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The Comparison of Two Supine Manikins and the Use of a Shock and Vibration Isolation System for Litter Patients in Air Medical Transport

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THE COMPARISON OF TWO SUPINE MANIKINS AND THE USE OF A SHOCK AND VIBRATION ISOLATION SYSTEM FOR LITTER PATIENTS IN AIR MEDICAL TRANSPORT

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ABSTRACT

The Comparison of Two Supine Manikins and the Use of a Shock and Vibration Isolation System for Litter Patients in Air Medical Transport

by

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Studies show that repeated shock and vibration during aero medical and ground transport are causing patient pain and may be adversely affecting patients' medical outcome. Patients with spine and head injuries and other severe neurological injuries are the most vulnerable to repeated shock and vibration exposure caused by the vehicle. It is crucial to minimize the effects of these forces on patients during air and ground medical transport. The development of new medical evacuation platforms creates a need to better understand the effects of human exposure to shock and vibration. The use of human subjects to measure whole body vibration for the evaluation of patient transport systems generates a challenge for designers of and evaluators of enroute care systems. Therefore two different supine manikins were created for this project, manikin 1 and manikin 2. Manikin 2 was a modification of manikin 1 so that it would have a closer biodynamic response to that of humans when subjected to repeated shock and vibration. The main objective of this project was to test the two manikins under various conditions and compare the results.

The manikins' design was based on the standards of a 95th percentile male. Another objective was to analyze the utilization of a litter air bladder to lower the consequences of human exposure to repeated shock and vibration due to aero medical transport.

The vibration signals used to perform the test were derived from research performed at the United States Army Aeromedical Research Laboratory at Fort Rucker Alabama. The vibration signals were captured from field tests conducted on a medevac litter mounted in a HH-60M Black Hawk helicopter in different modes of flight. After processing the recorded data, laboratory vibration tests were conducted on the manikins placed in the supine position to obtain the acceleration and transmissibility magnitudes at different locations on the manikins and the stirrup of the litter. The square root of the sum of the squares (RSS) acceleration in the real time was calculated to examine various strap restraint and stirrup clearance configurations and the effects of the use of the air bladder.

The results exposed the differences between manikin 1 and manikin 2. The resonant frequency of the manikins plus litter was approximately 4 Hz. In addition, the accelerations increased as the straps restraint was increased, which was expected as the manikins were less likely to move. For some conditions, the increase of stirrup clearance caused the acceleration values increase. Test results indicated the use of the air bladder between the manikins and litter resulted in an increase in acceleration values.

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CHAPTER 1 – INTRODUCTION

1.1. Literature Review

The transport and medical evacuation of wounded patients in a timely and efficient method is crucial to their survival. Today, the ability to evacuate patients from the battlefield has evolved into the most efficient transport and medically capable system in history so far. However, the military vehicles used to transport the injured soldiers from the battlefield to a medical treatment facility produce severe vibration environments experienced by the injured soldiers. Depending on the nature of the injury suffered, these vibrations may worsen the patient's health. The concern about the potential damage as a result of exposure to whole body vibration raises the issue of how to reduce the magnitude of the vibration. The implementation of an isolating system can help to reduce the vibrations wounded soldiers are exposed to during medical transport. However, the use of human subjects for the testing of this new technology brings medical and ethical responsibilities which can be avoided with the use of manikins.

A supine manikin that can mimic the same response characteristics to repeated shock and vibrations as a supine human would be an important tool for designing and developing shock and vibration isolation in enroute care systems. Currently, different industries make use of a manikin in seated applications for the development and safety of their equipment. The improvement of a passive manikin as a surrogate for supine human response to repeated shock and vibrations is considered as a first step forward development in different sectors. One application is in the design of vibration suppression or mitigation systems in this challenging environment. Another application is the evaluation of enroute care systems such as immobilization systems, litters, and transport vehicles. The passive supine manikin can be also adjusted in the future to be active with more capability to capture the behavior of people with different muscle forces and possibly to simulate injured patients.

U.S. Army Aeromedical Research Laboratory (USAARL) in conjunction with University of Nevada, Las Vegas (UNLV) discussed the physical requirements of the manikin and provided them to the manikin manufacturer. USAARL and UNLV also designed and constructed an air bladder system that can be placed between the human body and the stretcher to isolate the shock and vibration a human body is subjected to while being transported in a military vehicle. The air bladder cushion was originally created to attenuate the high shock acceleration experienced by occupants of military vehicles during mine blasts.

1.2. Manikins' Design

The manikins' design was based on the anthropometric data of a 95^{th} percentile male. According to NASA, a 95^{th} percentile male weighs 98.5 kg (217.2 pounds) and has a height of 190.1 cm (6 feet, 2 inches) (National Aeronautics and Space Administration, 2008). While manikin 1 is 178 cm (5 feet, 10 inches) and 81.9 kg (180.6 pounds), manikin 2 is 178 cm (5 feet, 10 inches) and 85 kg (187.4 pounds). The manikins' body was made of a polymer type material to reflect skin-like texture. Manikin 1 had a constant density throughout the body while manikin 2 had a density that increased toward its interior. The distribution of the body mass of the manikins was consistent with the weights of the head, chest, pelvis, and legs of at least 95^{th} percentile male. The manikins' skeletal system provided flexible joint movement. However, manikin 2 was adjusted to have looser joints because it was designed to more accurately simulate a human being's response when exposed to shock and vibration. Also, structure support in the chest and pelvis was added in manikin 2. In addition, both manikins have rigid necks, which did not allow obtaining good results if testing anything on the head area.

1.3. Litter Air Bladder System

The litter air bladder system was composed of two panels, the back and bottom panels that were bonded with an impermeable outer covering and connected by air vents that allowed the air to flow between the two panels. Figure 1.1 illustrates the schematic of the litter air bladder. The back air bladder panel supported the head, neck, trunk, hip, and buttock while the bottom air bladder panel supported the thighs, legs, and feet. Each panel was fabricated with low density, open-cell foam that had channels through it to facilitate the air flow within the foam as shown in Figure 1.2. Also, the air bladder system had a total of four air vents, one on each corner, that were used to passively inflate itself. In order to inflate the cushion the vents needed to be opened to atmospheric pressure then air came in to expand the foam and after that vents were closed to restrain the system. Figure 1.3 displays a litter air bladder with the air vents.

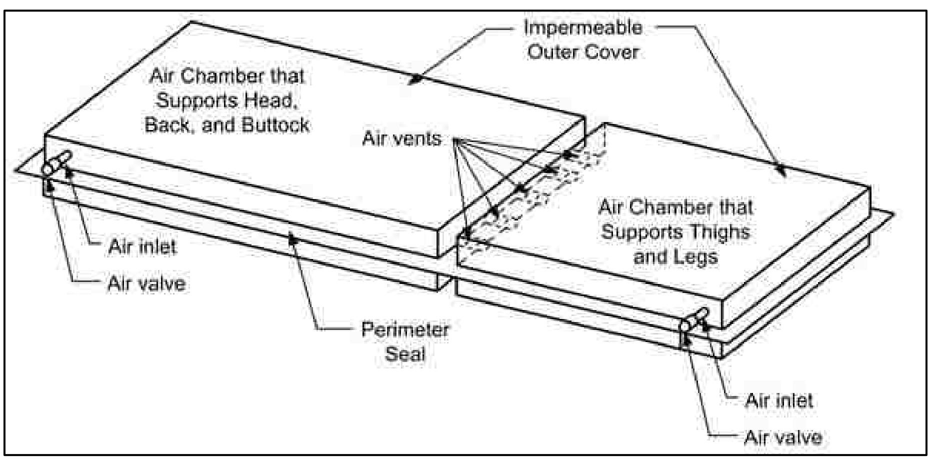

Figure 1.1: Schematic of the Litter Air Bladder [9]

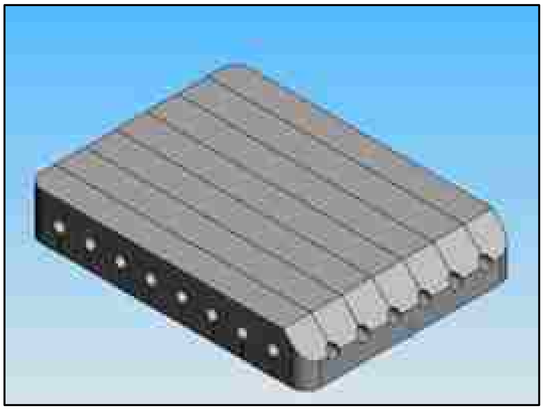

Figure 1.2: Channels within the Foam [9]

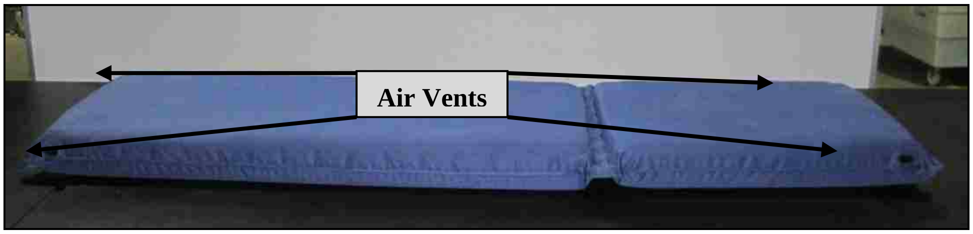

Figure 1.3: Litter Air Bladder

1.4. Motivation and Goals

Whole body exposure to shock and vibration during medical transport may worsen a soldier's health. The main objective of this project was to test and compare two different manikins, manikin 1 and manikin 2, where the second manikin was a modification of the first manikin. Manikin 2 was designed with more flexibility in the joints to better simulate the response of a human subject. The second goal of this thesis was to check the effectiveness of the litter air bladder system to mitigate the high shock energy that the patient was exposed to under various situations.

1.5. Overview and Organization of Thesis

The vibration signals of an actual field test conducted aboard a U.S. Army Black Hawk helicopter and a random vibration test with a constant acceleration spectral density of 0.0001 g^2/Hz [0.009617 $(m/s^2)^2/Hz$] were used to perform the experiments on the manikins under various conditions. The manikins were tested with and without the air bladder system. Using accelerometers that were placed under the shoulders, under the pelvis, and on the chest of each manikin, the acceleration magnitude and transmissibility magnitude of each location was recorded, processed, and plotted to be compared and analyzed. The root of the sum of the squares of the acceleration from the 1/3 octave band was calculated and gathered in tables to evaluate the effects of the straps restraint and stirrup clearance and the capability of the litter air bladder technology in mitigating patient experience to shock and vibration.

This thesis goes through the test standards and the details of the tests procedures and set-ups. It illustrates the processing of the data and the results. The comparison between the two manikins and the effect of the air bladder system in reducing high shock acceleration were examined from the results. The results were then analyzed and discussed. Finally, conclusions and recommendations for future work were given.

CHAPTER 2 – WHOLE BODY VIBRATION EXPOSURE

ISO 2631 (Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration) provides the standards for measurement and evaluation of human response to whole body vibration [10].

2.1. Coordinate System

In order to test the manikins on the single-axis vibration table and analyze the shock and vibration experienced by a human a coordinate system needed to be determined. Figure 2.1 shows the biodynamic coordinate system in terms of the x, y and z axes for the supine posture according to the ISO 2631.

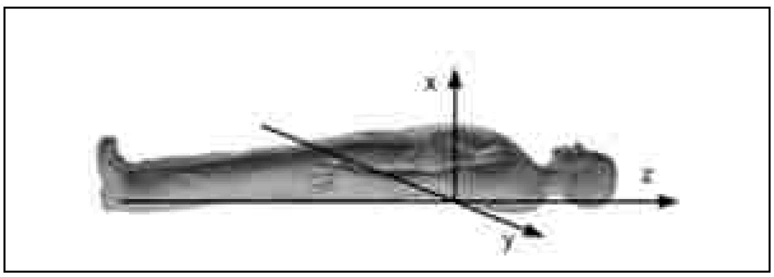

Figure 2.1: Supine Position Biodynamic Coordinate System [9]

2.2. Calculations

While there were several calculations given by PULSE (Brüel & Kjær Sound & Vibration Measurement A/S), there were other calculations that were computed using different formulas. The following sections show the calculations that were needed to analyze the results.

2.2.1. Acceleration Magnitude

Using the Autospectrum function in PULSE, the acceleration magnitude was determined. The FFT analyzer and CPB analyzer calculated the acceleration magnitude into frequency spectrums ranging from 1.50 Hz through 100 Hz. The FFT analyzer used the Fast Fourier Transformation algorithm to take a time varying input signal and calculate its frequency spectrum and the constant percentage bandwidth (CPB) analyzer produced 1/3 octave real time frequency spectral.

2.2.2. Vibration Transmissibility

Transmissibility is the ratio of the output to the input, and it is unit less. It determines the vibration transmitted from one location to another. Due to this principle, it can be observed how much vibration an element absorbs. The Frequency Response H2 function and CPB analyzer in PULSE were used to calculate the vibration transmissibility from the input (stirrup bottom) to the output (stirrup top), shoulder, pelvis, and chest. In addition, the vibration that was attenuated through the air bladder and the manikin was computed using the following definition:

$$T = \frac{Output\ Acceleration\ Value}{\text{Input}\ Acceleration\ Value} \tag{2.1}$$

2.2.3. RSS Acceleration

In order to observe the overall behavior of the shoulder, pelvis, and chest acceleration in the real time frequency spectral, the square root of the sum of the squares (RSS) was calculated. RSS was expressed in m/s^2 and given by:

$$a_{rss} = \sqrt{\sum_{i=1}^{n}(a_i^2)} \tag{2.2}$$

a_{rss} is the overall acceleration in m/s^2

a_i is the acceleration of the i^{th} for the 1/3 octave band frequency

CHAPTER 3 – TEST PROCEDURES

As previously mentioned, one of the objectives of this project was to determine the vibrational forces a human being would experience while laying down in a supine position on a litter mounted in a helicopter in flight under various litter mount conditions. Most measurement procedures could be disseminated into a logical sequence of events. The logical sequence of events included: transducer conditioning, basic measurement analysis, post-processing of analyzed data, displayed of results, and reported and documentation of results. Initiation of these events was usually achieved with the aid of vibration analysis software. In order to create a prototype, the elements of the procedure were divided into two primary areas, including hardware and software components. In addition, these two areas were subdivided. The hardware subsections included the hardware components and the physical layout of the hardware. The software subsections included the initiation of the logical sequence of events using the PULSE software and configuration of VibrationVIEW (Vibration Research Corporation). The following sections expound on these two areas using products specific to this project.

3.1. Hardware

3.1.1. Hardware Components

The hardware of the vibration test included the test element, the measurements devices, the signal controller and shaker system, and the data acquisition module. The test element was the system exposed to the vibration source, which in this case was manikin 1 and manikin 2. The measurement devices used for the vibration analysis were accelerometers. The signal controller provided the connection between the vibration software and the electrodynamic shaker system while the data acquisition module provided the link between electrodynamic shaker and the analysis software by way of the accelerometers. The hardware components of the system were as follows:

- Data Acquisition Unit & Analyzer – Brüel & Kjær Type 3560-C
- Test element – Manikin 1 and manikin 2
- Laptops equipped with Brüel & Kjær PULSE and VibrationVIEW software
- Accelerometers – PCB Piezotronics Type 352A21 & Dytran Triaxial Model 5313A
- Vibration View Signal Controller – Vibration Research Type VR8500
- Current Source Power Unit – Dytran Type 4103C
- Shaker Amplifier System – TIRA Vibration Systems TBS6000-P/MP

Table A.1 in Appendix A itemizes the specifications of the hardware components used during the experiment.

3.1.2. Hardware Layout

The hardware layout involved the placement of the accelerometers on each manikin and establishing the physical connection of each component. The first step was to place the accelerometers on each manikin and the stirrup of the litter. Two triaxial accelerometers were placed under each manikin; one was positioned under the shoulders and another was placed under the pelvis. In addition, one single axial accelerometer was attached to the manikin's chest, and two single axial accelerometers were placed on the stirrup of the litter; one on top and another below. The final accelerometer was used as an input from the Dytran power unit to the electrodynamic shaker. Figure 3.1 displays the location of the accelerometers. Once the accelerometers were securely positioned, the next step was to establish the physical connections between the components.

The five measurement accelerometers, positioned on each manikin and stirrup of the litter, were connected to the front panel of the Brüel & Kjær PULSE multi-analyzer using Bayonet Neill-Concelman (BNC) connectors. Also, the laptop containing the PULSE software was connected to the multi-analyzer using an Ethernet connection. Three components were connected to the VR8500 controller including, the TIRAvib amplifier, the Dytran power unit, and the laptop containing the VibrationVIEW software. Upon completion of connecting the hardware components, the next major procedural step was to configure the software. Figure 3.2 is a schematic depicting the connections between the hardware components.

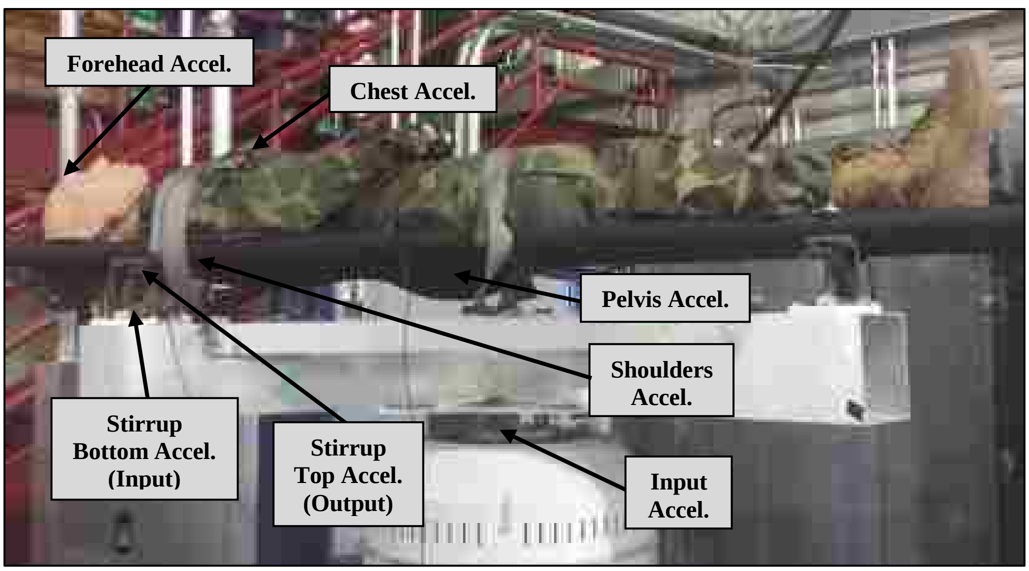

Figure 3.1: Accelerometer Locations

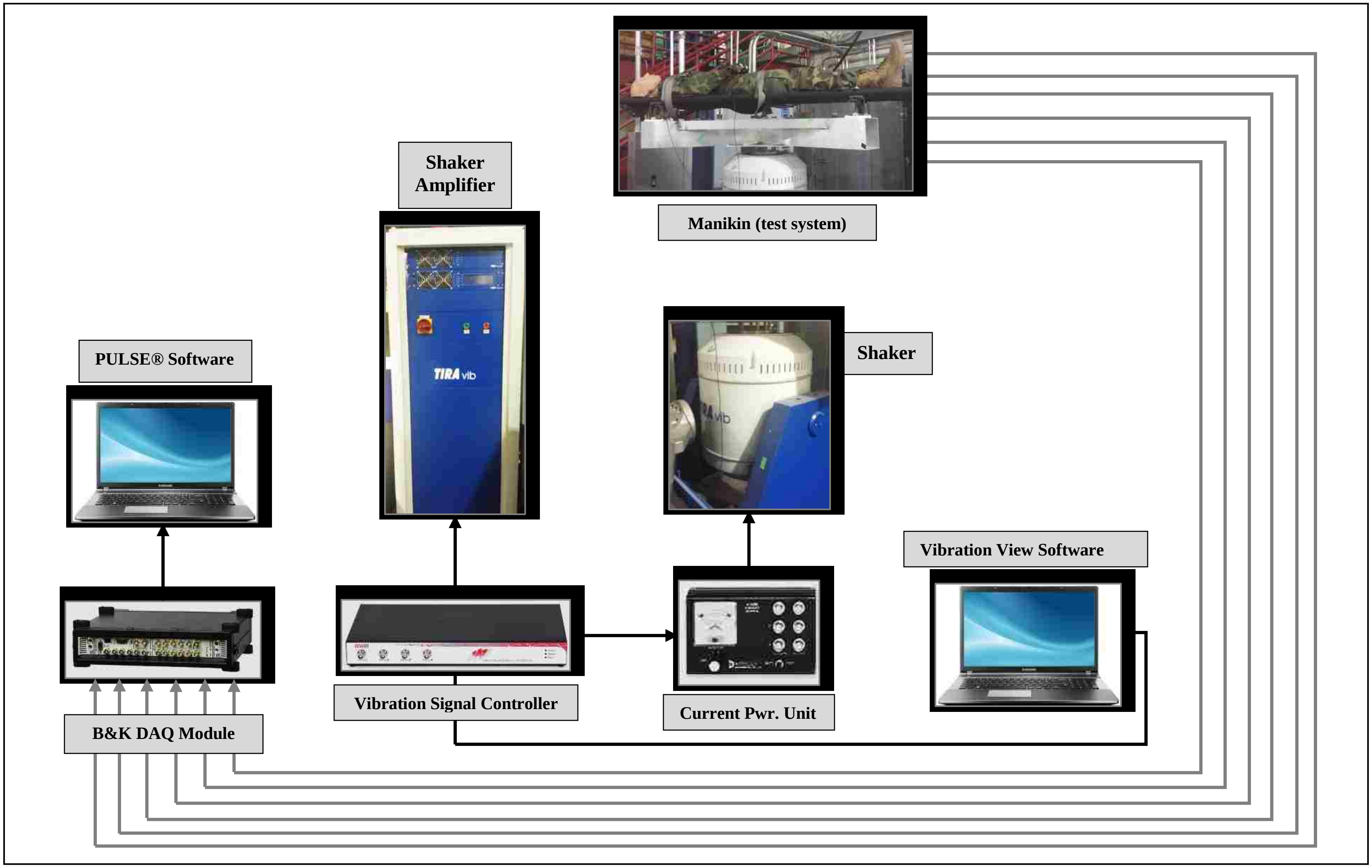

Figure 3.2: Hardware Connection Schematic

3.2. Software

3.2.1. Software Components

The two software systems used were Brüel & Kjær PULSE and Vibration Research's VibrationVIEW. PULSE was used as an interface to record and process the results of the measurements acquired by the accelerometers and to accomplish the logical sequence of events while VibrationVIEW was used as an interface to select and transmit the vibration signal data to the VR8500 vibration controller. The configuration of each system was based on setting certain system parameters and the selection of tools for data analysis and representation.

3.2.1.1. PULSE Configuration: Logical Sequence of Events

Similar to other windows based software systems, once the PULSE graphic user interface was accessed, a template for the forthcoming test had to be created and saved. The template contained a layout of all the functions that were required to initiate and carry-out the logical sequence of events. In PULSE each event within the sequence was implemented with an Organizer function. The event and its corresponding Organizer function within PULSE were as follows:

- Transducer Conditioning: Implemented with the Configuration Organizer
- Basic Measurement Analysis: Implemented with the Measurement Organizer
- Post-processing of Analyzed Data: Implemented with the Function Organizer
- Display of Results: Implemented with the Display Organizer

Organizer functions were located in the dropdown menu of the Organizer tab on the toolbar and were outlined in the following steps and screenshots. Figure 3.3 shows the screenshot of the dropdown menu of the Organizer tab.

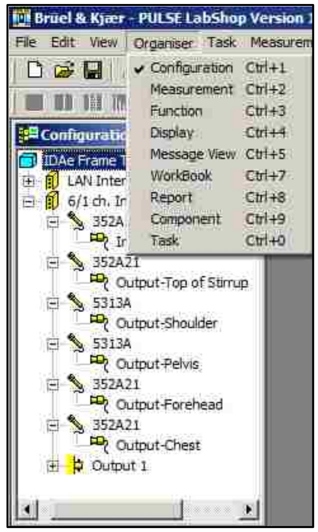

Figure 3.3: Dropdown Menu of Organizer Tab

Step 1: Configuration Organizer

The Configuration Organizer was used to set-up the accelerometers, that were connected to the front channels of the Brüel & Kjær data acquisition module. In this window, the accelerometers were selected from the transducer database. If they were not already in the database, they were added using the serial number, the type, the nominal sensitivity, and the actual sensitivity. Right clicking on each accelerometer gave the option to see the configuration properties of the accelerometer. Figure 3.4 and Figure 3.5 illustrate the Configuration Organizer and the Configuration Properties windows respectively.

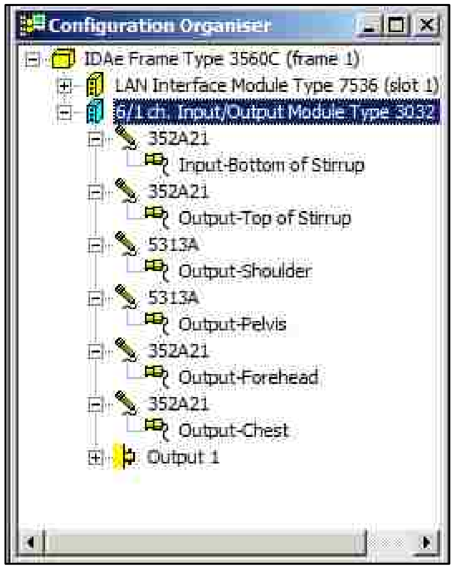

Figure 3.4: Configuration Organizer

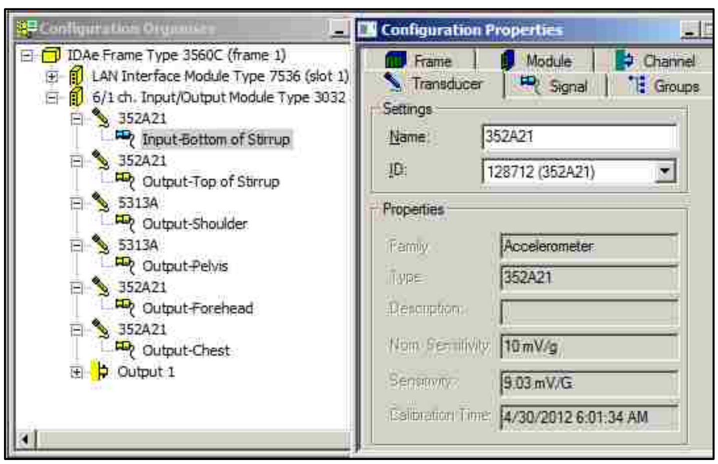

Figure 3.5: Configuration Properties

Step 2: Measurement Organizer

This organizer was used to arrange the accelerometers in a logical group and assign the adequate analyzers to evaluate the signals of the accelerometers. In addition, two analyzers were selected for the group. The two used analyzers for vibration analysis were the FFT and CPB analyzers.

As mentioned in section 2.2.1, the FFT analyzer computed the frequency components of the input signal and the CPB calculated the frequency spectrum using the 1/3 octave bands. The accelerometers properties could be adjusted by right clicking on an accelerometer. Similarly, the analyzers properties such as frequency lines, bandwidth, and averaging mode were adjusted by right clicking on each analyzer. Figure 3.6 depicts the Measurement Organizer while Figure 3.6Figure 3.7, Figure 3.8, and Figure 3.9 portray the property boxes for the accelerometer, and the FFT and CPB analyzers respectively.

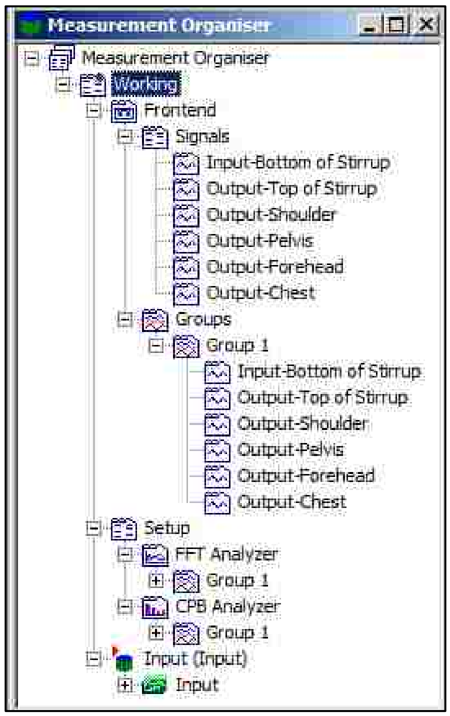

Figure 3.6: Measurement Organizer

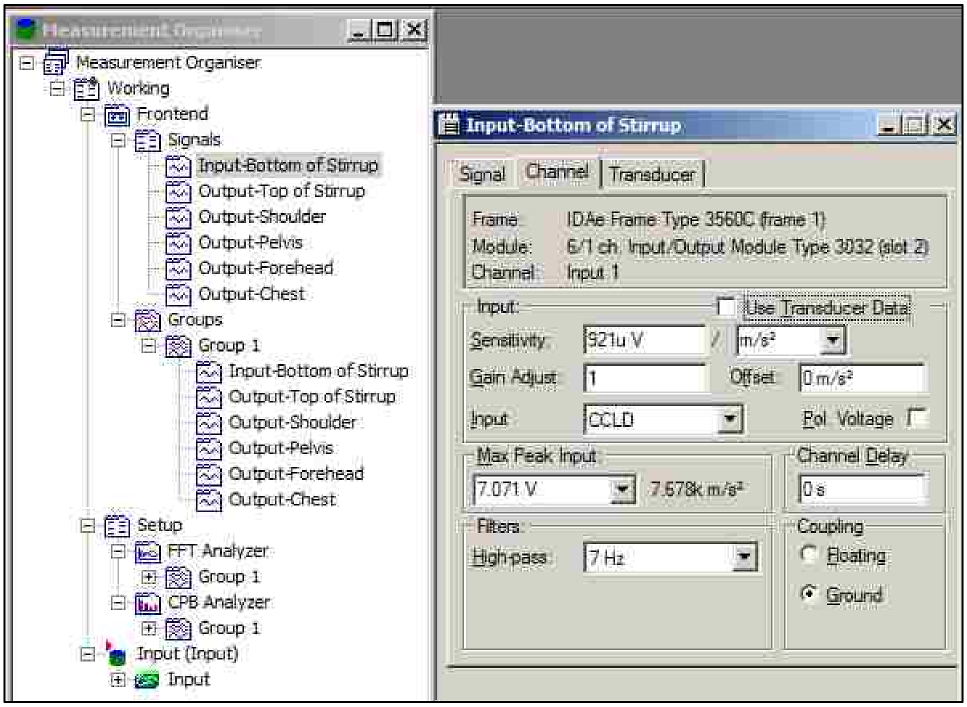

Figure 3.7: Accelerometer Properties

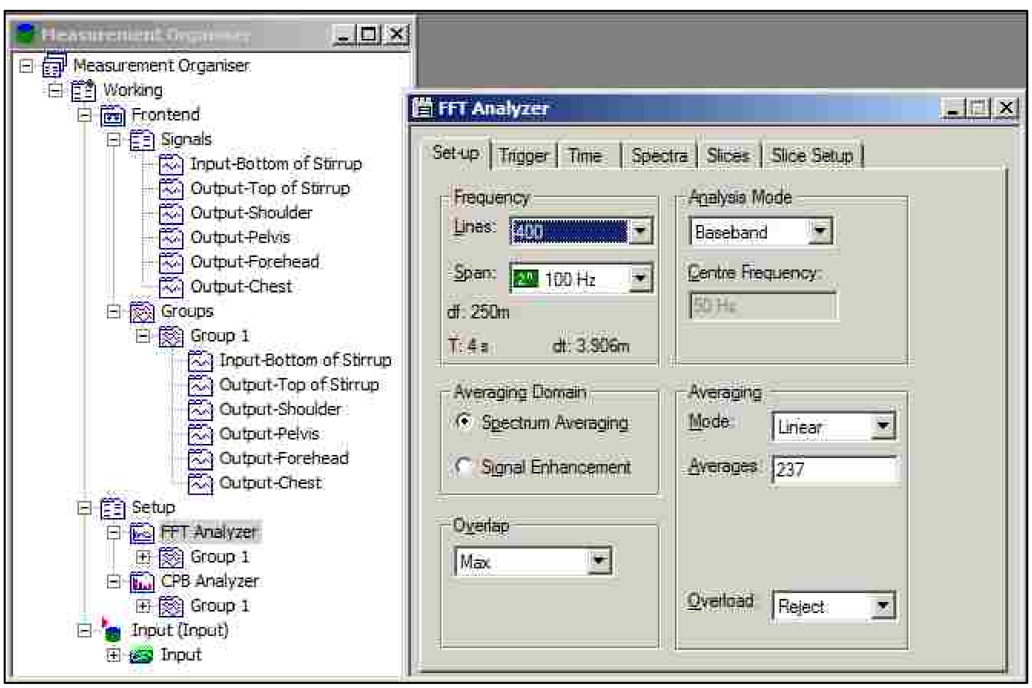

Figure 3.8: FFT Analyzer Properties

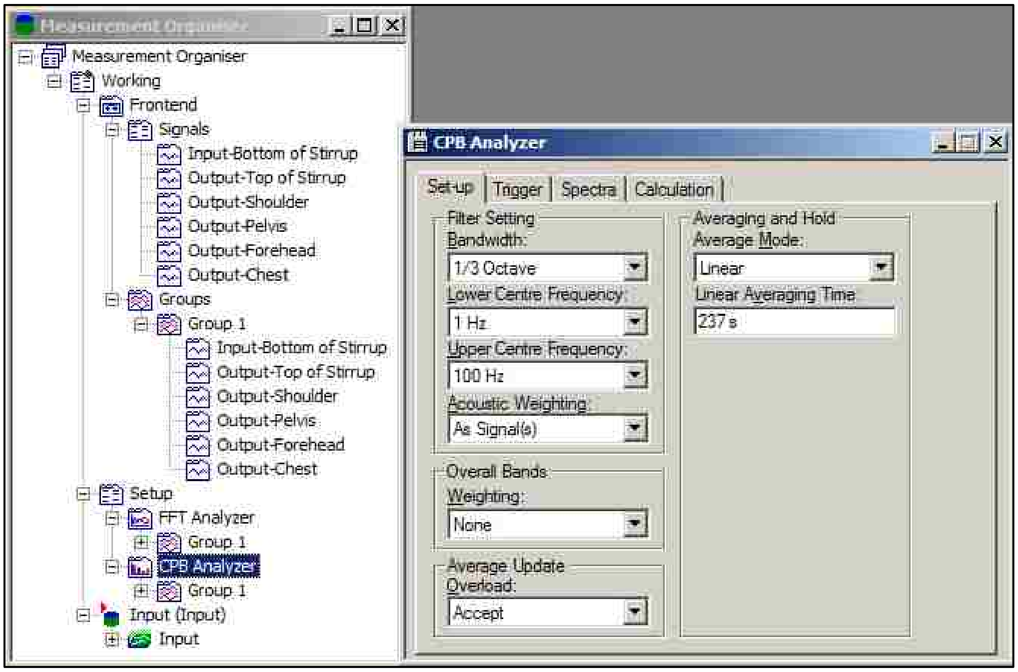

Figure 3.9: CPB Analyzer Properties

Step 3: Function Organizer

This organizer was used to implement different functions used to analyze the signals measured by the accelerometers, and its main use was the post-processing of the data. Through the use of the analyzers, the selected function was applied to any of the accelerometers. Two of the more useful functions used in vibration analysis included the Autospectrum and the Frequency Response H2 functions. The Autospectrum was used to derive the accelerations. The Frequency Response H2 generated a mathematical representation of the relation between the input and output of a linear time-invariant system. Right clicking on a function in the queue opened the Function window in which the function was applied to a signal (accelerometer) and implemented by an analyzer. Figure 3.10, Figure 3.11, and Figure 3.12 display the Function Organizer, the Frequency Response function implemented by the FFT analyzer, and the Autospectrum Function implemented by the CPB analyzer respectively.

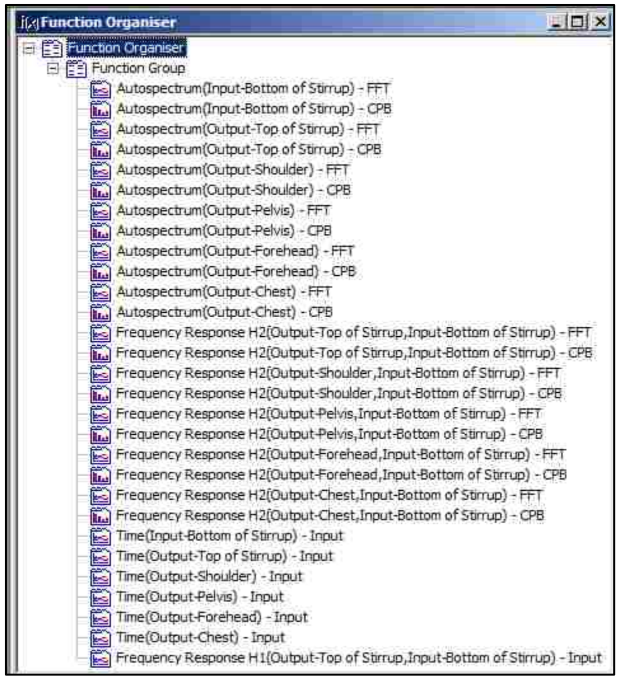

Figure 3.10: Function Organizer

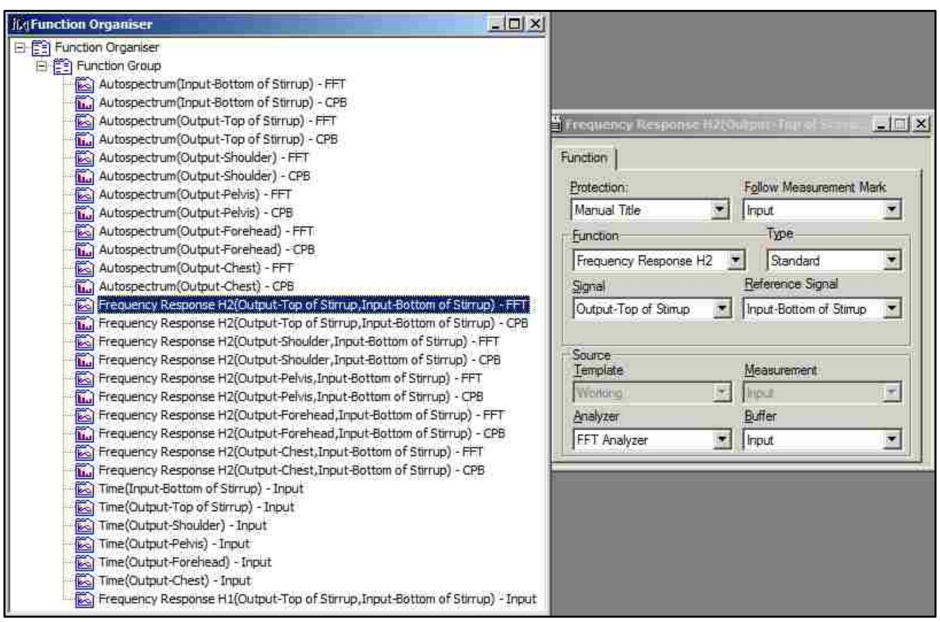

Figure 3.11: Function Window for Frequency Response

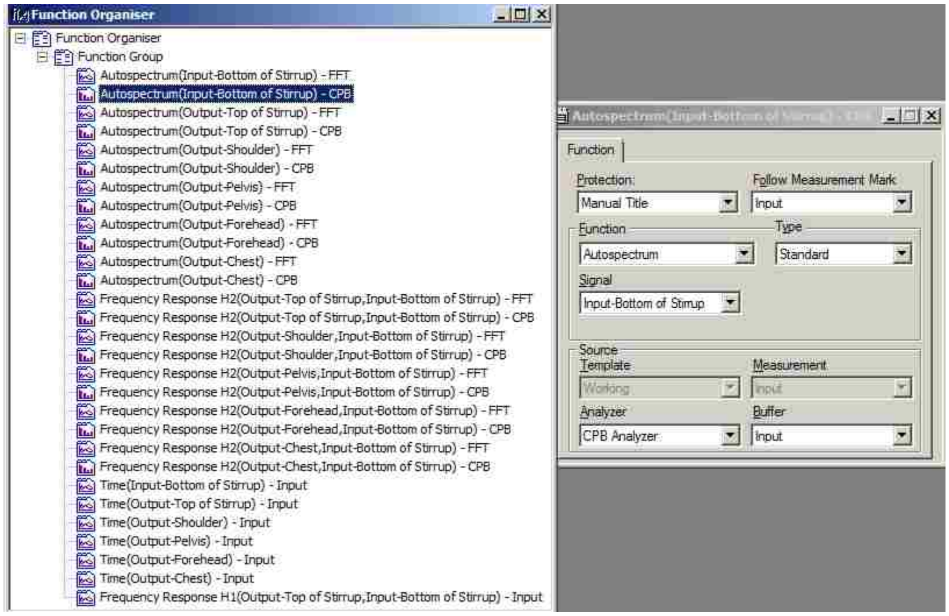

Figure 3.12: Function Window for Autospectrum

Step 4: Display Organizer

The Display Organizer was utilized to generate and display graphical representations of the data processed by the functions. Therefore, graphs were created for the Autospectrum and Frequency Response functions. With the exception of the icons, the Display Organizer dropdown queue was identical to the Function Organizer dropdown queue in terms of the listed functions. Right clicking on a function display in the queue opened the window used to format properties of the graph such as axis units, coordinates, and color palettes. Figure 3.13 illustrates the Display organizer with the Autospectrum display properties box opened.

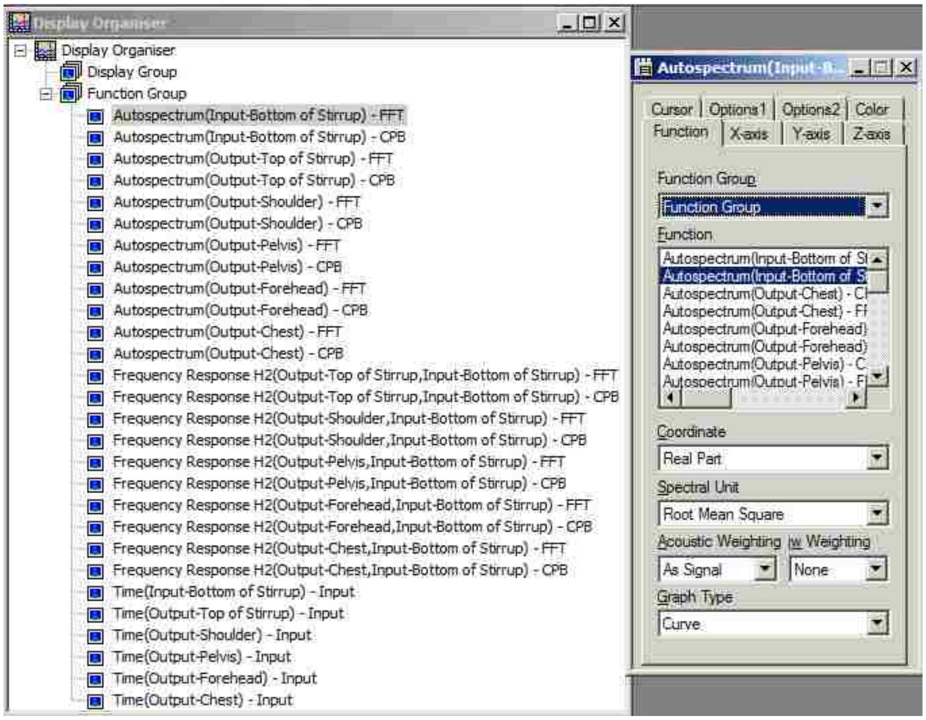

Figure 3.13: Display Organizer and Property Window for Autospectrum Display

Step 5: Workbook

The Workbook window was used to save a desired screen layout. Double clicking on the layout name in the Workbook queue opened that particular layout. Figure 3.14 is an image of the Workbook.

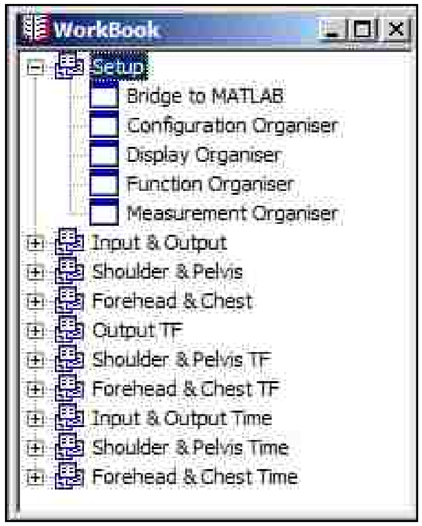

Figure 3.14: Workbook

Step 6: Bridge to Matlab

The Bridge to Matlab tool allowed data tables to be exported as text documents. Unlike the other organizer tools, the Bridge to Matlab tool was accessed by clicking on the Component Organizer icon on the tool bar. Figure 3.15 depicts the Bridge to Matlab window.

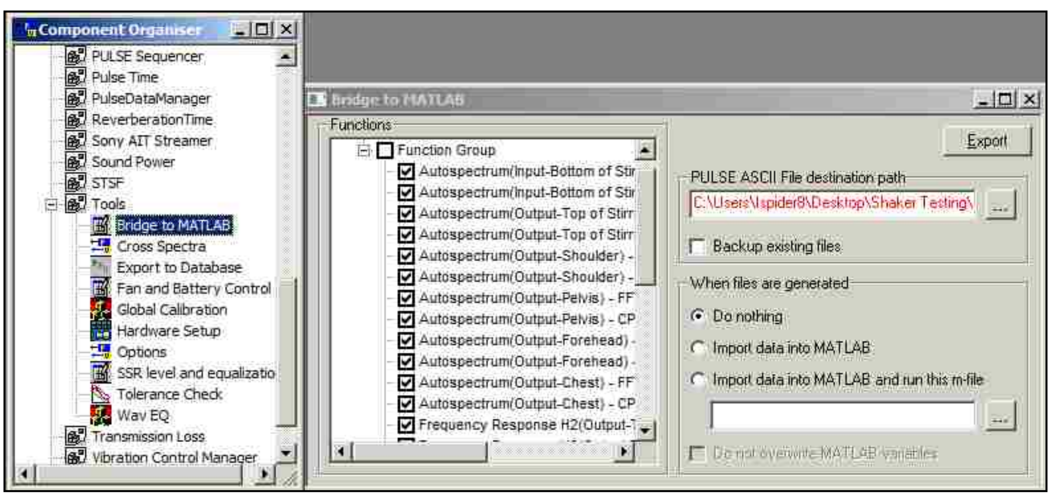

Figure 3.15: Bridge to Matlab

3.2.1.2. VibrationVIEW Configuration

Step 1: Test Type

For this project, two types of tests were run, which were the Field Data Replication (FDR) and Random tests. The FDR test chosen was one of the field tests with the highest peak acceleration of 0.906977 g (8.894406 m/s^2); this test was a recorded data from an April 12th, 2012 UH-60 Black Hawk field test with a rotary wing flight profile 2 that was out of ground effect hover (70 feet above ground hover performance). The random vibration test chosen was represented in the frequency domain by a power spectral density function, also called acceleration spectral density with a constant acceleration amplitude of 0.0001 g^2/Hz [0.009617 (m/s^2)^2/Hz] and a frequency range of 1 Hz – 100 Hz. Figure 3.16 displays the type of tests that could be loaded and run in VibrationVIEW.

Figure 3.16: Types of Tests

Step 2: Configure Test Settings

For the Field Data Replication Test, the Field Data Replication Test Settings-Import tab was selected and then the previously recorded data from the April test was chosen to be executed, as shown in Figure 3.17. The file units were selected and the file was then converted. Figure 3.18 shows the Playback tab, where the system specifications were displayed. In the Limits tab, the critical limits of the FDR were set, as displayed in Figure 3.19. The Max System Gain was the maximum Volts/G level allowed into channel 1 that was the control from the shaker accelerometer. The Max Output was the maximum output voltage allowed from the control loop. If the channel 1 output exceeded this value, the test was aborted.

