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QUANTIFYING PATIENT VIBRATION PATTERNS DURING C-130J AEROMEDICAL EVACUATION (AE)

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14. ABSTRACT The overall purpose of this flight test program was to collect human engineering data on the six-bladed C-130J to characterize and assess the exposure of patients to vibration during aeromedical evacuation (AE). The aircraft was owned and operated by the 146 Airlift Wing, Air National Guard Aeromedical Evacuation Squadron located at Channel Islands, CA. The Remote Vibration Environment Recorder (REVER) was used to collect tri-axial acceleration data in the forward and aft cabin at the back/pelvis interfaces, chest, head, and leg of the supine litter patient at two tier levels, and at the seat pan, seat back, chest, and leg of the seated patient. Flight conditions included Taxi, Take Off, Climb, Level Flight, Descent, and Landing. All measurement sites showed a major spectral peak in the three directions at approximately 102 Hz, the blade passage frequency of the C-130J. Higher levels of vibration occurred in the forward cabin in the vicinity of the propeller plane. For the litter patients, the highest overall unweighted accelerations occurred in the horizontal directions at the Tier 1 pelvis interface, and in primarily the lateral direction at both Tier 3 interfaces. The pelvis lateral vibration was significantly higher at Tier 3 as compared to Tier 1. For the seated patient, the highest overall unweighted levels occurred in the horizontal directions at the seat pan. Both litter and seated patients showed notable damping of the vibration at the chest and head (litter only) as compared to the interfaces. All measurement sites showed evidence of lower frequency vibration below 10 Hz during Taxi, Take Off, and Landing. The overall weighted accelerations used to assess comfort indicated that the exposures would primarily be considered "not uncomfortable" (ISO 2631-1: 1997). While the comfort thresholds could be dramatically lower in the injured patient, the results of this study suggest that transport aboard the fixed-wing C-130J propeller aircraft is not a threat to the health outcome of patients, particularly during airborne flight activity. However, any lower frequency vibration resulting from intermittent turbulence could exacerbate injury, particularly to the spine and head, without proper restraint. It is recommended that patients with more severe injuries be located aft of the propeller plane and patients with head/spine injuries be appropriately restrained to mitigate any low frequency vibration and minimize negative health outcomes.

15. SUBJECT TERMS Human Vibration, Military En-Route Care, Military Emergency Evacuation

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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 are used to conduct a comfort assessment of the exposures in accordance with existing standards. The data are also used to identify specific issues regarding the litter system and seats that may significantly affect the transmission of vibration and motion and exacerbate patient condition. This particular study focused on litter patient and seated patient vibration during aeromedical transport aboard the C-130J.

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 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 is being 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 C-130J aircraft was owned and operated by the 146 Airlift Wing, Air National Guard Aeromedical Evacuation Squadron located at Channel Islands, CA. The Remote Vibration Environment Recorder (REVER) was used to collect tri-axial acceleration data at the back/pelvis interfaces, chest, head, and leg of the supine litter patient, and at the seat pan, seat back, chest, and leg of the seated patient, located in the forward and aft cabin sections. Litter Tiers 1 and 3 were included. Flight conditions included Taxi, Take Off, Climb, Level Flight, Descent, and Landing. All measurement sites showed a major spectral peak in the three directions at approximately 102 Hertz (cycles per second) (Hz) that was associated with the blade passage frequency of the aircraft. The highest vibration occurred in the forward cabin in the vicinity of the propeller plane. Specifically, for the litter patients, the highest overall unweighted accelerations occurred in the horizontal directions of the aircraft at the Tier 1 pelvis interface, and in primarily the lateral direction a both Tier 3 interfaces. The pelvis lateral vibration was significantly higher at Tier 3 as compared to Tier 1. For the seated patient, the highest unweighted levels occurred in the horizontal directions at the seat pan. Both litter and seated patients showed notable damping of the vibration at the chest and head (litter only) as compared to the interfaces. However, all measurement sites showed evidence of lower frequency vibration below 10 Hz during Taxi, Take Off, and Landing. The overall weighted accelerations used to assess comfort indicated that the exposures would primarily be considered "not uncomfortable" (ISO 2631-1: 1997). While the comfort thresholds could be dramatically lower in the injured patient, the results of this study suggest that transport aboard the fixed-wing C-130J propeller aircraft is not a threat to the health outcome of patients, particularly during airborne flight activity. However, any lower frequency vibration resulting from intermittent turbulence could exacerbate injury, particularly to the spine and head, without proper restraint. It is recommended that patients with more severe injuries be located aft of the propeller plane and patients with

head/spine injuries be appropriately restrained to mitigate any low frequency vibration and minimize negative health outcomes.

The methods and procedures established in this study will help set the precedent for future operational and research activity related to AE and en route care with regard to vibration and motion encountered during patient transport aboard both military and civilian air and ground vehicles. The data gathered during this study can be used to re-create the patient/interface vibration in the laboratory for studying specific biodynamic, physiological, and psychological effects in a controlled environment, developing and evaluating mitigation strategies and equipment design options, and establishing appropriate standards and criteria for assessing patient exposures to transport vibration.

2.0 INTRODUCTION

Vibration is defined as a repeating, alternating, or oscillatory mechanical motion of a body about the point of equilibrium. The major internal source of vibration during aircraft flight is the propulsion system. The major external source of vibration during aircraft flight is aerodynamic turbulence. As one of the stressors of flight, vibration can affect occupant physical, physiological, and psychological responses, resulting in increased fatigue, discomfort, and heightened health risks. During AE, patients and medical monitoring equipment are exposed to vibration that could not only exacerbate the 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.

Three 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; and the third study targeted the Ambulance Bus (AMBUS) ground vehicle (Smith S. D. et al., 2019). This report documents the patient vibration measured aboard the C-130J during flight conditions representative of AE.

The first step in these studies was to clearly characterize the actual human multi-axis vibration exposure for both the supine litter patient and seated patient (C-130H/J only). The data were used to identify the frequency components, acceleration magnitudes, and direction of the vibration entering the occupant at the patient/litter and patient/seat interfaces, and to characterize the vibration transmitted to major patient body parts (such as the head, chest, and leg). 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. However, guidance on the assessment of health risk is currently limited to the seated posture 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 C-130J.
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

3.1 Overview

The AFRL 711 HPW, as the Responsible Test Organization (RTO), Participating Test Organization (PTO), and Lead Test Organization (LTO), 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). The study was approved by the 711 HPW Institutional Review Board (IRB) for human use. The aircraft was provided by the 146 Airlift Wing, Air National Guard Aeromedical Evacuation Squadron located at Channel Islands, CA. The Wing supports the Air Force Critical Care Air Transport (CCAT) AE training mission. Figure 1 illustrates the C-130J aircraft. Figure 2 depicts litter patients in the aft section of the aircraft during AE simulation.

Figure 1. C-130J Super Hercules Aircraft

The major difference between the C-130J and the C-130H is that the C-130J includes six blades on each of two engines as compared to four blades on each of two engines. As a result, while the propeller rotation frequency is similar on both aircraft (~17 Hz), the blade passage frequency associated with the C-130J (102 Hz) is 1.5 times the blade passage frequency associated with the C-130H (68 Hz) or six times the propeller rotation frequency as compared to four times the propeller rotation frequency. The REVER was used to collect the acceleration data aboard the aircraft. The installation of the system components on the litters, seats, and volunteer subject patients was identical to the installation on the C-130H. The measurement locations were similar on both aircraft. A mockup installation was accomplished using a C-130 AE training fuselage located in Bldg. 840, Area B, Wright-Patterson AFB, in the USAFSAM C-130 Facility.

For Flight Clearance Approval, the Air Mobility Command, Test and Evaluation, Mobility Test Management Division (HQ AMC/TEA) reviewed and validated the requirement to use REVER aboard C-130 variants (via AF 1067 Modification Proposal) at a Configuration Review Board (CRB), and forwarded the requirement to the Air Force Materiel Command, AF Life Cycle Management Center, Mobility Directorate, C-130 Hercules Division (AFMC AFLCMC/WLN). LCMC/WLN evaluated the requirement at their Configuration Control Board (CCB), and returned their positive recommendation back to AMC for final approval.

Two flights were conducted aboard the C-130J for collecting patient vibration. Three 711 HPW male volunteers of similar height and weight acted as patients; two were dedicated as litter patients, and one was dedicated as the seated patient. Two litters were attached to stanchions along the centerline of the aircraft at Tier 1 and Tier 3 as shown in Figure 2. The seated patient was located in a cloth seat attached to the sidewall of the aircraft. During the first flight, all measurements were obtained for the litter and seated patients located in the forward cabin section on the left side, near the forward side entrance and in the vicinity of the plane of the propeller. Flight 1A included taxi, takeoff, climb, and level flight. Flight 1B included level flight, descent, and landing. Once Flight 1A was completed, the two litters and designated occupants were switched between the two tiers, while the seated occupant remained at the same location. This was done to provide level flight data records at both litter tiers for both patients. During the second flight designated as Flight 2, all measurements were obtained for the litter and seated patients located in the aft cabin section of the aircraft located near the aft side entrance to the

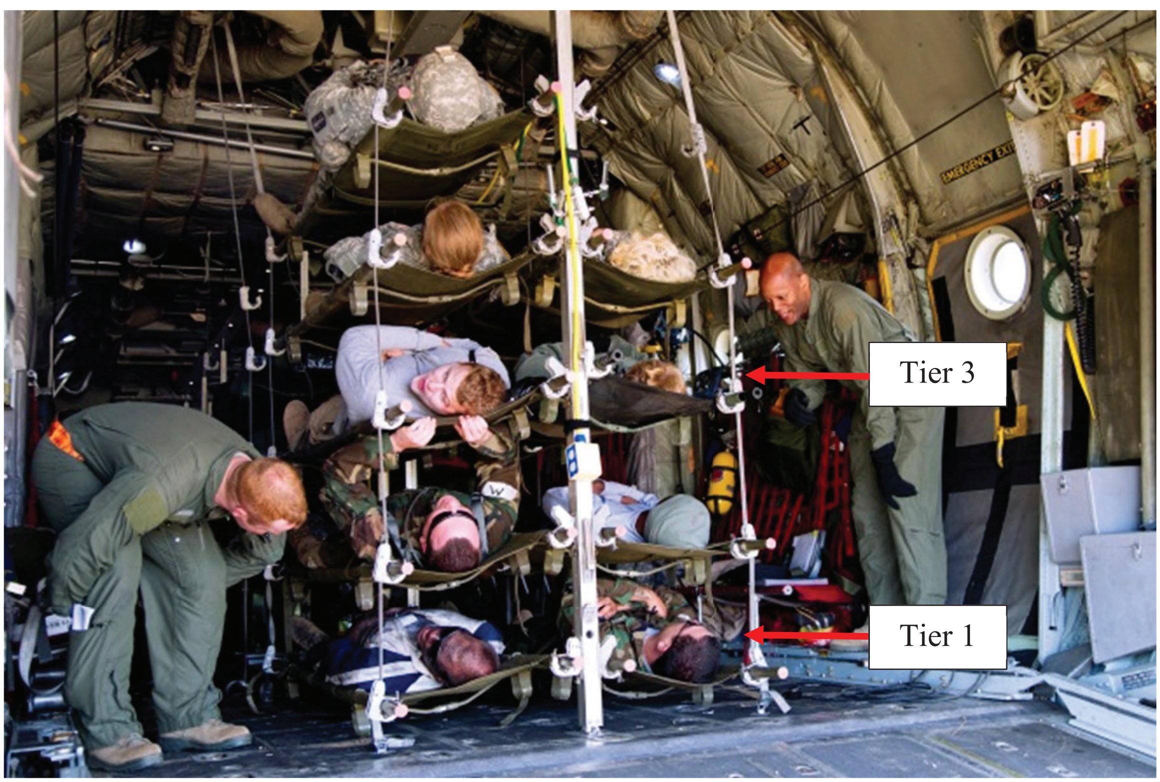

Figure 2. Patient Litter Simulation in the Aft Section of the C-130J

aircraft. One litter patient was located at Tier 1, and the second litter patient was located at Tier 3 for the entire flight.

