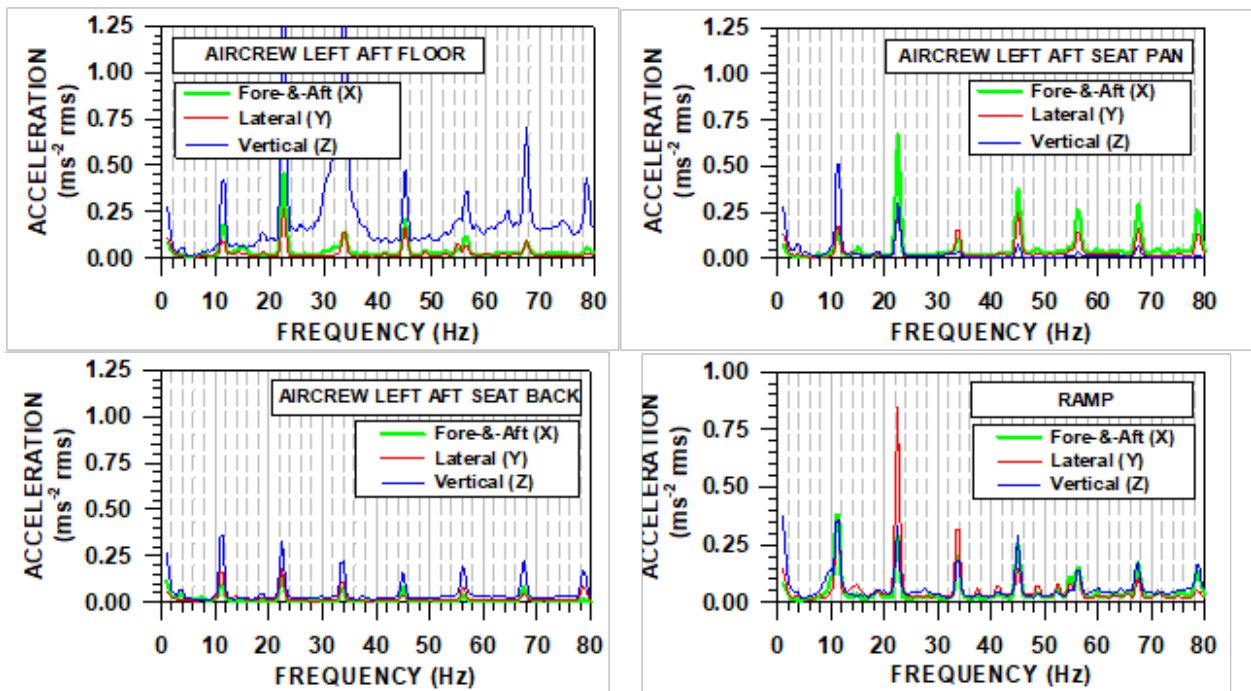


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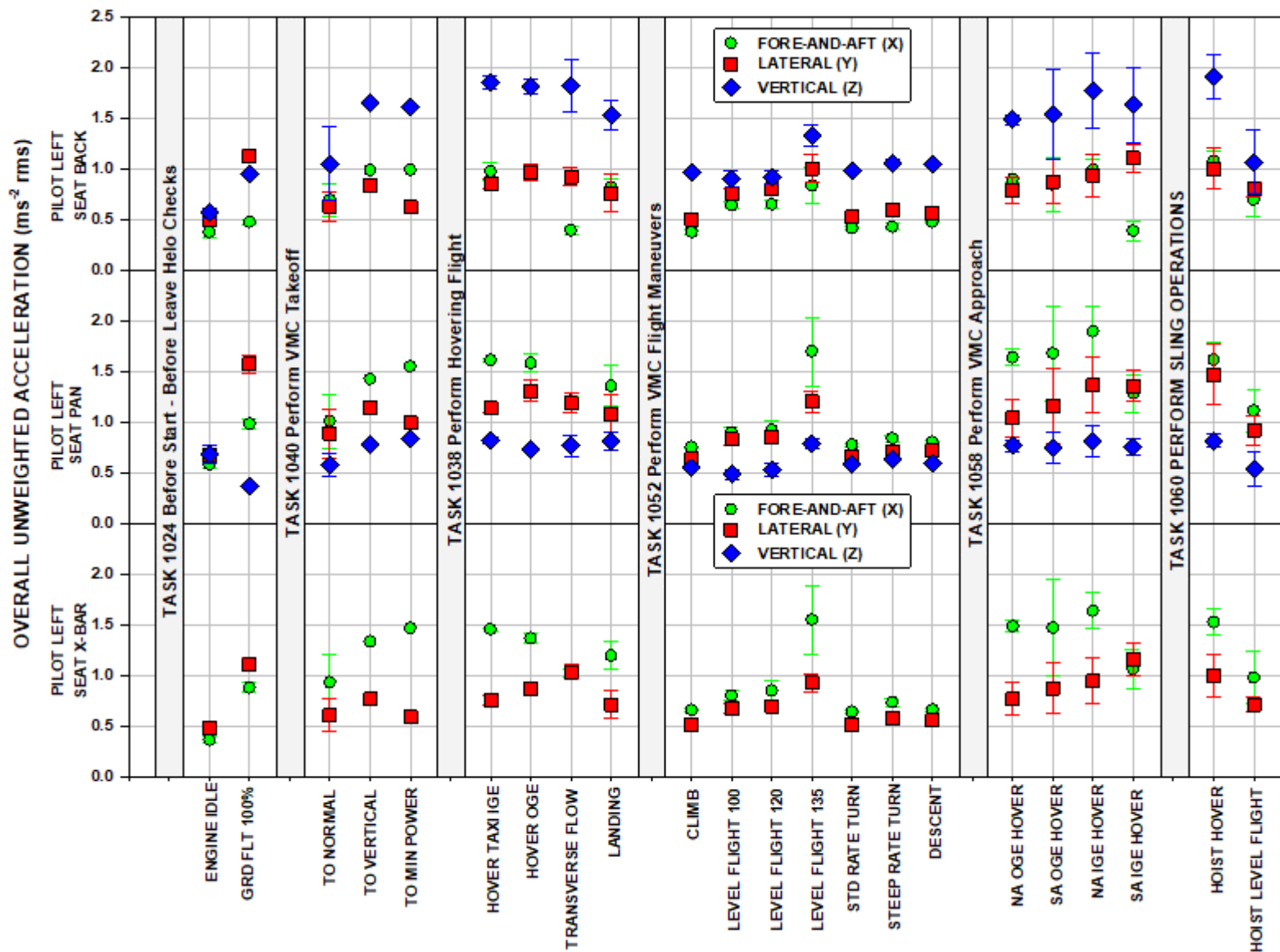


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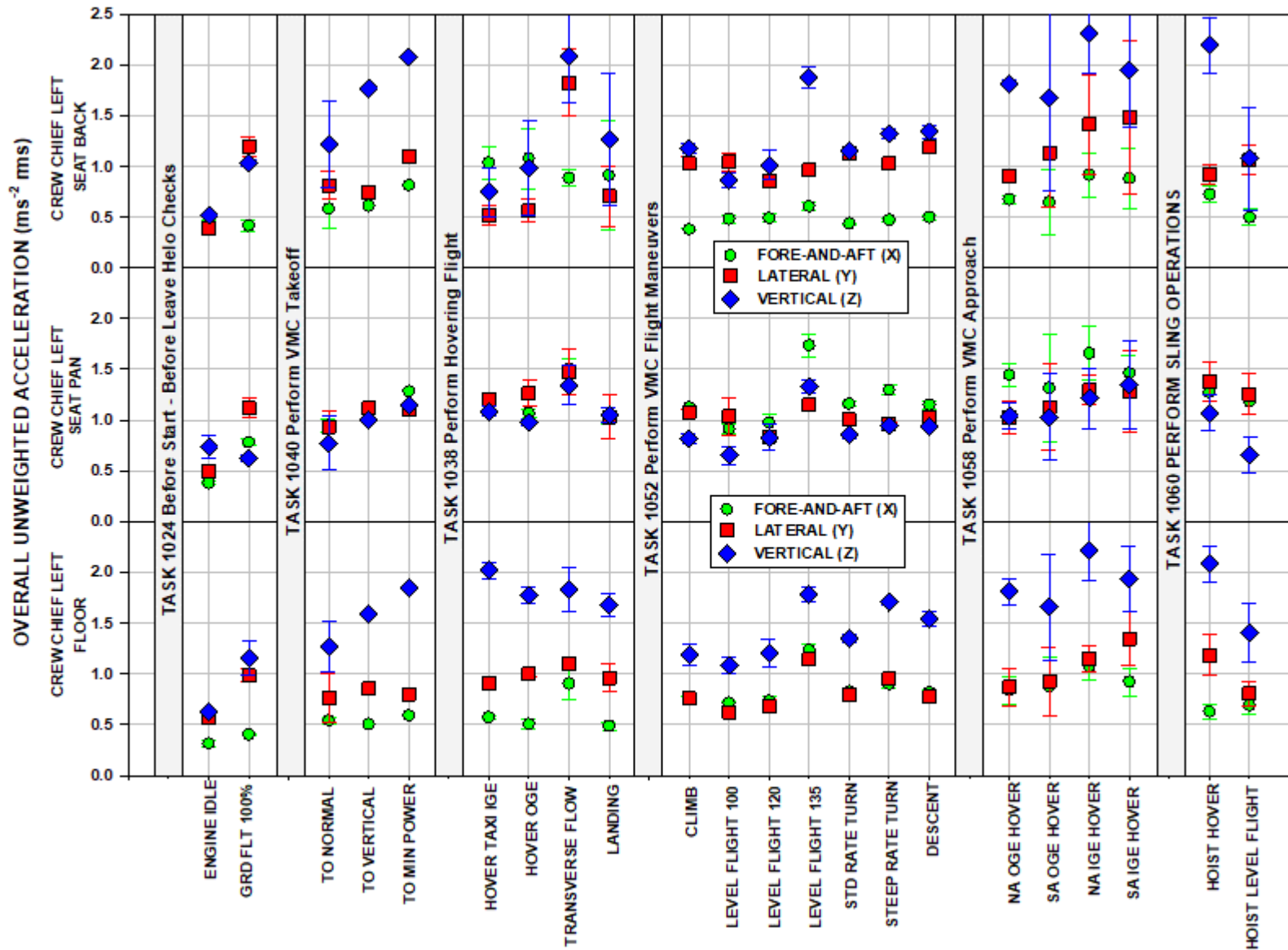


