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Defensive Surface Roadway Vibration Dampening Inertia Wave

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Defensive Surface Roadway Vibration Dampening Inertia Wave

by

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Abstract

The goal of this project is to investigate the amplitude, energy, and frequency of vibrations in the typical ambulance and the effects of these vibrations on the quality, comfort, and efficiency of care. Working with current Emergency Medical Technicians, and studying past research work on vibrations and ambulance care, this project developed an overview of implications related to vibrations during transport. The team proposed a means to diminish the transfer of road vibrations into the ambulance.

Authorship

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Chapter 1	JK	SC, GW, DS
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Chapter 2.1	SC	
Chapter 2.1.1	DS	SC
Chapter 2.1.2	JK	SC
Chapter 2.1.3	SC	
Chapter 2.1.4	GW	DS
Chapter 2.2	SC	GW
Chapter 2.2.1	JK, SC	DS
Chapter 2.2.2	GW	
Chapter 2.2.3	DS	GW
Chapter 2.3	SC	DS
Chapter 2.3.1	SC, JK	GW
Chapter 2.3.2	DS	GW
Chapter 2.4	SC	GW
Chapter 2.4.1	GW	
Chapter 2.4.2	DS	
Chapter 2.4.3	SC	
Chapter 3	SC	
Chapter 3.1	JK	
Chapter 3.1.1	JK	
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Chapter 3.1.3	JK	
Chapter 3.2	DS	SC, JK
Chapter 3.3	SC	
Chapter 3.3.1	SC	
Chapter 3.3.2	SC	
Chapter 3.3.3	SC	
Chapter 3.3.4	SC	
Chapter 3.4	JK	
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Chapter 4	GW	DS

All portions of this project were read and reviewed equally by all team members.

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CHAPTER 1. EMS AND LIFE SAVING PRACTICES

1. Introduction

Vibrations cause problems in the ambulance, and make Emergency Medical Technicians' (EMT) jobs more difficult. The EMT profession already consists of day-to-day tasks and decisions that leave a patient's life balanced precipitously in the EMT's hands. The majority of these tasks become increasingly difficult when the ambulance is in motion. Vibrations in a moving vehicle have the potential to disrupt even the simplest tasks. The motivation of this project is to provide a means for 1) patients to receive the best care possible, 2) to suppress vibrations so as to increase the comfort of the patients and EMTs, and 3) keep transport time to a minimum. Through the application of technology and engineering the project proposes efficient and effective means of suppressing vibration.

The objective of the project is to investigate how the vibration in the ambulance impacts the quality of patient and EMT comfort as well as the treatment the patient receives. The group also investigated how the vibrations in the ambulance impact the IV delivery, blood pressure measurement, and medical diagnosis. Reducing the vibrations results in patients receiving better care, easier patient treatment by EMT, and more comfortable ambulance ride. Through the conclusion of this project, the team encountered various constraints such as: be set to a specific time line ending at the completion of D-term 2012, make the EMT's job less challenging, not cause lawsuits, be easy to implement inside of the ambulance, and be affordable for every user. The benefits from the completion of this project are patients receiving better care, EMT performing their jobs more efficiently, patients experiencing a more comfortable ambulance ride, and ambulance transporting time will shorten. As well as causing disruption to patient care and medical diagnosis, vibration is a significant source of discomfort for both the sick patient and the working Emergency Medical Technician. The primary goal of this project was to lessen the vibration's effects on the riders of the ambulance. Technology that the group examined was current methods for reducing vibrations in ambulances. This includes aspects of the vehicle chassis designed to diminish vibrations as well as other equipment that abate vibrations. The group reviewed road vibrations in ambulances and other vehicles and analyzed the collected data. Furthermore, the group researched on mechanisms how the vibrations are dealt with in other vehicles and determine if these designs could be implemented in the ambulance. The internal social transformation or impact of the project was to save lives and improve the comfort of patients and the men and women providing care. The physical knowledge transformation was the application of basic mechanical and physical concepts obtained from courses at WPI. The team has applied knowledge gained from past courses relating to mechanics and vibrations to resolve this issue. The external social transformation was to investigate the vibrations in the ambulance and how they impact comfort and the effectiveness of ambulance equipment.

The literature review, or Chapter 2, consists of all pertinent background research. Specifically the project team has discussed a number of areas. First, the project has focused on the practices of EMTs in ambulances. Vibrations due to roadway conditions is the following topic. The next focus is on the care affected by vibrations within the ambulance. Some topics that are discussed are vital signs, intravenous therapy, Electrocardiograph and defibrillation, and Cardiovascular Pulmonary Resuscitation. Lastly, the team has investigated the effect of vibrations on patient and EMT comfort. Chapter 3 contains the methodology, data collection and analysis from roadway surface tests, as well as the proposed solutions to dampen or suppress these vibrations.

CHAPTER 2. EMS AND PATIENT-CENTRIC QUALITY CARE

2 Introduction

This chapter presents all pertinent background information to this study. To begin developing a solution to vibrations in the ambulance, a basic knowledge of several subjects must be obtained. The first part of this chapter describes the day to day job of the EMT, beginning with the history of the profession, progressing through an EMT's duties and ending with the average day of an EMT. Next, the paper discusses the vibrations felt in the ambulance as detailed in several studies. These studies looked at the impact of speed and road condition on the amplitude of cabin vibrations. The paper then moves on to the specific cares provided by ambulance EMTs that are affected by vibrations. A basic understanding of the purposes and methods for each care is given followed by the effects of the ambulance's movement. Lastly, this chapter considers how vibrations qualitatively affect the comfort of individuals in the ambulance. The section discusses both the long term affects on the EMT and the effects on the patient.

2.1 Scope of Practice

In this Chapter the team has discussed the Scope of Practice of an EMT. In the History of the EMS profession a brief history of an EMT's job, the different early ambulance types, and early regulations are discussed. The Scope of Practice goes into detail about the different EMS levels and what procedures each EMT is legally allowed to perform. The last two sections in this chapter, The Time Spend in the Ambulance and Average Driving and Response Times, discuss how driving and transport times differ and how they affect how long an EMT spends in the ambulance while on duty.

2.1.1 History of EMS Profession

The formal progression of an organized civilian Emergency Medical Service (EMS) system began in the 1960s and continued to evolve as further defined and enhanced within its structure, oversight, and organization. Historical development of EMS started around 1950s by American College of Surgeons. This resulted in the development of the first training program for ambulance attendants. There were several types of early ambulances including a sedan type, hearse or hatchback type, and van type ambulances. Figure 1 on the following page shows three ambulance types that were used in the 1950s. In 1966, The National Academy of Science published an article called *Accidental Death and Disability: The Neglected Diseased of Modern Society*. In this article, they quantified the scope of traffic-related death in U.S. and described the deficiencies in pre-hospital care in this country including several factors: calling for ambulance standards, state-level policies and regulations, and recommendations to adopt methods for providing consistent ambulance services at the local level. Then, in 1970, the National Registry of EMTs held first board meeting, with goal to provide uniform standards for credentialing ambulance attendants (reference).

The Ambulance on the right is a1951 Ford Custom Twin Spinner boot loading stretcher Ambulance. The stretcher and patient were loaded into this ambulance by the trunk. It was very difficult to provide en route treatment to patients in this type of ambulance.

The ambulance on the right is the 1952 Ford Customline Ambulance. This model replaced the 51 Customline and was styled like a hearse or hatchback. There was more room in the back of this ambulance so patient care could be provided.

The image on the left is 1947 WC Dodge Ambulance. This type of ambulance was adapted from the Dodge light weight military trucks from World War II It had room in the back for a patient and EMS responders.

Figure 1: Early ambulances used in the 1950s. Top is the 1951 Ford Custom Twin Spinner boot loading stretcher Ambulance, middle is Geelong's 1952 Ford Customline Ambulance, and the bottom image is a 1947 WC Dodge Ambulance (Chisholm, Ed et al).

The Emergency Medical Services Act of 1973 enacted by Congress as Title XII of the Public Health Services Act, could acquire over $ 300 million funding for EMS over 8 years, which allowed for EMS system planning and implementation, required states to focus on EMS personnel and training, and resulted in legislation and regulation of EMS personnel levels. Then, American Medical Association (AMA) recognized EMT-paramedic as an allied health occupation in 1975. National Registry of Emergency Medical Technicians (NREMT) Practice Analysis conducted practice analysis of EMTs and paramedics in 1994. It determined importance of EMS actions based on the assessment of frequency and potential for harm and to provide foundation for NREMT test blueprint. PEW Health Professions Commission Taskforce on Health Care Workforce Regulation published the article called *Strengthening Consumer Protection: Priorities for Health Care Workforce Regulation*. This article recommended National Policy Advisory Board to establish standards and model legislative language for uniform scope of practice authority for health professions and put emphasis on states' responsibility to enact uniform scope of practice consistent with the recommendations of the National Policy Advisory Board. In 2006, *EMS at the Crossroads* Institute of Medicine Report made recommendations related to EMS Education Agenda: State governments should adopt a common scope of practice for EMS personnel with state licensing reciprocity and states should require national accreditation of paramedic programs. Also, it stated that the states should accept national certification as a prerequisite for state licensure and local credentialing of EMS providers (National Highway Traffic Safety Administration).

The *National EMS Scope of Practice Model (Scope of Practice)* is a consensus document that was published in 2006. This document defines the levels of EMS personnel and delineates the practices and minimum competencies for each level of EMS personnel. The *Scope of*

Practice does not have regulatory authority, but provides guidance to States. Adherence to the *Scope of Practice* would increase uniformity in EMS practice throughout this country and facilitate reciprocity between states. The *Scope of Practice* describes four basic levels of EMS personnel licensure: Emergency Medical Responder (EMR), Emergency Medical Technician (EMT), Advanced Emergency Medical Technician (AEMT), and Paramedic. The Scope of Practice further defines practice, suggests minimum educational preparation, and designates appropriate psychomotor skills at each level of licensure. Further, the document describes each level of licensure as distinct and distinguished by unique “skills, practice environment, knowledge, qualifications, services provided, risk, level of supervisory responsibility, and amount of autonomy and judgment/critical thinking/decision-making.” (National Highway Traffic Safety Administration)

2.1.2 EMT Scope of Practice

In order to analyze the affect that vibrations have on the EMT and patient in an ambulance, it is important to develop a comprehensive understanding of the tasks that an EMT performs. The role of an EMT and his or her duties both during an emergency and during time not spent responding are described in the *scope of practice*. Scope of practice is a legal term defined simplistically as the skills that a health care provider is licensed to perform. Each health care profession including, but not limited to, EMT, registered nurse (RN), and even lifeguard has a unique scope of practice defined by the state government, federal government, or certification organization (“scope of practice”). In the legal sense, the scope of practice is a list of the skills that an EMT *must* perform in specific emergency situations else be eligible for indictment in court. EMTs have specific procedures they are legally allowed to perform, but this may differ from what an EMT is trained to do or authorized to perform. Figure 2 shows an image of the scope of practice and the circle is the crossover of all the regions: trained to do, certified as competent, state licensed to practice, and authorized by medical director.

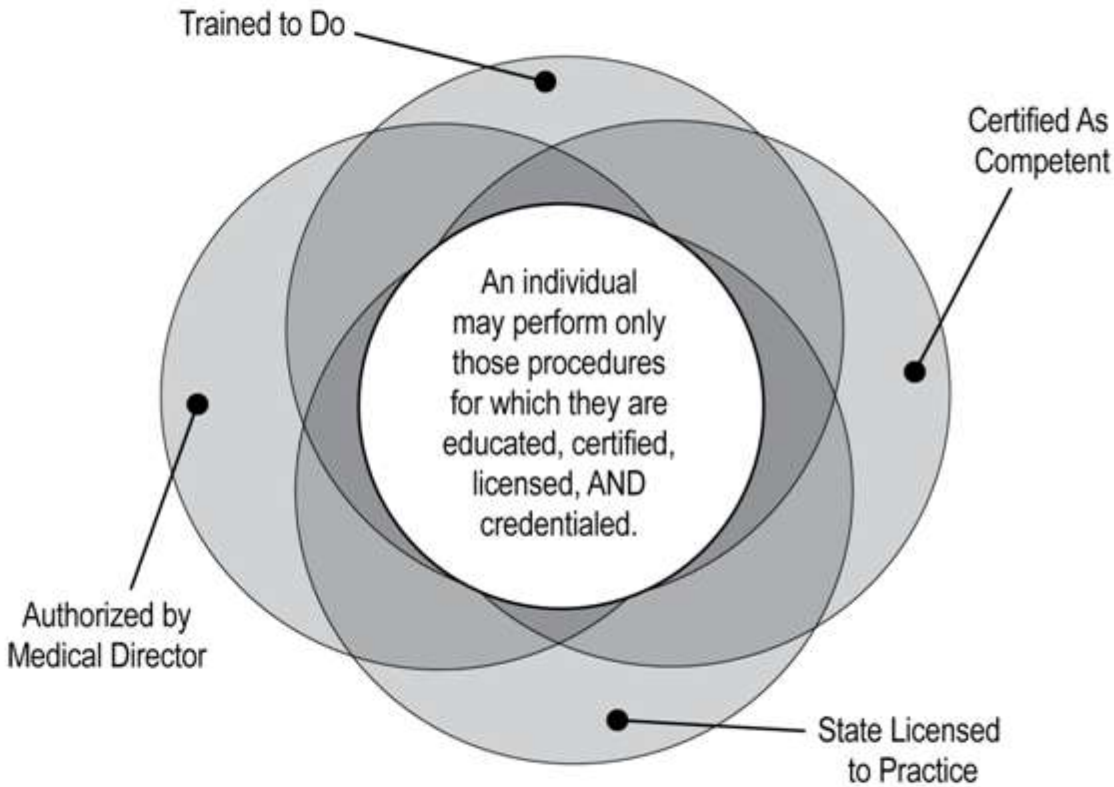


Figure 2: Scope of practice. Depending on the flowing four categories, an EMT can perform procedures that they are trained for, but also licensed, authorized, and certified to perform. Image from (Whitehead, 2010).

For the general profession titled Emergency Medical Technician, there are four levels of licensure recognized by the United States government. Progressing from lowest level of care to highest, these four levels are Emergency Medical Responder (EMR), Emergency Medical Technician (EMT), Advanced Emergency Medical Technician (AEMT), and Paramedic (National Highway Traffic Safety Administration). Most of the time, when a person refers to the EMT profession, they are speaking of Paramedics. Each of these levels is represented by its own, unique scope of practice, increasing in number and complexity of tasks with the sequential levels. An important realization is that each level builds upon the levels below; that is, in order to be a Paramedic, one must be trained in all the tasks that are in the scope of practice of lower levels. To illustrate the difference between levels, an EMR provides basic life saving assistance until one of the higher levels arrives, whereas a Paramedic provides advanced life saving assistance meant to directly increase the survival rate of patients while transporting them to an appropriate hospital.

The lowest level, EMR, is a person that is meant to be the first responder on an emergency scene. His or her job is to perform basic life-saving techniques while waiting for additional EMS personnel. The EMR is never the primary care giver during the pre-hospital treatment of a patient. An EMR is required to be trained in several basic areas. The first, airway and breathing, requires the responder to be able to insert airway adjuncts, supplemental oxygen, and positive pressure ventilation. For medical/cardiac care, the EMR must be able to use an AED (automated external defibrillator). Finally, for trauma care, the responder must be able to control bleeding, stabilize fractures and cervical spine injuries, and perform emergency moves of the patient. The second level of responder is the EMT. The biggest difference between EMT's and EMR's is the training to be capable of being the primary pre-hospital care responsible for transporting the patient to a health care facility. An EMT must be competent in all skills that an EMR is trained in. In addition to these skills, an EMT builds on the EMR training with several additions. An EMT is trained to provide assistance to patients in taking prescribed medications as well as several over the counter medications including oral glucose and aspirin in specific situations. For trauma patients, an EMT is trained in the proper use and application of a pneumatic anti-shock garment (PASG).