3.2 Equipment, Instrumentation, and Measurement Sites

Three REVERs, developed by the AFRL Human Effectiveness Directorate (711 HPW/RH), were used to collect the multi-axis vibration data during the test flights. Each REVER included the following components (Figure 3):

1. A 16-channel data acquisition unit (DAU)
2. Two battery packs (Large and Small)
3. Triaxial accelerometer packs
4. Triaxial acceleration pads
5. One trigger device
6. Connection/extension cables as required

Specifications for the REVER components, including dimensions and weights, are listed in the Appendix, Table A-1. The 16-channel DAU enclosure is fabricated using Delrin and 606-T6

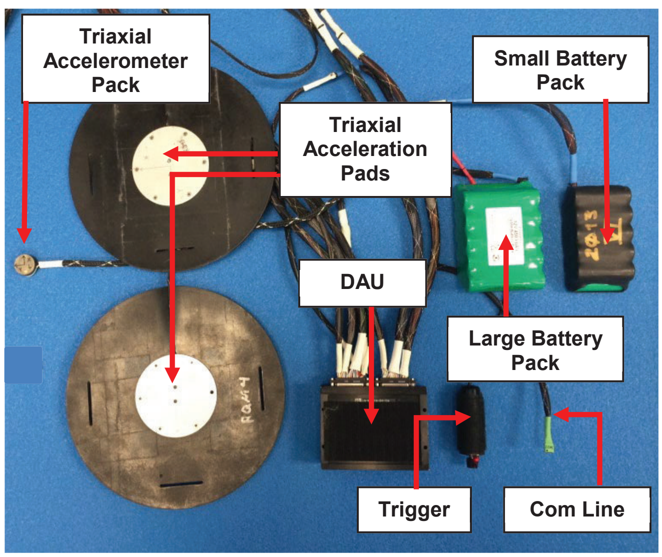

Figure 3. REVER Components

aluminum and provides electromagnetic interference (EMI) shielding (EME Corporation, Arnold, MD). The small battery pack is rated at 12 volts/2.7 amp-hours. The battery will operate for approximately 2.7 hours. The larger battery pack is rated at 12 volts/4.0 ampere (amp)-hours and can operate for approximately 4 hours. Each triaxial accelerometer pack includes three orthogonally-arranged miniature accelerometers (Entran EGAX-25, Entran Devices, Inc., Fairfield, NJ; EGAXT-25, TE Connectivity, Berwyn, PA) embedded in a Delrin® cylinder. Double-sided adhesive tape or mounting tape was used to secure the pack to the appropriate sites. The triaxial acceleration pad is a flat rubber disk that includes an embedded triaxial

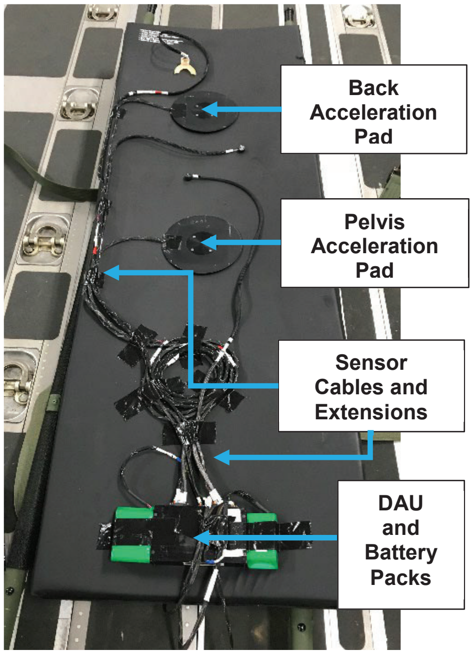

Figure 4. DAU and batteries, back and pelvis acceleration pads attached to litter

accelerometer pack. The pads were secured to occupant interface surfaces using double-side adhesive tape and duct tape. The triaxial acceleration pads were used for measuring the vibration transmitted to the occupant via the litter in accordance with ISO 2631-1: 1997. The triggering device was used to initiate the data collection.

One REVER system (PicoDas DAU, Table A-1) was required for measuring the vibration for each supine patient/litter configuration. Instrumentation of the litter and patient were similar to that used during previous flight tests (Smith et al., 2019). Triaxial acceleration pads were attached to the litter surface using double-sided adhesive tape at the interfaces between the participant's back and pelvis (Figure 4). The DAU and battery packs were attached to the litter between the participant's feet and secured with duct tape (Figure 5). A triaxial pack was attached to a bite bar (Figure 6) using double-sided adhesive tape for measuring head translation. A triaxial pack was directly attached to the participant's chest using double-sided adhesive tape (Figure 7). A triaxial accelerometer pack was also attached to the participant's leg at the top of the knee using double-sided adhesive tape (Figure 5). Packs attached to the body were further secured with medical tape, as necessary. Cables from the bite bar pack, chest pack, back pad, and pelvis pad were secured to the side of the litter using duct tape (Figure 5). 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 participants and test support personnel, particularly in the case of an emergency egress. The participant was restrained using a chest strap and leg strap.

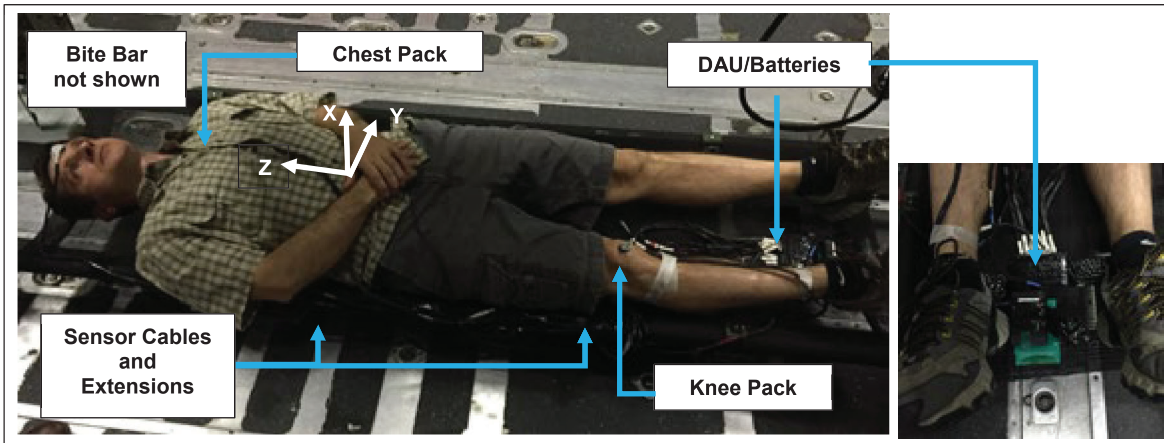

Figure 5. Patient litter configuration

Figure 6. Bite bar with accelerometer pack

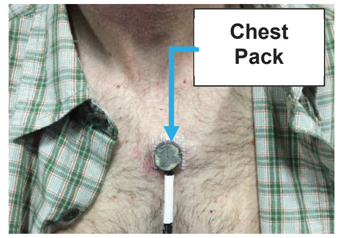

Figure 7. Chest accelerometer pack

A laptop computer system was used for initial calibrations and setup of the instrumentation, and to arm the system prior to the flight test. Specific sensors for each measurement site and direction were assigned to a specific channel in the DAU. Once armed, the computer was disconnected from the DAU and stowed during flight. A triggering device (Figure 3) was used to initiate data collection from each of the three DAUs. Upon completion of the test run, the laptop was reconnected to each DAU and all channels downloaded for subsequent processing.


Figure 8. Patient/Seat Configuration

One REVER system was used to measure vibration of the patient/seat configuration (Figure 8).
The DAU and battery packs were attached to a metal rail that, in turn, was attached to the floor (Figure 8). Triaxial acceleration pads were placed at the interfaces between the participant's buttocks and seat pan and participant's back and seat back (Figure 9). The seat pan pad was attached with double-sided adhesive tape and secured with duct tape. The seat back pad was secured to the seat back webbing using duct tape. A triaxial accelerometer pack was attached directly to the participant's chest using double-sided adhesive tape (Figure 7).

A triaxial accelerometer pack was attached to the leg at the top of the knee and to the rail located beneath the seat (Figures 8 and 10). (The accelerations measured at the rail are referred to as the

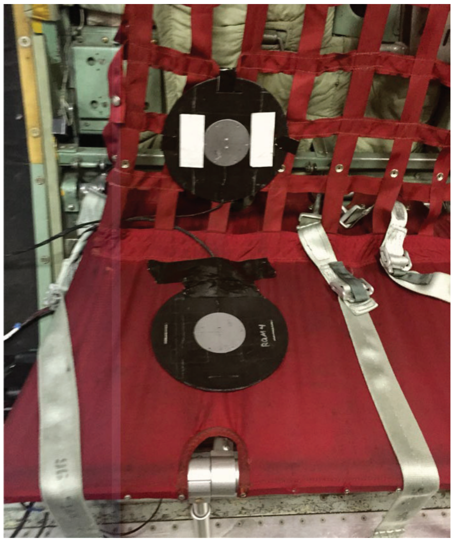

Figure 10. Seat Pan and Seat Back Acceleration Pads

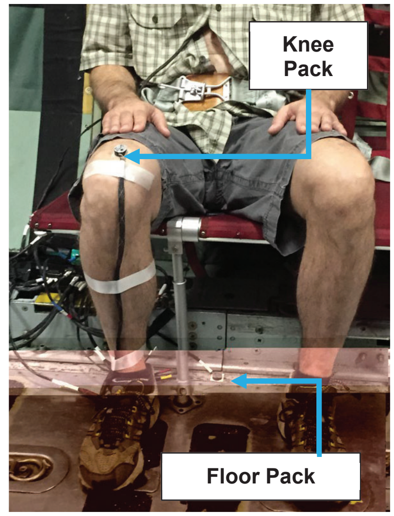

Figure 10. Knee and Floor Accelerometer Packs

floor accelerations throughout the remainder of this report.) Packs attached to the participant were further secured using medical tape as necessary. All cables were routed and secured to avoid any discomfort or hazard to the participant and test support personnel, particularly in the case of an emergency egress. The seated participant was restrained using the available seat restraint system.

A triggering device (Figure 3) was used to initiate data. 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, check sensor calibration, and arm each DAU. The computer was used to assign a specific sensor for each measurement site and direction to a specific channel in the DAU. Once armed, the computer was disconnected from the DAU. Upon return of the aircraft, the laptop was reconnected to the DAU and all channels downloaded for subsequent processing. Table 1 summarizes the final flight test matrix including the patient configurations and locations.

3.3 Data Collection, Processing, and Analysis

3.3.1. Data Collection

During each flight test, acceleration data were collected at the three patient locations and sites for the flight test conditions listed in the Appendix, Table A-2 Number of Test Records per Flight. This included taxi, take-off, climb, level flight at several altitudes, descent, and landing. As mentioned and shown in Table 1, the first flight was divided into two sections, one during the outbound leg (Flight 1A) and one during the return leg (Flight 1B). One AFRL member acted as the test conductor and prompted data collection once the pilot or copilot indicated that the aircraft was on the flight test condition. Multiple data records were collected for several conditions, particularly climb, level flight, and descent, in order to gauge the expected vibration

Table 1. Flight Test Matrix (Three Total Subjects)

Cabin Section	Tier Level/ Seat	Subject	Flight #
Forward	*Tier 1*	*1*	*1A*
	Tier 3	*2*	
	Seat	*3*	
Forward	*Tier 1*	*2*	*1B*
	Tier 3	*1*	
	Seat	*3*	
Aft	*Tier 1*	*2*	*2*
	Tier 3	*1*	
	Seat	*3*	

range. Data records were collected throughout each flight. 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, low-pass filter with a cutoff frequency of 250 Hz, and digitized at 1024 samples per second. Once Flight 1A was completed, the laptop was reconnected to each DAU and the time histories for each channel downloaded to the computer. The two litters were switched between Tiers 1 and 3 and each DAU was erased and reconfigured to collect data during Flight 1B. Upon return of the aircraft, the laptop was reconnected to the DAU, and the Flight 1B data was downloaded. Table A-2 includes the number of records collected for each flight test condition.

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. Since the vibration aboard the C-130J shows a distinct peak at 102 Hz associated with the blade passage frequency (BPF), the processing of the overall unweighted and weighted accelerations included the 100 Hz one-third octave frequency band. The overall unweighted acceleration level, a_{uw}, between 1 and 100 Hz was calculated at each patient location for all measurement sites:

$$a_{uw} = \left[\sum_i a_{rmsi}^2\right]^{1/2} \tag{1}$$

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

The assessment of discomfort (comfort reaction) for both the seated and supine patient followed the guidelines in ISO 2631-1: 1997 and the MIL-STD 1472H, 2020, using the frequency weightings and multiplying factors listed in Table 1 of ISO 2631-1: 1997. It is noted that the X direction of the supine body (spine-chest), denoted as vertical (VX), is in the vertical direction relative to the vehicle and to the seated patient (denoted as the Z-axis), while the Z direction of the supine body, denoted as longitudinal (LZ), is along the longitudinal or long axis of the supine body (feet-head) and corresponds to the longitudinal axis of the aircraft (denoted as the X-axis) and the fore-and-aft direction (denoted as the X-axis) of the seated occupant.

The overall weighted rms acceleration level, a_w, was calculated between 1 and 100 Hz in each axis (X, Y, and Z) relative to the coordinate system defined for the supine and seated occupants:

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

where *j* represents the particular frequency weighting (*d*, *k*, *c*, or *j*) depending on the location and direction, *i* represents the *ith* frequency component, and a_{rmsi} is the measured one-third octave acceleration level at center frequency *i*. While ISO 2631-1 does not use the weighted back interface accelerations for assessing comfort of the supine occupant, it was done for this study for comparison to the weighted pelvis accelerations. In addition, the ISO 2631-1 only recommends the weighting of the vertical head acceleration using W_j for the supine occupant, but does not provide specific guidance on comfort based on the head weighted value. In this study, the lateral (Y) and longitudinal (LZ), or horizontal, head accelerations for the supine patient were also weighted using W_d. For assessing comfort reaction, the point vibration total value (*pVTV*) was calculated as the vector sum of the overall weighted VX, Y, and LZ accelerations for the litter patient, and the X, Y, and Z accelerations for the seated patient, after applying the appropriate multiplying factors:

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

The overall vibration total value (*oVTV)* for the seated patient was calculated as the vector sum of the seat pan and seat back *pVTVs*, as defined in ISO 2631-1. The *pVTVs* and *oVTV*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".