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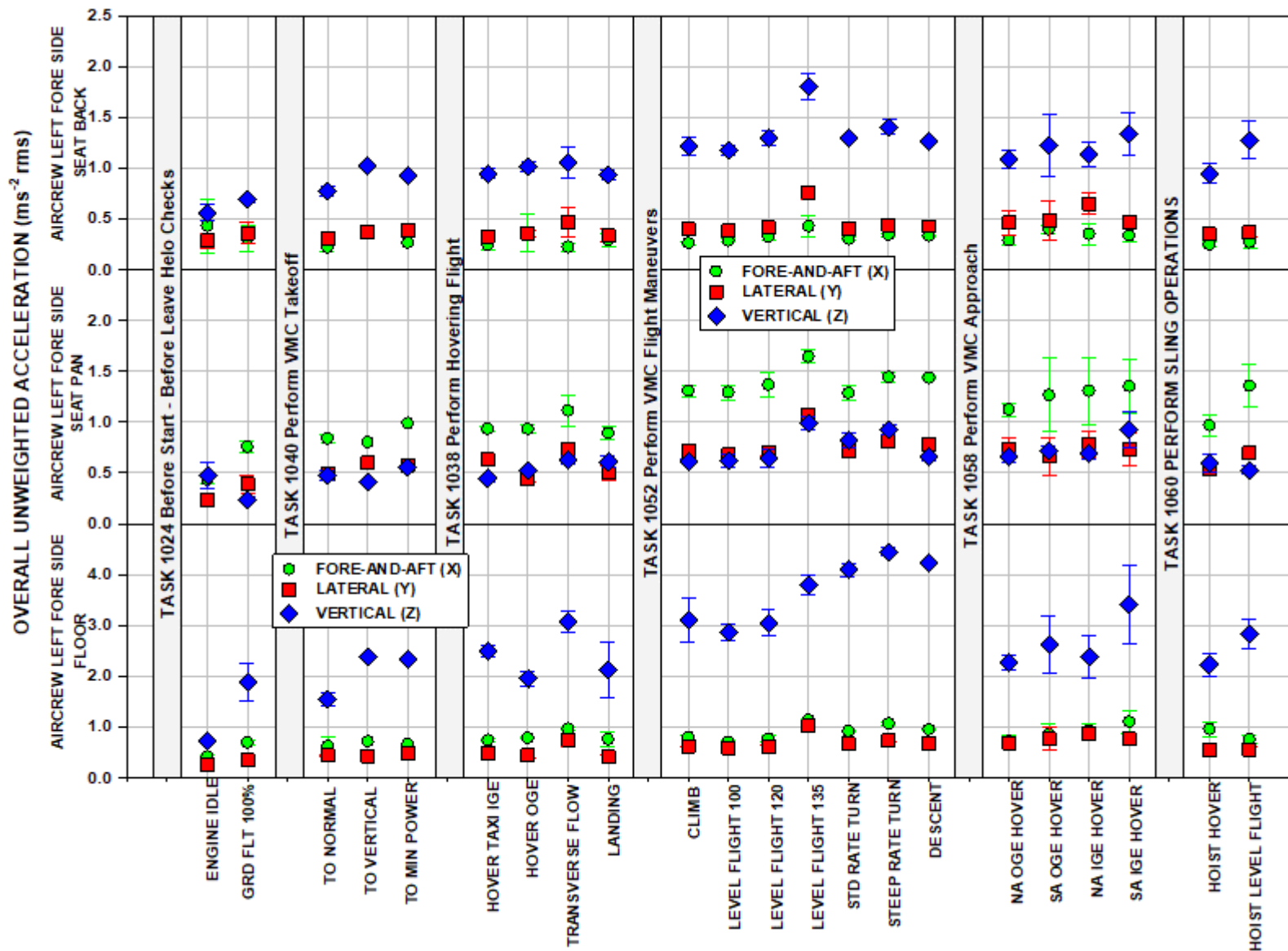


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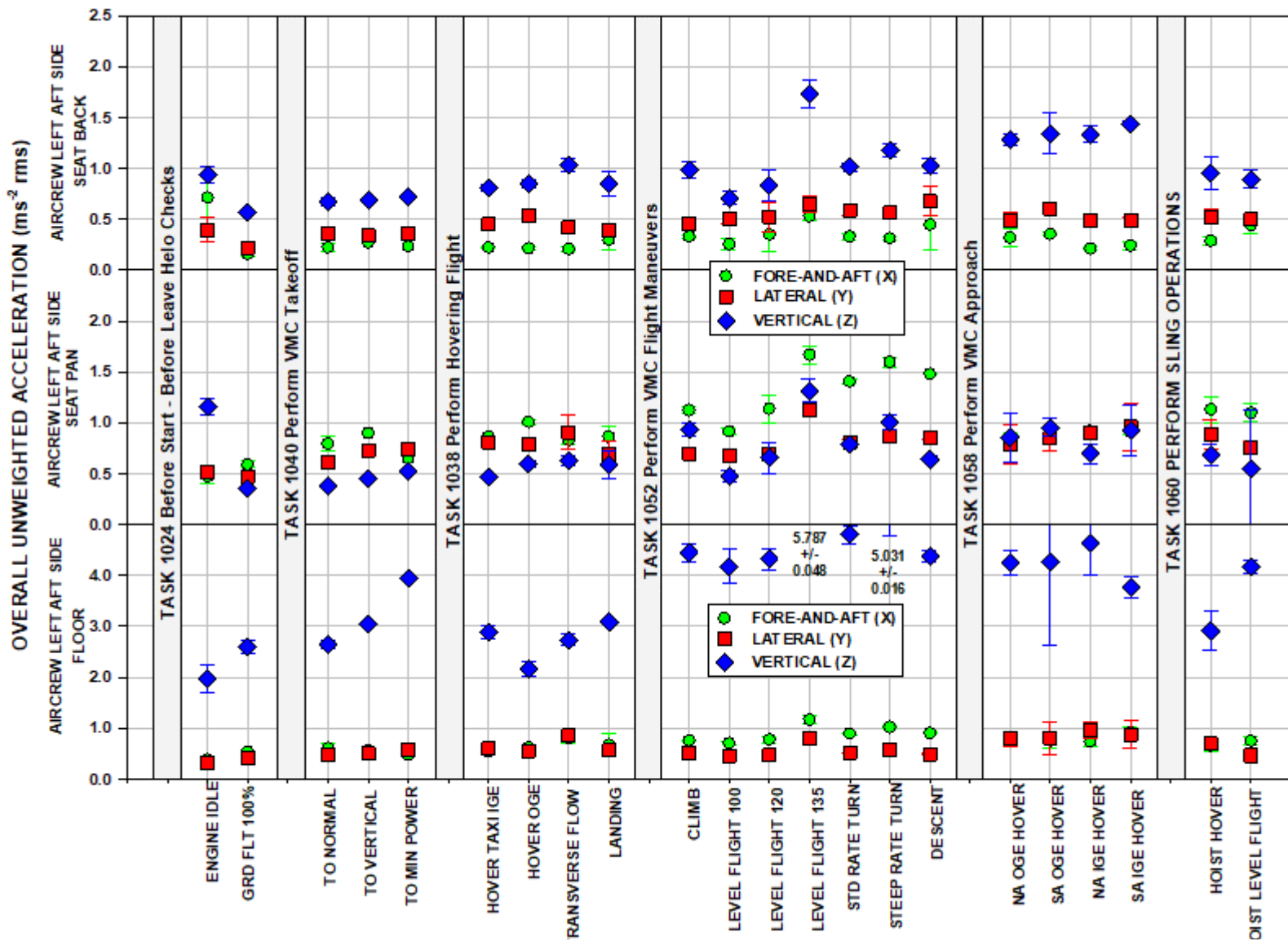


