



AFRL-RH-WP-TR-2024-0005

**QUANTIFYING PATIENT VIBRATION PATTERNS DURING
AEROMEDICAL EVACUATION (AE)
ABOARD THE CV-22 OSPREY**

**Suzanne D. Smith PhD
Consultant/Research Engineer, Infoscitex
Air Force Research Laboratory**

**Christopher J. Dooley
711 Human Performance Wing
Air Force Research Laboratory**

**FEBRUARY 2024
Final Report**

Distribution Statement A. Approved for public release. Distribution is unlimited.

See additional restrictions described on inside pages.

**AIR FORCE RESEARCH LABORATORY
711TH HUMAN PERFORMANCE WING,
HUMAN EFFECTIVENESS DIRECTORATE,
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE**

NOTICE AND SIGNATURE PAGE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report was cleared for public release by the Air Force Research Laboratory Public Affairs Office and is available to the general public, including foreign nationals. Copies may be obtained from the Defense Technical Information Center (DTIC) (<http://www.dtic.mil>).

AFRL-RH-WP-TR-2024-0005 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

ANNMARIE C. FLATTEN, Capt, USAF
Work Unit Monitor
Biomedical Impact of Flight Branch

COREY R. HART, PhD
Core Research Area Lead
Biomedical Impact of Flight Branch
Air and Space Biosciences Division

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY) 20-02-2024		2. REPORT TYPE Final		3. DATES COVERED (From - To) December 2019 – November 2022	
4. TITLE AND SUBTITLE Quantifying Patient Vibration Patterns During Aeromedical Evacuation (AE) Aboard the CV-22 Osprey				5a. CONTRACT NUMBER FA8650-20-F-6209 0002 FA8650-20-D-6207(IDIQ)	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 62202F	
6. AUTHOR(S) Suzanne D. Smith* Christopher J. Dooley**				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER H11N	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) *Consultant, Infoscitex, WPAFB, OH ** Airman Biosciences Division 2800 Ascani Street, Bldg. 824, Area B Biomedical Impact of Flight Branch Wright-Patterson AFB OH 45433 Wright-Patterson AFB OH 45433				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Materiel Command Air Force Research Laboratory 711 th Human Performance Wing Human Effectiveness Directorate Airman Biosciences Division Biomedical Impact of Flight Branch Wright-Patterson AFB, OH 45433				10. SPONSOR/MONITOR'S ACRONYM(S) 711 HPW/RHBF	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RH-WP-TR-2024-0005	
12. DISTRIBUTION / AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A. Approved for public release, distribution is unlimited.					
13. SUPPLEMENTARY NOTES AFRL-2024-1360, cleared 11 March 2024					
14. ABSTRACT This study characterized and assessed litter patient vibration exposure aboard the CV-22 Osprey tilt-rotor aircraft during aeromedical evacuation (AE). The study was supported by the 20 th Special Operations Squadron located at Cannon AFB, NM. The ISO 2631-1: 1997 was used as the guideline for assessing patient comfort. Triaxial accelerations were collected on the floor-mounted standard 7309 litter (forward cabin) and Stokes litter (aft cabin) at the pelvis and back interfaces, at the occupant's chest and head (bitebar), and at the floor. Multiple data records were collected for typical aircraft flight conditions. In both cruise airplane (APLN) mode and conversion (CONV) mode, multi-axis acceleration peaks were observed at all measurement sites between 5.5 and 6.5 Hz in the vicinity of the propeller rotation frequency (PRF), depending on the rotor RPM. Both flight modes also showed multi-axis acceleration peaks between 16.5 and 20 Hz associated with the blade passage frequency (BPF), as well as some peaks at multiples of the BPF. The highest overall unweighted accelerations (1-80 Hz) tended to occur in one or more horizontal directions at most measurement sites with Litter A. This was not necessarily the case with Litter B. The highest overall weighted accelerations (ISO 2631-1; 1-80 Hz) occurred in the vertical direction for both litters. For each record, the point vibration total value (pVTV) was calculated at the pelvis and back interfaces, and at the head (vector sum of the overall weighted accelerations in the three orthogonal directions). Based on the pVTVs, the ISO Comfort Reaction ranged from "not uncomfortable" to "a little uncomfortable" at the pelvis and back interfaces of Litter A during both flight modes. Discomfort with Litter B tended to be higher than Litter A in CONV mode; the pVTVs, where available, exceed 0.5 ms ⁻² rms and ranged from being "fairly uncomfortable" at the back and head (nacelle angle at 80 degrees), to "uncomfortable" at the head (nacelle angle of 60 degrees). Given the limited floor data (corrupted), it was difficult to determine if the higher discomfort associated with Litter B was actually due to the litter or due to the litter location in the aft cabin. Neither litter included a pad, which may have provided improved occupant comfort. It is recommended that patients suffering head or spine injury are provided with head cushioning and additional restraint to reduce the transmission of vibration and motion and mitigate possible injury exacerbation.					
15. SUBJECT TERMS Human Vibration, Military En-Route Care, Military Emergency Evacuation					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 41	19a. NAME OF RESPONSIBLE PERSON Christopher J. Dooley
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) N/A

TABLE OF CONTENTS

1.0	SUMMARY	1
2.0	INTRODUCTION	3
3.0	METHODS AND PROCEDURES.....	4
3.1	Aircraft and Measurement Locations.....	4
3.2	Equipment, Instrumentation, and Measurement Sites	4
3.3	Data Collection, Processing, and Analysis	8
3.3.1	Data Collection	8
3.3.2	Data Processing and Analysis	9
4.0	RESULT	12
4.1	Spectral Characteristics of the Multi-Axis Accelerations Onboard the CV-22.....	12
4.1.1	APLN Mode Spectra.....	13
4.1.2	CONV Mode Spectra.....	13
4.2	Overall Unweighted Accelerations (1 – 80 Hz).....	14
4.2.1	Litter A - Overall Unweighted Accelerations	14
4.2.2	Litter B - Overall Unweighted Accelerations	15
4.3	Overall Weighted Accelerations, pVTVs, and ISO Comfort Assessment.....	15
4.3.1	Litter A - Overall Weighted Accelerations, pVTVs, and ISO Comfort Assessment.....	15
4.3.2	Litter B - Overall Weighted Accelerations, pVTVs, and ISO Comfort Assessment.....	16
5.0	DISCUSSION AND CONCLUSIONS	18
6.0	REFERENCES	20
	APPENDIX: RESULTS – FIGURES AND TABLES	21
	LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS.....	35

LIST OF FIGURES

Figure 1.	Remote Vibration Environment Recorder (REVER)	5
Figure 2.	Example of Instrumented Litter Attached to Aircraft Floor (Forward Standard Litter). Note: DAU and battery packs were attached to fuselage.	6
Figure 3.	Stokes Litter Attached to Floor in Aft Cabin	7
Figure 4.	Example of Occupied Litter	7
Figure 5.	Chest Accelerometer.....	8
Figure 6.	Bitebar with attached Triaxial Accelerometer Pack	8

LIST OF TABLES

Table 1.	CV-22 Litter Locations, Measurement Sites, and Type of Sensors.....	5
Table 2.	CV-22 Flight Tasks and Flight Condition Records	9

ACKNOWLEDGEMENTS

The Air Force Research Laboratory (AFRL), 711 Human Performance Wing, thanks the Air Force Special Operations Command (AFSOC), 27th Special Operations Wing (SOW), 20th Special Operations Squadron (SOS), Cannon Air Force Base (AFB), NM, for their support in the collection of both patient and aircrew vibration data aboard the CV-22. The author also extends her sincere gratitude to Mr. Bob Pincince, 413th Flight Test Squadron (FLTS), for his guidance on all aspects of this effort.

The views expressed are those of the authors and do not reflect the official views of the United States Air Force, nor the Department of Defense. Mention of trade names, commercial products, or organizations do not imply endorsement by the U.S. Government.

1.0 SUMMARY

The overall purpose of this flight test program was to collect engineering data for characterizing exposure of patients to vibration during all stages of military aeromedical evacuation (AE), including both ground and air vehicle transport. The data were used to conduct a comfort assessment of the exposures in accordance with existing standards. The data were also used to identify specific issues regarding the litter systems and seats that may significantly affect the transmission of vibration and motion and exacerbate patient condition. This particular study focused on collecting vibration data from two supine litter patients during aeromedical transport aboard the CV-22.

This test program supports the need for information to help en route patient care meet future challenges as cutting-edge treatments are introduced to support the wounded during combat and disasters. The study aligns with Air Force Medical Service (AFMS) Strategic Objectives A1, E3, and E6, and will help bridge the gaps identified by the 2014 AFMS Doctrine Change Recommendation (DCR) 1 (Surgery during long-range transport), Research Knowledge (32, Pain management for patients with low back pain), and Air Mobility Command's (AMC's) gap 11 (related to AFMS Research Knowledge gaps 1-5 and 20) regarding the cumulative effects of the stressors of flight. The study was funded by the Joint Program Committee 6/Combat Casualty Care Research Program (JPC-6/CCCRP) Joint En Route Care (J-ERC) Award solicited for the Defense Health Agency, Research, Development, and Acquisition (DHA RDA) Directorate.

The CV-22 aircraft used in this study was owned and operated by the AFSOC, 27th SOW, 20th SOS located at Cannon AFB, NW. The Remote Vibration Environment Recorder (REVER) was used to collect multi-axis acceleration data in the three orthogonal directions of the supine occupant at the pelvis and back interfaces with the litter, the chest, and the head; one occupant secured in the standard 7309 litter (forward cabin) and one occupant secured in the Stokes litter (aft cabin). Both litters were attached to the floor of the aircraft. Data were also collected at the floor beneath each litter. Multiple data records were collected by aircraft task and the associated flight conditions, including ground operations, takeoff, hover flight, flight maneuvers in airplane (APLN) and conversion (CONV) modes, approach, and landing.

The acceleration spectra showed that, in both cruise APLN mode and CONV mode, multi-axis peaks were observed at all measurement sites of both litters between 5.5 and 6.5 hertz (Hz) in the vicinity of the CV-22 propeller rotation frequency (PRF). In APLN mode, multi-axis peaks were observed at 16.5 Hz and associated with the CV-22 blade passage frequency (BPF) when operating at 84 percent (%) revolutions per minute (RPM). In CONV mode, multi-axis peaks were observed around 17 Hz (~84% RPM) as well as 20 Hz (BPF typically 100% RPM in CONV mode). Both modes showed notable peaks of variable magnitudes at multiples of the BPF.

The highest overall unweighted accelerations (1-80 Hz) tended to occur in one or more horizontal directions at most measurement sites with Litter A. This was not necessarily the case with Litter B. The highest overall weighted accelerations (International Organization for Standardization (ISO) 2631-1; 1-80 Hz) occurred in the vertical direction for both litters. For each record, the point vibration total value (pVTV) was calculated at the pelvis and back

interfaces, and at the head (vector sum of the overall weighted accelerations in the three orthogonal directions). Based on the pVTVs, the ISO Comfort Reaction ranged from “not uncomfortable” to “a little uncomfortable” at the pelvis and back interfaces of Litter A during both flight modes. Discomfort with Litter B tended to be higher than Litter A in CONV mode; the pVTVs, where available, exceed 0.5 meters per second squared (ms^{-2}) root-mean-square (rms) and ranged from being “fairly uncomfortable” at the back and head (nacelle angle at 80 degrees), to “uncomfortable” at the head (nacelle angle of 60 degrees). Given the limited floor data (corrupted), it was difficult to determine if the higher discomfort associated with Litter B was actually due to the litter or due to the litter location in the aft cabin.

It is strongly emphasized that the comfort reactions defined in ISO 2631-1 are based on the responses expected of relatively healthy occupants during relatively short duration public transport, and not traumatically injured supine patients. While neither litter used in this project included a cushioned mat, it is recommended that such a mat be used during actual medical transport, if not already, for improving the injured patient’s comfort at the support interfaces. Additionally, it is recommended that patients suffering head or spine injury be provided with head cushioning and restraint to reduce the transmission of vibration and motion to the head and neck and mitigate possible injury exacerbation.

The CV-22 is the final vehicle targeted for this test program entitled "Quantifying Operational Vibration Patterns and the Effects on Patients". This test program was approved by the AFRL Institutional Review Board (IRB) as FWR-2015-0143-H.

2.0 INTRODUCTION

As one of the stressors of military flight, vibration can affect occupant physical, physiological, and psychological responses, resulting in increased fatigue, discomfort, and heightened health risks. During AE, patients are exposed to vibration that could not only exacerbate patient medical condition but challenge the ability of medical personnel to monitor patient status and administer medical procedures (Fromm R. and Duvall J., 1990). Research on the effects of vibration on patients and litter systems during AE aboard military fixed-wing and rotary-wing aircraft is critically limited.

Five studies have been completed by the Air Force Research Laboratory (AFRL) 711 Human Performance Wing (HPW) onboard military emergency evacuation transport vehicles to characterize and assess patient vibration exposure. The first study targeted the C-130H (Smith S.D. et al., 2019); the second study targeted the C-130J (Smith S.D. et al., 2021), the third study targeted the Ambulance Bus (AMBUS) ground vehicle (Smith S.D. et al., 2019), the fourth study targeted the UH-60L Blackhawk (Smith S.D., 2022), and the fifth study targeted the CV-22 Osprey. This report documents the patient vibration measured aboard the CV-22 to include flight conditions representative of AE. These studies were all funded by the JPC-6/CCCRP J-ERC Award solicited for the DHA RDA Directorate.

Current vibration exposure guidelines and standards recommend the measurement of vibration at the interfaces between the supporting surface and the occupant. For the recumbent or supine occupant, these interfaces include the pelvis, back, and head (ISO 2631-1: 1997 and ISO 2631-1: 1997/Amd. 1: 2010). Guidance on the assessment of comfort and perception is provided for all postures including the seated, standing, and recumbent or semi-supine occupant and is independent of time. However, guidance on the assessment of health risk is currently limited to the seated posture for daily repeated exposures, and is time dependent, due to the lack of health effects data for other postures.

The specific objectives of this study are:

1. Collect multi-axis acceleration data to characterize the supine patient and seated patient vibration exposures during transport aboard the CV-22 Osprey.
2. Assess the vibration exposures at the patient/litter and patient/seat interfaces in accordance with existing human vibration guidelines and standards to estimate patient comfort and perception levels and to gauge potential health outcomes.
3. Document data in the Collaborative Biomechanics Data Network (CBDN) for use by researchers, equipment designers, and health care providers.