AEMT is the next licensure level in the EMS system. As an Advanced EMT, a person is trained in performing low risk, high benefit advanced tasks to provide limited advanced life support. Advanced EMTs are also called EMT – Intermediate. The main skill differentiating AEMTs from EMTs is the training to provide pharmacological interventions. As an AEMT, a person is trained to insert airways that aren't placed in the trachea and apply tracheobronchial suctioning of intubated patients. In the pharmacological area, the AEMT is taught the skills necessary to place and maintain intravenous (vein) and intraosseous (bone, only children) access, administer intravenous fluid therapy, sublingual nitroglycerine, subcutaneous epinephrine, and beta agonists, and several more. The final and highest level in the EMS systems is the Paramedic. A paramedic requires skills necessary to form a field impression of the patient and perform advanced life support accordingly. A Paramedic is trained and is competent is all the skills that EMRs, EMTs, and AEMTs are trained in as well as many advanced skills. A few of these advanced skills are decompression of the pleural space, endotracheal intubation, administer prescription medications, administer medications by intravenous, maintain a blood infusion, and perform manual defibrillation. An important skill to mention is performing cardiac pacing using a 12-lead electro-cardiogram. The 12-lead, as it is referred to by EMS in the field, is highly sensitive to motion and vibration, and cannot be performed in a moving ambulance. As such, it will be a focus later on in this paper (National Highway Traffic Safety Administration). Figure 3 shows the different EMT levels and other medical certifications that require similar training.

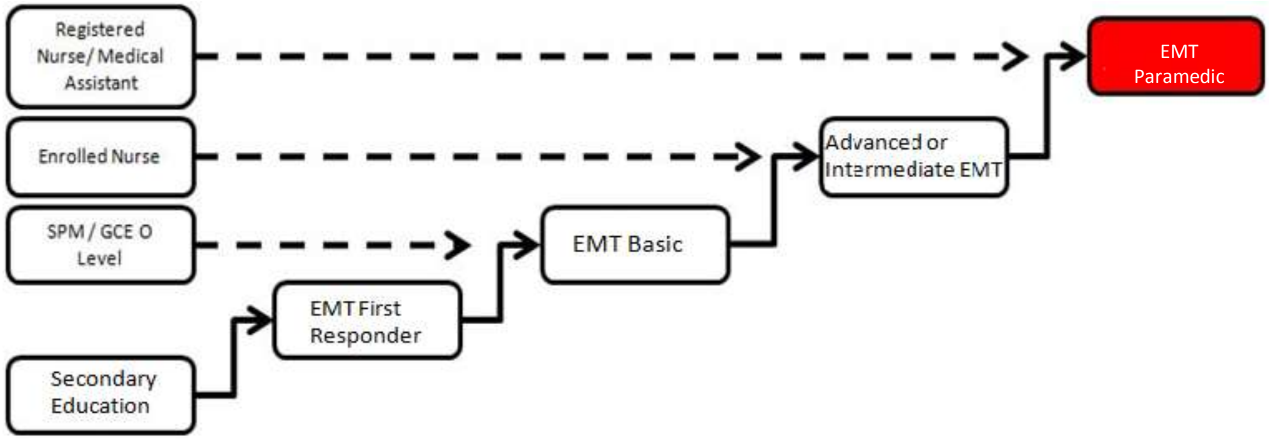


Figure 3: EMT certifications and equivalent certifications. Image adapted from (Most Common EMT Certifications Levels, 2010).

The equivalent certifications require similar skills and amount of training required. This does not mean that a Registered Nurse is an EMT Paramedic, but means that an EMT-Paramedic requires a similar knowledge set and similar training hours.

2.1.3 Time Spent in Ambulance

An EMT's profession requires them to be on duty for up to 50 hours per week (Cydulka MD, 2008). During that time, they must constantly be prepared to respond to any medical emergency. EMTs also spend regular hours in the ambulance. In the city of Worcester and town of Shrewsbury MA, there are about 30,000 calls a year. These 30,000 calls refer to the number of 9-1-1 calls that EMTs responded to and transported patients to the hospital (Restuccia, 2011).

The UMASS Medical Center/UMASS Memorial Health Care is the primary provider of EMS services to the city of Worcester. Figure 4 on the following page is the University of Massachusetts Medical Center Worcester EMS patch (KaizenVerdant, 2009). In 2004, the average response time to a call was five minutes and fifty-six seconds (Worcester Regional, 2011). In that time, the 9-1-1 call was made and the EMTs arrived to assist the patient. This time does not include the time it takes to transport the patient to the hospital. The transport time depends on a number of factors, including how serious the condition of the patient is. In a 1999 study, the transport time was compared between ambulances with light and sirens and ambulances with no lights or sirens. This study showed that ambulances with no sirens and lights had an average transport time of fourteen minutes and fifty-six seconds. The ambulance with lights and sirens had a transport time of eleven minutes and six seconds (O'Brien, 1999). Transport and response time greatly depend and vary on many factors such as traffic, stoplights, and the distance needed to travel; this will affect the amount of time an EMT will spend in the ambulance. Using the number of calls per year (30,000), response time (5:56), transport times (11:06 and 14:56), and at least two ambulances in the station, an EMT can spend all of their work hours in the ambulance. An EMT being in the ambulance for this long and being subjected to vibrations for such an extended period of time can negatively affect the EMT.

Figure 4: University of Massachusetts Medical Center Worcester EMS patch, (KaizenVerdant, 2009).

2.1.4 Average Driving and Response Times

Having a quick response and driving time to an emergency call directly correlates to a speedy recovery of a patient, and may even prevent unnecessary death. The response time is defined as the time it takes when the dispatcher receives the call from the 911 operator until the time when the ambulance unit signals its arrival on scene. The industry's standard of ambulance response times is arriving within 8 minutes 90% of the time. Also, the driving time is the time it takes to bring the patient to a hospital, and depending on the condition of the patient, it may take longer in a life threatening emergency than in a non-life threatening case (Pell, 2001).

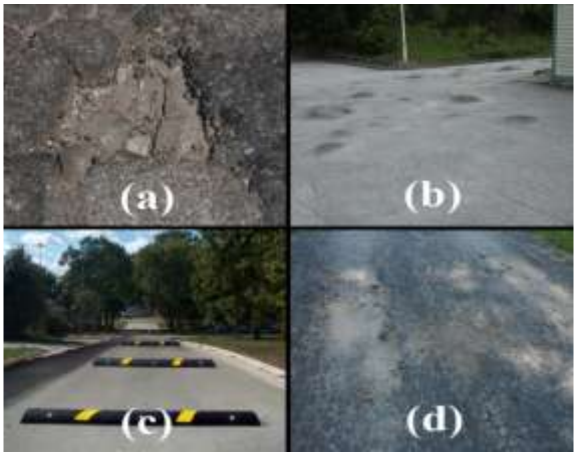


Figure 5: Roadway Conditions: (a) Pot Hole (b) Frost Heaves (c) Speed Bump (d) Worn Pavement. Image from (Cotnoir, 2010)

Response and driving times are dependent upon many factors including traffic, driving, and roadway conditions, the distance to the emergency, and the priority of the call. Figure 5, on the right, shows several road conditions that can affect the ambulance ride. It is very logical to assume that if there is a heavy amount of traffic, the response time gets longer. The main times of traffic jams and rush hour traffic are during the hours leading up to work, lunch time, and after work. And if there is a heavy volume of cars on important main roads and highways, it takes a great deal of time for an ambulance to wade through those streets and let the cars move out of its way. Most of the dangerous driving conditions that slow down the ambulance are due to the weather. Rain, snow, and other precipitation, along with low ambient light levels all play a factor into how quick the driver can navigate the roads while maintaining safe driving practices. Precipitation not only reduces the visibility of the driver, but it also affects how well the ambulance handles on the pavement. Roadway conditions can vary vastly depending on the location such as in the country or the city, and even the road surface can cause concern in certain areas. Snaking and winding roads in heavily wooded areas, or hilly terrain would not only take the ambulance in an indirect path, but force the ambulance driver to drive slower, resulting in longer travel times. While in the city, even if all traffic lights have an emergency system built in, which can change the traffic light in the ambulance's favor; it still takes a good amount of time for the ambulance to navigate through the cars. Many perturbations that an ambulance may encounter are due to improperly maintained roads are pot holes, frost heaves, ice, debris, speed bumps, worn pavement, and maybe the occasional dirt road or animal (see Figure 5). These conditions not only reduce ambulance speed, but also increase the vibrations upon the ambulance, which in turn could cause ride-induced patient impacts. It is also pertinent to mention that the further the emergency is from the station, the longer the response time is. When the ambulance has to drive a really long distance, the chance of encountering other hindrances increases. And lastly, the priority of the dispatch call has a significant impact on how much the driver of the ambulance has to rush to get to the scene of the emergency. There are eight priority levels, 1 being cardiac arrest and choking, 2 and 3 being life threatening medical emergencies, and 4 through 8 being non-life threatening. Even though all ambulance drivers are required to obey safe driving practices, they focus on arriving on scene in a quicker manner for higher priority calls than for non-life threatening issues. All together, there are many obstacles for ambulance drivers to overcome in order to achieve an expeditious response time, but there are also some major problems with the driving the patient back to the hospital.

The biggest factor that affects the driving time as opposed to the response time is that there is a patient in the back of the ambulance. During transport, the patient is usually strapped down supine in the stretcher, which in turn is locked to the floor of the ambulance. Any substantial vibration, bump, or dip caused by the road directly translates into impact upon the patient. If the patient is in critical condition, with head trauma or other precarious complications, ambulance drivers must be tremendously careful on how they drive. They inherently have to drive slower, and take time to avoid any road perturbations. The survivability of the patient in a high priority case is any EMT's first responsibility, so they have to weigh how important avoiding ride-induced patient impacts are compared to arriving at the hospital in a prompt manner. This is how the driving time may take longer in a life threatening case than in a non-life threatening case.

Having quick response times and driving times could be the decisive factor in saving someone's life. In fact, the difference between a five minute response time compared to an eight minute response time for a priority one cardiac arrest would increase the probability of survival from 8% to 10-11%. This may seem like an insignificant success rate, but when compared to New York City's 20,000 priority one calls in 2010 alone, the time difference could mean saving several hundred people from death (New York Fire Department, 2010).

Overall, there are a plethora of factors that impact the response and driving times of ambulances. Although they may not individually slow the ambulance by much, the accumulation of the hindrances may take away precious minutes from the time an emergency call is made, and getting the patient to the hospital. The most important factor about response and driving times is the safety and survivability of the patient. Saving a life is saving a life, and the transportation takes a vital role in the ability to help those in need.

2.2 Roadway Vibrations

Road vibrations are caused by imperfections and changes in the height of the road way surface. There are many variables that may affect the amount of vibration felt by the patient and the EMT in the ambulance. Some of these factors include: road conditions, vehicle speed, and the suspension system. All of these topics are discussed in the following sections of Chapter 2.2 Roadway Vibrations.

2.2.1 Road Conditions driving at Constant Velocity

Paul Cotnoir, PhD, conducted a study in 2010 focused on classifying the various modes of vibration experienced by riders in an ambulance. The purpose of his study was to develop a computation model to describe these vibrations in order to facilitate further research into the pathophysiological affects of vibrations on ambulance patients and EMTs. To determine the vibrations, Dr. Cotnoir conducted a series of tests using various ambulance models. These tests accounted for differing roadway conditions as well as vehicle velocities. The end result of the experiment was an analytical model that can be used to create control law equations for use in active vibration dampening systems.

Throughout the course of the testing, four different ambulances were used, each of which met current standards outlined by KKK-A-1822 star-of-life standards. The first vehicle was a Type I model built by Horton. For reference, the "Type" of an ambulance describes the type of chassis the vehicle is based off of; I being a truck and III being a van. Its chassis was a 2005 Ford F450 with a standard leaf spring and shock absorber suspension weighing a total of 16000 lbs. This vehicle was borrowed from UMASS. A second ambulance was also borrowed from UMASS. This ambulance was a 2008 Chevrolet C4500 from the body manufacturer Braun. This second vehicle was also a Type I model with a standard leaf spring and shock absorber suspension, although it only weighed 16500 lbs. The third vehicle was a 2001 Ford E450 borrowed from Putnam, CT EMS, also with the standard leaf spring and shock absorber suspension weighing 14050 lbs. Unlike the two previously mentioned ambulances, this was a Type III. The final ambulance used for the testing was a Type III, 2009 Ford F550 with an air ride suspension. This ambulance, weighing 17950 lbs., was borrowed from Woodstock, CT EMS. Images of the four ambulances used in Cotnoir's study are seen in Figures 6.

Figure 6: The ambulances used in Cotnoir's Vibration Study. Top left – Horton 2005 Ford F450 (borrowed from UMASS), Top Right – Braun 2008 Chevrolet C4500 (borrowed from UMASS) Bottom Left – 2001 Ford E450 (borrowed from Putnam, CT EMS) Bottom Right – 2009 Ford F550 (borrowed from Woodstock, CT EMS). Image from (Cotnoir, 2010)

Using these four vehicles Dr. Cotnoir measured vibrations on varying road surface conditions and at varying speeds. Each vehicle was driven on four different road conditions characterized visually. From most vibration excitation to least, these conditions were unpaved road, paved secondary road, paved city street, and finally paved multi-lane highway. Although generally in that order, all roads contained random points of irregularity including potholes, frost heaves, speed bumps, and severely worn sections of road. The intent of the testing was to characterize each surface condition using the full range of velocities, but due to speed limits, only certain speeds could be tested on each road type. As previously mentioned the various road surfaces tested were the unpaved roads, paved secondary roads, paved city streets, and highways. Figure 7 below shows images of the four different road types used in Cotnoir's study.

Figure 7: Images of local road surface characterization including (a) unpaved roads, (b) paved secondary roads, (c) paved city streets and, (d) paved multi-lane highways

The unpaved road consists of dirt, stone, gravel or sand with variable methods of construction. The road width varied with location but usually stays under 9.1 meters (30 feet) wide. The maximum allowable speed differed or was not shown at the various locations. The paved secondary road, or rural paved road, is broken into a new and old subclass based on different construction methods and compositions of when it was paved. The new rural paved road consists of 76 to 102 millimeters (3 to 4 inches) of bituminous concrete or hot-mix asphalt (HMA), which is poured over a base of gravel approximately 305 millimeters (12 inches) deep. The old rural paved road is constructed using up to 127 millimeters (5 inches) of asphalt paving on an existing base. The width of the rural roads is typically less than 9.1 meters (30 feet). And the maximum allowable speed ranged from 56 to 72 kilometers per hour (35 to 45 miles per hour).

The paved city street and parking lot also is broken into a new and old subclass. The new city street, like the paved secondary road, is composed of 76 to 102 millimeters (3 to 4 inches) of bituminous concrete or hot-mix asphalt (HMA) poured over a gravel base approximately 305 millimeters (12 inches). And the old city street uses 127 millimeters (5 inches) of asphalt paving on an existing concrete or cobblestone base. Even though the paved city street is composed of the same material as the rural paved roads, the city street has a 2-3% cross slope for drainage of rain water, and the speed limit varied from 24 to 56 kilometers per hour (15 to 35 miles per hour). Other differences between the city street and the rural road are the volume of traffic flow, how often it is maintained, and other minor variables.

The paved highway has three different construction methods. The flexible pavement uses three to four courses of hot mix asphalt (HMA) over a granular sub-base. The rigid pavement is either a plain and jointed or continuously reinforced layer of Portland cement concrete over a granular sub-base. And the composite pavement consists of one or more courses of hot mix asphalt (HMA) over a Portland cement concrete base. These three subclasses of the paved highway are used for the various locations of where it needs to be laid, such as on an overpass or on the earth.