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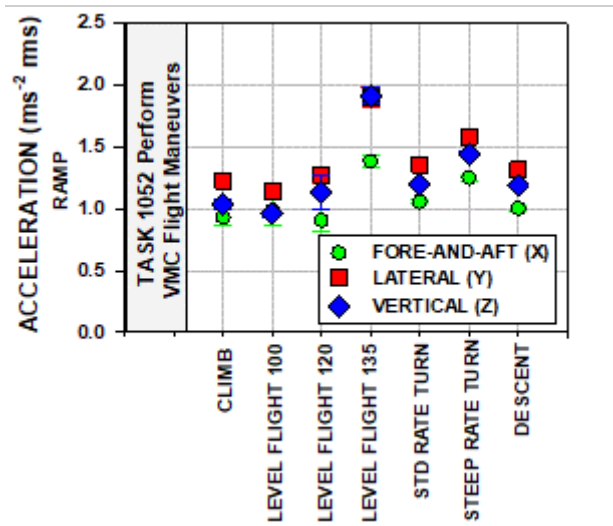


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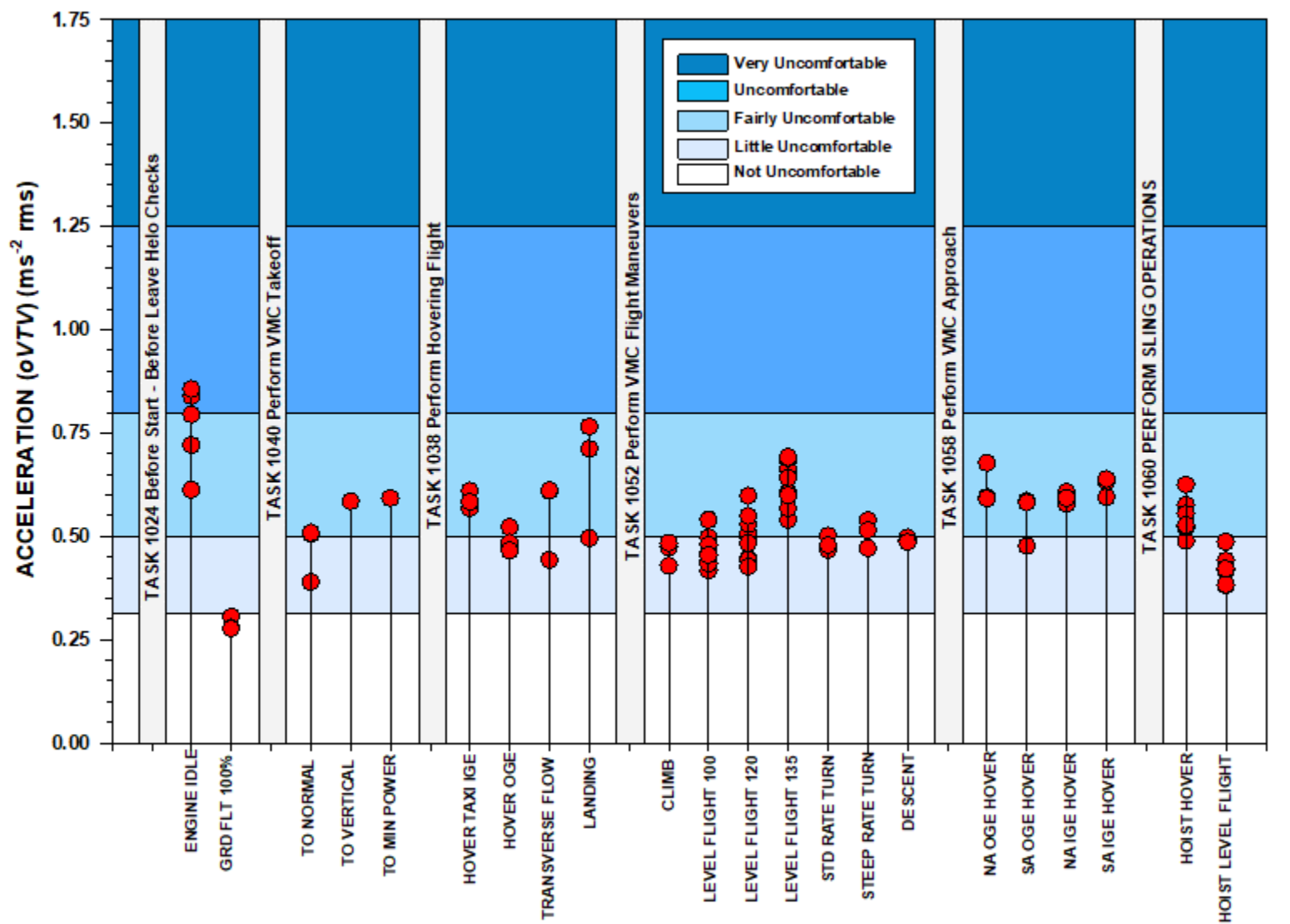


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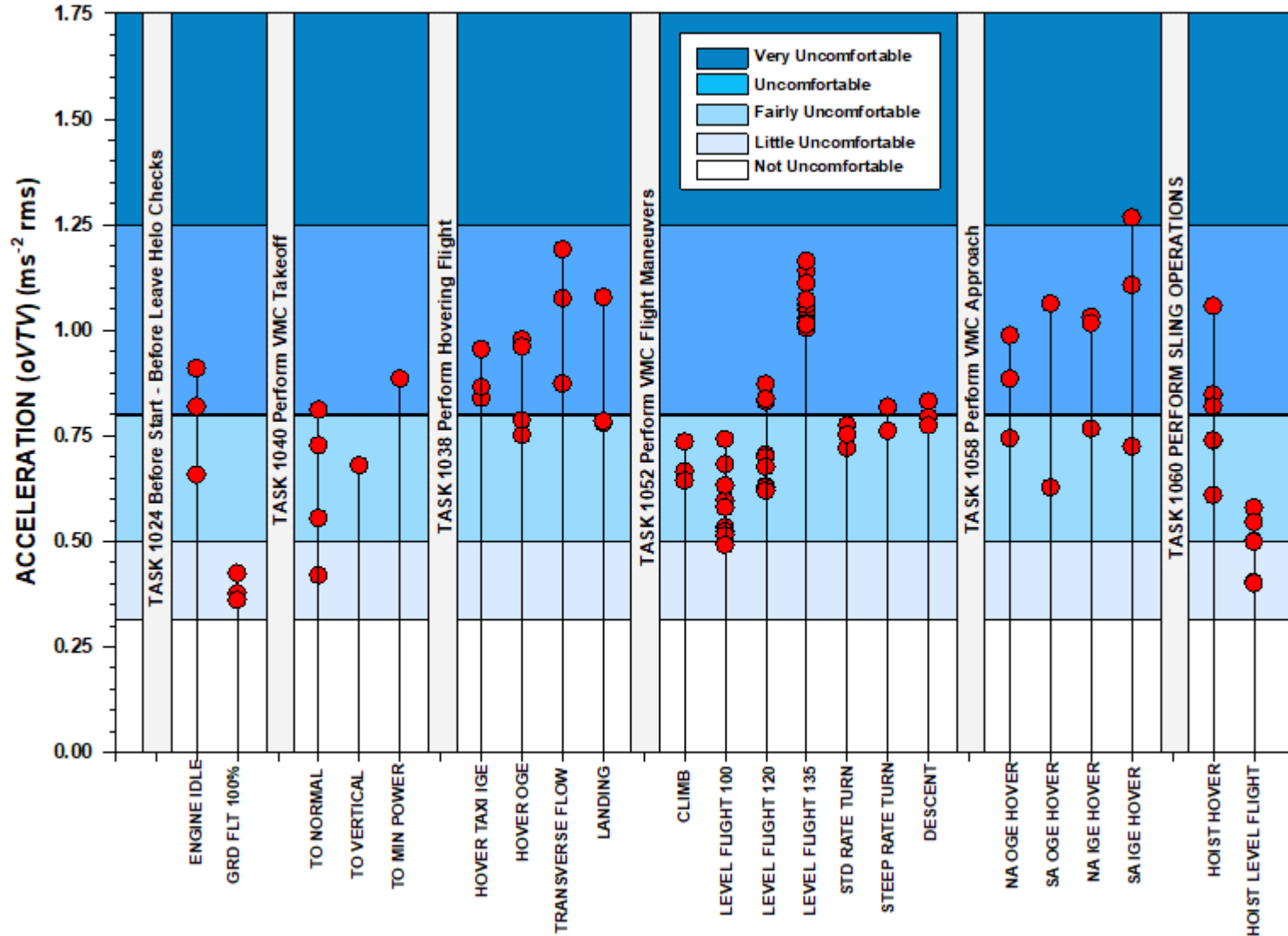