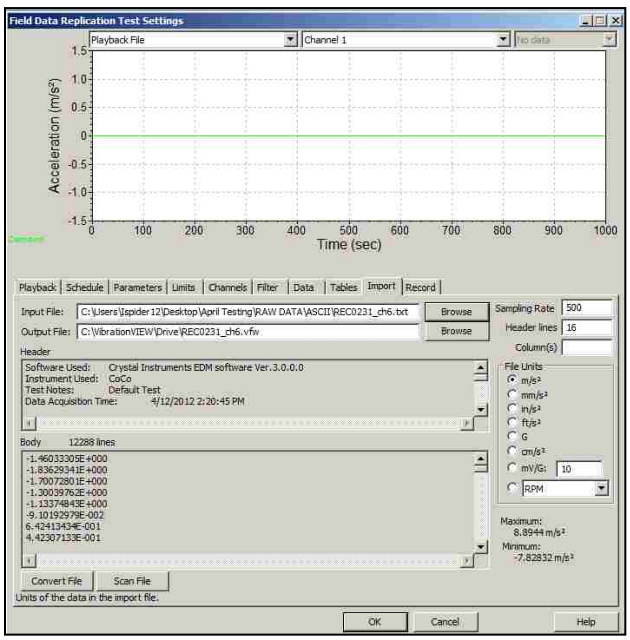

Figure 3.17: Field Data Replication Test Settings-Import Tab

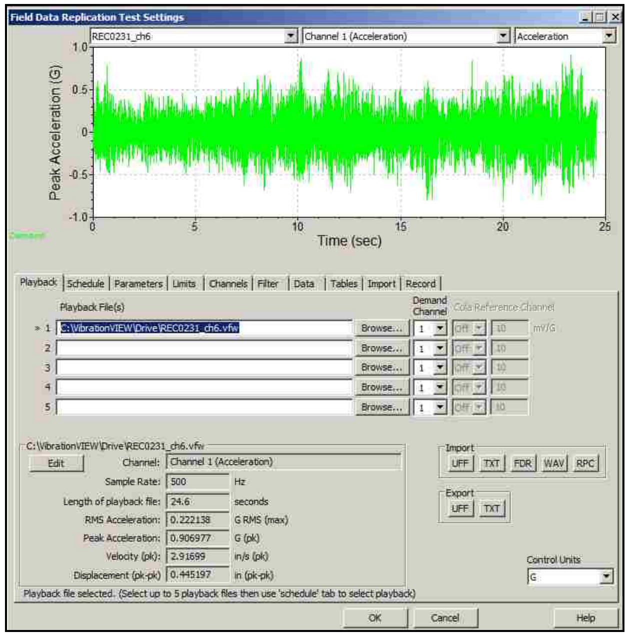

Figure 3.18: Field Data Replication Test Settings-Playback Tab

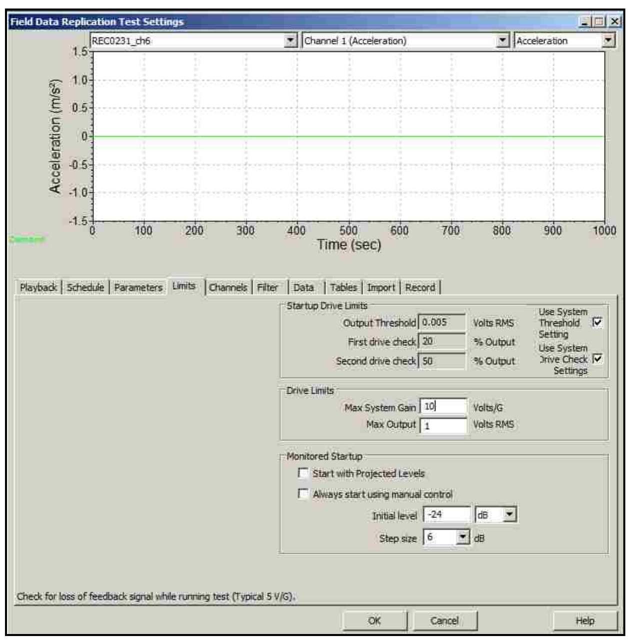

Figure 3.19: Field Data Replication Test Settings-Limits Tab

For the random test, the frequency range and the acceleration amplitude were entered in a table, as shown in Figure 3.20. Subsequently, the limits of the test were set in the Limits tab and the file was saved.

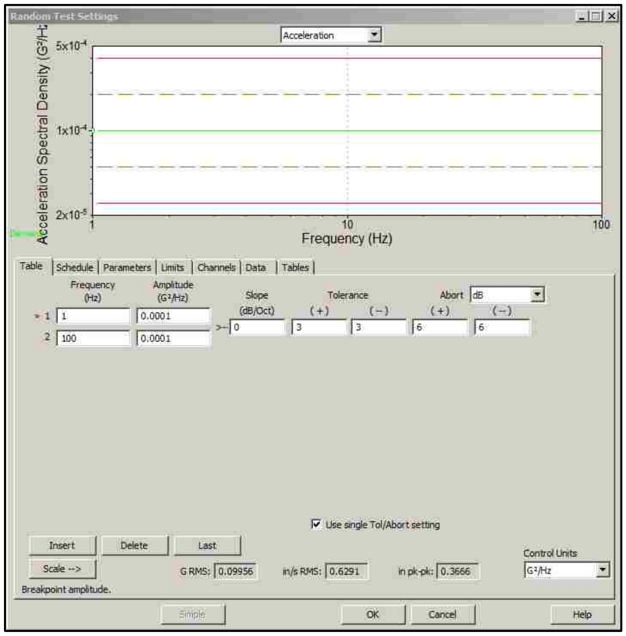

Figure 3.20: Random Test Settings

Step 3: Initiating the Test

Each test was started by clicking on the green arrow in the Control Buttons box. Figure 3.21 shows the acceleration spectral density versus frequency graph and the acceleration versus time graph of the selected previously recorded data. The green line represented what was being demanded by the loaded system, and the blue line represented the control, which was the actual output from the shaker accelerometer.

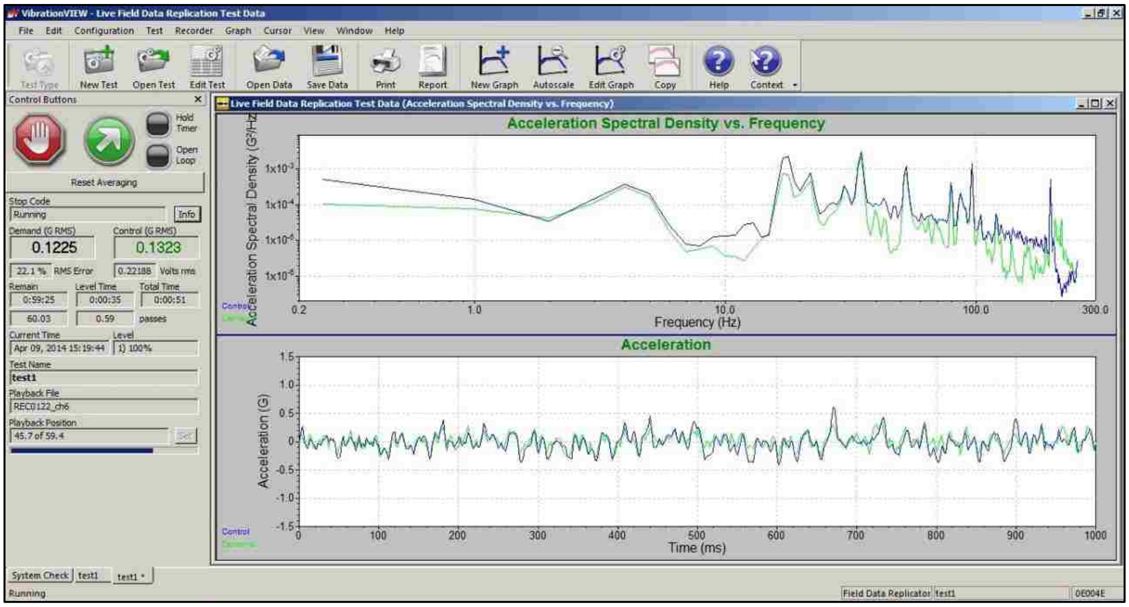

Figure 3.21: The Acceleration Graphs from a Field Data Replication Test

CHAPTER 4 – TEST SET-UP

As previously mentioned, the principle aim of this project was to compare the responses of two different manikins and to prevent exacerbation of existing patient injuries during transport. This chapter will describe the set-ups and conditions for the Black Hawk helicopter and random tests. Figure 4.1 displays a flowchart of the tests configurations. As stated before, the Black Hawk helicopter test chosen was an April field test that had a duration of 24.6 sec. For the random vibration test, the magnitude of the acceleration spectral density was kept constant at 0.0001 g^2/Hz [0.009617 $(m/s^2)^2$/Hz], and the test was run for 30 sec. Manikin 1 and 2 were tested in a supine position on a litter. Although manikin 2 had better flexibility in all the joints to better resemble the biodynamic response of a human subject, both manikins had a rigid neck design, which made it difficult to simulate the response of the human head.

Before beginning the tests, the manikins' hands were secured with tape and the feet were secured with string. Each manikin was tested with the air bladder and without the air bladder to examine the effects of the air bladder on the response. Besides, three straps configurations were implemented on each test. The first set of tests was run without straps; another was performed with a 15 lb_f. straps restraint, and the last one was executed with a 35 lb_f. straps restraint. For the straps configurations, two straps were tightened around the manikins; one around the chest and the second one around the thighs. Figure 4.2 depicts the straps placed around the manikins. Finally, two different arrangements were made on the stirrup of the litter. The first arrangement had the stirrup rigidly fixed to the surface and the second one had a 0.25 inch gap between the bracket used to secure the stirrup and the surface, allowing movement in the vertical direction. Figure 4.3 and Figure 4.4 illustrates the 0 in. and 0.25 in. stirrup clearance.

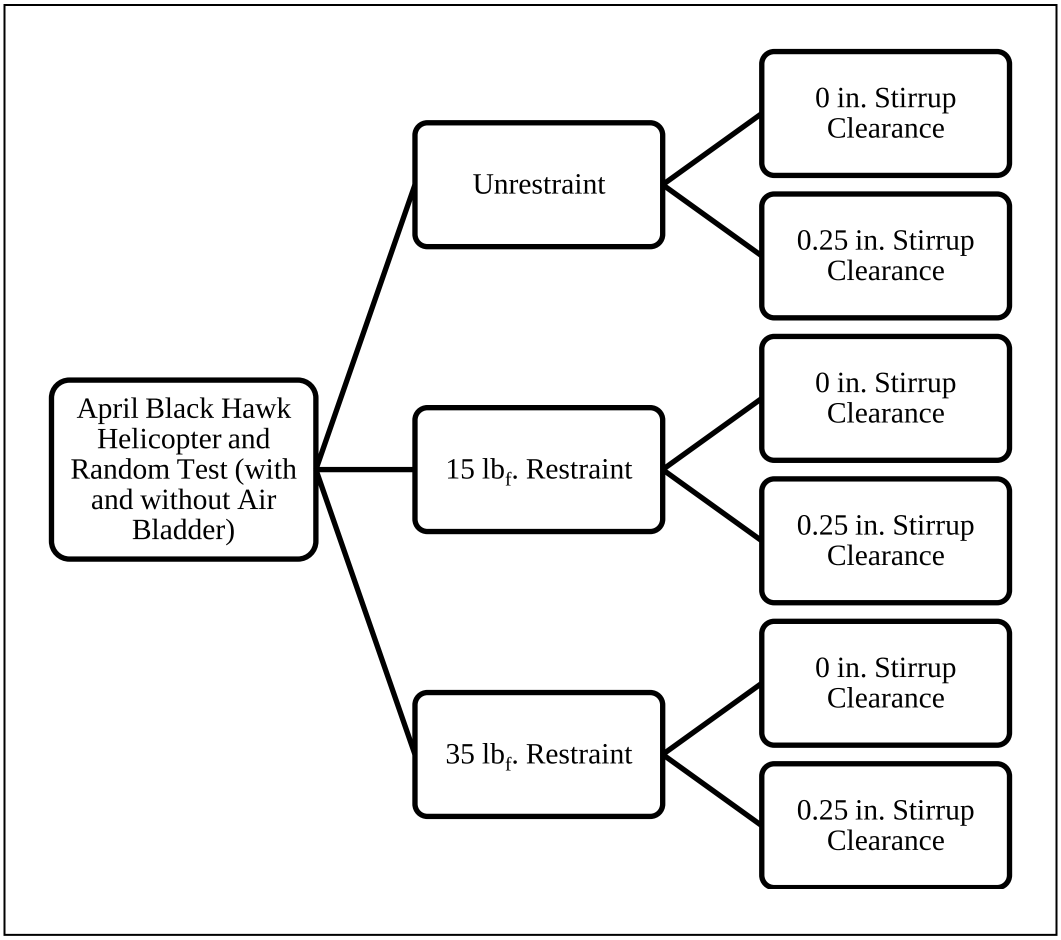

Figure 4.1: Conditions Used for Each Manikin

Figure 4.2: Manikin with Straps

Figure 4.3: 0 in. Stirrup Clearance

Figure 4.4: 0.25 in. Stirrup Clearance

CHAPTER 5 – TEST RESULTS AND DISCUSSION

After running the tests under all the various conditions, the acceleration magnitude and vibration transmissibility were plotted in the FFT and CPB frequency spectrums to evaluate the differences between the two manikins. However, possibly due to a system error the transmissibility plots in the FFT frequency spectrum derived by PULSE did not correlate with the other generated plots. Consequently, the transmissibility magnitude in the FFT frequency spectrum was not included in the results. After running all the tests and analyzing the data, it was noticed that the ideal scenario was when the litter was rigidly fixed to the surface (0 in. clearance) and the straps were restrained by a 35 lb_f. Furthermore, the RSS acceleration values from the CPB frequency spectrum for each manikin and condition were summarized on a table at various frequency ranges to examine the effects of the straps restraint, the stirrup clearance, and the use of the air bladder technology to reduce shock and vibration experienced by a subject during medical transport.

5.1. Black Hawk Helicopter Test Results

Using the Autospectrum and Frequency Response functions from the PULSE FFT and CPB analyzers, the accelerations and transfer functions of the measurements taken from each accelerometer location were plotted for the Black Hawk helicopter tests that were run. The input (stirrup bottom location) and the output (stirrup top location) showed an acceleration magnitude graph almost identical due to the fact that they were relatively close. The two important properties that were gleaned from the plots were the resonant and harmonic frequencies of the system. The results revealed that the resonant frequency of the input and output was estimated to occur at 32 Hz. On the other hand, the resonant frequency of the shoulders, pelvis, and chest was at 4 Hz. This value was consistent among the results of the tests using 0 and 0.25 in. stirrup clearance and 0 lb_f, 15 lb_f, and 35 lb_f straps restraint. For the output and input plots, the harmonic frequencies occurred at 4 Hz, 8 Hz, 16 Hz, 52 Hz, 63 Hz, 80 Hz, and 97 Hz. In addition, the harmonic frequencies occurring at 8 Hz, 16 Hz, 32 Hz, 52 Hz, 63Hz, 80 Hz, and 97 Hz were clearly identifiable in the shoulders, pelvis, and chest plots of each manikin. From the plots, it was also observed that the shoulders acceleration magnitude of manikin 2 was higher than that of manikin 1 between 16 Hz and 32 Hz and lower between 55 Hz and 77 Hz. Moreover, the acceleration magnitude of the pelvis of manikin 2 was higher between 16 Hz and 32 Hz and lower between 42 Hz and 62 Hz, and the acceleration magnitude of the chest of manikin 2 was lower over a frequency range from 22 Hz to 42 Hz.

The Frequency Response function was used to calculate the vibration transmissibility for each test condition. The amplitude of the transfer function was simply the ratio of the output signal divided by the input signal. The vibration transmissibility between the stirrup bottom and top had a magnitude of 1 from 1.6 Hz to 100 Hz. However, the output had a transmissibility peak value of 2 at 4 Hz for the unrestraint configuration and 3 at 2.50 Hz for the 35lb_f. straps restraint configuration. The shoulders, the chest, and pelvis of both manikins had vibration transmissibility greater than 1 over the frequency range of 1.6 Hz to 10 Hz. Beyond 10 Hz the transmissibility was less than 1 for the shoulders, chest, and pelvis.

Figure 5.1 through Figure 5.11 show the plots of the acceleration magnitude versus frequency for the Black Hawk helicopter test using the FFT and CPB analyzers and the related plots of the vibration transmissibility for the shoulders, the pelvis, and the chest with 35 lb_f. straps restraint and 0 in. stirrup clearance. The figures of the shoulders, pelvis and chest with 0 in. and 0.25 in stirrup clearance of the unrestrained tests are in Appendix B. The figures of the shoulders, pelvis, and chest with 0 in. and 0.25 in. clearance and 15 lb_f. restraint are in Appendix C. The figures of the shoulders, pelvis, and chest with 0.25 in. clearance and 35 lb_f. restraint are in Appendix D.

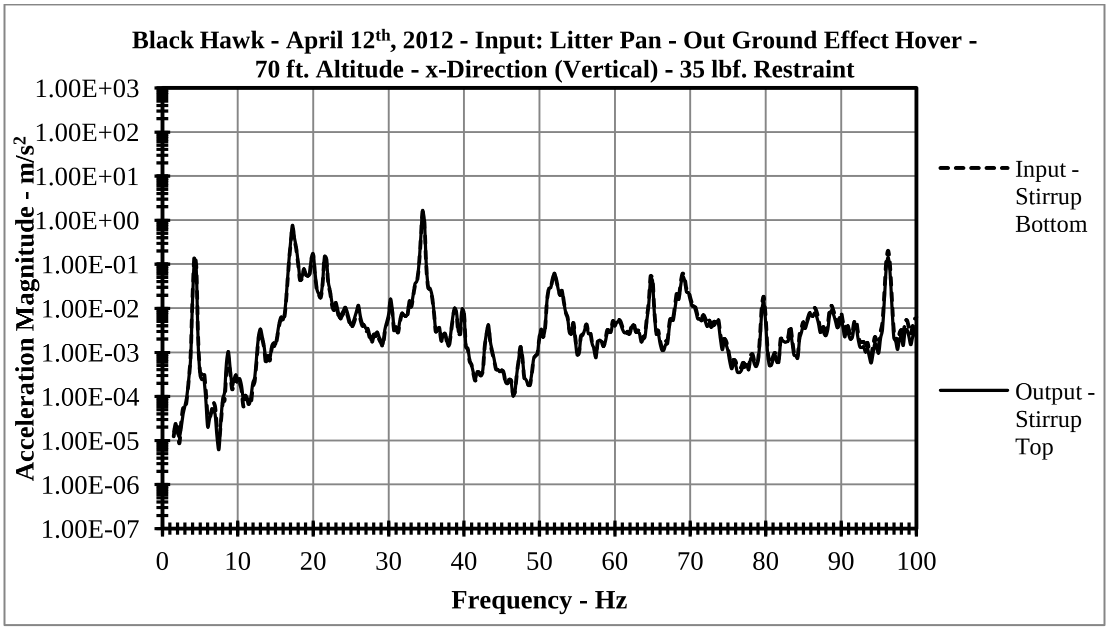

Figure 5.1: Acceleration Magnitude of the Input and Output for the Black Hawk Test – 35 lbf. Restraint

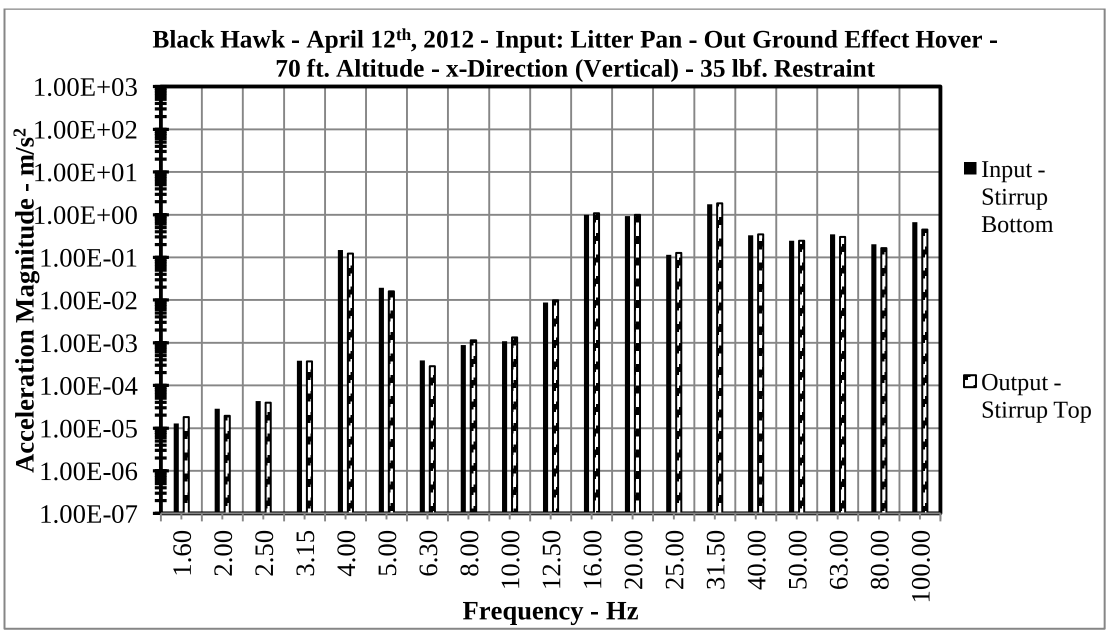

Figure 5.2: 1/3 Octave Band Acceleration Magnitude of the Input and Output for the Black Hawk Test – 35 lbf. Restraint

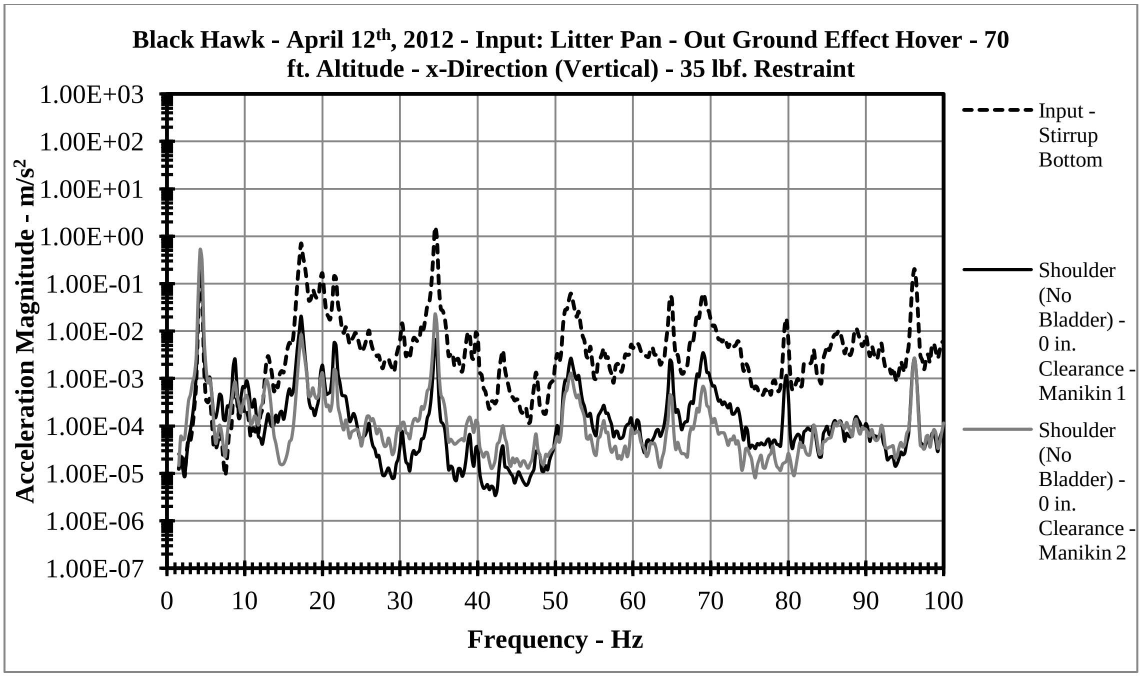

Figure 5.3: Acceleration Magnitude of the Shoulders for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

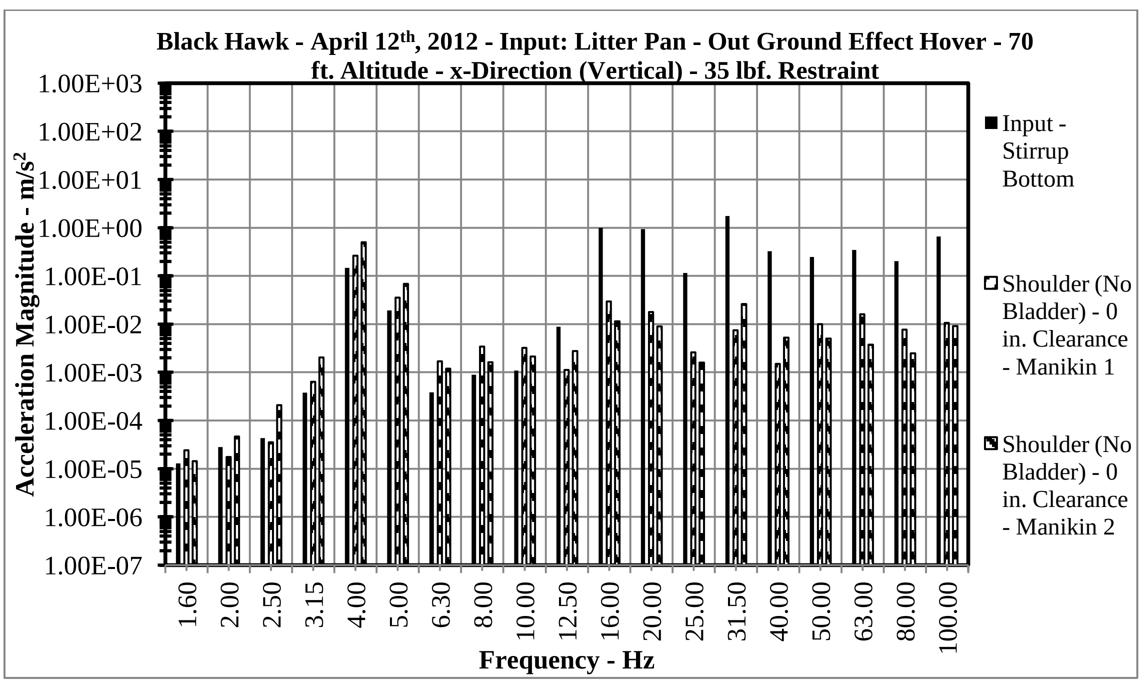

Figure 5.4: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

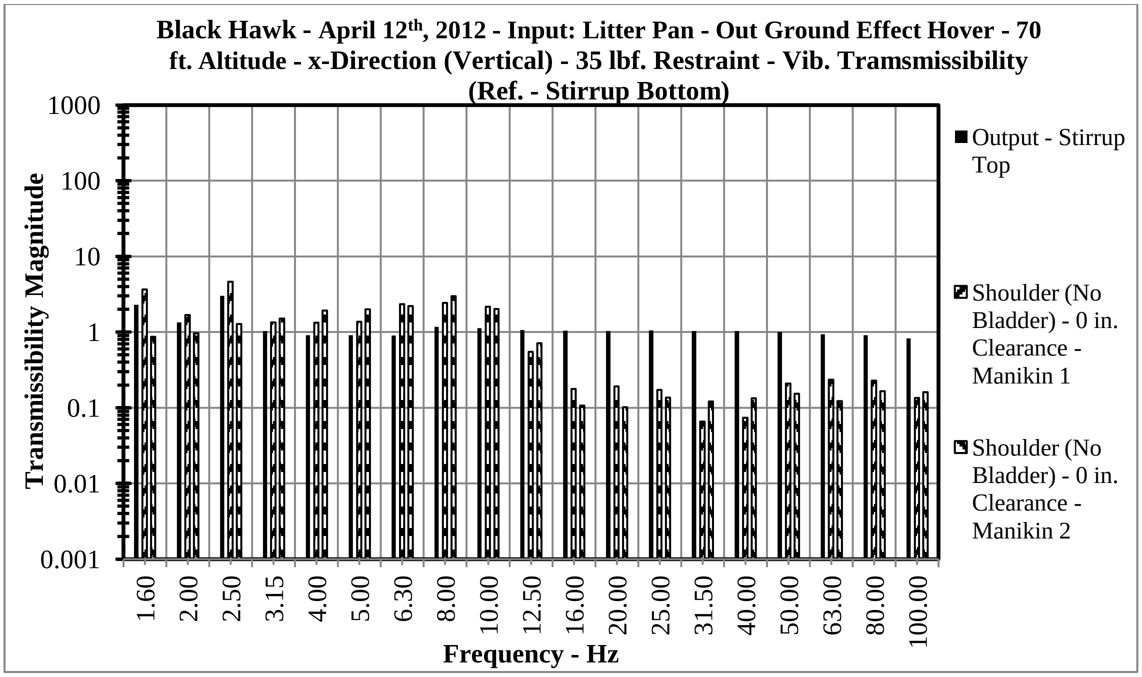

Figure 5.5: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

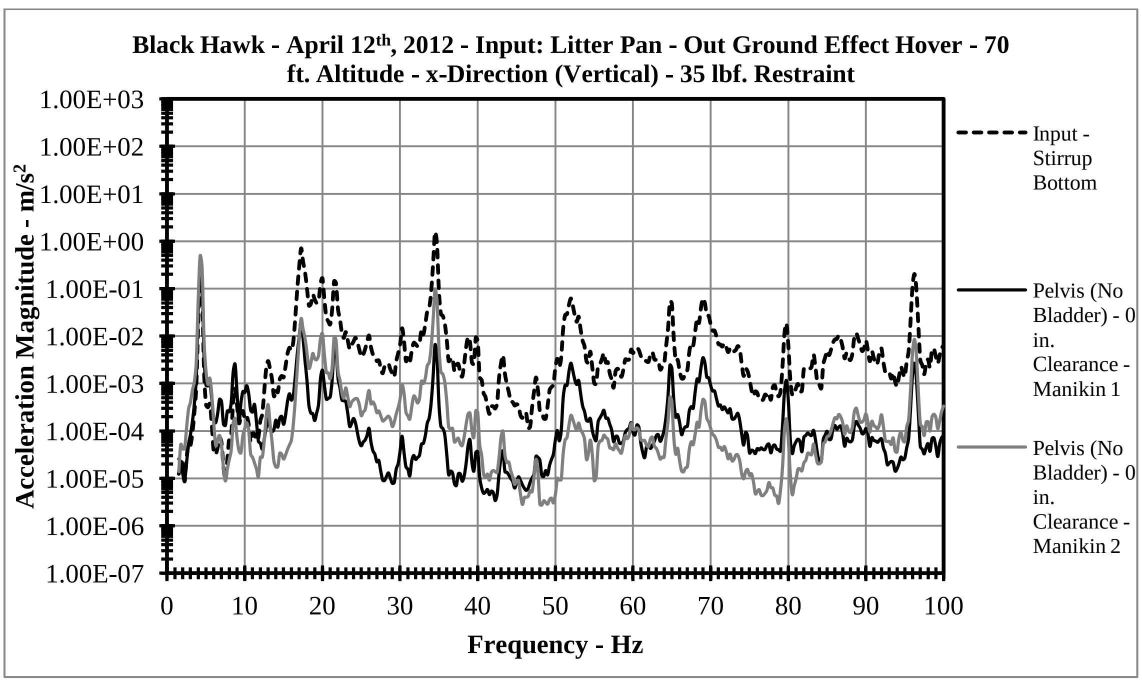

Figure 5.6: Acceleration Magnitude of the Pelvis for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

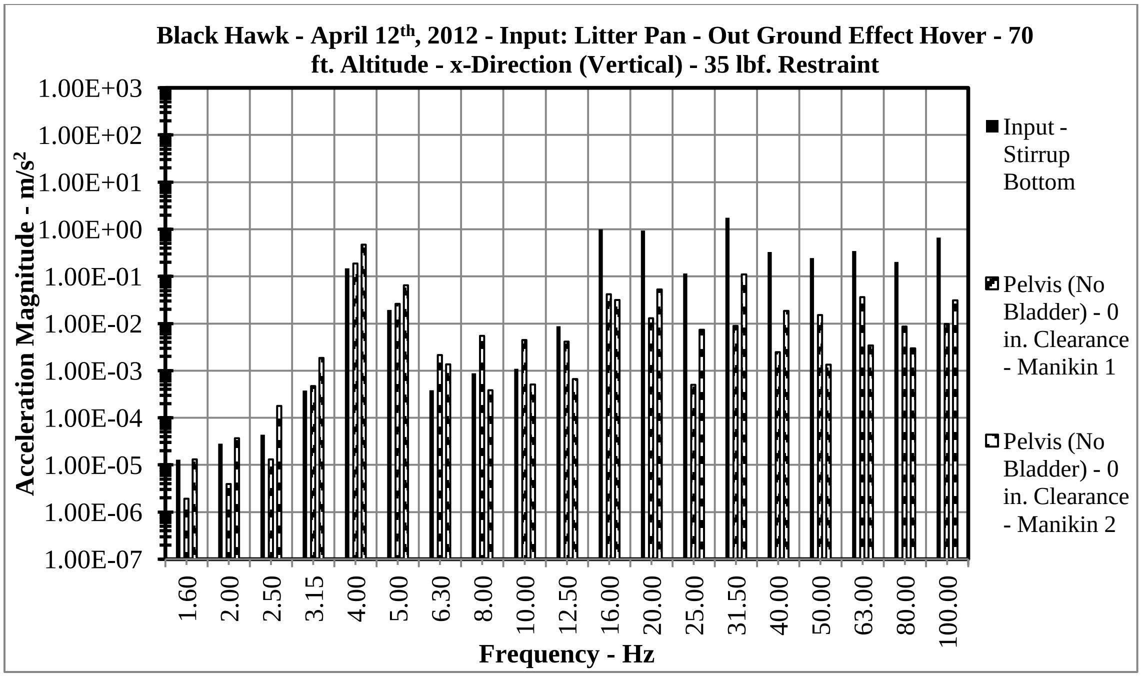

Figure 5.7: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

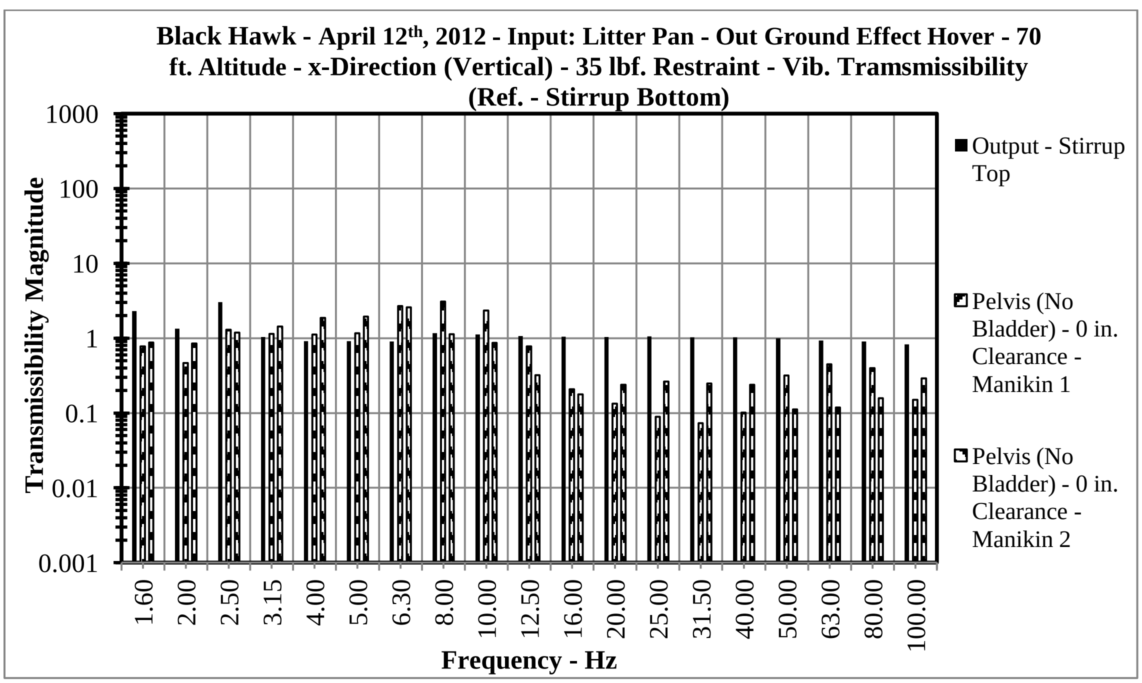

Figure 5.8: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

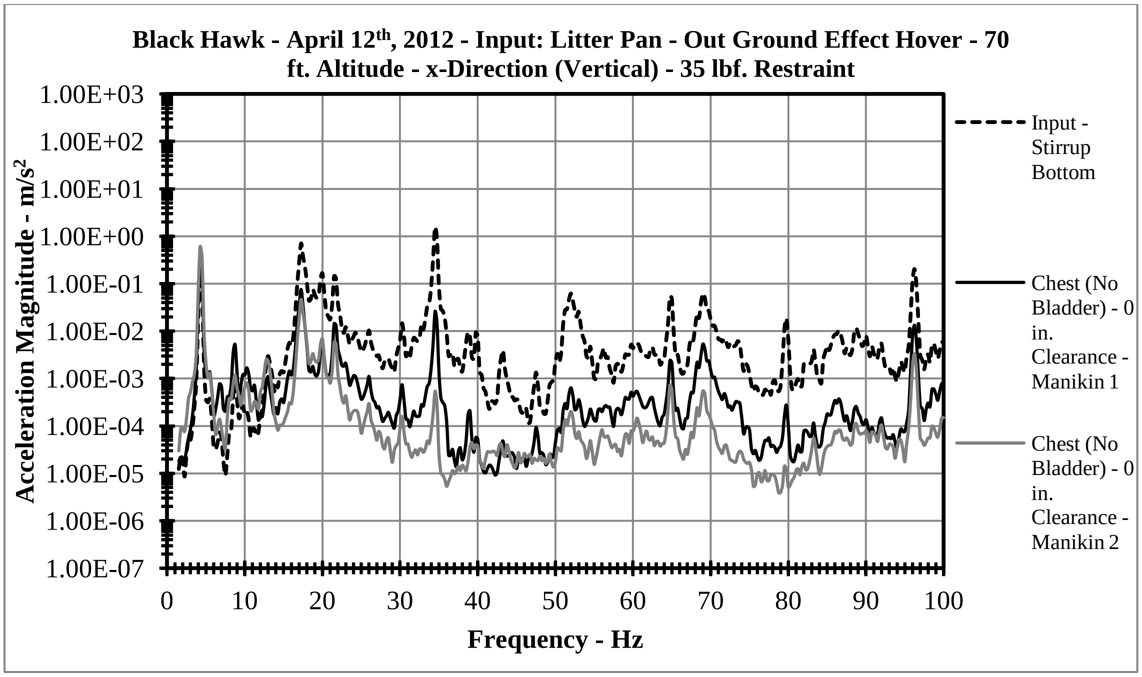

Figure 5.9: Acceleration Magnitude of the Chest for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

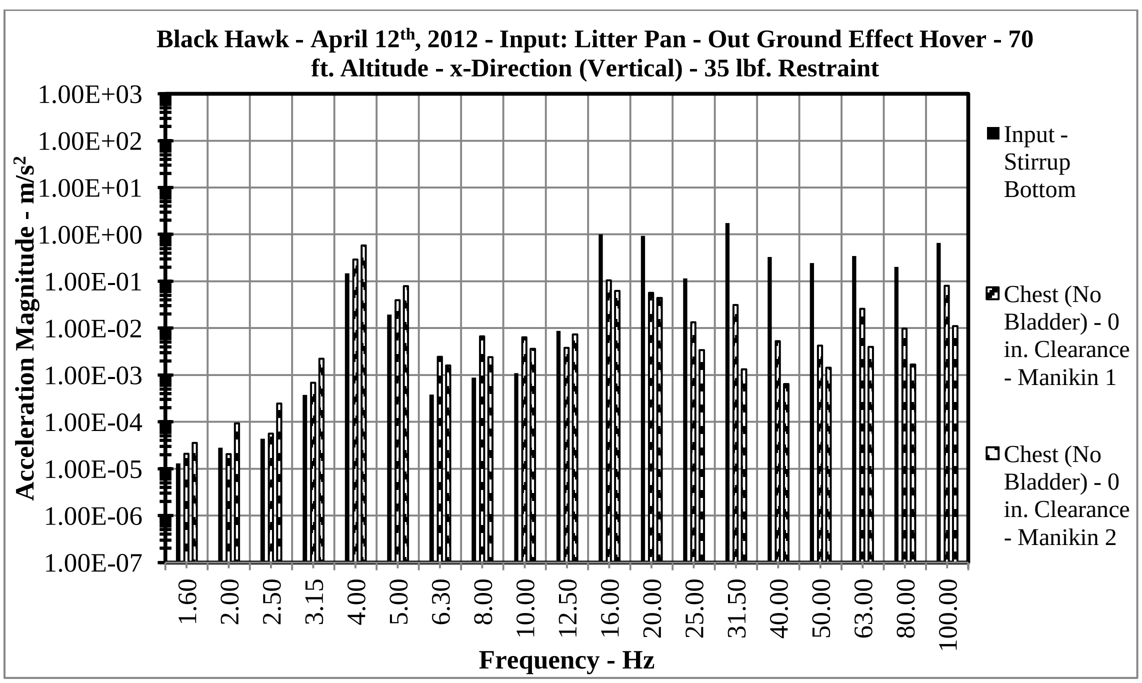

Figure 5.10: 1/3 Octave Band Acceleration Magnitude of the Chest for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

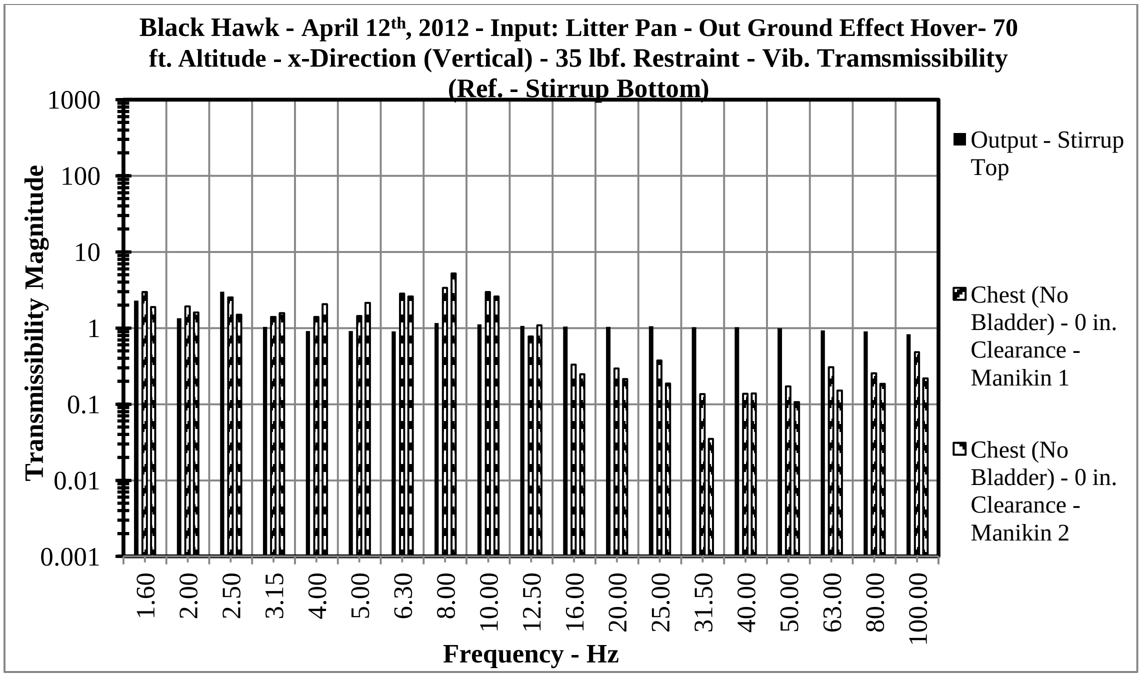

Figure 5.11: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – 35 lbf. Restraint with 0 in. Clearance

Table 5.1, 5.2, and 5.3 depict the RSS acceleration values of the shoulders, pelvis, and chest, respectively, with and without air bladder from 1.6 Hz to 100 Hz for the Black Hawk helicopter test. Table 5.4, 5.5, and 5.6 illustrate the acceleration values from 1.6 Hz to 10 Hz. Table 5.7, Table 5.8, and Table 5.9 display the vibration transmissibility magnitude between 1.6 Hz and 100 Hz. Table 5.10 and Table 5.11 reveal the vibration transmissibility through the bladder at the shoulders and the pelvis. The tables of the RSS acceleration values at 4 Hz, between 12.5 Hz and 40 Hz and from 50 Hz to 100 Hz for the April Black Hawk helicopter test are shown in Appendix E.

In order to examine the effects of the straps restraint, the stirrup clearance, and the use of the air bladder technology, the values of the RSS acceleration in m/s^2 in various frequency ranges were summarized in tables. After evaluating the results, it was revealed that:

- The values between 1.6 Hz and 10 Hz controlled the overall RSS acceleration values, as shown in Table 5.4, 5.5, and 5.6.
- For the shoulders, pelvis, and chest of manikin 1 with and without the air bladder and with 0 in. and 0.25 in. clearance, it was detected that the acceleration values decreased as the straps restraint was increased, which was expected as the manikin was more restricted to movement.
- Overall, the results for the shoulders, pelvis, and chest of manikin 2 showed that the acceleration was reduced between 0 lb_f. and 35 lb_f. straps restraint, an anomaly might have occurred when running the tests at 15 lb_f. straps restraint that resulted in increased acceleration values. In addition, the results for the shoulders, pelvis, and chest of manikin 2 without the bladder and with 0 in. clearance depicted an increased in the acceleration.
- Mostly, the results for the shoulders, pelvis, and chest of manikin 1 with and without the air bladder displayed that while the stirrup clearance was increased from 0 in. to 0.25 in. the acceleration also increased.
- However, the results of manikin 2 did not follow this pattern because for most of the cases the acceleration decreased as the stirrup clearance increased.
- The acceleration values for manikin 1 and manikin 2 increased when the tests were run with the air bladder at the various configurations. Unfortunately, the use of the air bladder worsened the situation by increasing the accelerations.
- From the transmissibility tables, Table 5.7, 5.8, and 5.9, it was observed that the vibration transmissibility for the output of manikin 1 and 2 was approximately 1.
- The vibration transmissibility magnitude of both manikins decreased as the straps restraint increased from 0 lb_f. to 35 lb_f.

- Also, the vibration transmissibility values were larger for the results with the bladder.
- From the transmissibility through the bladder results for manikin 1 and 2, it was discovered that the transmissibility increased as the straps restraint went down from 35 lb_f to 0 lb_f.
- For the shoulders and pelvis locations, the transmissibility through the bladder increased when the stirrup clearance was increased from 0 in. to 0.25 in.
- The transmissibility through the bladder of manikin 2 is higher than that of manikin 1.