All roads that vibration data were collected from were categorized into those four road types. A simple visual classification method was used to establish whether it was unpaved, secondary, city, or highway. All tests were conducted using four different ambulances which were set up as similar to one another as possible. Each ambulance and the data collection apparatuses were set up in the same manner every time it went out on the test runs to remove variables. Overall the major contributing factors that affected the vibration sensors were the road type, the ambulance that was used, and the speed at which the ambulance was driving.

Table 1: Test Summary. Consists of the number of events recorded.

Amb #	Total # events	Event[1] #'s							
		Highway			Secondary road		City street		Un-paved road
		≤35 mph	36-64 mph	≥65 mph	≤35 Mph	36-64 mph	≤35 mph	36-64 mph	≤35 mph
1	64	1-3	4-6; 15-20	7-14	21-23; 27-29	24-26; 30-32	41-64	38-40	33-37
2	63	1-3	4-6; 10-15	7-9; 16-18	25-27; 50-52	31-33; 58-60;	19-24; 44-49; 61-63	28-30	34-43
3	71	1-3	4-6	7-15	16-18; 22-24	19-21	34-58	31-33	25-30
4	93	16-18	19-24; 31-35	25-30	4-6; 10-12	1-3; 13-15; 41; 43-45	7-9; 34-36; 49-58; 68-70; 77-82; 91-93	37-39; 59-67	71-76

[1]Each event represents a 10 second recording interval.

Data is categorized by ambulance, vehicle speed, and road condition or surface.

In Table 1, the number of events in which data was acquired from the experiment has been compiled and sorted by road type, ambulance, and speed. Each event is a ten second time frame in which vibrations were recorded while driving in the appropriate categories. For safety reasons and obeying the speed limit, not all road types were tested at the higher speeds. The data recovered from these events follows ISO and British vibration measurement standards. The focus of this study is vertical vibration. Z-axis vibration is the most present vibrations affecting the patient lying supine in the stretcher.

Table 2: Vibration amplitude data characterized by road surface.

Overall amplitude of vibrations (z-axis)					Amplitude of bumps and shocks (z-axis)					Uniformity of vibration amplitudes (z-axis)				
Mean r.m.s. (m/sec^2)					Mean peak (m/sec^2)					Mean crest factor				
For all speeds, all ambulances, highway travel														
$\bar{x}$	Min	Max	*s*	n	$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	s	n
0.89	0.59	1.63	0.31	73	**4.28**	3.07	7.25	1.20	73	**5.20**	4.04	6.98	0.99	73
For all speeds, all ambulances, secondary road travel														
$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	s	n
0.93	0.50	1.34	0.28	49	**4.65**	2.50	6.42	1.40	49	**5.18**	4.20	6.06	0.56	49
For all speeds, all ambulances, city street travel														
$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	s	n
0.90	0.60	1.29	0.26	110	**4.90**	2.92	8.03	1.71	110	**5.71**	4.47	7.70	1.00	110
For all speeds, all ambulances, unpaved road travel														
$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	**s**	n
1.54	0.46	2.55	1.09	27	**8.44**	1.87	15.45	7.06	27	4.97	3.95	5.99	0.96	27

In Table 2, all the raw data have been analyzed and sorted by road type. The vibrations gathered from the experiments were then calculated into the mean r.m.s, mean peak, and mean crest factor as can be seen in that chart as well. The mean r.m.s is an analysis upon the acceleration where the average of the root mean squares is taken for all the ten second interval recordings. The root mean squares are calculated by squaring each crest peak number in each ten second time frame, then taking the square root of the average of those numbers. The mean r.m.s. shows the average acceleration due to the vibrations. The mean peak acceleration takes the largest absolute amplitude value from each ten second time frame and then finds the average of all the combined maximum peak values. The mean peak acceleration displays the average of the largest impacts in each ten second recording time frame. The mean crest factor is calculated by dividing the mean peak acceleration for each ten second event by the r.m.s acceleration of that sample. All these are broken up into standard deviation format.

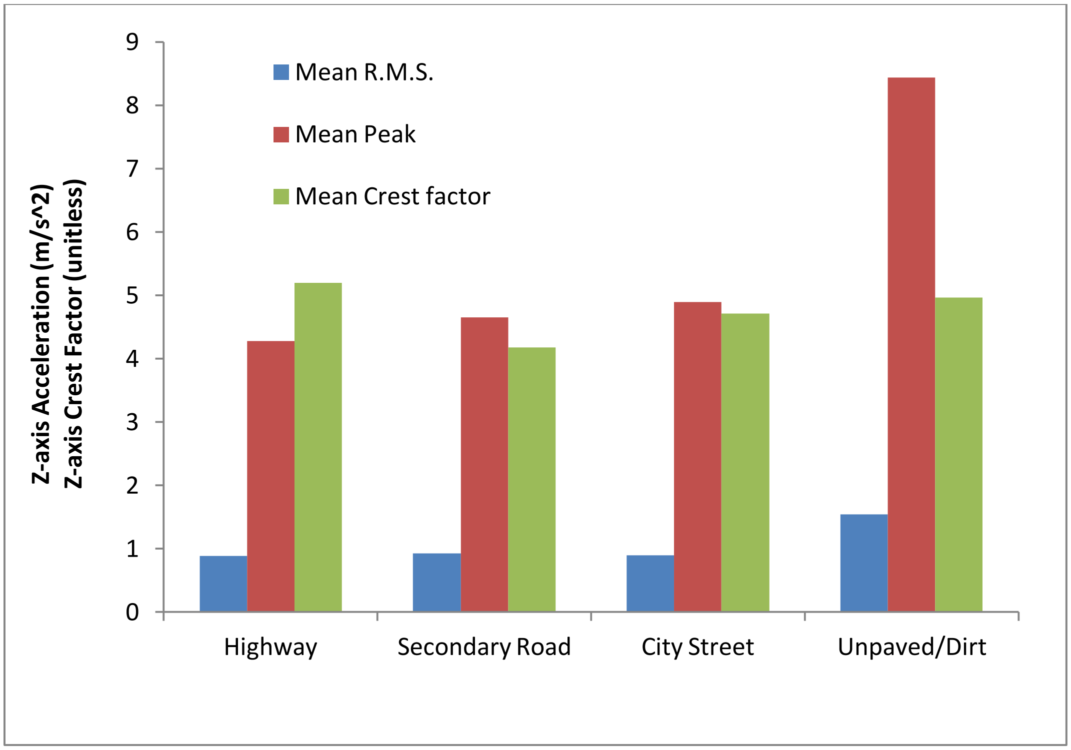


Figure 8: Graph of z-axis mean r.m.s. acceleration, mean peak acceleration and crest factor for each road surface for all ambulances at all speeds.

This graph summarizes Cotnoir's data by ambulance data. The graph separates the data by road type. The y-axis is the z-axis acceleration in (meters/second^2) and the z-axis crest factor (unit-less). For the most part, the mean r.m.s. and crest factor appear to be relatively consistent between road types, the mean peak acceleration on the other hand is much higher for the unpaved/dirt road.

2.2.2 Vehicle Velocities maintaining same Road Conditions

Each roadway surface was tested using the maximum velocity allowed by law within the range in the experimental design, as well as the lower velocities in the design where possible. The velocities used were broken into three categories, namely ≤ 35 mph, 35 – 64, and ≥ 65 mph.

Table 3 includes the velocities used with each condition. The paved highway was tested with the entire range of velocities.

Table 3: Velocities used per surface condition.

Road Surface	≥ 65 mph*	Speed 36-64 mph*	≤ 35 mph*
Highway	✓	✓	✓
Paved secondary road		✓	✓
Paved city street		✓	✓
Unpaved road			✓
Speed bump			✓

The provided velocities summarized above are relatively large and non-descriptive ranges meant as guidelines to remain within during testing.

During testing, an accelerometer was placed on floor of the ambulance approximately below the location of a patient's chest. The device, an Instrumented Sensor Technology EDR-3C-10 Shock & Vibration Sensor/Recorder, is capable of measuring and recording acceleration in three axis. To mimic accurate weight loading of the ambulance during a call, an anatomically accurate nursing trainer manikin was strapped to a stretcher, and put in position in the compartment. Each vehicle experienced 70, 10 s events distributed over the various conditions.

Paul Cotnoir preformed many tests to investigate the vibration in the ambulance. All accelerations were measured in meters per second squared ($^{m}/_{sec^2}$). Each trail was called an "event" and consisted a 10 second acceleration reading. Accelerations were recorded in the x, y, z, and the tri-axial resultant was recorded. The z-axis is considered as the up-down plane, and is the much more important for this study than x and y. Approximately 70 tests were performed on each test group. Test conditions differed in road condition, ambulance model, and vehicle speed. See Table 1 for number of events and condition of each test.

International Organization for Standardization (ISO) has an accepted, standard method for the measurement of: vibration amplitude, shock amplitude, smoothness of ride, and frequency. Accelerations were gathered using International Organization for Standardization 1997 (ISO 2631-1) and British Standards Institution 1987, (BS 6841).

During Cotnoir's study, many values were calculated. Vibration Dose Value (VDV) is a ISO and BS standard for vibration amplitude. VDV provided an acceleration value weighted for the frequency as well as amplitude and exposure length. Un-weighted mean root means squared (r.m.s) acceleration is the average r.m.s for all of the ten second events. The R.M.S. is the square root of the sum of the squares. The un-weighted mean r.m.s acceleration is the ISO standard for sample amplitude. The un-weighted max peak acceleration is the absolute value of the greatest (or most negative) acceleration from the ten second interval. This value showed the very worst shocks or jolts of the event. The mean peak acceleration is the average of the max peaks for a certain road type at a certain speed range. This value gives you an idea of the amplitude vibrations from shocks and is used in comparing events to each other. The un-weighted mean crest factor is calculated by dividing the mean peak acceleration for each ten second event, by the r.m.s acceleration of that sample. Average these values for each road surface, speed, and ambulance to calculate the un-weighted mean crest factor.

Table 4: Shock, Z-axis vibration, and uniformity, categorized by road type.

Overall amplitude of vibrations z-axis					Amplitude of bumps and shocks z-axis					Uniformity of vibration amplitudes z-axis				
Mean r.m.s. (m/sec^2)					Mean peak (m/sec^2)					Mean crest factor				
For ambulance #1, all speeds, all road surfaces														
$\bar{x}$	Min	Max	*s*	**n**	$\bar{x}$	Min	Max	S	**n**	$\bar{x}$	Min	Max	s	**n**
1.15	0.60	2.41	.55	64	**6.08**	3.44	13.56	3.2	64	**5.61**	4.17	6.80	0.76	64
For ambulance 2, all speeds, all road surfaces														
$\bar{x}$	Min	Max	s	**n**	$\bar{x}$	Min	Max	S	**n**	$\bar{x}$	Min	Max	s	**n**
0.83	0.62	1.05	0.16	63	**3.88**	2.88	5.36	0.96	63	**4.84**	3.95	6.06	0.73	63
For ambulance #3, all speeds, all road surfaces														
$\bar{x}$	Min	Max	s	**n**	$\bar{x}$	Min	Max	S	**n**	$\bar{x}$	Min	Max	s	**n**
1.34	0.71	2.55	0.56	71	**7.03**	3.90	15.45	3.64	71	**5.42**	4.20	7.70	1.10	71
For ambulance #4, all speeds, all road surfaces														
$\bar{x}$	Min	Max	s	**n**	$\bar{x}$	Min	Max	S	**n**	$\bar{x}$	Min	Max	s	**n**
0.64	0.46	0.96	0.16	93	**3.20**	1.87	4.40	0.86	93	**5.32**	4.37	6.98	0.92	93

This table contains the overall shock, z-axis vibration, and z axis crest factor for the recorded ambulance data.

$\bar{x}$ - mean Min – minimum Max – maximum s – standard deviation n – number of events

In this test, ambulances 1 and 3 were driven and recorded accelerations on roads in Worcester Massachusetts. Ambulances 2 and 4 were tested on roads in northwestern Connecticut. This table shows that the Worcester ambulances had higher r.m.s and mean accelerations and slightly higher crest factors, than the Connecticut counterparts. The Worcester mean r.m.s vibration were 39% and 109% higher than the Connecticut values and peak Worcester accelerations were 57% and 120% higher than Connecticut. In this study, no significant variations were measured in the vibrations between ambulances for tests on the same road type at the same speeds. The minor differences that did occur most likely occurred from the difference in driver or the different segments of road in the same general "road surface."

The next topic that was investigated by Cotnoir was the effect of the ambulance speed on the vibrations. Table 5 includes information similar to Table 4 (mean r.m.s., mean peak, and crest factors), but instead of being split up by ambulance/geographical location, the data is separated by vehicle speed.

Table 5: Shock, Z-axis vibration, and uniformity, categorized by ambulance speed.

Overall amplitude of vibrations z-axis					Amplitude of bumps and shocks z-axis					Uniformity of vibration amplitudes z-axis				
Mean r.m.s. (m/sec^2)					Mean peak (m/sec^2)					Mean crest factor				
For all road types, all ambulances, speed ≤ 35 mph														
$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	S	n	$\bar{x}$	Min	Max	s	N
0.94	0.46	2.55	0.62	151	5.18	1.87	15.45	3.78	151	5.50	3.95	6.98	0.73	151
For all road types, all ambulances, speed 36 – 64 mph														
$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	S	n	$\bar{x}$	Min	Max	s	N
0.99	0.60	1.34	0.26	57	4.92	2.62	8.03	1.68	57	5.33	4.16	7.70	1.06	57
For all road types, all ambulances, speed ≥ 65 mph														
$\bar{x}$	Min	Max	s	n	$\bar{x}$	Min	Max	S	n	$\bar{x}$	Min	Max	s	N
1.18	0.96	1.63	0.31	29	4.90	3.50	7.25	1.63	29	4.40	4.04	4.79	.35	29

$\bar{x}$ - mean Min – minimum Max – maximum s – standard deviation n – number of events

While one might think that as the vehicle speed increases the amplitude of the vibration will also increase, this is not true. From the data that Cotnoir collected, there is no evidence to suggest a significant effect on vibration based on the ambulance speed. The lowest speeds have slightly higher values, as seen in Table 5, but the worst road conditions usually have the lowest posted speed limits (the under 35 mph group). As a result the low speed has slightly higher mean r.m.s., mean peak, and mean crest factors. These values are graphed in Figure 9.

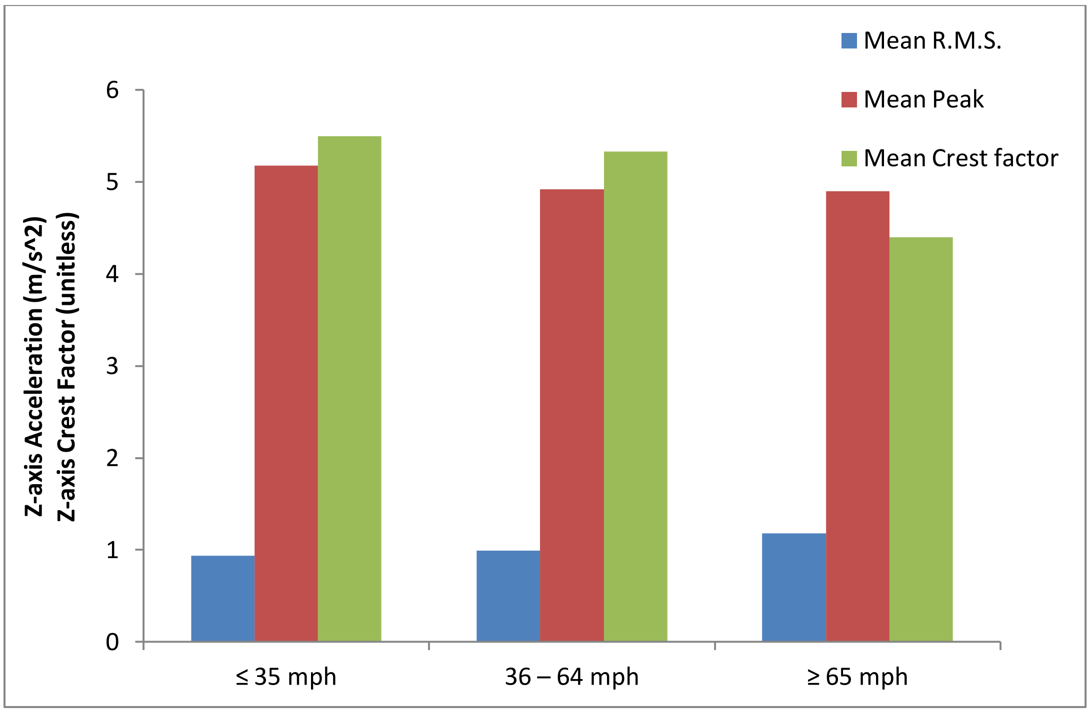


Figure 9: Z-Axis Vibration vs. Vehicle Speed.