3.0 METHODS AND PROCEDURES

The mention of any non-federal entity and/or its products is for informational purposes only, and not to be construed or interpreted, in any manner, as federal endorsement of that non-federal entity or its products.

3.1 Aircraft and Measurement Locations

The CV-22 aircraft used in this study is owned and operated by the 20th SOS located at Cannon AFB, NM. Two flight tests were conducted. One flight focused on measuring the vibration exposure of patients during emergency medical transport and targeted one seated occupant in the cabin and two supine litter occupants in the cabin area. A second flight test focused on measuring the vibration exposure of the aircrew and targeted the pilot and FE stations in the cockpit. Both flight tests included the same flight conditions (see Section 3.3). This technical report addresses the supine patient vibration of two occupied litters attached to the floor of the aircraft. A Standard 7309 litter (Litter A) was attached to the floor along the right side of the forward cabin. A Stokes litter (Litter B) was attached to the floor along the right side of the aft cabin. Data collected on the seated cabin occupant were used to assess aircrew comfort and health risk and included in the CV-22 aircrew vibration report (Smith S.D., 2023). This report should be referenced for information regarding the vibration exposure of the seated patient. During both flights, the test conductor was located in the forward cabin seat.

3.2 Equipment, Instrumentation, and Measurement Sites

The REVER, developed by the AFRL Human Effectiveness Directorate (711 HPW/RH), was used to collect multi-axis vibration data at the two litter locations. Each REVER, illustrated in Figure 1, consists of the following:

1. A 16-channel Data Acquisition Units (DAU)
2. Two battery packs (Large and Small)
3. Triaxial accelerometer packs
4. Triaxial accelerometer seat pads
5. One trigger device
6. Connection/extension cables as required
7. Laptop computer

Two REVERs were used, one for each litter location. Specifications for the REVER components, including dimensions and weights, are listed in Table A-1. Each accelerometer pack consisted of three orthogonally arranged miniature accelerometers embedded in a Delrin® cylinder. Double-sided adhesive tape was used to secure the pack to the appropriate site. Triaxial accelerometer pads were used to measure the vibration transmitted to the supine occupant via the litter interfaces at the pelvis and back in accordance with the 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). Double-sided adhesive tape and duct tape were used to secure the pads to the litter surface. Table 1 lists the litter occupant

locations and measurement sites targeted for data collection, including the type of instrumentation.

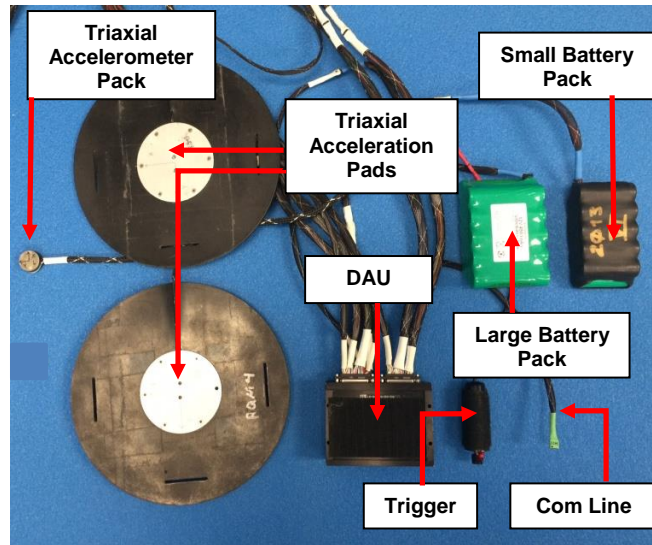


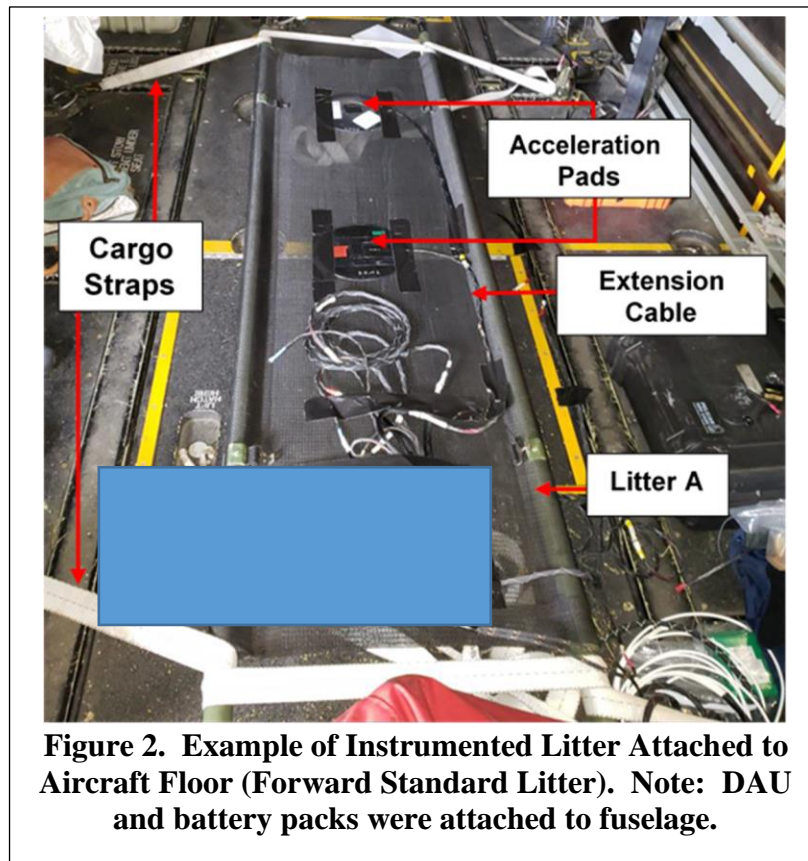
Figure 1. Remote Vibration Environment Recorder (REVER)

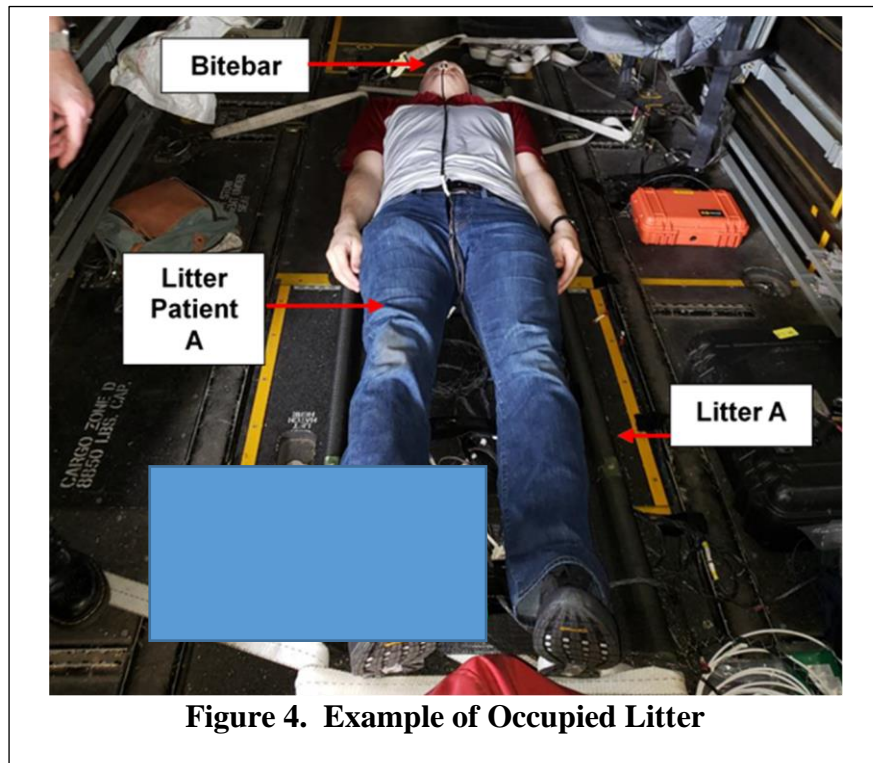
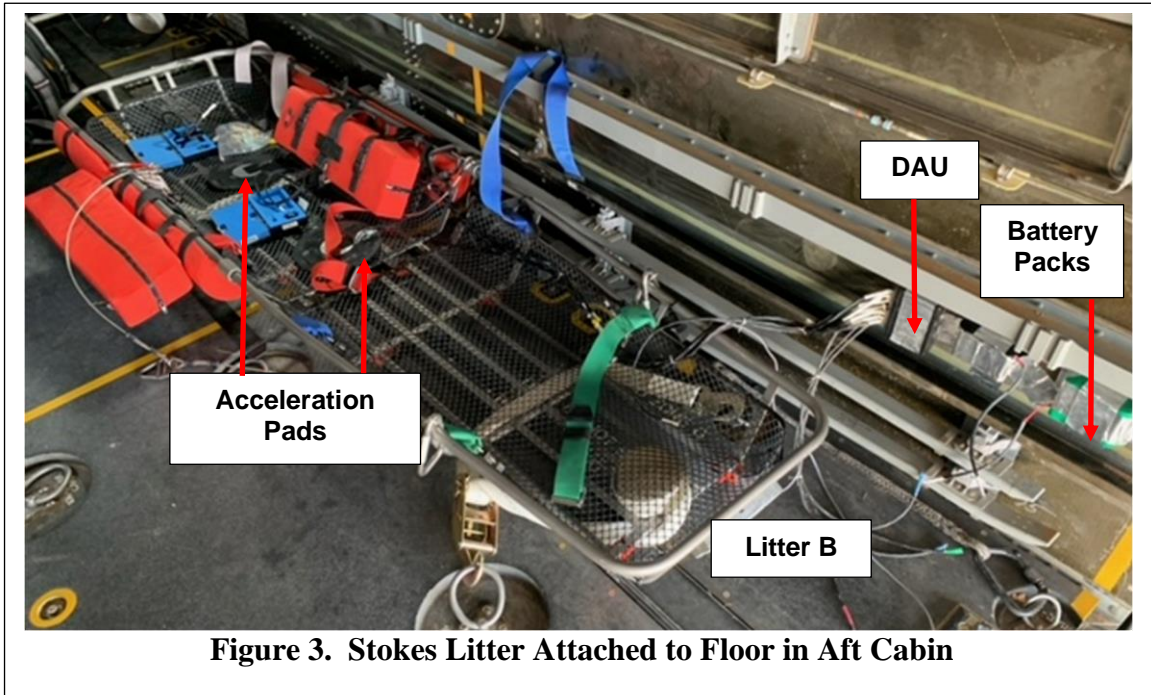
Table 1. CV-22 Litter Locations, Measurement Sites, and Type of Sensors

Litter/Location	Measurement Site	Instrumentation
Litter A Standard 7309 Litter (Forward Right Floor)	Floor	Triaxial Accelerometer Pack
	Pelvis Interface	Triaxial Acceleration Pad
	Back Interface	Triaxial Acceleration Pad
	Chest	Triaxial Accelerometer Pack
	Head (Bitebar)	Triaxial Accelerometer Pack
Litter B Stokes Litter (Aft Right Floor)	Floor	Triaxial Accelerometer Pack
	Pelvis Interface	Triaxial Acceleration Pad
	Back Interface	Triaxial Acceleration Pad
	Chest	Triaxial Accelerometer Pack
	Head (Bitebar)	Triaxial Accelerometer Pack

Figure 2 illustrates an example of the instrumented Standard 7309 litter (Litter A) attached to the floor of the aircraft. Figure 3 illustrates the instrumented Stokes litter (Litter B) attached to the floor of the aircraft. Figure 4 illustrates the occupied Litter A. As mandated by the NAVAIR-4.0P Flight Clearance Recommendation, Subject: CV-22B Flight Clearance Recommendation for Patient-Aircrew/Vibration Monitoring Equipment, FCR-01, a wiring assessment was conducted by AIR-4.4.5.3 on board the aircraft. As a result, the DAU and battery packs were attached to the wall of the fuselage next to the litter as illustrated in Figure 3. Triaxial acceleration pads were attached to the litter surface using double-sided adhesive tape at the interfaces between the participant’s back and pelvis (Figures 2 and 3). A triaxial pack was

directly attached to the occupant's chest using double-sided adhesive tape (Figure 5). A triaxial pack was attached to a bite bar (Figures 4 and 6) using double-sided adhesive tape for measuring occupant head translation. Packs attached to the body were further secured with medical tape, as necessary. The wiring assessment also required that the cables from the bite bar pack, chest pack, back pad, and pelvis pad were secured to the side of the fuselage (not shown). Extension cables were used to connect cables from the packs and pads to the DAUs as necessary. All cables were routed and secured to avoid any discomfort and hazard to the litter occupants and test support personnel, particularly in the case of an emergency egress. The litter occupants were restrained using a chest strap and leg strap (not shown in Figure 3).





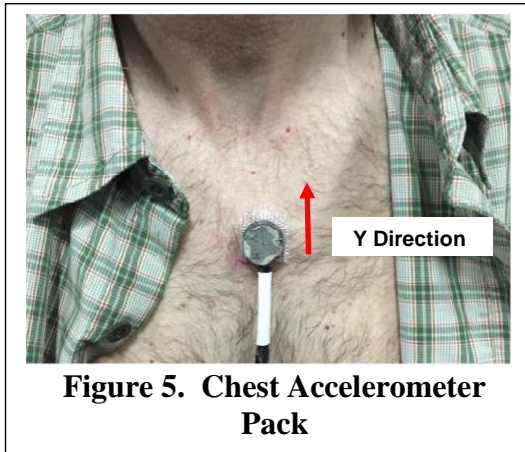


Figure 5. Chest Accelerometer Pack

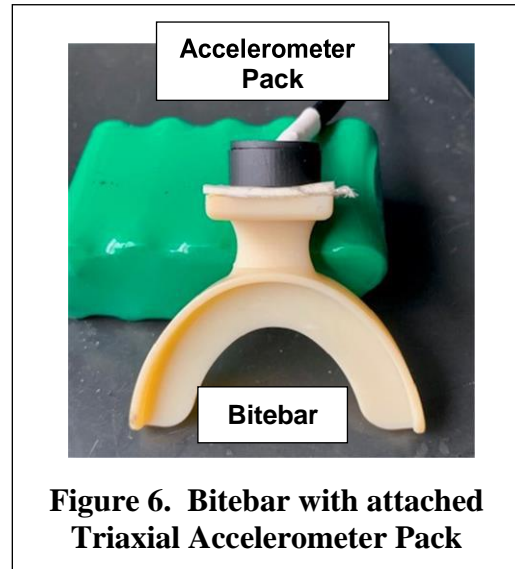


Figure 6. Bitebar with attached Triaxial Accelerometer Pack

A trigger device (Figure 1) was attached to each of the three cables routed from the DAUs to the forward left cabin seat occupied by the test conductor (also cabin aircrew station) who was 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 via the communication cable (Com Line, Figure 1). 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.