Table 5.1: RSS Acceleration Values in m/s^2 for the Shoulders of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Shoulders - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.269	0.326	0.585	0.892	0.899	4.034
0 in. Clearance Manikin 2	2.421	0.507	1.188	0.729	2.696	0.420	2.386
0.25 in Clearance Manikin 1	2.902	0.310	0.473	0.459	1.429	0.958	6.819
0.25 in Clearance Manikin 2	2.361	0.395	0.946	0.616	2.742	0.511	1.962

Table 5.2: RSS Acceleration Values in m/s^2 for the Pelvis of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Pelvis - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.199	0.254	0.422	0.796	0.823	3.192
0 in. Clearance Manikin 2	2.421	0.494	1.053	0.415	2.574	0.175	2.321
0.25 in Clearance Manikin 1	2.902	0.230	0.507	0.350	2.309	0.784	5.559
0.25 in Clearance Manikin 2	2.361	0.344	0.882	0.548	2.753	0.350	1.937

Table 5.3: RSS Acceleration Values in m/s^2 for the Chest of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Chest - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.328	0.644	0.610	1.571	1.141	6.130
0 in. Clearance Manikin 2	2.421	0.588	0.761	0.784	3.822	0.437	2.637
0.25 in Clearance Manikin 1	2.902	0.391	0.569	0.538	2.095	1.115	6.686
0.25 in Clearance Manikin 2	2.361	0.371	0.596	0.639	2.647	0.530	1.991

Table 5.4: RSS Acceleration Values in m/s^2 for the Shoulders of the Black Hawk Helicopter Test between 1.6 Hz and 10 Hz

Black Hawk - Shoulders - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-10 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.266	0.316	0.578	0.891	0.898	4.034
0 in. Clearance Manikin 2	2.421	0.506	1.186	0.728	2.695	0.418	2.384
0.25 in Clearance Manikin 1	2.902	0.297	0.472	0.458	1.427	0.955	6.819
0.25 in Clearance Manikin 2	2.361	0.382	0.944	0.609	2.740	0.483	1.960

Table 5.5: RSS Acceleration Values in m/s^2 for the Pelvis of the Black Hawk Helicopter Test between 1.6 Hz and 10 Hz

Black Hawk - Pelvis - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-10 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.189	0.249	0.404	0.795	0.819	3.191
0 in. Clearance Manikin 2	2.421	0.476	1.052	0.392	2.574	0.118	2.321
0.25 in Clearance Manikin 1	2.902	0.214	0.503	0.336	2.307	0.781	5.558
0.25 in Clearance Manikin 2	2.361	0.294	0.882	0.524	2.753	0.296	1.936

Table 5.6: RSS Acceleration Values in m/s^2 for the Chest of the Black Hawk Helicopter Test between 1.6 Hz and 10 Hz

Black Hawk - Chest - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-10 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.292	0.427	0.607	1.571	1.140	6.130
0 in. Clearance Manikin 2	2.421	0.582	0.759	0.783	3.822	0.434	2.637
0.25 in Clearance Manikin 1	2.902	0.337	0.566	0.531	2.095	1.115	6.686
0.25 in Clearance Manikin 2	2.361	0.365	0.590	0.637	2.646	0.528	1.991

Table 5.7: Transmissibility Magnitude for the Shoulders of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Shoulders - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.107	0.130	0.232	0.354	0.371	1.663
0 in. Clearance Manikin 2	2.421	0.210	0.491	0.303	1.120	0.177	1.006
0.25 in Clearance Manikin 1	2.902	0.107	0.163	0.162	0.504	0.401	2.855
0.25 in Clearance Manikin 2	2.361	0.167	0.401	0.256	1.138	0.209	0.802

Table 5.8: Transmissibility Magnitude for the Pelvis of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Pelvis - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.079	0.101	0.168	0.316	0.339	1.315
0 in. Clearance Manikin 2	2.421	0.204	0.435	0.172	1.069	0.074	0.978
0.25 in Clearance Manikin 1	2.902	0.079	0.175	0.123	0.814	0.328	2.327
0.25 in Clearance Manikin 2	2.361	0.146	0.374	0.228	1.143	0.143	0.792

Table 5.9: Transmissibility Magnitude for the Chest of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Chest - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	2.519	0.130	0.256	0.242	0.624	0.470	2.526
0 in. Clearance Manikin 2	2.421	0.243	0.315	0.325	1.587	0.184	1.112
0.25 in Clearance Manikin 1	2.902	0.135	0.196	0.190	0.739	0.467	2.799
0.25 in Clearance Manikin 2	2.361	0.157	0.252	0.265	1.099	0.217	0.814

Table 5.10: Transmissibility Magnitude through the Bladder at the Shoulders of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Transmissibility through Bladder - April 12th, 2012
Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground
Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint	15 lb_f. Restraint	0 lb_f. Restraint
0 in. Clearance - Manikin 1	2.519	0.312	0.532	1.232
0 in. Clearance - Manikin 2	2.421	1.399	1.084	1.409
0.25 in Clearance - Manikin 1	2.902	0.439	0.848	1.620
0.25 in Clearance - Manikin 2	2.361	1.544	1.300	1.241

Table 5.11: Transmissibility Magnitude through the Bladder at the Pelvis of the Black Hawk Helicopter Test between 1.6 Hz and 100 Hz

Black Hawk - Transmissibility through Bladder - April 12th, 2012
Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground
Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint	15 lb_f. Restraint	0 lb_f. Restraint
0 in. Clearance - Manikin 1	2.519	0.390	0.604	1.290
0 in. Clearance - Manikin 2	2.421	1.523	1.041	1.713
0.25 in Clearance - Manikin 1	2.902	0.668	1.594	1.607
0.25 in Clearance - Manikin 2	2.361	1.644	1.338	1.231

5.2. Random Test Results

The plots for input and output of the random vibration test, where the magnitude of the acceleration spectral density was kept constant did not show any harmonic frequencies. The plots of the shoulders, pelvis, and chest exposed a resonant frequency at around 8 Hz for manikin 1 and 4 Hz for manikin 2. The harmonic frequencies of the shoulders and pelvis were observed at approximately 10 Hz and 55 Hz; and the chest had a harmonic frequency detected at 10 Hz. From the plots, it was observed that manikin 2 with 0 in. stirrup clearance had a larger shoulders acceleration between 22 Hz and 40 Hz and a lower acceleration from 42 Hz to 90 Hz. Manikin 2 with 0.25 in. stirrup clearance had a larger shoulders acceleration between 20 Hz and 45 Hz, a lower shoulders acceleration from 45 Hz to 70 Hz, and a larger shoulders acceleration between 70 Hz to 100 Hz. In addition, the acceleration of the pelvis of manikin 2 was larger from 16 Hz to 35 Hz and lower between 35 Hz and 65 Hz. Finally, manikin 2 with 0 in. stirrup clearance had a lower chest acceleration magnitude over the entire frequency range while manikin 2 with 0.25 in. stirrup clearance had a chest acceleration magnitude almost identical to that of manikin 1.

Once again, the transmissibility of the output was a magnitude of 1 from 16 Hz to 100 Hz that was expected as the location of the output accelerometer was just above the input accelerometer. The shoulders, pelvis, and chest of manikin 1 with 0 lb_f. and 15 lb_f. straps restraint peaked at 6.3 Hz with a transmissibility magnitude of 4. However, the peak value of the transmissibility magnitude of the shoulders, pelvis, and chest of manikin 1 with 35lb_f. straps restraint was approximately 9 at 8 Hz. For manikin 2 with 0 lb_f, 15 lb_f, and 35 lb_f straps restraint, the transmissibility of the shoulders, pelvis, and chest peaked at 5 Hz with a magnitude of 2.5. The transmissibility magnitude was mostly under 1 past the 10 Hz for the shoulders, pelvis, and chest of both manikins.

Figure 5.12 and Figure 5.13 illustrate the acceleration magnitude versus frequency of the input and output of the random test. Figure 5.14 through Figure 5.22 show the plots of the acceleration magnitude and the transmissibility magnitude of the shoulders, pelvis, and chest with 35lb$_f$. straps restraint and 0 in. clearance for the random test. The plots of the acceleration and transmissibility magnitude of the shoulders, pelvis, and chest unrestrained with 0 in. and 0.25 in. clearance, with 15 lb$_f$. straps restraint and 0 in. and 0.25 in. clearance, and with 35 lb$_f$. restraint and 0.25 in. clearance are displayed in Appendix F, Appendix G, and Appendix H, respectively.

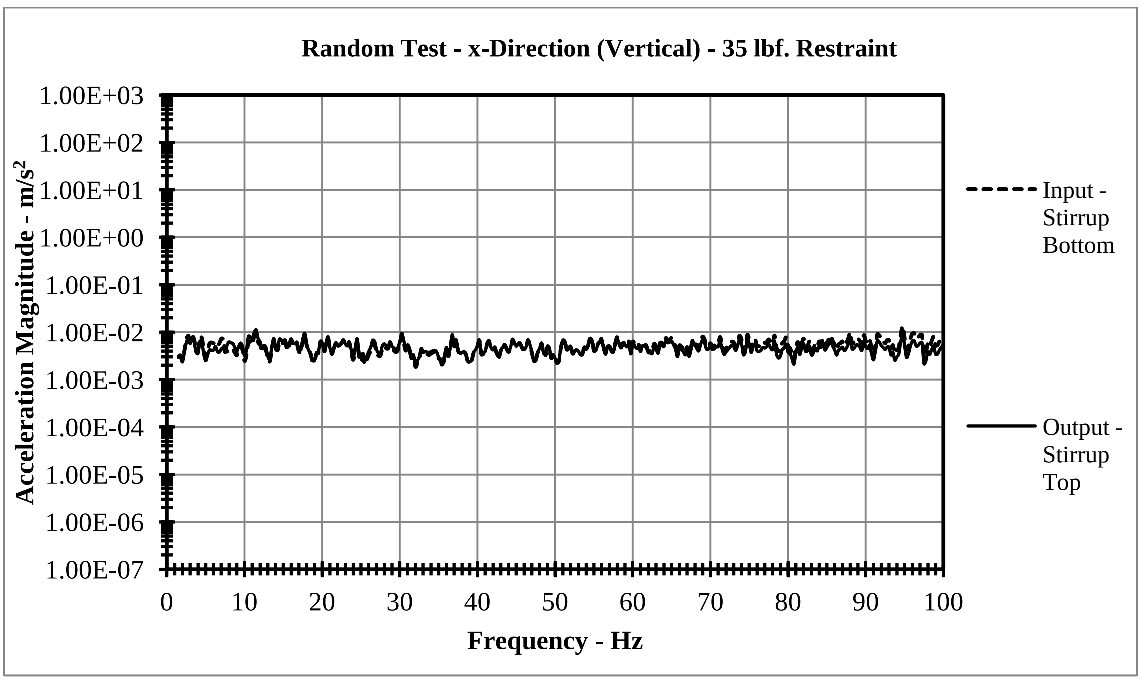

Figure 5.12: Acceleration Magnitude of the Input and Output for the Random Test – 35 lbf. Restraint

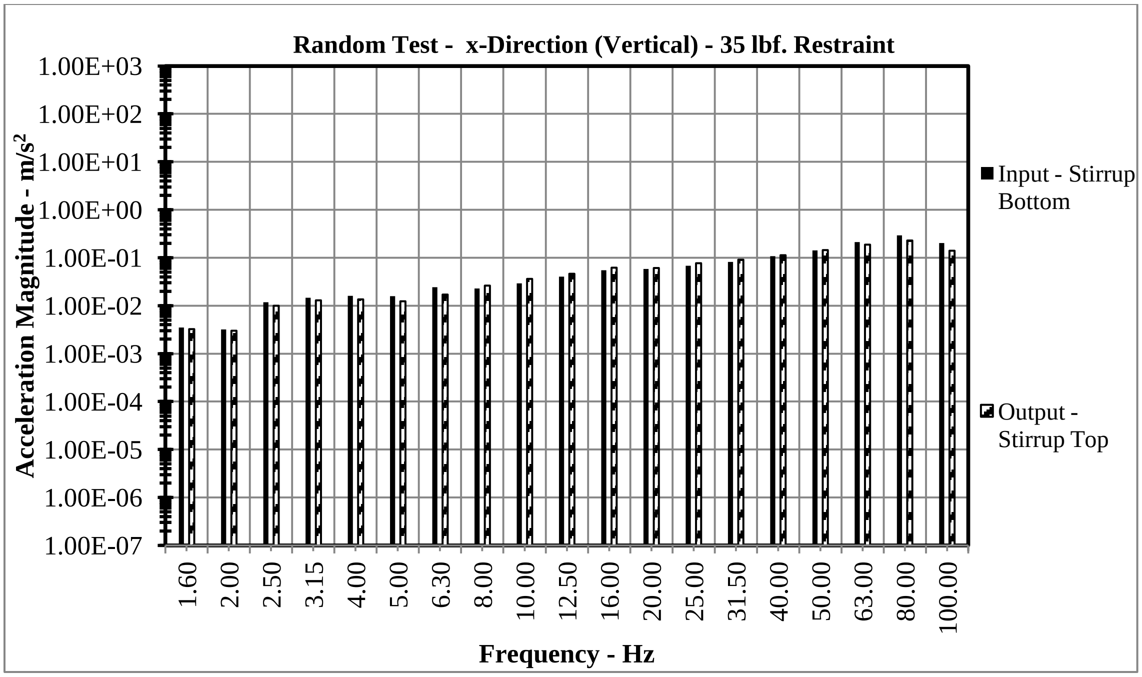

Figure 5.13: 1/3 Octave Band Acceleration Magnitude of the Input and Output for the Random Test – 35 lbf. Restraint

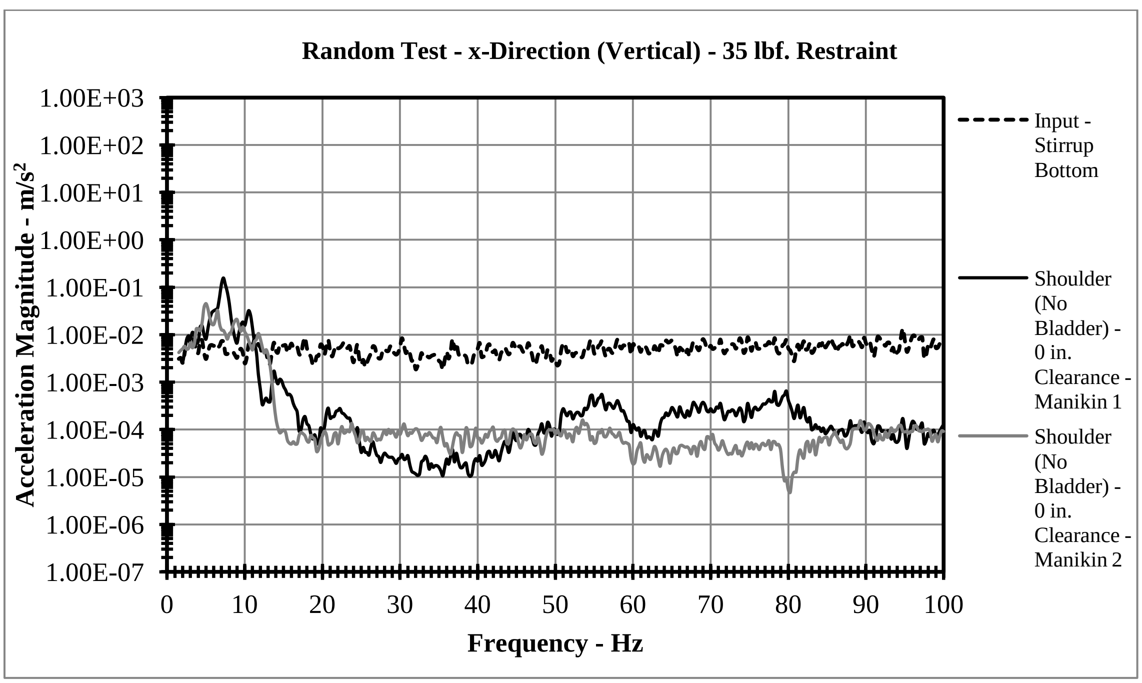

Figure 5.14: Acceleration Magnitude of the Shoulders for the Random Test – 35 lbf. Restraint with 0 in. Clearance

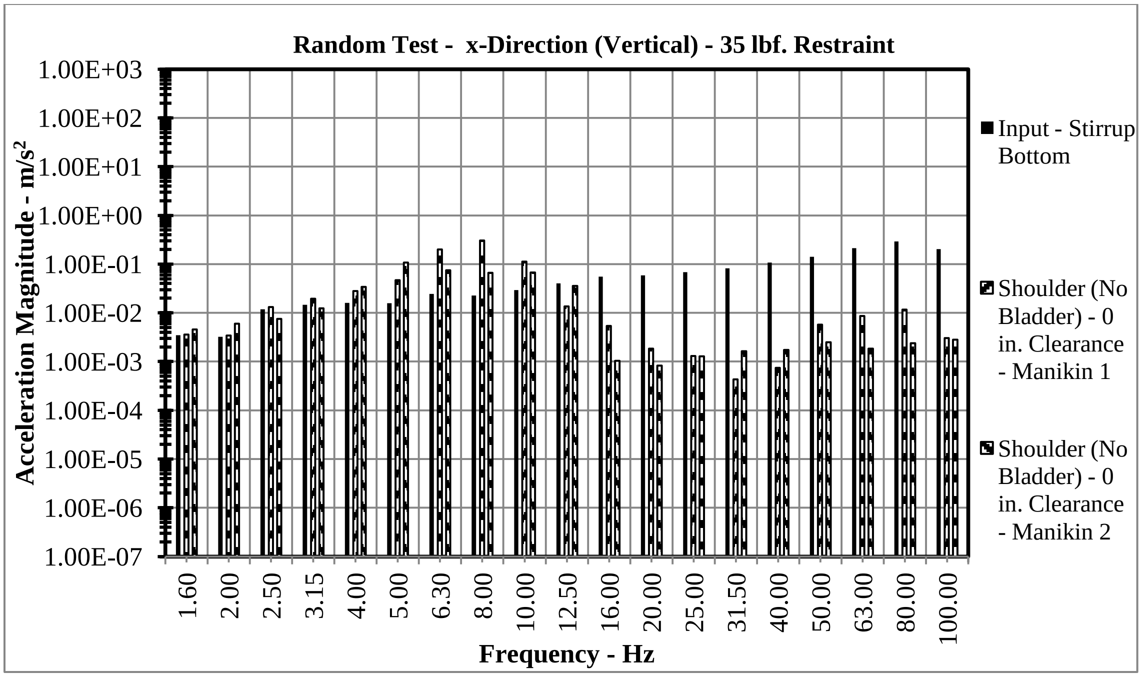

Figure 5.15: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Random Test – 35 lbf. Restraint with 0 in. Clearance

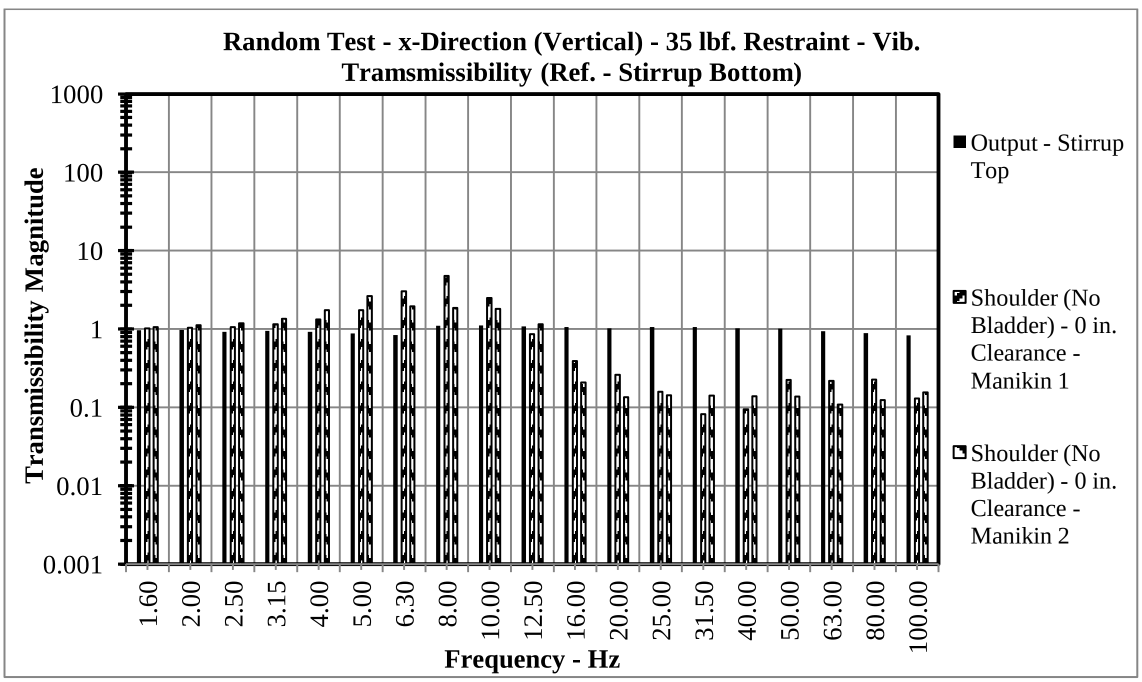

Figure 5.16: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Random Test – 35 lbf. Restraint with 0 in. Clearance

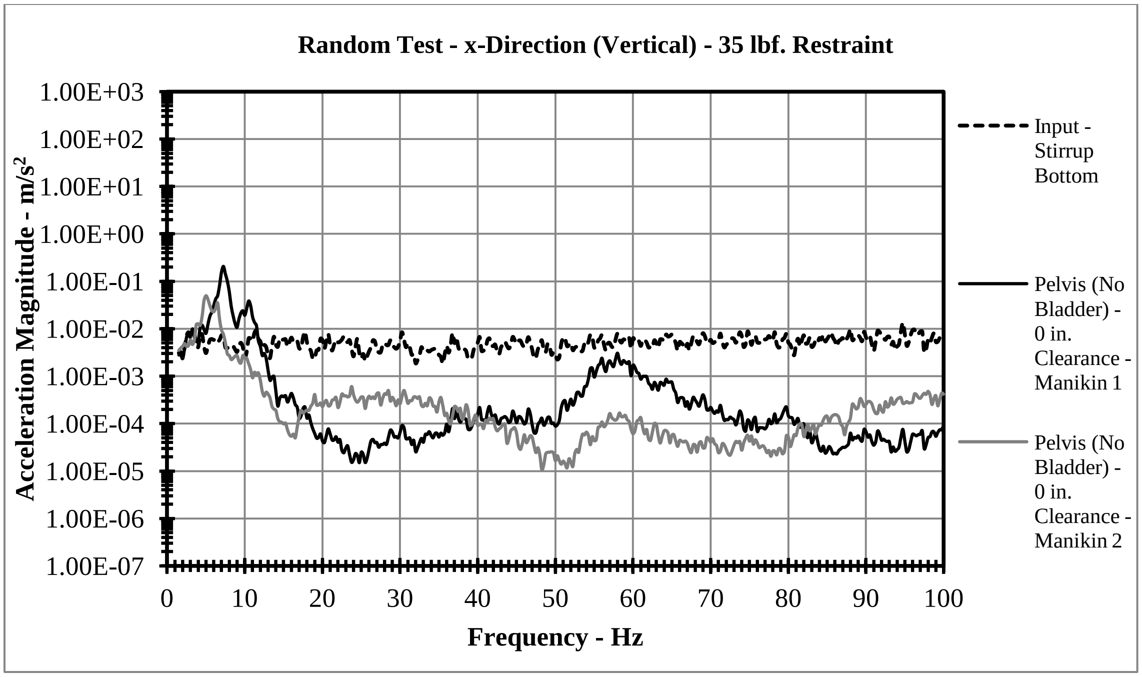

Figure 5.17: Acceleration Magnitude of the Pelvis for the Random Test – 35 lbf. Restraint with 0 in. Clearance

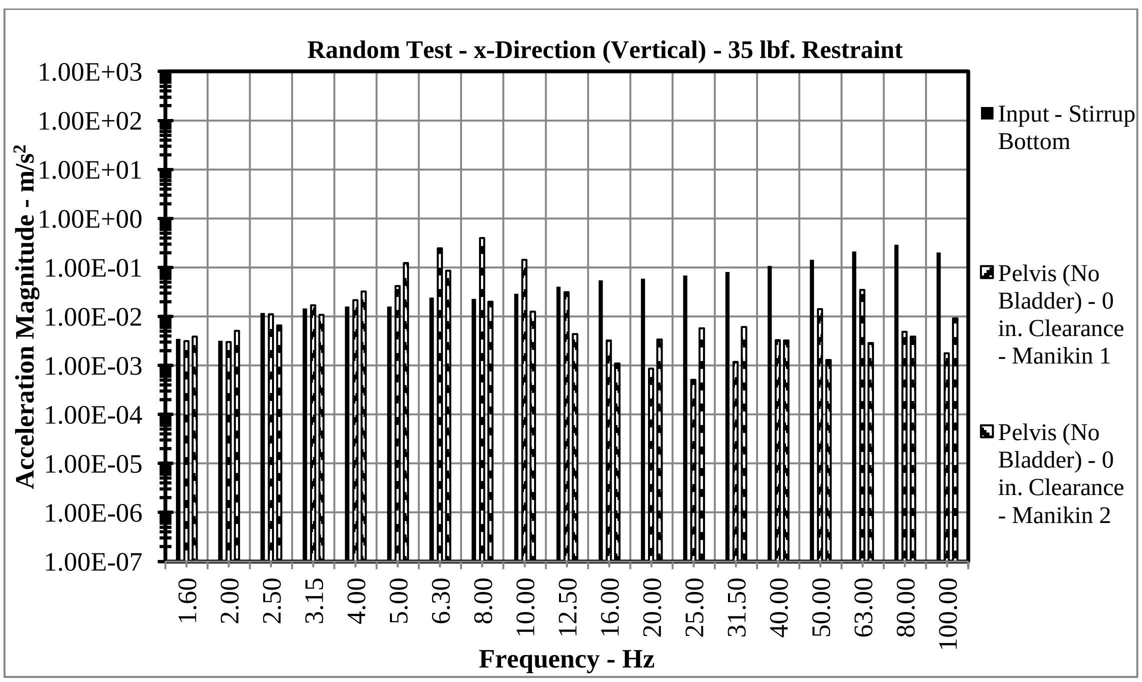

Figure 5.18: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

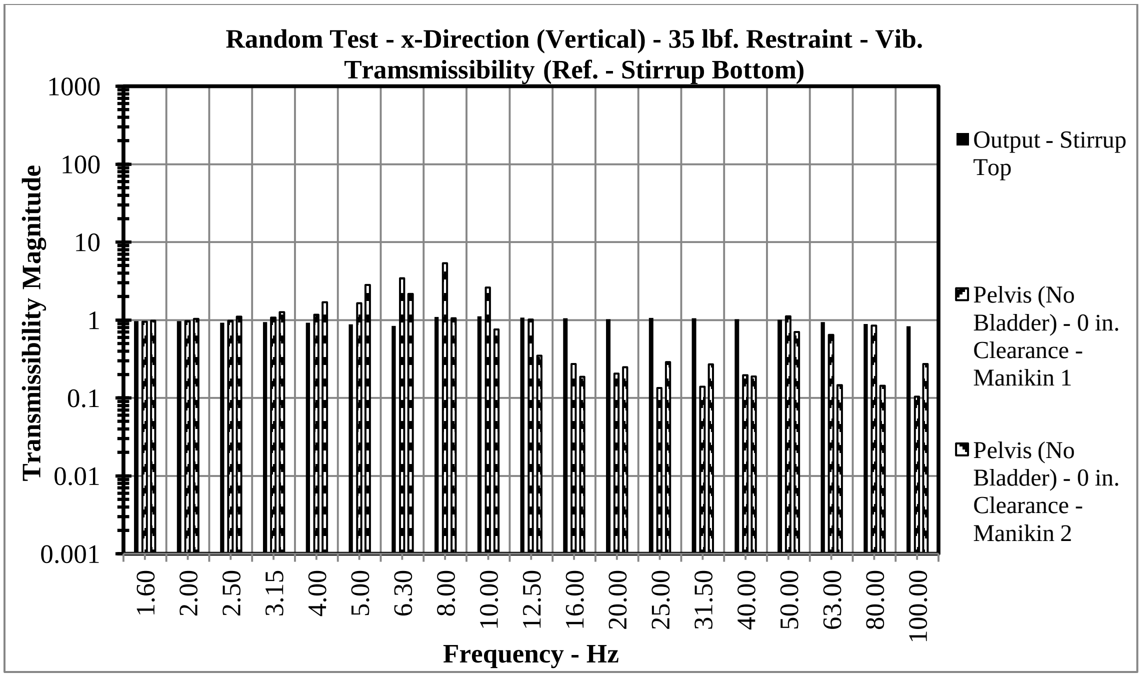

Figure 5.19: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Random Test – 35 lbf. Restraint with 0 in. Clearance

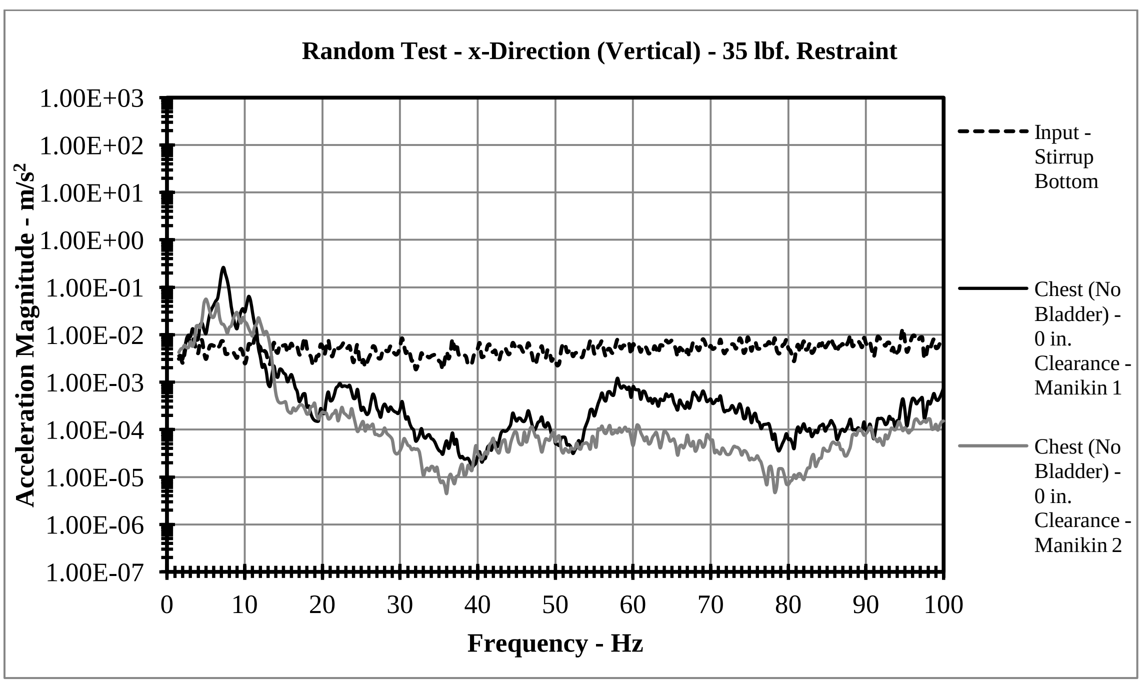

Figure 5.20: Acceleration Magnitude of the Chest for the Random Test – 35 lbf. Restraint with 0 in. Clearance

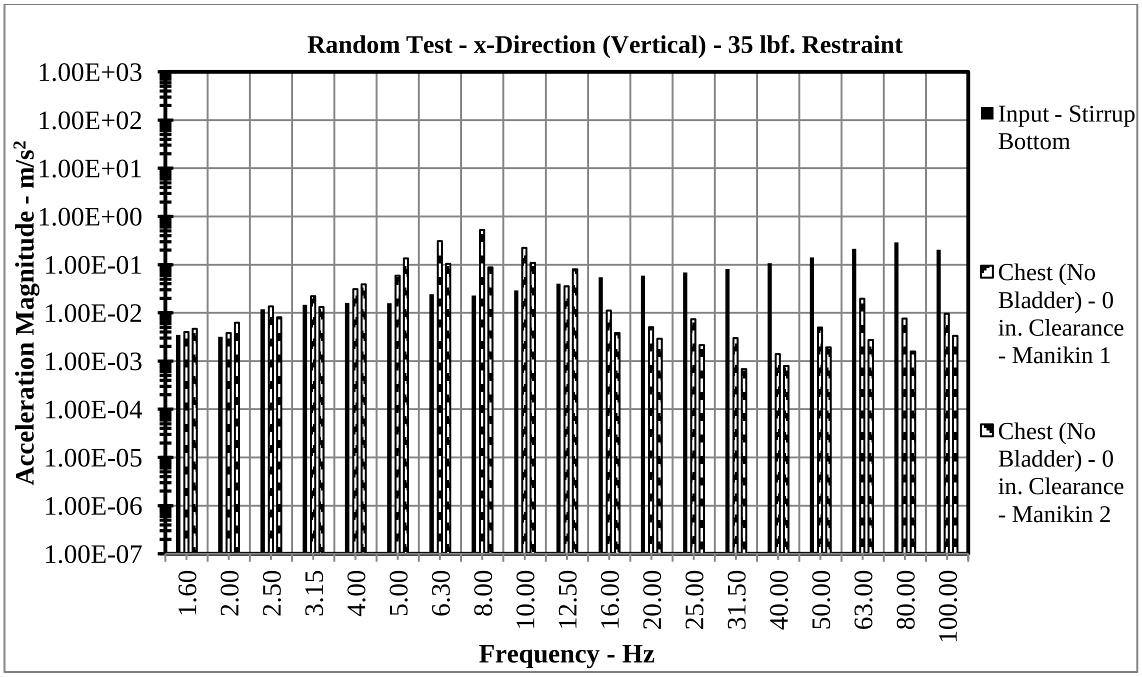

Figure 5.21: 1/3 Octave Band Acceleration Magnitude of the Chest for the Random Test – 35 lbf. Restraint with 0 in. Clearance

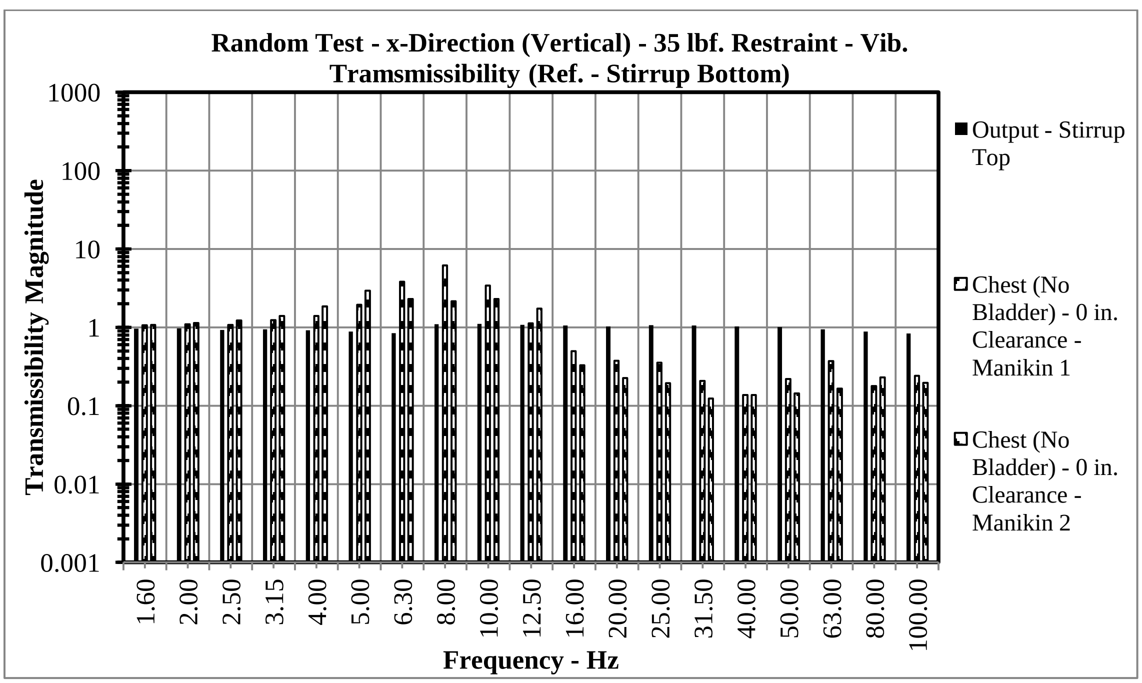

Figure 5.22: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Random Test – 35 lbf. Restraint with 0 in. Clearance

Table 5.12, Table 5.13, and Table 5.14 depict the RSS acceleration values for the shoulders, pelvis, and chest of the random vibration test between 1.6 Hz and 100 Hz. Table 5.15, Table 5.16, and Table5.17 expose the acceleration values from 1.6 Hz to 10 Hz. Table 5.18, Table 5.19, and Table 5.20 illustrate the vibration transmissibility magnitudes obtained from the RSS acceleration values between 1.6 Hz and 100 Hz. The tables that summarize the RSS acceleration values at 4Hz, between 12.5 Hz and 40 Hz and from 50 Hz to 100 Hz for the random test are shown in Appendix I. Observations from Tables 5.12 through 5.20 were:

- The overall RSS acceleration values of the random vibration test were controlled by the values from 1.6 Hz to 10 Hz.
- From the results, it was found that for most of the cases the acceleration at the shoulders, pelvis, and chest of manikin 1 and 2 increased between 0 lb_f. and 35 lb_f. straps restraint.
- Overall, the acceleration for the shoulders, pelvis, and chest of the manikin 1 increased as the gap between the bracket of the stirrup and the surface was increased from 0 in. to 0.25 in, which was expected as the litter had a gap to move in the vertical direction. The accelerations of manikin 2 without the air bladder increased as the stirrup clearance was increased while the accelerations of manikin 2 with the air bladder decreased as the stirrup clearance was increased.
- The acceleration values of manikin 1 and 2 with the air bladder were larger than the acceleration values without the air bladder, confirming one more time that the air bladder did not bring any benefits to mitigate the shock and vibration.
- The transmissibility magnitudes for the shoulders, pelvis, and chest of manikin 1 and 2 were mostly below 1. The transmissibility magnitudes of manikin 1 and 2 increased as the straps restraint was increased.

- The transmissibility values of manikin 1 and 2 were larger when the tests were run with the air bladder.
- The transmissibility through the bladder at the shoulders and pelvis for manikin 1 and 2 with 0 in. clearance increased as the straps restraint increased while the transmissibility through the bladder decreased as the straps restraint increased when the clearance was 0.25 in.
- In general, the transmissibility through the bladder at the shoulders and pelvis of manikin 1 and 2 was higher when the stirrup clearance was increased from 0 in. to 0.25 in.

Table 5.12: RSS Acceleration Values in m/s^2 for the Shoulders of the Random Test between 1.6 Hz and 100 Hz

Random Test - Shoulders - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lbf. Restraint (No Bladder)	35 lbf. Restraint (Bladder)	15 lbf. Restraint (No Bladder)	15 lbf. Restraint (Bladder)	0 lbf. Restraint (No Bladder)	0 lbf. Restraint (Bladder)
0 in. Clearance Manikin 1	0.501	0.388	0.427	0.156	0.288	0.284	0.246
0 in. Clearance Manikin 2	0.391	0.170	0.172	0.124	0.285	0.108	0.253
0.25 in Clearance Manikin 1	0.565	0.847	0.275	0.220	0.402	0.162	0.352
0.25 in Clearance Manikin 2	0.372	0.144	0.171	0.151	0.206	0.115	0.252

Table 5.13: RSS Acceleration Values in m/s^2 for the Pelvis of the Random Test between 1.6 Hz and 100 Hz

Random Test - Pelvis - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	0.501	0.496	0.529	0.143	0.268	0.143	0.229
0 in. Clearance Manikin 2	0.391	0.157	0.283	0.080	0.273	0.073	0.267
0.25 in Clearance Manikin 1	0.565	0.688	0.330	0.163	0.499	0.117	0.360
0.25 in Clearance Manikin 2	0.372	0.160	0.269	0.150	0.212	0.081	0.259

Table 5.14: RSS Acceleration Values in m/s^2 for the Chest of the Random Test between 1.6 Hz and 100 Hz

Random Test - Chest - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)							
Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lbf. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	0.501	0.652	0.347	0.243	0.497	0.337	0.394
0 in. Clearance Manikin 2	0.391	0.239	0.253	0.160	0.251	0.138	0.348
0.25 in Clearance Manikin 1	0.565	1.135	0.563	0.298	0.431	0.198	0.459
0.25 in Clearance Manikin 2	0.372	0.216	0.225	0.204	0.225	0.166	0.191

Table 5.15: RSS Acceleration Values in m/s^2 for the Shoulders of the Random Test between 1.6 Hz and 10 Hz

Random Test - Shoulders - Frequency Range: 1.6 Hz-10 Hz - x-Direction (Vertical)							
Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	0.501	0.388	0.427	0.151	0.288	0.283	0.245
0 in. Clearance Manikin 2	0.391	0.166	0.172	0.123	0.285	0.107	0.253
0.25 in Clearance Manikin 1	0.565	0.847	0.275	0.219	0.401	0.160	0.352
0.25 in Clearance Manikin 2	0.372	0.139	0.171	0.151	0.206	0.113	0.252

Table 5.16: RSS Acceleration Values in m/s^2 for the Pelvis of the Random Test between 1.6 Hz and 10 Hz

Random Test - Pelvis - Frequency Range: 1.6 Hz-10 Hz - x-Direction (Vertical)							
Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	0.501	0.494	0.528	0.137	0.267	0.142	0.229
0 in. Clearance Manikin 2	0.391	0.156	0.283	0.079	0.273	0.071	0.267
0.25 in Clearance Manikin 1	0.565	0.687	0.330	0.161	0.499	0.116	0.360
0.25 in Clearance Manikin 2	0.372	0.157	0.269	0.149	0.212	0.079	0.259

Table 5.17: RSS Acceleration Values in m/s^2 for the Chest of the Random Test between 1.6 Hz and 10 Hz

Random Test - Chest - Frequency Range: 1.6 Hz-10 Hz - x-Direction (Vertical)							
Test Condition	**Input Stirrup Bottom**	**35 lb_f. Restraint (No Bladder)**	**35 lb_f. Restraint (Bladder)**	**15 lb_f. Restraint (No Bladder)**	**15 lb_f. Restraint (Bladder)**	**0 lb_f. Restraint (No Bladder)**	**0 lb_f. Restraint (Bladder)**
0 in. Clearance Manikin 1	0.501	0.651	0.321	0.242	0.497	0.336	0.394
0 in. Clearance Manikin 2	0.391	0.225	0.253	0.158	0.251	0.136	0.348
0.25 in Clearance Manikin 1	0.565	1.135	0.562	0.296	0.431	0.194	0.459
0.25 in Clearance Manikin 2	0.372	0.204	0.225	0.200	0.225	0.164	0.191

Table 5.18: Transmissibility Magnitude for the Shoulders of the Random Test between 1.6 Hz and 100 Hz

Random Test - Shoulders - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)							
Test Condition	**Input Stirrup Bottom**	**35 lb_f. Restraint (No Bladder)**	**35 lb_f. Restraint (Bladder)**	**15 lb_f. Restraint (No Bladder)**	**15 lb_f. Restraint (Bladder)**	**0 lb_f. Restraint (No Bladder)**	**0 lb_f. Restraint (Bladder)**
0 in. Clearance Manikin 1	0.501	0.775	0.852	0.324	0.598	0.687	0.594
0 in. Clearance Manikin 2	0.391	0.435	0.439	0.369	0.850	0.284	0.668
0.25 in Clearance Manikin 1	0.565	1.498	0.486	0.341	0.623	0.436	0.948
0.25 in Clearance Manikin 2	0.372	0.387	0.460	0.402	0.547	0.296	0.650

Table 5.19: Transmissibility Magnitude for the Pelvis of the Random Test between 1.6 Hz and 100 Hz

Random Test - Pelvis - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)							
Test Condition	**Input Stirrup Bottom**	**35 lb_f. Restraint (No Bladder)**	**35 lb_f. Restraint (Bladder)**	**15 lb_f. Restraint (No Bladder)**	**15 lb_f. Restraint (Bladder)**	**0 lb_f. Restraint (No Bladder)**	**0 lb_f. Restraint (Bladder)**
0 in. Clearance Manikin 1	0.501	0.990	1.056	0.297	0.555	0.347	0.554
0 in. Clearance Manikin 2	0.391	0.400	0.722	0.239	0.813	0.191	0.702
0.25 in Clearance Manikin 1	0.565	1.217	0.584	0.253	0.773	0.315	0.968
0.25 in Clearance Manikin 2	0.372	0.430	0.725	0.398	0.562	0.210	0.668

Table 5.20: Transmissibility Magnitude of the Chest of the Random Test between 1.6 Hz and 100 Hz

Random Test - Chest - Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint (No Bladder)	35 lb_f. Restraint (Bladder)	15 lb_f. Restraint (No Bladder)	15 lb_f. Restraint (Bladder)	0 lb_f. Restraint (No Bladder)	0 lb_f. Restraint (Bladder)
0 in. Clearance Manikin 1	0.501	1.302	0.691	0.504	1.031	0.816	0.954
0 in. Clearance Manikin 2	0.391	0.610	0.647	0.476	0.748	0.364	0.916
0.25 in Clearance Manikin 1	0.565	2.008	0.995	0.462	0.668	0.532	1.234
0.25 in Clearance Manikin 2	0.372	0.580	0.607	0.543	0.599	0.428	0.495

Table 5.21: Transmissibility through the Bladder at the Shoulders of the Random Test between 1.6 Hz and 100 Hz

Random Test - Transmissibility through Bladder
Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lb_f. Restraint	15 lb_f. Restraint	0 lb_f. Restraint
0 in. Clearance - Manikin 1	0.501	1.147	0.778	0.761
0 in. Clearance - Manikin 2	0.391	0.839	1.256	0.736
0.25 in Clearance - Manikin 1	0.565	0.604	1.470	1.059
0.25 in Clearance - Manikin 2	0.372	0.988	1.175	1.301

Table 5.22: Transmissibility through the Bladder at the Pelvis of the Random Test between 1.6 Hz and 100 Hz

Random Test - Transmissibility through Bladder
Frequency Range: 1.6 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Input Stirrup Bottom	35 lbf. Restraint	15 lbf. Restraint	0 lbf. Restraint
0 in. Clearance - Manikin 1	2.519	0.888	0.391	0.585
0 in. Clearance - Manikin 2	2.421	1.149	0.863	0.807
0.25 in Clearance - Manikin 1	2.902	0.773	1.229	1.252
0.25 in Clearance - Manikin 2	2.361	1.271	0.957	0.978

5.3. Discussion of Black Hawk Test Results

The results revealed the differences between manikin 1 and manikin 2. However, it was not possible to determine how close the manikins' responses were to that of a human subject. Running the tests with a human subject and plotting the results can give a better idea of how much improvement was made with manikin 2. The resonant frequency of the manikins was 4 Hz, which seemed to be correct as the resonant frequency of a whole body is between 4 Hz and 8 Hz. In addition, the prominent resonant frequency at around 4 Hz was observed because the helicopter had 4 blades and a rotor rpm of 4 Hz. The blade pass frequency was then 16 Hz, which was produced by each blade passing through the helicopter tail in one revolution. The harmonic frequencies occurred at approximately 16 Hz, 32 Hz, 48 Hz, 64 Hz, 80 Hz, and 96 Hz due to the blade pass frequency. Moreover, the transmissibility magnitude peaking at low frequencies may have been caused by the stirrup acting as a spring at lower frequencies. Overall, the increase of the straps restraint caused the decrease of the accelerations, which was anticipated as the manikins were less likely to move. The stirrup clearance affected the results by increasing the acceleration values while increasing the clearance only for some conditions. There might have been some irregularities attributed to experimental error. In addition, the use of the air bladder was not beneficial in mitigating the shock and vibration experienced by a subject during an aeromedical transport. The RSS acceleration values increased when the air bladder was placed on the litter. The air bladder might have been acting as a spring amplifying the acceleration values. More work needs to be done in designing a better isolation system.

5.4. Discussion of Random Test Results

The results exposed once again how manikin 1 differed from manikin 2. The resonant frequency for manikin 1 was at around 8 Hz and 4 Hz for manikin 2. The peaks at low frequencies in the vibration transmissibility plots might have been the result of the stirrup or the litter mesh acting as a spring. Mostly, the shoulders, pelvis, and chest acceleration of manikin 1 and manikin 2 decreased as the straps restraint was increased from 0 lbf. to 35 lbf., which made sense since the manikins were more restricted from movement. The accelerations at the shoulders, pelvis, and chest increased while the stirrup clearance was increased from 0 in. to 0.25 in. for manikin 1 with and without the air bladder and for manikin 2 without the bladder. The human error of hands-on experimentation may have affected the results. Also, the complexity of the vibration signals may have caused a discrepancy in the results. Finally, the results showed that the air bladder did not reduce the shock and vibration. In contrast, the air bladder made the acceleration increase.

CHAPTER 6 – CONCLUSIONS AND FUTURE WORK

6.1. Conclusions

The main goal of this project was to test and compare the differences of two manikins, where the second manikin was a variation of the first manikin to closely recreate the response a human subject experienced when exposed to shock and vibration during an aeromedical evacuation. Another goal was to analyze the effects of using an air bladder isolation system that would absorb the shock and vibration. In order to accomplish the project two vibration analyses were performed with signals generated from a Black Hawk Helicopter field test and a random vibration test. Brüel & Kjær's PULSE system was used to conduct the vibration analyses and obtain the acceleration magnitude and transmissibility magnitude at different locations of the manikins.

The results showed that the resonant frequency of the manikins occurred between 4 Hz and 8 Hz, which agreed with the resonant frequency of a whole body that is between 4 Hz and 8 Hz. Overall, manikin 2 had higher accelerations than manikin 1 at frequencies between 16 Hz and 35 Hz. The plots of the transmissibility magnitude peaked between 5 Hz and 8 Hz that might have occurred as a result of the stirrup acting as a spring at lower frequencies. After 10 Hz the vibration transmissibility was mostly under 1. The data also proved that the shock and vibration was less when the manikin was more securely fastened. In addition, the use of the air bladder worsened the shock and vibration experienced by the manikins. The results revealed an amplification of the accelerations when the tests where run with the air bladder.

Although there were several factors during the experiments that might have affected the results, the goals were achieved. Further research will be necessary to optimize the design of a supine manikin and the design of an air bladder isolation system. The insights presented here are intended to continue and advance the discussion of improving the design of a supine manikin that closely simulates the response of a human subject as well as the design of a shock and vibration isolation system.

6.2. Future Work

The results show that there needs to be more progress towards creating an effective manikin that can be used to recreate the response of a human subject. A manikin's design with better articulations, especially in the head that currently is very rigid would optimize the results. Also, testing and recording the data of an actual human could be beneficial to check the performance of the manikins. Rolling and pitching of the manikin on the air bladder also would have affected the results. Therefore, additional work needs to be done on the design of the litter air bladder. The air bladder needs to be enhanced, so it can efficiently absorb the shock and vibration. Also, the mesh of the stretcher had some resilience that might have amplified the accelerations. One more alternative may be to consider a stretcher designed with firmer material.

Further research and analysis is needed before moving forward. The first step should be to test and plot the data of a human subject, so it can be compared to the response of manikin 1 and 2. Second, the manikins' design should be adjusted to have more flexibility in all the joints. Finally, the air bladder should be modified to reduce the shock and vibration. Taking these recommendations into consideration will definitely give results that are more accurate.