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 RESULTS

All figures and tables referred to in this section are located in the Appendix. A review of the time history data indicated that several records were associated with corrupted sensors at certain measurement sites. The corrupted data were eliminated and are annotated on the plots of the overall unweighted acceleration levels. Other records showed isolated spikes in the acceleration time history that were associated with sudden voluntary movement of the patient and not the vehicle vibration. These excluded data records are annotated in Table A-2. The results do not include the data collected at the leg for either the litter or seated patients. It is noted that the seated subject is oriented 90 degrees from the longitudinal axis of the aircraft. All measurements at the seat location are relative to the subject coordinate system. Therefore, the fore-and-aft (X) direction of the seat and subject are oriented in the lateral direction of the aircraft, while the lateral (Y) direction of the seat and subject are oriented along the longitudinal axis of the aircraft.

4.1 Characteristics of the C-130J Acceleration Spectra

It was expected that peaks in the acceleration spectra would occur in the vicinity of the propeller rotation frequency (PRF) and the BPF associated with the aircraft propulsion system. The BPF is equal to the number of blades times the PRF. The PRF for the C-130J is 17 Hz. The BPF is 102 Hz. Vibration associated with these peaks were expected to persist throughout the flight. Lower frequency peaks below 10 Hz could occur if the aircraft encountered turbulence during collection of the data. Figures A-1 through A-3 illustrate examples of the spectra occurring at the Tier 1 litter, Tier 3 litter, and seat, respectively, at selected measurement sites during level flight at 24K feet (ft) Mean Sea Level (MSL) in the forward cabin (Flight 1A). For the illustrated examples, at Tier 1, the most prominent BPF peak was observed at the pelvis (Figure A-1). Tier 3 showed prominent peaks associated with the BPF at both the pelvis and back interfaces, particularly in the Y direction (Figure A-2). The BPF peaks at the chest and head of the litter patients were notably lower as compared to the pelvis at both tiers. Small peaks were observed at the measurement sites in the vicinity of the PRF (17 Hz). At the seat, a prominent peak associated with the BPF was observed at the floor and back in the Z direction. A prominent BPF peak was observed in the Y direction at the seat pan (longitudinal axis of the aircraft). The associated chest peak was quite low (Figure A-3). More detail on the trends are provided in Section 4.2.

In general, those records collected during actual flight, i.e., climb, level flight, and descent, showed minimal vibration at frequencies below 10 Hz. However, during taxi, take-off, and landing, both the litter and seated patients showed variable but notable levels of low frequency vibration below 10 Hz. These characteristics will be discussed further in the sections on the overall unweighted and weighted acceleration levels.

4.2 Overall Unweighted Acceleration Levels

The overall unweighted accelerations for level flight, calculated between 1 and 100 Hz in accordance with Equation 1, were used to evaluate the effects of vibration direction, altitude, tier level (litter patients), and cabin section.

4.2.1. Litter Patients

Figures A-4 and A-5 illustrate the mean overall unweighted accelerations ± one standard deviation for all flight test conditions in the forward and aft cabin for selected measurement sites at Tiers 1 and 3, respectively. The figures show that, to varying degrees, the unweighted overall levels tended to be higher during taxi, take-off, and landing. Figures A-7 and A-8 illustrate the mean overall unweighted accelerations during level flight for subjects 1 and 2, respectively, at both tiers and both cabin locations.

In the forward cabin, Tier 1 showed the greatest effect of direction at the pelvis interface, while Tier 3 also showed an effect of direction at the seat back, particularly during Flight 1A. At these measurement sites, the lowest overall unweighted vibration was observed in the VX direction (Figures A-4 and A-5). The overall unweighted Y acceleration levels at the pelvis interface for Tier 1, and at both interfaces for Tier 3, appeared either similar to or higher than the overall interface levels in the LZ direction during flight. The overall levels observed at the head and chest were more similar among the three directions. Figures A-7 and A-8 confirm that, for level flight in the forward cabin, the highest overall unweighted pelvis accelerations at Tier 1 occurred in both the Y and LZ directions, or horizontal plane of the aircraft, while the highest pelvis and back interface levels at Tier 3 primarily occurred in the Y direction. In addition, there was a tendency for higher pelvis levels to occur at the higher altitudes. These observations were not necessarily observed at the back interface. In the aft cabin, all overall levels at all measurement sites appeared more similar among the three directions as compared to the levels occurring in the forward cabin (Figures A-4 and A-5). An analysis was not conducted to determine statistical significance.

The Analysis of Variance (ANOVA) and Bonferroni Comparison Test were conducted to compare differences in the overall unweighted accelerations between Tiers 1 and 3 at the pelvis interface in the forward cabin during level flight. Table A-3 lists the results. While mixed results were observed in the VX and LZ directions for both subjects, significantly higher overall levels in the Y direction occurred for Tier 3 as compared to Tier 1 (probability value $(P)<0.05$). As noted above, the highest overall levels did tend to occur in the Y direction as compared to the other directions. This difference is evidenced in the middle plots illustrated in Figures A-7 and A-8 for Subjects 1 and 2, respectively.

Similar statistical analysis was also conducted to compare the overall unweighted acceleration levels between the forward and aft cabin locations at Tier 1 for Subject 2 and Tier 3 for Subject 1 during level flight. Table A-4 lists the results. While mixed results were again observed in the VX and LZ directions for both subjects, significantly higher overall levels were observed in the forward cabin in the Y direction as compared to the aft cabin ($P<0.05$), which tended to show the highest accelerations among the three directions. These results are illustrated in Figure A-7 for Tier 3 and Figure A-8 for Tier 1.

4.2.2. Seated Patient

Figure A-6 illustrates the mean overall unweighted acceleration ± one standard deviation in each direction for all flight test conditions for Subject 3 in the forward and aft cabin, respectively, for selected measurement sites at the seat. Figure A-9 illustrates the mean overall unweighted accelerations during level flight for Subject 3 at both cabin locations. The overall Z floor accelerations measured beneath the seat in the forward cabin and associated with Flight 1A tended to be higher than the overall floor Z accelerations during Flight 1B. This is illustrated in Figure A-9 at the floor for level flight. Both Figures A-6 and A-9 illustrate relatively large differences in the overall Y seat pan accelerations between Flights 1A and 1B in the forward cabin for Subject 3. A comparison of the spectra data indicated that the differences in the overall levels were not contributed to by lower frequency vibration associated with turbulence.

Figures A-6 and A-9 show the variations in the overall unweighted seat accelerations and the directional effects between Flights 1A and 1B in the forward cabin. During Flight 1A, the largest differences were observed at the seat pan; the lowest levels during flight occurring in the Z direction, with notably higher levels occurring in the X and Y or horizontal directions. The overall seat pan levels tended to be lower during Flight 1B, most notably in the Y direction (Figures A-6 and A-9). This appears to coincide with the differences observed in the Z floor data between Flights 1A and 1B noted above. There were variable directional effects particularly in the X and Y directions. As shown in Figure A-9 for level flight in the forward cabin, the overall unweighted seat pan accelerations tended to be the highest in the horizontal directions, but lowest in the vertical direction at the higher altitudes. At the back interface in the forward cabin, the overall unweighted Z accelerations tended to be the highest. As shown in Figure A-9, the highest Z seat back levels occurred at the higher altitudes with some differences observed between Flights 1A and 1B. The overall unweighted chest accelerations were relatively low compared to the interfaces, and where relatively similar among the three directions for both Flights 1A and 1B. Figures A-6 and A-9 show that, in the aft cabin, the highest overall unweighted seat pan accelerations tended to occur in the X direction. The overall levels at the seat back showed mixed results depending on whether the conditions were measured during climb and level flight (Flight 1A), or descent and level flight (Flight 1B). As in the forward cabin, the overall unweighted chest accelerations in the aft cabin were relatively low with minimal directional effects.

The ANOVA and Bonferroni Comparison Test were applied to compare the differences between the overall unweighted seat pan accelerations between Flights 1A and 1B. The results are listed in Table A-5. At the lower altitudes (7K – 11K ft MSL), there were no significant differences between the two flights in any direction. At 15K – 16K ft MSL, the overall unweighted seat pan accelerations were significantly higher during Flight 1A for all three directions ($P<0.05$). At 23K – 24K ft MSL, the overall seat pan accelerations were significantly higher during Flight 1A in the Y direction (Figures A-6 and A-9) ($P<0.05$). No differences were observed in the X direction. While statistical significance did occur in the Z direction, Figure A-9 shows that these levels were relatively low.

Statistical analysis was also applied to compare the overall unweighted seat pan accelerations in the forward and aft cabin during level flight. For this comparison, similar level flight data collected during Flight 1B were compared to similar level flight data collected during the first half of Flight 2 (denoted Flight 2A in Figure A-9). The results are listed in Table A-6. For both the lower altitudes (7K – 11K ft MSL) and highest altitudes (23K – 24K ft MSL) the overall seat pan accelerations were significantly higher at the forward cabin for all three directions. Mixed results were observed at 15K – 16K ft MSL depending on the direction (Table A-6); Figure A-9 does show that the differences were not dramatic. As described above, the figure and Table A-5 do indicate significantly higher overall unweighted seat pan levels in all three directions for Flight 1A compared to Flight 1B at 15K – 16K ft MSL.

4.3 Weighted Accelerations and Vibration Total Values (*VTV*s, *oVTV*s) for Comfort Assessment

The overall weighted accelerations, *pVTV*s, and *oVTV*s (seat only) were calculated between 1 and 100 Hz in accordance with Equations 2 and 3, respectively.

4.3.1. Litter Patients

It is noted that the ISO 2631-1 only provides guidance for comfort and perception reactions for the supine posture using the measurement at the pelvis interface with the supporting surface. For this study, the overall weighted back accelerations were also calculated using the same frequency weightings and multiplying factors applied to the pelvis interface data. In addition, the weighted VX accelerations at the head were calculated using frequency weighting W_j, while the weighted horizontal (Y and LZ) accelerations at the head were calculated using frequency weighting W_d. While not illustrated, the overall weighted accelerations at the back and head were similar to the levels observed at the pelvis.

Figures A-10 and A-11 illustrate the overall weighted accelerations and *pVTV*s estimated at the pelvis interface in the forward and aft cabin at Tiers 1 and 3, respectively, for each flight test condition. Also included are the comfort reaction categories defined in ISO 2631-1. The figures show the relatively higher overall weighted accelerations associated with taxi, takeoff, and landing. The weighted levels indicate that comfort reactions associated with these conditions ranged from "not uncomfortable" to "uncomfortable" (specifically noted in the aft cabin during landing), and also confirmed the contribution of low frequency vibration. However, in both the forward and aft cabins, at both Tiers 1 and 3, the airborne flight conditions (climb, level flight, descent) produced a comfort reaction of "not uncomfortable". The overall weighted accelerations at the back and head occurring during the airborne flight conditions were also associated with a comfort reaction of "not uncomfortable".

4.3.2. Seated Patients

Figure A-12 illustrates the overall weighted accelerations, seat pan *pVTV*s, and *oVTV*s estimated for the seated patient in the forward and aft cabin. Also included are the comfort reaction categories defined in ISO 2631-1. The figure shows the relatively higher levels associated with taxi, takeoff, and landing which produced comfort reactions ranging from "not uncomfortable" to "a little uncomfortable". As with the litter data, both the forward and aft cabins, those conditions associated with flight produced a comfort reaction of "not uncomfortable". While the *oVTV*s included the contribution of both the overall weighted seat pan and seat back accelerations, Figure A-12 shows negligible influence on the comfort reaction.

5.0 DISCUSSION AND CONCLUSIONS

This project sought to collect and characterize vibration transmitted to litter patients and seated patients during a typical AE transport scenario aboard the C-130J. Triaxial accelerations were collected at the interfaces between the patient and litter or seated surfaces, and at selected anatomical sites. Two litter tiers were included for the supine or recumbent patient. Both litter patient and seated patient vibration were compared at the forward and aft cabin sections. Three subjects participated in the flight tests. It was expected that subject posture and anthropometry could have an influence on the measurement of acceleration. In addition, it was expected that certain weather conditions and/or flight conditions could also affect the accelerations transmitted to the subject patients. In order to evaluate the effects of tier level for the litter patient, data were collected for both litter patients at both Tier 1 and Tier 3 in the forward cabin during Flight 1.

There were several consistent vibration characteristics and trends revealed from these flight tests. First, the most prominent vibration acceleration at the litter/subject and seat/subject interfaces, especially during airborne flight, occurred around 102 Hz and was associated with the blade passage frequency of the aircraft propulsion system. This peak dominated in the calculation of the overall unweighted accelerations used in the data analysis. As mentioned, taxi, takeoff, and landing included contributions from low frequency vibration occurring below 10 Hz, which dominated the overall unweighted accelerations during these flight test conditions.