3.3 Data Collection, Processing, and Analysis

3.3.1 Data Collection

Acceleration data were collected at the litter measurement sites for the flight conditions listed in Table 2. The flight conditions were organized relative to specific flight tasks. The test conductor triggered data collection for the two occupied litters once the pilot or copilot indicated that the aircraft was on the flight condition. Multiple data records were collected for several of the conditions as annotated in Table 2 for each of the two litter locations. Data records were collected throughout the flight and not necessarily collected in the order presented in Table 2. The test conductor assured that the data records were numbered consecutively in the order they were collected. A total of 207 (Litter A) and 230 (Litter B) records were collected. The lower number of records collected for Litter A was due to limitations of the DAU memory.

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.

Table 2. CV-22 Flight Tasks and Flight Condition Records

Task/Condition	# of Records	
	LITTER A	LITTER B
TASK: GROUND OPERATIONS		
Ground Taxi	7	7
TASK: TAKEOFF MANEUVERS		
Normal Takeoff	1	3
Short Takeoff	3	3
60 Degree RTO	1	1
Climb Airplane Mode	4	4
TASK: CRUISE AIRPLANE (APLN) MODE		
10K ft MSL	10	10
10K ft MSL AVSS Off	10	10
7K ft MSL	10	10
7K ft MSL AVSS Off	10	10
5K ft MSL	10	10
5K ft MSL AVSS Off	10	10
200 ft AGL	10	10
200 ft AGL AVSS Off	9	9
TASK: CRUISE CONVERSION (CONV) MODE		
500 ft AGL 80 Degrees	10	10
500 ft AGL 80 Degrees AVSS Off	9	9
500 ft AGL 60 Degrees	10	10
500 ft AGL 60 Degrees AVSS Off	9	9
200 ft AGL 80 Degrees	10	10
200 ft AGL 80 Degrees AVSS Off	9	9
200 ft AGL 60 Degrees	10	10
200 ft AGL 60 Degrees AVSS Off	9	9
TASK: APPROACHES AND HOVERING FLIGHT		
Approach OGE Hover	4	4
OGE Hover	12	12
Approach IGE Hover	3	4
IGE Hover	3	12
TASK: DESCENT AND LANDING		
Descent	6	6
Landing from Hover	5	16
Roll on Landing	3	3
TOTAL RECORDS	207	230
MSL: Mean Sea Level AGL: Above Ground Level AVSS: Active Vibration Suppression System IGE: In Ground Effect OGE: Out of Ground Effect RTO: Running Takeoff		

3.3.2 Data Processing and Analysis

A computer program developed by 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[®] Signal

Processing Toolbox (The MathWorks, Inc., Natick, MA) to estimate the constant bandwidth spectral content. Using Welch's Method (Welch P.D., 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 up to 150 Hz. The constant bandwidth rms acceleration spectra were used to identify peak accelerations and associated frequencies.

Each acceleration time history was also processed in one-third octave proportional frequency bands using a software program developed for MATLAB® (Couvreur 1997). The accelerations were reported at the center frequency of each respective one-third octave band. The one-third octave data were used to calculate the overall unweighted and weighted rms accelerations between 1 and 80 Hz. The overall unweighted acceleration level, a_{uw} , between 1 and 80 Hz was calculated at each litter location for all measurement sites:

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

where a_{rmsi} is the rms acceleration associated with the i th frequency component (at the center frequency of the one-third octave band for proportional bandwidth analysis).

The assessment of discomfort (comfort reaction) for the supine occupant followed the guidelines in ISO 2631-1: 1997 using the frequency weightings and multiplying factors listed in Table 1 of ISO 2631-1: 1997. It is noted that the vertical axis or direction of the supine occupant (VX) (spine-chest) is in the vertical (Z) direction relative to the vehicle and floor. The longitudinal axis or direction of the supine body (LZ) corresponds to the longitudinal (X) direction relative to the vehicle and floor. The ISO 2631-1 recommends that vibration should be measured at the supporting interfaces, which include the pelvis, back, and head for the supine or recumbent occupant. In this study, head vibration was measured using a bitebar (Figure 6).

The overall weighted rms acceleration level, a_w , was calculated between 1 and 80 Hz in each of the three orthogonal axes relative to the coordinate system defined for the supine occupant:

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

where l represents the particular frequency weighting (d , k , c , or j) depending on the location and direction, i represents the i th frequency component, and a_{rmsi} is the measured one-third octave acceleration level at center frequency i . The ISO 2631-1 recommends that the head accelerations be frequency weighted using W_j instead of W_k in the vertical (VX) direction for the supine occupant but does not provide specific guidance on comfort based on the weighted head values. In addition, multiplying factors are only provided for the pelvis interface in all three directions, and at the head for vertical vibration using W_j . In this study, the same frequency weightings were used at both the pelvis and back interfaces. The lateral (Y) and longitudinal (LZ), or horizontal, head accelerations for the supine occupant were weighted using W_d (same as pelvis and back interfaces). The $pVTV$ was calculated as the vector sum of the overall weighted VX, Y, and LZ accelerations at the interfaces (pelvis and back) and the head after applying the appropriate multiplying factors (equal to 1):

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

The interface $pVTV$ s were compared to the weighted accelerations associated with the comfort reactions given in ISO 2631-1: 1997, Annex C. The comfort reactions include “Not Uncomfortable”, “A Little Uncomfortable”, “Fairly Uncomfortable”, “Uncomfortable”, “Very Uncomfortable”, and “Extremely Uncomfortable”. Both the overall weighted vertical (VX) accelerations and $pVTV$ s were used to assess comfort relative to the head.

The assessment of health risk, in accordance with the ISO 2631-1, is based on repeated daily exposures to occupational vibration. The assessment is primarily focused on the seated worker or occupant. Patients being transported for medical care are not exposed to vibration on a daily basis. Therefore, the assessment of health risk was not appropriate for the transported patient.

4.0 RESULT

All figures and tables referred to in this section are located in the Appendix. A review of the time history data indicated that certain records contained corrupted data channels. These channels were eliminated from the record and not included in the analysis. In addition, if the corrupted channel was associated with the calculation of the pVTV, these calculations were eliminated from the analysis. For Litter A, all FLOOR Y data were corrupted for all flight conditions. Otherwise, very few records included corrupted channels. For Litter B, all FLOOR Z data were corrupted for all flight conditions. Many more records were corrupted for Litter B. This was particularly true for BACK LZ during cruise in both APLN and CONV modes, and PELVIS Y during cruise in CONV mode. The figures included in the Appendix reflect those conditions where no data were available, particularly for Litter B.

4.1 Spectral Characteristics of the Multi-Axis Accelerations Onboard the CV-22

Rotary-wing and tilt-rotor aircraft exhibit persistent vibration generated by the propulsion system at frequencies associated with the rotor speed. For the purpose of this report, the frequency associated with the rotor speed is referred to as the PRF. A peak is typically expected to occur in the vicinity of the BPF, which is predicted as the number of blades multiplied by the PRF. Additional peaks are also expected at multiples of the BPF. The BPF peak may or may not be the highest in magnitude depending on the aircraft and flight condition. The PRF and BPF may vary slightly depending on the flight maneuver and whether the aircraft is operated at 100% power. The CV-22 can operate in two modes: APLN mode and CONV mode. In addition, in CONV mode, the aircraft nacelle can be oriented at different angles (see Table 2). In APLN mode, the aircraft typically operates at approximately 84% RPM. In CONV mode, the aircraft typically operates at 100% RPM. In some cases, the aircraft operates at 103.5% RPM. Table 3 lists the %RPM values and the associated spectra components in cycles per second or Hz. Peaks may also be generated at other frequencies which may not be easily associated with specific dynamic structures or coupling behavior between dynamic components. Section 4.1.1 summarizes the spectral characteristics observed at the litter locations during cruise in APLN mode. Section 4.1.2 summarizes the spectral characteristics observed during cruise in CONV mode.

Table 3. CV-22 Propulsion Frequency Spectra Components

%RPM	SPECTRA COMPONENT (Hz)					
	1P (PRF*)	2P	3P (BPF**)	6P	9P	12P
84	5.6	11.1	16.7	33.3	50.0	66.7
100	6.6	13.2	19.8	39.7	59.6	79.4
103.5	6.9	13.7	20.6	41.2	61.8	82.4

*PRF = Propeller Rotation Frequency, **BPF = Blade Passage Frequency
 Note: These are approximate values based on 100% RPM = 397 revolutions per minute

4.1.1 APLN Mode Spectra

Figures A-1 and A-2 illustrate examples of the CV-22 unweighted multi-axis acceleration spectra at the Litter A and Litter B measurement sites, respectively, during cruise APLN mode. The examples represent the spectra at 10K feet (ft) MSL with the AVSS ON and AVSS OFF. In APLN mode, with both the AVSS ON and AVSS OFF, all measurement sites showed multi-axis peaks between 5.5 and 6.5 Hz, in the vicinity of the CV-22 PRF. With reference to Table 3, the peaks occurring at 5.5 Hz were assumed to coincide with operating the aircraft at 84% RPM during APLN mode, while the peaks occurring at 6.5 Hz were assumed to coincide with operating at 100% RPM during CONV mode. For the pelvis and back interfaces shown in Figures A-1 and A-2, it appeared that the lateral (Y) peak occurred at 6.5 Hz, even though the aircraft was in APLN mode. While not shown, a small peak was observed at 5.5 Hz in the fore-and-aft (X) direction at the floor beneath both Litter A and Litter B (longitudinal (LZ) direction of litter) during cruise APLN mode. A more substantial peak was observed at 6.5 Hz in the lateral (Y) direction at the floor beneath Litter B (Litter A FLOOR Y corrupted). Both Figures A-1 and A-2 show substantial vibration at the head between 5.5 and 6.5 Hz. These peaks were also observed at the other altitudes. During cruise APLN mode, both litters and all sites did show multi-axis peaks of various magnitudes at 16.5 Hz, the BPF expected to occur when operating at 84% RPM in APLN mode. Additional peaks were also observed at multiples of the BPF. With Litter A, the multiple peaks were notably dominant in the longitudinal (LZ) axis at all altitudes, particularly at the back (Figure A-1) and floor (FLOOR X, not shown). Both the head and chest showed variable peaks associated with the BPF. For both litters, the head vibration beyond the BPF was quite low. This was also observed at the chest with Litter A. However, with Litter B, vertical (VX) chest peaks were observed at 33 Hz or two times the APLN mode BPF (16.5 Hz). It did appear that some damping of the BPF peaks occurred with the AVSS OFF at all measurement sites, depending on the direction, as observed in both Figures A-1 and A-2. It was difficult to determine if this was a consistent trend using the spectral data. The effects of the AVSS status and altitude during cruise APLN mode are evaluated further for the overall acceleration levels in Sections 4.2 and 4.3.

4.1.2 CONV Mode Spectra

Figures A-3 and A-4 illustrate examples of the CV-22 unweighted multi-axis acceleration spectra at Litter A and Litter B measurement sites, respectively, during cruise CONV mode. The examples represent the spectra at 500 ft AGL at the two tested nacelle angles of 80 and 60 degrees with the AVSS ON. As was observed for cruise APLN mode, cruise CONV mode also showed multi-axis peaks between 5.5 and 6.5 Hz with both nacelle angles. For the pelvis and back interfaces shown in Figures A-3 and A-4, it appeared that the lateral (Y) peak tended to occur at 6.5 Hz. Small peaks were observed at 6.5 Hz at the floor beneath Litter A (FLOOR Y corrupted). A small peak was observed at 6.5 Hz at the floor beneath Litter B in the fore-and-aft (X) direction (FLOOR Z corrupted), while a more substantial peak was observed at 6.5 Hz at the floor beneath Litter B in the lateral (Y) direction. For both litters, with both nacelle angles, two peaks tended to occur between about 17 and 20 Hz depending on the measurement site and direction. These peaks were in the vicinity of the BPFs associated with both APLN and CONV modes (Table 3). The pelvis and back interfaces showed a distinct peak at 40 Hz or two times the CONV mode BPF (20 Hz) and was more prominent with the 80 degree nacelle angle. The peaks at 17 and 20 Hz and the peak at 40 Hz tended to be more substantial with Litter B (Figure

A-4). The Litter A pelvis and back interfaces did show a small lateral (Y) band of vibration between about 22 and 30 Hz with a nacelle angle of 60 degrees (Figure A-3). Of particular interest for Litter B were the substantial peaks observed below about 14 Hz with both nacelle angles (Figure A-4). There was a notable lateral (Y) peak between 10 and 12 Hz at the floor (not shown). Unfortunately, the lateral (Y) floor data for Litter A were corrupt. In summary, and with reference to Figures A-3 and A-4, Litter B generally showed higher vibration levels between 4 and 20 Hz as compared to Litter A during cruise CONV mode. As with cruise APLN mode, it was difficult to determine any consistent effects of AVSS status from the spectral data. The effects of the AVSS status and altitude during cruise CONV mode are evaluated further for the overall acceleration levels in Sections 4.2 and 4.3.

4.2 Overall Unweighted Accelerations (1 – 80 Hz)

The overall unweighted accelerations, calculated between 1 and 80 Hz in accordance with Equation 1, were used to visualize the vibration levels among the flight conditions and in the three directions prior to frequency weighting in accordance with the ISO 2631-1. Figures A-5 and A-6 illustrate the mean overall multi-axis unweighted accelerations \pm one standard deviation for all tasks and flight conditions at the pelvis and back interfaces, head, and chest for Litter A and Litter B, respectively. Figure A-7 shows the mean overall multi-axis unweighted accelerations \pm one standard deviation for all tasks and flight conditions at the floor of both litters. Figures A-8 and A-9 include the mean overall multi-axis floor, pelvis, back, and head unweighted accelerations (blue bars) \pm one standard deviation for Litters A and B, respectively, during cruise APLN mode (top) and cruise CONV (bottom). The means represent the combined values across all altitudes and nacelle angles. Due to the differences observed between the two litters, the results for each litter are presented separately.