APPENDICES

Appendix A – Hardware Components

Table A.1: Hardware Components

Component	Manufacturer/ Purpose	Specifications
	PCB Piezotronics/Measurement Device: Accelerometer placed on item being tested	Sens. (±15 %) =0.25 mV/(m/s²) Meas. Range = ±19600 m/s² pk Freq. Range (±5 %) = 1.0 to 10000 Hz Freq. Range (±10 %) = 0.7 to 13 kHz Freq. Range (±3 dB) = 0.3 to 20000 Hz Res. Freq. = ≥80 kHz Brdband. Res. (1) = 0.1 m/s² rms
	Dytran/ Measurement Device: Triaxial Accelerometer placed on item being tested	SENS., EACH AXIS, ± 5% = 100 mV/g RANGE F.S. FOR +/- 5 VOLTS OUTPUT = ± 50 g's FREQ. RANGE ± 5% = 0.5 to 3000 Hz RES. FREQ., NOM. = 25 kHz EQUIVALENT ELECTRICAL NOISE FLOOR .0007 g's RMS LINEARITY = ± 1% % F.S. TRANS. SENS. = MAX. 5 % STRAIN SENS = .012 g's/μσ @ 250 μσ MAXIMUM VIBRATION/SHOCK 400/1500 ± g's/g's PEAK
	Vibration Research/ Signal Controller. Link between vibration software and shaker system	Lines of resolution = 13,000 Max control frequency for Sine = 0.1 to 20,000 Hz Max control frequency for Random = 0.5 to 20,000 Hz Sample frequency = Up to 52,000 Hz Dynamic range = >120dB

Component	Manufacturer/ Purpose	Specifications
	Dytran/ Current Source Power Unit. Gain adjust for vibration signal	SENSOR SPLY CURRENT, FIXED = 2.0 mA COMP. VOLT. = +18 VDC VOLT. GAIN = UNITY COUP. TIME CONSTANT INTO 10M OHM LOAD = 10s COUP. TIME CONSTANT INTO 1M OHM LOAD = 5s LOW FREQ. -3db FREQ., 10M OHM LOAD = 0.016 Hz LOW FREQ. -3db FREQ., 1M OHM LOAD =.032Hz COUPLING CAPACITOR, NOM. = 10µF PULLDOWN RESISTOR =1.0 M OHMS MONITOR VOLTMETER RANGE, F.S. = 20VDC ELEC. NOISE, WIDEBAND = 60µV, RMS
	Brüel & Kjær/Data Acquisition Module. Link between analysis software and shaker	25 kHz analysis frequency range Five input channels Two generators with 25 kHz frequency range
 	TIRA Vibration Systems/Electrodynamic Shaker Amplifier. Controller for shaker TIRA Vibration Systems/ Electrodynamic Shaker. Used to impose vibration on test item	• Cont. Sin-wave Power = 12.00VA • Power Range = DC-5 KHz • Optimum Load Resist. = 0,1 Ohm • Switching Freq. = 81 KHz • Voltage max = 110V • Current max = 100A • Voltage Amplification = 28 dB • Max voltage full drive = <10V • Max volt. Input res. = >200kOhm • Distortion @ 900W & 6kW = <1% • Signal-to-noise ratio = >80dB

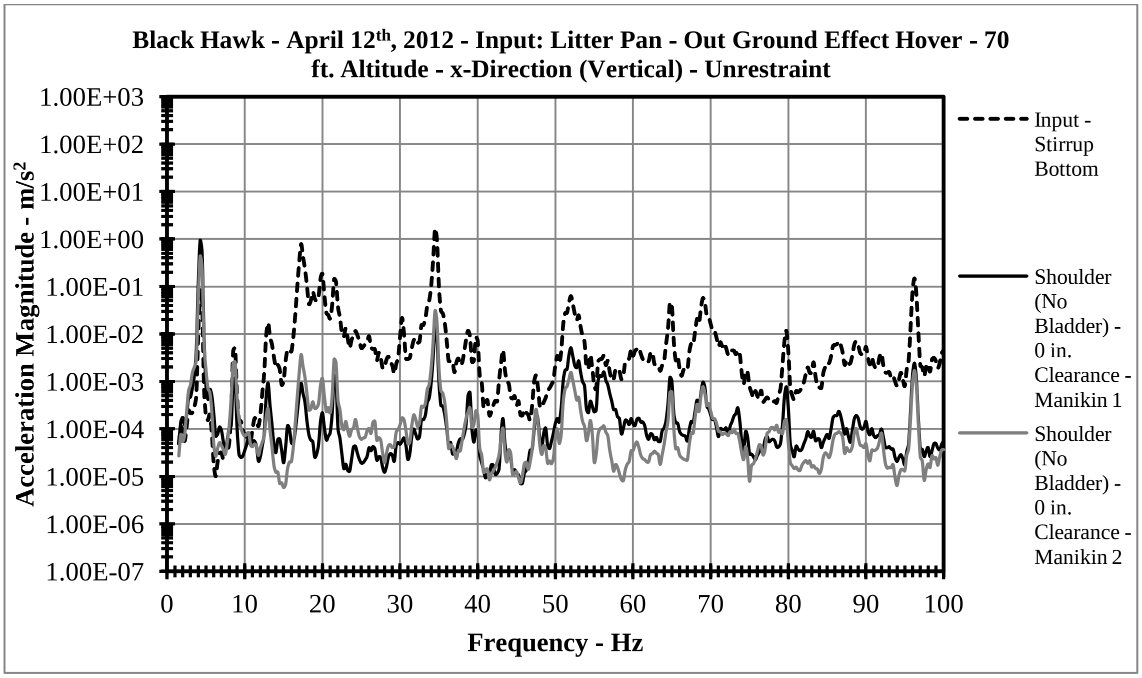

Figure B.1: Acceleration Magnitude of the Shoulders for the Black Hawk Test – Unrestraint with 0 in. Clearance

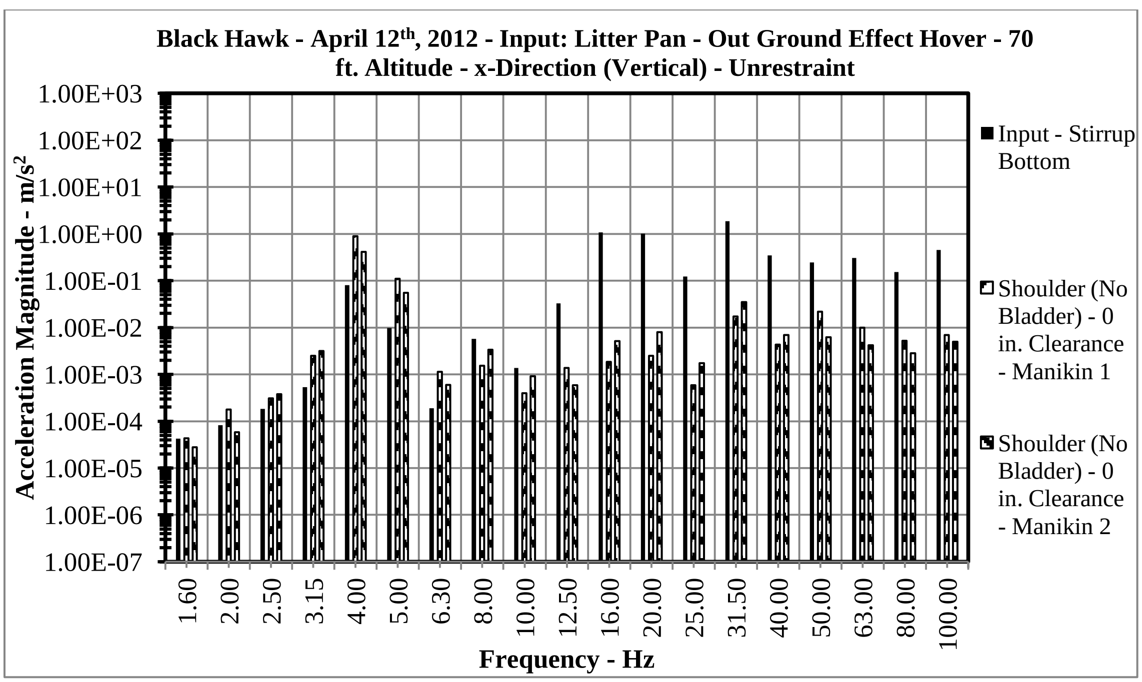

Figure B.2: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Black Hawk Test – Unrestraint with 0 in. Clearance

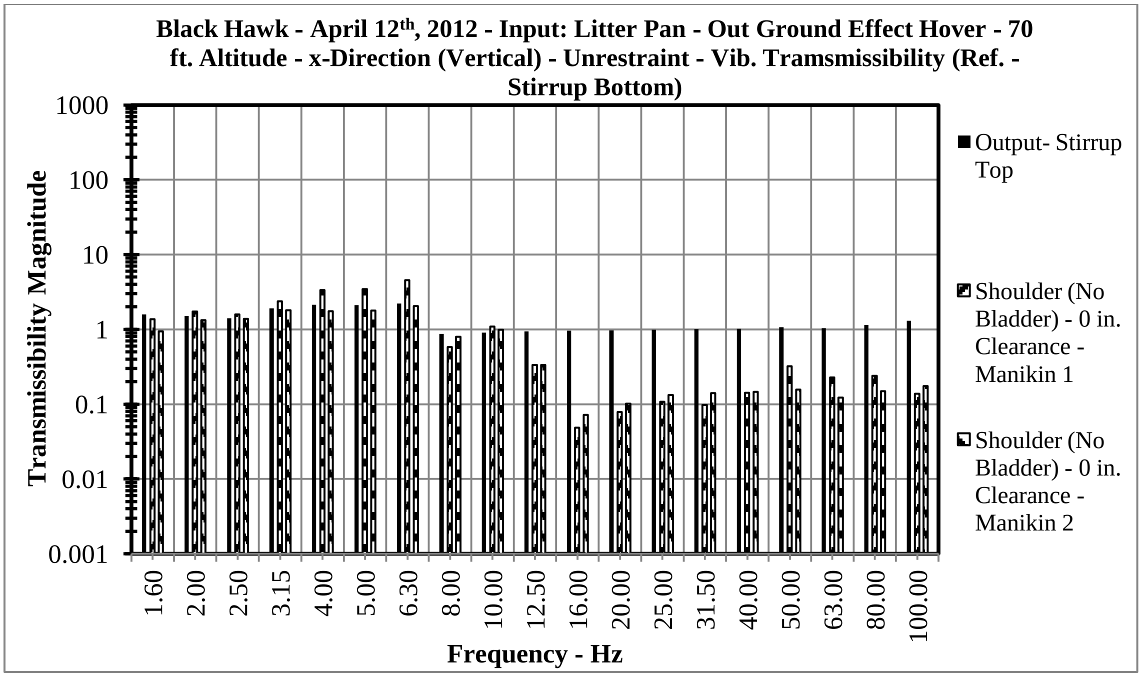

Figure B.3: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Black Hawk Test – Unrestraint with 0 in. Clearance

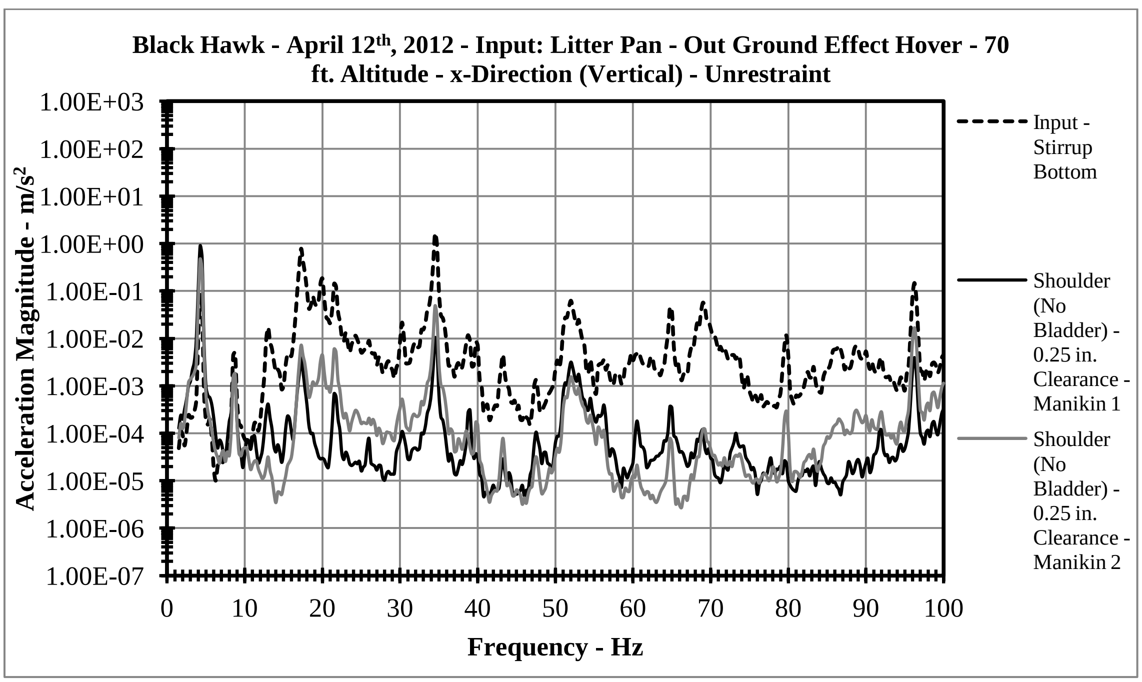

Figure B.4: Acceleration Magnitude of the Shoulders for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

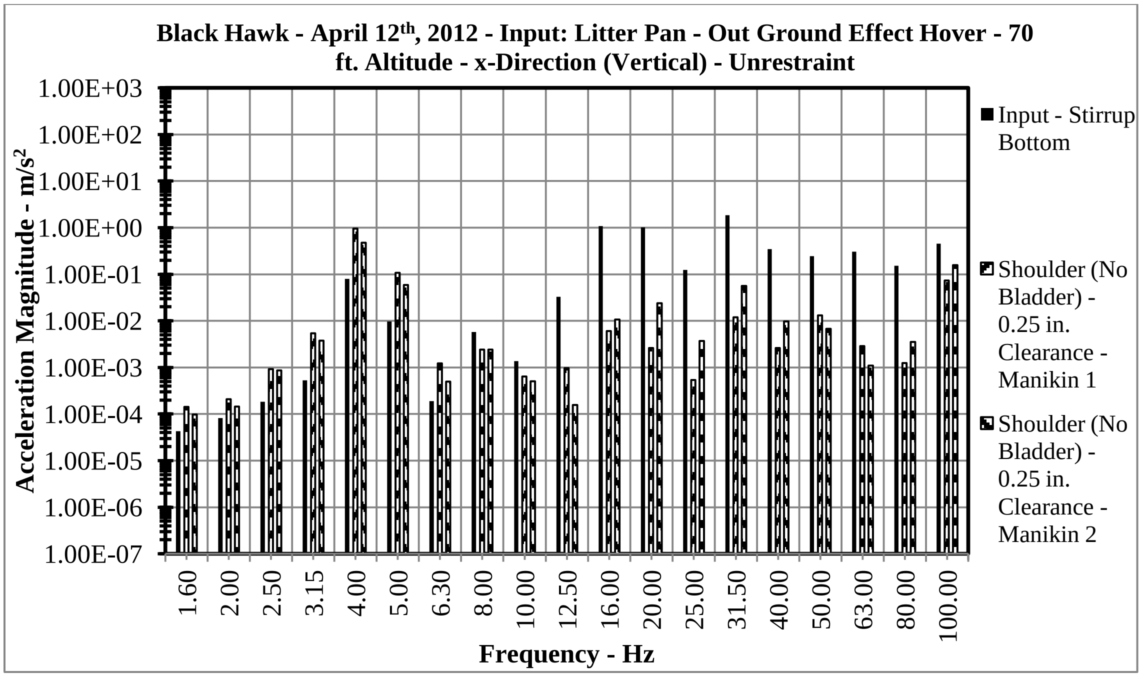

Figure B.5: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

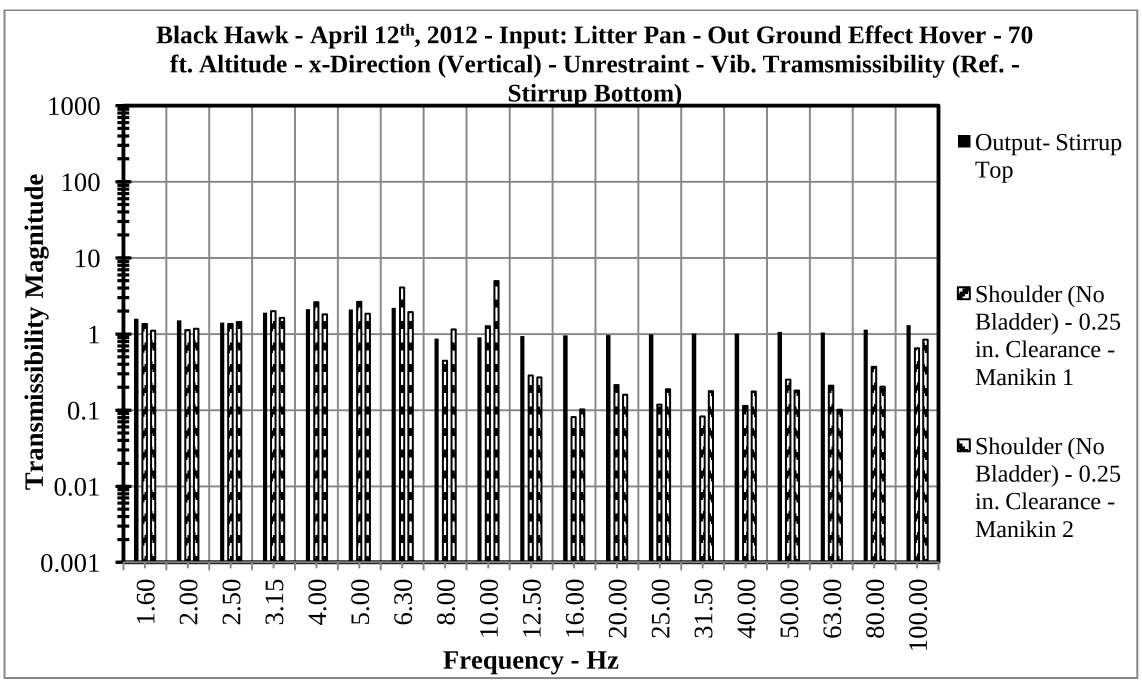

Figure B.6: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

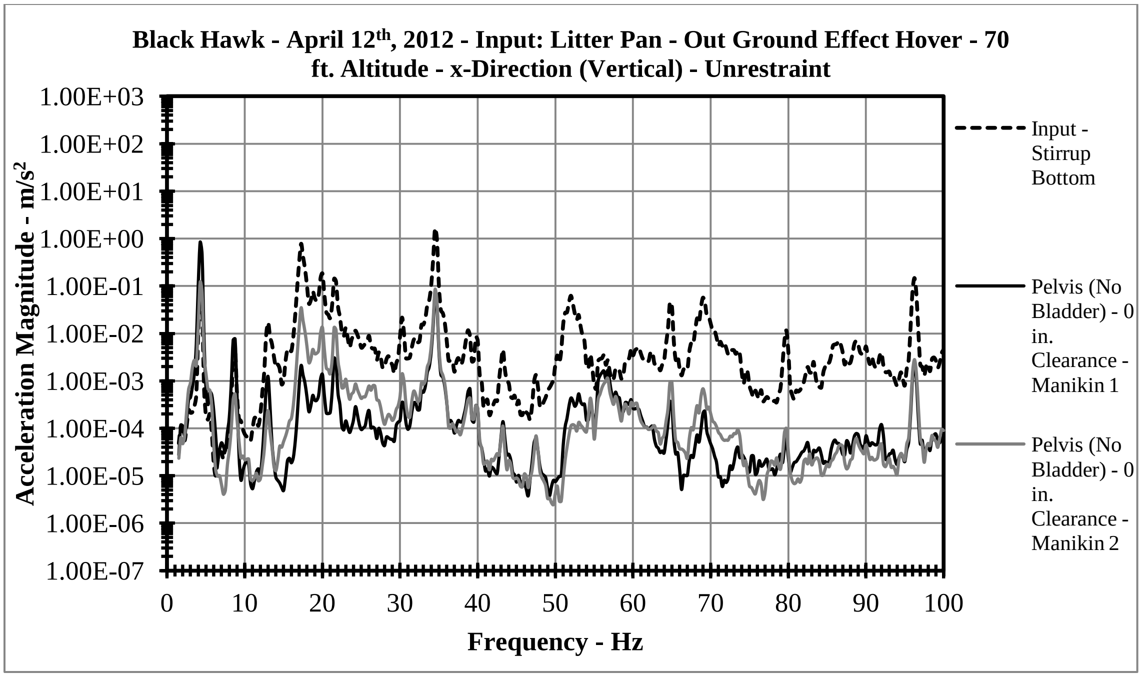

Figure B.7: Acceleration Magnitude of the Pelvis for the Black Hawk Test – Unrestraint with 0 in. Clearance

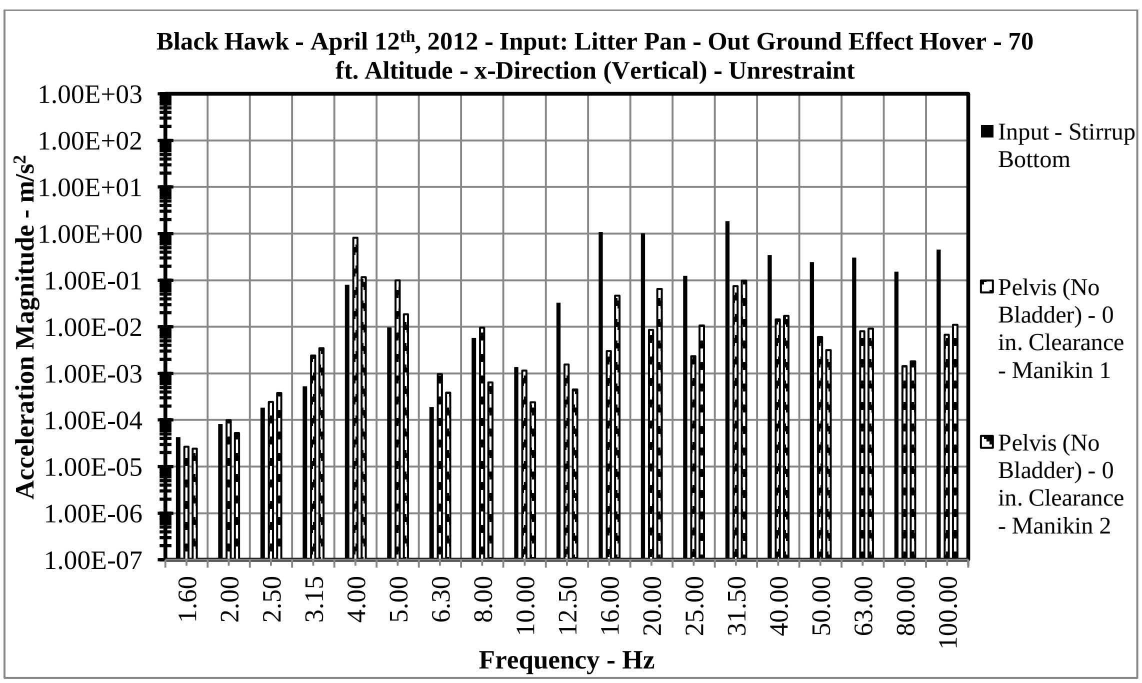

Figure B.8: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Black Hawk Test – Unrestraint with 0 in. Clearance

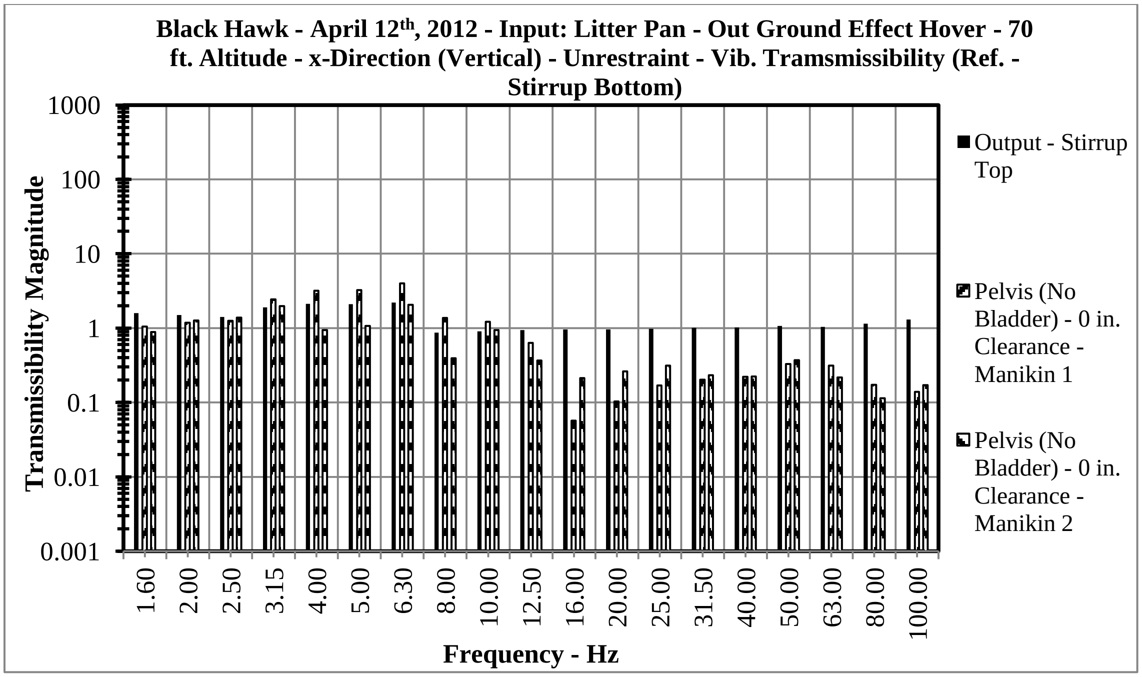

Figure B.9: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Black Hawk Test – Unrestraint with 0 in. Clearance

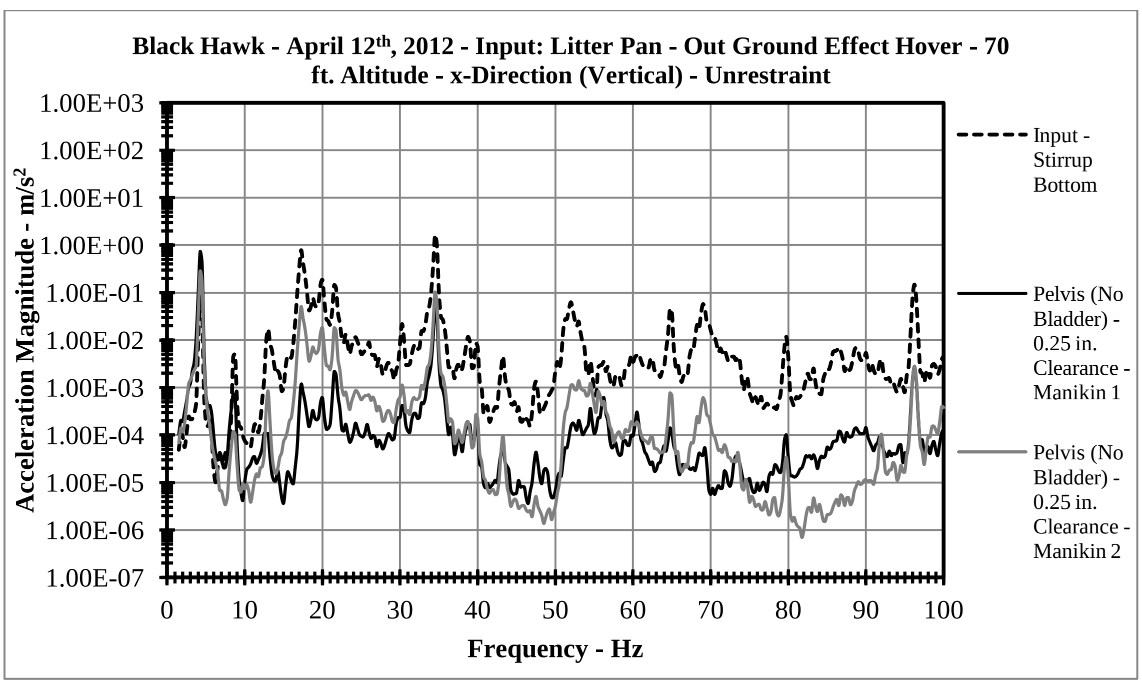

Figure B.10: Acceleration Magnitude of the Pelvis for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

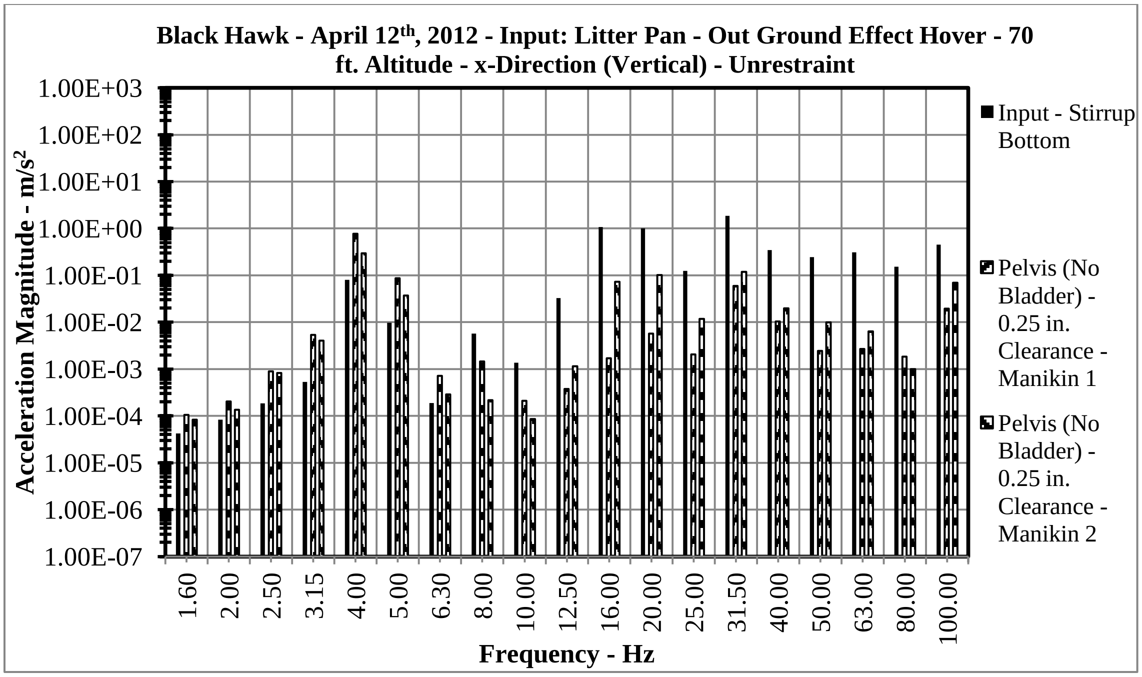

Figure B.11: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

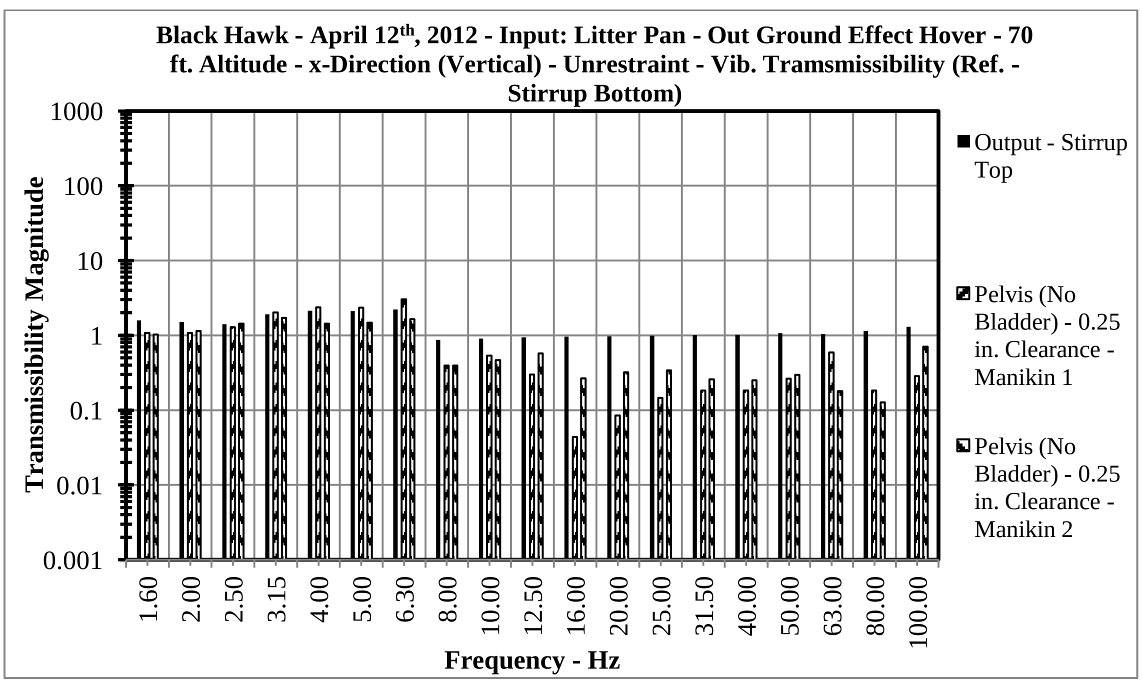

Figure B.12: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

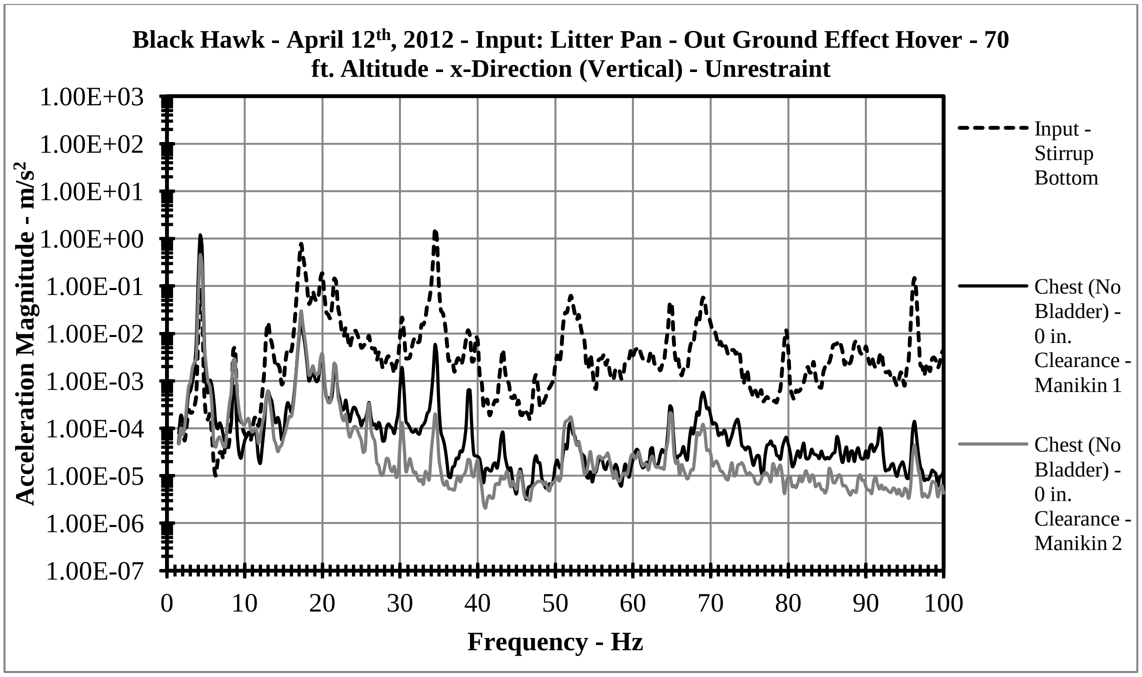

Figure B.13: Acceleration Magnitude of the Chest for the Black Hawk Test – Unrestraint with 0 in. Clearance

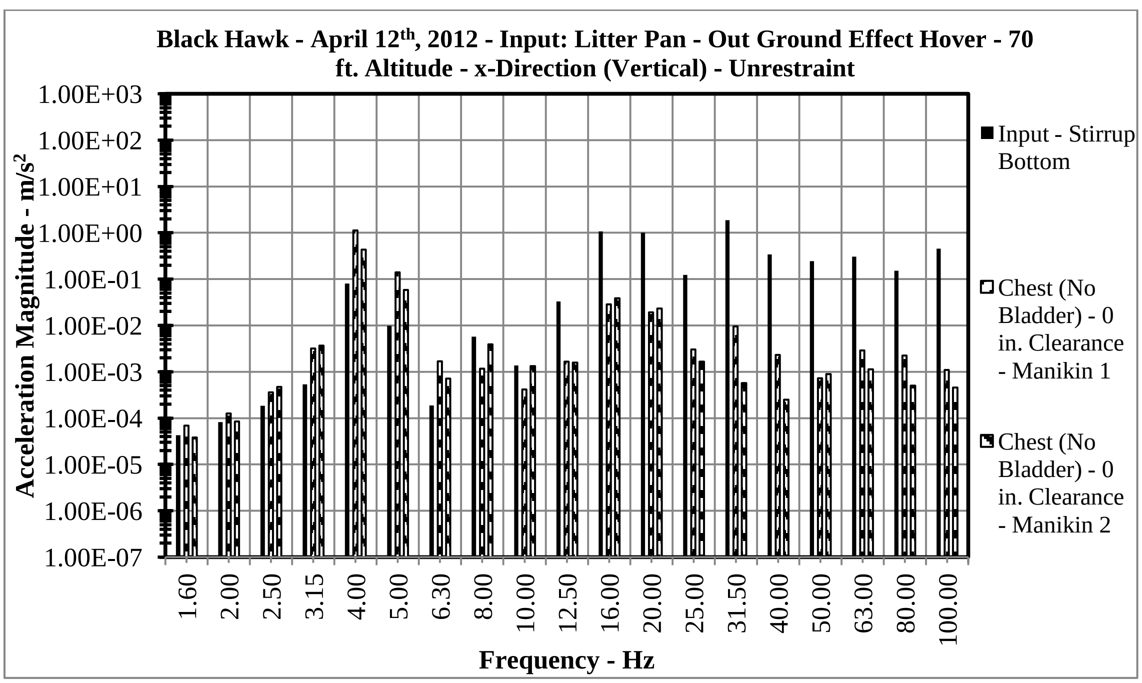

Figure B.14: 1/3 Octave Band Acceleration Magnitude of the Chest for the Black Hawk Test – Unrestraint with 0 in. Clearance

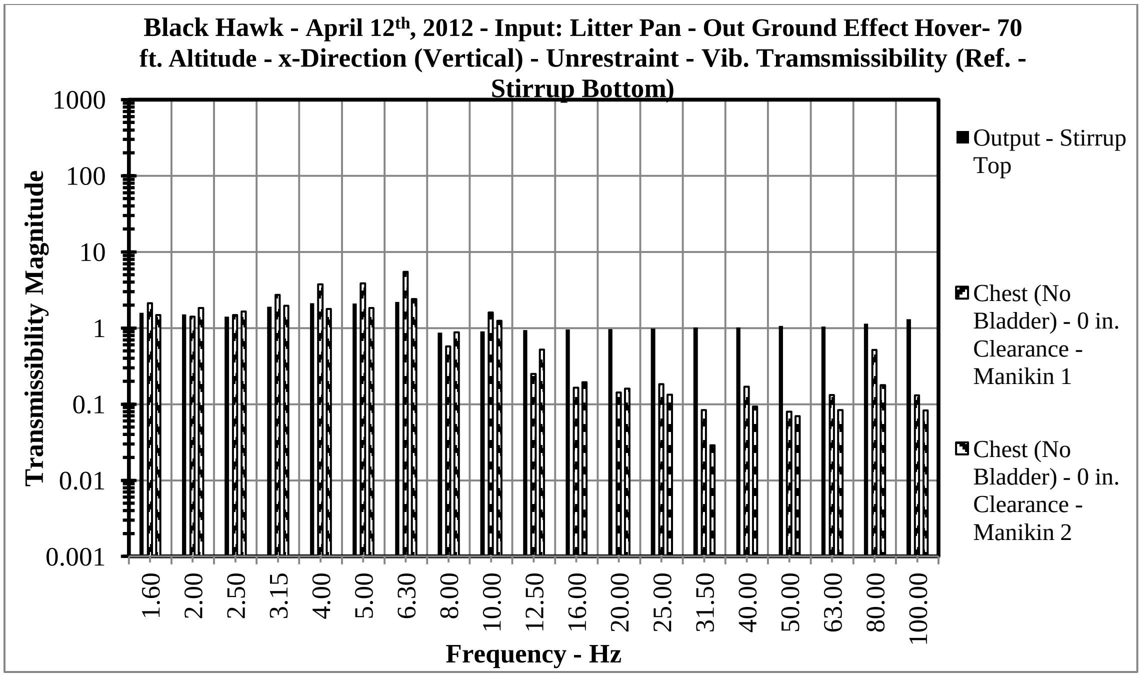

Figure B.15: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – Unrestraint with 0 in. Clearance

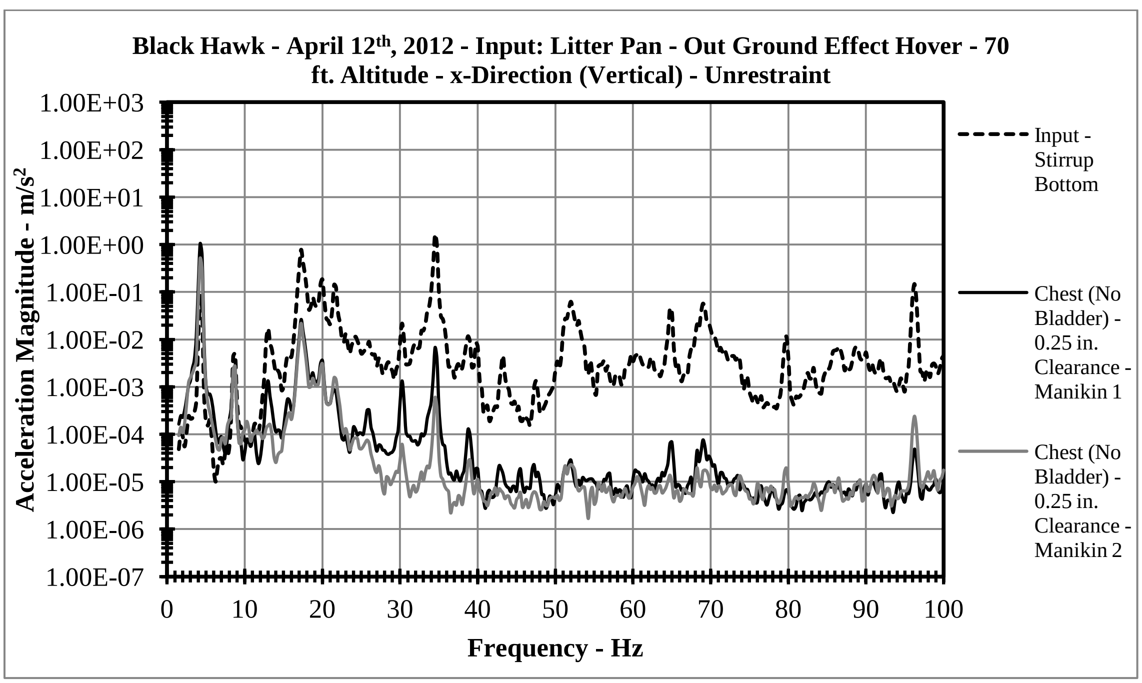

Figure B.16: Acceleration Magnitude of the Chest for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

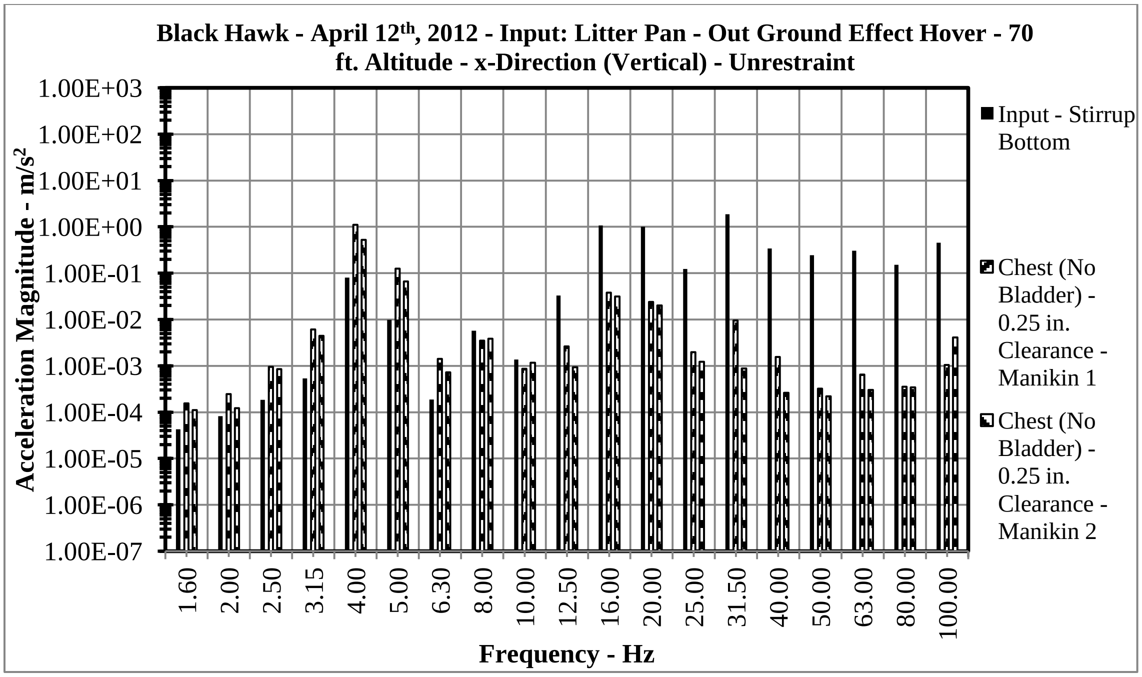

Figure B.17: 1/3 Octave Band Acceleration Magnitude of the Chest for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

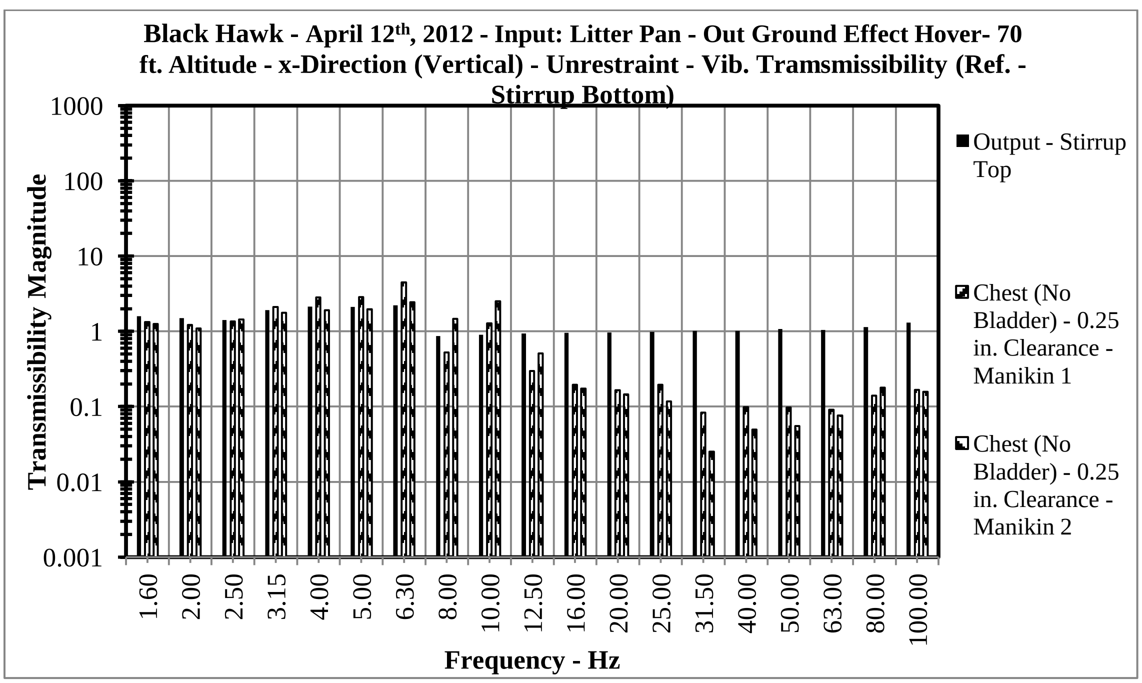

Figure B.18: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – Unrestraint with 0.25 in. Clearance