For the litter patients, the highest unweighted overall accelerations occurred in the forward cabin at the litter/patient interfaces, dominating in the pelvis horizontal (Y and LZ) directions at Tier 1, and dominating at both interfaces specifically in the Y direction at Tier 3. The overall unweighted Y pelvis accelerations were significantly higher at Tier 3 as compared to Tier 1. The vibration reaching the chest and head were relatively low, as observed in Figures A-7 and A-8. The higher accelerations were significantly damped in the aft cabin. The *pVTV*s calculated from the overall weighted accelerations indicated that, for the healthy supine occupant, the vibration would be considered “not uncomfortable” for all flight test conditions except taxi, takeoff, and landing as illustrated in Figures A-10 – A-11. Similar characteristics were observed in the overall unweighted interface accelerations estimated for the litter patients aboard the C-130H, showing the higher overall Y levels at the pelvis, and relatively low overall levels at the chest and head, particularly in the forward cabin. However, the overall unweighted levels measured on the C-130H were notably higher as compared to the C-130J, and primarily associated with the lower C-130H BPF at 68 Hz as compared to C-130J 102 Hz. Regardless, the pelvis *pVTV*s estimated for the C-130H also indicated that the exposures would primarily be considered “not uncomfortable”.

For the seated patient, all measurements were made with Subject 3. A review of the floor data collected beneath the forward seated patient showed notable differences in the overall unweighted Z accelerations at similar altitudes for Flight 1A as compared to Flight 1B. In addition, the rms acceleration spectra attributed these differences to the peaks occurring at the BPF, and not to lower frequency vibration caused by turbulence. Certain trends in the seat interface data may have been related to these differences. The significantly higher overall unweighted Y seat pan accelerations (longitudinal axis of the aircraft) during Flight 1A as compared to Flight 1B may have been influenced by whatever affected the differences in the floor data (Figure 9). There were also notable levels of X vibration at the seat pan (lateral direction of the aircraft) in the forward cabin that only showed significant effects during the level flight conditions between 15K – 16K ft MSL. Interestingly, the Z acceleration levels tended to be the lowest at the seat pan, while tending to be the highest at the seat back. It is very likely that the attachment of the cloth seat to the fuselage at the back of the seat pan and top of the seat back, and to the floor at the front of the seat pan, influenced the interface measurements. The vibration levels occurring at the chest were relatively low, as observed in Figure A-9. Significantly higher Y vibration levels occurred at the seat pan for the forward seated patient as compared to the aft cabin location at all altitudes, and in all three directions at the lowest and highest altitudes. The effect of cabin location was also observed for the seated patient in the C-130H. As observed for the litter patients, the overall unweighted accelerations measured on the C-130H were notably higher as compared to the C-130J. While the seated patient overall seat pan data in the C-130H were substantially higher in the fore-and-aft (X) direction (lateral direction of the aircraft) as compared to the other two directions in the forward cabin, this was not necessarily the case with the C-130J, where the highest overall seat pan levels tended to occur in the Y direction (longitudinal axis of the aircraft), with some higher levels also observed in the X direction of the seat. Both the *oVTV*s during flight estimated for the C-130H and the C-130J indicated that the vibration would primarily be considered “not uncomfortable”.

The higher vibration levels occurring in the forward cabin have been attributed to the location of the litters and seats being in close proximity to the plane of the propeller, where the highest and most consistent propulsion-related vibration was expected. The litters are cantilevered using straps to metal poles attached at the floor and ceiling near the centerline of the aircraft. This configuration most likely influences the tendency for higher Y vibration at the litter interfaces. The dynamics are more complicated at the cloth seat given the attachments described above.

The weighted accelerations depicted in Figures A-10 – A-12 indicate that the vibration levels aboard the C-130J would be primarily considered “not uncomfortable” by both the seated and supine occupants according to the ISO 2631-1 guidelines. This is primarily influenced by the relatively high ISO frequency weightings that are associated with 102 Hz. While the weighted levels were quite low, it is cautioned that the ISO 2631-1 comfort reactions were approximated based on passenger expectations during public transport. The comfort reaction thresholds are expected to be lower for the injured patient during emergency evacuation and transport, and could vary dramatically depending on the type of injury, treatment regime, flight conditions, and flight duration. Regardless, the results of this study strongly suggest that transport aboard the fixed-wing C-130J propeller aircraft is not a threat to the health outcome of patients, particularly during airborne flight conditions. However, any lower frequency vibration resulting from intermittent turbulence could exacerbate injury, particularly to the spine and head, without proper restraint.

6.0 RECOMMENDATIONS

1. It is recommended that the most critically injured patients be located aft of the propeller plane in the C-130J.
2. Patients with upper torso/head wounds should be appropriately restrained to limit low frequency motions during initial and final aircraft maneuvers as well as during flight aboard the C-130J, where intermittent turbulence may be present. This does emphasize the need for research into patient body motion mitigation concepts for minimizing adverse health outcomes.

7.0 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.

Department of Defense, *Department of Defense Design Criteria Standard, Human Engineering*, MIL-STD-1472H, 15 Sep 2020.

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., 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, Human Effectiveness Directorate, Wright-Patterson AFB OH, 2019.

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, Human Effectiveness Directorate, Wright-Patterson AFB OH, 2020

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

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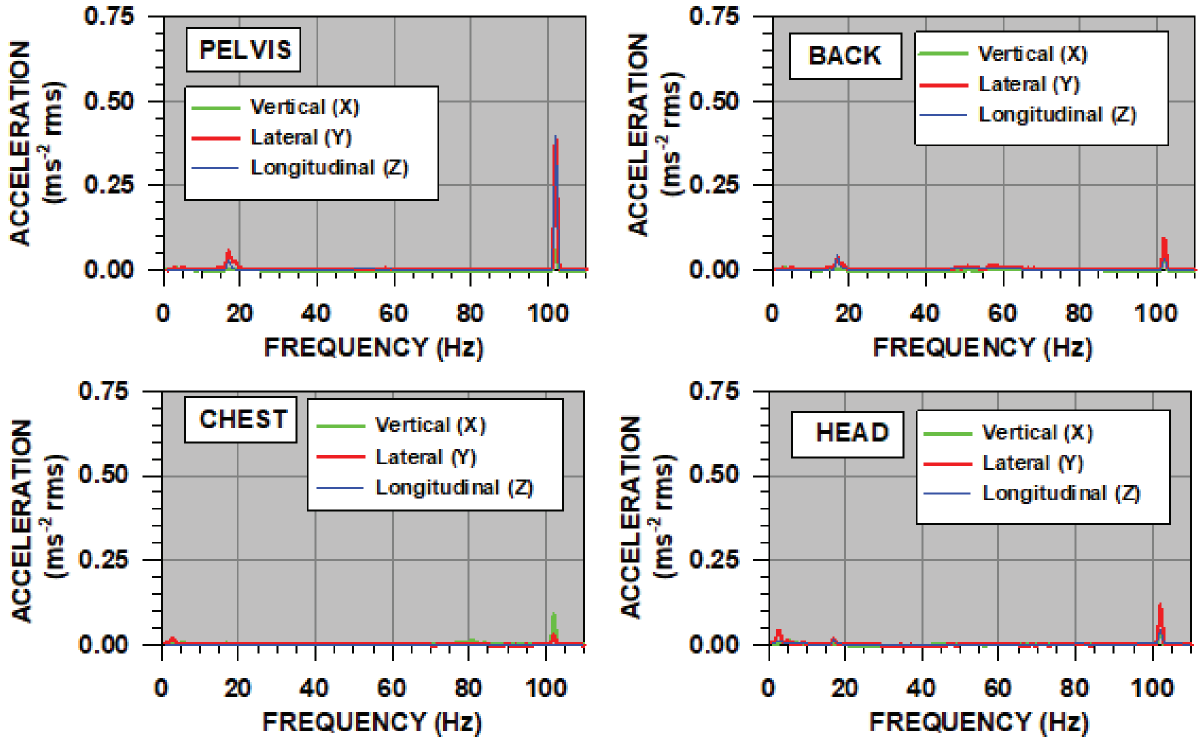

Figure A- 1. Example Acceleration Spectra at Left Forward Tier 1 Level Flight 24K

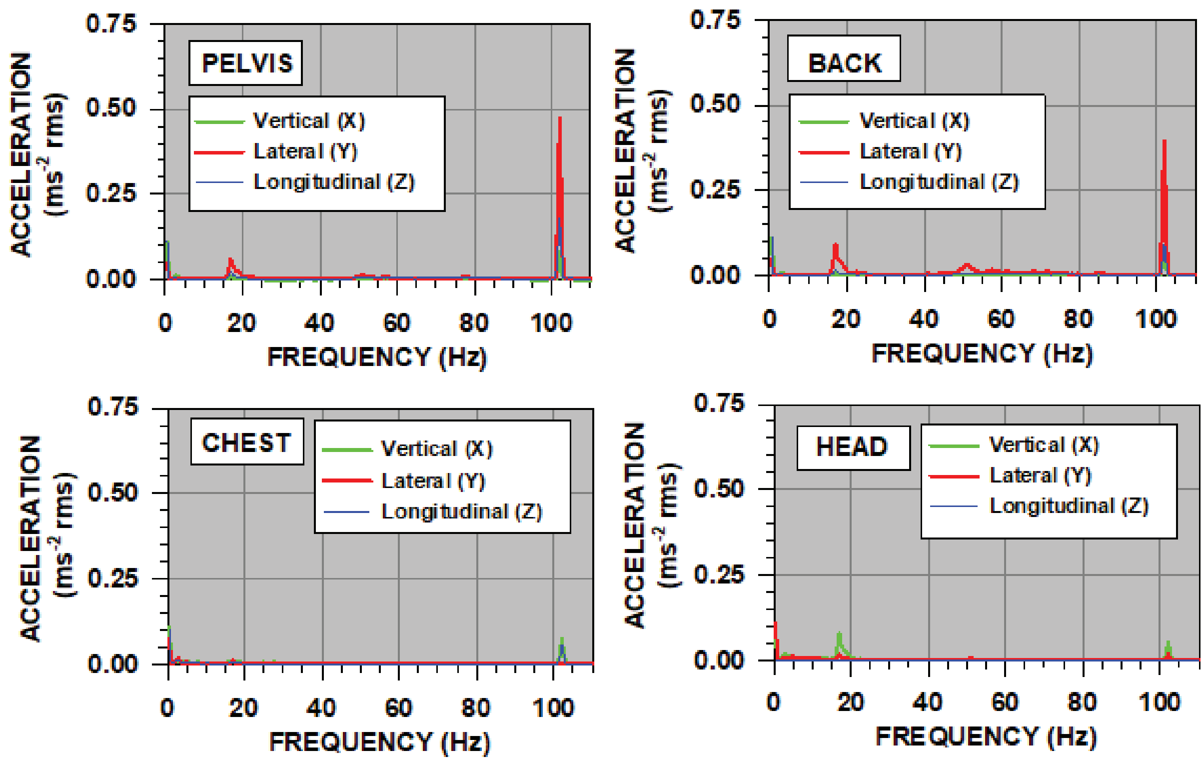

Figure A- 2. Example Acceleration Spectra at Left Forward Tier 3 Level Flight 24K