4.2.1 Litter A - Overall Unweighted Accelerations

With reference to Figure A-5 for Litter A, considering the low standard deviations observed among the multiple records collected for the same flight condition, the highest overall unweighted vibration tended to occur in one or both horizontal directions (Y and LZ) as compared to the vertical (VX) direction. This behavior was specifically observed at the pelvis and back interfaces and head during cruise flight in both modes (Figure A-5). Altitude effects were suggested in some cases. For example, during cruise APLN mode, the back longitudinal (LZ) direction did show higher unweighted accelerations at the higher altitudes (10K ft MSL and 7K ft MSL) (Figure A-5). Interestingly, Figure A-7 shows this trend in the floor vertical (VX) direction for Litter A. Figure A-8 (top) shows the higher overall unweighted vertical (VX) accelerations at the floor (lateral (Y) data corrupted), and the higher unweighted lateral (Y) and longitudinal (LZ) accelerations at the pelvis, back, and head with Litter A during cruise APLN mode (blue bars). There were limited effects of the AVSS status on the overall unweighted vibration levels during cruise APLN mode for Litter A; certain altitudes showed a tendency for decreases in the vertical (VX) levels with the AVSS OFF. This was particularly noticed at the back interface at 7K ft MSL. Figure A-7 does suggest lower unweighted accelerations at the floor in the longitudinal (LZ) direction and vertical (VX) direction (lateral data corrupted) at certain altitudes with the AVSS OFF. Again, it was noted that there was very little variation among the acceleration records collected at a specific site, in a specific direction, and for a specific flight condition. During cruise CONV mode, the highest overall unweighted

accelerations were specifically observed in the lateral (Y) direction at the pelvis and back interfaces and head (Figure A-5). Figure A-8 (bottom) reflects the higher mean lateral (Y) values at the interfaces and head (blue bars). In addition, at both altitudes (500 ft AGL and 200 ft AGL), the pelvis and back interfaces showed higher overall lateral (Y) vibration levels with a nacelle angle of 60 degrees as compared to 80 degrees (Figure A-5). There were no noticeable effects of the AVSS status during cruise CONV mode.

4.2.2 Litter B - Overall Unweighted Accelerations

With reference to Figure A-6 for Litter B, it was more difficult to identify trends due to data corruption. Litter B showed a tendency for higher overall unweighted vibration in one or both horizontal (Y, LZ) directions as compared to the vertical (VX) direction. However, due to corrupt back data, this was mostly observed at the pelvis and head during cruise APLN mode (Figure A-6). During cruise CONV mode at both altitudes and both nacelle angles, the back interface showed relatively high levels of unweighted vertical (VX) vibration. The back interface showed similar unweighted levels in the lateral (Y) direction with a nacelle angle of 60 degrees. These unweighted lateral (Y) levels were notably higher as compared to the lateral (Y) levels observed with a nacelle angle of 80 degrees (Figure A-6). Both the head and chest showed higher overall unweighted accelerations, depending on the direction, with a nacelle angle of 60 degrees as compared to 80 degrees (Figure A-6). Figure A-7 clearly shows the effect of the nacelle angle in the floor lateral (Y) direction for Litter B. Figure A-9 (bottom) reflects the higher unweighted vertical (VX) accelerations at the back with Litter B (blue bars) during cruise CONV mode.

4.3 Overall Weighted Accelerations, pVTVs, and ISO Comfort Assessment

The overall multi-axis weighted acceleration levels and pVTVs calculated between 1 and 80 Hz in accordance with Equations 2 and 3. Figures A-10 and A-11 illustrate the mean overall multi-axis weighted accelerations and the pVTVs \pm one standard deviation for all tasks and flight conditions at the pelvis and back interfaces and head for Litter A and Litter B, respectively. The figures include color-coded bands associated with the ISO 2631-1 Annex C Comfort Reactions. Figures A-8 and A-9 include the mean overall multi-axis pelvis, back, and head weighted accelerations (yellow bars) and the pVTVs (green bars) \pm one standard deviation for Litters A and B, respectively, during cruise APLN mode (top) and cruise CONV (bottom). The means represent the combined values across all altitudes and nacelle angles. Due to the differences observed between the two litters, the results for each litter are presented separately.

4.3.1 Litter A - Overall Weighted Accelerations, pVTVs, and ISO Comfort Assessment

For Litter A, Figure A-10 shows that the highest overall weighted accelerations consistently occurred in the vertical (VX) direction at the pelvis and back interfaces and head for all tasks and flight conditions, regardless of the directional trends observed in the unweighted values. This is further illustrated in Figure A-8 (yellow bars). At the Litter A pelvis and back interfaces, the similarity between the overall weighted levels in the vertical (VX) direction and the pVTVs indicated that the vertical (VX) accelerations were the primary contributors to the pVTV levels at these sites. These similarities can also be seen in Figure A-8 for both flight modes (yellow and green bars). During cruise CONV mode, the effects of the nacelle angle on the overall

unweighted lateral (Y) accelerations at the pelvis and back interfaces (Figure A-5) were not reflected in the overall weighted accelerations or the pVTVs (Figure A-10). There appeared to be a slightly larger difference between the overall weighted vertical (VX) head accelerations and the pVTVs, with some contributions from the horizontal (Y and LZ) directions to the pVTVs (Figure A-10). This is suggested in Figure A-8 for Litter A for both flight modes, where the head pVTV (green bar) tends to be higher as compared to the overall weighted accelerations in the respective directions (yellow bars), particularly given the small standard deviations.

For Litter A, Figure A-10 shows that the vibration occurring during CV-22 transport would primarily range from being considered “not uncomfortable” to “fairly uncomfortable”, according to the ISO 2631-1 Comfort Reactions. These assessments do depend on the specific flight condition. At the Litter A pelvis and back interfaces during the two cruise modes (APLN and CONV), the vibration ranged from being “not uncomfortable” to “a little uncomfortable”. It was even more difficult to determine any effects of altitude from the weighted accelerations. Figure A-10 does show a tendency for a reduction in the overall weighted vertical (VX) accelerations and pVTVs at the back during cruise APLN mode, particularly at 7K ft MSL, with the AVSS OFF (as also observed in the overall unweighted accelerations). This did have an influence on the ISO Comfort Reaction to some extent; with a tendency to be “a little uncomfortable” with the AVSS ON, and “not uncomfortable” with the AVSS OFF.

Figure A-10 and Figure A-8 show that the highest pVTVs occurred at the head. During cruise APLN mode, all head pVTVs reflected an ISO Comfort Reaction of “a little uncomfortable”, with a tendency for the pVTVs at the lowest and highest altitudes to enter the Comfort Reaction band considered “fairly uncomfortable” (AVSS ON). It should be noted that, based on the head vertical (VX) accelerations weighted with W_j , the Comfort Reaction during cruise APLN mode bordered on the threshold of being “a little uncomfortable”, indicating slightly less discomfort than reflected by the pVTVs. During cruise CONV mode, the head pVTVs fell slightly below to slightly above the “fairly uncomfortable” threshold. The one exception was observed at 500 ft AGL and nacelle angle of 60 degrees, which clearly reflected a Comfort Reaction of “fairly uncomfortable”, as shown in Figure A-10. Using the weighted head vertical (VX) accelerations, only the exposures to 500 ft AGL with a nacelle angle of 60 degrees showed a comfort reaction of “fairly uncomfortable”. This effect of the nacelle angle at 500 ft AGL was not very prominent in the unweighted accelerations at the head (Figure A-5) and may have been influenced by the vertical (VX) frequency weightings at low frequencies in the vicinity of the PRF.

4.3.2 Litter B - Overall Weighted Accelerations, pVTVs, and ISO Comfort Assessment

For Litter B, Figure A-11 also showed the highest overall weighted accelerations consistently occurring in the vertical (VX) direction for all tasks and flight conditions, as was observed for Litter A. This is further illustrated in Figure A-9. The weighted vertical (VX) accelerations also had the greatest influence on the pelvis, back, and head pVTVs for both flight modes as shown in Figure A-9.

For Litter B, Figure A-11 does show that the vibration occurring during CV-22 transport would range from being considered “not uncomfortable” to “uncomfortable” according to the ISO Comfort Reactions. During cruise APLN mode, both the pelvis and back interfaces showed discomfort associated with being “not uncomfortable” to “a little uncomfortable”. During cruise

CONV mode, the discomfort at the pelvis interface was primarily considered “a little uncomfortable” but did border on being “fairly uncomfortable”. The discomfort at the back interface was considered “fairly uncomfortable”. In addition, both the weighted vertical (VX) accelerations and the pVTVs at the back were notably higher at both altitudes with a nacelle angle of 60 degrees and even bordered on being “uncomfortable”. The effect of the nacelle angle was not easily seen in the unweighted vertical (VX) accelerations (but notable in the unweighted lateral (Y) accelerations) (Figure A-6) and may have been influenced by the vertical (VX) frequency weightings in the vicinity of the PRF.

Figure A-11 and Figure A-9 show that the highest pVTVs with Litter B occurred at the head. All head pVTVs during cruise APLN mode were associated with being “fairly uncomfortable”; the head vertical (VX) accelerations weighted with W_j being only slightly lower than the pVTVs (Figure A-11 and Figure A-9). During cruise CONV mode, both altitudes (500 ft AGL and 200 ft AGL) showed notably higher weighted head vertical (VX) accelerations and pVTVs with a nacelle angle of 60 degrees that entered the comfort band considered “uncomfortable”. This was also observed in the overall weighted head vertical (VX) accelerations (Figure A-11 and A-9).

5.0 DISCUSSION AND CONCLUSIONS

This project sought to collect and characterize vibration transmitted to litter patients attached to the floor during a typical AE transport scenario aboard the CV-22. Two subjects participated as litter patients or occupants; one located in the forward cabin using the standard 7903 litter (Litter A), and one located in the aft cabin using the Stokes litter (Litter B). Tri-axial accelerations were collected at the pelvis and back interfaces between the patient and litter, at the occupant head and chest, and on the floor beneath the litter. It is noted that the flight conditions included in this study were similar to the conditions included in a second flight that focused on collecting aircrew vibration data (Smith S.D. 2023).

As mentioned in the recent aircrew study (Smith S.D., 2023) and in the Results Section 4.1, the CV-22 has the unique capability to fly in APLN mode as well as CONV mode, which is more similar to a helicopter. These modes are associated with operating at a different RPM that will generate vibration at specific frequencies, as defined in Table 3. The acceleration spectra illustrated in Figures A-1 – A-4 of this study show substantial low frequency vibration at all of the litter measurement sites in the vicinity of the PRF that, depending on the direction, did not necessarily coincide with the specific flight mode. During cruise CONV mode, a similar tendency was observed in the BPF. This behavior was also observed at the aircrew stations during cruise CONV mode (Smith S.D., 2023). It was not clear if there may have been fluctuations in the RPM during flight or if other factors could have contributed to these observations. It is interesting that, beyond the BPF, the peaks did reflect the expected frequency component associated with the %RPM and mode. Regardless, at the PRF, the peaks were within 1 Hz of each other, and at the BPF, within about 3 Hz of each other, which will be helpful in developing vibration mitigation strategies that target both modes.

The CV-22 is equipped with the AVSS, which is typically flown in the ON status. The concept is focused on mitigating vertical (Z) vibration. At the request of the aircrew, data were collected for both modes with the AVSS ON and the AVSS OFF. With AVSS ON, there was a notable reduction in the vertical (Z) vibration at the pilot station but a tendency for increased vibration at the forward cabin aircrew station during cruise APLN mode, with minimal effect while in cruise CONV mode. The effect of the AVSS at the cabin aircrew station was suggested in limited cases at the cabin litters. In general, the AVSS status on board the CV-22 aircraft in this study appeared to have the most positive influence in the cockpit, with minimal effect in the cabin.

Based on the overall weighted acceleration levels, the greatest discomfort associated with the vibration would occur with the Stokes litter located in the aft cabin. Unfortunately, given the corrupt floor data, it was difficult to determine if the litter location (forward vs aft cabin) may have contributed to the higher overall weighted accelerations. Both litters did show higher discomfort at the head. The Stokes litter also showed notably higher weighted vibration during cruise CONV mode. This was specifically observed in both the overall unweighted and weighted vertical (VX) accelerations and pVTVs (where available) illustrated in Figures 8 and 9 (bottom). The overall weighted vertical (VX) accelerations and pVTVs were either in the vicinity of, or greater than, 0.5 ms^{-2} rms with Litter B and associated with higher discomfort relative to the ISO Comfort Reactions. It is strongly emphasized that the comfort reactions defined in ISO 2631-1 are based on the expected responses of relatively healthy occupants during public

transport and are independent of time. It is speculated that most occupants of public transport are in a seated posture, only exposed to relatively short transit durations, and certainly not suffering any traumatic injury. As suggested in Section 3.0 Methods and Procedures, the ISO 2631-1 is not clear on assessing the discomfort of the supine occupant, particularly at the head. Regardless, the relative weighted values and associated discomfort levels were influenced by the ISO frequency weightings. At the pelvis and back interfaces, the ISO frequency weighting W_k allowed the greatest contribution from vertical (VX) vibration in the low frequency range between about 4 and 12.5 Hz (one-third octave frequency bands). This resulted in a notable contribution of vibration at the PRF, and some contribution of vibration at the BPF, to the assessment. At the head, the ISO frequency weighting W_j allowed the greatest contribution from vertical (VX) vibration in the frequency range of about 6.3 to 63 Hz (one-third octave frequency bands). Very little vibration was transmitted to the head above 20 Hz during operation of the CV-22. The lower frequency vibration is associated with greater head motion that could exacerbate any head/neck and even upper spine injury. It is noted that the ISO 2631-1 calls for the measurement of vibration between the head and supporting surface (similar for pelvis and back). This was not practical given the relatively small contact surface of the head to the litter. Regardless, the weighted bitebar data revealed relatively high levels of vibration at the head as compared to the other interfaces, particularly with Litter B located in the aft cabin.

Neither litter used in this project included a cushioned mat for supporting the occupant's body. It is recommended that this be done during actual medical transport, if not already, for improving the injured patient's comfort at the supporting surfaces. Additionally, it is recommended that patients suffering head, neck, or spine injury be provided with head cushioning and restraint to reduce the transmission of vibration and motion for mitigating possible injury exacerbation.

The CV-22 and variants are also capable of transporting patients via a tiered litter system that would allow for the emergency transport of many more patients. It is recommended that future studies be conducted to characterize and assess the vibration exposure during AE transport using the tiered system. It is also recommended that the equipment used to collect the vibration be solely mounted and contained on the occupied litter as was done in previous studies (Smith S.D. et al., 2019; Smith S.D. et al., 2020; Smith S.D. et al., 2021; Smith S.D., 2022) to minimize cable connection issues and the loss of data.