Appendix C – Black Hawk Helicopter Test – 15 lb_f. Restraint

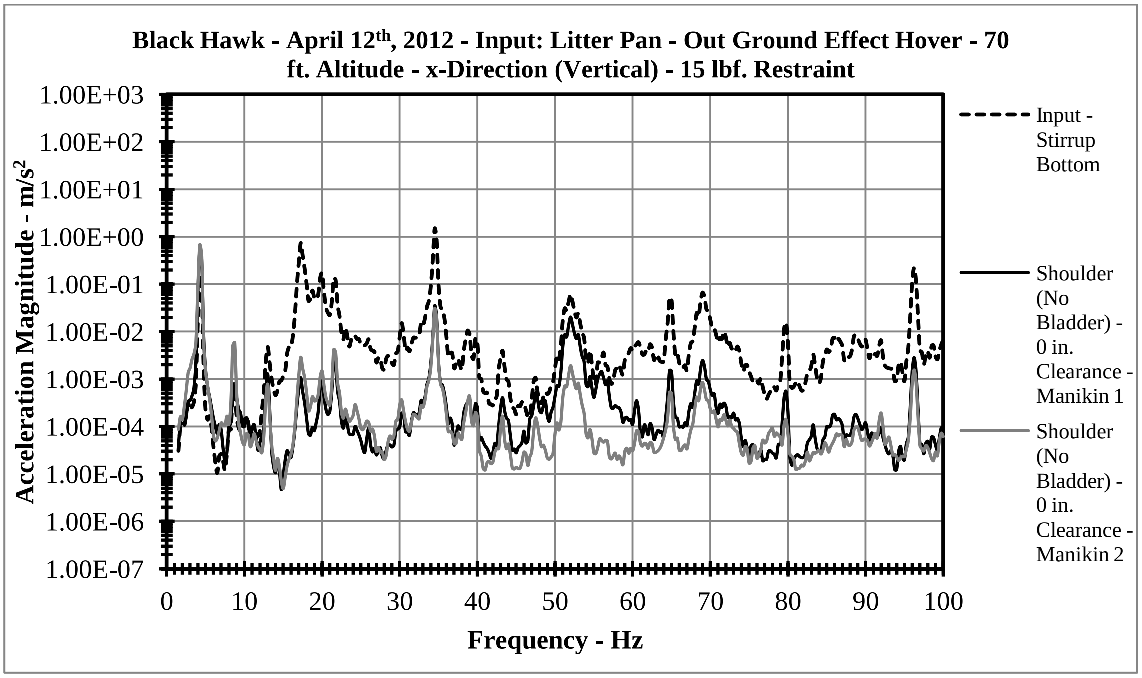

Figure C.1: Acceleration Magnitude of the Shoulders for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

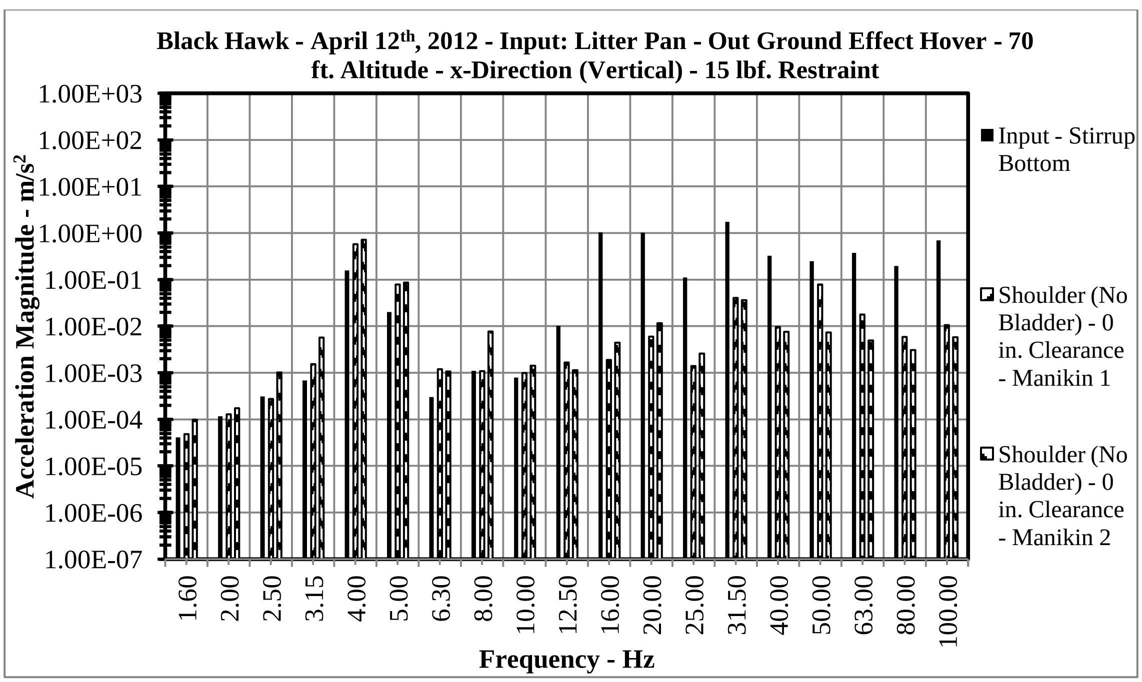

Figure C.2: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

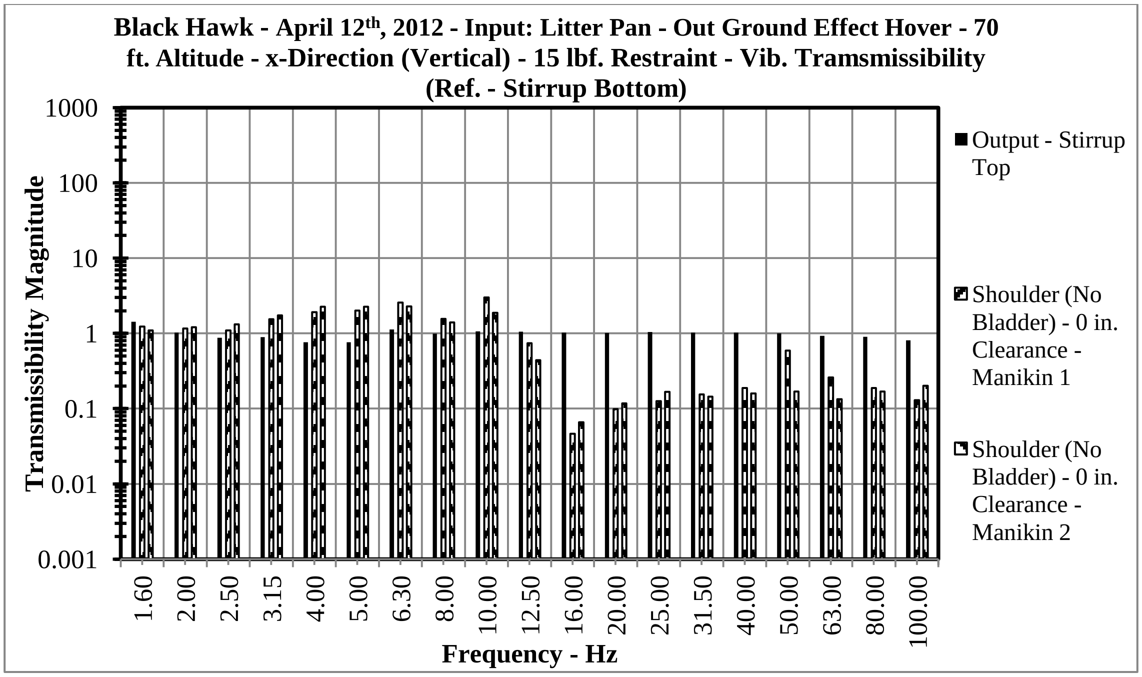

Figure C.3: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

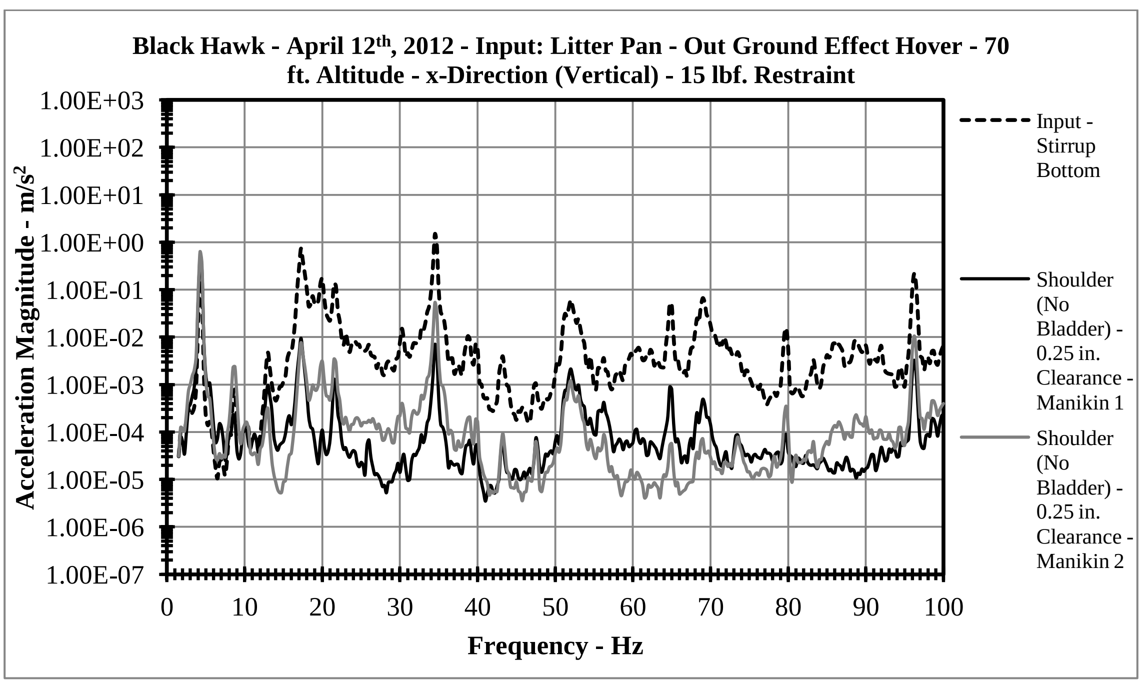

Figure C.4: Acceleration Magnitude of the Shoulders for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

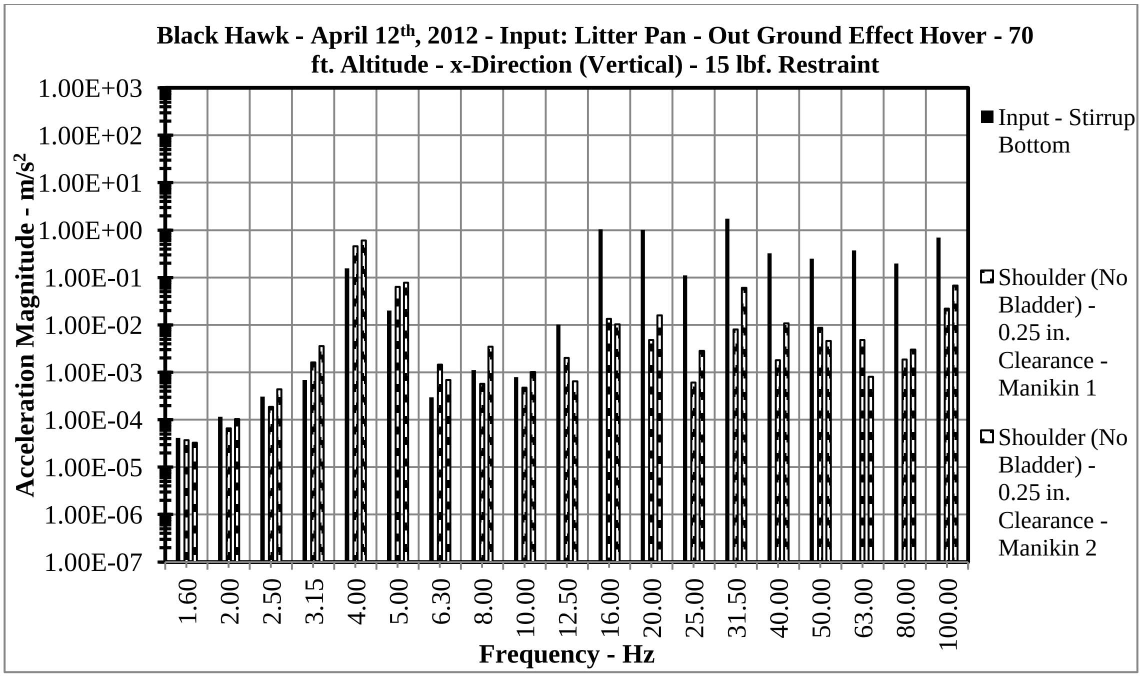

Figure C.5: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

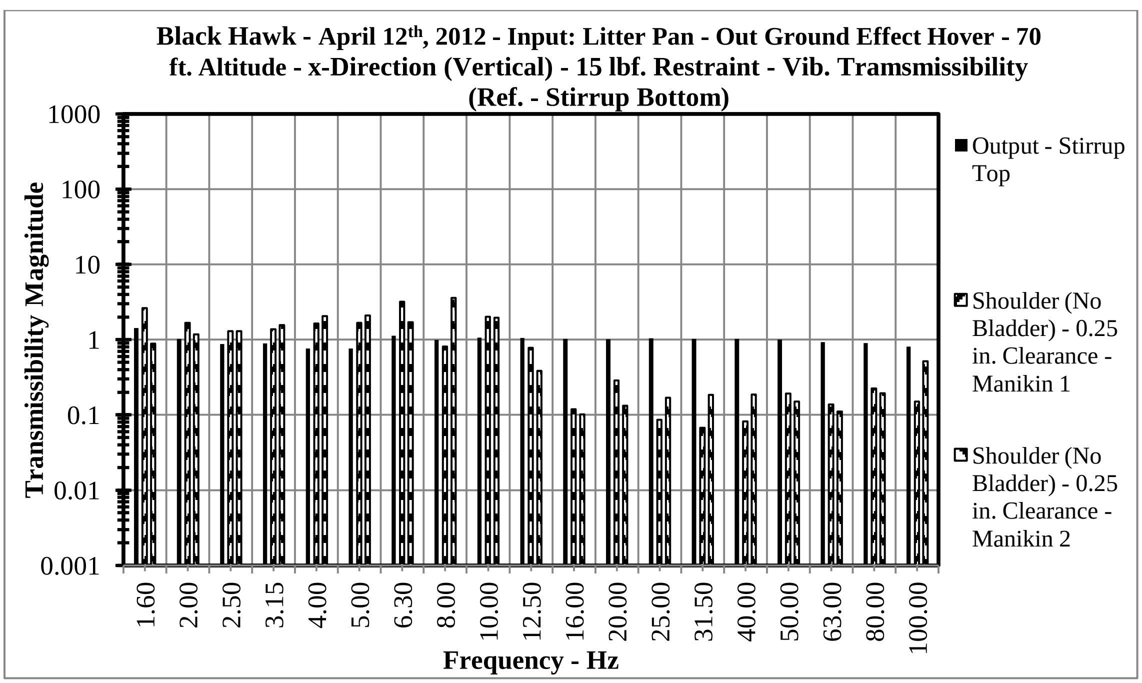

Figure C.6: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

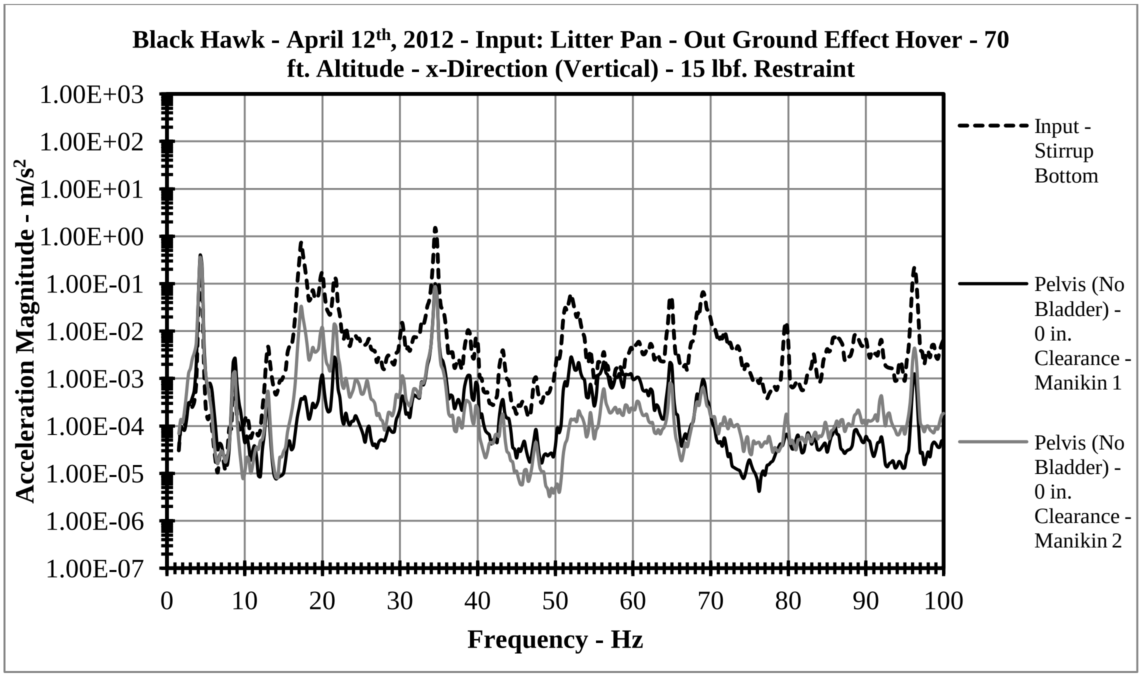

Figure C.7: 1/3 Acceleration Magnitude of the Pelvis for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

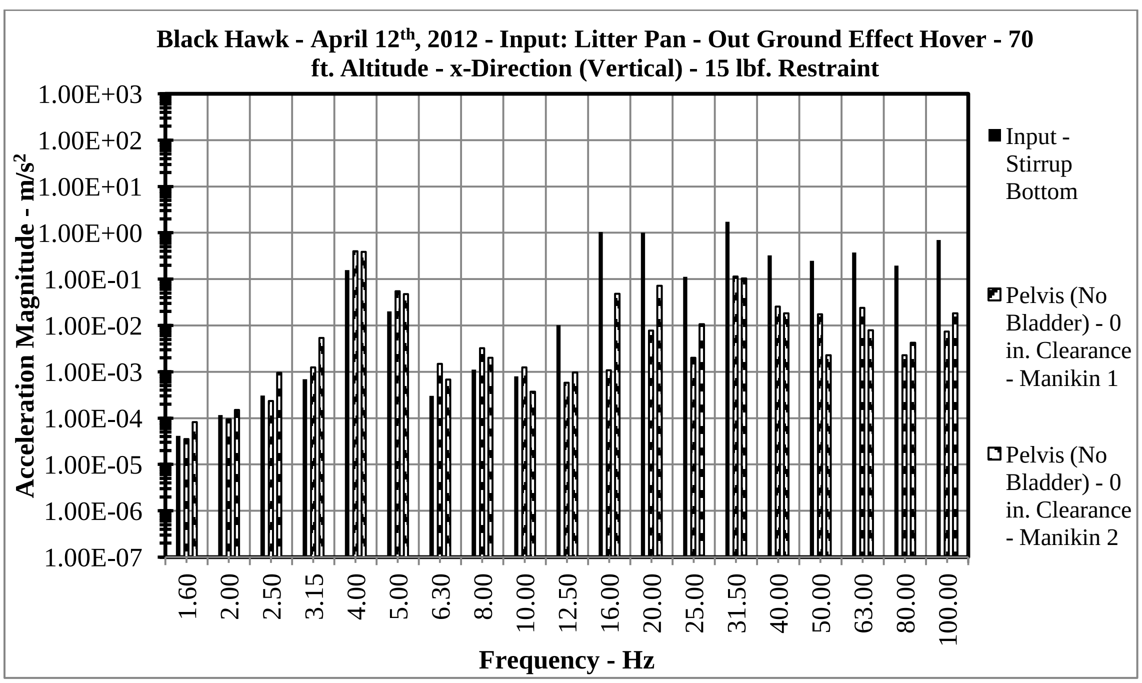

Figure C.8: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

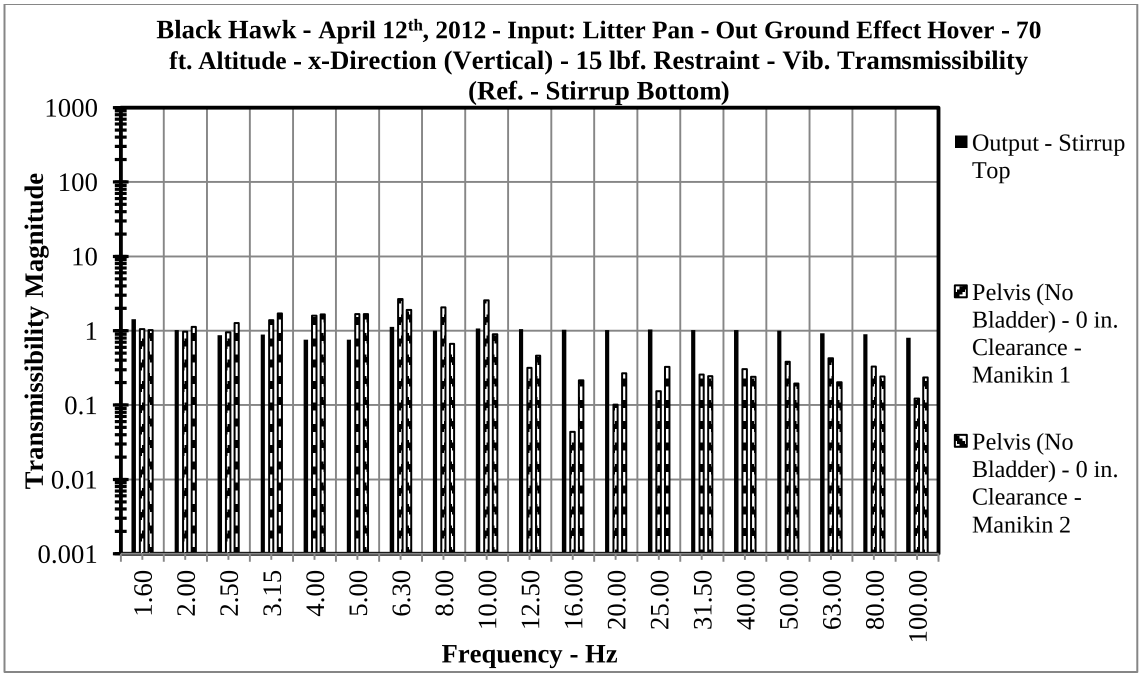

Figure C.9: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

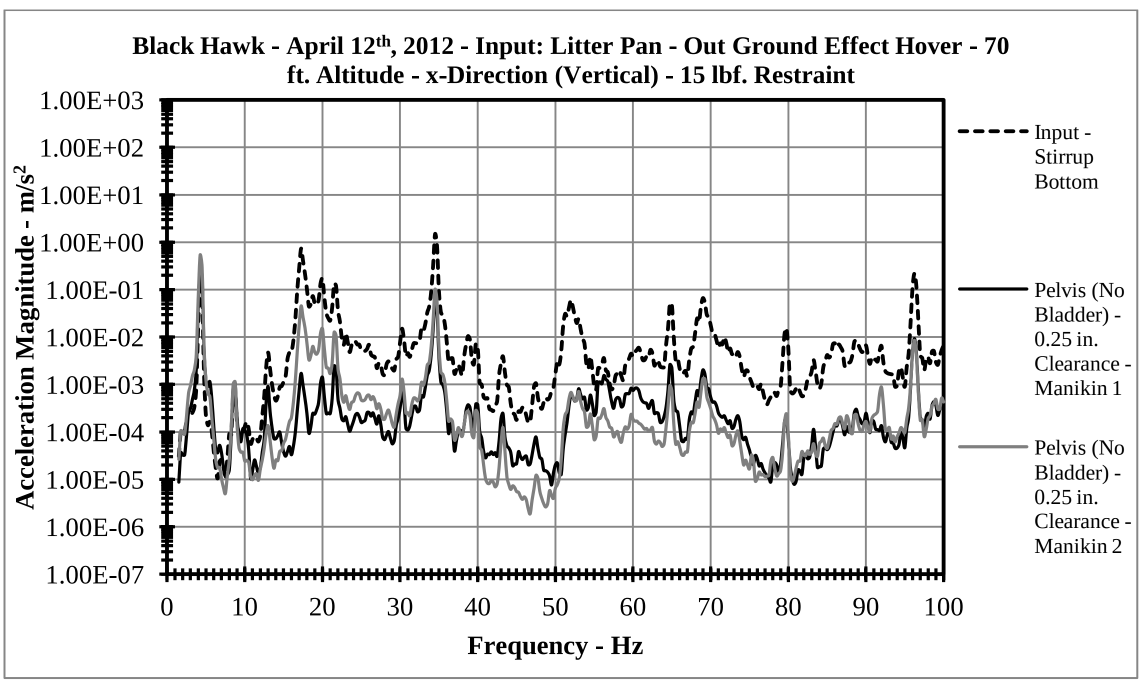

Figure C.10: Acceleration Magnitude of the Pelvis for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

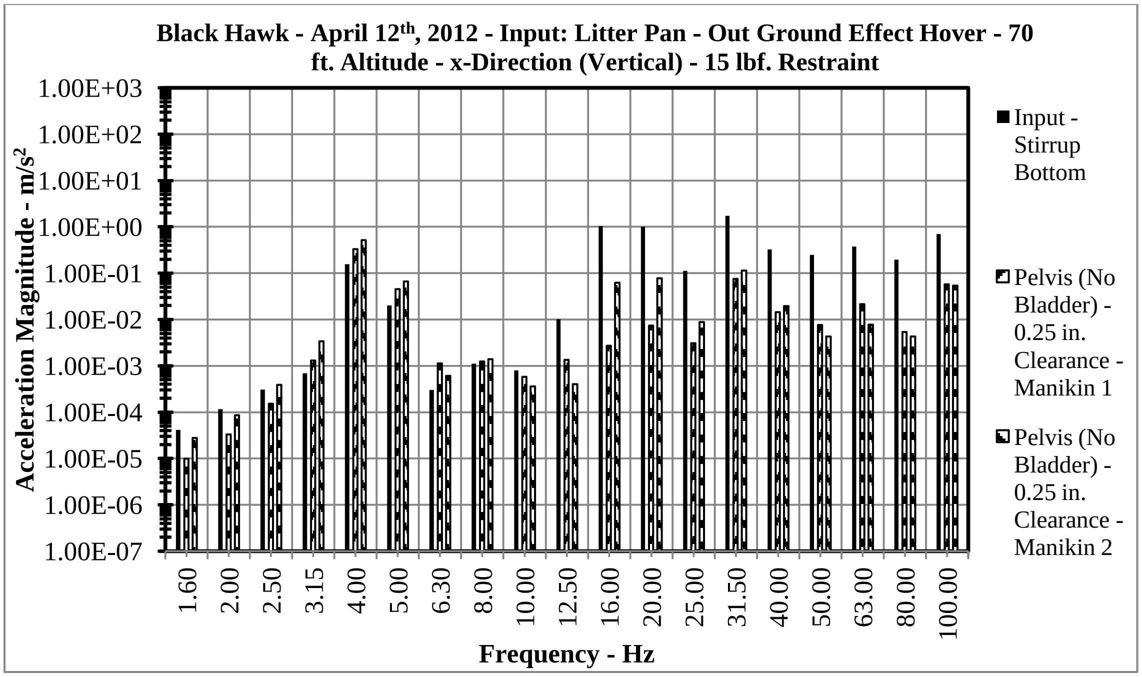

Figure C.11: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

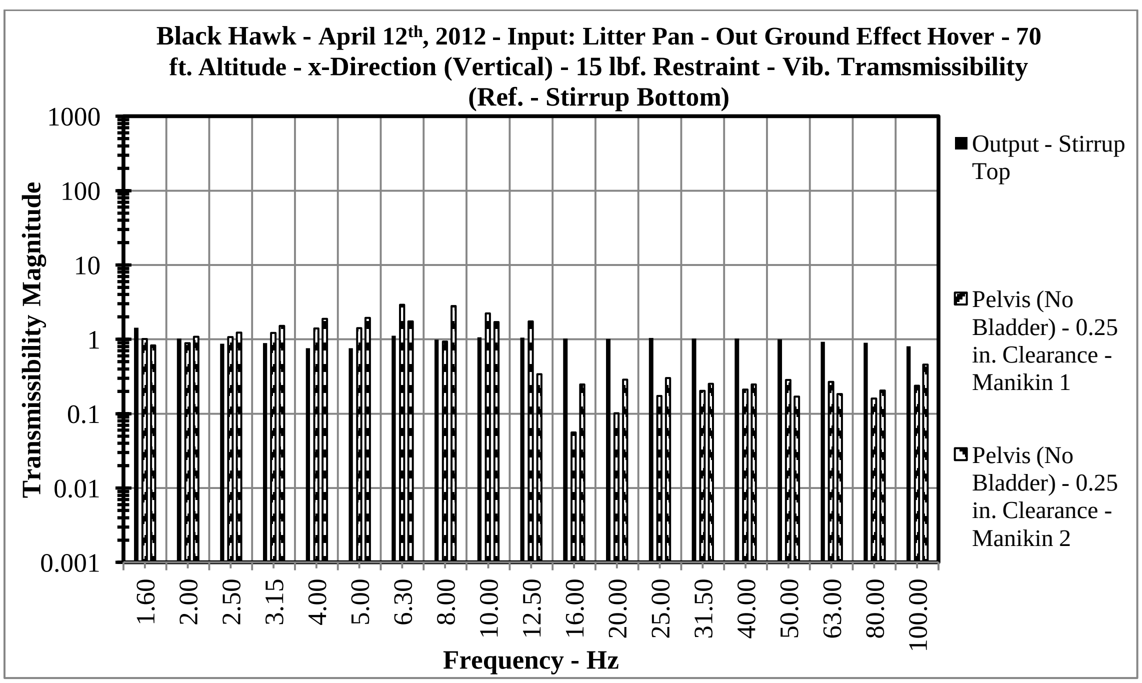

Figure C.12: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

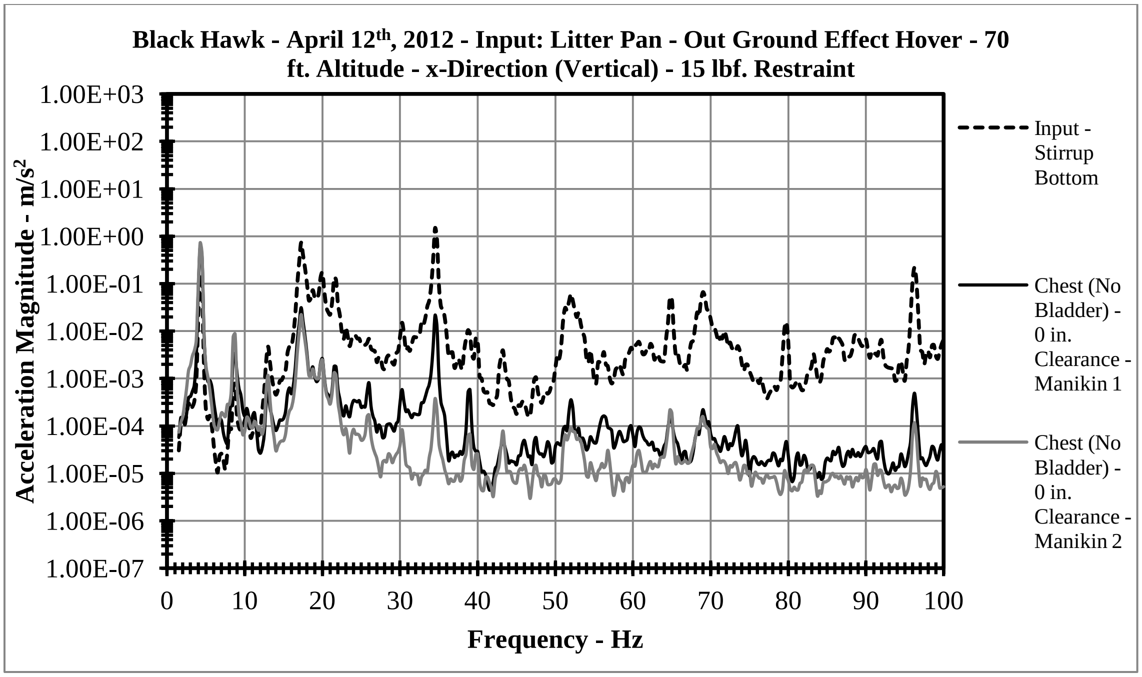

Figure C.13: Acceleration Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

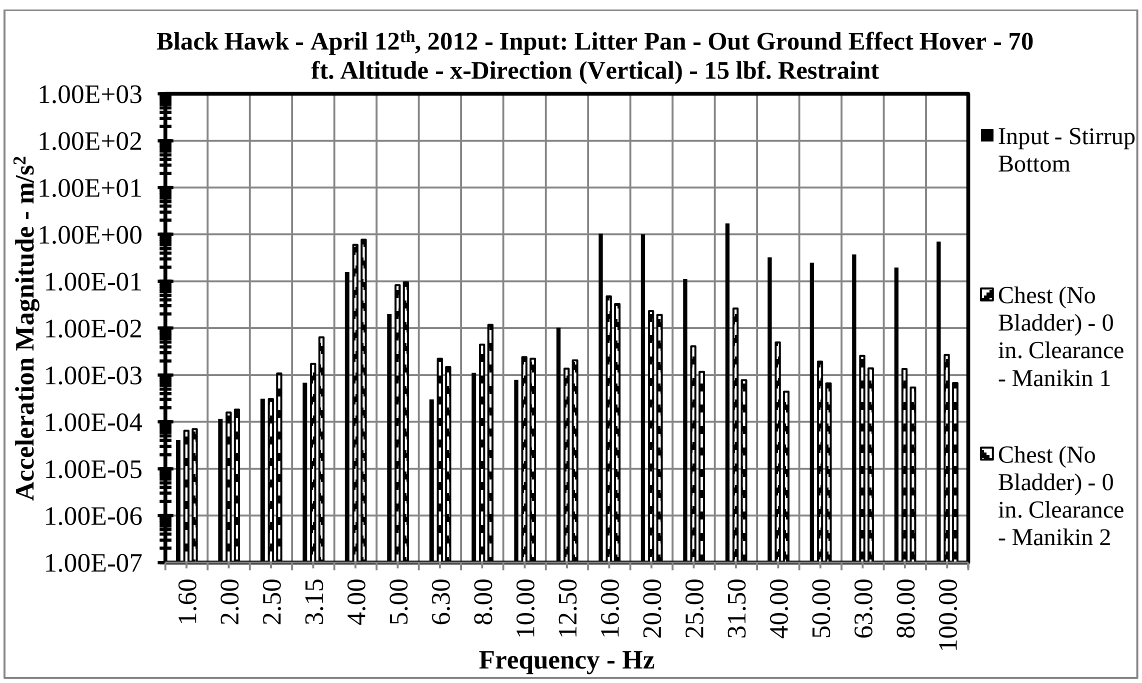

Figure C.14: 1/3 Octave Band Acceleration Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

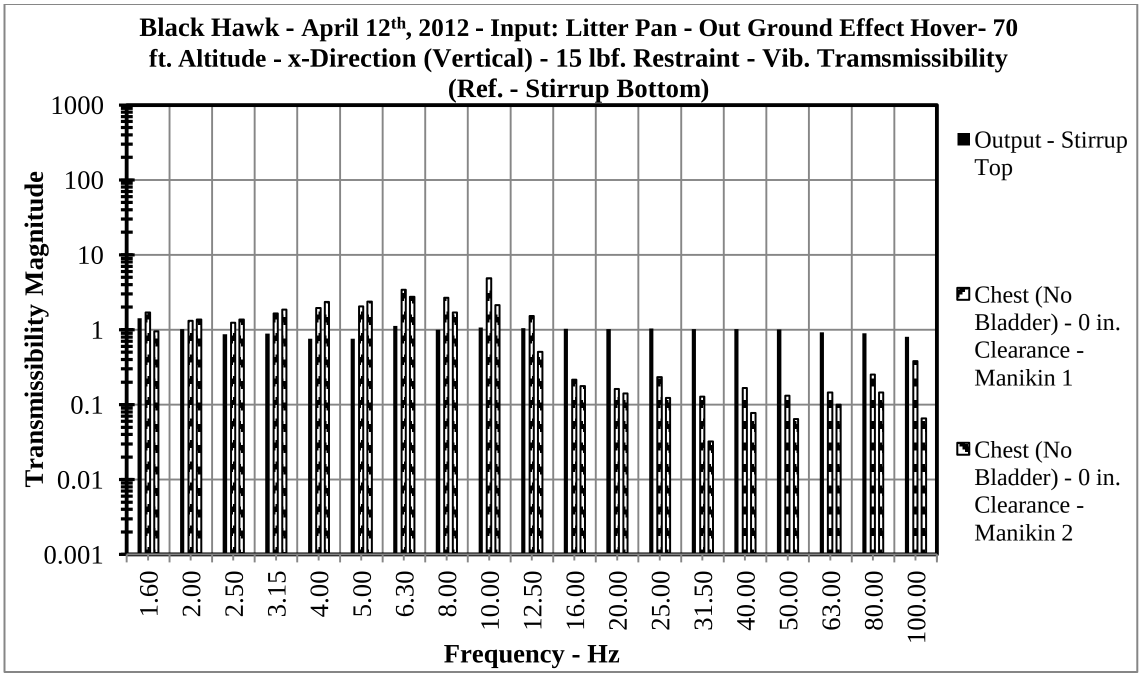

Figure C.15: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0 in. Clearance

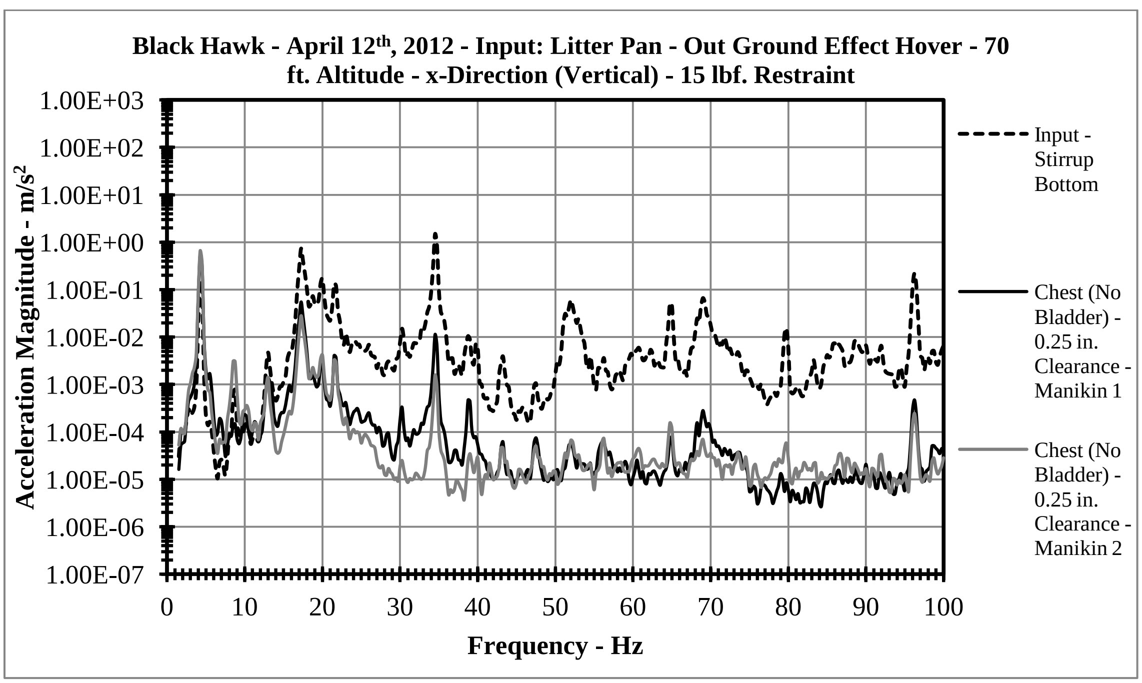

Figure C.16: Acceleration Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

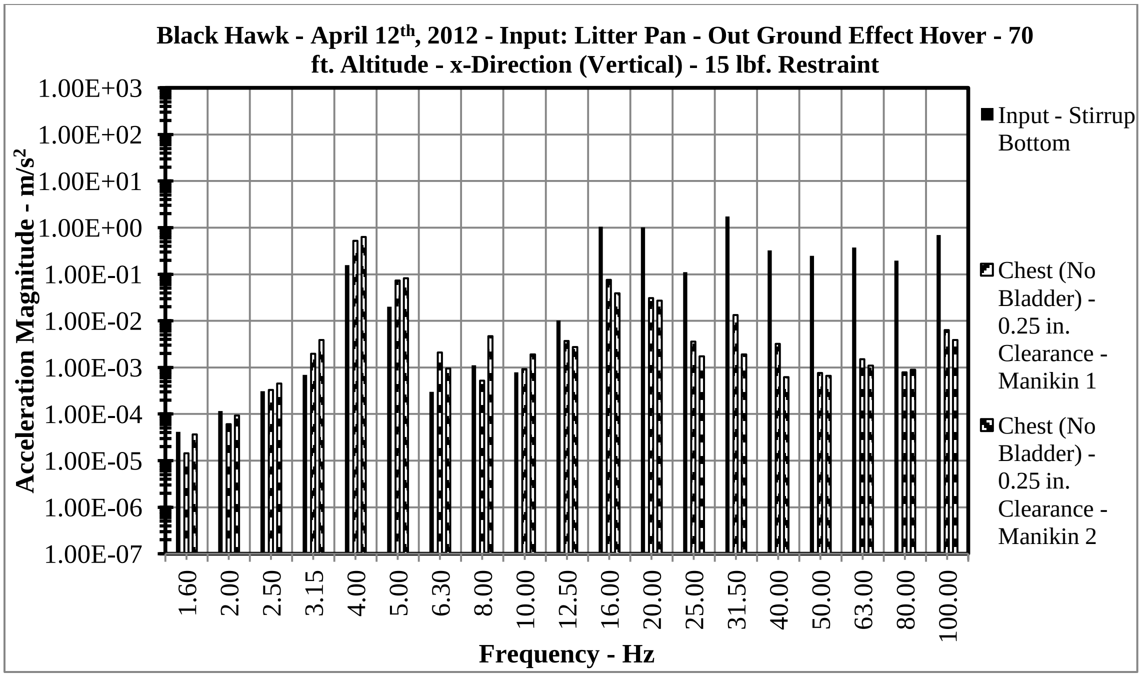

Figure C.17: 1/3 Octave Band Acceleration Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

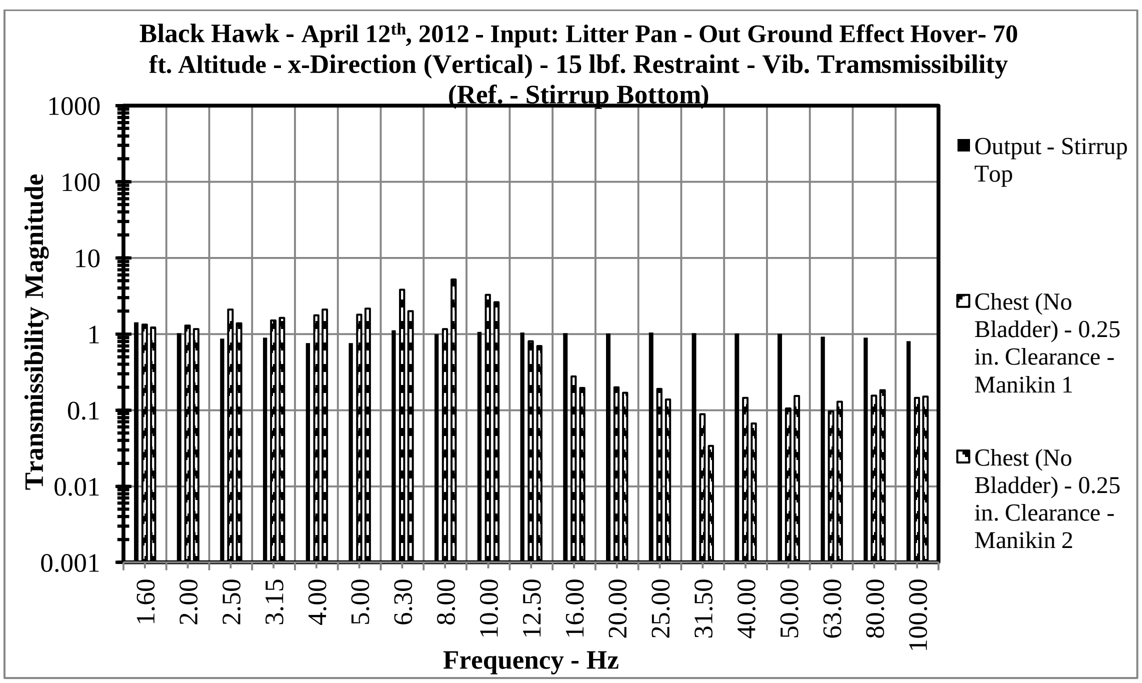

Figure C.18: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – 15 lbf. Restraint with 0.25 in. Clearance

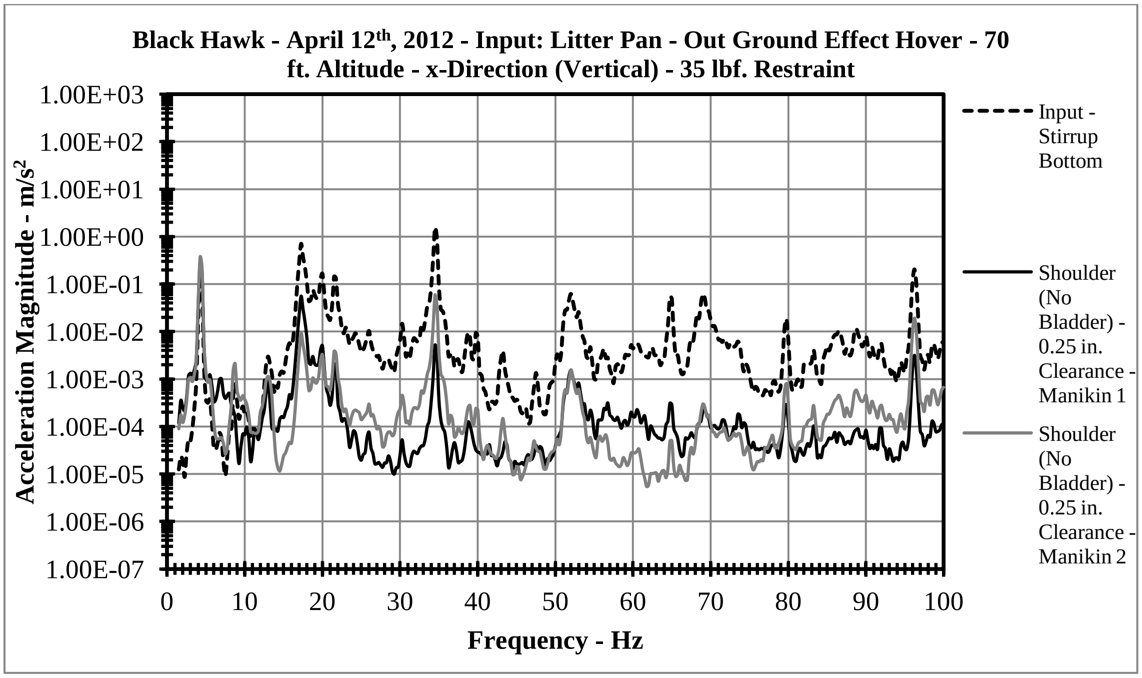

Figure D.1: Acceleration Magnitude of the Shoulders for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