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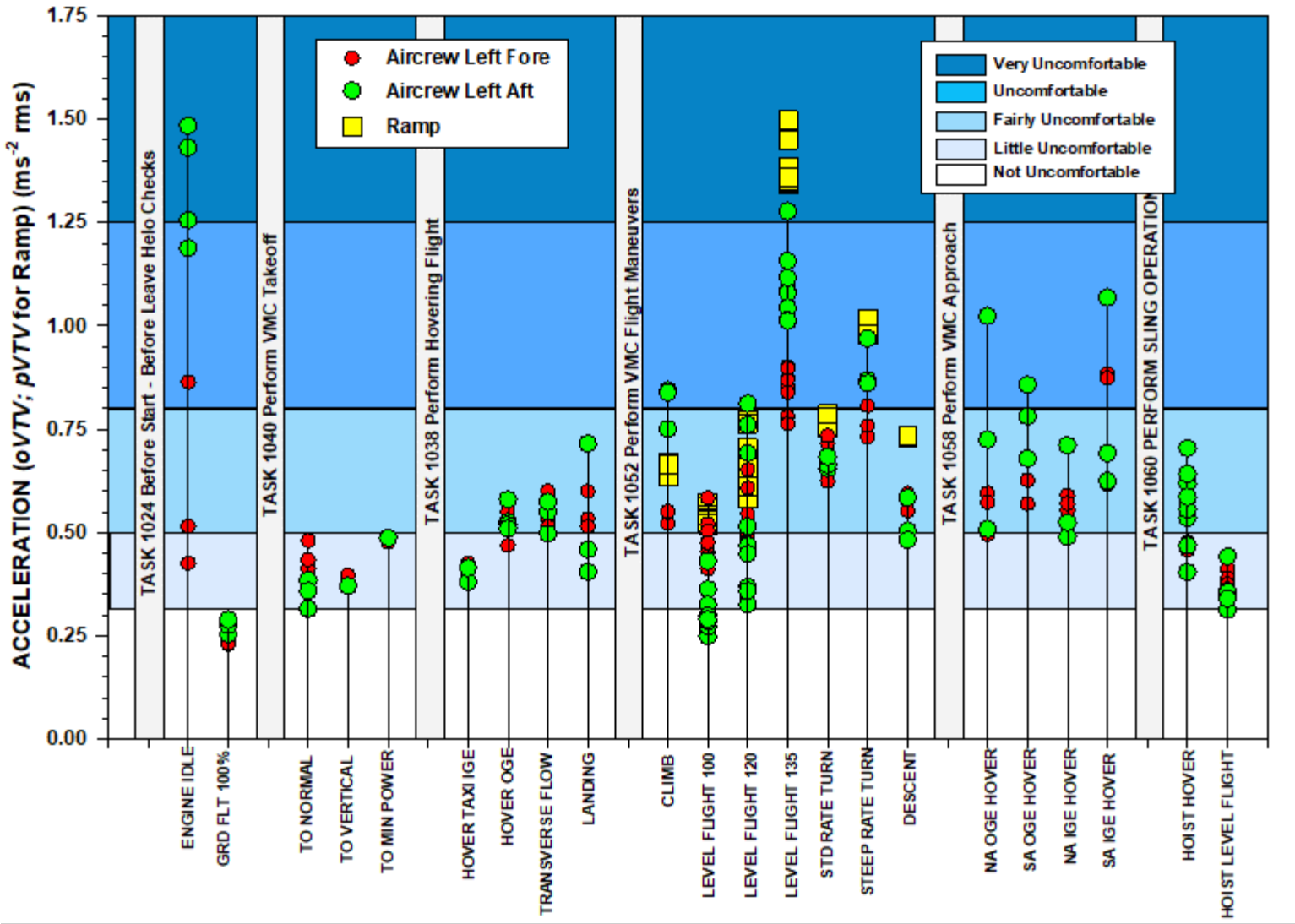


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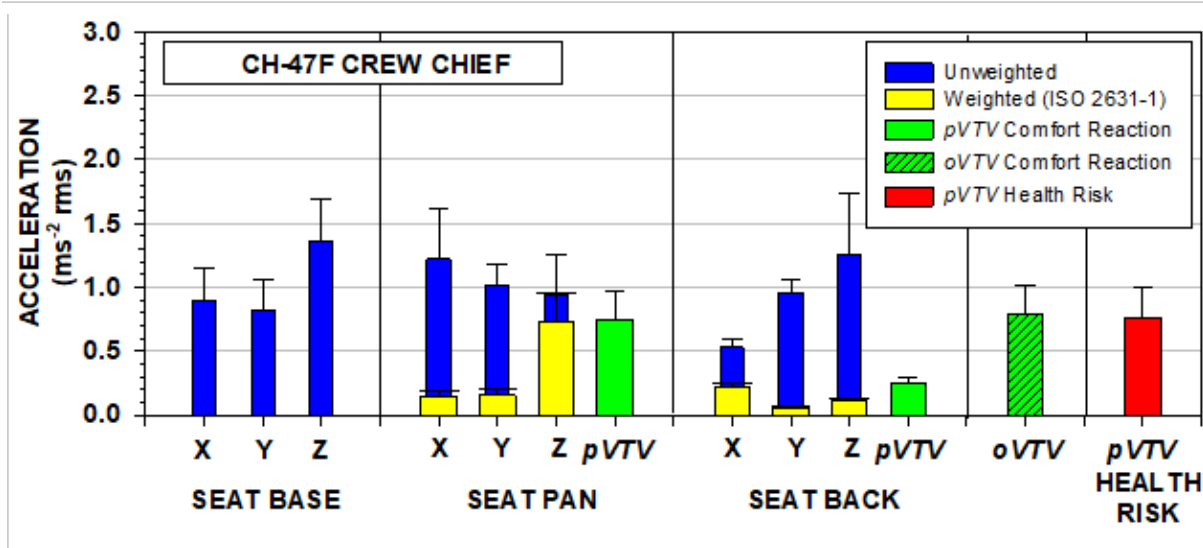
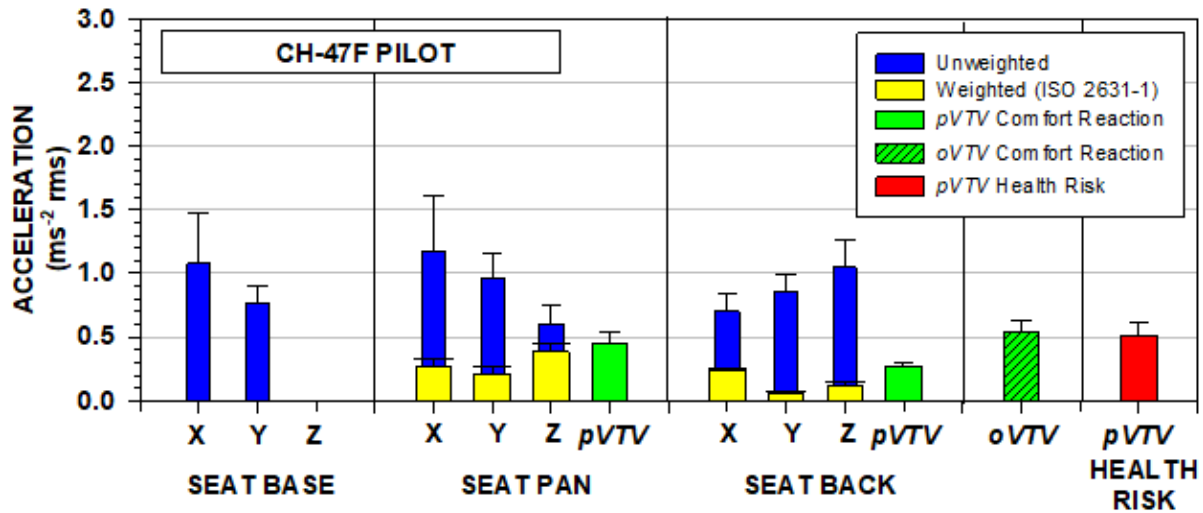