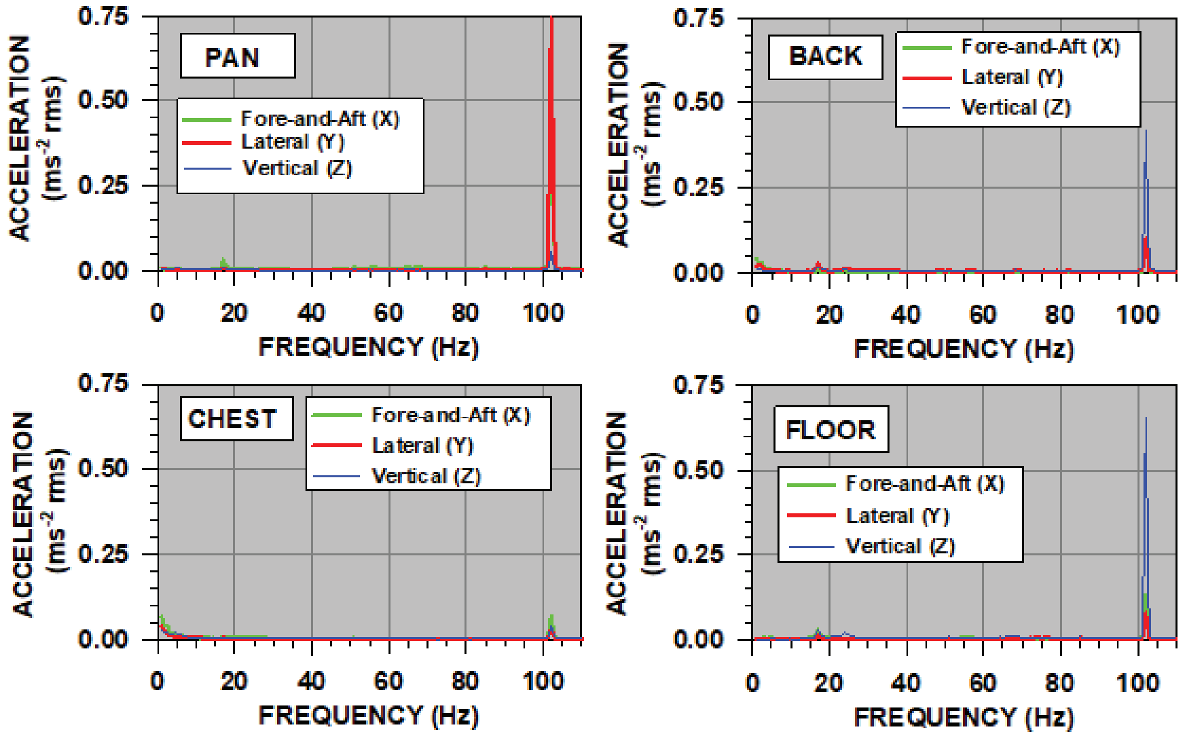

Figure A- 3. Example Acceleration Spectra at Left Forward Seat Level Flight 24K

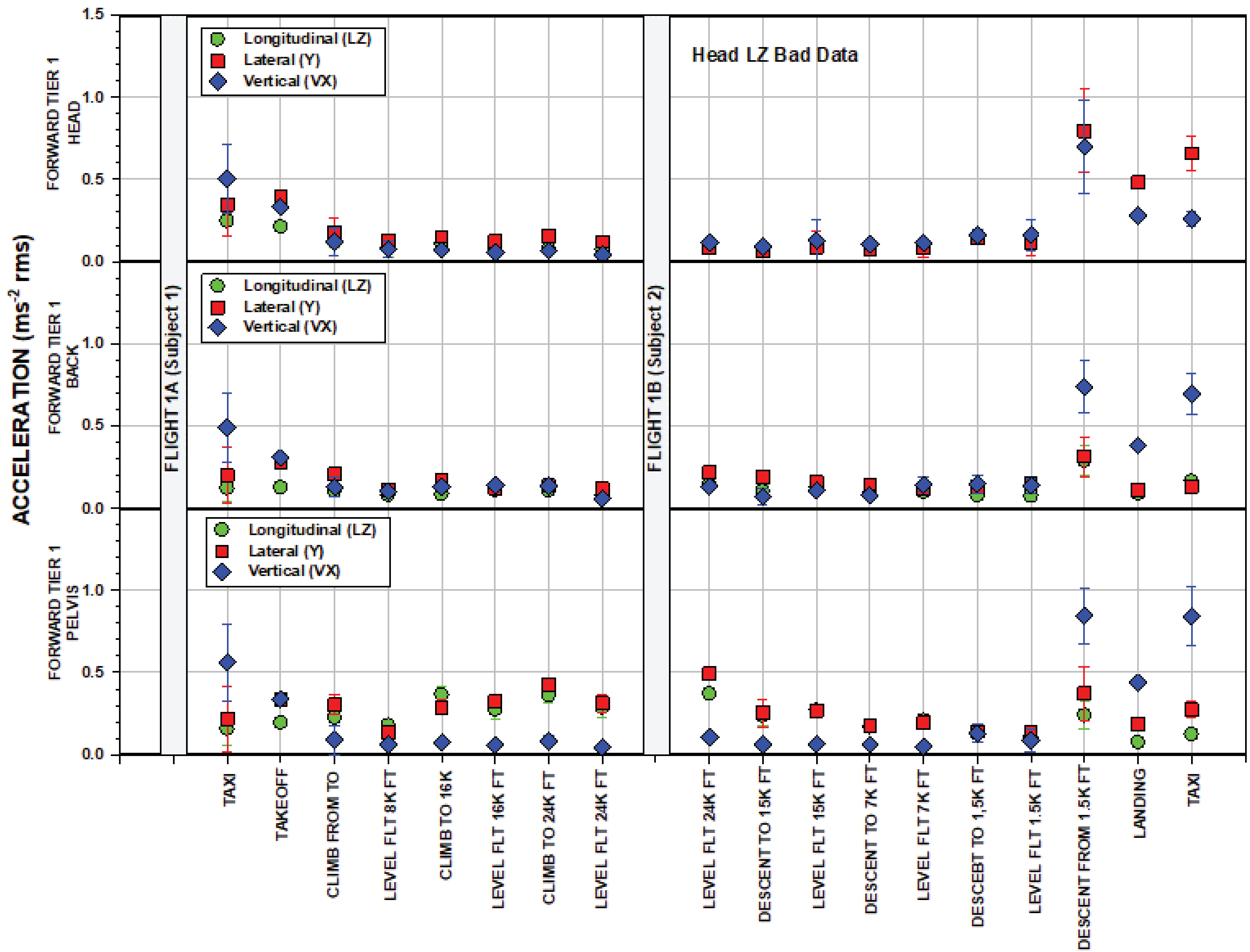

Figure A- 4. Overall Unweighted Acceleration Levels ± One Standard Deviation – Forward Tier 1

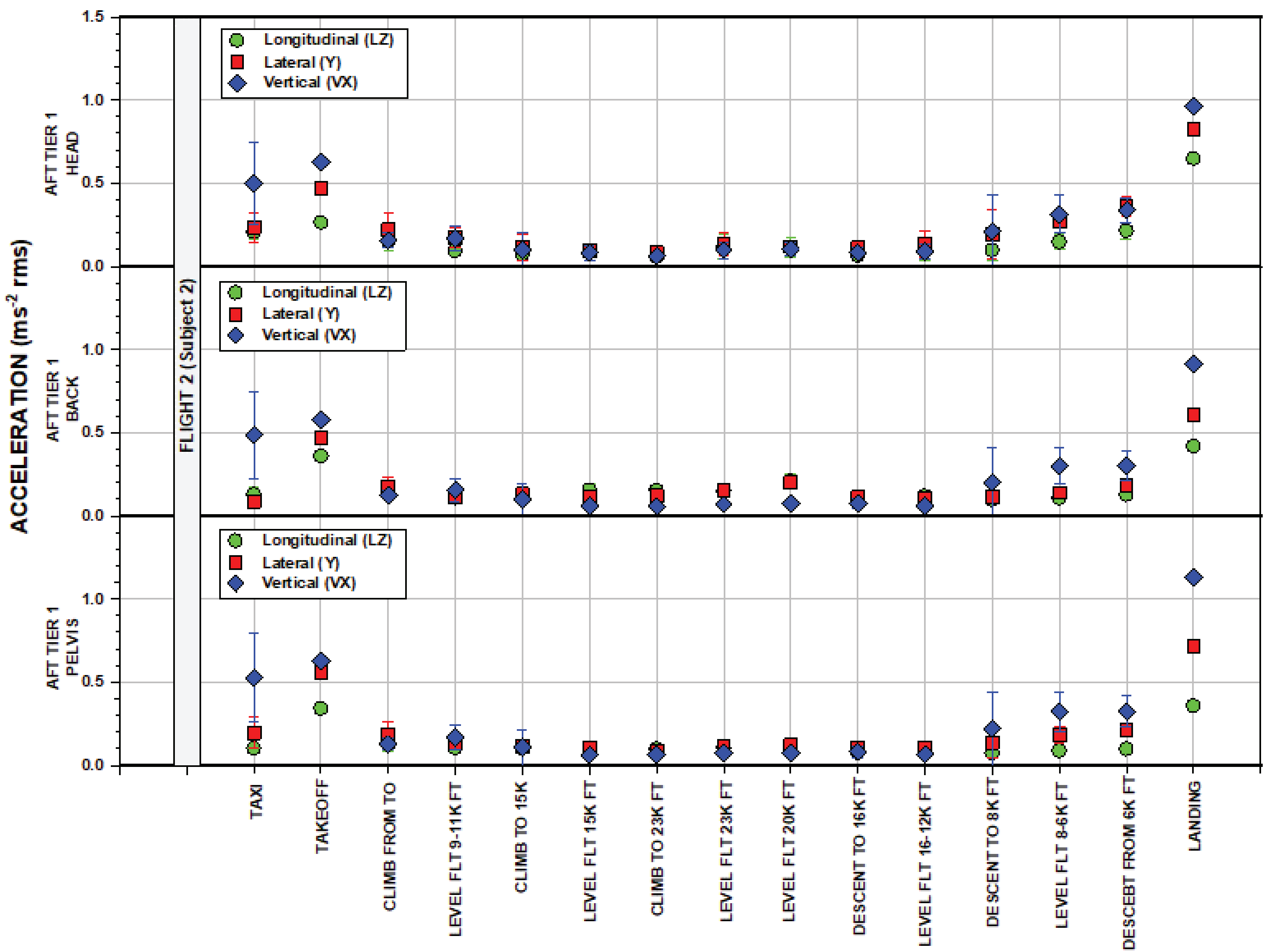

Figure A-4 (continued). Overall Unweighted Acceleration Levels ± One Standard Deviation – Aft Tier 1

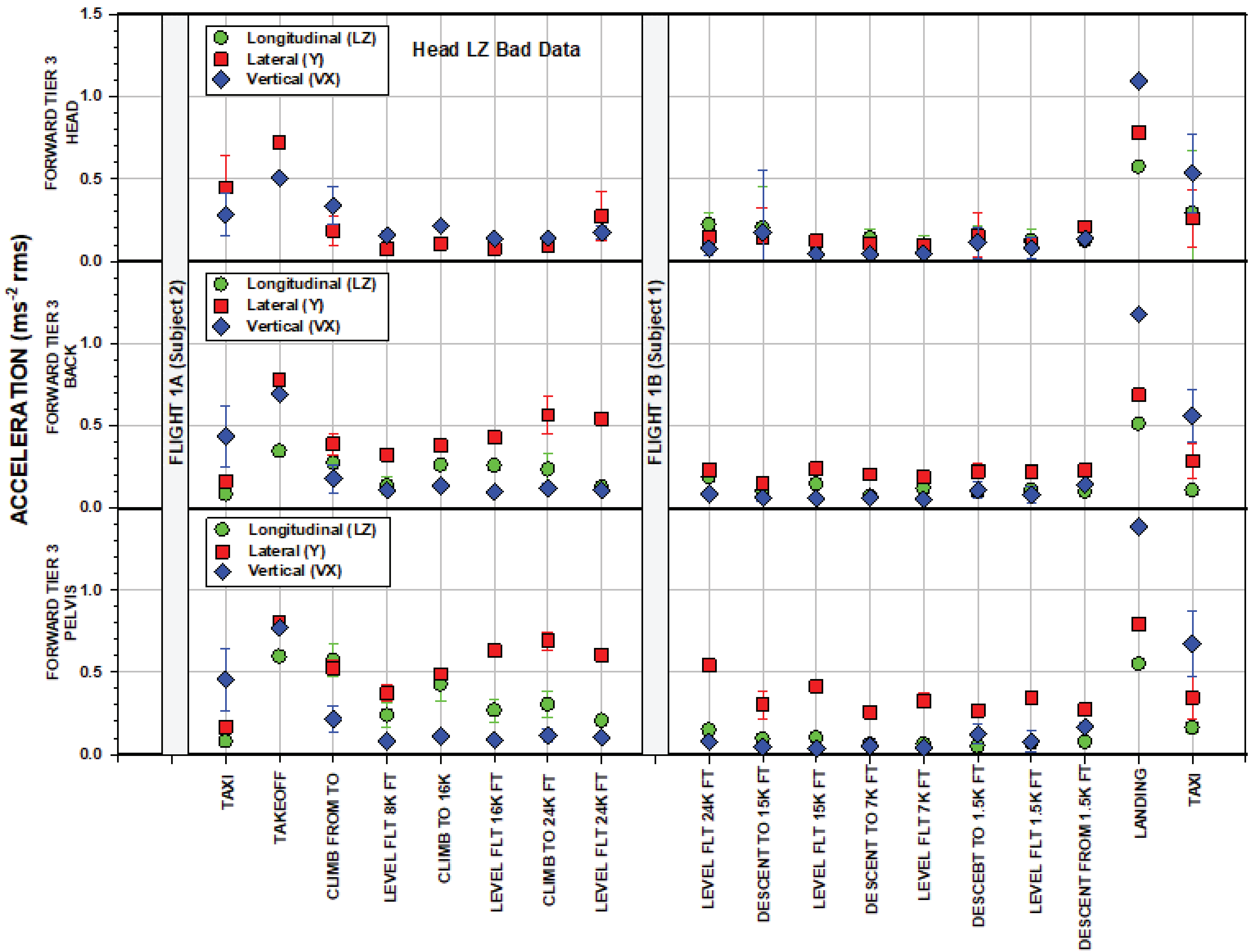

Figure A- 5. Overall Unweighted Acceleration Levels ± One Standard Deviation – Forward Tier 3