6.0 REFERENCES

- Air Force Research Laboratory, *Instruction 61-103, Scientific /Research and Development, AFRL Research Test Management*, AFRLI 61-103, 28 Oct 2015.
- Couvreur, C., *FILTBANK - One-Third-Octave Band Frequency Analyzer* [computer program, MATLAB®], Faculte Polytechnique de Mons, Belgium, 1997.
- Fromm R, Duvall J., “Medical aspects of flight for civilian aeromedical transport,” *Probl Crit Care*, 1990, **4**, pp. 495-507.
- International Organization for Standardization, *Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements*, ISO 2631-1: 1997. Geneva, Switzerland.
- International Organization for Standardization, *Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements-Amendment 1*, ISO 2631-1/Amd1:2010. Geneva, Switzerland.
- Smith S.D., *Aircrew Vibration Exposure Characterization and Health Risk Assessment of the CV-22 Osprey*, AFRL-RH-WP-TR-2023-0070, Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB OH, 2023.
- Smith S.D., *Quantifying Patient Vibration Patterns During Aeromedical Evacuation (AE) Aboard the UH-60L Equipped with the Interim Medevac Mission Support System (IMMSS)*, AFRL-RH-WP-TR-2022-4752, Air Force Research Laboratory, Airman Systems Directorate, Wright-Patterson AFB OH, 2022.
- Smith S.D., Dooley C.J., Burch D.S., *Quantifying Patient Vibration Patterns During C-130J Aeromedical Evacuation (AE)*, AFRL-RH-WP-TR-2021-0016, Air Force Research Laboratory, Airman Systems Directorate, Wright-Patterson AFB OH, 2021.
- Smith, S. D., Dooley, C. J., Burch, D. S. *Quantifying Patient Vibration Patterns During Ambulance Bus (AMBUS) Ground Transport*, AFRL-RH-WP-TR-2020-0057, Air Force Research Laboratory, Airman Systems Directorate, Wright-Patterson AFB OH, 2020.
- Smith S.D., Burch D.S., Fouts B.L., *Quantifying Patient Vibration Patterns During Aeromedical Evacuation Aboard the C-130H*, AFRL-RH-WP-TR-2019-0086, Air Force Research Laboratory, Airman Systems Directorate, Wright-Patterson AFB OH, 2019.
- Welch P.D., “The Use of Fast Fourier Transform for the Estimation of Power spectra: A method Based on Time Averaging Over Short, Modified Periodograms,” *IEEE Trans. Audio Electroacoust.*, **AU-15**, Jun 1967, pp. 70-73.

APPENDIX: RESULTS – FIGURES AND TABLES

LIST OF FIGURES

Figure A- 1. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in APLN Mode (10K ft MSL) at the Forward Litter A 23

Figure A- 2. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in APLN Mode (10K ft MSL) at the Aft Litter B 24

Figure A- 3. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in CONV Mode (500 ft AGL) at the Forward Litter A 25

Figure A- 4. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in CONV Mode (500 ft AGL) at the Aft Litter B 26

Figure A- 5. Mean Overall Unweighted Accelerations \pm One Standard Deviation at the CV-22 Forward Patient Litter A 27

Figure A- 6. Mean Overall Unweighted Accelerations \pm One Standard Deviation at the CV-22 Aft Patient Litter B 28

Figure A- 7. Mean Overall Unweighted Accelerations \pm One Standard Deviation at the CV-22 Floor Beneath Litters A and B 29

Figure A- 8. Mean Unweighted and Weighted Overall Accelerations and pVTVs \pm One Standard Deviation During Cruise APLN and CONV Modes – Forward Patient Litter A 30

Figure A- 9. Mean Unweighted and Weighted Overall Accelerations and pVTVs \pm One Standard Deviation During Cruise APLN and CONV Modes -Aft Patient Litter B 31

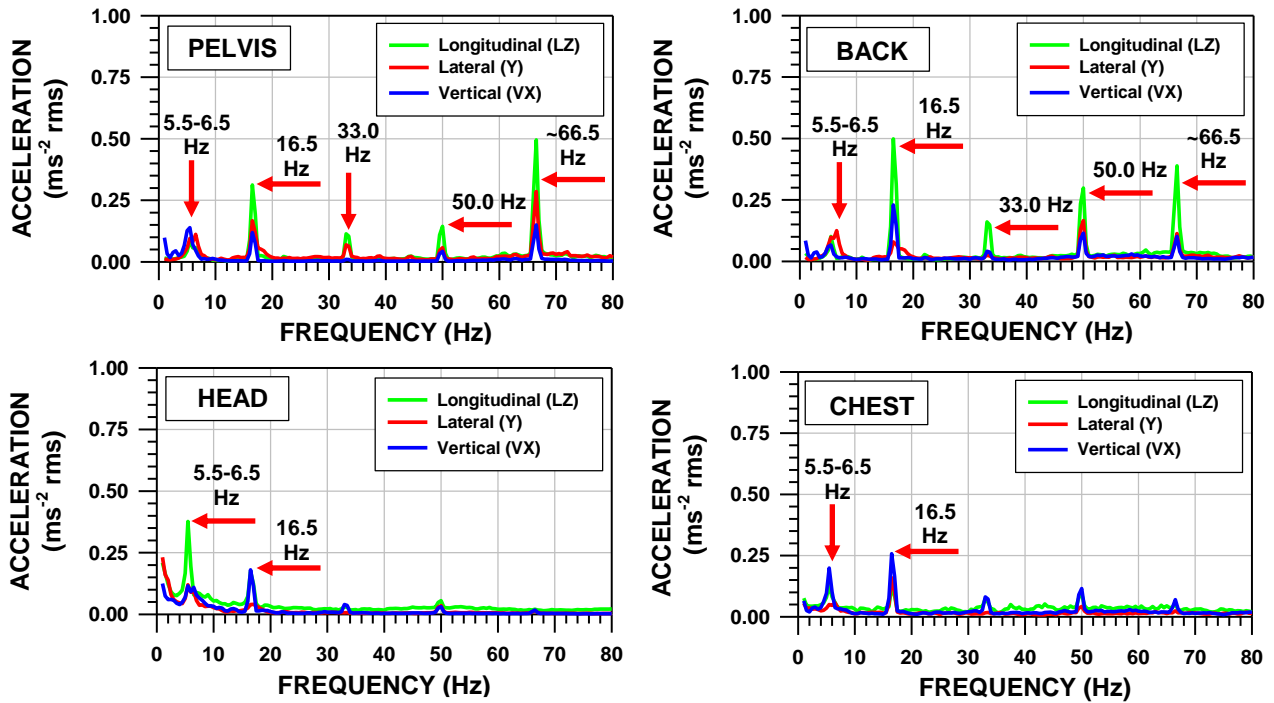
Figure A- 10. Mean Overall Weighted Accelerations and pVTVs \pm One Standard Deviation for Assessing Comfort Reaction (ISO 2631-1) at the CV-22 Forward Patient Litter A 32

Figure A- 11. Mean Overall Weighted Accelerations and pVTVs \pm One Standard Deviation for Assessing Comfort Reaction (ISO 2631-1) at the CV-22 Aft Patient Litter B 33

LIST OF TABLES

Table A- 1. REVER Component Details 34

AVSS ON APLN MODE 10K FT MSL



AVSS OFF APLN MODE 10K FT MSL

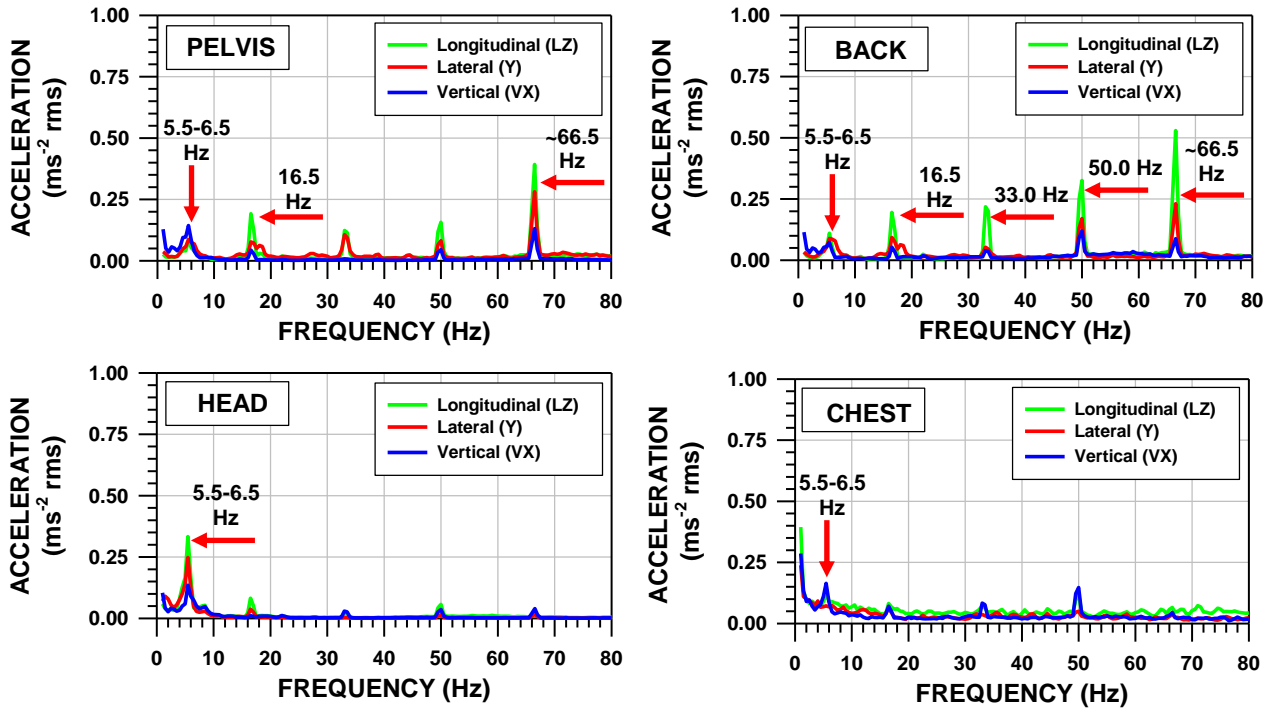
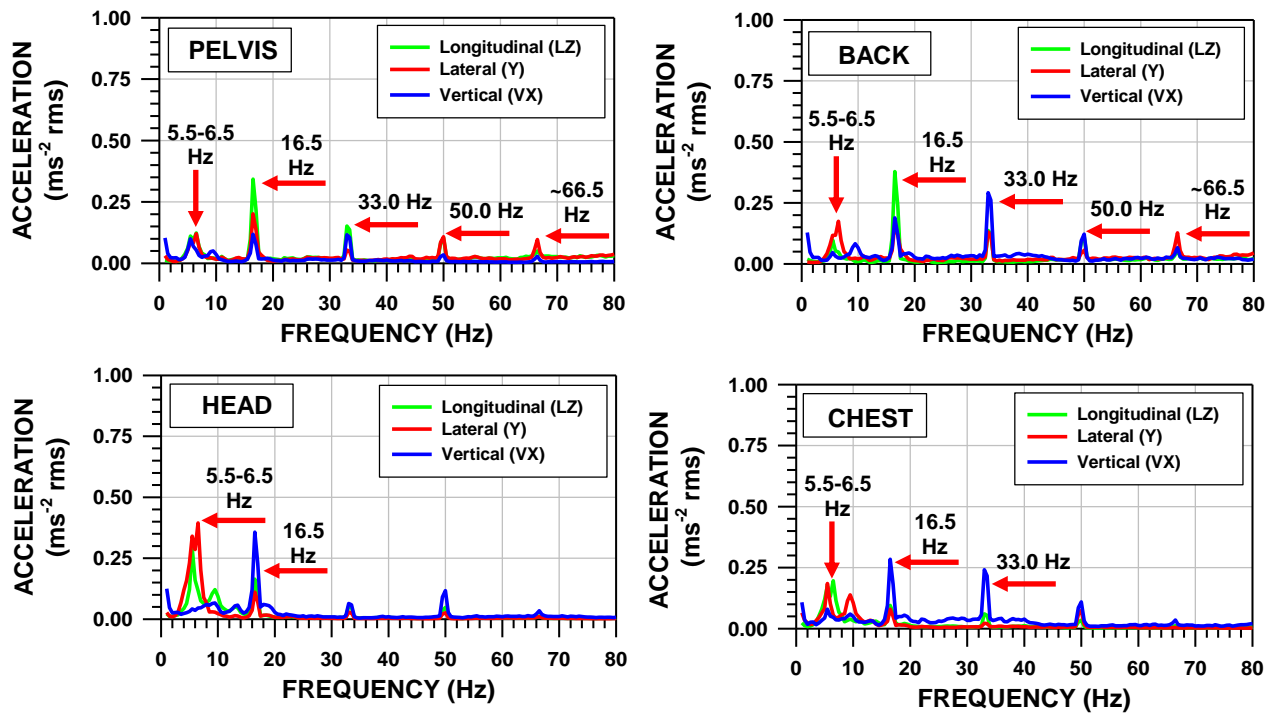


Figure A- 1. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in APLN Mode (10K ft MSL) at the Forward Litter A