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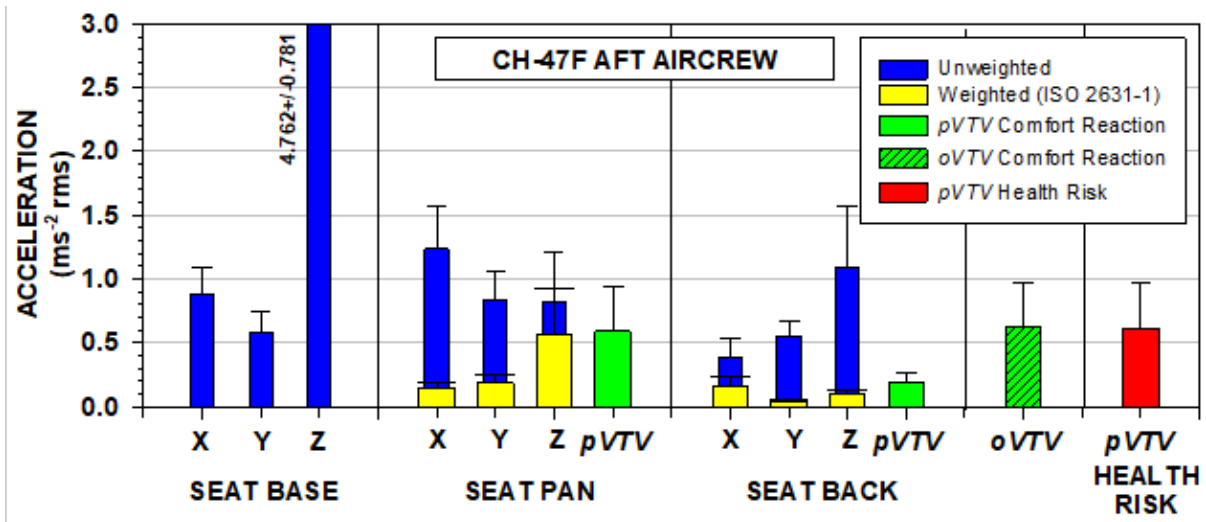
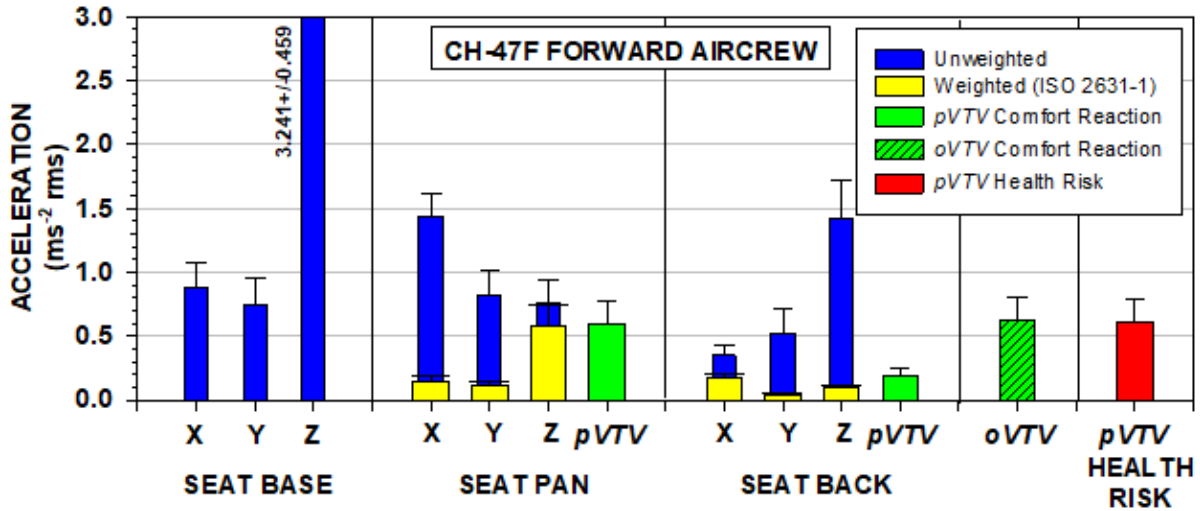


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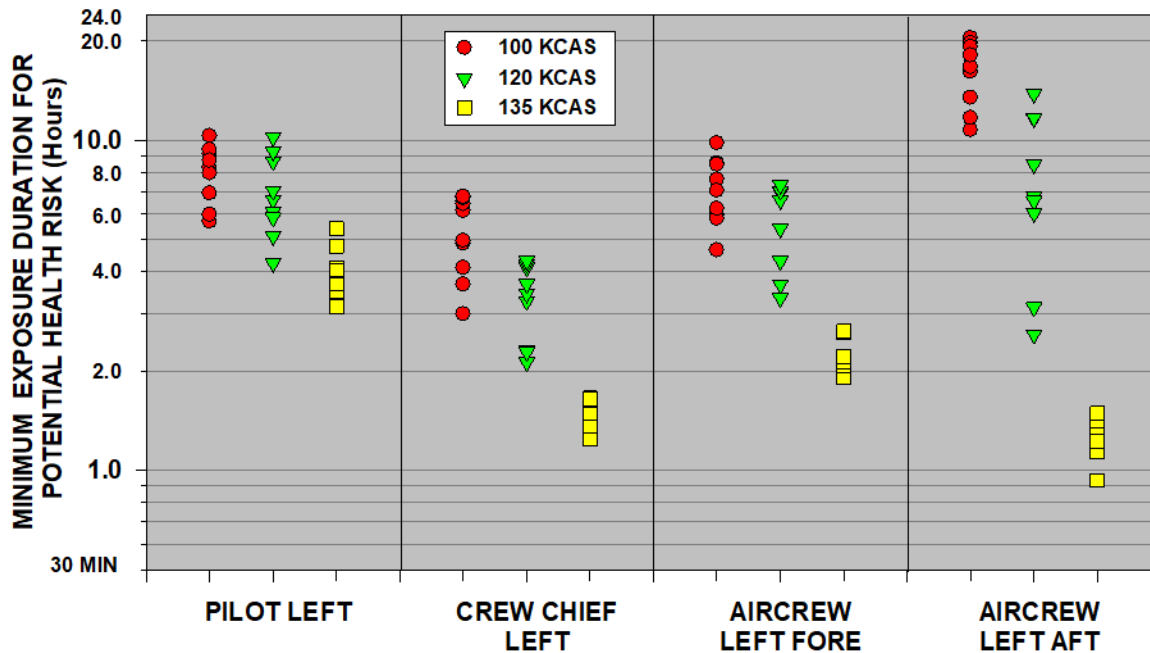


Figure A- 14. CH-47F Level Flight Minimum Exposure Duration for “Potential Health Risk” in a 24-Hour Period (ISO 2631-1)

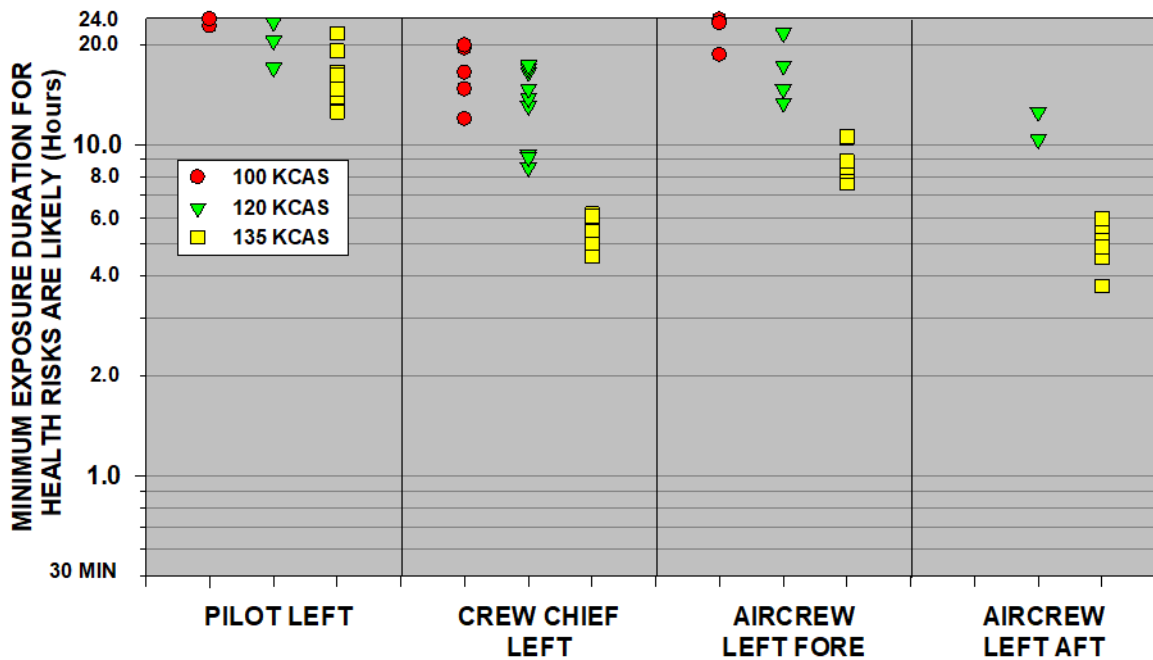


Figure A- 15. CH-47F Level Flight Minimum Exposure Duration for “Health Risks Likely” in a 24-Hour Period (ISO 2631-1)