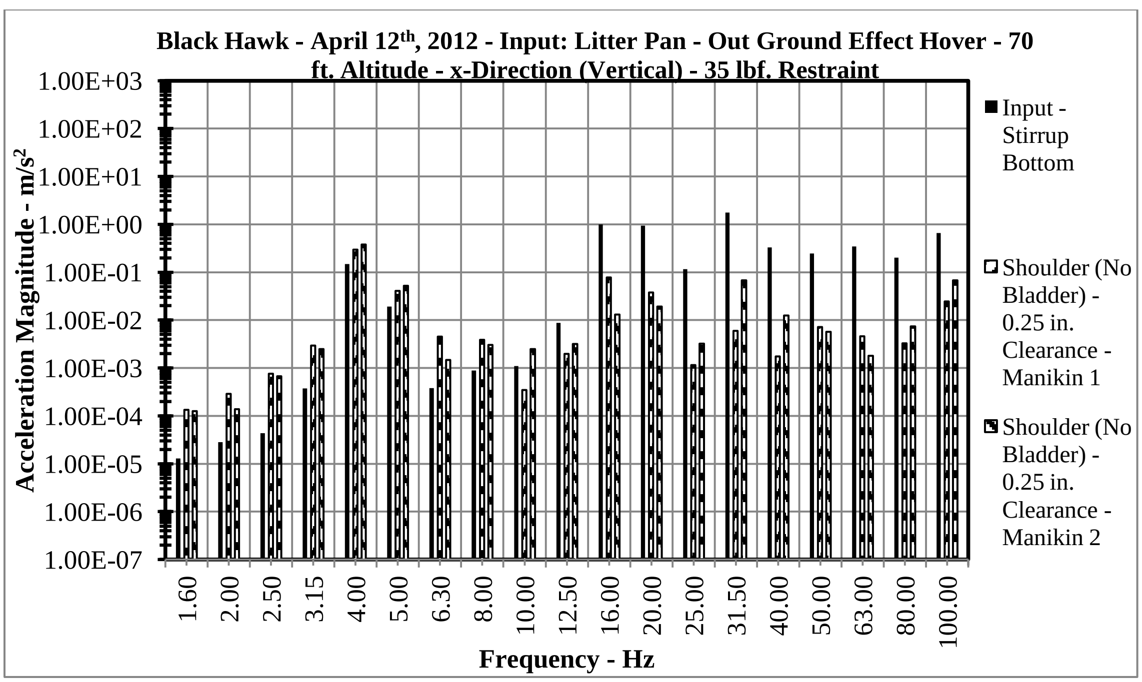

Figure D.2: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

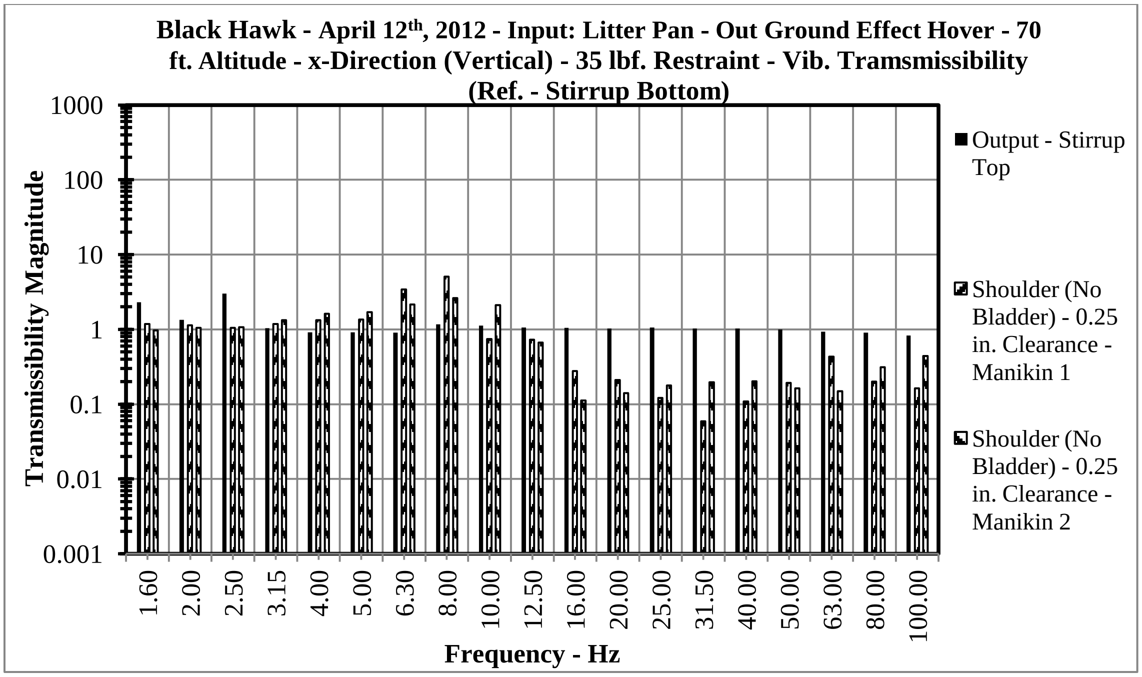

Figure D.3: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

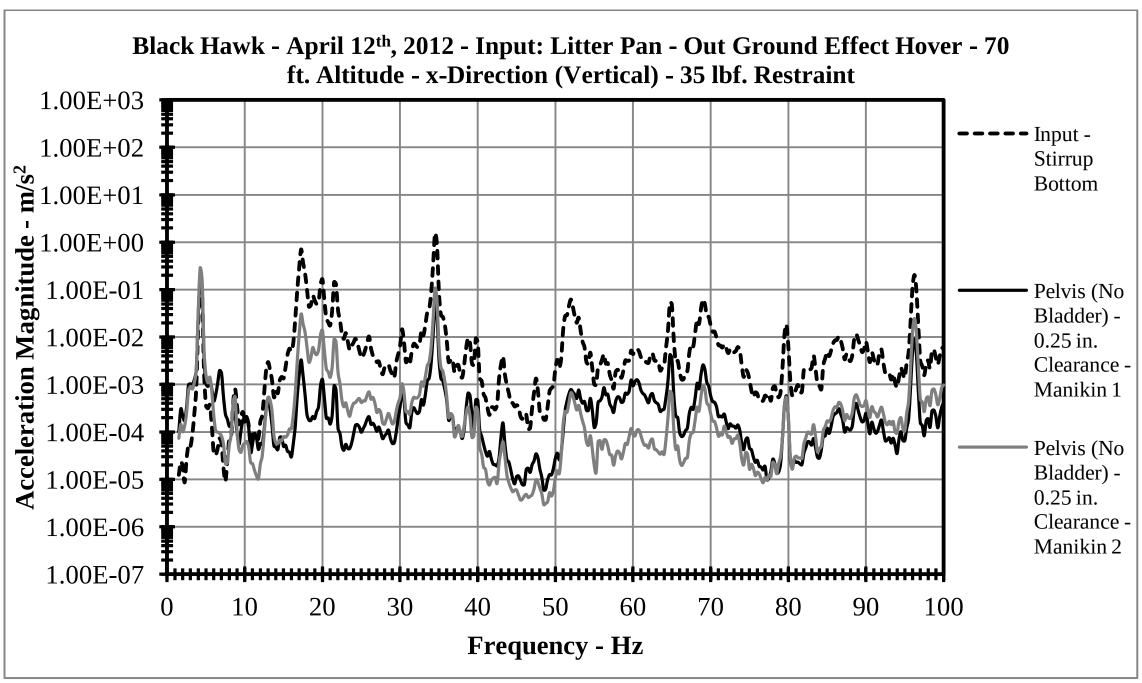

Figure D.4: Acceleration Magnitude of the Pelvis for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

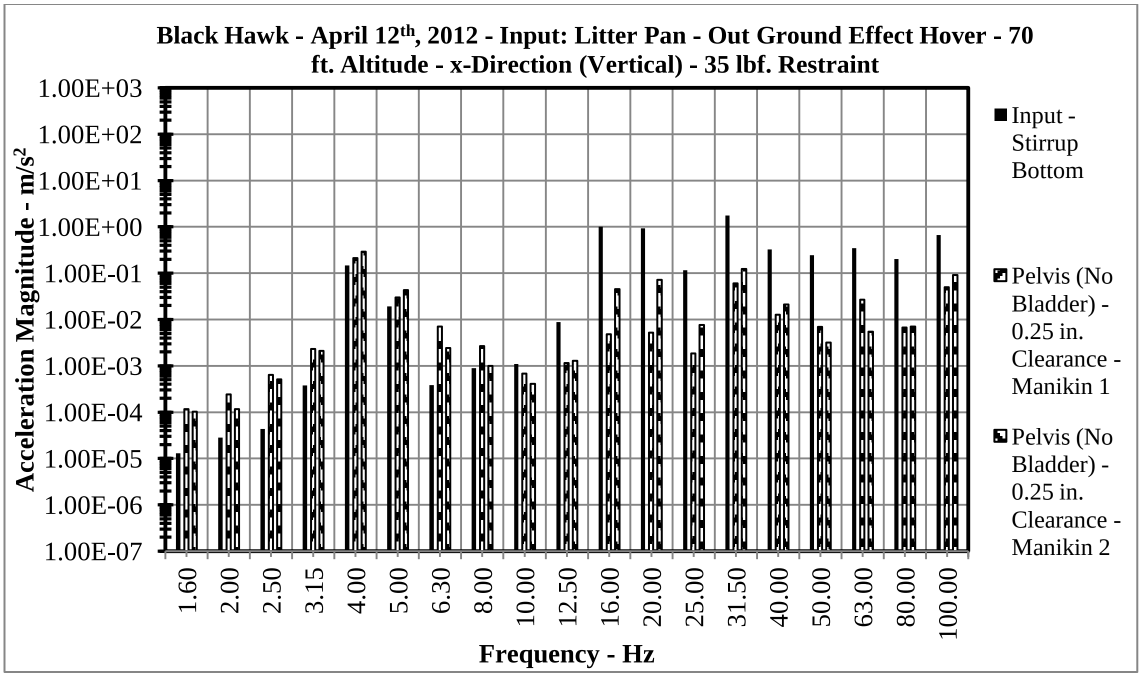

Figure D.5: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

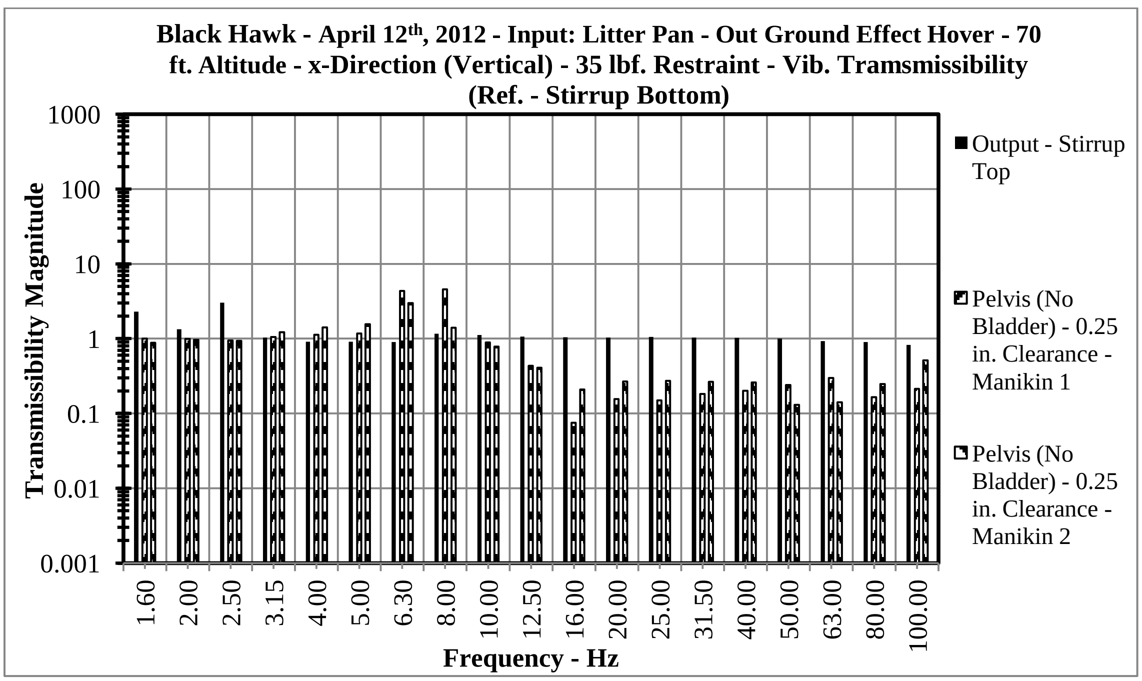

Figure D.6: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

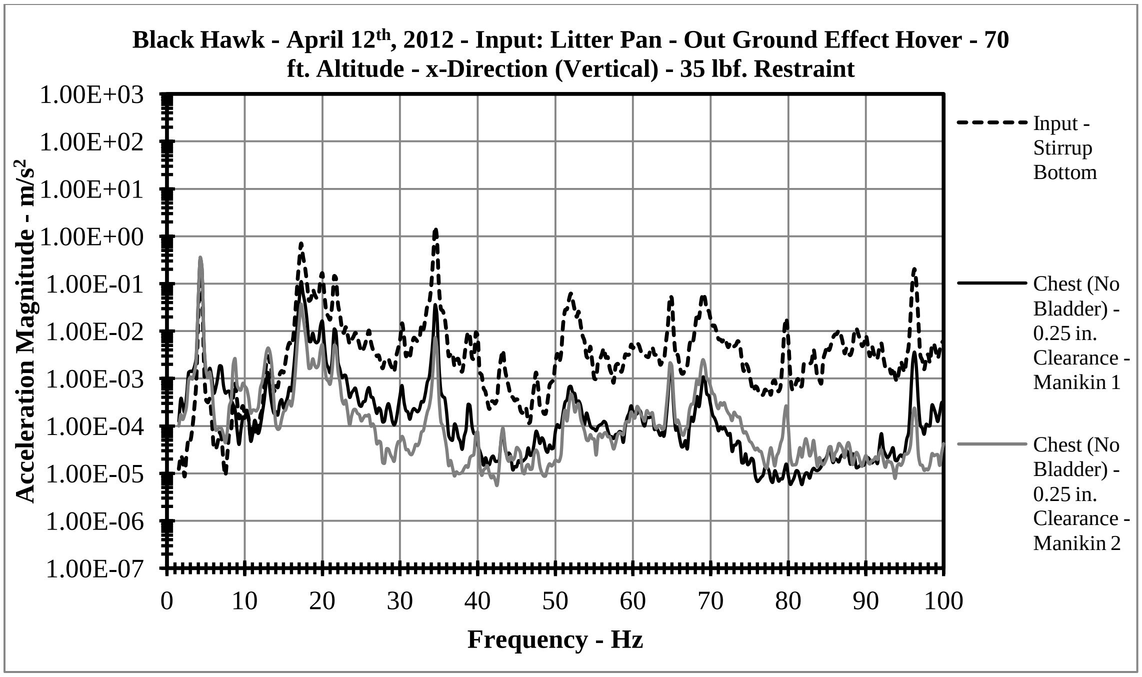

Figure D.7: Acceleration Magnitude of the Chest for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

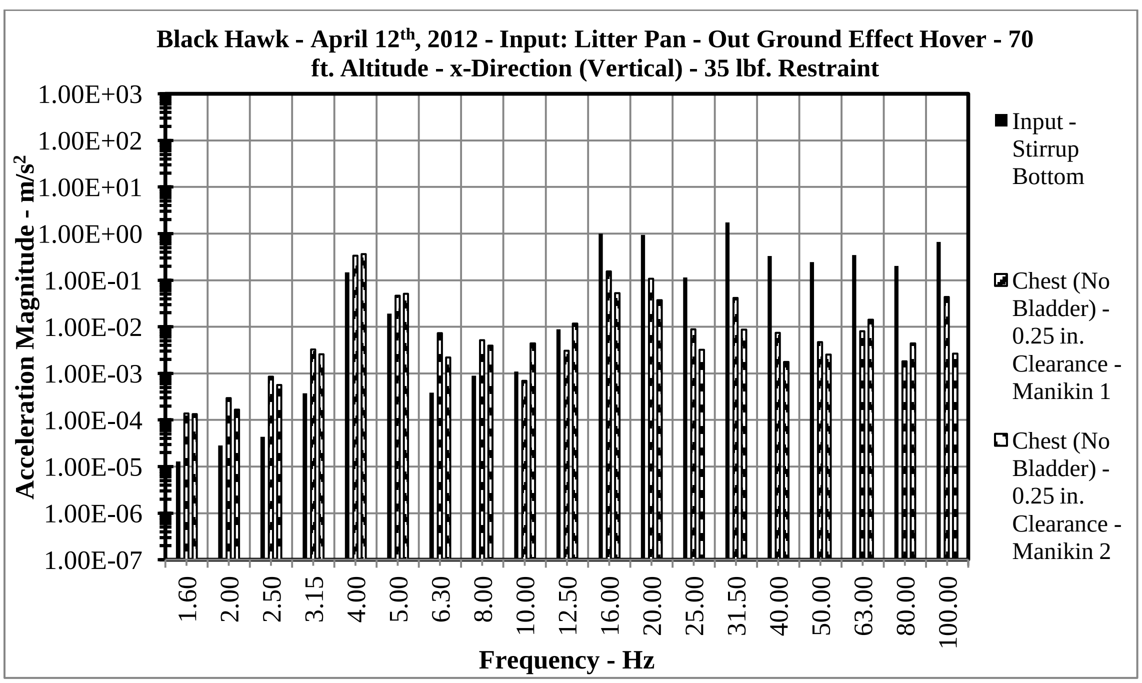

Figure D.8: 1/3 Octave Band Acceleration Magnitude of the Chest for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

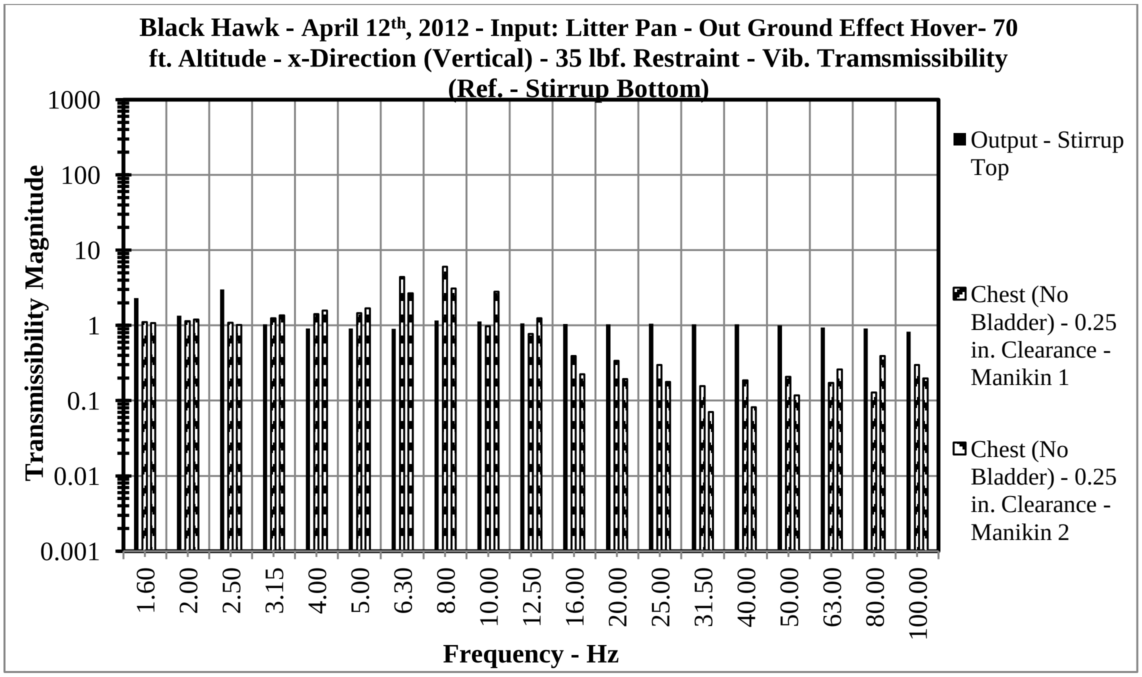

Figure D.9: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Black Hawk Test – 35 lbf. Restraint with 0.25 in. Clearance

Appendix E – RSS Acceleration Values in m/s^2 for the Black Hawk Helicopter Test

Table E.1: RSS Acceleration Values in m/s^2 for the Black Hawk Helicopter Test at 4 Hz

Black Hawk - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 4 Hz - x-Direction (Vertical)

Test Condition	Output Shoulder (No Bladder)	Output Shoulder (Bladder)	Output Pelvis (No Bladder)	Output Pelvis (Bladder)	Output Chest (No Bladder)	Output Chest (Bladder)
Unrestraint - 0 in. Clearance Manikin 1	0.892	4.008	0.813	3.169	1.131	6.092
Unrestraint - 0 in. Clearance Manikin 2	0.415	2.368	0.117	2.305	0.430	2.619
Unrestraint - 0.25 in Clearance Manikin 1	0.949	6.773	0.776	5.519	1.107	6.641
Unrestraint - 0.25 in Clearance Manikin 2	0.479	1.947	0.293	1.923	0.524	1.978
15 lbf. Restraint - 0 in. Clearance Manikin 1	0.572	0.881	0.401	0.787	0.601	1.555
15 lbf. Restraint - 0 in. Clearance Manikin 2	0.723	2.676	0.389	2.556	0.777	3.795
15 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.454	1.414	0.333	2.284	0.526	2.075
15 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.604	2.720	0.519	2.731	0.632	2.626
35 lbf. Restraint - 0 in. Clearance Manikin 1	0.264	0.313	0.187	0.246	0.289	0.424
35 lbf. Restraint - 0 in. Clearance Manikin 2	0.502	1.178	0.472	1.044	0.577	0.753
35 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.294	0.467	0.212	0.498	0.334	0.561
35 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.379	0.936	0.291	0.874	0.361	0.585

Table E.2: RSS Acceleration Values in m/s^2 for the Black Hawk Helicopter Test between 12.5 Hz and 40 Hz

Black Hawk - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 12.5 Hz-40 Hz - x-Direction (Vertical)

Test Condition	Output Shoulder (No Bladder)	Output Shoulder (Bladder)	Output Pelvis (No Bladder)	Output Pelvis (Bladder)	Output Chest (No Bladder)	Output Chest (Bladder)
Unrestraint - 0 in. Clearance Manikin 1	0.018	0.044	0.077	0.026	0.036	0.022
Unrestraint - 0 in. Clearance Manikin 2	0.037	0.094	0.128	0.029	0.045	0.024
Unrestraint - 0.25 in Clearance Manikin 1	0.014	0.026	0.061	0.027	0.046	0.020
Unrestraint - 0.25 in Clearance Manikin 2	0.063	0.090	0.174	0.029	0.037	0.029
15 lbf. Restraint - 0 in. Clearance Manikin 1	0.042	0.033	0.117	0.021	0.059	0.032
15 lbf. Restraint - 0 in. Clearance Manikin 2	0.039	0.092	0.136	0.030	0.038	0.036
15 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.017	0.062	0.078	0.059	0.084	0.024
15 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.065	0.087	0.153	0.026	0.047	0.039
35 lbf. Restraint - 0 in. Clearance Manikin 1	0.035	0.082	0.045	0.036	0.124	0.305
35 lbf. Restraint - 0 in. Clearance Manikin 2	0.031	0.070	0.128	0.027	0.077	0.057
35 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.087	0.037	0.062	0.028	0.193	0.045
35 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.073	0.061	0.152	0.025	0.066	0.057

Table E.3: RSS Acceleration Values in m/s² for the Black Hawk Helicopter Test between 50 Hz and 100 Hz

Black Hawk - April 12th, 2012 - Input: Litter Pan - Out Ground Effect Hover - 70 ft. Above Ground - Frequency Range: 50 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Output Shoulder (No Bladder)	Output Shoulder (Bladder)	Output Pelvis (No Bladder)	Output Pelvis (Bladder)	Output Chest (No Bladder)	Output Chest (Bladder)
Unrestraint - 0 in. Clearance Manikin 1	0.025	0.034	0.012	0.034	0.004	0.001
Unrestraint - 0 in. Clearance Manikin 2	0.009	0.008	0.015	0.015	0.002	0.001
Unrestraint - 0.25 in Clearance Manikin 1	0.075	0.015	0.020	0.096	0.001	0.001
Unrestraint - 0.25 in Clearance Manikin 2	0.157	0.038	0.071	0.037	0.004	0.002
15 lbf. Restraint - 0 in. Clearance Manikin 1	0.081	0.016	0.031	0.034	0.004	0.012
15 lbf. Restraint - 0 in. Clearance Manikin 2	0.011	0.008	0.020	0.012	0.002	0.003
15 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.024	0.034	0.062	0.038	0.007	0.011
15 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.068	0.023	0.055	0.020	0.004	0.015
35 lbf. Restraint - 0 in. Clearance Manikin 1	0.023	0.004	0.042	0.039	0.085	0.372
35 lbf. Restraint - 0 in. Clearance Manikin 2	0.011	0.003	0.031	0.006	0.012	0.005
35 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.026	0.017	0.057	0.057	0.044	0.040
35 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.069	0.008	0.092	0.006	0.015	0.061

Appendix F – Random Test – Unrestraint

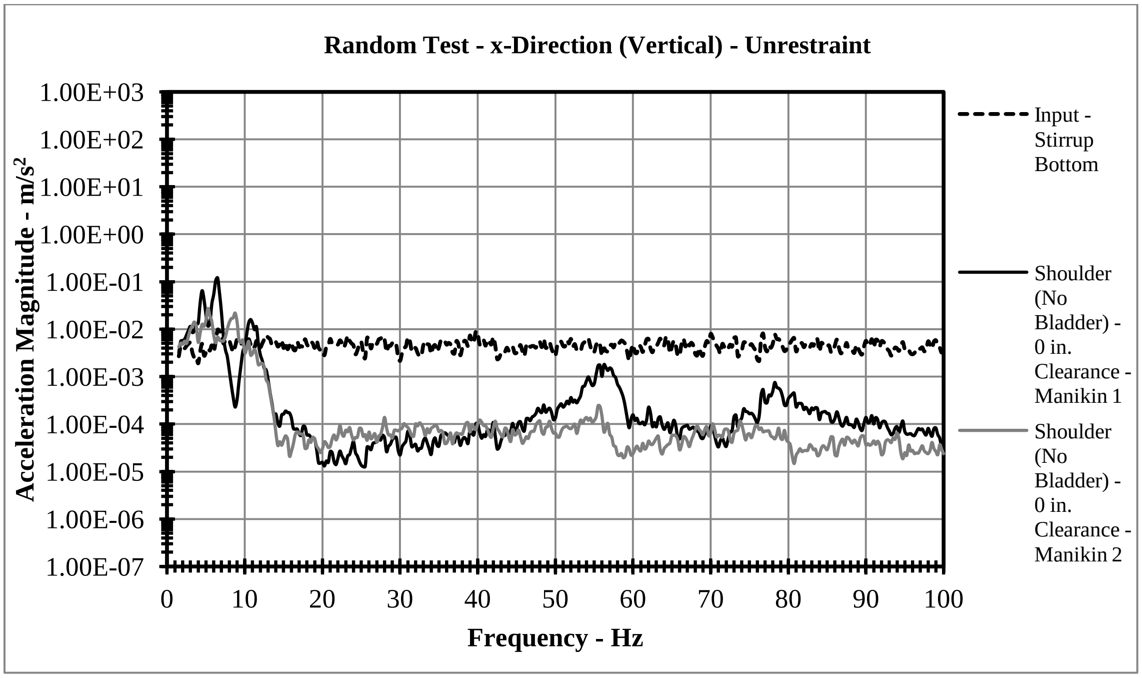

Figure F.1: Acceleration Magnitude of the Shoulders for the Random Test – Unrestraint with 0 in. Clearance

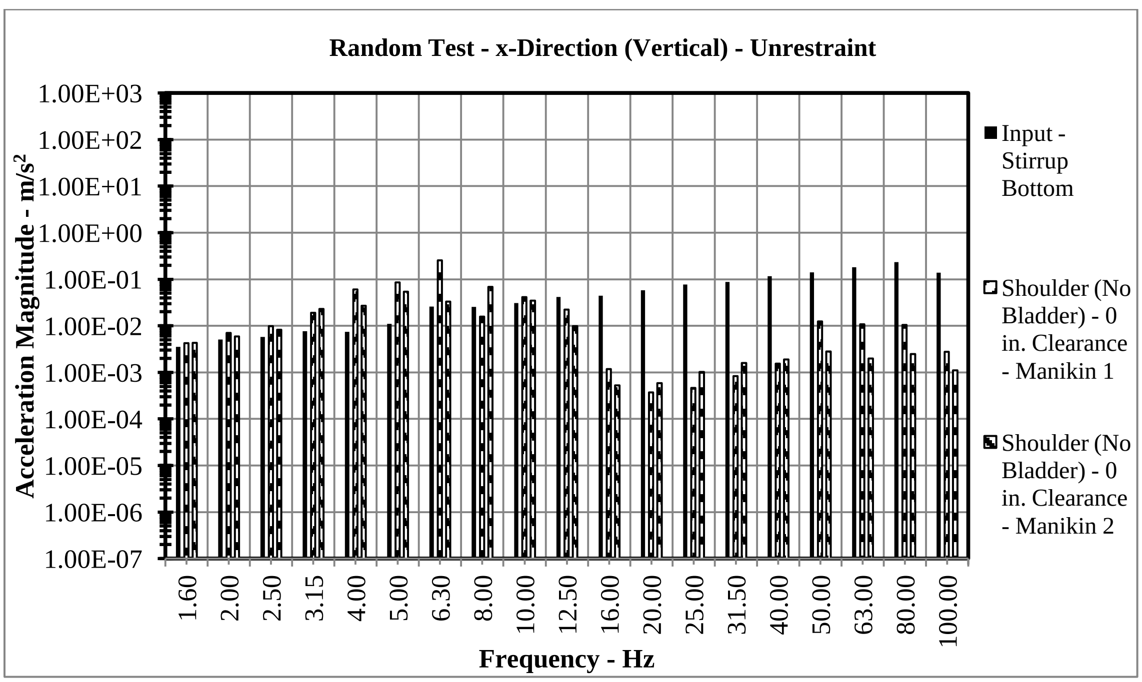

Figure F.2: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Random Test – Unrestraint with 0 in. Clearance

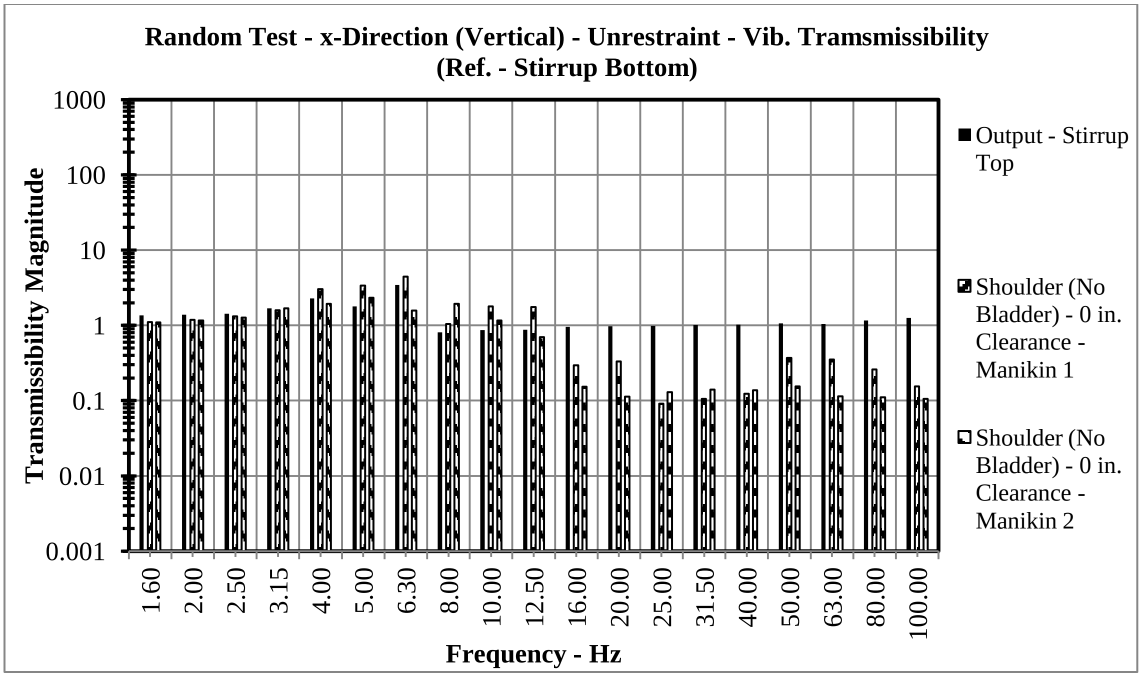

Figure F.3: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Random Test – Unrestraint with 0 in. Clearance

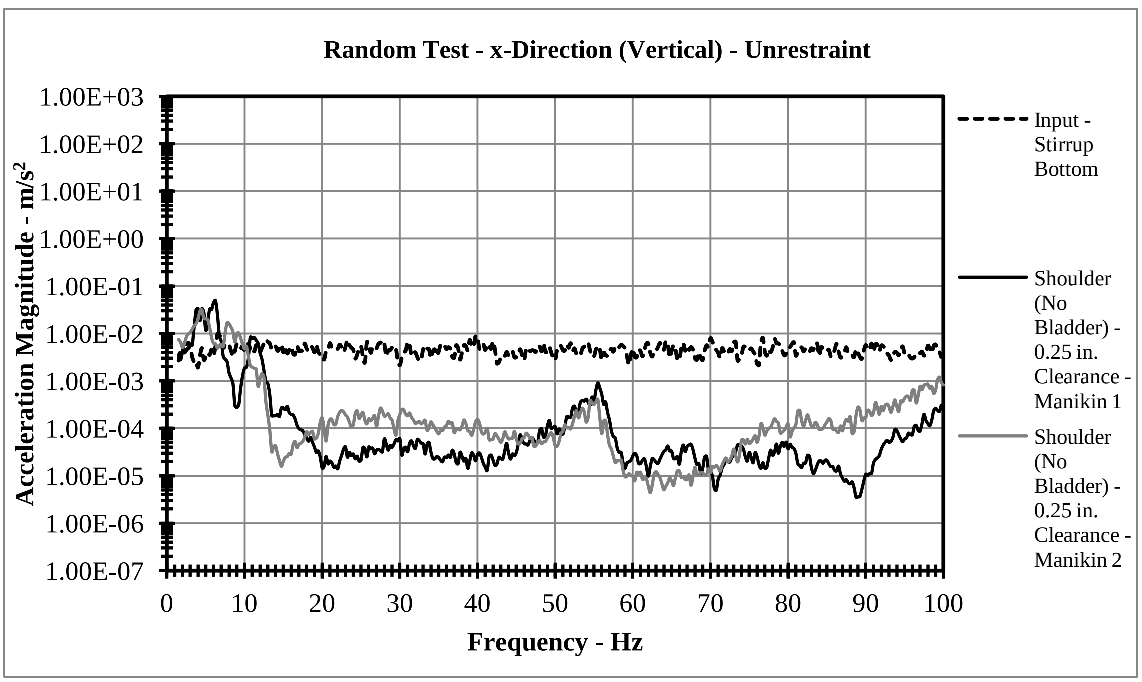

Figure F.4: Acceleration Magnitude of the Shoulders for the Random Test – Unrestraint with 0.25 in. Clearance

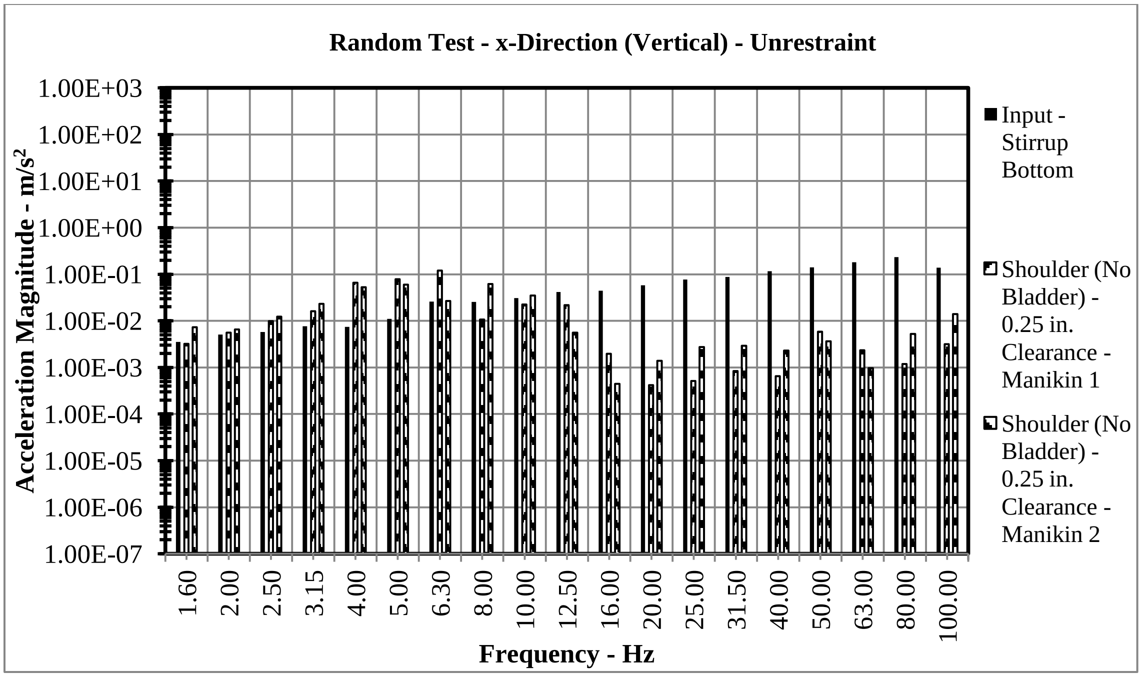

Figure F.5: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Random Test – Unrestraint with 0.25 in. Clearance

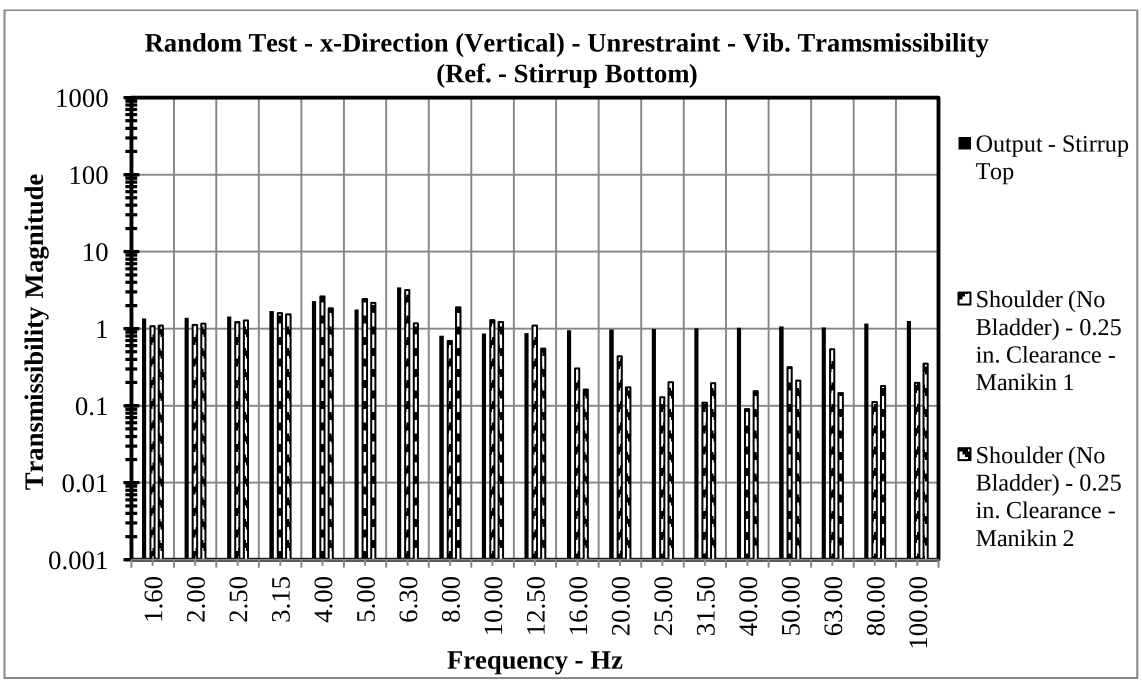

Figure F.6: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Random Test – Unrestraint with 0.25 in. Clearance

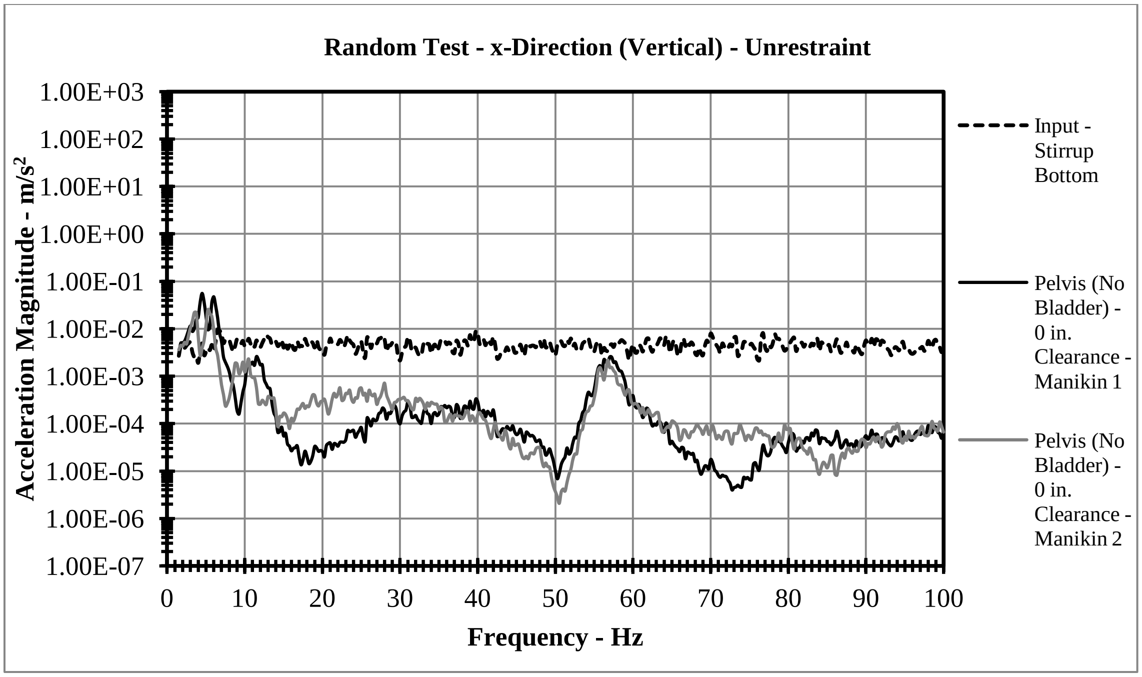

Figure F.7: Acceleration Magnitude of the Pelvis for the Random Test – Unrestraint with 0 in. Clearance

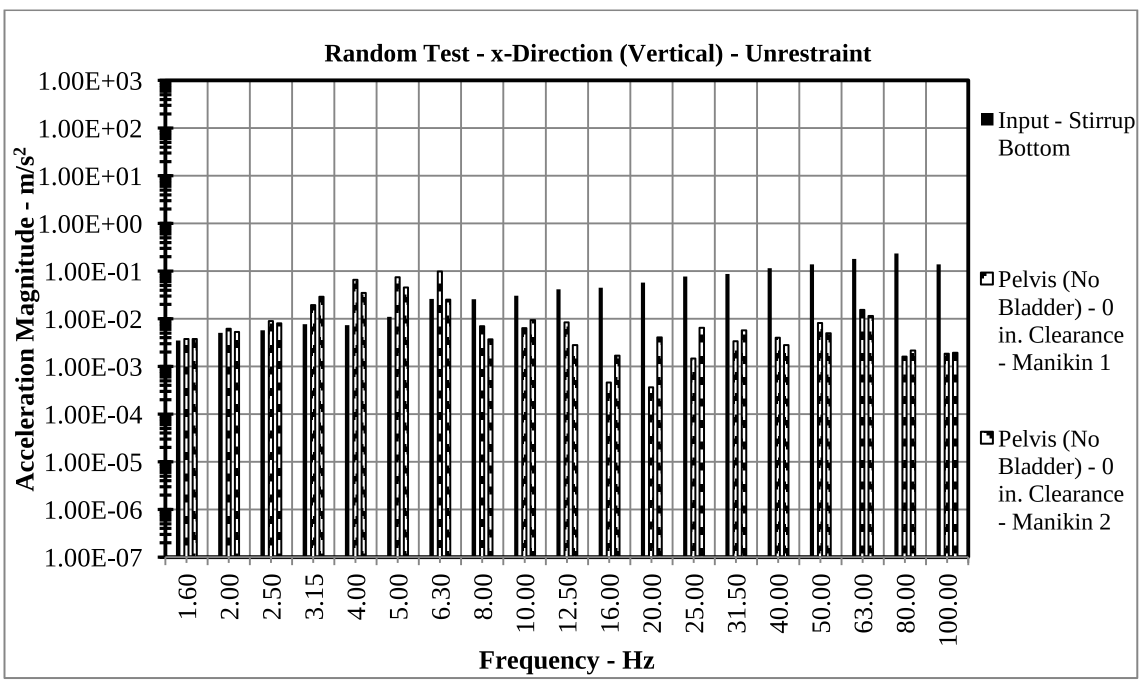

Figure F.8: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Random Test – Unrestraint with 0 in. Clearance

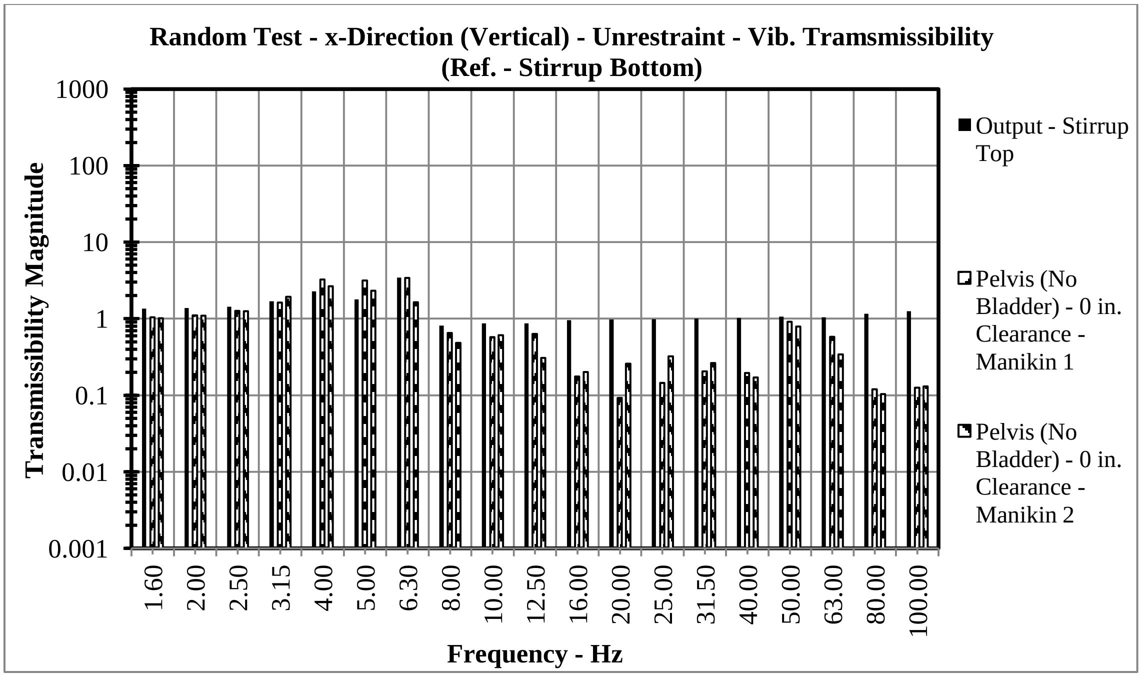

Figure F.9: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Random Test – Unrestraint with 0 in. Clearance

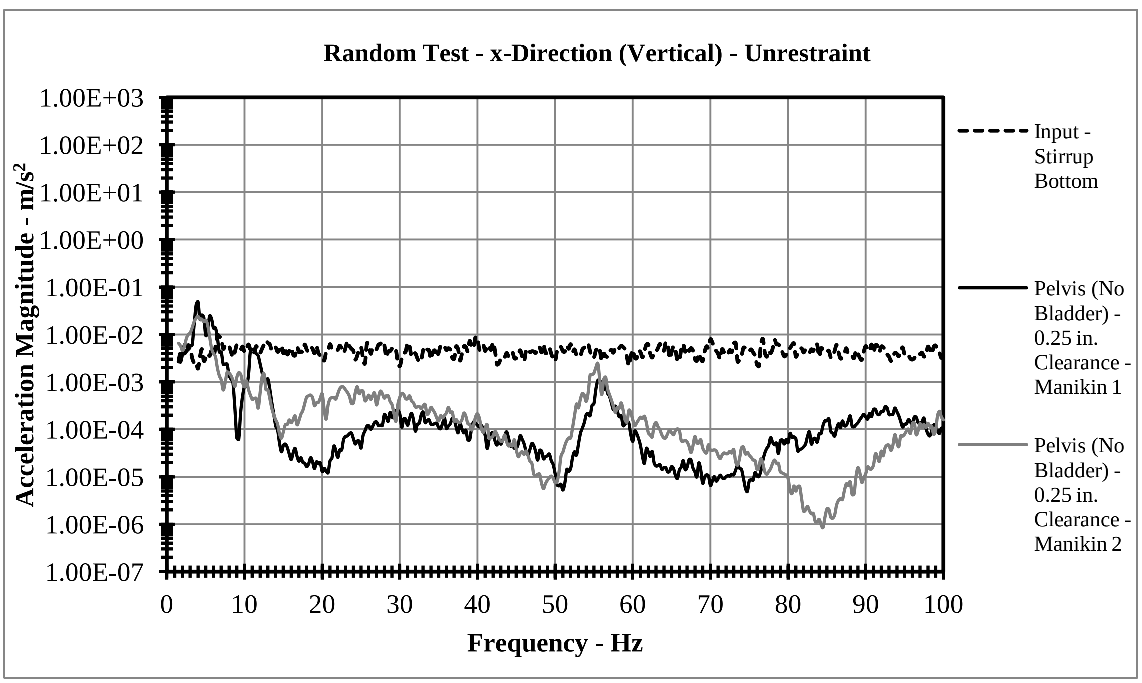

Figure F.10: Acceleration Magnitude of the Pelvis for the Random Test – Unrestraint with 0.25 in. Clearance