AVSS ON APLN MODE 10K FT MSL



AVSS OFF APLN MODE 10K FT MSL

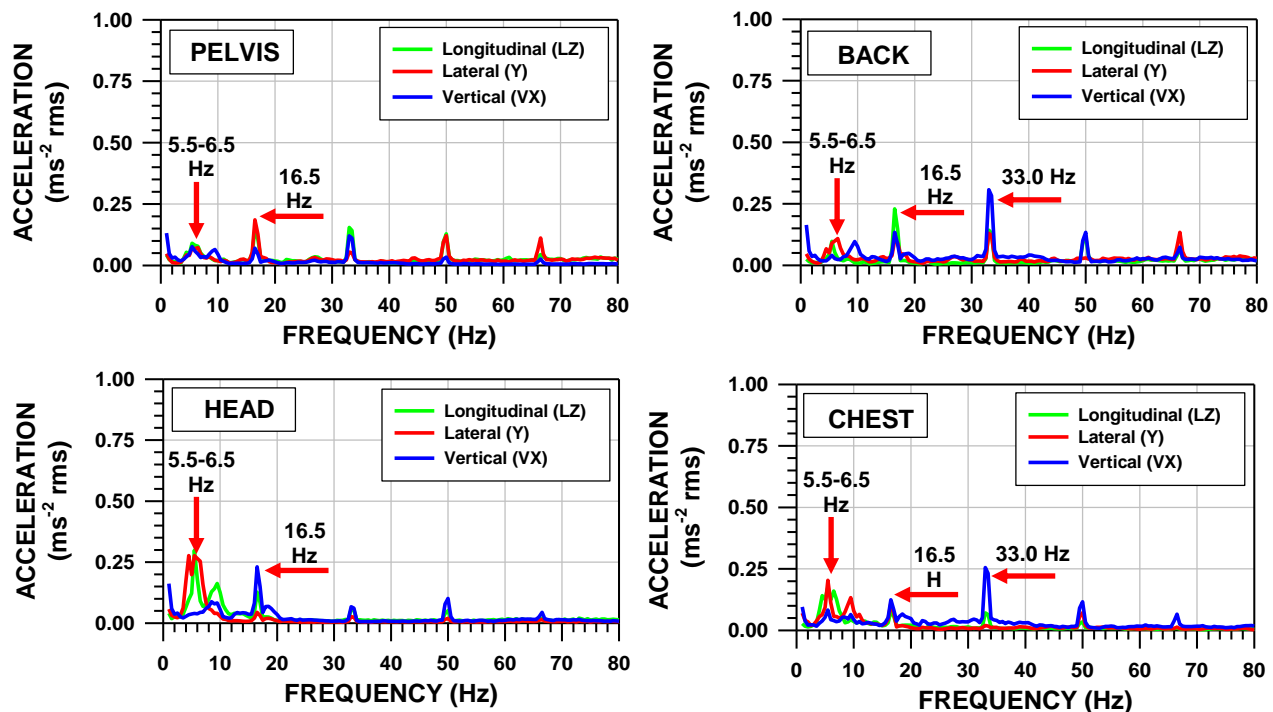
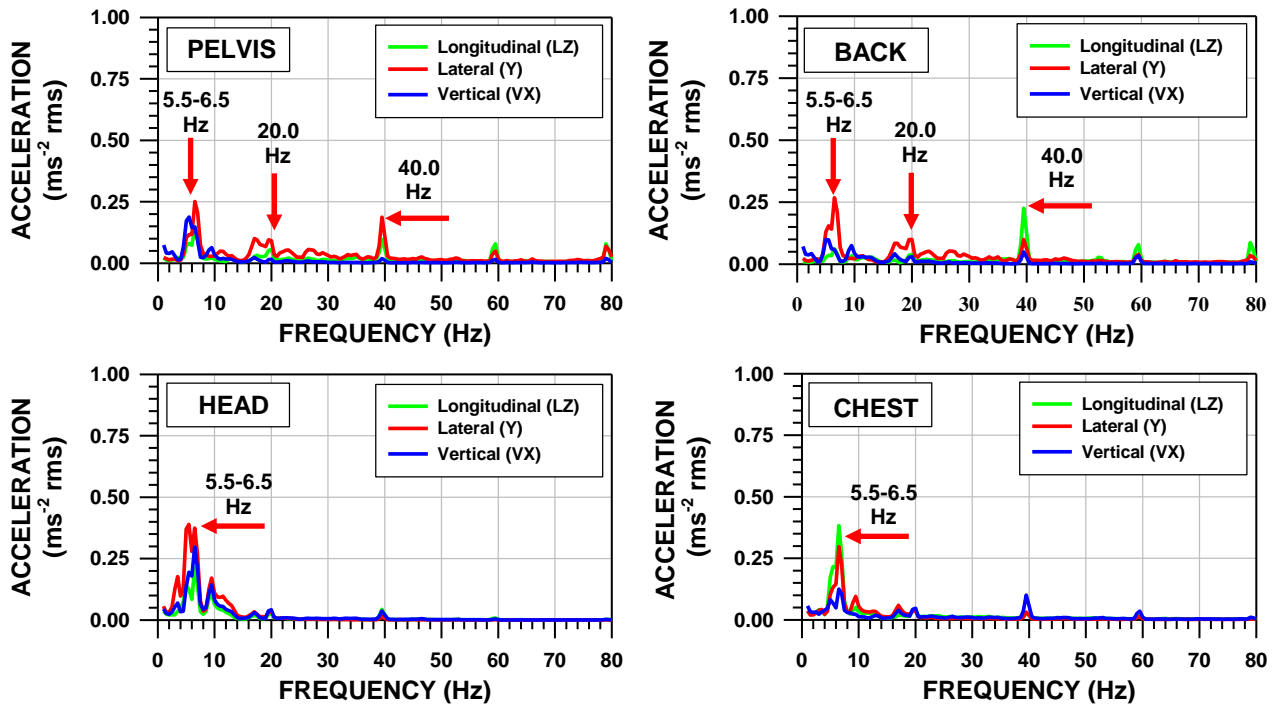


Figure A- 2. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in APLN Mode (10K ft MSL) at the Aft Litter B

AVSS ON CONV MODE 500 FT AGL NACELLE 80°



AVSS ON CONV MODE 500 FT AGL NACELLE 60°

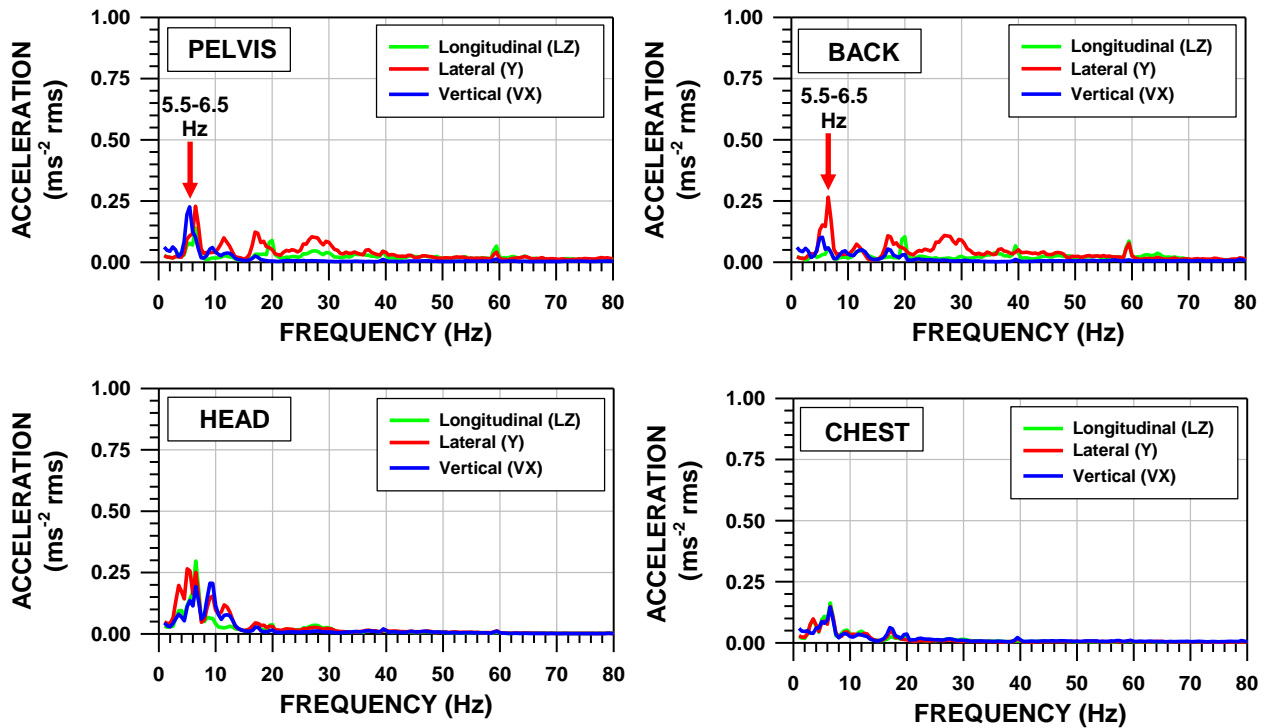
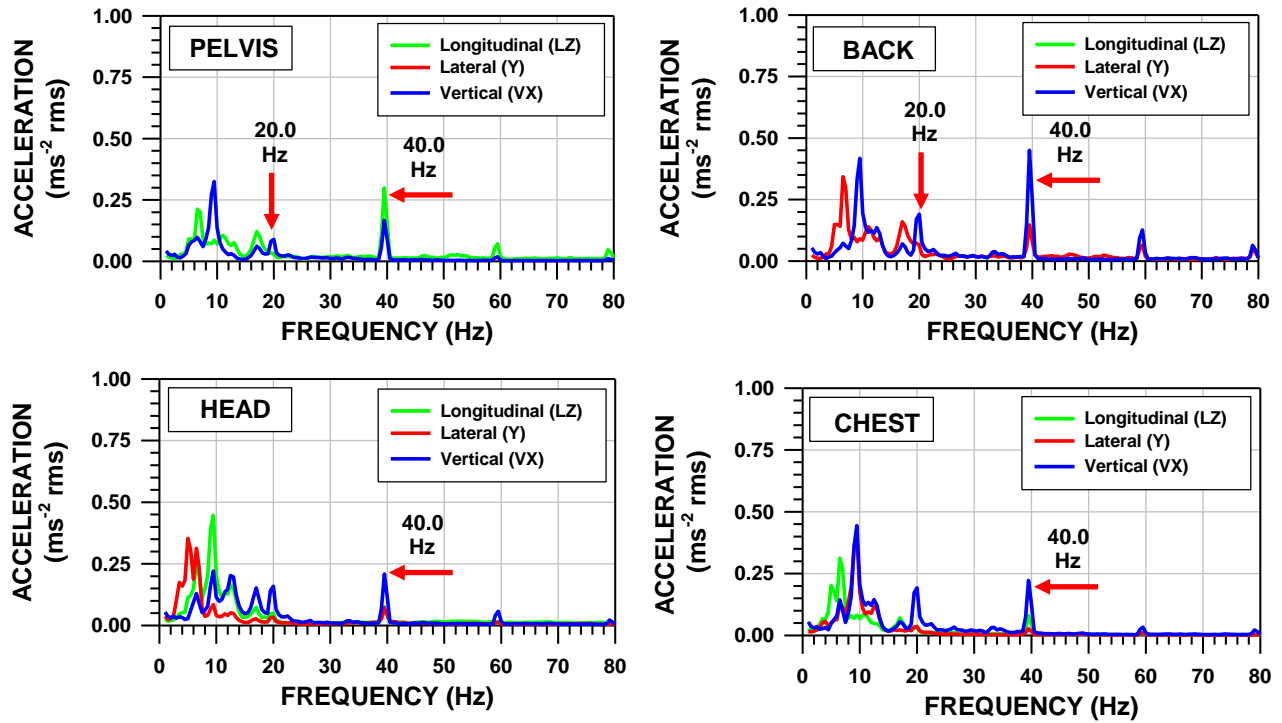


Figure A- 3. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in CONV Mode (500 ft AGL) at the Forward Litter A

AVSS ON CONV MODE 500 FT AGL NACELLE 80°



AVSS ON CONV MODE 500 FT AGL NACELLE 60°

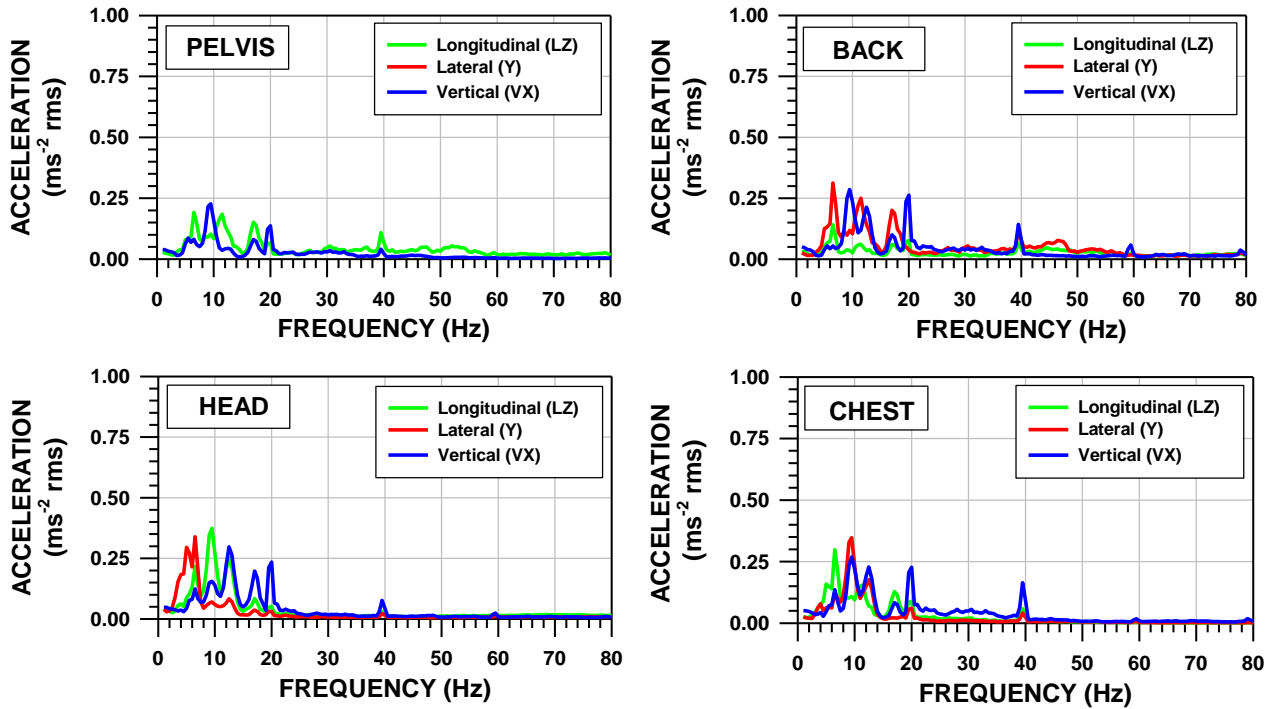


Figure A- 4. Example of the CV-22 Unweighted Multi-Axis Acceleration Spectra During Cruise Flight in CONV Mode (500 ft AGL) at the Aft Litter B