**Table A- 1. CH-47F Stations/Locations, Measurement Sites and Type of Sensors**

Station	Measurement Site	Instrumentation
Pilot Station (Left Side Cockpit) CBDN Test: CH47FPILOT	Rigid X-Bar Behind Seat	Triaxial Accelerometer Pack
	Seat Pan	Triaxial Acceleration Pad
	Seat Back	Triaxial Acceleration Pad
	Helmet	Six-Axis Helmet Mount
Crew Chief Station (Forward Cabin, Left Side, Rearward Facing) CBDN Tests: CH47FCCLEFT	Floor beneath seat	Triaxial Accelerometer Pack
	Seat Pan	Triaxial Acceleration Pad
	Seat Back	Triaxial Acceleration Pad
Aircrew Locations (Forward and Aft Cabin, Left Side, Sideward Facing; Ramp) CBDN Test: CH47FACLEFTFORE CH47FACLEFTAFT (note: Ramp data are included with the AFT aircrew data)	Floor beneath each seat	Triaxial Accelerometer Pack
	Seat Pan	Triaxial Acceleration Pad
	Seat Back	Triaxial Acceleration Pad
	Ramp	Triaxial Acceleration Pad

**Table A- 2. CH-47F Flight Tasks and Flight Test Condition Records**

<b>Task/Condition</b>	<b># of Records</b>	<b>Bad Records</b>
<b>TASK 1024 Before Starting Through Before Leaving Helo Checks</b>		
Engine Idle	3-5 <sup>1</sup>	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Ground Flight 100%	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
<b>TASK 1040 Perform VMC Takeoff</b>		
Takeoff Normal	4	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Takeoff Vertical	1	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Takeoff Minimum Power	1	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
<b>TASK 1038 Perform Hovering Flight</b>		
Hover Stationary IGE	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Hover OGE	4	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Transverse Flow	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Landing	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
<b>TASK 1052 Perform VMC Flight Maneuvers</b>		
Climb	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Level Flight 100 KCAS	10	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Level Flight 120 KCAS	9-10 <sup>2</sup>	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Level Flight 135 KCAS	10	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Standard Rate Turn	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Steep Rate Turn	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Descent	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
<b>TASK 1058 Perform VMC Approach</b>		
Normal Approach to OGE Hover	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Steep Approach to OGE Hover	2-3 <sup>3</sup>	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Normal Approach to IGE Hover	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Steep Approach to IGE Hover	3	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
<b>TASK 2048 Perform Sling Load Operations (simulated)</b>		
Sling Load Hover	7-8 <sup>4</sup>	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
Sling Load Level Flight	6	All Pilot Seat X-Bar Vertical (Z) Pilot Helmet X1 data replaced with X2 data
<sup>1</sup> Pilot (5), Crew Chief (3), Aircrew Fore (3), Aircrew Aft (4) <sup>2</sup> Aircrew Aft (10) <sup>3</sup> Crew Chief (2) <sup>4</sup> Aircrew Aft (8)		VMC: Visual Meteorological Conditions KCAS: Knots Calculated Airspeed IGE: In Ground Effect OGE: Out of Ground Effect

**Table A- 3. CH-47F Pilot Station Overall Unweighted and Weighted Seat Pan Accelerations, *pVTVs*, and Allowable Exposure Durations to Potential Health Risks (Lower HGCZ Boundary) and Health Risks Likely (Upper HGCZ Boundary)**

FLIGHT #	AIRSPEED (KCAS)	RECORD #	PANX	PANY	PANZ	WT PANX	WT PANY	WT PANZ	<i>pVTV</i>	POTENTIAL HLTH RISKS WT PANZ	HLTH RISKS LIKELY WT PANZ	POTENTIAL HLTH RISKS PAN <i>pVTV</i>	HLTH RISKS LIKELY PAN <i>pVTV</i>
			ACCELERATION (ms <sup>-2</sup> rms)							EXPOSURE DURATION (Hours)			
1	100	56	0.788	0.697	0.454	0.207	0.163	0.302	0.401	16.447	65.787	9.328	37.313
1	100	57	0.911	0.871	0.503	0.246	0.192	0.346	0.466	12.551	50.206	6.916	27.666
1	100	58	0.900	0.830	0.454	0.213	0.151	0.311	0.406	15.528	62.114	9.113	36.454
1	100	59	0.878	0.849	0.424	0.181	0.161	0.295	0.381	17.283	69.133	10.312	41.247
1	100	60	0.910	0.831	0.443	0.212	0.155	0.302	0.400	16.479	65.917	9.380	37.519
1	100	61	0.972	0.921	0.553	0.281	0.195	0.383	0.514	10.204	40.818	5.682	22.728
1	100	62	0.940	0.803	0.564	0.286	0.177	0.372	0.502	10.828	43.311	5.957	23.828
1	100	63	0.846	0.793	0.472	0.196	0.155	0.345	0.426	12.602	50.410	8.266	33.062
1	100	64	0.910	0.838	0.490	0.218	0.162	0.339	0.434	13.068	52.271	7.953	31.811
1	100	65	0.974	0.904	0.462	0.221	0.171	0.308	0.415	15.843	63.372	8.693	34.771
<b>MEAN</b>			0.903	0.834	0.482	0.226	0.168	0.330	0.435	14.083	56.334	8.160	32.640
<b>STDEV</b>			0.056	0.063	0.046	0.035	0.015	0.031	0.045	2.538	10.151	1.537	6.149
1	120	47	0.865	0.837	0.484	0.193	0.164	0.331	0.417	13.699	54.797	8.639	34.554
1	120	48	0.879	0.770	0.463	0.149	0.135	0.326	0.383	14.149	56.596	10.236	40.946
1	120	49	0.888	0.836	0.517	0.265	0.191	0.347	0.476	12.472	49.888	6.609	26.437
1	120	50	0.856	0.879	0.528	0.288	0.195	0.354	0.496	11.963	47.852	6.092	24.369
1	120	51	0.813	0.788	0.504	0.233	0.175	0.358	0.462	11.717	46.867	7.043	28.171
1	120	52	0.824	0.828	0.445	0.186	0.174	0.312	0.403	15.439	61.756	9.259	37.036
1	120	53	1.059	0.893	0.643	0.337	0.246	0.423	0.594	8.383	33.533	4.250	16.999
1	120	54	1.035	0.877	0.587	0.250	0.186	0.399	0.507	9.403	37.613	5.840	23.360
1	120	55	1.039	0.905	0.599	0.271	0.238	0.402	0.541	9.268	37.072	5.131	20.523
<b>MEAN</b>			0.918	0.846	0.530	0.241	0.189	0.361	0.475	11.833	47.330	7.011	28.044
<b>STDEV</b>			0.098	0.047	0.067	0.058	0.035	0.039	0.068	2.415	9.661	1.989	7.955
1	135	66	1.993	1.362	0.854	0.340	0.302	0.517	0.689	5.603	22.413	3.161	12.643
1	135	67	1.911	1.141	0.714	0.252	0.219	0.408	0.527	9.011	36.044	5.401	21.604
1	135	68	1.911	1.277	0.819	0.360	0.278	0.479	0.660	6.540	26.161	3.442	13.770
1	135	69	1.817	1.258	0.758	0.303	0.263	0.450	0.603	7.398	29.590	4.124	16.496
1	135	70	1.688	1.191	0.701	0.253	0.247	0.435	0.560	7.934	31.737	4.781	19.126
1	135	71	1.771	1.229	0.788	0.367	0.308	0.465	0.667	6.952	27.809	3.368	13.470
1	135	72	1.903	1.260	0.796	0.348	0.271	0.462	0.639	7.018	28.074	3.674	14.694
1	135	73	1.793	1.179	0.806	0.403	0.299	0.472	0.689	6.739	26.955	3.163	12.650
1	135	74	1.131	1.110	0.855	0.337	0.269	0.542	0.692	5.110	20.440	3.132	12.530
1	135	75	1.019	0.992	0.741	0.332	0.253	0.443	0.609	7.636	30.546	4.047	16.188
<b>MEAN</b>			1.694	1.200	0.783	0.329	0.271	0.467	0.634	6.994	27.977	3.829	15.317
<b>STDEV</b>			0.338	0.103	0.054	0.048	0.028	0.039	0.057	1.120	4.479	0.766	3.062

**Table A- 4. CH-47F Crew Chief Overall Unweighted and Weighted Seat Pan Accelerations,  $pVTV$ s, and Allowable Exposure Durations to Potential Health Risks (Lower HGCZ Boundary) and Health Risks Likely (Upper HGCZ Boundary)**