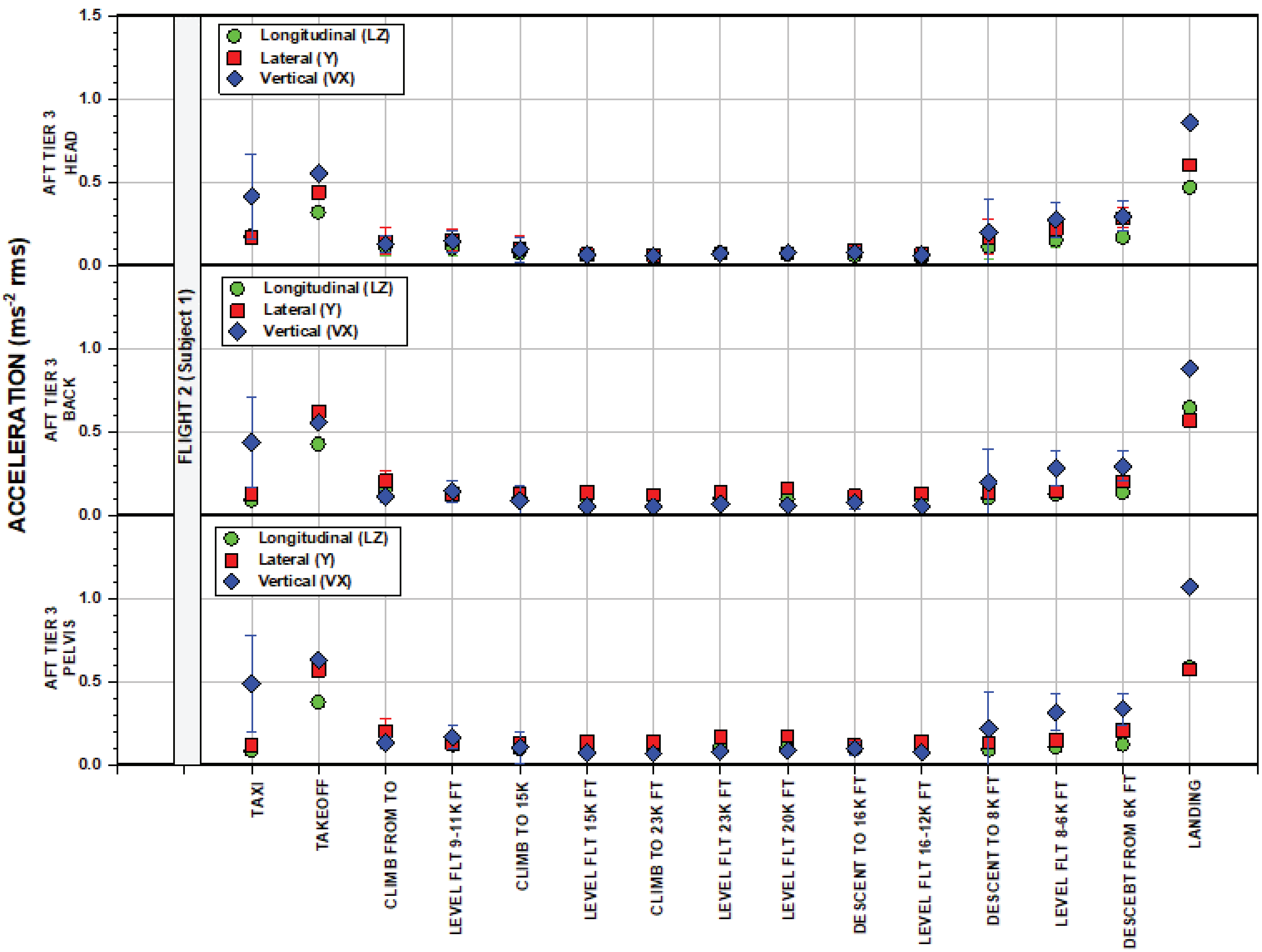

Figure A-5 (continued). Overall Unweighted Acceleration Levels ± One Standard Deviation – Aft Tier 3

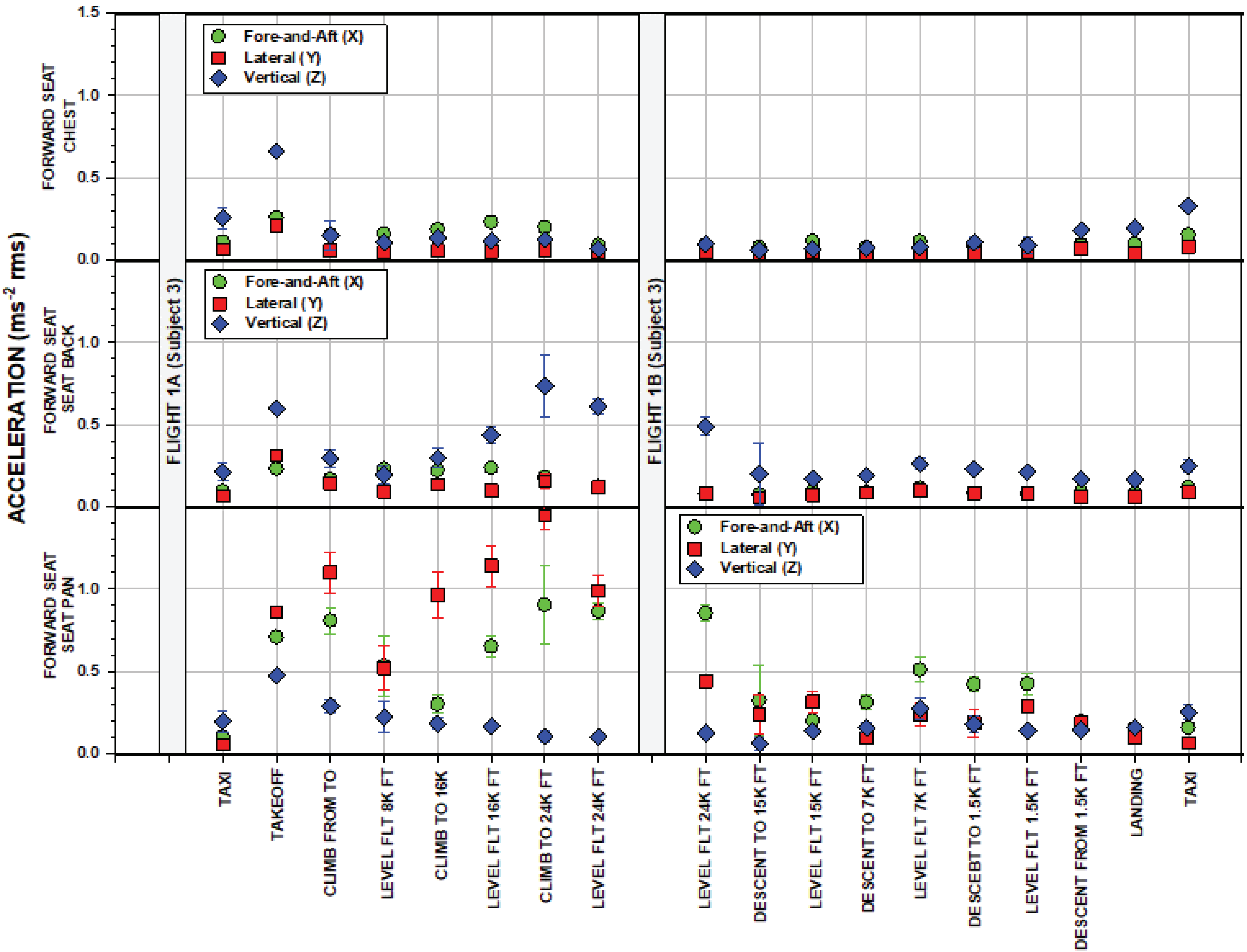

Figure A- 6. Overall Unweighted Acceleration Levels ± One Standard Deviation – Forward Seat

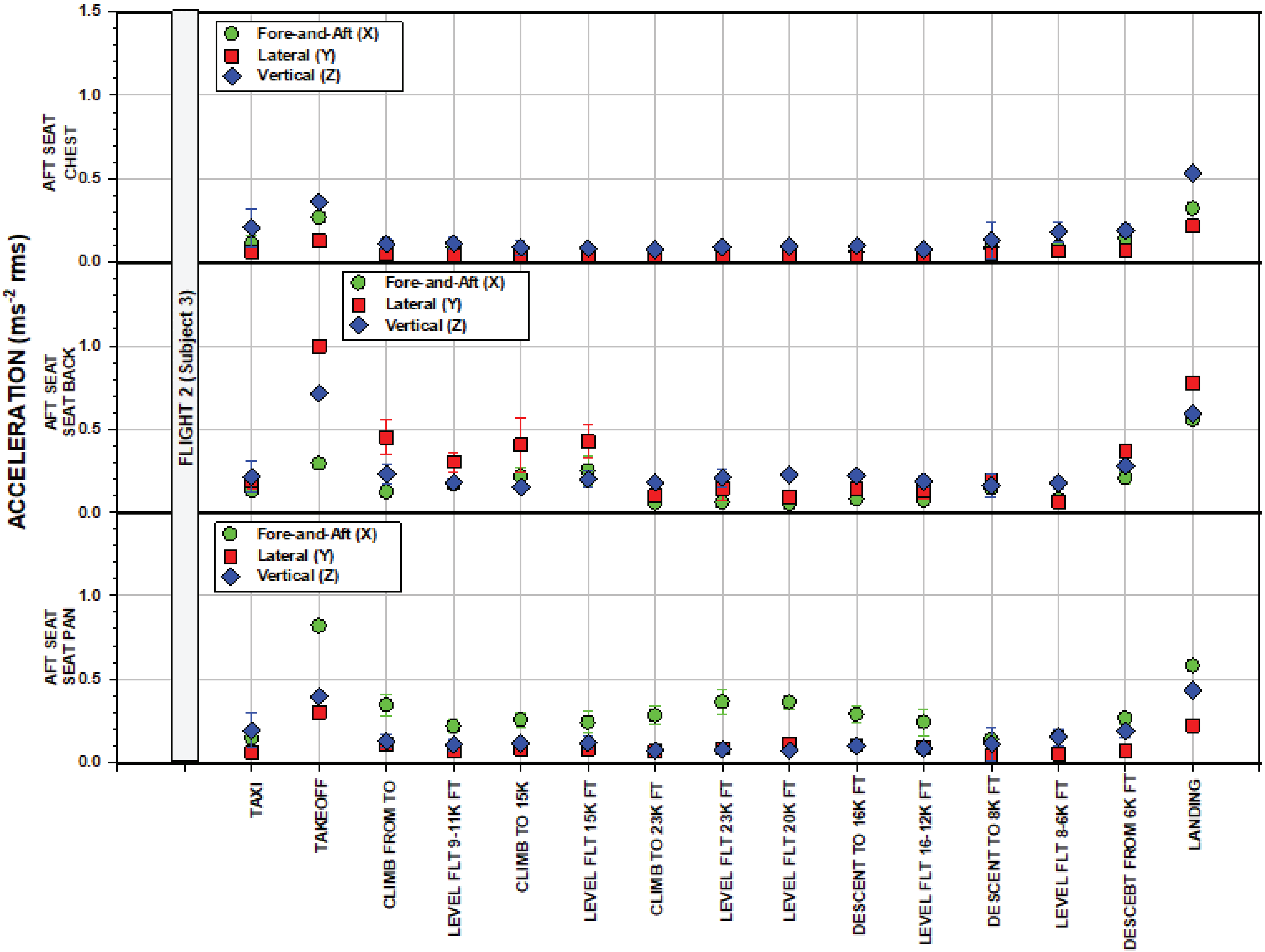

Figure A-6 (continued). Overall Unweighted Acceleration Levels ± One Standard Deviation – Aft Seat

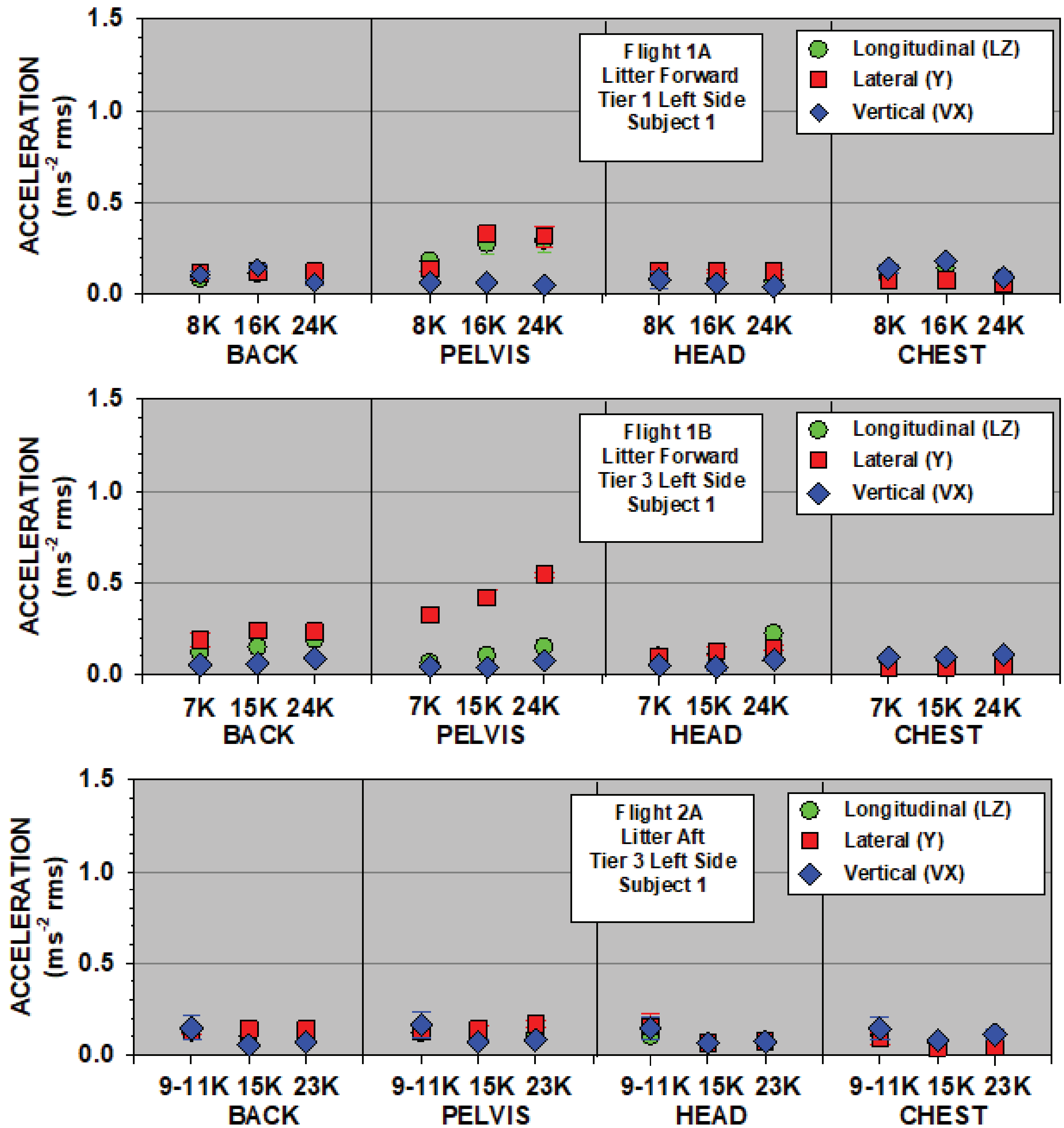

Figure A- 7. Level Flight Overall Unweighted Acceleration Levels ± One Standard Deviation – Subject 1