In this figure you can clearly see that there is no real difference between the mean r.m.s. accelerations and mean peak accelerations. The crest factor does decrease slightly as the speed increases.

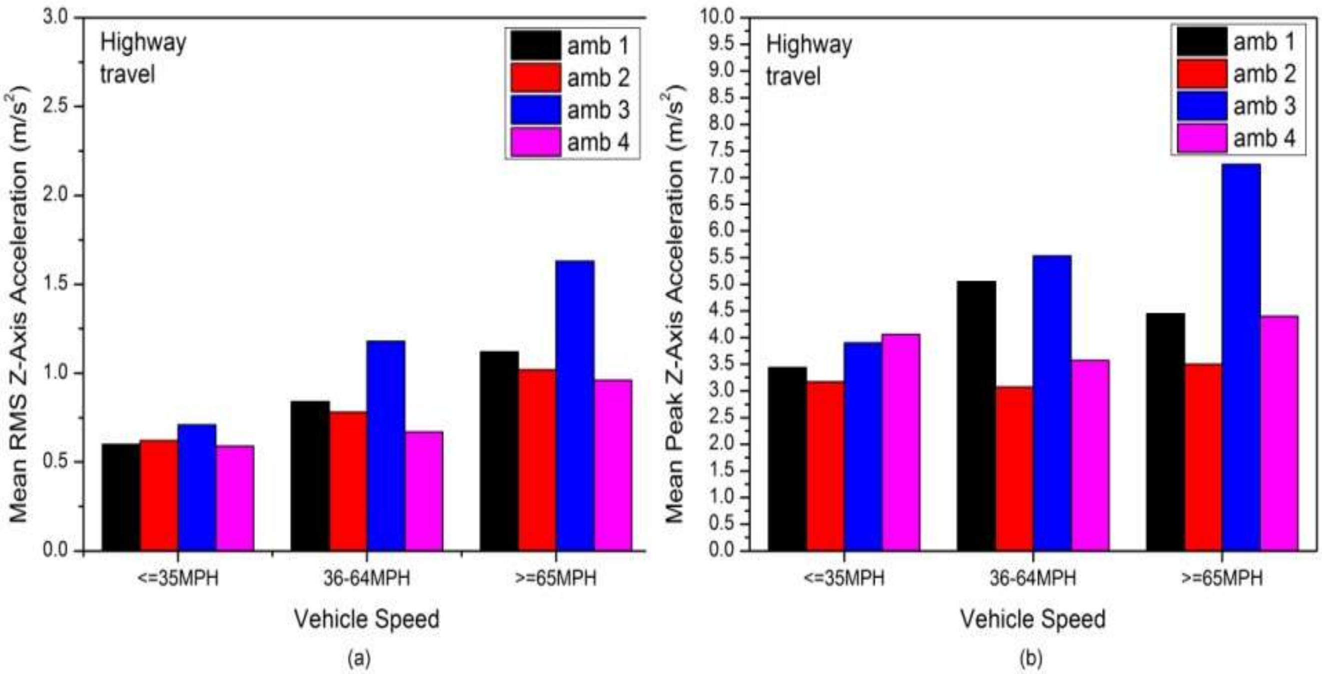


Figure 10: (a) Mean RMS z-axis acceleration vs. vehicle speed and (b) Mean peak RMS Z-axis acceleration vs. vehicle speed.

Figure 10 (a) Displays the mean r.m.s. in the z-direction and it appears that there is an increase in vibrations as the speed increases, but when the mean peak z-direction is graphed against speed, in Figure 10 (b) this correlation is not so evident.

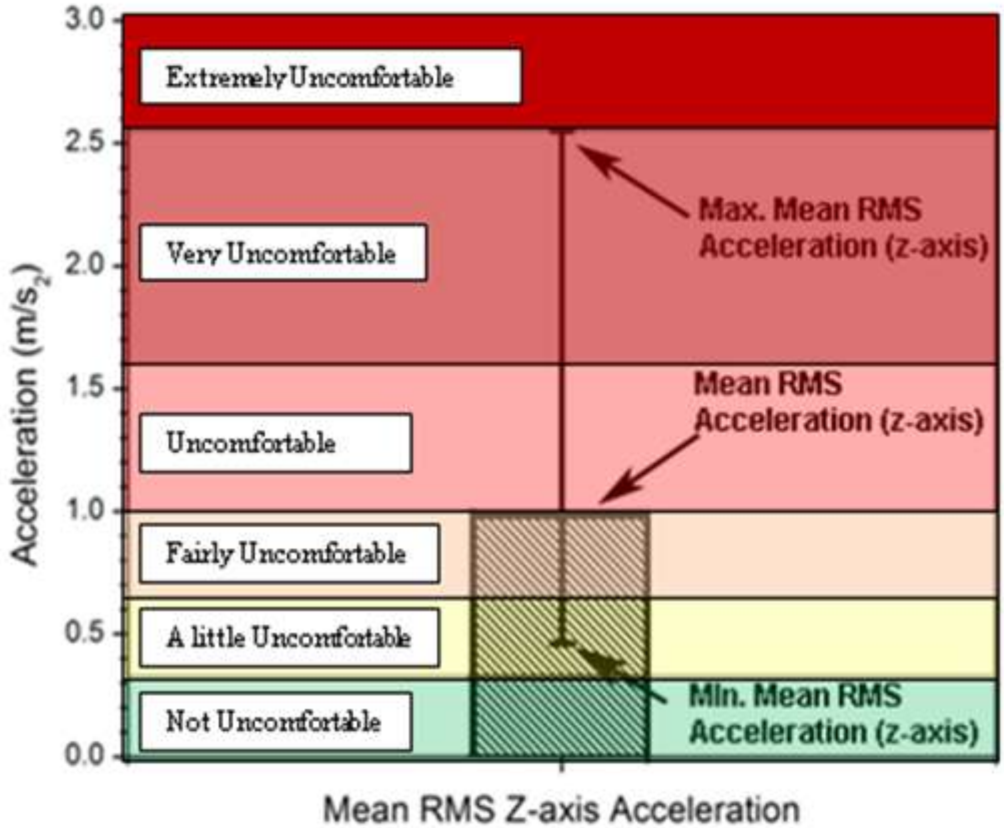


Figure 11: Z-axis accelerations and comfort ranges. Image adapted from (Cotnoir, 2010)

This visually displays the range of accelerations that were measured in Cotnoir's study. This figure also shows what ranges of accelerations are in the comfortable and uncomfortable ranges.

A summary of acceleration values gathered in this study are as follows. The z-axis vibration amplitudes in the ambulance, over all of the events, varied from 0.46 to 2.55 m/sec^2 with a mean of 0.99 m/sec^2. The resultant accelerations varied from 0.66 to 2.55 m/sec^2 with the mean 1.33 m/sec^2. This vibration is quite large considering the acceleration due to gravity is 9.81 m/sec^2 and the measured accelerations in the ambulance are approximately double the average vibration felt in a typical automobile. As expected the shock and jolt z-axis vibration amplitudes would be much higher, ranging from 4.16 to 15.45m/sec^2, with a standard deviation of 5.00. These shock or jolts could be from, speed bumps, pot holes, or frost heaves. The crest factors ranged from 4.16 in the resultant-axis and 5.08 in the z-axis. To determine how these vibrations impact health the frequency of the vibrations must also be investigated.

Cotnoir also investigated the frequency and energy analysis. For this segment of the study, Instrumented Sensor Technology Dynamax software was used to collect and analyze the data. This software was also used to calculate the Power Spectral Density, which is a graph that identifies the frequencies where vibrational energy is concentrated. From the events that were tested, most vibrations exhibited peaks between 0.12 and 6 Hertz. Most of the data was concentrated in the sub 6 Hz area, but some point exceeded to the sub10 Hz range. The 10 Hz range has the largest ramifications on the human body and is very uncomfortable. Currently there is no standard to judge the comfort of a vehicle ride. It is generally agreed that the human body is sensitive to z accelerations in the 4 to 8 Hz ranges.

2.2.3 Current Suspension Mechanisms designed to Dampen Vibrations

There are many types of suspension which are currently in use in various types of vehicles around the world. Further, many different car companies develop their own, unique suspension system to have stable driving independent from the conditions of the road. This chapter will attempt to outline the universal types of the suspension mechanisms. Namely, these are the hydrolastic, the hydragas, the hydraulic, and the air suspensions.

The hydrolastic suspension uses fluid flow to maintain a level ride. The system composes of hydrolastic displacers that is interconnected between the front and rear suspension by a narrow pipe containing hydraulic fluid. Each side has its own separate hydrolastic displacer system. As the front wheel is deflected upward by a road perturbation, the front displacer pressurizes the fluid and transfers it to the rear suspension, which has lower pressure. This in turn raises the back of the vehicle. The opposite happens when the rear is deflected upwards. A diagram of the leveling effect of the hydrolastic suspension can be seen in Figure 12. This theoretically will maintain a level ride as the vehicle drives over bumpy surfaces. To dampen the vibrations caused by the road perturbations, the suspension unit uses rubber springs and rubber valves to absorb any extraneous vibrations (Car Bibles, 2012).

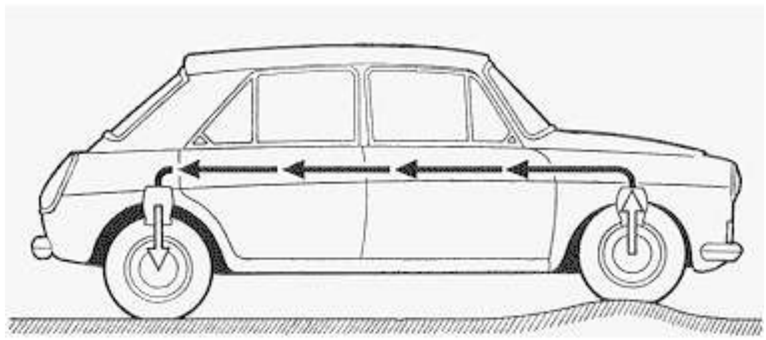


Figure 12: Self-leveling effect. Image from (Car Bibles, 2012)

If the vehicle encounters road perturbations that induce an upward deflection on both front and rear wheels at the same time at the same magnitude, neither wheel will take precedence over the other. Instead, the deflection in both tires will cause the fluid to pressurize and compress the rubber springs, which in turn will dampen the overall impact of the perturbation. This will still maintain a level motion of the car, even though the car is displaced vertically. In many situations, the hydrolastic suspension system will maintain stability pitch-wise while driving on an everyday, normal circumstance roadway (Car Bibles, 2012).

Figure 13: Typical lateral installation for hydrolastic rear suspension. Image from (Car Bibles, 2012)

The hydrolastic rear suspension can be seen in Figure 13. The gray suspension swing arm located on the left of the diagram is attached to the main sub-frame. The fluid displacer units, which are seen in red, contain the rubber spring and the hydraulic fluid used to dampen and shift weight. And the red tubes are the pipes that connect the rear hydrolastic displacer system to the front system.

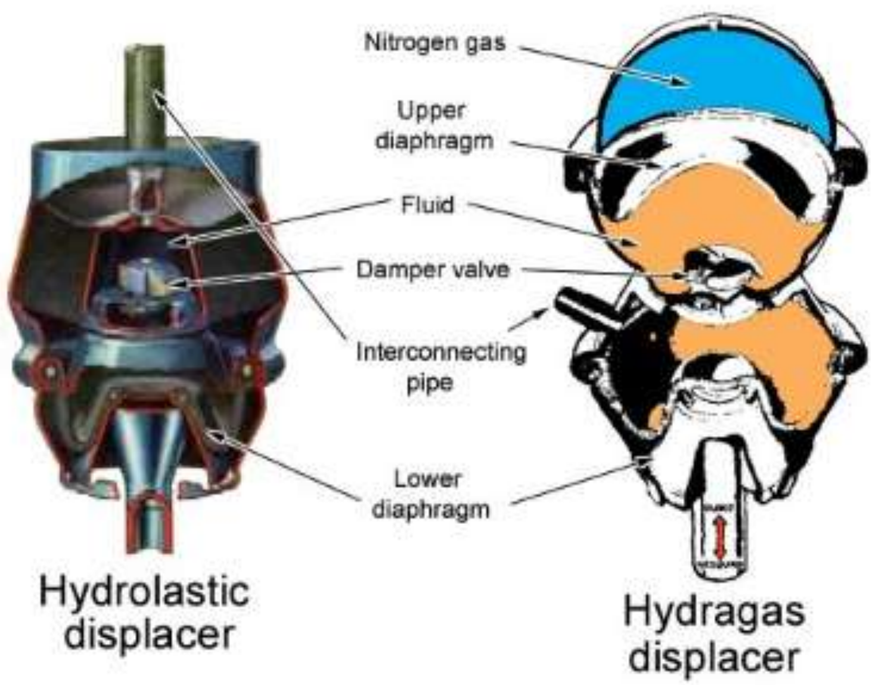


Figure 14: Hydragas Suspension displacers. Image from (Car Bibles, 2012)

The Hydragas suspension mechanism, depicted in Figure 14, is the second suspension system being looked at. The Hydragas displacer is an upgrade of the Hydrolastic displacer. The idea and basic functions remains the same, to maintain level driving conditions by transfer of fluids between the front and rear suspension systems. The only difference is that the rubber spring dampener in the Hydrolastic system is replaced by a nitrogen gas dampening system. The hydraulic fluid is separated from the nitrogen gas with a flexible diaphragm to allow for the gas to be compressed when the wheel is displaced; note that the hydraulic fluid is still free to flow from the front to the rear units and back through the interconnecting pipe. This allows for a greater dampening effect compared to the rubber spring in the Hydralastic displacer, especially when both wheels are deflected simultaneously, and the hydraulic fluid does not flow between the front and rear suspension systems (Car Bibles, 2012).

Figure 15: Hydraulic Suspension. Image from (Car Bibles, 2012)

The third suspension mechanism is a Hydraulic suspension, as seen in Figure 15. It is designed by a Spanish company called Creuat. They created an interlinked suspension system that focuses on controlling the four main suspension parameters: roll, pitch, bump and warp. Their system allows for a different spring and damper rate to be set for each dynamic mode of suspension using four different gas spring chambers; one for each function. Typically, the results of this hydraulic suspension are seen in active systems, but their unique design is still a passive design, meaning there does not need to be an onboard computer to control the spring rate and dampening. This system has only been implemented in racecars, and is not yet commercially available since not much is known about it (Car Bibles, 2012).

The last common suspension mechanism is an air suspension. Air suspension is simply using polyurethane rubber air bags filled with pressurized air to dampen and reduce road vibrations. The system is primarily used for logistic trucks that carry heavy goods that are susceptible to damage from extraneous accelerations and need to be able to maintain a level ride. The polyurethane bladders are flexible and made to sustain high tensile stresses from the air pressure within, caused by the load of the vehicle. The air suspension system typically replaces the springs, and provides better shock absorption than the metal suspension. In addition, each bladder is connected to a small compressed air reservoir and an air compressor through a valve system. By opening and closing the valves, it allows for the level of damping that the system has to be adjusted, along with the height of the vehicle (Car Bibles, 2012).