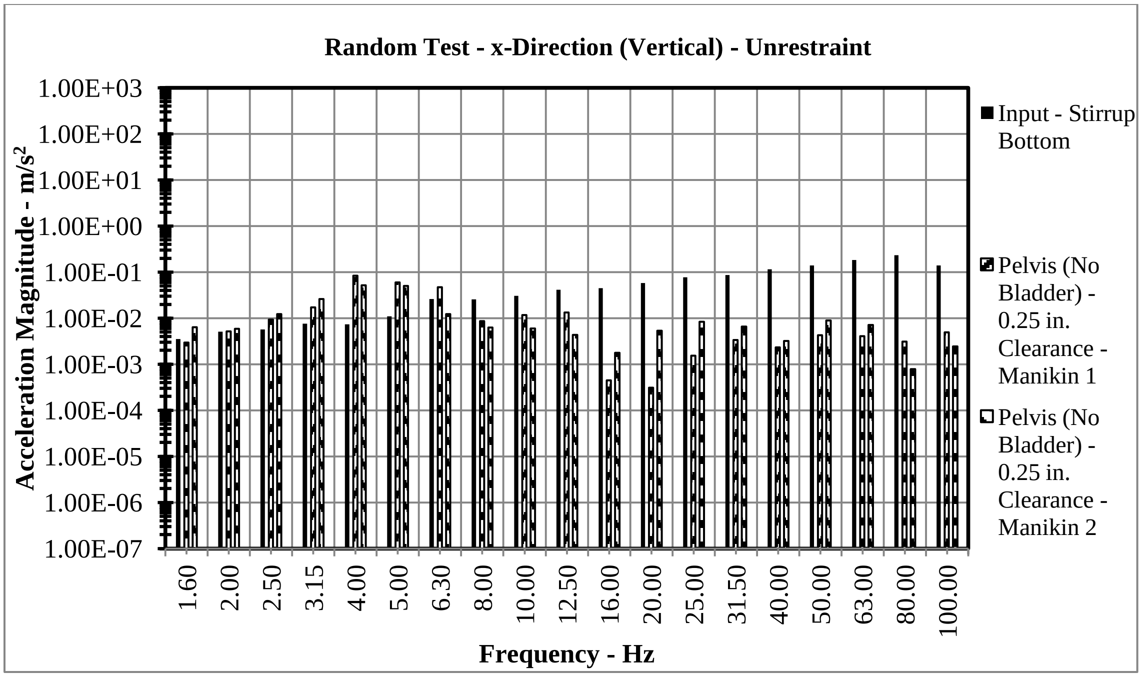

Figure F.11: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Random Test – Unrestraint with 0.25 in. Clearance

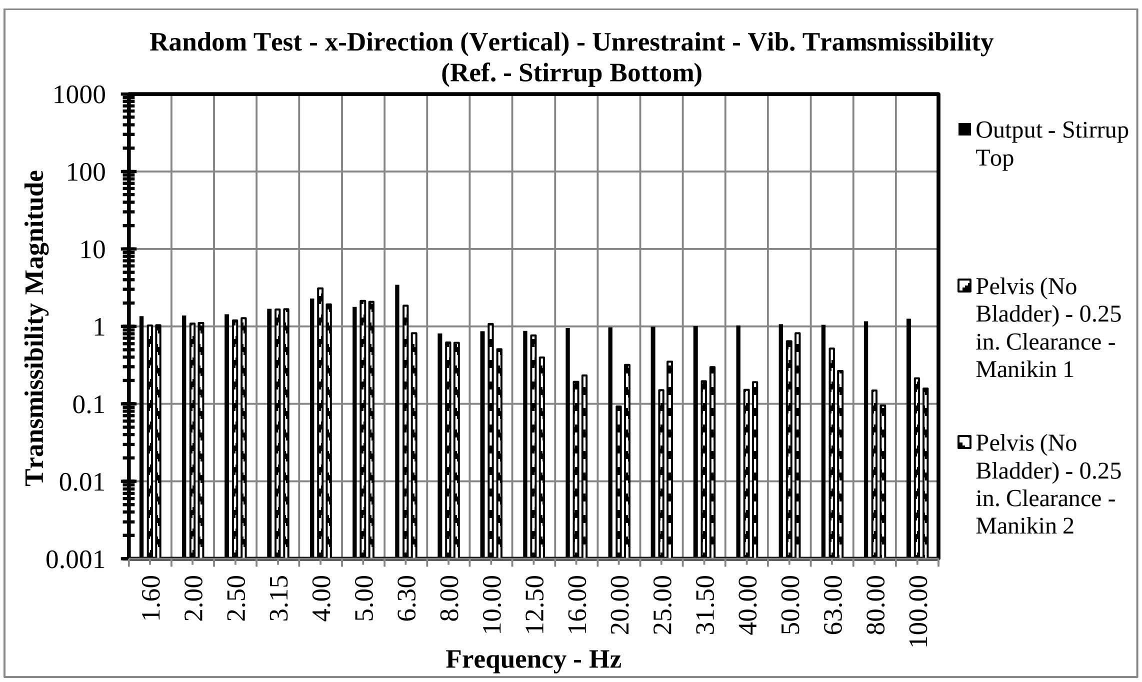

Figure F.12: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Random Test – Unrestraint with 0.25 in. Clearance

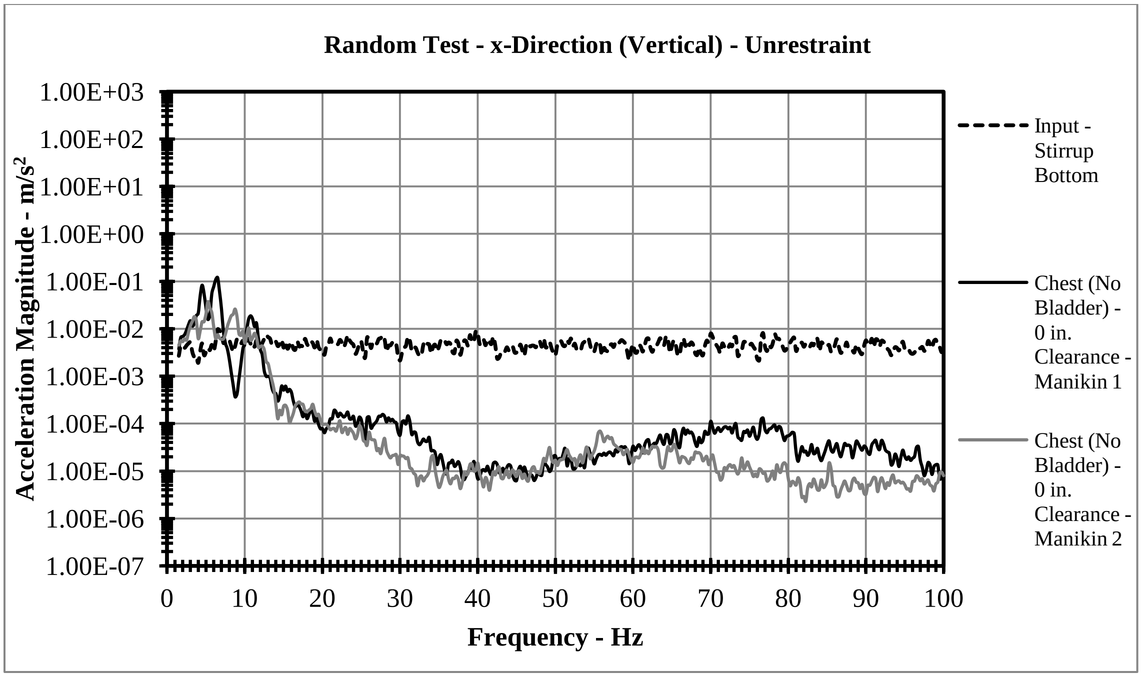

Figure F.13: Acceleration Magnitude of the Chest for the Random Test – Unrestraint with 0 in. Clearance

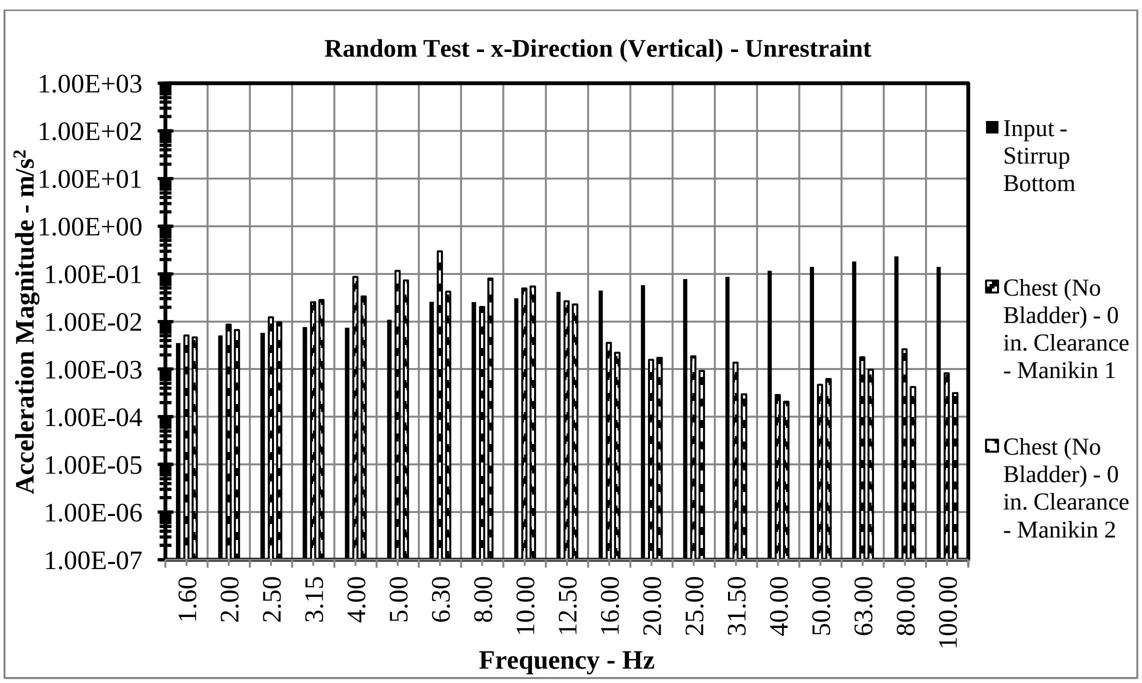

Figure F.14: 1/3 Octave Band Acceleration Magnitude of the Chest for the Random Test – Unrestraint with 0 in. Clearance

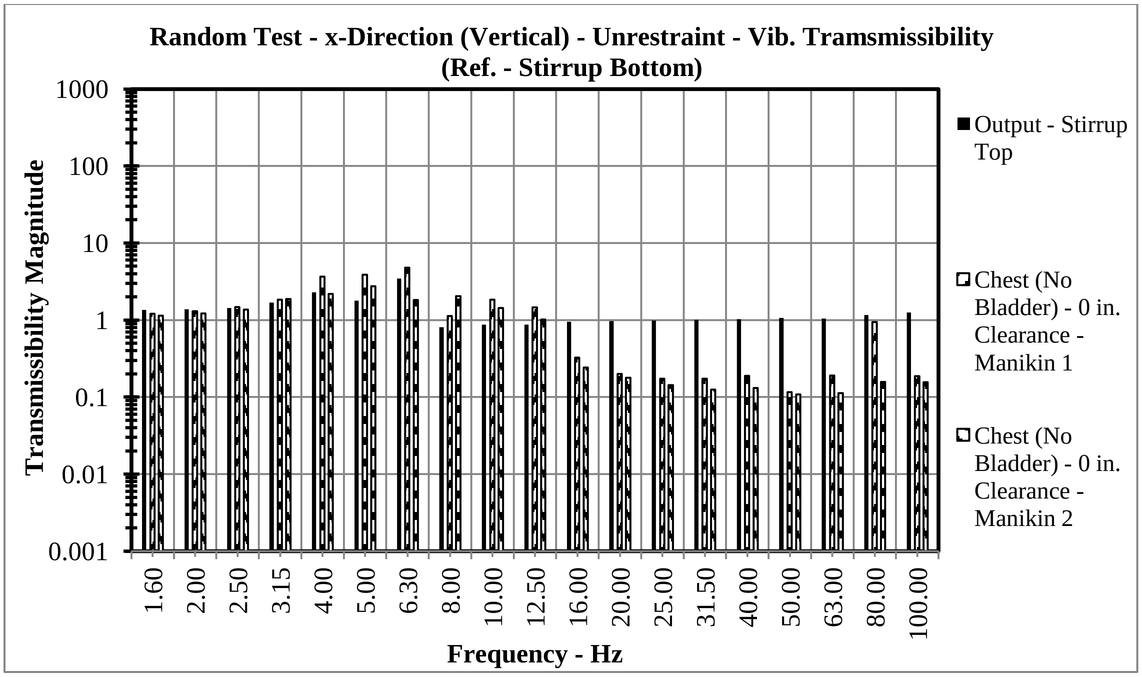

Figure F.15: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Random Test – Unrestraint with 0 in. Clearance

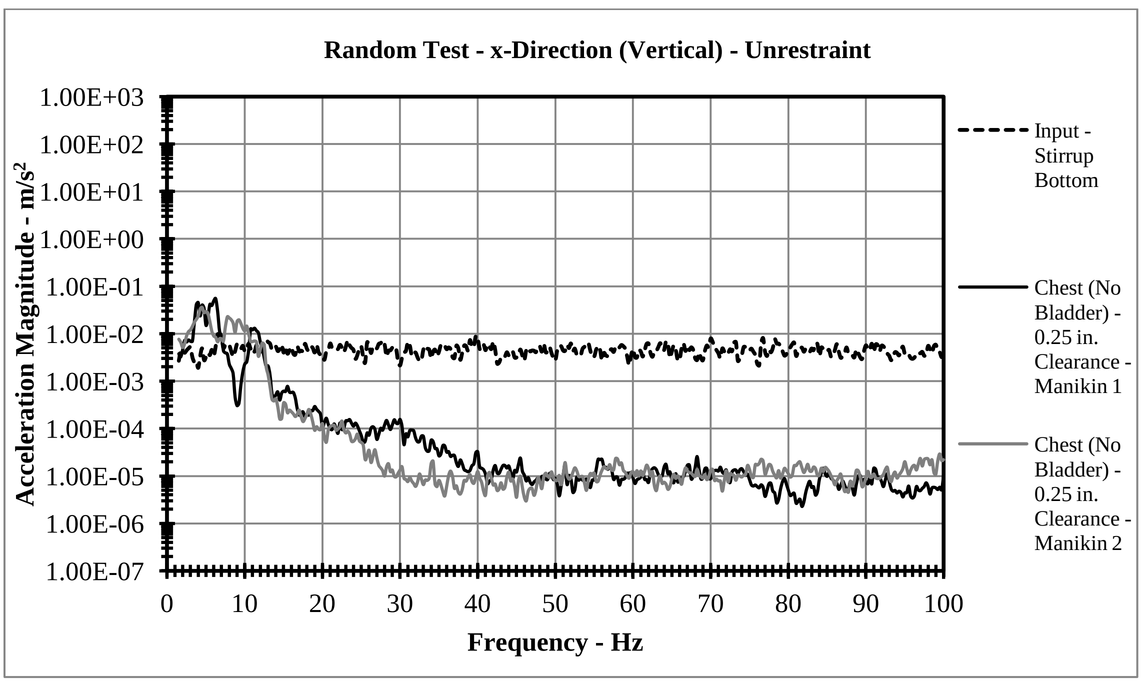

Figure F.16: Acceleration Magnitude of the Chest for the Random Test – Unrestraint with 0.25 in. Clearance

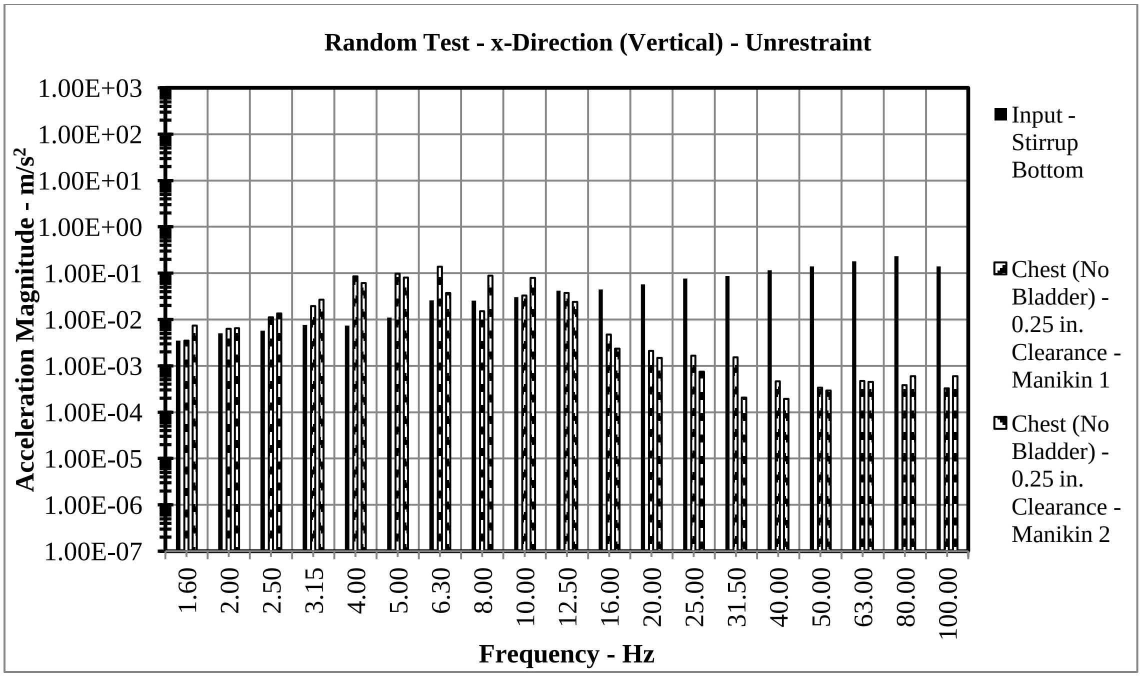

Figure F.17: 1/3 Octave Band Acceleration Magnitude of the Chest for the Random Test – Unrestraint with 0.25 in. Clearance

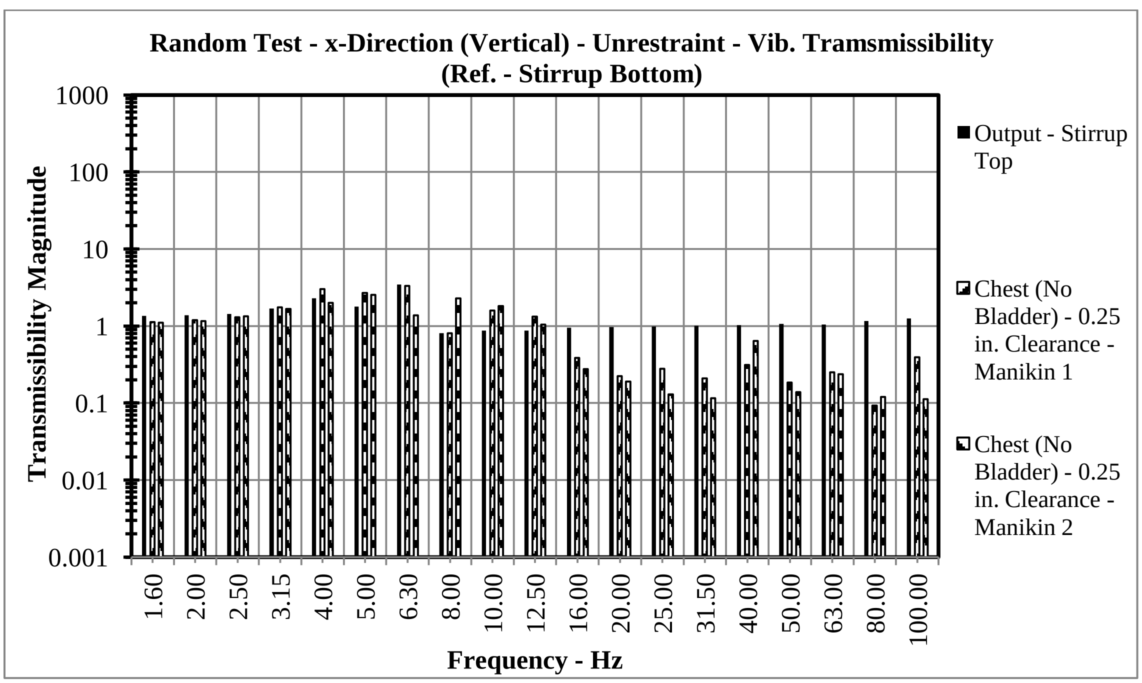

Figure F.18: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Random Test – Unrestraint with 0.25 in. Clearance

Appendix G – Random Test – 15lb$_f$. Restraint

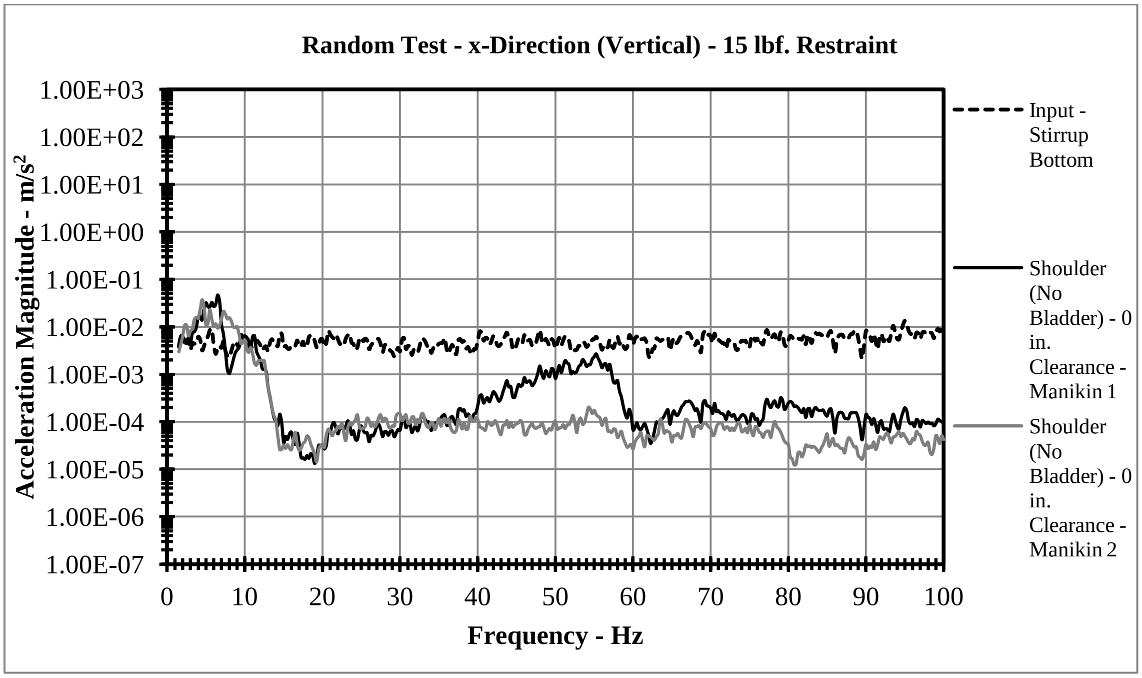

Figure G.1: Acceleration Magnitude of the Shoulders for the Random Test – 15 lbf. Restraint with 0 in. Clearance

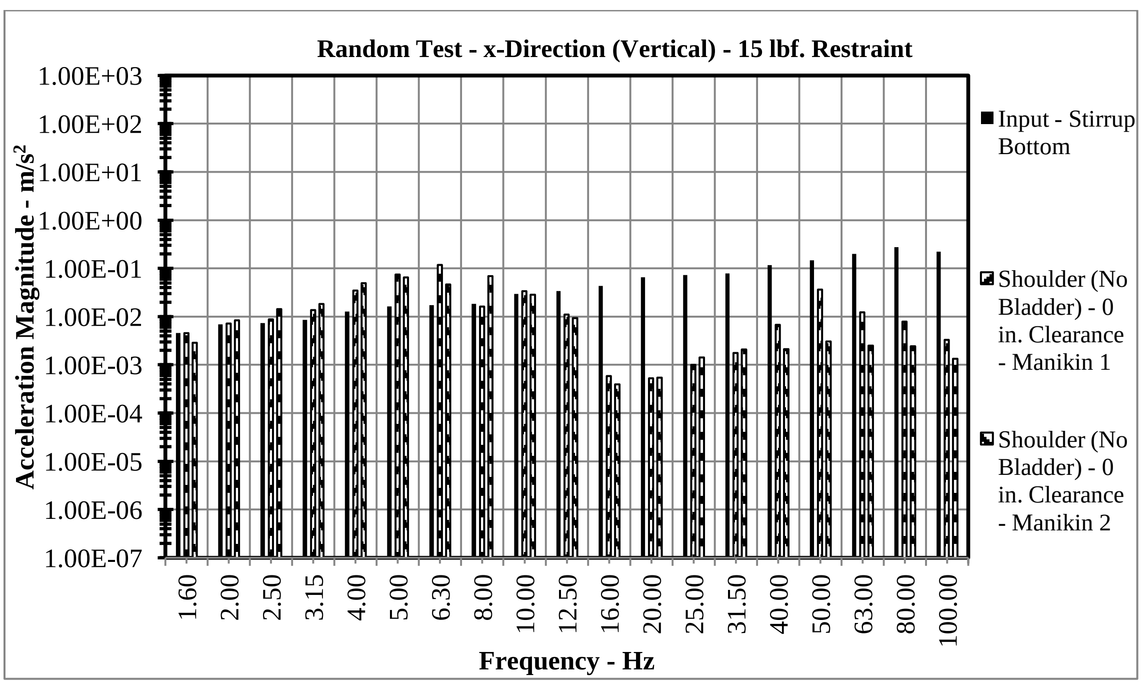

Figure G.2: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Random Test – 15 lbf. Restraint with 0 in. Clearance

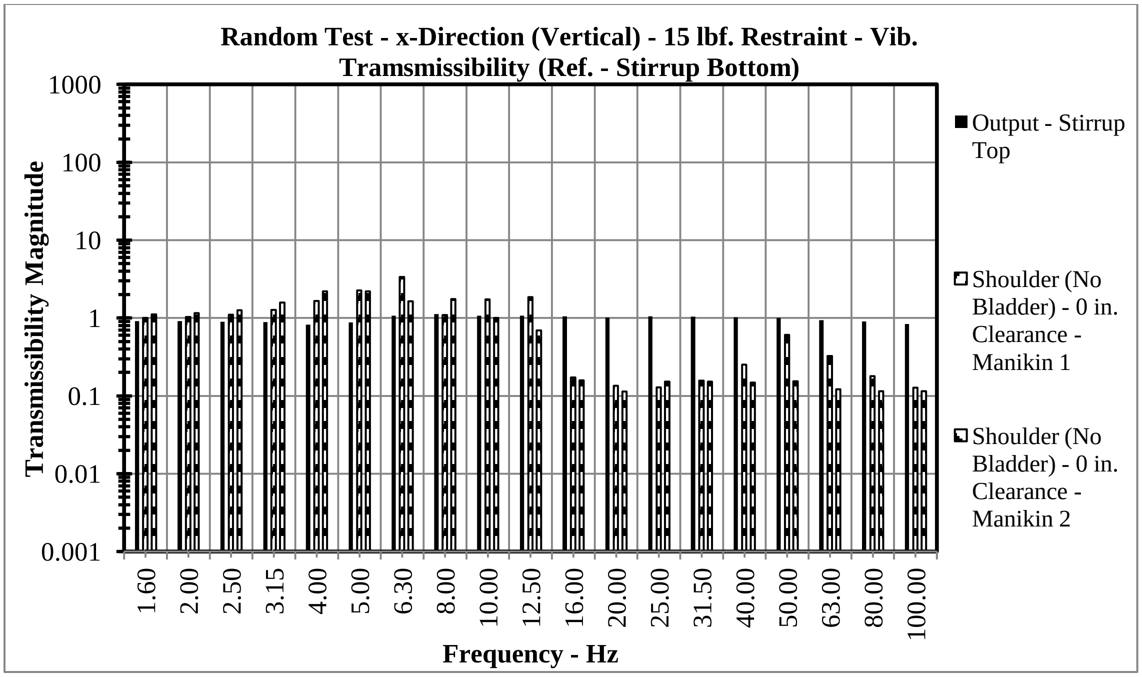

Figure G.3: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Random Test – 15 lbf. Restraint with 0 in. Clearance

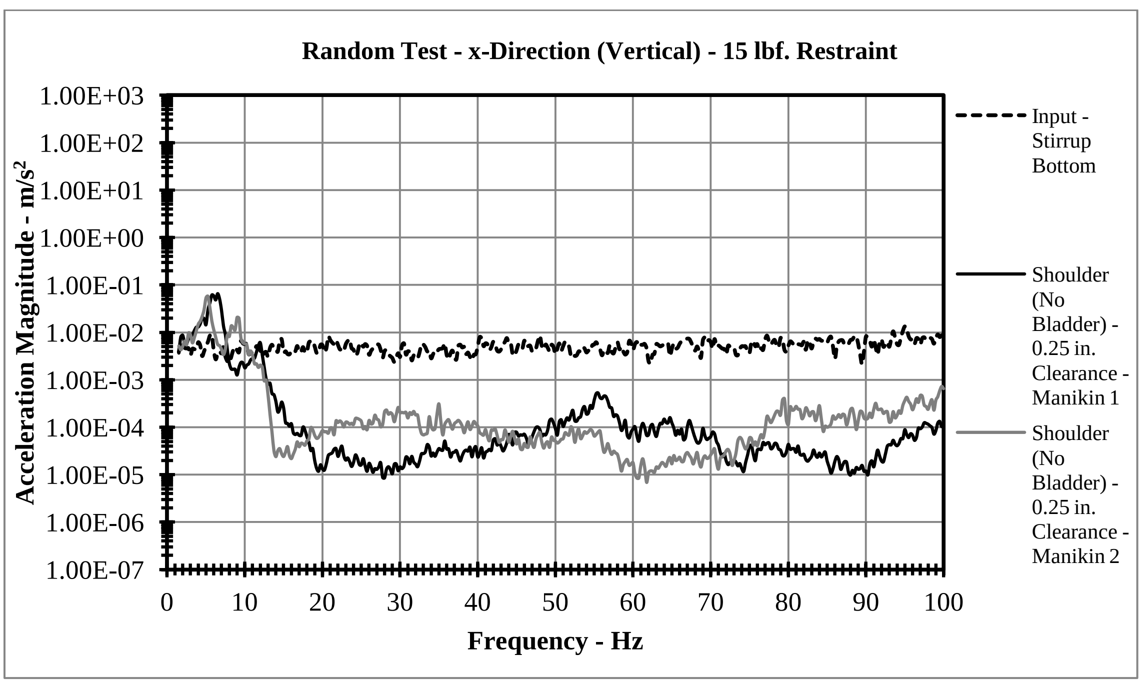

Figure G.4: Acceleration Magnitude of the Shoulders for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

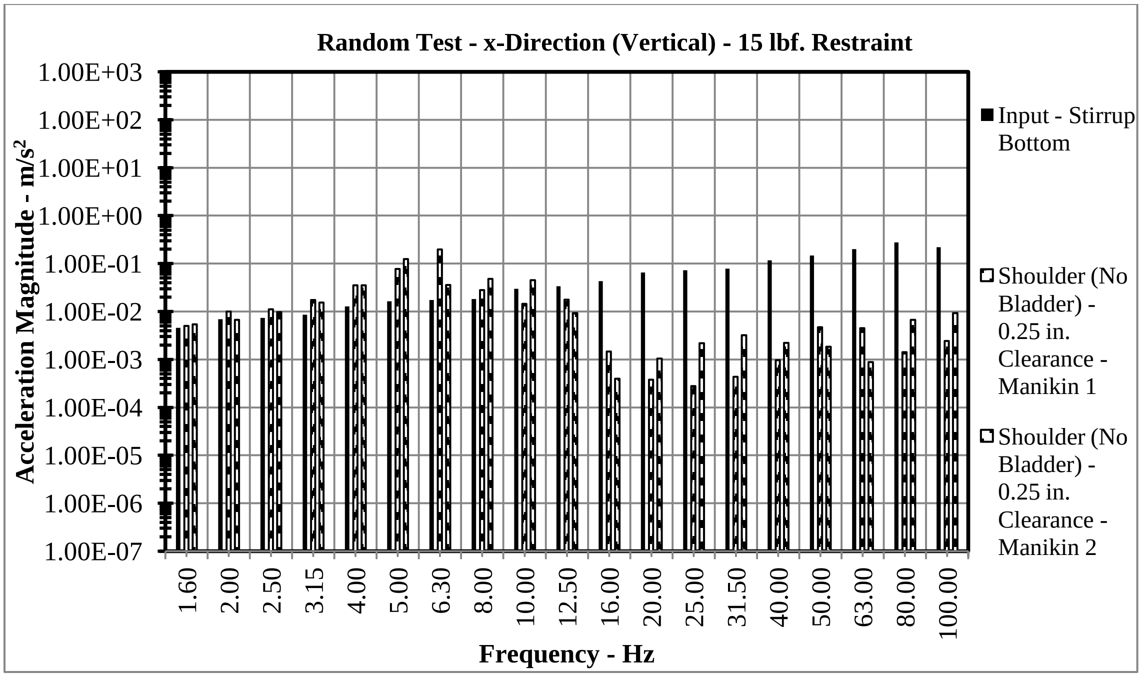

Figure G.5: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

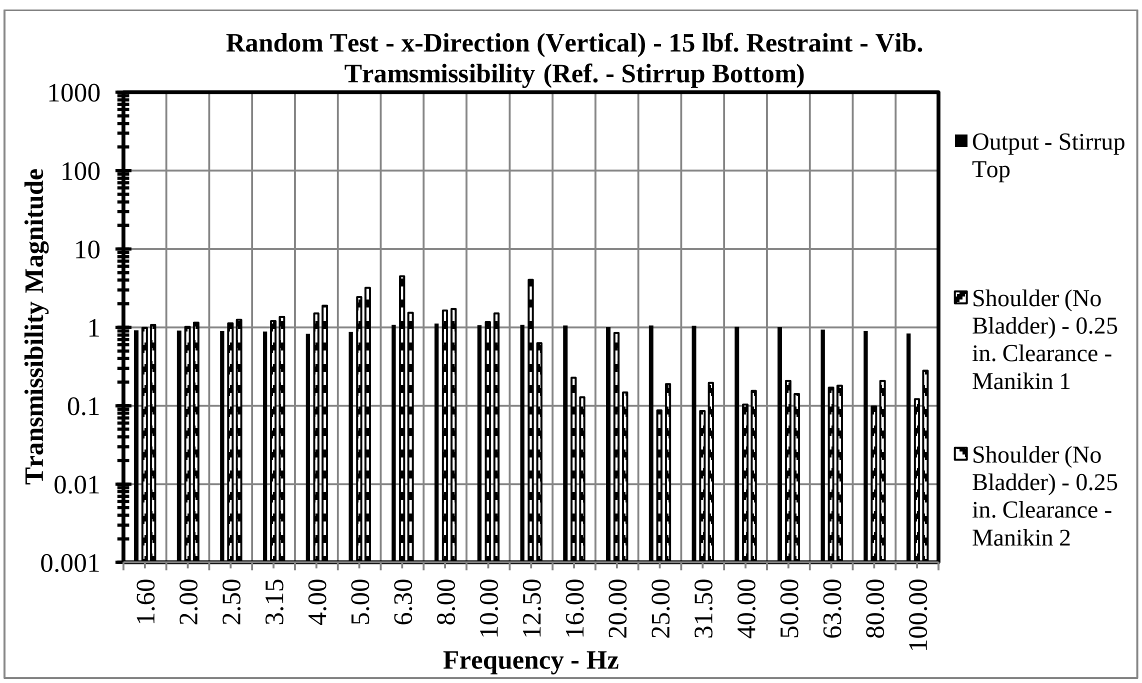

Figure G.6: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

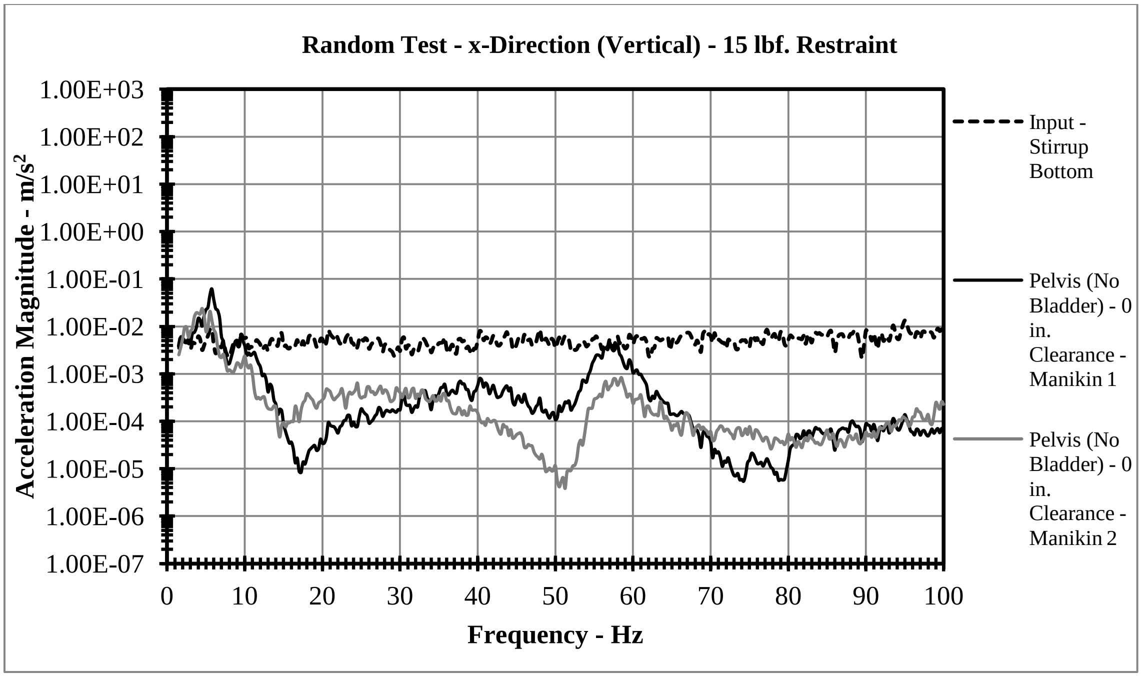

Figure G.7: Acceleration Magnitude of the Pelvis for the Random Test – 15 lbf. Restraint with 0 in. Clearance

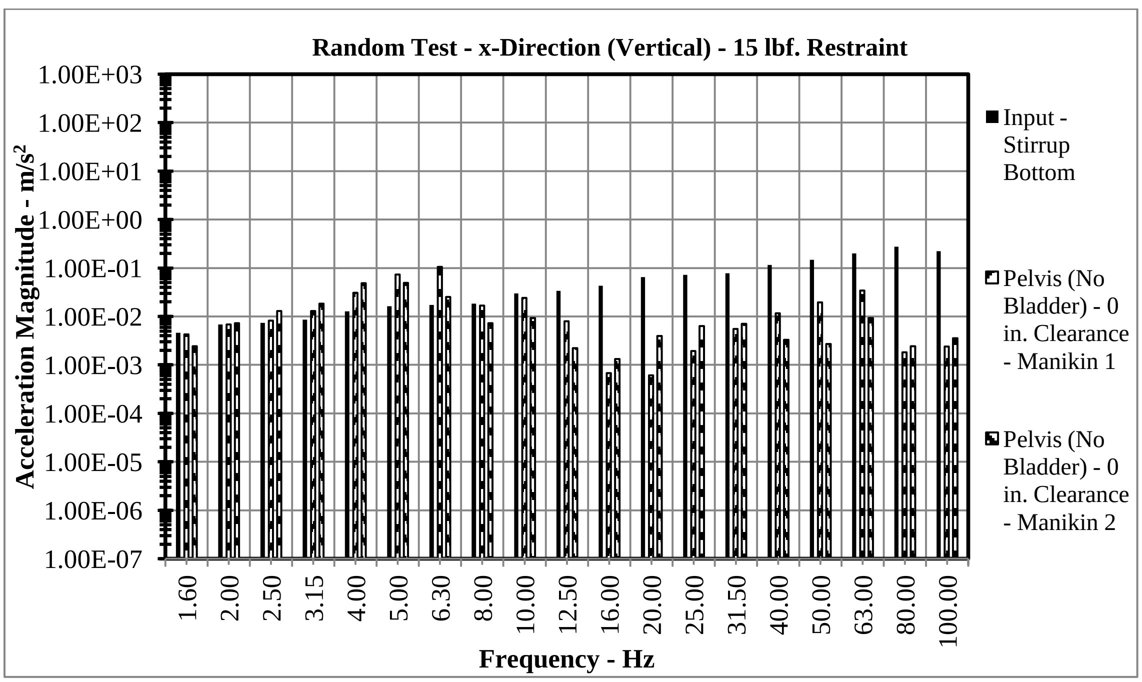

Figure G.8: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Random Test – 15 lbf. Restraint with 0 in. Clearance

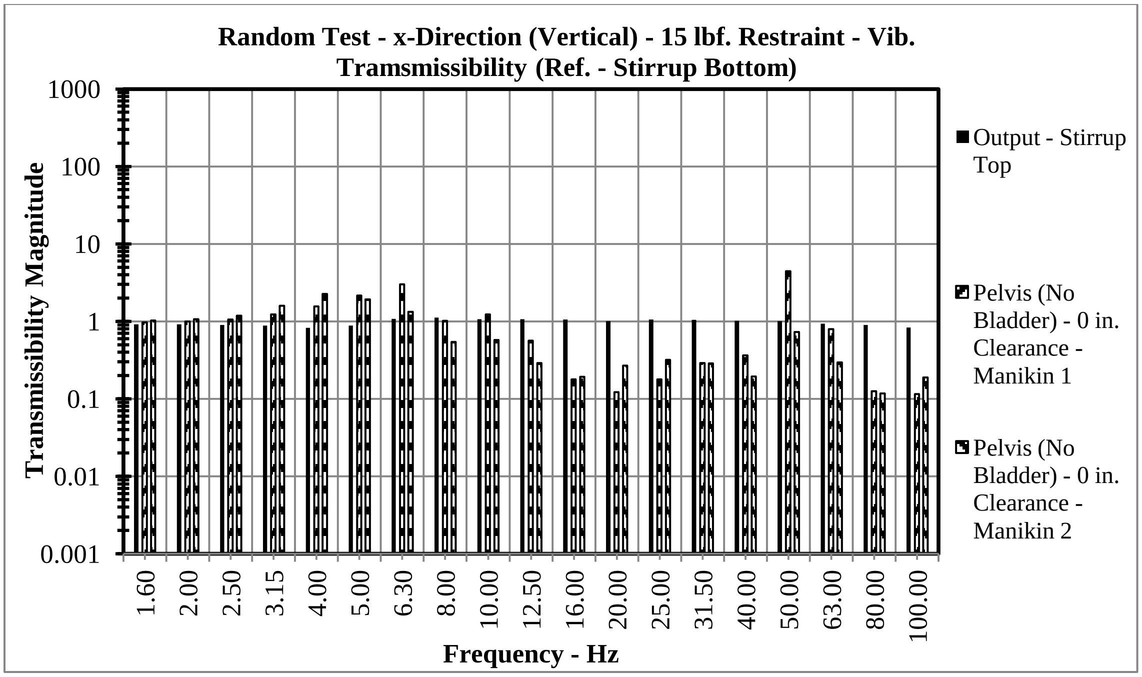

Figure G.9: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Random Test – 15 lbf. Restraint with 0 in. Clearance

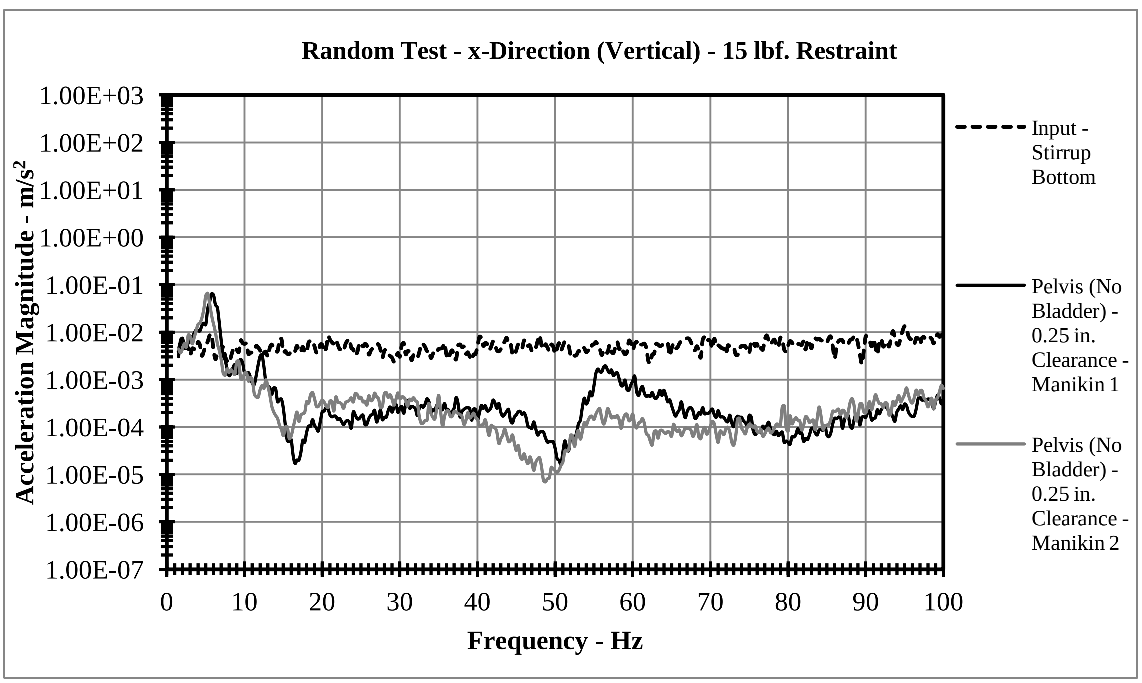

Figure G.10: Acceleration Magnitude of the Pelvis for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