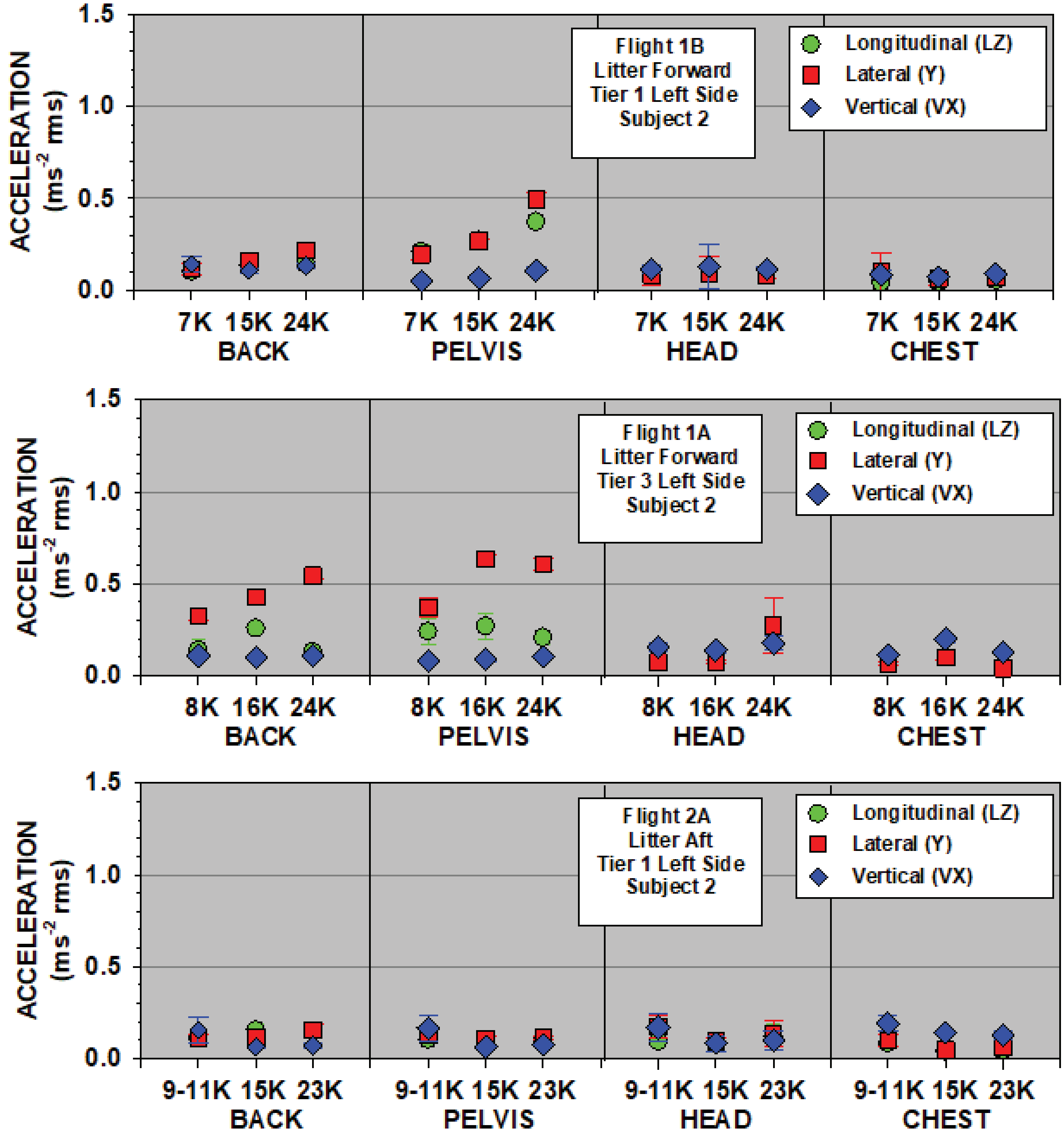

Figure A- 8. Level Flight Overall Unweighted Acceleration Levels ± One Standard Deviation – Subject 2

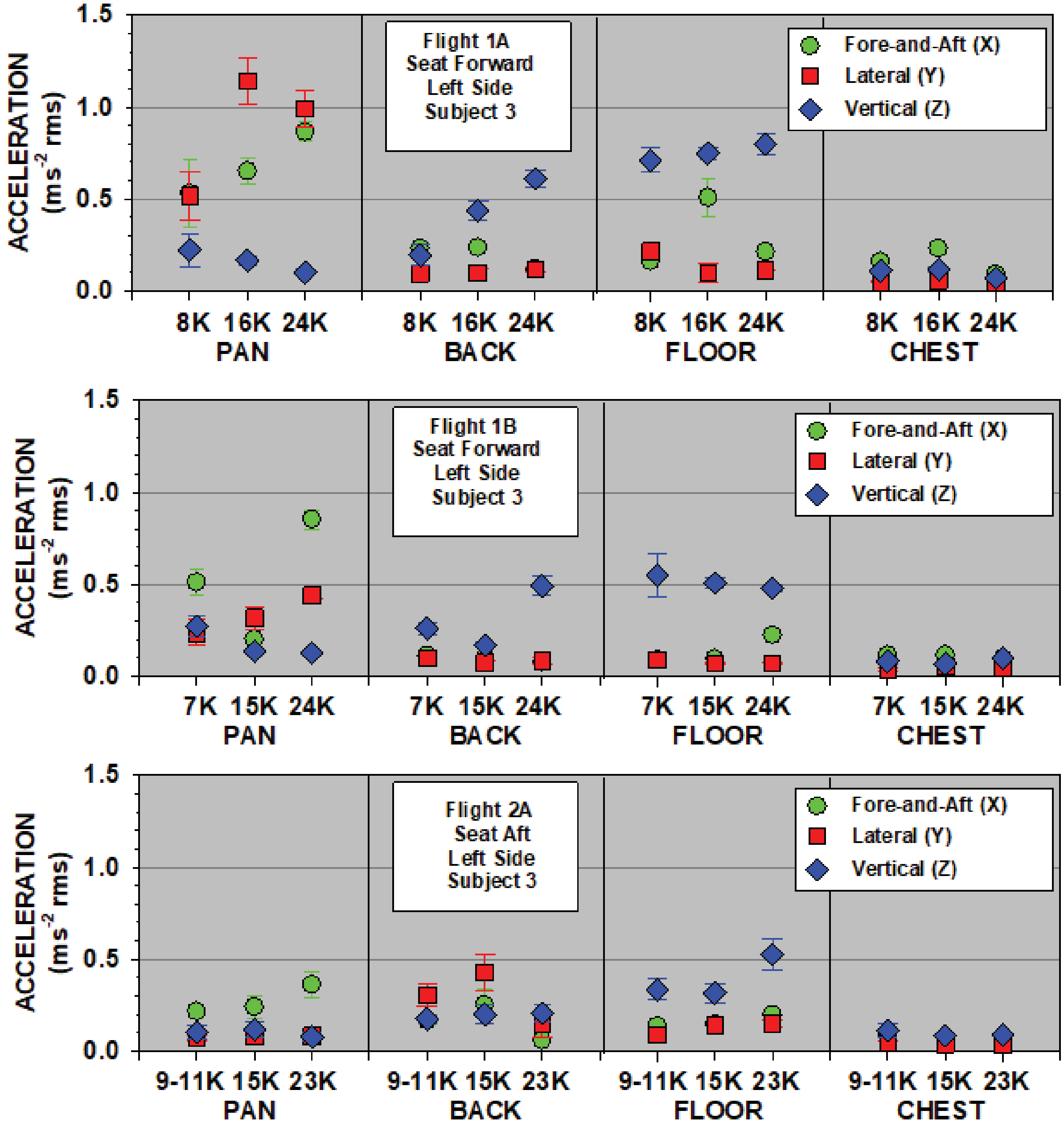

Figure A- 9. Level Flight Overall Unweighted Acceleration Levels ± One Standard Deviation – Subject 3

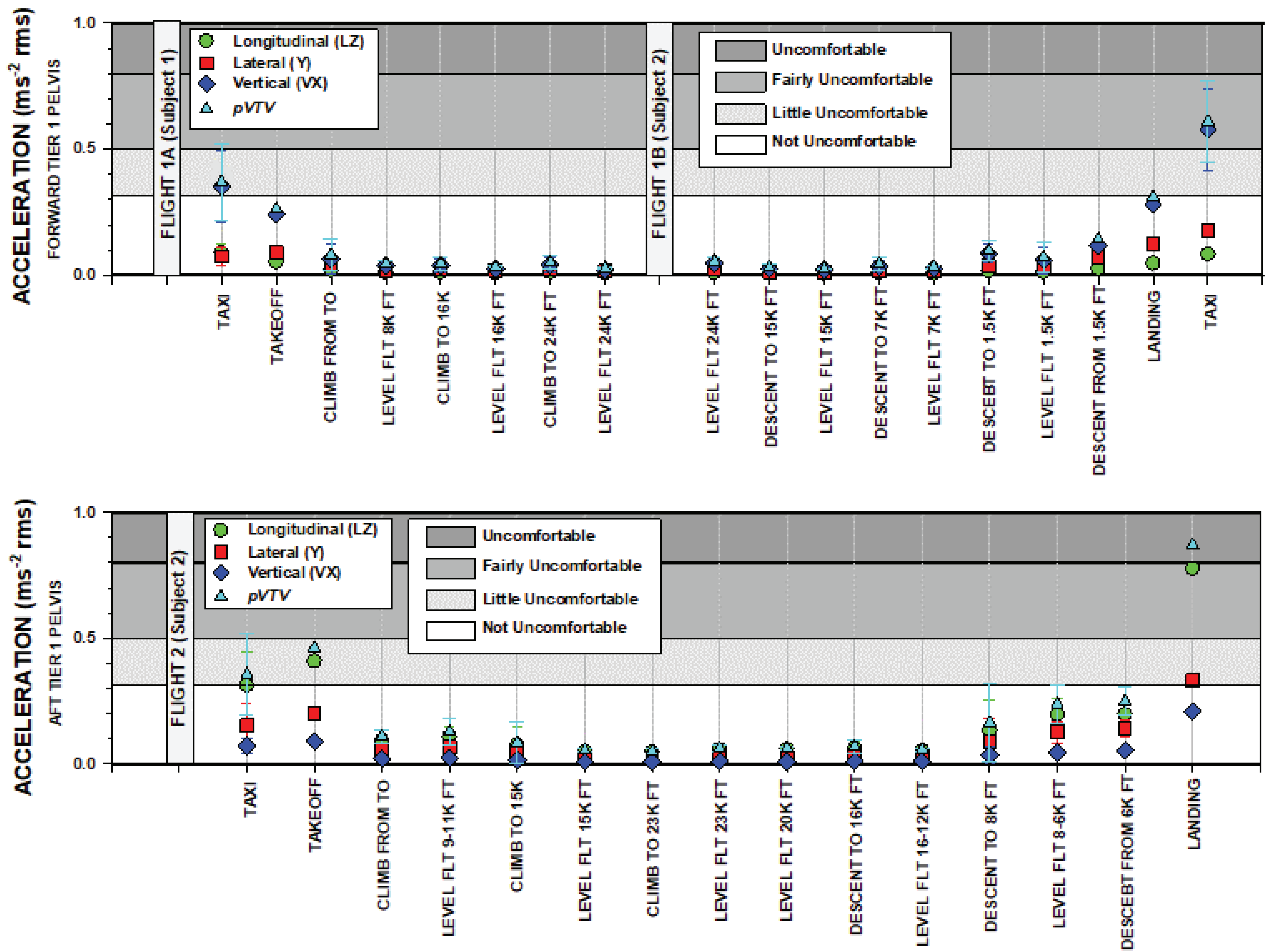

Figure A- 10. Overall Weighted Acceleration Levels ± One Standard Deviation – Tier 1