Figure 16: Air Suspension Bag. Image from (Car Bibles, 2012)

To replace leaf-spring suspension systems, air suspension bags are used, seen in Figure 16. Furthermore, this air suspension bag could be adapted to practically fit any swinging-arm type suspension system. Due to the simplicity of the system, the air bag suspension is a very reliable system to be used (Car Bibles, 2012).

Figure 17: Air Suspension Strut Image from (Car Bibles, 2012)

The air strut system replaces the spring struts. It has a more complex design, and can come in a simple strut, depicted in Figure 17, or a pivoting strut. It uses the same principle of pressurized air, but with a different structure than the air suspension bag. To replace a MacPherson strut, the pivoting strut has a complex twisting double-doughnut design that still allows the shock absorber to pass through the middle (Car Bibles, 2012).

Most air suspension systems are enhanced by a ride-height system which monitors the height of the vehicle as it drives over road perturbations. The ride-height system uses a pivoting mechanical lever that is attached to the chassis of the vehicle and the suspension system. As the suspension deflects, an onboard computer system reads an electrical resistance pot located at the chassis pivot. The computer then interprets the signal, and can increase the pressure in the suspension at the different corners of the vehicle so that the vehicle remains level. For example, if the vehicle is taking a sharp right turn, the suspension on the left side of the vehicle is being deflected much more than the suspension on the right. The computer recognizes that left side is lower, and therefore pressurizes that side to level the vehicle as it takes the turn, then reduces the pressure as the vehicle gets out of the turn. This works for when the vehicle accelerates or engages road perturbations. This system is an active suspension system, since it uses a computer to monitor level of the vehicle, and tends to cost more than a passive system (Car Bibles, 2012).

If the vehicle has a factory built in air suspension system, it will have a ride height system built in with an integrated control panel and computer system. Otherwise, if it is an aftermarket installation, the control panel typically is a hand-held device with a small display and control buttons. Regardless, the driver is able to alter the system to vary the stiffness, dampening, and ground clearance of the vehicle (Car Bibles, 2012).

2.3 Affected Care

In this section of Chapter 2, the team has discussed the cares that are affected by ambulance vibrations. Vibrations have a physiological effect on the body and this will alter how procedures are performed or how the results of some tests are determined. Procedures that are discussed in this chapter are Lead Electrocardiograms, Automated External Defibrillator, blood pressure readings, and intravenous therapy.

2.3.1 Lead Electrocardiogram and Automated External Defibrillator

Automated External Defibrillator (AED) is a portable, typically battery powered, device that analyzes the heart rhythm a patient's heart and can deliver an electric shock to attempt to restore the normal heart rhythm. Figure 18 shows an AED that may be used by EMS personnel. Sudden Cardiac Arrest (SCA) is the sudden unexpected loss of: heart function, breathing, and consciousness. SCA is usually caused by an electrical disturbance in the heart that interrupts the normal heart pumping function. If cardiac arrest is not treated immediately, death will usually occur. AED are carried ambulances and can be found most public areas and schools (What is an, 2009).

Figure 18: A typical AED. Image from (CPR and First Aid Retention – Revisited, 2012)

The heart is controlled by a series of electrical impulses. With each heartbeat, these impulses travel through the heart and cause it to contract. The heart contracting heart pumps blood through the body. An abnormal heart rhythm caused by a problem with the electrical impulses may cause the heart to beat too fast, too slow, or irregularly. This is called an arrhythmia. Ventricular fibrillation is a common cause of an arrhythmia, in which the ventricles beat irregularly. Another cause of arrhythmia is ventricular tachycardia where the ventricles experience a series of very fast beats (What is an, 2009).

An AED sometimes can be used to correct arrhythmia. An AED consists of a device with two electrode pads. The two pads are placed on the patient's chest, and the AED analyzes the patient's heart rhythm. If the heart has an irregular rhythm, the AED can deliver an electric shock that may correct the heart beat and restore the normal heart beat (What is an, 2009).

A twelve lead electrocardiogram (12-lead ECG) uses electrodes placed in various places on the body, to record and measure detailed electrical activity of the heart. The electrical information measured by the ECG is translated into spikes and dips in line tracings. As a result, these waves can be used to diagnose various heart conditions. There are many symptoms that will usually result in an EMT taking a 12-lead ECG. These symptoms include: chest pain or discomfort, shortness of breath, nausea, weakness, heart palpitations, anxiety, abdominal pain, or fainting. An ECG is an easy, non-invasive was to determine and problem with the patient's heart and therefore often used by EMTs. ECGs are able to detect any of the following problems: arrhythmias, heart defects, problems with the heart valves, blocked or narrowing arteries (coronary artery disease), heart attack, and a previous heart attack (Cohen, 2011).

The 12-lead ECG attaches electrodes to twelve locations on the patient's body. Figure 19 shows the placement for the electrodes of the 12-lead ECG.

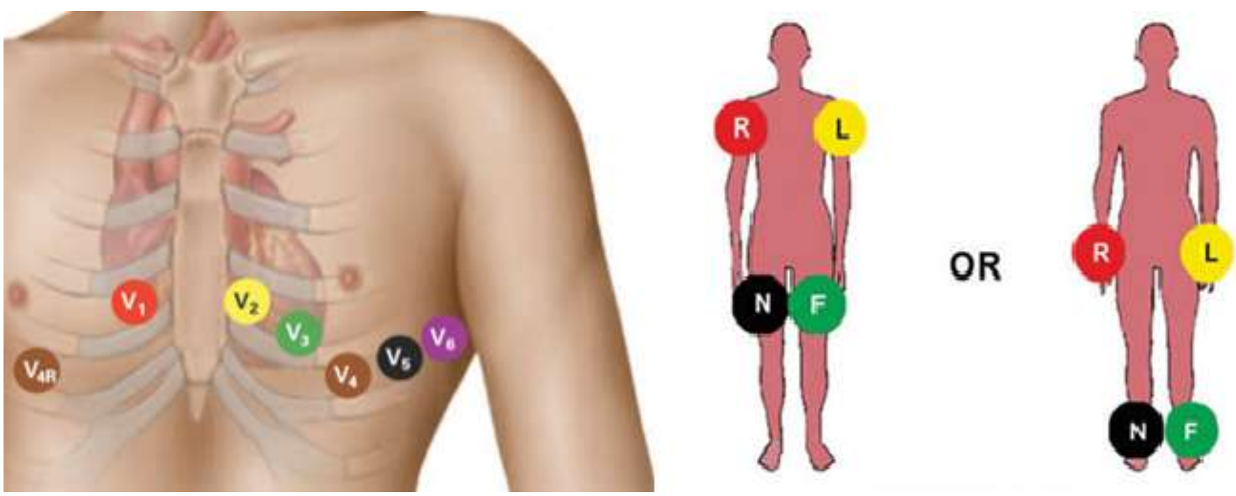


Figure 19: Placement location of 12-lead ECG electrodes. Image adapted from (The ECG Leads, 2010) and (Biolog 3000i, 2011)

V_1 through V_6 are placed in the following locations: V1: Fourth intercostal space to the right of the sternum, V2: Fourth intercostal space to the Left of the sternum, V3: Directly between leads V2 and V4, V4: Fifth intercostal space at midclavicular line, V5: Level with V4 at left anterior axillary line, V6: Level with V5 at left midaxillary line (Directly under the midpoint of the armpit). R is the electrode place lower right forearm, right below the wrist or on the shoulder. L is placed on the below the left wrist on the forearm or on the shoulder. Electrode N is on the upper right leg or on the lower leg near the ankle. F is placed on the left upper leg or lower leg. A gel is usually applied so the electrode will stick to the skin and get a better reading (The ECG Leads, 2010).

Each heart beat has a PQRST wave that is displayed on the ECG. Each part of this wave can tell the interpreter vital information. The P wave is the sequential activation (depolarization) of the right and left atria. The right and left ventricular depolarization (normally the ventricles are activated simultaneously) is known as the QRS complex. ST-T wave corresponds to ventricular repolarization. The origin of the U wave is unknown, but it most likely represents "after-depolarizations" in the ventricles. The PR interval is the period from onset of atrial depolarization (P wave) to onset of ventricular depolarization (QRS complex). The QRS interval duration is the segment of ventricular muscle depolarization. QT interval is the duration of ventricular depolarization and repolarization. RR interval is the duration of ventricular cardiac cycle (an indicator of ventricular rate), while the PP interval indicates the duration of atrial cycle (an indicator of atrial rate). A trained person will be able to interpret abnormalities in the PQRST wave, determine possible causes of the problems, and recommend possible treatment (Yanowitz, 2006).

In both Electrocardiograms and Automated External Defibrillators, false cardiac rhythms can be recorded. These false signals are called artifacts by the health industry. An artifact is defined as any false electrocardiographic signal, not caused by an actual heart rhythm, but rather, by a different internal or an external source. Artifacts can be caused by a large number of interferences. Physiological sources include breathing and diaphragm movements like hiccups (Yassar, 2006), Cardiopulmonary Resuscitation (Eilevstjønn, 2003), muscle contractions, and even stretching of the epidermis (skin). In addition to the physiological sources, nearby power outlets, power-lines, and malfunctioning components of the ECG machine can all cause artifacts in the reading (Chase and Brady, 2000). Vibration of the body, like that experienced by a patient during driving, causes movements of the body which in turn cause false heart signals on the output from the ECG. These artifacts can easily cause a misdiagnosis by the paramedic as well as incorrect analysis by an AED.

The appearance of artifacts during vibration in and ECG readout translates into several problems for the Paramedics. The ECG is an integral tool for determining an early diagnosis of serious heart problems in the field. Whenever a cardiac emergency is expected, a Paramedic will use an ECG to observe the heart rhythm. In cardiac emergencies, time is especially crucial to the survival of the patient. ECG's allow the receiving team at the hospital to have an early indication of the nature of the illness, making preparation for the patients' arrival less of a guessing game. The use of the ECG in the pre-hospital environment often leads to quicker treatment of life threatening conditions and a decreased mortality rate in patients (Diercks et al., 2009). Often, incorrect heart rhythms are different from normal rhythms by a single peak on the readout.

The presence of artifacts during the analysis of an AED is even more troubling. While ECG is required for a paramedic to interpret the electrical signals of the heart, an AED automatically records and analyzes the results. After this analysis is complete, the AED will either shock the patient or advise the care giver to press the shock button, depending on the AED being an automatic or semi-automatic, respectively. This automatic analysis realistically means that artifacts will not be recognized as false anomalies. An AED is designed for the early application of life-saving defibrillation for a specific pair of conditions, or heart rhythms. If an artifact causes the AED to misread the rhythm, the required defibrillation has a potential to not be delivered. This one shock could mean the life of the patient.

As stated earlier, there are many causes for artifact presence in ECG cardiac rhythm input. The focus for this study is mechanical vibration of the patient due to ambulance vibration or patient movement. Often, the artifacts due to this movement can closely resemble cardiac dysrhythmias, leading to false diagnosis. Figure 20 (Top) is an example of a cardiac rhythm of a patient experiencing atrial fibrillation, a life threatening condition resulting in insufficient blood pressure and circulation. Figure 20 (Bottom) displays ECG readout of a patient experiencing intermittent shivers due to hypothermia (Chase and Brady, 2000). The patient shivering is causeing the artifacts in the ECG, this shivering is similar to vibrations experienced in the ambulance. Paramedics are trained to recognize artifacts and correct, but a greater solution is to remove the presence of the artifacts all together.

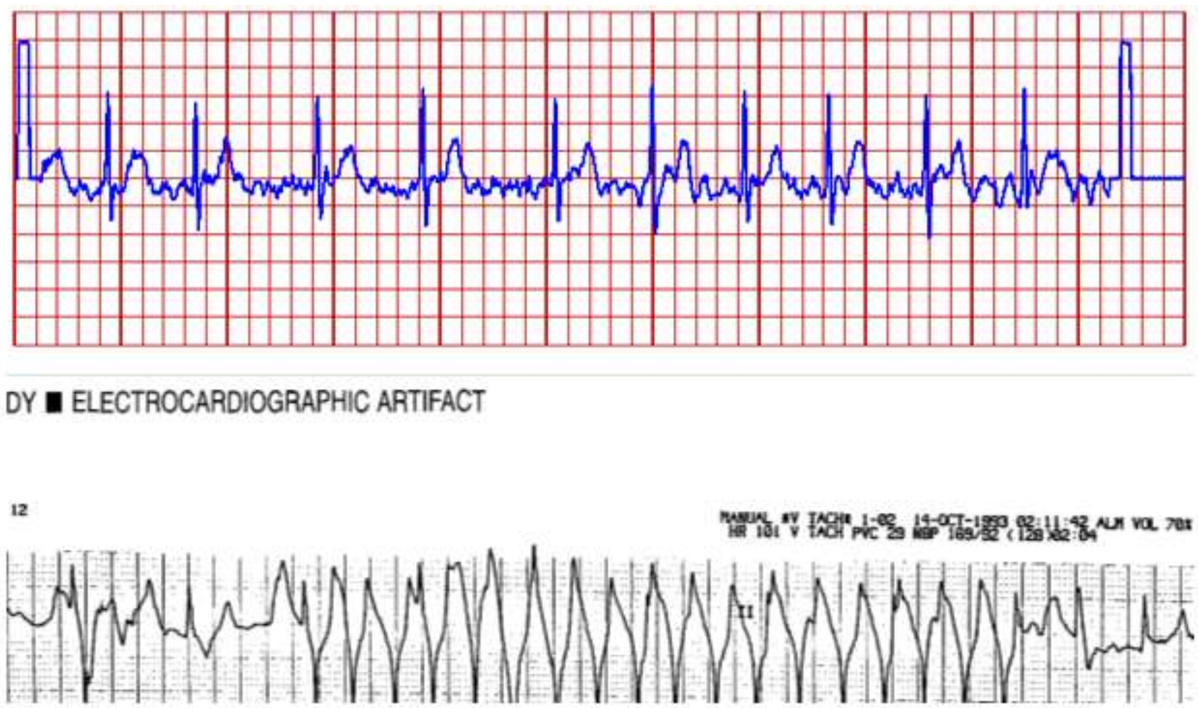


Figure 20: Heart Rhythms. (Top) Cardiac Rhythm of Atrial Fibrillation and (Bottom): Cardiac Rhythm of shivering Hypothermia patient.

(Top) Cardiac Rhythm of Atrial Fibrillation - the rapid fluctuation of the signal showing atrial fibrillation is apparent in between the large peaks of the QRS wave. (Bottom): Cardiac Rhythm of shivering Hypothermia patient – Similar to Figure 20 (Top), there are rapid fluctuations in between every QRS Wave peak.

AEDs respond to artifacts differently from Paramedics observing an ECG heart rhythm strip. Since AEDs do the analysis of the heart rhythm digitally, each requires specific programming to analyze the input from the leads. There is a large industry dedicated to developing algorithms to analyze and filter the signal input for accurate diagnosis. Through the different manufacturers and models of AED on the market, each has diverse performance statistics under mechanical vibration for artifact removal. Studies tasked with researching the effectiveness of these AED's show mixed results. One such study focusing on the performance of AEDs in a moving ambulance found one model of AED was correctly advised shock for ventricular fibrillation (VF) 92% of the time during driving on unpaved roads while a different was greatly degraded to 74%. Both AEDs correctly advised for shock during VF, while driving on paved roads. Neither device performed at required standards for asystole on during any driving conditions (Jong Geun Yun et al., 2009).