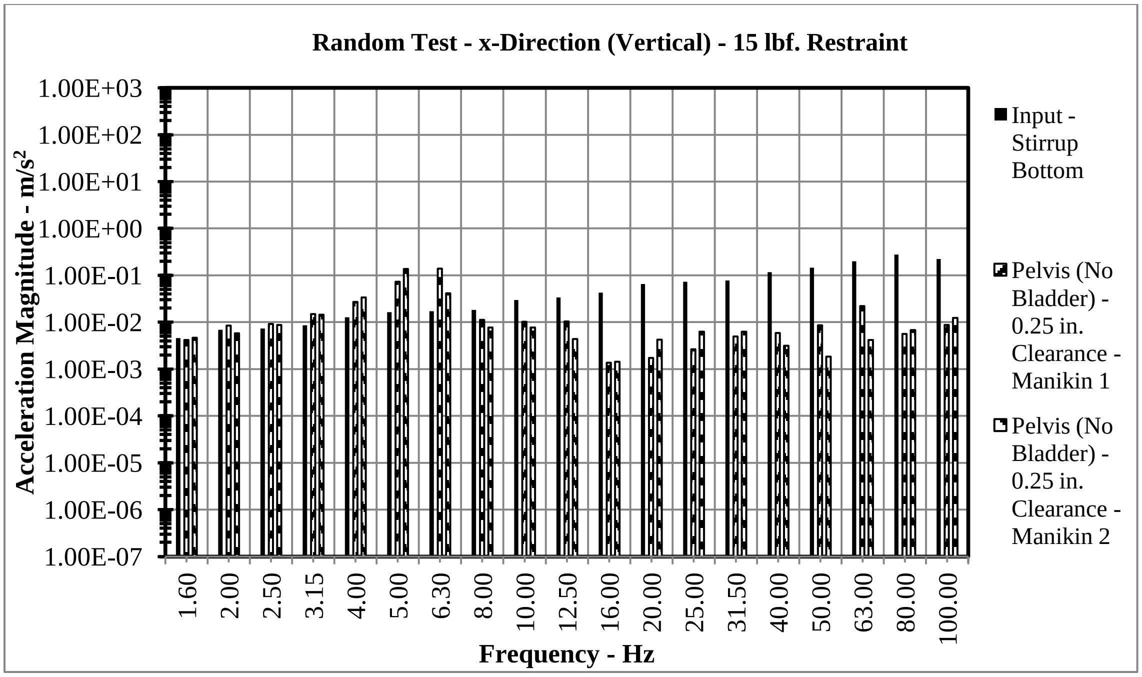

Figure G.11: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

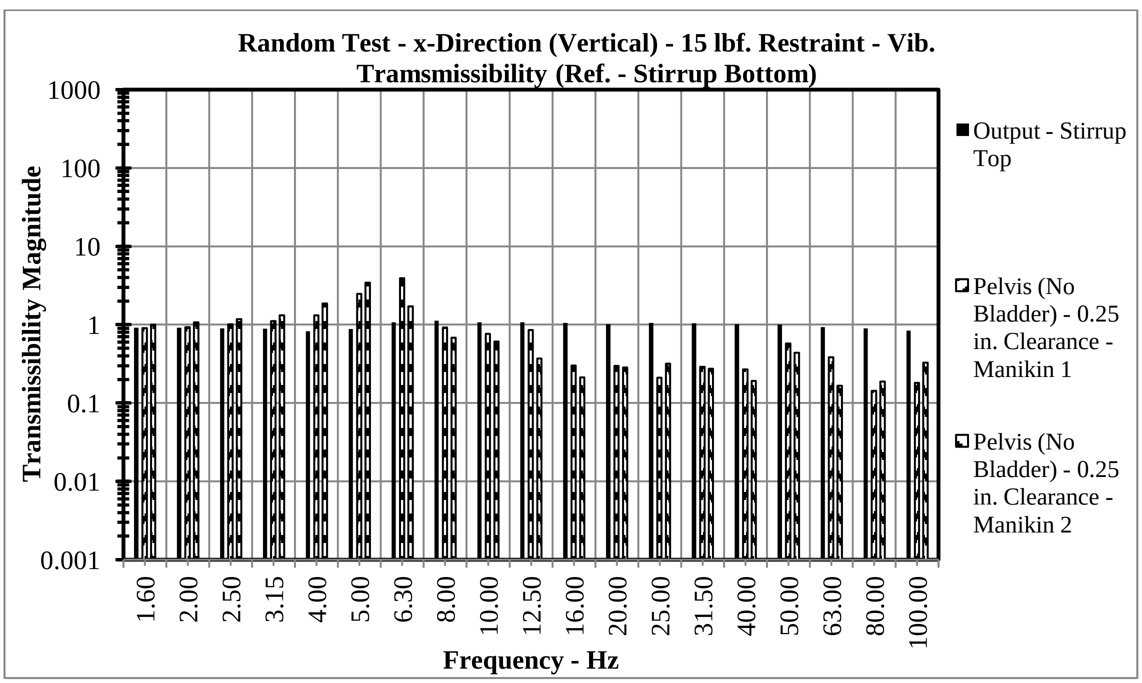

Figure G.12: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

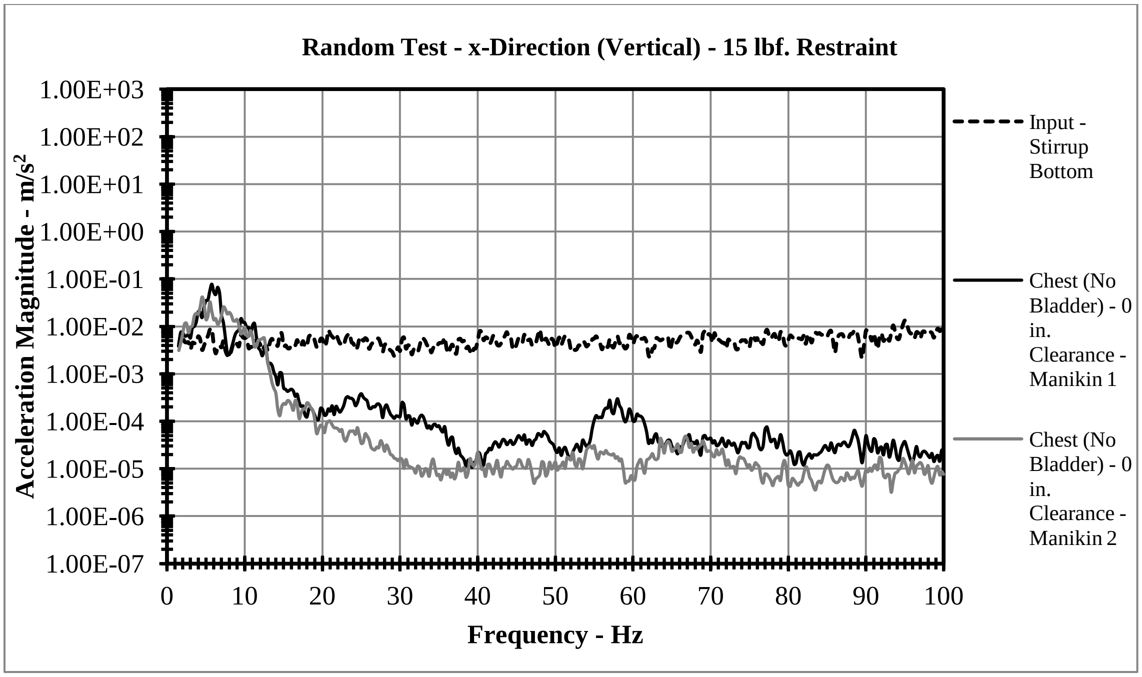

Figure G.13: Acceleration Magnitude of the Chest for the Random Test – 15 lbf. Restraint with 0 in. Clearance

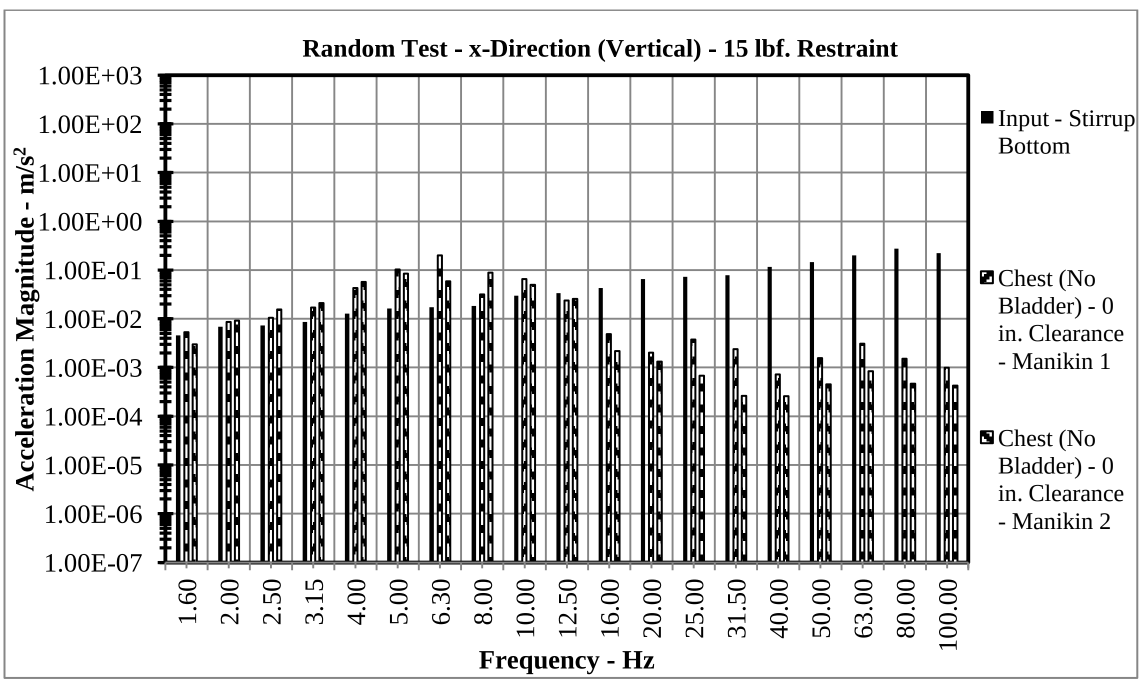

Figure G.14: 1/3 Octave Band Acceleration Magnitude of the Chest for the Random Test – 15 lbf. Restraint with 0 in. Clearance

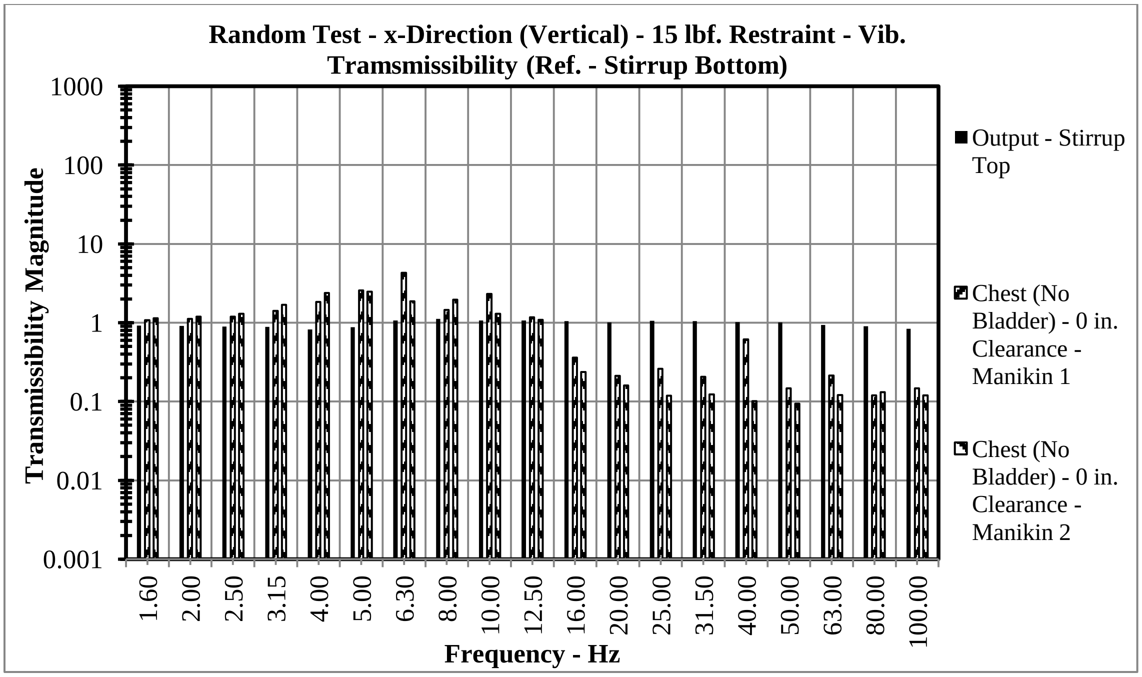

Figure G.15: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Random Test – 15 lbf. Restraint with 0 in. Clearance

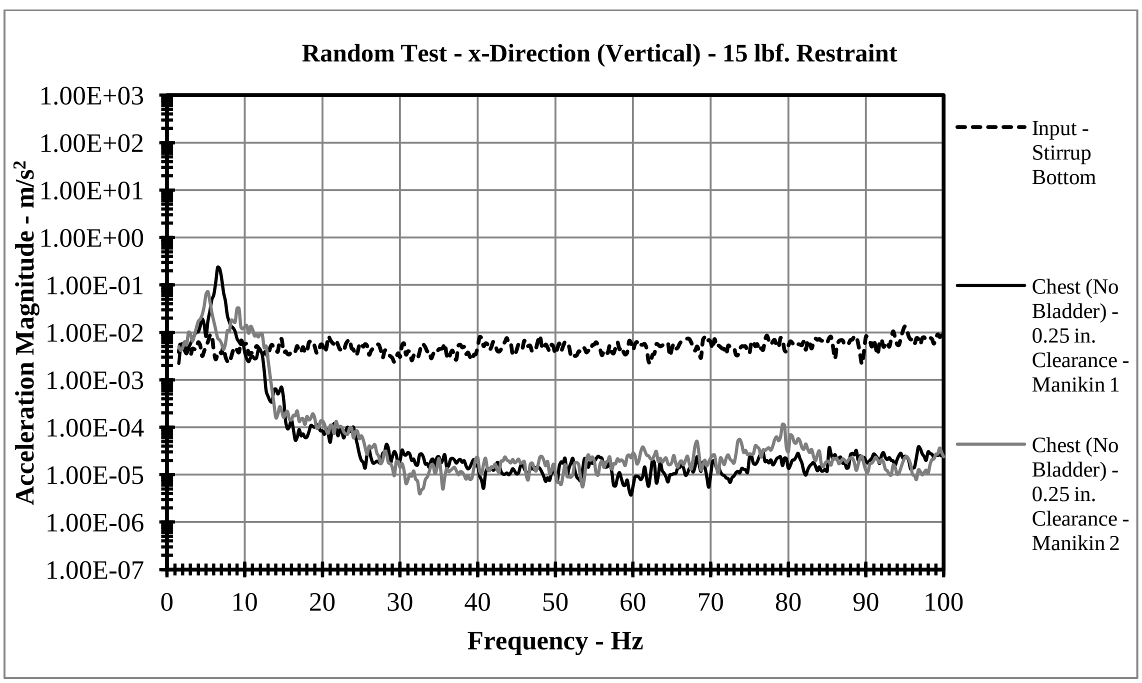

Figure G.16: Acceleration Magnitude of the Chest for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

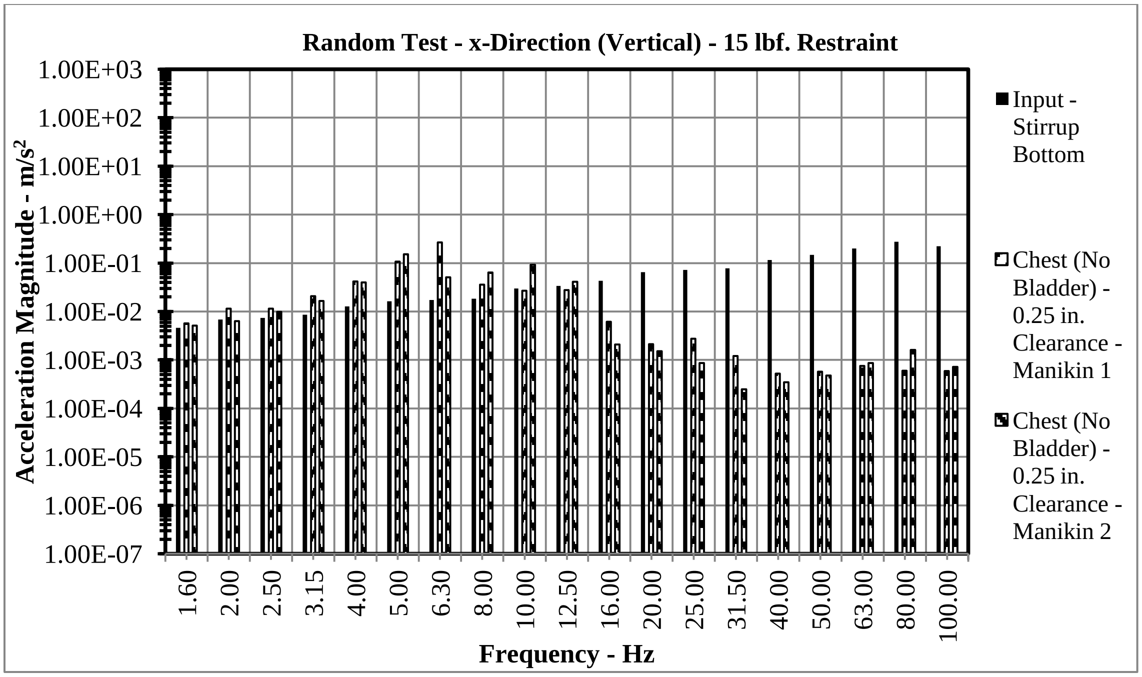

Figure G.17: 1/3 Octave Band Acceleration Magnitude of the Chest for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

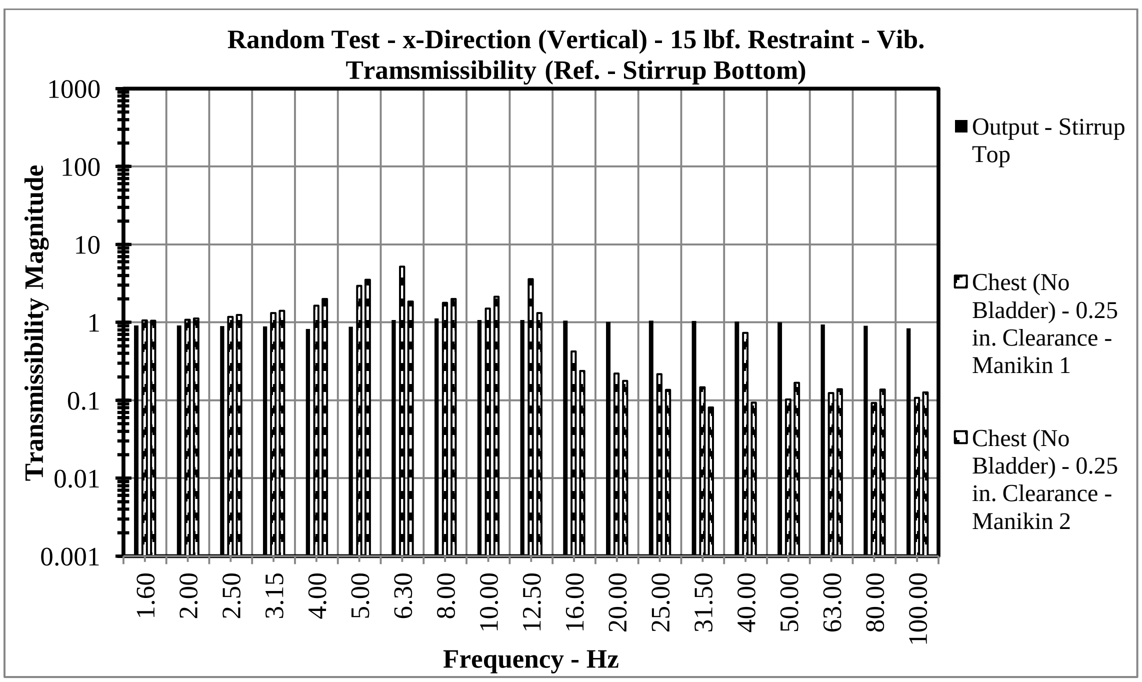

Figure G.18: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Random Test – 15 lbf. Restraint with 0.25 in. Clearance

Appendix H – Random Test – 35 lb_f. Restraint

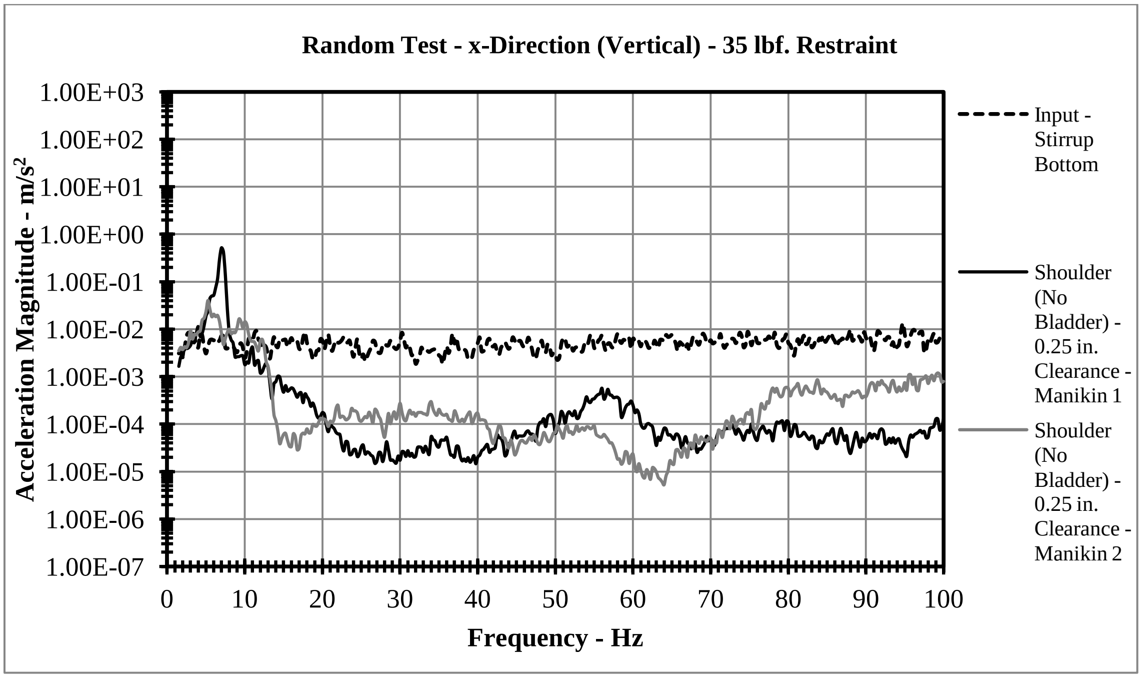

Figure H.1: Acceleration Magnitude of the Shoulders for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

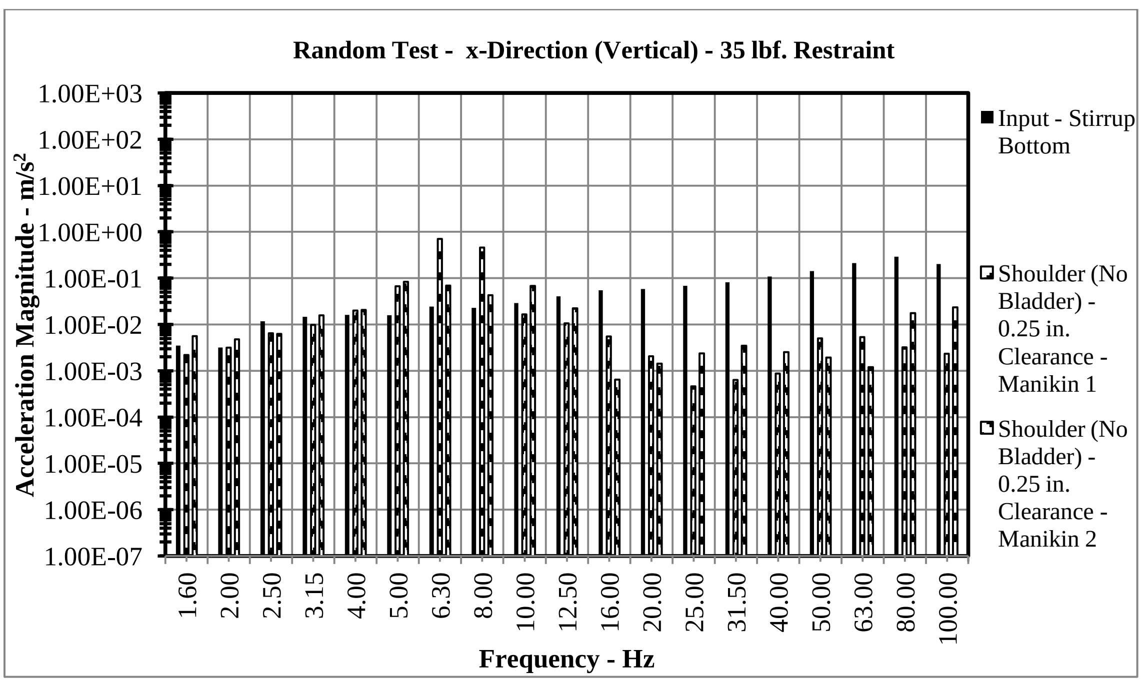

Figure H.2: 1/3 Octave Band Acceleration Magnitude of the Shoulders for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

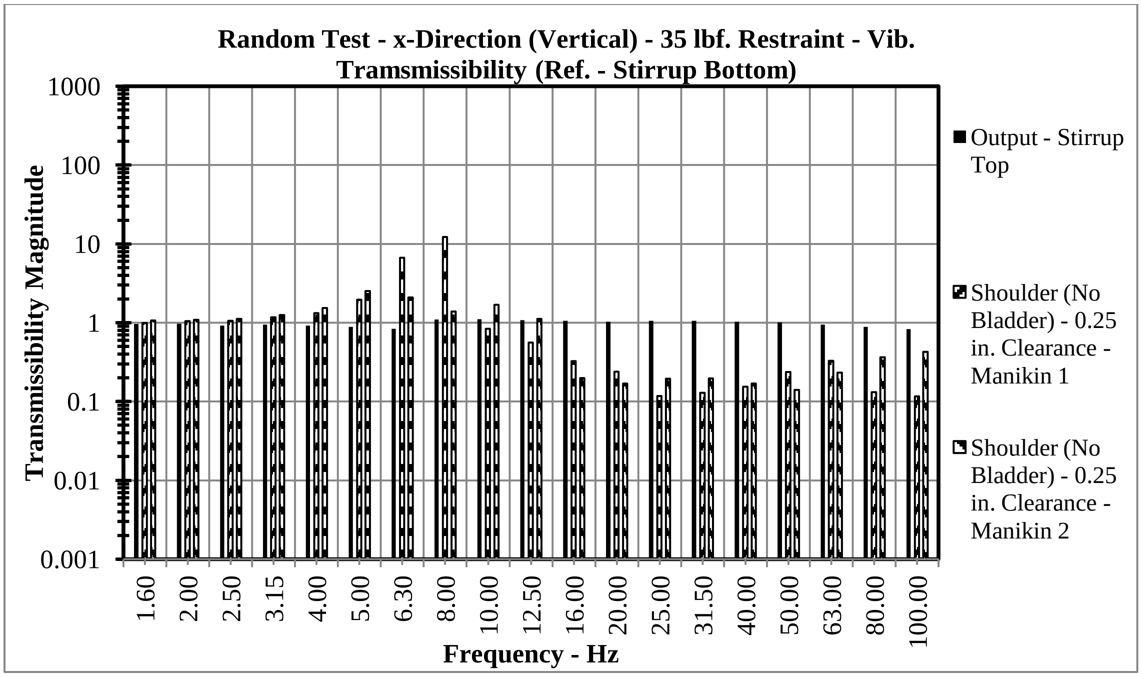

Figure H.3: 1/3 Octave Band Transmissibility Magnitude of the Shoulders for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

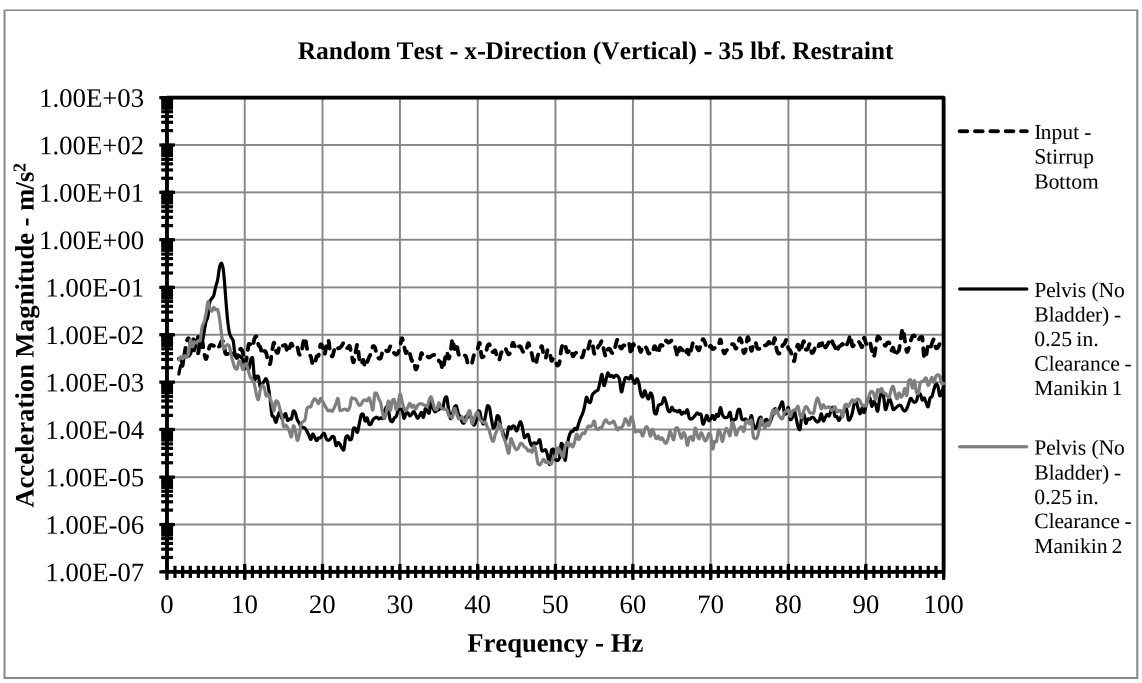

Figure H.4: Acceleration Magnitude of the Pelvis for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

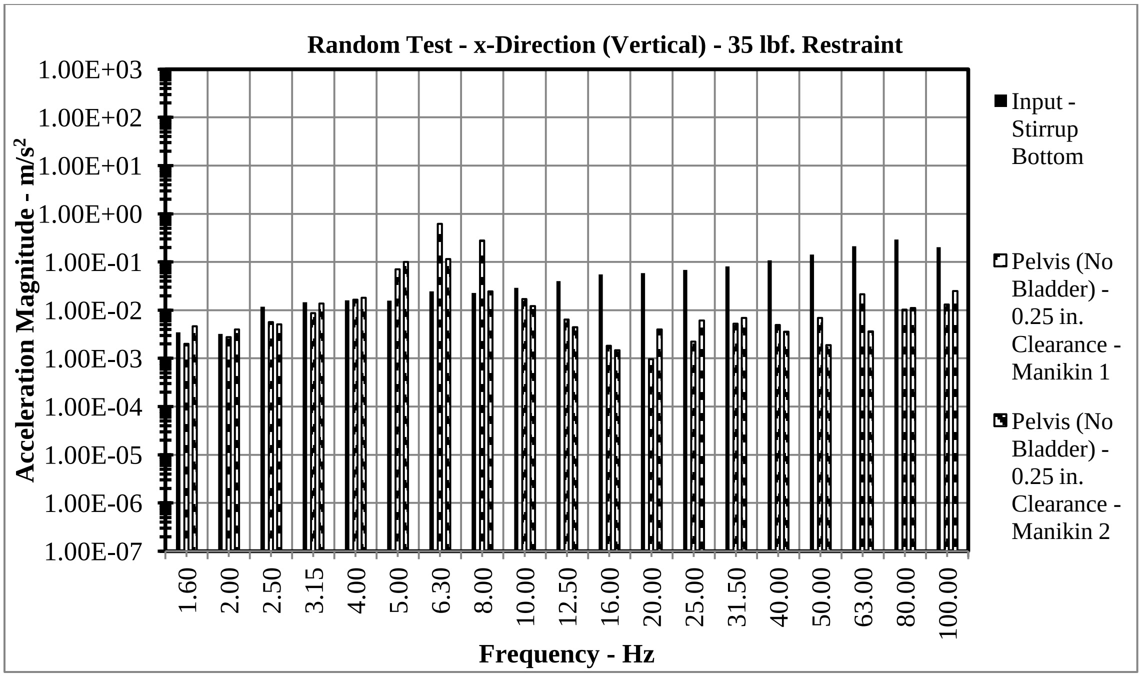

Figure H.5: 1/3 Octave Band Acceleration Magnitude of the Pelvis for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

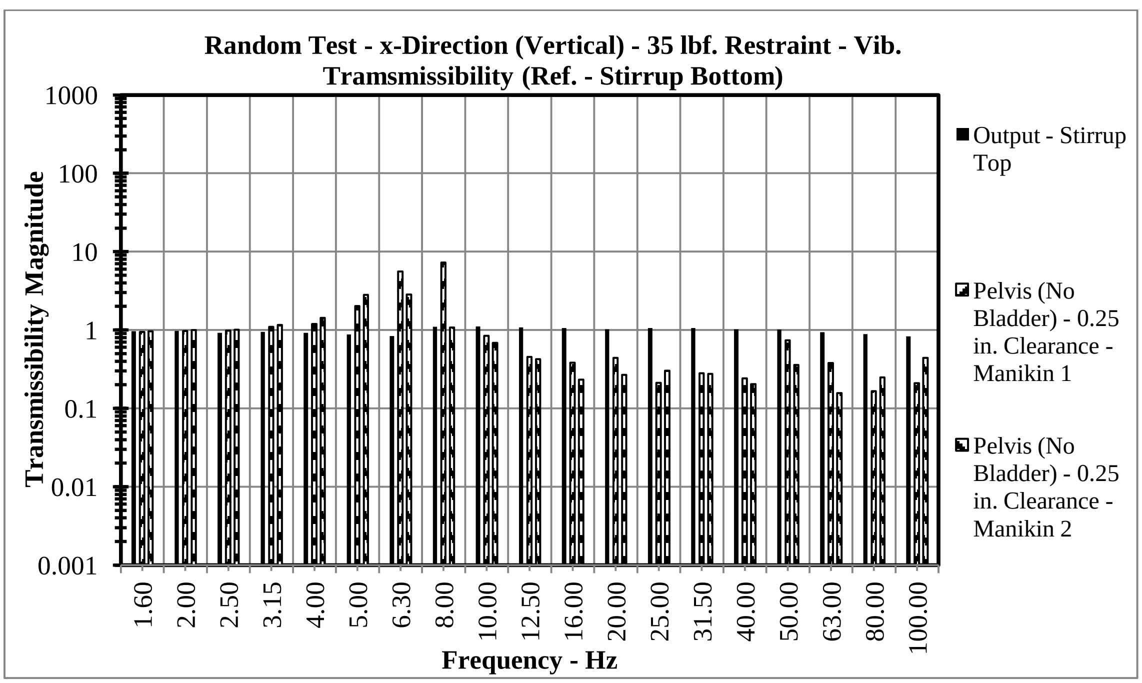

Figure H.6: 1/3 Octave Band Transmissibility Magnitude of the Pelvis for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

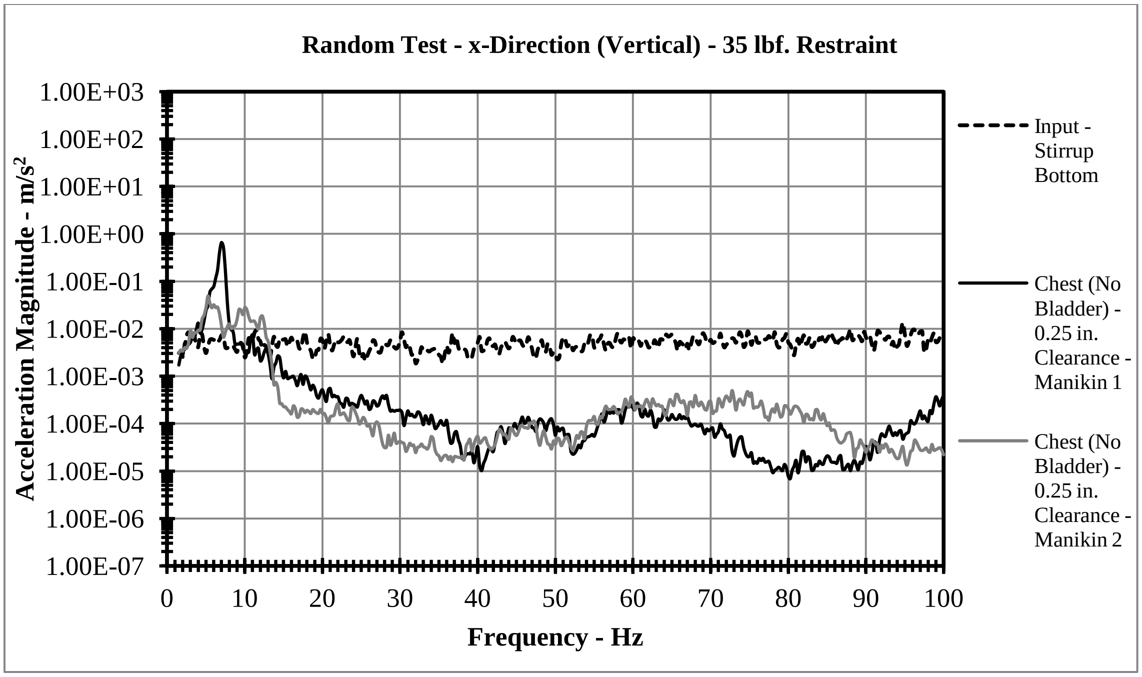

Figure H.7: Acceleration Magnitude of the Chest for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

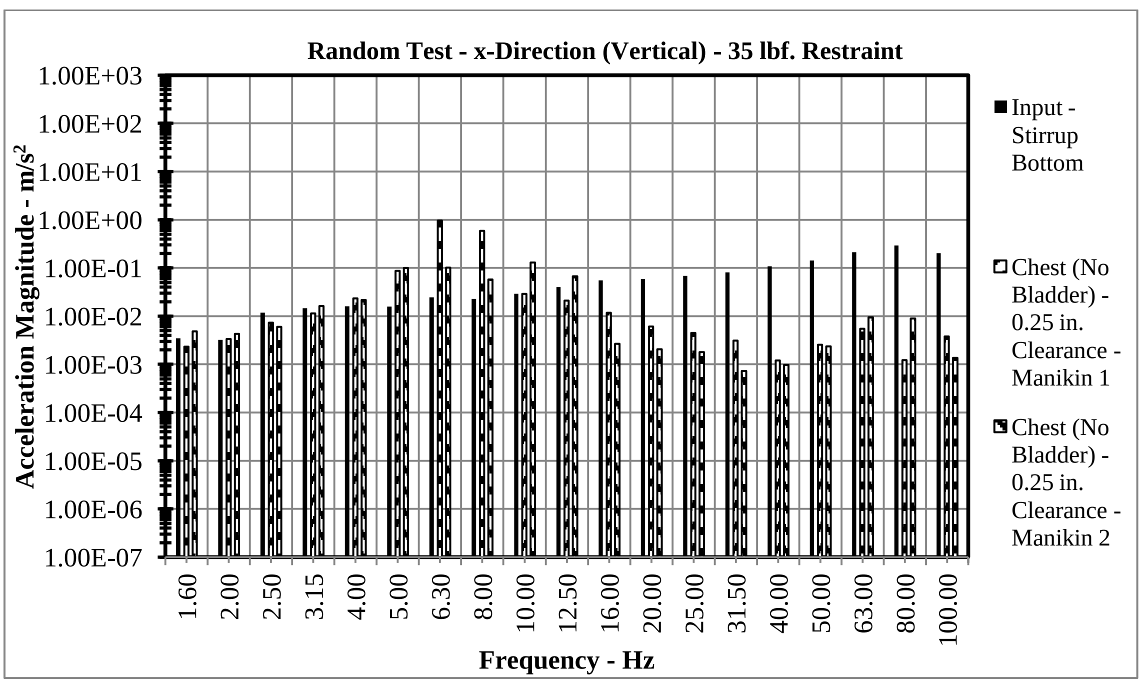

Figure H.8: 1/3 Octave Band Acceleration Magnitude of the Chest for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

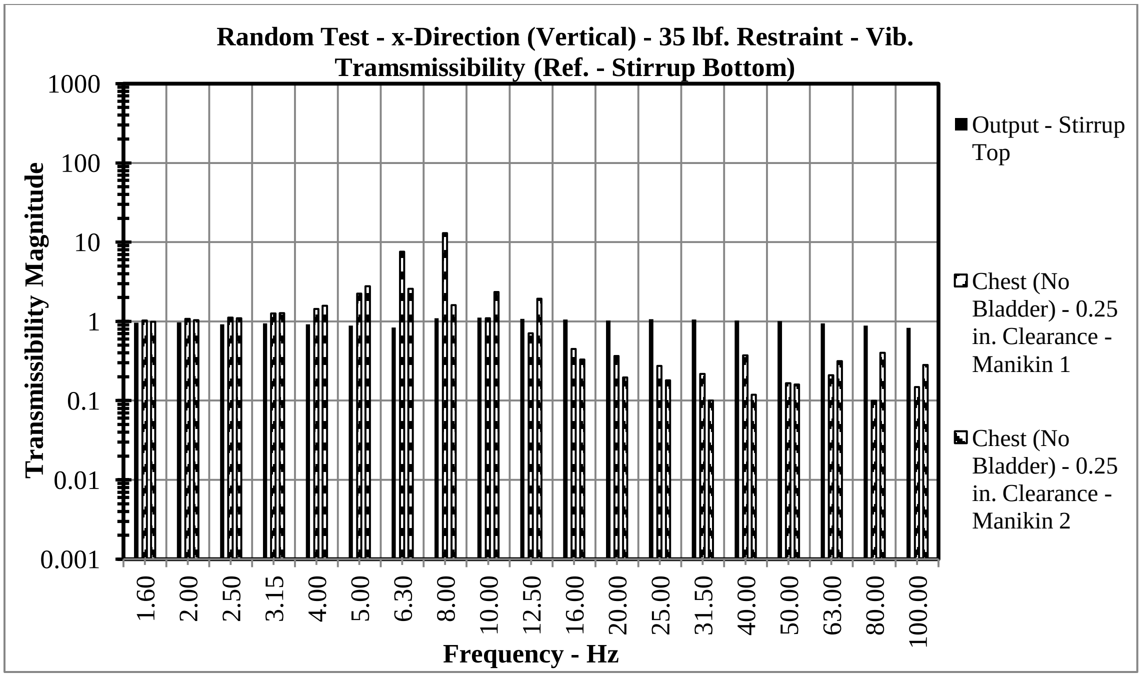

Figure H.9: 1/3 Octave Band Transmissibility Magnitude of the Chest for the Random Test – 35 lbf. Restraint with 0.25 in. Clearance

Appendix I – RSS Acceleration Values in m/s^2 for the Random Test

Table I.1: RSS Acceleration Values in m/s^2 for the Random Test at 4 Hz

Random Test - Frequency Range: 4 Hz - x-Direction (Vertical)

Test Condition	Output Shoulder (No Bladder)	Output Shoulder (Bladder)	Output Pelvis (No Bladder)	Output Pelvis (Bladder)	Output Chest (No Bladder)	Output Chest (Bladder)
Unrestraint - 0 in. Clearance Manikin 1	0.061	0.187	0.066	0.159	0.086	0.301
Unrestraint - 0 in. Clearance Manikin 2	0.027	0.227	0.035	0.229	0.034	0.298
Unrestraint - 0.25 in Clearance Manikin 1	0.066	0.198	0.083	0.185	0.086	0.298
Unrestraint - 0.25 in Clearance Manikin 2	0.053	0.227	0.052	0.223	0.061	0.167
15 lbf. Restraint - 0 in. Clearance Manikin 1	0.035	0.055	0.031	0.036	0.043	0.083
15 lbf. Restraint - 0 in. Clearance Manikin 2	0.050	0.172	0.049	0.147	0.057	0.187
15 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.035	0.088	0.027	0.081	0.042	0.088
15 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.035	0.109	0.034	0.090	0.040	0.107
35 lbf. Restraint - 0 in. Clearance Manikin 1	0.028	0.023	0.022	0.016	0.031	0.025
35 lbf. Restraint - 0 in. Clearance Manikin 2	0.034	0.051	0.032	0.039	0.039	0.043
35 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.020	0.028	0.016	0.021	0.024	0.023
35 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.021	0.048	0.018	0.040	0.022	0.040

Table I.2: RSS Acceleration Values in m/s^2 for the Random Test between 12.5 Hz and 40 Hz

Random Test - Frequency Range: 12.5 Hz-40 Hz - x-Direction (Vertical)						
Test Condition	**Output Shoulder (No Bladder)**	**Output Shoulder (Bladder)**	**Output Pelvis (No Bladder)**	**Output Pelvis (Bladder)**	**Output Chest (No Bladder)**	**Output Chest (Bladder)**
Unrestraint - 0 in. Clearance Manikin 1	0.023	0.004	0.010	0.003	0.027	0.007
Unrestraint - 0 in. Clearance Manikin 2	0.010	0.005	0.011	0.002	0.023	0.006
Unrestraint - 0.25 in Clearance Manikin 1	0.022	0.005	0.014	0.004	0.038	0.008
Unrestraint - 0.25 in Clearance Manikin 2	0.007	0.004	0.013	0.003	0.024	0.006
15 lbf. Restraint - 0 in. Clearance Manikin 1	0.013	0.005	0.015	0.010	0.025	0.006
15 lbf. Restraint - 0 in. Clearance Manikin 2	0.010	0.005	0.011	0.003	0.026	0.006
15 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.018	0.005	0.013	0.006	0.028	0.005
15 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.010	0.005	0.011	0.003	0.041	0.007
35 lbf. Restraint - 0 in. Clearance Manikin 1	0.015	0.011	0.032	0.024	0.038	0.027
35 lbf. Restraint - 0 in. Clearance Manikin 2	0.036	0.008	0.011	0.006	0.081	0.014
35 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.012	0.005	0.010	0.013	0.025	0.013
35 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.023	0.007	0.012	0.005	0.067	0.015

Table I.3: RSS Acceleration Values in m/s^2 for the Random Test between 50 Hz and 100 Hz

Random Test - Frequency Range: 50 Hz-100 Hz - x-Direction (Vertical)

Test Condition	Output Shoulder (No Bladder)	Output Shoulder (Bladder)	Output Pelvis (No Bladder)	Output Pelvis (Bladder)	Output Chest (No Bladder)	Output Chest (Bladder)
Unrestraint - 0 in. Clearance Manikin 1	0.020	0.020	0.018	0.011	0.003	0.001
Unrestraint - 0 in. Clearance Manikin 2	0.004	0.002	0.013	0.005	0.001	0.001
Unrestraint - 0.25 in Clearance Manikin 1	0.007	0.002	0.008	0.004	0.001	0.001
Unrestraint - 0.25 in Clearance Manikin 2	0.015	0.002	0.012	0.004	0.001	0.001
15 lbf. Restraint - 0 in. Clearance Manikin 1	0.040	0.009	0.039	0.015	0.004	0.007
15 lbf. Restraint - 0 in. Clearance Manikin 2	0.005	0.001	0.011	0.003	0.001	0.001
15 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.007	0.011	0.026	0.008	0.001	0.008
15 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.012	0.002	0.015	0.003	0.002	0.002
35 lbf. Restraint - 0 in. Clearance Manikin 1	0.016	0.003	0.038	0.020	0.024	0.128
35 lbf. Restraint - 0 in. Clearance Manikin 2	0.005	0.001	0.010	0.002	0.005	0.003
35 lbf. Restraint - 0.25 in. Clearance Manikin 1	0.008	0.003	0.028	0.015	0.007	0.017
35 lbf. Restraint - 0.25 in. Clearance Manikin 2	0.030	0.001	0.027	0.001	0.013	0.010

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CURRICULUM VITAE

Karina K Saenz Acosta

EDUCATION

University of Nevada, Las Vegas
M.S., Mechanical Engineering, Anticipated Fall 2015
Advisor: Dr. Douglas Reynolds

University of Nevada, Las Vegas
B.S., Mechanical Engineering, May 2012

College of Southern Nevada
Associate of Science Degree with Honors, December 2009
Associate of General Studies Degree with Honors, December 2009

ACADEMIC ENGINEERING PROJECTS

EmeraChem Muffler Model EC-2150-C-XX, December 2013
University of Nevada, Las Vegas

- Determined the sound attenuation of Catalytic Reactor Housing and Silencer using Brüel & Kjær's Acoustic Analyzer

Phase Change Material (PCM) Enhanced Turn-Out Coat, May 2012
University of Nevada, Las Vegas

- Worked as a part of a team to develop a model which incorporated a phase change material layer in an fireman's turn-out coat

WORK EXPERIENCE

8/2013-7/2015 — Research Assistant, (during M.S. program), UNLV

- Perform vibration tests to evaluate the effectiveness of air bladder technology in reducing patient exposure to whole body shock and vibration during medical transport

6/2004-12/2013 — Front Desk Agent, Fairfield Inn & Suites by Marriott, Las Vegas, NV

- Greeted, registered, and assigned rooms to guests
- Verified customers' credit, and established how the customer will pay for the accommodation

- Kept records of room availability and guests' accounts, manually or using computers
- Computed bills, collected payments, and made change for guests
- Performed simple bookkeeping activities, such as balancing cash accounts
- Reviewed accounts and charges with guests during the check-out process
- Posted charges, such as those for rooms, food, or telephone calls, to ledgers manually or by using computers
- Transmitted and received messages, using telephones or telephones switchboards. Contacted housekeeping and maintenance staff when guests report problems

SKILLS

- Proficient in Brüel & Kjær's PULSE®, MATLAB®, Marriott's Fosse system, Microsoft Office ®, Pro Engineer, SolidWorks®
- Fluent in Spanish
- Excellent customer service skills and strong interpersonal skills to deal effectively with people

AWARDS

- Student of the Year, Howard R. Hughes College of Engineering, UNLV, 2012
- Dean's List 2012

PROFESSIONAL AFFILIATIONS

- Phi Theta Kappa
- Golden Key International Honour Society
- Tau Beta Pi