FLIGHT #	AIRSPEED (KCAS)	RECORD #	PANX	PANY	PANZ	WT PANX	WT PANY	WT PANZ	$pVTV$	POTENTIAL HLTH RISKS WT PANZ	HLTH RISKS LIKELY WT PANZ	POTENTIAL HLTH RISKS PAN $pVTV$	HLTH RISKS LIKELY PAN $pVTV$
			ACCELERATION (ms <sup>-2</sup> rms)							EXPOSURE DURATION (Hours)			
1	100	55	0.827	0.872	0.592	0.096	0.110	0.457	0.480	7.176	28.704	6.510	26.042
1	100	56	0.876	0.913	0.676	0.112	0.119	0.530	0.555	5.338	21.352	4.873	19.493
1	100	57	0.882	0.892	0.599	0.103	0.112	0.471	0.495	6.753	27.012	6.114	24.458
1	100	58	0.881	0.845	0.584	0.097	0.111	0.460	0.483	7.077	28.306	6.422	25.687
1	100	59	0.918	0.911	0.578	0.103	0.109	0.449	0.474	7.434	29.735	6.688	26.750
1	100	60	0.942	0.969	0.765	0.119	0.134	0.614	0.640	3.979	15.915	3.666	14.662
1	100	61	1.000	1.356	0.818	0.120	0.149	0.683	0.709	3.215	12.858	2.981	11.926
1	100	62	0.913	1.166	0.697	0.105	0.128	0.581	0.604	4.451	17.805	4.116	16.463
1	100	63	0.927	1.218	0.650	0.114	0.130	0.522	0.549	5.513	22.053	4.970	19.878
1	100	64	0.982	1.215	0.570	0.119	0.141	0.433	0.471	7.986	31.943	6.759	27.035
<b>MEAN</b>			0.915	1.036	0.653	0.109	0.124	0.520	0.546	5.892	23.568	5.310	21.239
<b>STDEV</b>			0.052	0.184	0.086	0.009	0.014	0.083	0.082	1.630	6.520	1.382	5.526
1	120	46	0.981	0.852	0.801	0.115	0.116	0.659	0.678	3.459	13.837	3.260	13.041
1	120	47	0.965	0.817	0.774	0.112	0.106	0.643	0.661	3.634	14.535	3.437	13.749
1	120	48	0.972	0.846	0.757	0.113	0.121	0.617	0.639	3.939	15.756	3.674	14.694
1	120	49	0.899	0.834	0.744	0.122	0.143	0.573	0.603	4.565	18.262	4.120	16.479
1	120	50	0.867	0.793	0.714	0.102	0.115	0.576	0.596	4.523	18.091	4.221	16.885
1	120	51	0.895	0.821	0.698	0.104	0.119	0.567	0.589	4.664	18.657	4.328	17.313
1	120	52	1.067	0.843	0.982	0.144	0.175	0.771	0.803	2.526	10.104	2.325	9.298
1	120	53	1.067	0.863	1.006	0.124	0.125	0.821	0.840	2.226	8.906	2.128	8.514
1	120	54	1.064	0.901	0.990	0.127	0.163	0.784	0.810	2.442	9.769	2.285	9.138
<b>MEAN</b>			0.975	0.841	0.830	0.118	0.131	0.668	0.691	3.553	14.213	3.309	13.235
<b>STDEV</b>			0.078	0.031	0.126	0.013	0.024	0.099	0.100	0.963	3.850	0.873	3.491
1	135	65	1.930	1.196	1.442	0.224	0.223	1.075	1.121	1.298	5.190	1.195	4.778
1	135	66	1.791	1.144	1.264	0.193	0.185	0.971	1.007	1.591	6.364	1.479	5.915
1	135	67	1.859	1.161	1.431	0.213	0.228	1.098	1.141	1.244	4.977	1.151	4.605
1	135	68	1.702	1.130	1.300	0.198	0.189	0.991	1.028	1.526	6.106	1.418	5.673
1	135	69	1.633	1.101	1.281	0.187	0.188	0.950	0.987	1.661	6.643	1.541	6.163
1	135	70	1.708	1.126	1.341	0.206	0.220	0.995	1.039	1.516	6.063	1.388	5.554
1	135	71	1.821	1.164	1.381	0.209	0.222	1.047	1.091	1.368	5.472	1.261	5.044
1	135	72	1.666	1.188	1.311	0.213	0.220	1.001	1.046	1.499	5.994	1.370	5.481
1	135	73	1.656	1.129	1.293	0.196	0.198	0.957	0.997	1.638	6.551	1.510	6.039
1	135	74	1.590	1.146	1.281	0.192	0.202	0.954	0.993	1.650	6.599	1.521	6.082
<b>MEAN</b>			1.736	1.148	1.332	0.203	0.207	1.004	1.045	1.499	5.996	1.383	5.533
<b>STDEV</b>			0.109	0.029	0.064	0.012	0.017	0.052	0.055	0.149	0.597	0.139	0.557

**Table A- 5. CH-47F Aircrew Forward Cabin Overall Unweighted and Weighted Seat Pan Accelerations,  $pVTVs$ , and Allowable Exposure Durations to Potential Health Risks (Lower HGCZ Boundary) and Health Risks Likely (Upper HGCZ Boundary)**

FLIGHT #	AIRSPEED (KCAS)	RECORD #	PANX	PANY	PANZ	WT PANX	WT PANY	WT PANZ	$pVTV$	POTENTIAL HLTH RISKS WT PANZ	HLTH RISKS LIKELY WT PANZ	POTENTIAL HLTH RISKS PAN $pVTV$	HLTH RISKS LIKELY PAN $pVTV$
1	100	55	1.369	0.612	0.519	0.108	0.079	0.367	0.391	11.113	44.450	9.817	39.266
1	100	56	1.412	0.648	0.553	0.116	0.103	0.390	0.420	9.862	39.448	8.520	34.078
1	100	57	1.343	0.678	0.568	0.112	0.090	0.394	0.419	9.673	38.690	8.536	34.144
1	100	58	1.226	0.687	0.591	0.155	0.081	0.408	0.444	9.015	36.062	7.616	30.463
1	100	59	1.232	0.724	0.579	0.102	0.088	0.399	0.421	9.417	37.669	8.459	33.836
1	100	60	1.300	0.698	0.671	0.127	0.113	0.473	0.503	6.705	26.818	5.940	23.762
1	100	61	1.317	0.705	0.732	0.120	0.110	0.544	0.568	5.071	20.282	4.654	18.617
1	100	62	1.183	0.675	0.652	0.098	0.087	0.492	0.509	6.207	24.827	5.799	23.195
1	100	63	1.291	0.664	0.668	0.102	0.093	0.472	0.491	6.744	26.978	6.212	24.847
1	100	64	1.266	0.687	0.646	0.114	0.092	0.437	0.461	7.840	31.361	7.049	28.196
<b>MEAN</b>			1.294	0.678	0.618	0.115	0.094	0.438	0.463	8.165	32.659	7.260	29.041
<b>STDEV</b>			0.070	0.031	0.066	0.016	0.012	0.056	0.054	1.938	7.752	1.603	6.412
1	120	46	1.513	0.710	0.633	0.124	0.088	0.504	0.527	5.898	23.592	5.407	21.628
1	120	47	1.596	0.713	0.595	0.110	0.075	0.445	0.464	7.575	30.299	6.958	27.833
1	120	48	1.388	0.698	0.582	0.122	0.117	0.430	0.462	8.109	32.435	7.022	28.086
1	120	49	1.220	0.639	0.577	0.141	0.115	0.441	0.477	7.716	30.865	6.593	26.370
1	120	50	1.250	0.667	0.577	0.110	0.094	0.439	0.462	7.794	31.176	7.031	28.123
1	120	51	1.312	0.724	0.567	0.115	0.088	0.429	0.453	8.166	32.662	7.326	29.303
1	120	52	1.332	0.724	0.754	0.187	0.142	0.595	0.640	4.236	16.942	3.663	14.653
1	120	53	1.323	0.722	0.796	0.125	0.101	0.652	0.671	3.533	14.132	3.332	13.326
1	120	54	1.381	0.761	0.720	0.156	0.107	0.559	0.590	4.807	19.229	4.313	17.254
<b>MEAN</b>			1.368	0.706	0.645	0.132	0.103	0.499	0.527	6.426	25.704	5.738	22.953
<b>STDEV</b>			0.120	0.035	0.088	0.026	0.020	0.083	0.085	1.830	7.319	1.593	6.371
1	135	65	1.756	1.169	1.040	0.215	0.155	0.820	0.862	2.231	8.925	2.021	8.082
1	135	66	1.597	1.036	0.989	0.183	0.120	0.803	0.832	2.327	9.310	2.166	8.664
1	135	67	1.667	1.100	1.042	0.223	0.153	0.843	0.885	2.112	8.447	1.915	7.659
1	135	68	1.651	1.050	1.016	0.179	0.137	0.806	0.837	2.310	9.241	2.143	8.571
1	135	69	1.538	1.112	0.901	0.177	0.133	0.724	0.757	2.865	11.459	2.619	10.476
1	135	70	1.573	1.096	0.999	0.201	0.161	0.791	0.832	2.400	9.599	2.170	8.678
1	135	71	1.671	1.110	1.016	0.214	0.151	0.810	0.852	2.284	9.136	2.068	8.273
1	135	72	1.662	1.022	1.036	0.206	0.149	0.800	0.839	2.344	9.375	2.129	8.516
1	135	73	1.728	1.040	0.988	0.203	0.138	0.784	0.822	2.439	9.757	2.222	8.889
1	135	74	1.608	0.980	0.878	0.201	0.148	0.711	0.753	2.967	11.869	2.643	10.573
<b>MEAN</b>			1.645	1.071	0.990	0.200	0.144	0.789	0.827	2.428	9.712	2.210	8.838
<b>STDEV</b>			0.068	0.055	0.057	0.016	0.012	0.041	0.042	0.273	1.094	0.239	0.955