The presence of artifacts induced while driving has caused an industry wide practice of performing the ECG in the field prior to transport. While the use of the ECG in the field has decreased patient mortality, it has also increased the time from the arrival on scene to the arrival at the hospital with the patient. This time is crucial to the survival of a patient, especially for a patient suffering from a cardiac emergency. The ability to perform an ECG test or AED analysis and shock while en route to the receiving hospital could greatly reduce the time between an arrival on scene and an arrival at the hospital, thus providing the potential for better survival rates.

2.3.2 Additional Cares

Intravenous therapy, or IV therapy, is the injection of liquid solution, containing water, electrolytes, sugars, and sometimes medications, directly into a vein as seen in Figure 22. The word 'intravenous' simply means *within a vein*. Intravenous therapy may be used to correct electrolyte imbalances and to carry medications for transferring blood or as fluid replacement to correct dehydration. When compared to orally consuming food and medication administration, the intravenous route is a much faster and more effective way to deliver fluids and medications throughout the body (Martin, 2003).

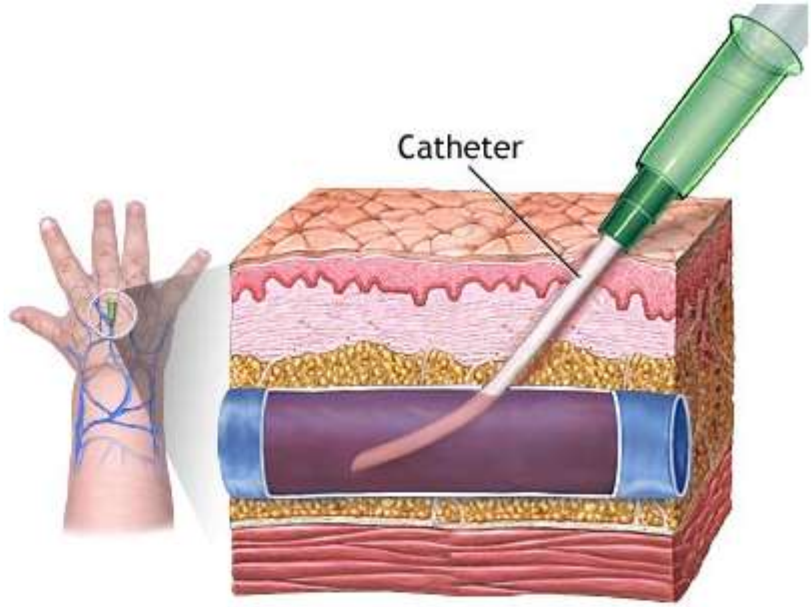


Figure 21: IV catheter inserted in a vein, in the patient's hand. Image adapted from (Intravenous catheter, 2011)

There are three types of needles and catheters used for supplying IV to the vein. The first type is a steel needle. It is also known as a butterfly catheter named after the plastic tabs that look like wings, located on both sides of the needle, as seen in Figure 22 on the right. Butterfly catheters are

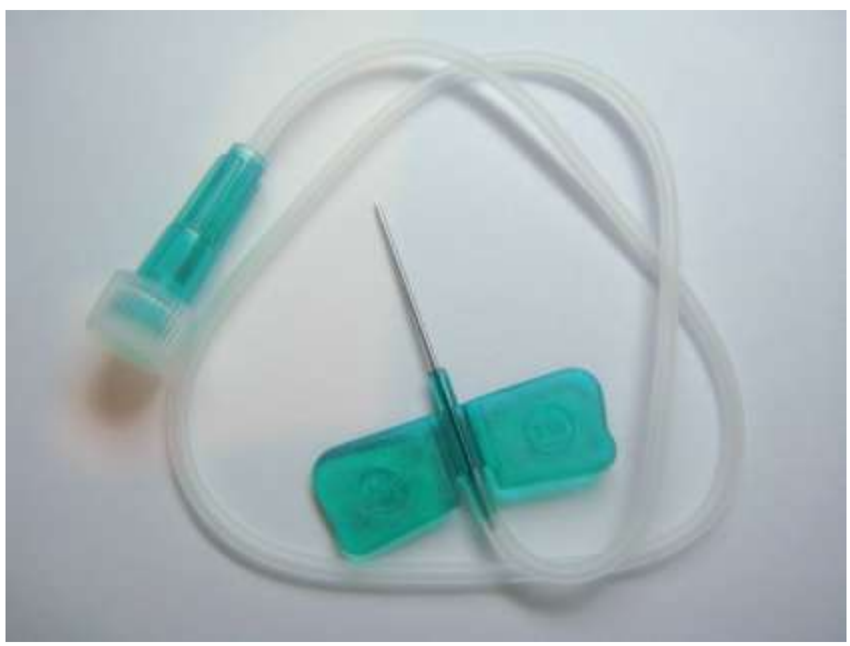


Figure 22: A butterfly IV catheter and needle. Image from (Safety-Tec Butterfly IV Cannula, 2010)

generally used injections of small quantities of medication and use with infants. When drawing blood through the small size of this catheter, blood cell damage will usually occur, this is why butterfly catheters are typically only used for small quantity injections. An over-the-needle catheter is the second type of IV needle. In this peripheral-IV catheter, a catheter is around the needle and once the needle and catheter are placed in the vein, the needle is removed, see Figure 23 for a diagram of how an over-the-needle catheter in placed in the vein (Martin, 2003).

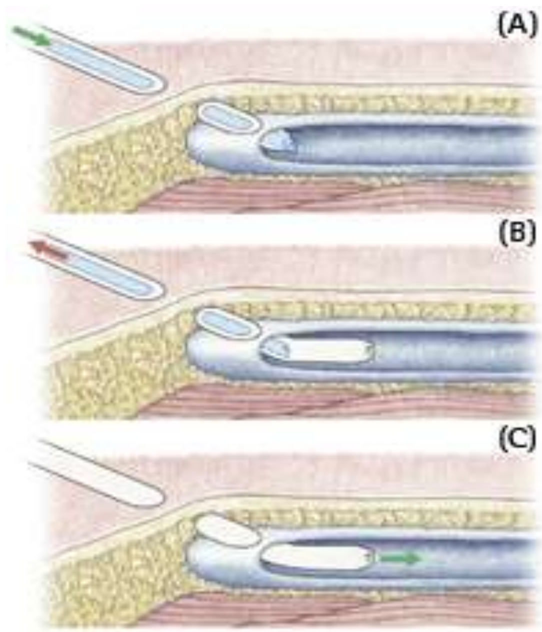


Figure 23: Insertion of an over-the-needle catheter. (A) The needle with the catheter around is inserted into the vein (B) The needle is removed (C) The catheter is kept in the vein. Image from (Catheter-over-needle, 2012)

Peripheral-IV catheters are usually made of various types of Teflon or silicone. Which material used determines how long the catheter can remain in person's vein in a stable position. This type of catheter typically needs to be replaced about every 1 to 3 days (Martin, 2003).

The last type of needle used with the IV is an inside-the-needle catheter. It is larger than over-the-needle catheter and usually used for injecting through the central lines. Injecting into central lines, larger gauge needles are needed. Using larger gauge needles, it is easy for the needle to stab the other side of the blood line. Figure 24 shows an example of an inside-the-needle catheter (Martin, 2003).

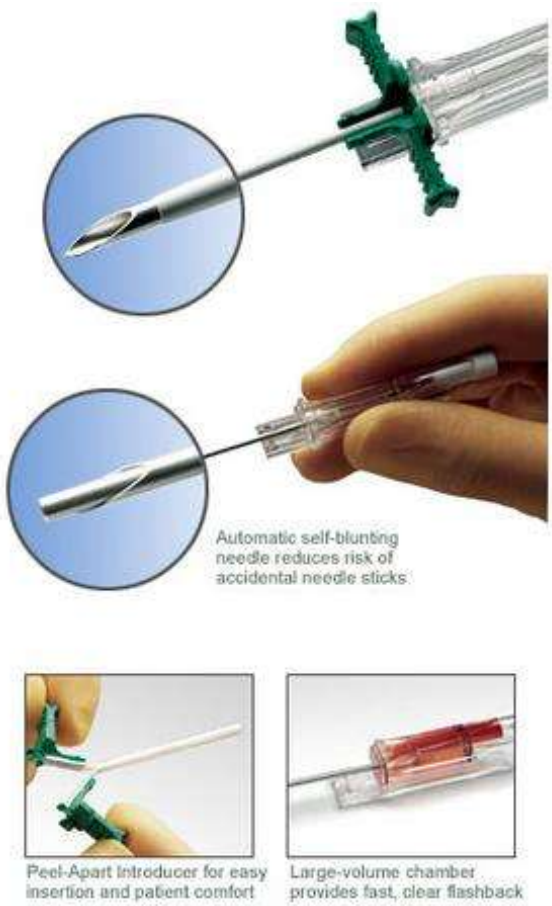


Figure 24: An inside-the-needle catheter. The catheter inside the needle prevents damage to the patient. Image from (Safety Excalibur Introducer Needle, 2012)

For each type of catheter, there are many sizes of needles that are used. Gauge refers to the diameter of the needle, a higher gauge refers to a smaller needle; some of the commonly used needle gauges are shown in Figure 25 (Martin, 2003).

Figure 25: Common IV needle sizes. Sizes are measured in Gauges, which refer to the diameter of the needle. Left to right: 26 G, 25 G, 23 G, 22 G, 21 G, 20 G, and 18 G. Image adapted from (Nipro Needles, 2012)

There are main three types of IV fluids. The first type one is the isotonic fluids, which have the same osmolarity, the measure of solute concentration defined as the number of osmoles (Osm), unit of measurement that defines the number of moles of a chemical compound that contribute to a solution's osmotic pressure, of solute per liter (L) of solution (Osm/L), with the serum, a component of blood which is collected after coagulation, the complex process of clotting of blood. These fluids remain intravascularly momentarily, so that it could expand the volume. It is helpful with patients who are hypotensive or hypovolemic. Hypotensive patients have an abnormally low blood pressure, especially in the arteries of the systemic circulation, while hypovolemic patients have a state of decreased blood volume, specifically decreased volume of blood plasma. However, it has a risk that fluid would overload when it is injected in the blood vessel. Therefore, paramedics should be careful with dealing with patients with left ventricular dysfunction, history of CHF or hypertension. Also, the fluids avoid volume hyperexpension in patients with intracranial pathology or space occupying lesions (Martin, 2003).

The second IV fluid type is the hypotonic fluids. It has a less osmolarity than serum, which means that, in general, it has a less sodium ion concentration that serum. These fluids dilute serum thus decreases the osmolarity. The water moves from the vascular compartment into the interstitial fluid compartment, then interstitial fluid becomes diluted, then osmolarity decreases, and water is drawn into adjacent cells. These fluids are helpful when cells are dehydrated from the conditions or treatments such as dialysis or diuretics or patients with DKA (high serum glucose causes fluid to move out of the cells into the vascular and interstitial compartments). However, the paramedics should be aware with the use of these fluids because sudden fluid shifts from the intravascular space to cells can cause cardiovascular collapse and increased ICP in certain patients (Martin, 2003).

The last IV fluid is the hypertonic fluids. These fluids have a higher osmolarity than serum. These fluids pull fluid and sometimes electrolytes from the intracellular or interstitial compartments into the intravascular compartments. It is useful for stabilizing blood pressure, increasing urine output, correcting hypotonic hyponatremia, and decreasing edema. They are dangerous in the cause of cell dehydration (Martin, 2003).

There are two main groups of fluids: crystalloids and colloids. Crystalloids are clear solutions –fluids that are made up of water and electrolyte solutions. These fluids are useful for volume expansion. However, both water and electrolytes will cross a semi-permeable membrane into the interstitial space and attain equilibrium in two or three hours. The paramedics should remember that 3 mL of isotonic crystalloid solution are needed to replace 1 mL of patient blood. This is because approximately two-thirds of the solution will leave the vascular space in approximately one hour. In the management of hemorrhage, initial replacement should not exceed 3 L before you start using whole blood because of risk of edema, especially pulmonary edema. Some of the advantages of crystalloids are that they are inexpensive, easy to store with long shelf life, readily available with a very low incidence of adverse reactions, and variety of formulations that are available that are effective for use as replacement fluids or maintenance fluids. A major disadvantage is that it takes approximately two or three times of volume of a crystalloid to cause the same intravascular expansion as a single volume of colloid (Martin, 2003).

The second group of IV fluids is the colloids. Colloids are large molecular weight solutions (nominally Molecular Weight > 30,000 Daltons). The solutes of the colloids will not easily cross semi-permeable membranes or form sediments. The primary reason for this is the solutes are macromolecular substances made of gelatinous solutions which have particles suspended in the solution. Because of their high osmolarities, these are important in capillary fluid dynamics because they are the only constituents which are effective at exerting an osmotic force across the wall of the capillaries. These work well in reducing edema, an abnormal accumulation of fluid beneath the skin or in body cavities that produces swelling, drawing fluid from both interstitial and intracellular compartments into the vascular compartments. Initially these fluids stay almost entirely in the intravascular space for a prolonged period of time compared to crystalloids. These will leak out of the intravascular space when the capillary permeability is unbalanced or leaky. The albumin solutions are available for use as colloids for volume expansion in the setting of CHF; however, the albumin is currently in short supply. There are other available solutions containing artificial colloids (Martin, 2003).

One of the general problems with colloid solutions is the higher cost as compared to crystalloid solutions. Also, it is small but significant incidence of adverse reactions, because of gelatinous properties, colloid solutions can cause platelet dysfunction and interfere with fibrinolysis and coagulation factors. The interference between the solution and the clotting factors can sometimes cause coagulopathy (clotting or bleeding disorder), this is more common when large volumes of colloid solutions are used. Another problem is that these fluids can cause dramatic fluid shifts, which in turn can be dangerous if they are not administered in a controlled setting (Martin, 2003).

Patients who have an IV placed in an out-of-hospital setting are at risk for experiencing infection, pain, discomfort, and distress. There is some evidence that risk of infection may be higher in the field than in hospital. Lawrence and Lauro's 1988 study found that patients were nearly five times more likely to develop phlebitis from IVs started in the field than from IVs started in the hospital environment. Although this study has been criticized for the method of patient recruitment, the points that Lawrence and Lauro make concerning the demand for short scene times and expectations of fast IV placement may result in traumatic insertion and/or not allow for proper aseptic technique, both of which have been shown to increase the risk of infection. Contrary to expectations, no patients reported any infections in this study. It can be speculated that six months after the event, patients may not have remembered any infection, or in the case of phlebitis, patients may not have necessarily considered inflammation around the IV site to have been an infection. However, it is reasonable to presume that there was no significant infection at the cannula site in this sample of patients, but some minor infections may have been experienced. The prevalence and incidence of other health costs had not been estimated in this patient group prior to the study. In line with previous research carried out in other settings, patients in this study population did report the disadvantages of IV placement—discomfort, pain, or distress—when the IV was placed and during the time it remained in. Although this did not appear to detract from their satisfaction with the care delivered by the ambulance service and by individual ambulance personnel, other factors had an important impact on the results. Patients who did not know why the IV had been placed reported greater distress associated with the placement of the IV (Halter, 2000).

Nevertheless, it is important to recognize the responses given by patients to the crews for many aspects of their care. Many patients delivered feedback about the care they received and their satisfaction with their treatment through the questionnaire about a specific intervention by paramedics. The health costs of having placed the IV are usually high and therefore should not be underestimated. It is important to balance the opportunity for health gain afforded by the timely placement of an IV against these costs to the patient. As a result of this study, it has been recommended that protocols for IV placement should be explicit about the risks of pain, discomfort, and distress to patients found in this study along with others, and about infection rates from previous studies associated with IV placement. Explaining all procedures to patients should be re-emphasized in paramedic training, and is important because it not only lets the patient know what treatment is being done, it also reinforces the treatment to the medical personnel. In this way, findings from this patient-focused study can be used to directly affect the field of practice (Halter, 2000).