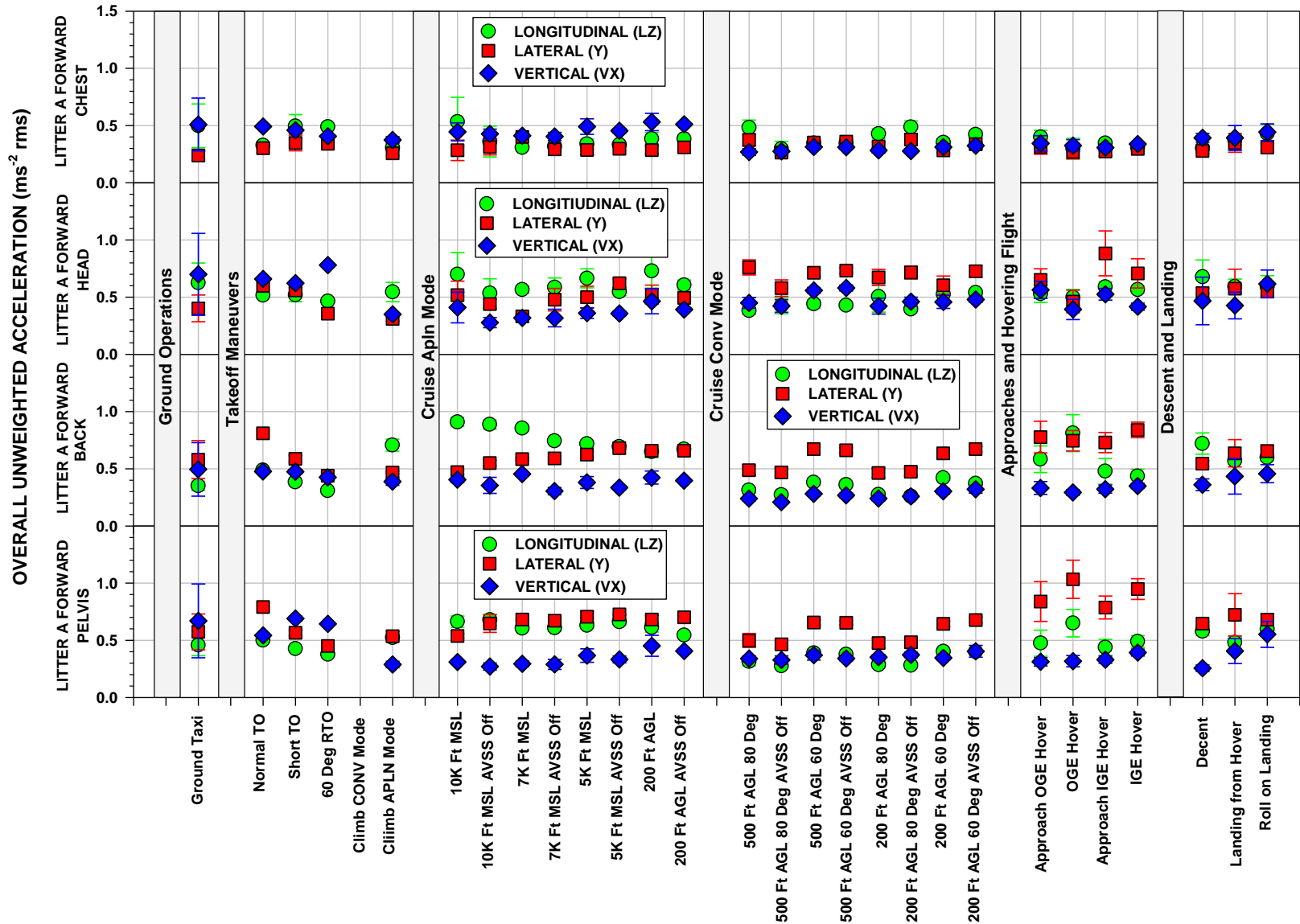


Figure A- 5. Mean Overall Unweighted Accelerations \pm One Standard Deviation at the CV-22 Forward Patient Litter A

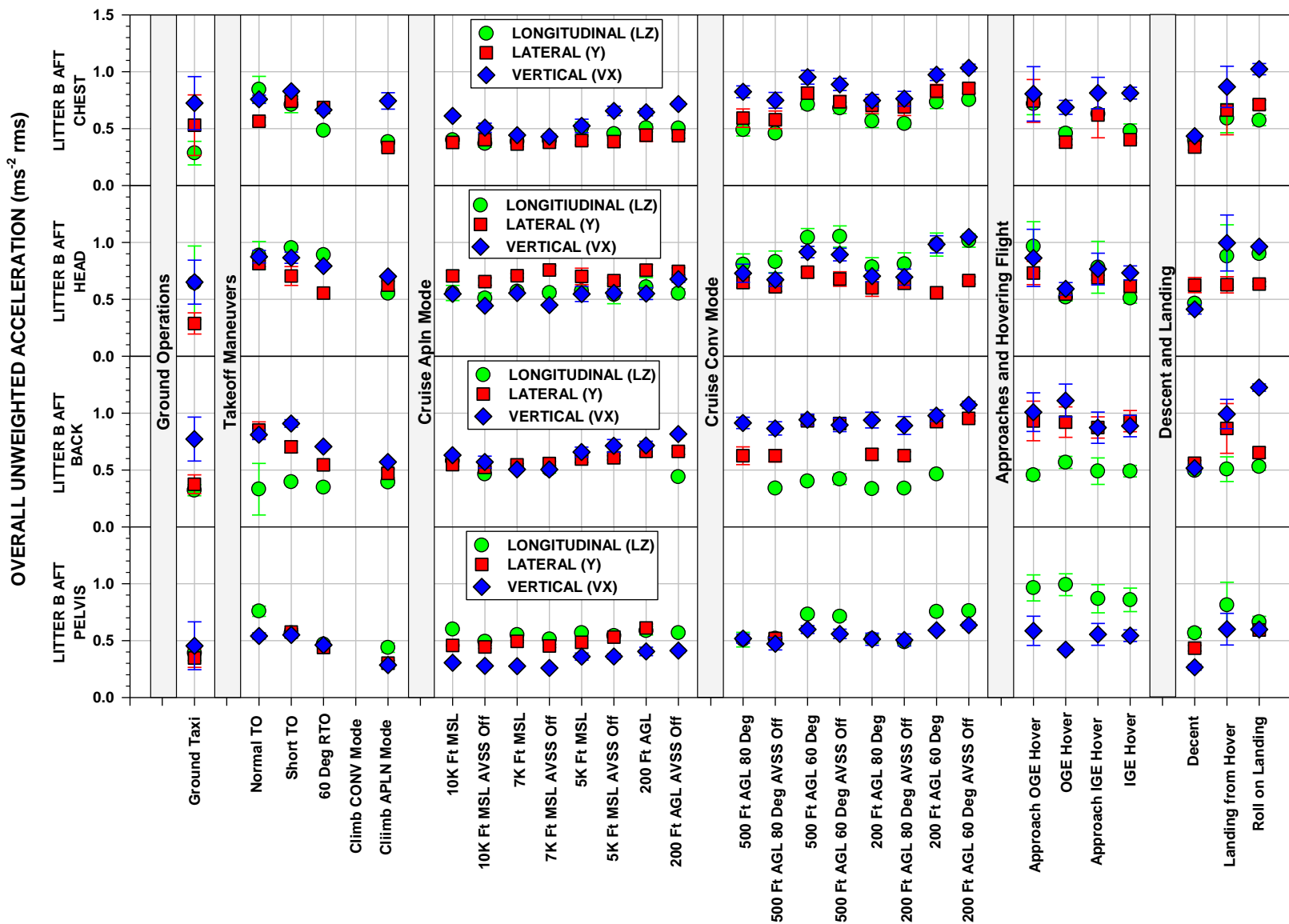


Figure A- 6. Mean Overall Unweighted Accelerations \pm One Standard Deviation at the CV-22 Aft Patient Litter B

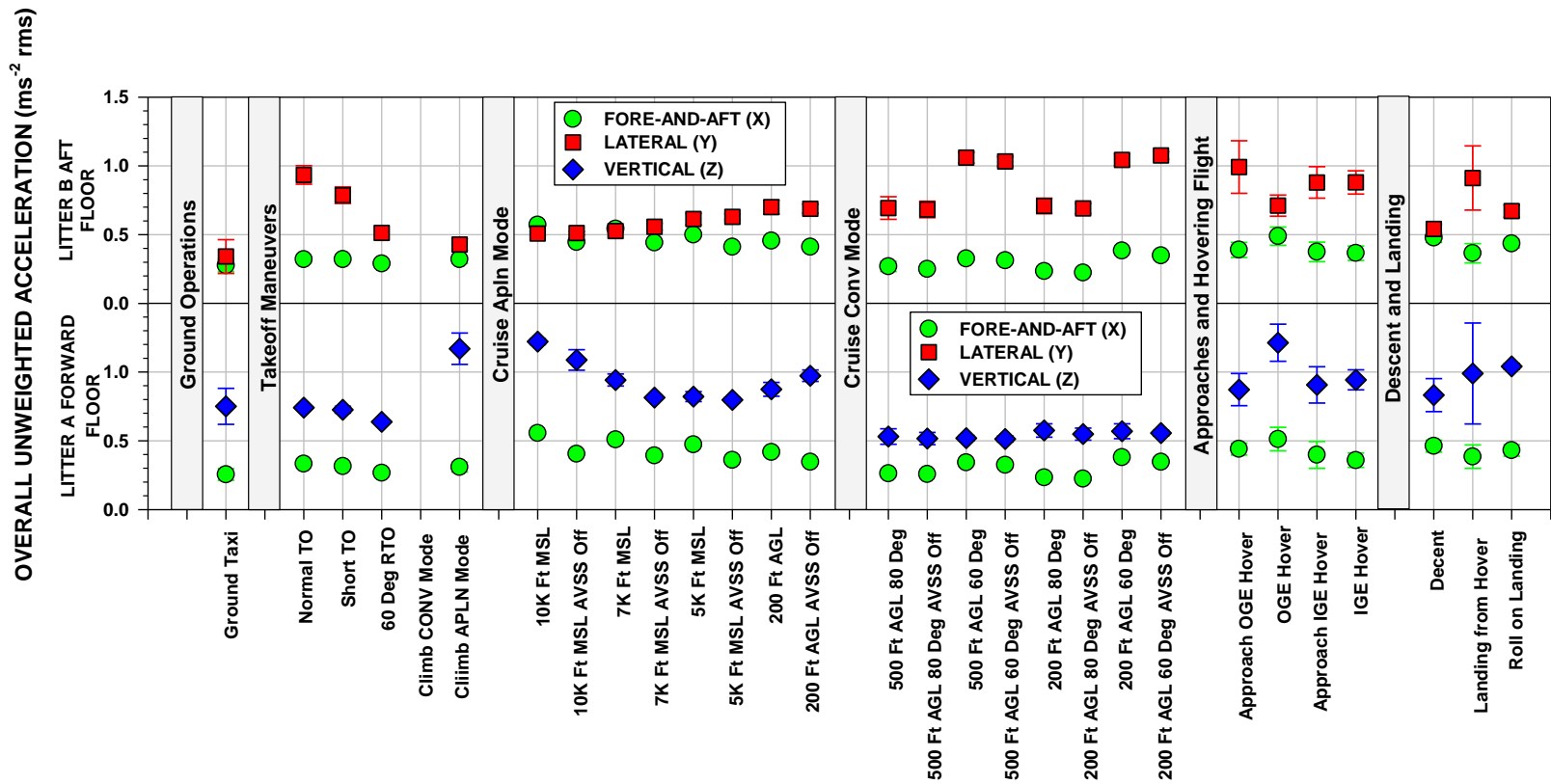


Figure A- 7. Mean Overall Unweighted Accelerations \pm One Standard Deviation at the CV-22 Floor Beneath Litters A and B

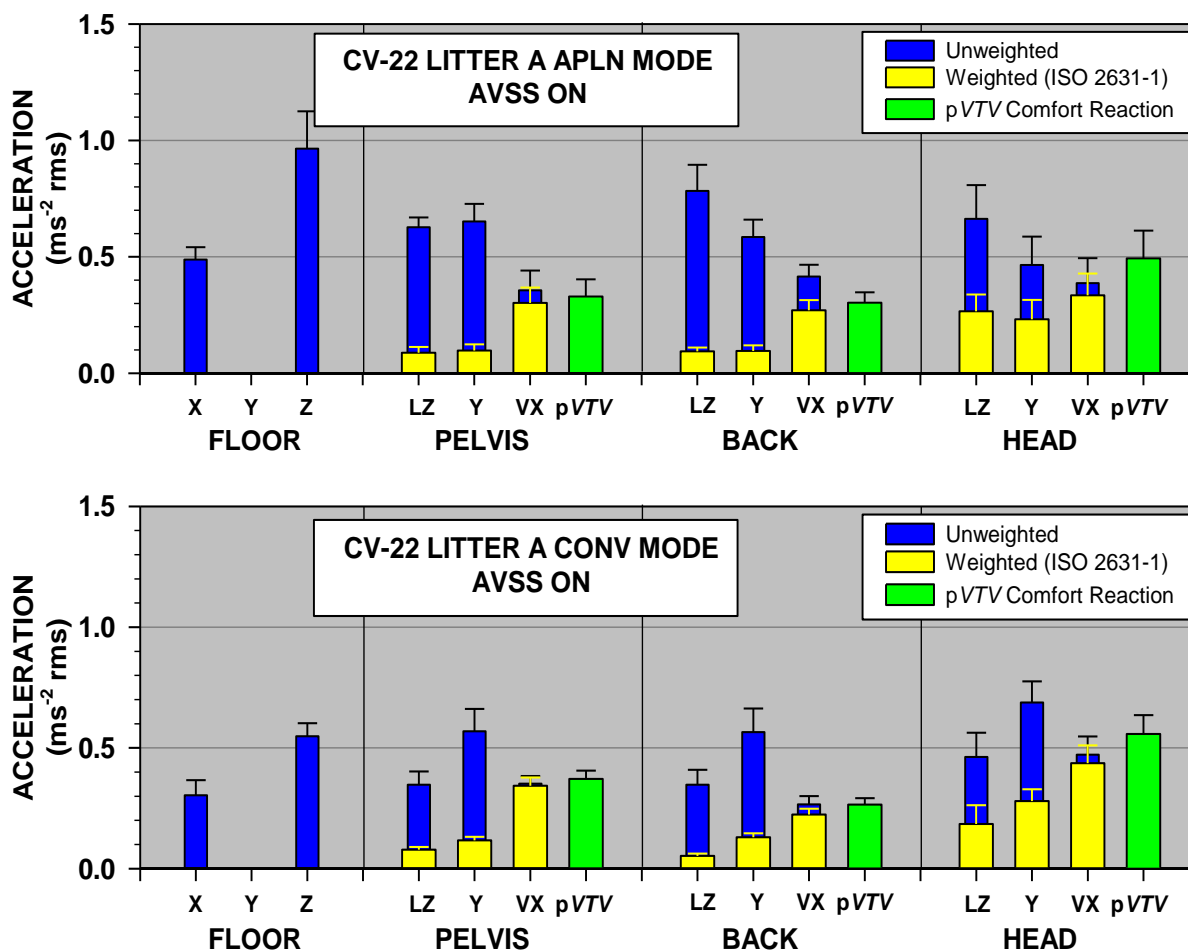


Figure A- 8. Mean Unweighted and Weighted Overall Accelerations and pVTVs ± One Standard Deviation During Cruise APLN and CONV Modes – Forward Patient Litter A