**Table A- 6. CH-47F Aircrew Aft Cabin Overall Unweighted and Weighted Seat Pan Accelerations, *pVTVs*, and Allowable Exposure Durations to Potential Health Risks (Lower HGCZ Boundary) and Health Risks Likely (Upper HGCZ Boundary)**

FLIGHT #	AIRSPEED (KCAS)	RECORD #	PANX	PANY	PANZ	WT PANX	WT PANY	WT PANZ	<i>pVTV</i>	POTENTIAL HLTH RISKS WT PANZ	HLTH RISKS LIKELY WT PANZ	POTENTIAL HLTH RISKS PAN <i>pVTV</i>	HLTH RISKS LIKELY PAN <i>pVTV</i>
1	100	58	0.959	0.631	0.570	0.109	0.128	0.334	0.374	13.470	53.881	10.753	43.010
1	100	59	0.951	0.679	0.459	0.119	0.164	0.228	0.305	28.880	115.521	16.146	64.583
1	100	60	0.951	0.679	0.459	0.100	0.134	0.214	0.271	32.908	131.630	20.409	81.638
1	100	61	0.881	0.618	0.408	0.095	0.102	0.207	0.249	35.074	140.298	24.135	96.540
1	100	62	0.883	0.656	0.449	0.105	0.132	0.218	0.276	31.563	126.252	19.734	78.936
1	100	63	0.960	0.749	0.580	0.124	0.185	0.280	0.358	19.146	76.585	11.704	46.815
1	100	64	0.946	0.752	0.486	0.120	0.176	0.257	0.334	22.710	90.842	13.470	53.881
1	100	65	0.884	0.671	0.428	0.097	0.127	0.229	0.279	28.604	114.414	19.215	76.860
1	100	66	0.898	0.730	0.489	0.102	0.133	0.249	0.300	24.213	96.850	16.689	66.756
1	100	67	0.881	0.705	0.453	0.106	0.136	0.230	0.288	28.282	113.126	18.097	72.388
<b>MEAN</b>			0.919	0.687	0.478	0.108	0.142	0.245	0.303	26.485	105.940	17.035	68.141
<b>STDEV</b>			0.036	0.046	0.057	0.010	0.025	0.038	0.040	6.641	26.564	4.170	16.678
1	120	48	1.084	0.656	0.690	0.140	0.131	0.430	0.471	8.109	32.435	6.770	27.081
1	120	49	1.169	0.676	0.581	0.123	0.089	0.325	0.359	14.219	56.875	11.665	46.658
1	120	50	1.013	0.721	0.547	0.119	0.143	0.272	0.330	20.260	81.039	13.816	55.264
1	120	51	1.036	0.651	0.548	0.127	0.158	0.296	0.359	17.109	68.434	11.645	46.581
1	120	52	1.045	0.643	0.591	0.174	0.243	0.374	0.478	10.747	42.987	6.554	26.216
1	120	53	1.040	0.649	0.478	0.119	0.152	0.302	0.358	16.458	65.830	11.697	46.789
1	120	54	1.055	0.664	0.543	0.123	0.162	0.369	0.421	11.010	44.042	8.451	33.804
1	120	55	1.211	0.720	0.868	0.161	0.238	0.706	0.762	3.010	12.041	2.583	10.333
1	120	56	1.211	0.720	0.868	0.159	0.162	0.655	0.693	3.497	13.989	3.122	12.486
1	120	57	1.368	0.815	0.902	0.179	0.179	0.721	0.500	2.882	11.529	6.012	24.048
<b>MEAN</b>			1.123	0.691	0.662	0.142	0.165	0.445	0.473	10.730	42.920	8.232	32.926
<b>STDEV</b>			0.114	0.054	0.160	0.024	0.046	0.178	0.147	6.297	25.190	3.867	15.467
1	135	68	1.819	1.296	1.580	0.226	0.285	1.214	1.267	1.018	4.074	0.935	3.739
1	135	69	1.771	1.118	1.371	0.204	0.195	1.036	1.074	1.396	5.586	1.300	5.200
1	135	70	1.710	1.169	1.394	0.217	0.284	1.090	1.147	1.263	5.054	1.141	4.563
1	135	71	1.640	1.145	1.305	0.195	0.222	0.991	1.034	1.529	6.116	1.404	5.617
1	135	72	1.567	1.057	1.211	0.181	0.189	0.969	1.003	1.599	6.397	1.490	5.962
1	135	73	1.638	1.116	1.285	0.224	0.292	1.006	1.071	1.482	5.929	1.307	5.230
1	135	74	1.715	1.164	1.349	0.211	0.278	1.048	1.105	1.365	5.462	1.230	4.918
1	135	75	1.679	1.094	1.273	0.214	0.309	0.961	1.032	1.623	6.491	1.408	5.631
1	135	76	1.581	1.079	1.221	0.194	0.251	0.953	1.004	1.652	6.609	1.487	5.950
1	135	77	1.549	1.053	1.192	0.212	0.286	0.938	1.003	1.705	6.821	1.491	5.964
<b>MEAN</b>			1.667	1.129	1.318	0.208	0.259	1.020	1.074	1.463	5.854	1.319	5.277
<b>STDEV</b>			0.089	0.071	0.115	0.014	0.043	0.083	0.083	0.209	0.838	0.180	0.719

**Table A- 7. CH-47F Statistical Results for Directional Effects  
(Significant differences at P<0.05)**

	Pilot			Crew Chief		
	Seat Base	Seat Pan	Seat Back	Floor	Seat Pan	Seat Back
100 KCAS	X>Y	X>Y>Z	Z>Y>X	Z>X>Y	Y>X>Z	Y>Z>X
120 KCAS	X>Y	X>Y>Z	Z>Y>X	Z>(X=Y)	X>(Y=Z)	Z>Y>X
135 KCAS	X>Y	X>Y>Z	Z>Y>X	Z>X>Y	X>Z>Y	Z>Y>X
	Forward Aircrew			Aft Aircrew		
	Floor	Seat Pan	Seat Back	Floor	Seat Pan	Seat Back
100 KCAS	Z>X>Y	X>(Y=Z)	Z>Y>X	Z>X>Y	X>Y>Z	Z>Y>X
120 KCAS	Z>(X=Y)	X>(Y=Z)	Z>Y>X	Z>X>Y	X>(Y=Z)	Z>Y>X
135 KCAS	Z>(X=Y)	X>Y>Z	Z>Y>X	Z>X>Y	X>Z>Y	Z>Y>X
	Ramp					
100 KCAS	Y>(X=Z)					
120 KCAS	Y>Z>X					
135 KCAS	(Y=Z)>X					

## LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

711 HPW	711 Human Performance Wing
AFRL	Air Force Research Laboratory
APHC	Army Public Health Center
CBDN	Collaborative Biomechanics Data Network
DAU	Data Acquisition Units
HGCZ	Health Guidance Caution Zones
Hz	Hertz (cycles per second)
ISO	International Organization for Standardization
MIL-STD	Military Standard
MD ARNG	Maryland Army National Guard
NDCEE	National Defense Center for Energy and Environment
MOA	Memorandum of Agreement
REVER	Remote Vibration Environment Recorder
RH	Airman Systems Directorate
SRB	Safety Review Board
TRB	Technical Review Board
VMC	Visual Meteorological Conditions
VT ARNG	Vermont Army National Guard
rms	root-mean-square
%	percent
$a_{rms}$	root-mean-square (rms) acceleration
$a_{uw}$	Overall Unweighted Acceleration Level
$a_w$	Overall Weighted Acceleration Level
$k$	Multiplying Factor (ISO 2631-1)
$oVTV$	Overall Vibration Total Value
$pVTV$	Point Vibration Total Value
$W$	Frequency Weighting (ISO 2631-1)