Blood pressure is considered one of the four main vital signs of the body and must remain within a certain range to avoid complications. Blood pressure is the amount of force per area in which one's blood is pushing outward against the arterial walls as it flows throughout the body. As the heart beats, the pressure varies. The systolic blood pressure is the pressure which results when the heart beats, or contracts, pushing the blood through the circulatory system. The diastolic blood pressure occurs when the heart is resting between beats and is filling up with blood again. During a heartbeat cycle, the systolic blood pressure is the highest pressure output while the diastolic blood pressure is the lowest. Blood pressure is typically measured in millimeters of mercury, or mmHg. The standard way of writing down blood pressure readings is placing the systolic number in the numerator and the diastolic number in the denominator followed by the unit mmHg. A normal healthy person has a blood pressure reading of no greater than $\frac{120}{80} mmHg$, which is read as 120 over 80 millimeters of mercury; 120 being the systolic pressure and 80 being the diastolic (American Heart Association, 2011). Blood pressure is measured with a sphygmomanometer, which can be aneroid, electric, or mercury. Figure 26 shows the different types of sphygmomanometers. Typical EMS will use an aneroid sphygmomanometer, but sometimes an electric one is used. A mercury sphygmomanometer is very difficult to use in an ambulance because the EMT must read the meniscus of the mercury, which is difficult to do while the ambulance is in motion.

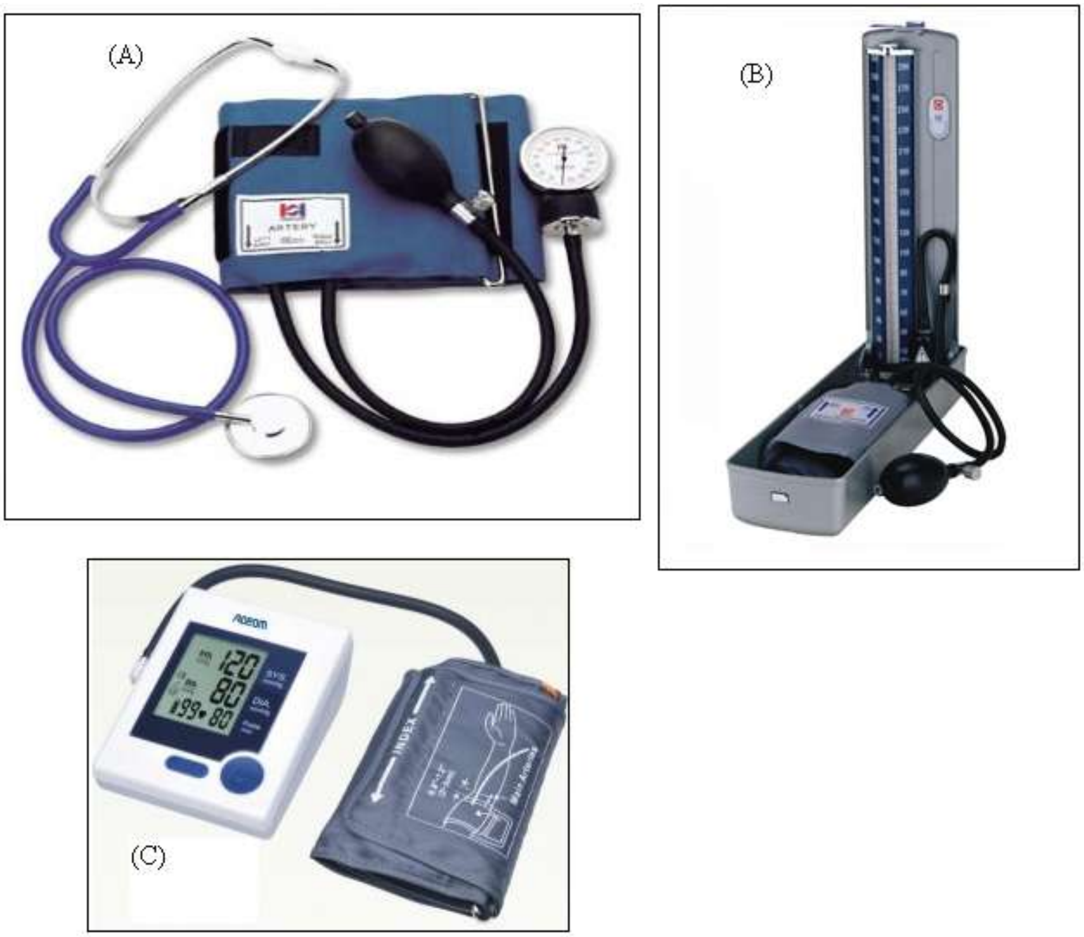


Figure 26: The different types of sphygmomanometers. Images from: (Aneroid Sphygmomanometer, 2011), **(S-MS01 Mercury Sphygmomanometer, 2011),** (**Portable Blood Pressure Monitors, 2011**).

Figure 26 (A) Aneroid, most common once trained is fairly easy to use and accurate. Image from adapted from (Aneroid Sphygmomanometer, 2011). Figure 26 (B) Mercury, most accurate, difficult to use in an ambulance, and presence of mercury is also a potential health risk Image from adapted (S-MS01 Mercury Sphygmomanometer, 2011). Figure 26 (C) Electric, very easy to use, but the accuracy of these devices varies. Image from adapted (Portable Blood Pressure Monitors, 2011).

High blood pressure, also known as hypertension, is defined as a systolic pressure of 140 mmHg or higher, or a diastolic pressure of 90 mmHg or greater. An extreme case of high blood pressure is known as a hypertensive crisis which is a systolic pressure greater than 180 mmHg or a diastolic pressure greater than 110 mmHg and requires immediate emergency care. High blood pressure is a chronic condition. Some symptoms are severe headache, shortness of breath, nose bleeds, and severe anxiety. Hypertension can result in stroke, loss of consciousness, memory loss, heart attack, damage to the eyes or kidneys, loss of kidney function, aortic dissection, angina (unstable chest pain), pulmonary edema (fluid backup in the lungs), and eclampsia (American Heart Association, 2011).

Low blood pressure, also known as hypotension, does not have a definite numerical boundary in which blood pressure is considered low; rather it can be diagnosed through symptoms. Some signs of low blood pressure are dizziness, weakness, fainting, dehydrations or unusual thirst, lack of concentration, blurred vision, nausea, cold pale skin, rapid shallow breathing, fatigue, and depression. Low blood pressure could be caused by prolonged bed rest or a sudden change in body position, but also could be caused by significant blood loss, endocrine problems, severe infection/septic shock, anaphylactic shock from an allergic reaction, nutritional deficiency, and certain medication/drugs including heart medication, beta blockers, narcotics, and alcohol. Low blood pressure may result in vital organs and muscles not receiving enough oxygenated blood (American Heart Association, 2011).

In an ambulance, blood pressure is typically measured using the auscultation method. This is the same method used in regular medical exams. A sphygmomanometer, or inflatable cuff with a pressure gauge, is placed around the upper arm at the approximate level of the heart. The sphygmomanometer is then manually inflated using the attached rubber bulb until it is above the systolic blood pressure. The examiner then uses a stethoscope to listen to the brachial artery located at the inner elbow region. While the examiner slowly releases the pressure in the sphygmomanometer, he or she will eventually hear the first Korotkoff sound, or pounding sound. When this is heard, the pressure gauge is read, and the systolic blood pressure is established. As the pressure continues to be released from the cuff, eventually the heart beat can no longer be heard. This establishes the diastolic blood pressure. This method is the easiest non-invasive method to determine someone's blood pressure, and requires the EMT to listen for the heartbeat through the stethoscope.

Every day, EMTs have to establish the blood pressure while the ambulance is in motion. This is a very tricky feat because of how it is measured. EMTs have to listen for the heartbeat, and road vibrations, engine and siren noises, perturbations, and other distractions may lead to inconsistent or inaccurate readings.

In an UMASS Medical School study, blood pressure readings were taken on a training arm with a constant systolic pressure output while in a stationary and moving ambulance. They attached a pump to a vascular tube which was embedded within an intravenous training arm. The pump produced an oscillating pulse similar to a heartbeat, and used a fluid solution composed of 50% water and 50% alcohol. The pump had a high and low pressure setting, which corresponded to the systolic pressure, to add a variable to the test so subjects won't assume the same systolic pressure. Diastolic pressures were neither set up to be measured, nor was data taken on it. A sphygmomanometer and the diaphragm head of a stethoscope were pre-attached to the training arm to restrain the test to the subject's ability to listen for the systolic blood pressure. There were forty-nine participants whose range of experience was from one to twenty-seven years, with a mean of 7.4 years. Two were ambulance attendants, 14 were emergency medical technicians (EMTs), 17 were EMT-Defibrillators, 11 were EMT-Intermediates, one was an EMT-Advanced Intermediate, one was an EMT-Paramedic, and three were emergency medicine residents (Prasad, 1994).

The auscultations were always taken in the same ambulance that was set up the same for all the tests. The variables were the high and low setting on the systolic pressure, and more importantly, the ambulance was either stationary or mobile. Each subject had to determine the blood pressure five times stationary and five times mobile; the pressures were randomly set as the high or low setting for each auscultation. The mean reported systolic blood pressure at the stationary high setting was 133±5mmHg; the range was from 60mmHg to 190mmHg, with a median of 132mmHg. The mean reported systolic blood pressure at the mobile high setting was 86±7mmHg; the range was from 0mmHg to 205mmHg, with a median of 87mmHg. The mean reported systolic blood pressure at the stationary low setting was 45±6mmHg; the range was from 0mmHg to 170mmHg, with a median of 41mmHg. And the mean reported systolic blood pressure at the mobile low setting was 41±7mmHg; the range was from 0mmHg to 165mmHg, with a median of 29mmHg. As can be seen through the difference in the data of the high systolic pressure readings while stationary and mobile, the ability to deduce a precise pressure is inhibited by everything else going on in a moving ambulance. In the low systolic pressure test, there were quite a bit of pressure readings of zero for the moving scenario, meaning the other data collected may have even been guesses. The ability to listen for the beat is disrupted by the road vibrations, perturbations, siren noise, and many other factors. Even though this experiment was conducted on a training arm instead of a real person, the data gathered shows the inaccuracy and difficulty of trying to auscultate within a moving ambulance (Prasad, 1994).

2.4 Comfort

This chapter will discuss the comfort of the patient and the EMT while traveling in the ambulance. Vibrations in the ambulance are uncomfortable and cause short and long term damage to the patients and EMT. Topics discussed in this chapter include: how the vibration affects the human body, vibrations and the stretcher, comfort of the patient, and the comfort of the EMT.

2.4.1 Effect of Vibration on the Body

The human body is very sensitive to vibrations. Even though ambulances have suspension systems which reduce the vibrations encountered by driving on roads, the oscillating accelerations can greatly affect the people on board. EMTs constantly have to endure the road vibrations while working on patients. And the patients, who might not be in the best of conditions, feel the effect of the vibrations even more due to the fact that they are lying supine.

Vibration is composed of two main components. The frequency is how often the oscillatory wave pattern occurs within a specific amount of time. The oscillatory wave pattern could be, but is not necessarily, a sinusoidal pattern in which the displacement of an object moves back and forth in a repeating manner. The frequency of a wave is measured in hertz [Hz]. Hertz is the amount of cycles per second in which the wave repeats itself. Hertz is also the reciprocal of the period, or the seconds it takes a wave to make its cycle. The other main component of a vibration wave is the amplitude. The amplitude is the magnitude of the wave, and defines how strong a vibration is. The amplitude of a vibration is measured as an acceleration, which in turn can cause forces and impacts upon objects.

Just about every object and its components have a natural frequency range in which it resonates; this includes human beings and their organs. An object that resonates has a natural frequency that matches the frequency of the originating vibration, but has greater amplitude. This greater magnitude is caused by vibrational energy being added to the system over time. An example of resonance can be seen in a child being pushed in a swing; if the swing is pushed at the correct timing, the child is able to swing higher and higher. When vibrations occur in the ambulance from driving, they travel up and through anyone who is inside. These vibrations may or may not be at resonating frequencies of the people and their organs. Regardless, these vibrations are known as Whole Body Vibrations (WBV), and are known to cause health issues.

WBV exposure may cause minor problems such as discomfort and annoyance, but it also can influence an EMT's capability to perform procedures, or present health and safety risks. The frequency that affects the human body ranges from 0.5 to 80 Hz. Through various studies, the natural frequencies of the various body parts and organs have been distinguished, and can be seen in Table 6 and on the following page, Table 7.

Table 6: Resonance frequencies of the human body parts/organs (Raemaekers,2009).

Natural Frequencies of the Body and Its Organs	
Body Part	**Resonance Frequency (Hz)**
Head (axial mode)	± 25
Eyeball (Intraocular structure)	30 – 80
Shoulder Girdle	4 – 5
Chest Wall	± 60
Chest and Belly Cavity	3 – 6
Abdominal Mass	4 – 8
Spinal Column (axial mode)	10 – 12
Lower Arm	16 – 30
Hand Grip	50 – 200
Legs (knees flexed)	± 2
Legs (stretched)	± 20

Table 7: Resonance frequencies for different body parts and organs (Paschold, 2008).

Natural Frequencies of the Body and Its Organs The natural frequencies of the human body and select body parts and organs. The following data has been reported in multiple sources. Data from Kroemer and Grandjean was recorded with the patient in a seated position.		
Whole Body, Body Part, or Organ	**Natural Frequency (Hz)**	**Study Source**
Whole Body, standing	12.3	Randall
Whole Body, seated	4 – 6	Brauer
Whole Body, prone	3 – 4	Brauer
Whole Trunk, vertical	4 – 8	Wassermann
Lumbar vertebrae	4	Kroemer and Grandjean
Hand Relative to Body	20 – 30	Brauer
	5 – 30	Kroemer and Grandjean
	20 – 30	SafetyLine Institute
Eyes	20	Mansfield
	20 – 70	Kroemer and Grandjean
	20 – 90	SafetyLine Institute
Shoulder Girdle	5	Kroemer and Grandjean
Stomach	3 – 6	Kroemer and Grandjean
	4 – 5	SafetyLine Institute
Heart	4 – 6	Kroemer and Grandjean
Bladder	10 – 18	Kroemer and Grandjean

The natural frequency or resonance frequency is the range in which that specific organ or body part is apt to resonate, and thus may be damaged if the magnitude is strong enough. Fortunately, regular muscle and fat tissue does dampen the vibrations to a degree, and has no real adverse effect on said tissue other than fatigue. Regardless of dampening, these frequencies may add on to the pain of existing injuries or may create chronic problems if exposed to the vibrations for long periods of time. For example, a patient that has a blunt force injury to the head not only would be in more pain because he’s laying supine with his head on the stretcher taking direct vibrations, but if the vibrations were around 25Hz, he would agitation would increase dramatically. Another example, many EMTs have had lower back or spinal issues due abnormal postures and exposure to hours of vibrations on end. Other detrimental effects of vibrations could be bone density lose, health effects to the genitals, urinary system, and female reproductive organs, cardiovascular disturbances such as an increase or decrease in blood pressure, and even a drop in survival rate in trauma patients.

According to ISO standards categorize vibration magnitude ranges into discomfort levels as seen in Figure 27 and Table 8. This subjective discomfort range is for someone in the sitting position. For someone in the supine position, the magnitudes would be much less for the same discomfort level due to the fact that more surface area is in contact with the vibrating surface, and the vital organs and body parts are closer to the source of the vibration.