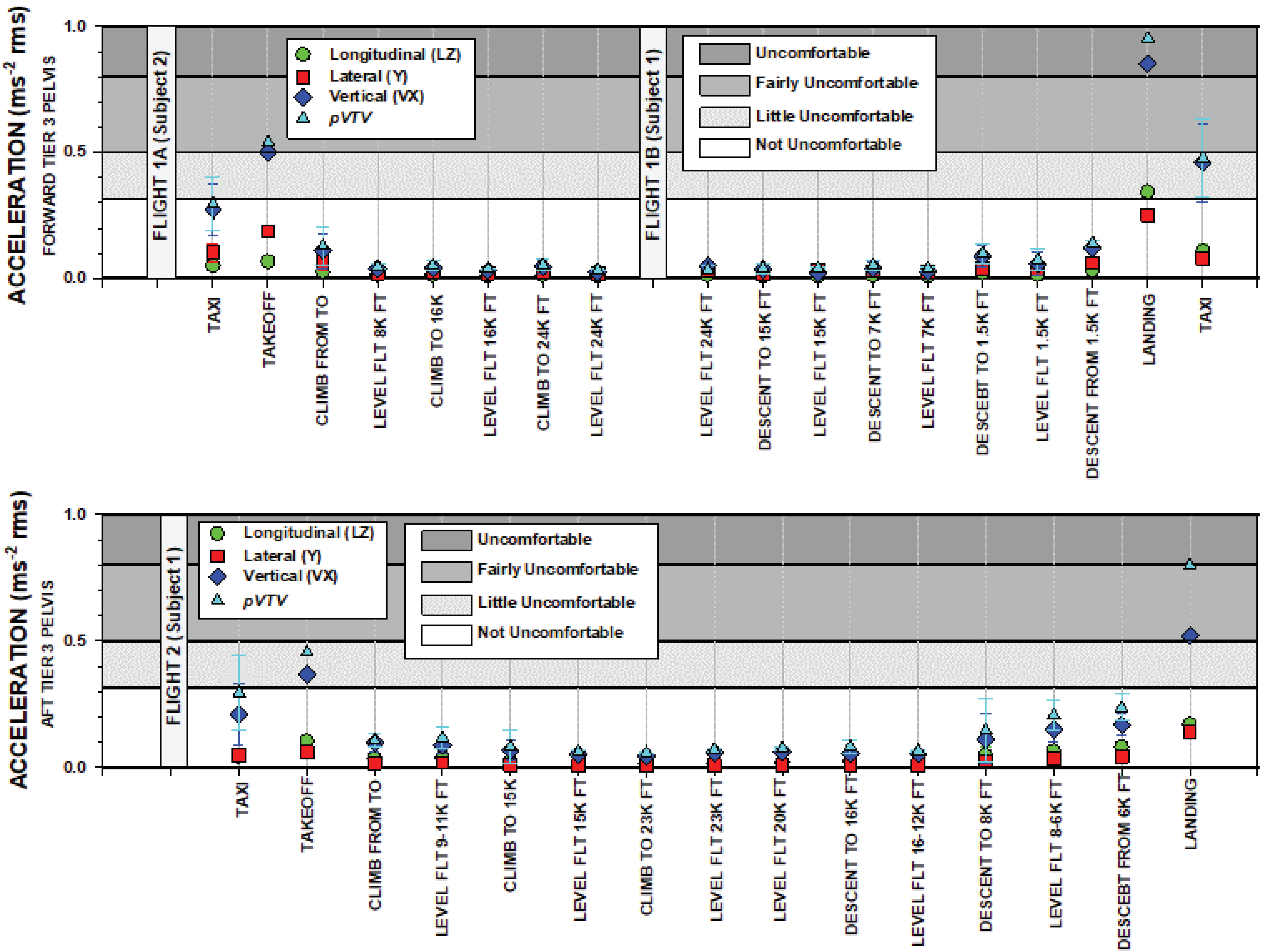

Figure A- 11. Overall Weighted Acceleration Levels ± One Standard Deviation – Tier 3

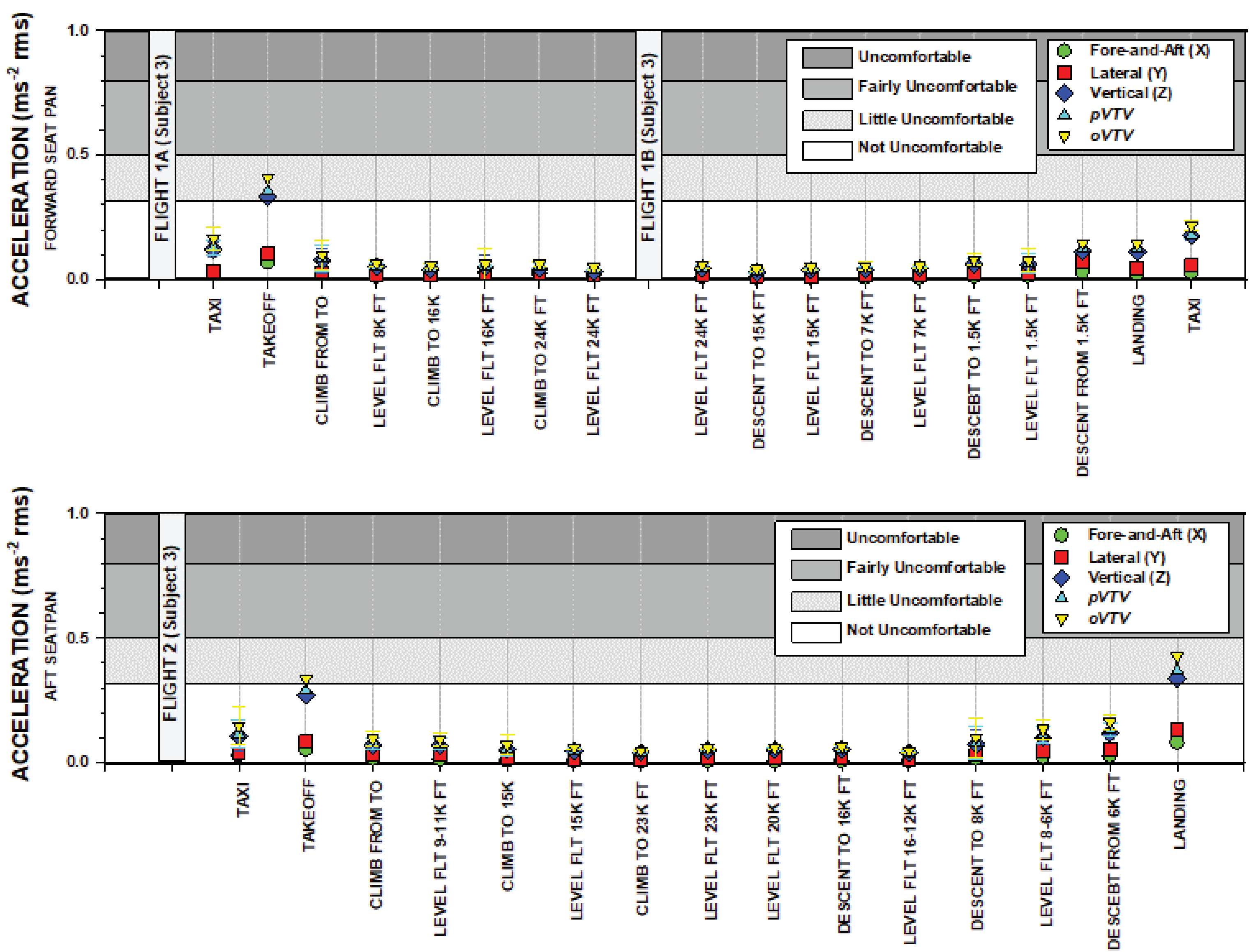

Figure A- 12. Overall Weighted Acceleration Levels ± One Standard Deviation – Seat

Table A- 1. REVER Component Details

Component	Dimensions (L/W/H cm)	Weight (Kg)	Item Identification or Number
DAU (PicoDas)	9.5/6.0/2.9	0.370 w/cables	EME S/N 04-22
			EME S/N 10-31
			EME S/N 10-41
Large Batteries	10.0/7.0/3.5	0.645	TOTAL: 3
Small Batteries	9.0/5.0/3.5	0.395	TOTAL: 3
Accelerometer Packs	1.9 (diameter) 0.86 (thickness)	0.005 (0.060 w/ cable)	TOTAL: 9 (3 accelerometers each)
Acceleration Pads	20.0 (diameter)	0.340 w/ cables	TOTAL: 6 (1 accelerometer pack each)
Triggers	7.6 (length) 2.2 (diameter)	0.030 w/cable	TOTAL: 3
Extension Cables	Various lengths	-	

Table A- 2. Number of Test Records per Flight

FLIGHT TEST CONDITION	Flight 1A	Flight 1B	Flight 2
	# Data Records		
Taxi	5	5[4]	5
Takeoff (TO)	1		1
Climb from TO	8		8
Climb to 6-8K ft MSL			
Climb to 12-16K ft MSL	8		8
Climb to 23-24K ft MSL	8[1]		8
Level Flight 1.5K ft MSL		16[5]	
Level Flight 6- 8K ft MSL	15	15	16
Level Flight 9-11K ft MSL			19
Level Flight 12-16K ft MSL	15[2]	15	28
Level Flight 20K ft MSL			15
Level Flight 23-24K ft MSL	14[3]	15	15
Descent to 12-16K ft MSL		8	6
Descent to 6-8K ft MSL		8	6
Descent to 1.5K ft MSL		8	
Descent to Landing		2[6]	7
Landing		1	1
TOTAL	74	93	143
[1]Tier 3: 1 bad records [2]Seat: 2 bad records [3]Tier 3: 1 bad record [4]Tier 1: 1 bad record; Seat: 1 bad record [5]Tier 1: 3 bad records; Seat: 1 bad record [6]Tier 1: 1 bad record; Seat: 1 bad record			

Table A- 3. Overall Accelerations: Litter Patient Statistical Results-Effect of Litter Tier (significant difference: P<0.05)

ALTITUDE	7K-11K ft MSL		15K-16K ft MSL		~23K-24K ft MSL	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
DIRECTION						
VX	T1>T3	T3>T1	T1>T3	T3>T1	T3>T1	T1=T3
Y	T3>T1	T3>T1	T3>T1	T3>T1	T3>T1	T3>T2
LZ	T1>T3	T1=T3	T1>T3	T1=T3	T2>T3	T1>T3
VX=Vertical; Y=Lateral; LZ=Longitudinal; T1=Tier 1; T3=Tier 3						

Table A- 4. Overall Accelerations: Litter Patient Statistical Results-Effect of Cabin Location (significant difference: P<0.05)

ALTITUDE	7K-11K ft MSL		15K-16K ft MSL		~23K-24K ft MSL	
	Subject 1	Subject 2	Subject 1	Subject 2	Subject 1	Subject 2
DIRECTION						
VX	A>F	A>F	A>F	F=A	F=A	F>A
Y	F>A	F>A	F>A	F>A	F>A	F>A
LZ	A>F	F>A	F=A	F>A	F>A	F>A
VX=Vertical; Y=Lateral; LZ=Longitudinal; A=Aft Cabin; F=Forward Cabin						

Table A- 5. Overall Accelerations: Seated Patient Statistical Results-Comparison of Flights A1 and B1 (significant difference: P<0.05)

ALTITUDE	7K-11K ft MSL	15K-16K ft MSL	~23K-24K ft MSL
	Subject 3	Subject 3	Subject 3
DIRECTION			
Z	1A=1B	1A>1B	1B>1A
Y	1A=1B	1A>1B	1A>1B
X	1A=1B	1A>1B	1A=1B
X=Fore-and-Aft; Y=Lateral; Z=Vertical			

Table A- 6. Overall Accelerations: Seated Patient Statistical Results-Effects of Cabin Location (significant difference: P<0.05)

ALTITUDE	7K-11K ft MSL	15K-16K ft MSL	~23K-24K ft MSL
	Subject 3	Subject 3	Subject 3
DIRECTION			
Z	F>A	F=A	F>A
Y	F>A	F>A	F>A
X	F>A	A>F	F>A
X=Fore-and-Aft; Y=Lateral; Z=Vertical; A=Aft Cabin; F=Forward Cabin			

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

711 HPW	711 Human Performance Wing
AE	Aeromedical Evacuation
AFRL	Air Force Research Laboratory
AFMS	Air Force Medical Service
amp	Ampere
ANOVA	Analysis of Variance
BPF	Blade Passage Frequency
CBDN	Collaborative Biomechanics Data Network
DAU	Data Acquisition Unit
DCR	Doctrine Change Recommendation
ft	Feet
HGCZs	Health Guidance Caution Zones (ISO 2631-1, Annex B)
Hz	Hertz (cycles per second)
ISO	International Organization for Standardization
MIL-STD	Military Standard
MSL	Mean Sea Level
P	Probability Value
PRF	Propeller Rotation Frequency
REVER	Remote Vibration Environment Recorder
RH	Airman Systems Directorate
rms	Root-Mean-Square
a_{rms}	Acceleration Root-Mean-Square
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)