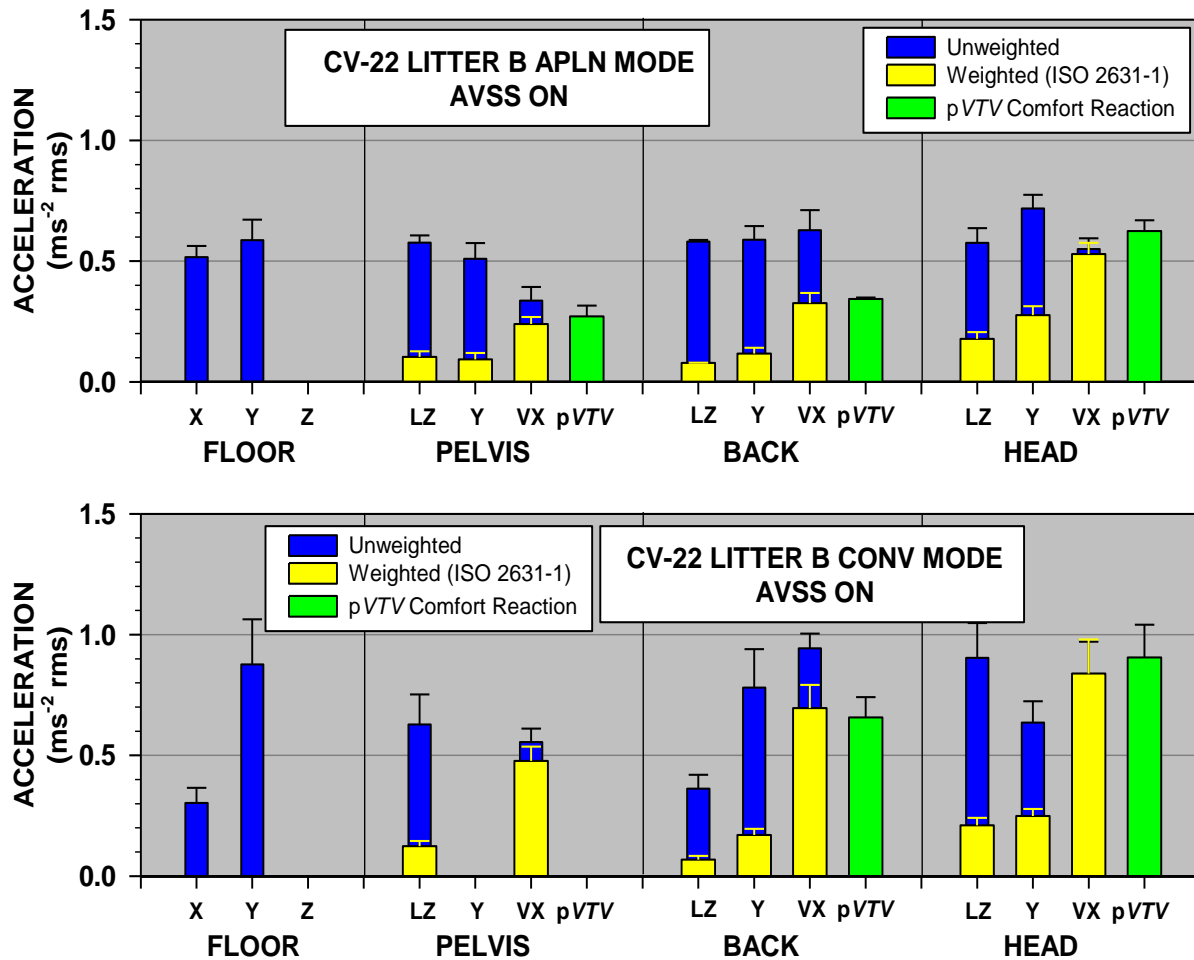


Figure A- 9. Mean Unweighted and Weighted Overall Accelerations and pVTVs ± One Standard Deviation During Cruise APLN and CONV Modes - Aft Patient Litter B

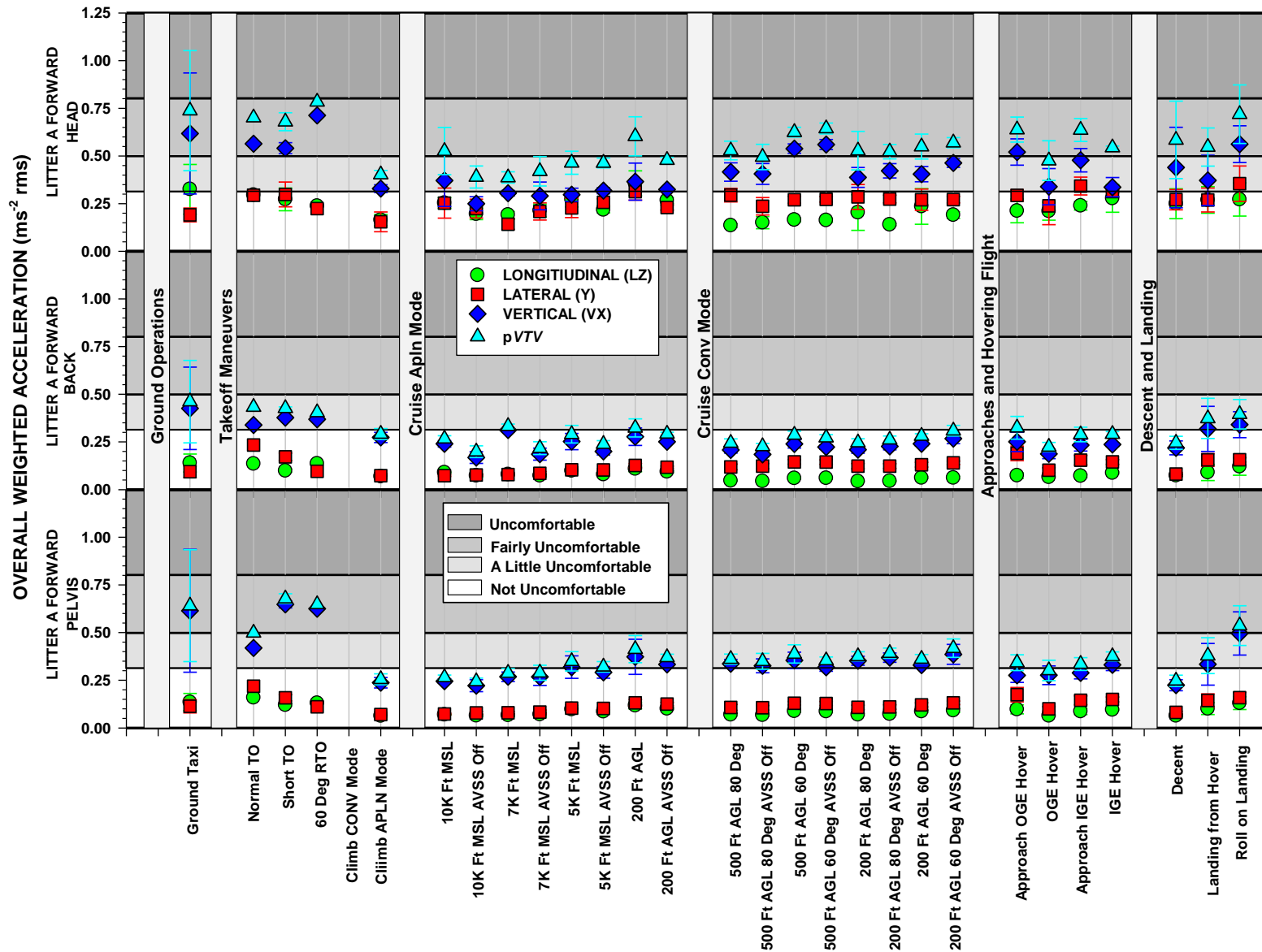


Figure A- 10. Mean Overall Weighted Accelerations and pVTVs \pm One Standard Deviation for Assessing Comfort Reaction (ISO 2631-1) at the CV-22 Forward Patient Litter A

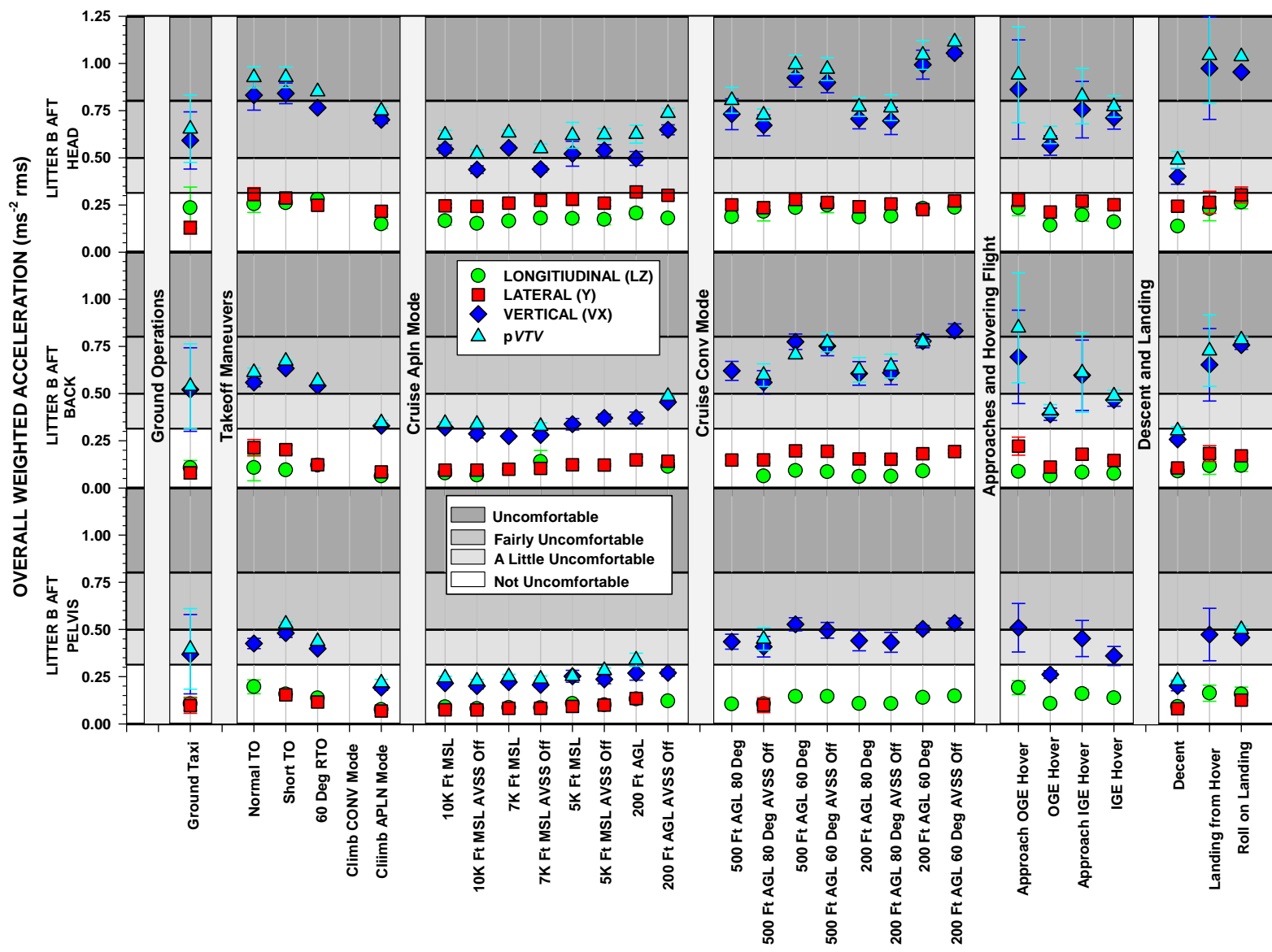


Figure A- 11. Mean Overall Weighted Accelerations and pVTVs \pm One Standard Deviation for Assessing Comfort Reaction (ISO 2631-1) at the CV-22 Aft Patient Litter B

Table A- 1. REVER Component Details

Component	Dimensions (L/W/H cm)	Weight (Kg)
Small DAUs	9.5/7.0/2.8	0.370 w/cables
Large Batteries	10.0/7.0/3.5	0.645
Small Batteries	9.0/5.0/3.5	0.395
Accelerometer Packs (Entran EGAX-25; TE Connectivity/Masurement Specialties EGAXT-25)	1.9 (diameter) 0.86 (thickness)	0.005 (0.060 w/ cable)
Accelerometer Pad (Entran EGAX-25; TE Connectivity/Masurement Specialties EGAXT-25)	(Ride Quality Meter, RQM) 20.0 (diameter)	0.340 w/ cables
Triggers	7.6 (length) 2.2 (diameter)	0.030 w/cable

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

711 HPW	711th Human Performance Wing
ACGIH	American Conference of Governmental Industrial Hygienist
AE	Aeromedical Evacuation
AFB	Air Force Base
AGL	Above Ground Level
AFMS	Air Force Medical Service
AMC	Air Mobility Command
APLN	Airplane
APHC	Army Public Health Center
AFRL	Air Force Research Laboratory
AFSOC	Air Force Special Operations Command
AVSS	Active Vibration Suppression System
BPF	Blade Passage Frequency
CBDN	Collaborative Biomechanics Data Network
CONV	Conversion
DAU	Data Acquisition Units
DHA RDA	Defense Health Agency, Research, Development, and Acquisition
DHP	Defense Health Program
FLTS	Flight Test Squadron
Hz	Hertz (cycles per second)
IGE	In Ground Effect
ISO	International Organization for Standardization
JPC-6/CCCRP	Joint Program Committee 6/Combat Casualty Care Research Program
J-ERC	Joint En Route Care
K	One Thousand (1000)
MSL	Mean Sea Level
OGE	Out of Ground Effect
PRF	Propeller Rotation Frequency
REVER	Remote Vibration Environment Recorder
RH	Human Effectiveness Directorate
SOS	Special Operations Squadron
RPM	Revolutions per Minute
SOW	Special Operations Wing
ft	feet
ms ⁻²	meters per second squared
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)
$pVTV$	Point Vibration Total Value
W	Frequency Weighting (ISO 2631-1)

VX Vertical axis or direction of supine occupant (spine-chest)
Y Lateral axis or direction of supine occupant
LZ Longitudinal axis or direction of supine occupant (feet-head)