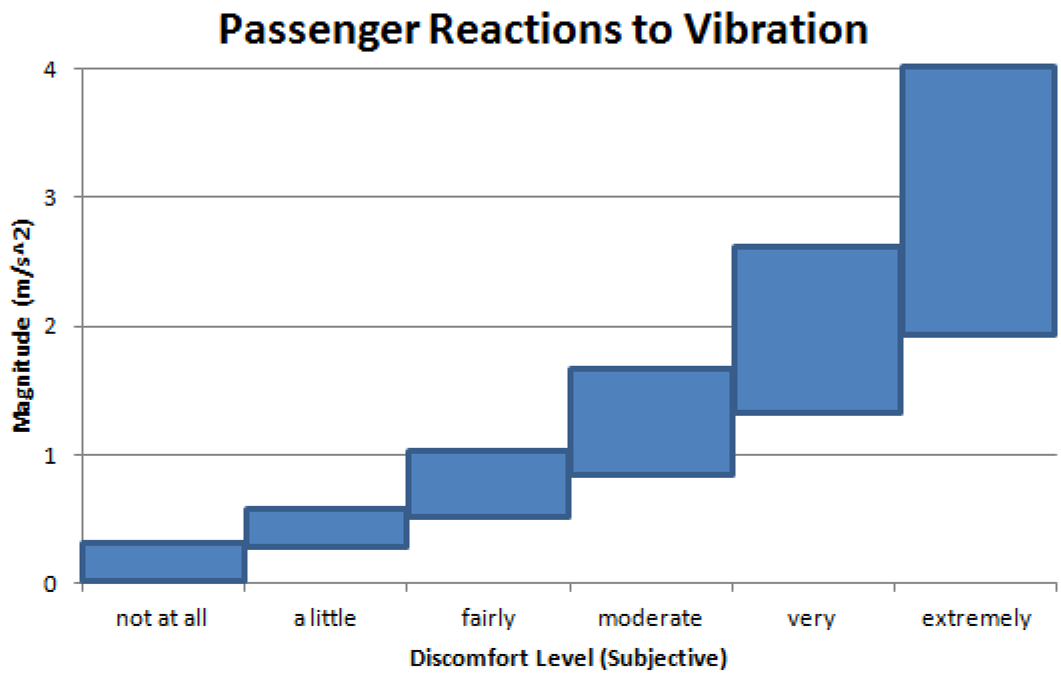


Figure 27: Passenger Reactions to Vibrations. Data from (Paschold, 2008).

Discomfort reactions of passengers in the sitting position on public transportation over increasing levels of vibration [ISO 2631-1:1997(E)].

Table 8: ISO standard vibration ranges for discomfort levels (Raemaekers, 2009).

Acceleration [m/s^2]	Scale of discomfort (suggested by ISO 2631)
Less than 0.315	Not uncomfortable
0.315-0.63	A little uncomfortable
0.5-1	Fairly uncomfortable
0.8-1.6	Uncomfortable
1.25-2.5	Very uncomfortable
Larger than 2	Extremely uncomfortable

The magnitude of the vibration causes displacement which in turn causes impact upon patients and EMTs alike. When the magnitude is great, such as hitting a pot hole or going over a speed bump, it is extremely uncomfortable and even sometimes unbearable. This is the main reason why ambulance drivers sometimes take longer alternate routes, to keep the uncomfortable vibrations to a minimum.

Altering ambulance suspension systems to allow for better passenger comfort could compromise handling of the vehicle. That is why alternative methods of increasing patient and EMT comfort must be looked at. To isolate areas where vibrations could possibly be reduced, all aspects of the patient and EMT transport must be analyzed.

2.4.2 Comfort of Patients

A stretcher is a medical device used to carry a casualty or an incapacitated person from one place to another. A stretcher is usually moved by two people, one at the head and the other at the feet. The casualty is placed on the stretcher, and can then be carried or wheeled away. Stretchers are used when a person is unable to walk by themselves, or if a "stair chair" (wheelchair) or similar device cannot be used. Most modern civilian stretchers include carrying straps to avoid further injury to the patient. Figure 28 shows the type of stretcher that has been used by the UMASS EMS (Hillberry, 2003).

Figure 28: Current stretcher used by UMASS EMTs. Personal photograph Dong-Uk Shin October 4, 2011

Stretchers have been used for hundreds of years, on battlefields and in emergency situations. Stretchers make it easier to transport patients where wheeled vehicles are hindered by rough terrain, inside buildings, or small area. In their simplest form, they generally consist of a canvas sling with long edges sewn to itself to form long pockets. Wooden poles or metal poles could inserted and slid into place in these pockets to form handles and support the patient being transported. This form was common with the military right through the middle of the 20th century, and in disaster situations, where rapid response or transport and movement of patients based on severity of injuries is critical; they are still used by emergency response providers (Hillberry, 2003).

The stretchers used in ambulances have wheels that would be able to make transportation over pavement easier. Inside the ambulance, there is a lock to secure the stretcher during transport. "Normalized" stretchers, or folding stretchers, are the simplest type. They are made of two poles, two transversal hinged bars with a cloth stretched between the poles, and four feet as seen in Figure 29. The bars can be folded for storage. They are now rarely used by modern emergency services, but are still widely used by organizations for which the storage space is an important factor, e.g. first aid associations or French companies (a stretcher is mandatory). These stretchers are often used as beds. Another type of stretcher is the Disaster stretcher, which is designed for easy storage and transport. They consist of a tubular aluminum structure with a washable cloth. They cannot be folded, but can be piled up. As normalized or disaster stretcher have no wheels, they are usually carried by three or four people. When they must be carried by only two people, they tie straps to the poles, so the weight is supported by the shoulders and not by the hands (First Aid Stretcher, 2012).

Figure 29: Simplest type of stretcher. Image from (First Aid Stretcher, 2012)

An ambulance stretcher support is composed of a vibration reduction device with a hard surface above it, on which the stretcher can be positioned over. The stretcher support is embedded within the ambulance floor with the top support surface level with the ambulance floor. In one embodiment, each support includes a stretcher leg receiving member that is adapted to lock an ambulance stretcher leg in place. The base mounts the stretcher leg receiving member so it can move between a position substantially coplanar with the top floor surface and a position below the top floor surface. A vibration reduction device is mounted between the base and the stretcher leg receiving member. Figure 30 shows a diagram of this type of device. The vibration reduction device will reduce transfer of vibration from the moving ambulance floor to the stretcher (Cotnoir, 2010).

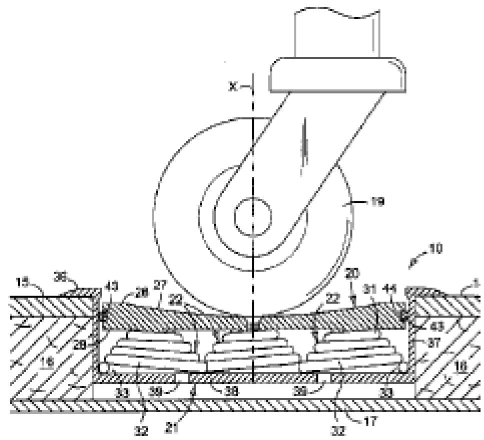


Figure 30: Single leg supporter. Image from (Cotnoir, 2010)

Patient transport by ambulance can result in shock or vibration induced trauma due to road conditions encountered by the ambulance during transit. A degree of ride roughness may be taken into account by the ambulance suspension. However, an ambulance suspension has yet to be developed that is sufficiently compliant for comfort but also allows for safe vehicle operation. A need is thus recognized for some form of compliant patient for a support within an ambulance that will allow use of normal vehicle suspension and yet reduce potential ride induced trauma to the patient (Cotnoir, 2010).

Various patient and stretcher suspension devices have been developed in recognition of the above problem. However, most are costly, complex, and do not adapt well to standardized ambulance lock down arrangements. To make things worse, there is no standard ambulance stretcher configuration, and it remains a problem faced by those wishing to supplement ambulance suspension systems to improve patient comfort. In fact, there are several stretcher configurations currently available in the marketplace. Stretcher configuration and weight may vary, as may lock down arrangements to accommodate the various cot structures. Such variations increase the difficulty in designing a simple universal vibration damping system (Cotnoir, 2010).

Figure 31: Floor of ambulance. Personal photograph Dong-Uk Shin October 4, 2011

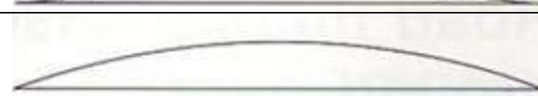
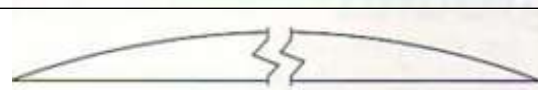
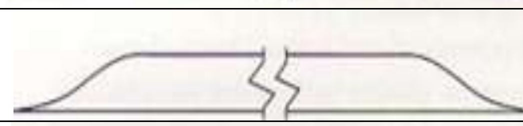
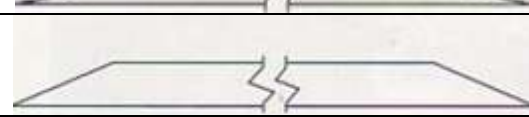
The ambulance floor typically includes a floor covering placed over a subfloor sheet of plywood and the antennae like mocking mechanism shown in Figure 31. The plywood is placed over a metal pan that is either mounted to, or is an integral part of the ambulance chassis. The pan protects and seals the plywood from the outside environment. The plywood, along with the floor covering, provides a degree of sound and heat insulation for the interior of the ambulance. The combination of the covering and plywood presents a floor thickness between the covering and pan that is typically less than about one inch. Without destroying the pan, the thin floor structure limits the use of subfloor mounted vibration reduction mechanisms. Floor mounted vibration reduction systems have been mounted above the floor surfaces to maintain the integrity of the pan. Figure 30 shows a diagram of one of these devices. However, such structures may obstruct access, hinder cleaning, and are very difficult to manufacture and put in the ambulances (Hillberry, 2005).

Motion sickness is a normal response to an abnormal environment. The duration of exposure to the unfamiliar motion increases the severity of its effects. Susceptibility to motion sickness increases with age. Females are also more susceptible to motion sickness compared to males of the same age. Patients under transport are often prone to nausea and vomiting as a result of their disorder, their mental state, or because they have been given opiates. Vibration of low frequencies (0.1 to 1 Hz) may contribute to motion sickness. When lying in a compartment without a view of the horizon or another stable visual reference outside the vehicle increases their susceptibility. A supine position can reduce the incidence of motion sickness. It may also help to close the eyes, unless it is possible to give the patient an outlook. Head movements should be reduced to a minimum. Fresh air can cause symptomatic improvement. If not contraindicated, antiemetic drugs such as metclopramide or droperidol should be given generously. The patient's attention should be drawn away from the state of one's stomach (Soreide, 2001).

The Department for Transport in the United Kingdom, preformed a study on road bump profiles in 2000. Acceptance of road humps schemes depends in part on whether traffic speeds are reduced. However, it is also influenced by the degree of discomfort to the vehicle occupants, and the effect the road humps may have on traffic noise and ground-borne vibrations. The Transport Research Laboratory (TRL) was commissioned by the Department of the Environment, Transport and the Regions (DETR) to investigate the effects on discomfort, noise, and ground-borne vibrations of sinusoidal profile road humps compared with flat-top and round-top road humps (Department of Transport, 2000).

The dimensions of the profiles chosen for evaluation are shown on the Table 9. The five hump profiles used in the trials included three profiles not commonly used: a 3.7m long sinusoidal profile, a 5m long round-top profile and an 8m long flat-top with sinusoidal ramps. Two standard profiles were included for comparison: a 3.7m long round-top profile and an 8m long flat-top hump with straight ramps. All the hump profiles were 75 mm high (Deaprtment of Transport, 2000).

Table 9: Profile Dimensions. Data from (Department for Transport, 2000)

Profile Type	Length of Bump (m)	Max Height of Bump (mm)	Plateau Length (m)	Ramp Gradient	Profile Detail Image
Sinusoidal	3.7	75	-	-	
Round-top	3.7	75	-	-	
Round-top	5.0	75	-	-	
Flat-top with sinusoidal ramps	8.0	75	6.0	-	
Flat-top with straight ramps	8.0	75	6.0	1:13	

The vehicle, approximately the size of an ambulance, was used in the trial to assess discomfort, noise, and ground borne vibrations. Figure 32 illustrates how a small change in speed can lead to a large increase in discomfort. While Figure 33 shows the average of the values in Figure 32, with a best fit line. For this size of a vehicle driving at 15 mph or less, passengers generally experienced less discomfort with the round-top and sinusoidal profiles than with the flat-top profiles. At speeds above 15 mph, general levels of discomfort were unacceptable for all the profiles tested. Data for Figures 32 and 33 was obtained from Department of Transport, 2000 and can be found in Appendix B, along with similar graphs, including bump/speed profiles for motorcycles, buses, and double-decker buses.

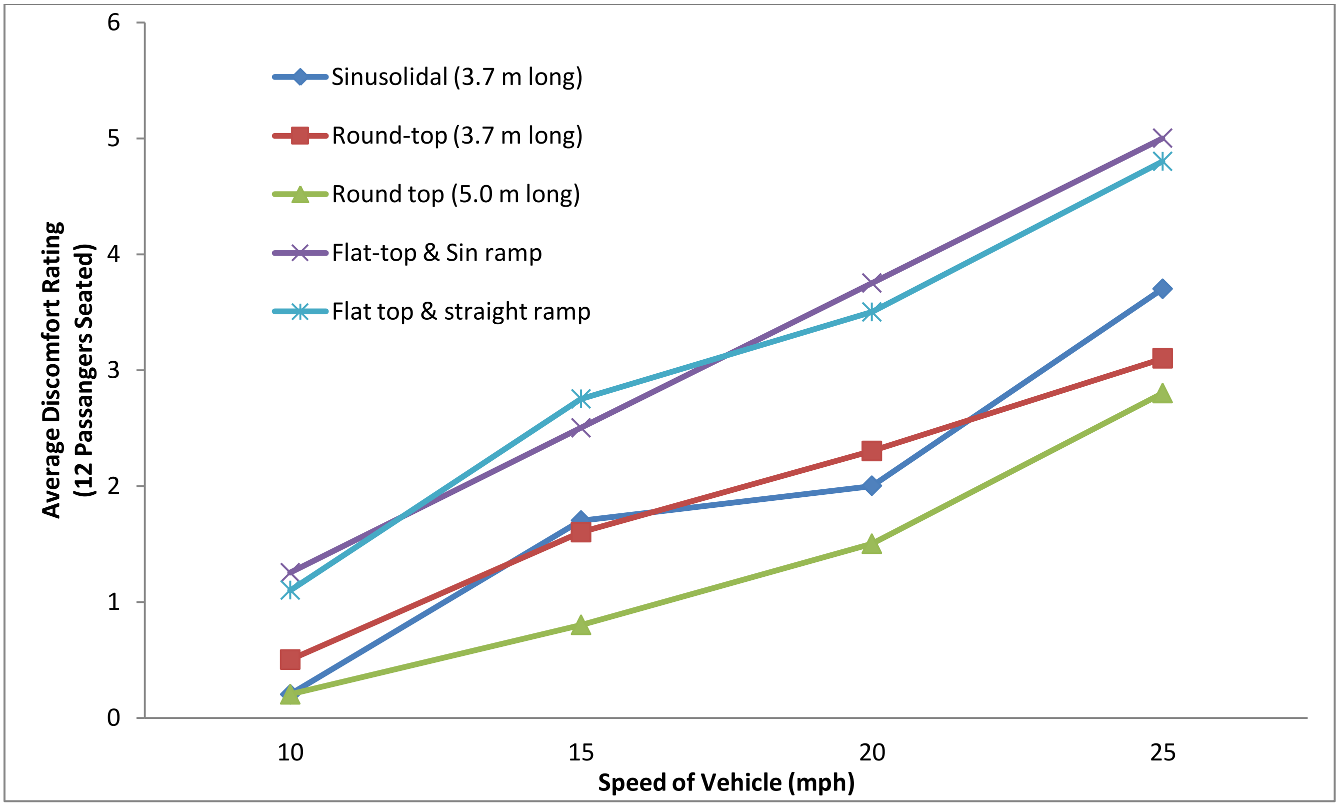


Figure 32: Discomfort rating vs. vehicle speed. This test was preformed with 12 passengers in a minibus.

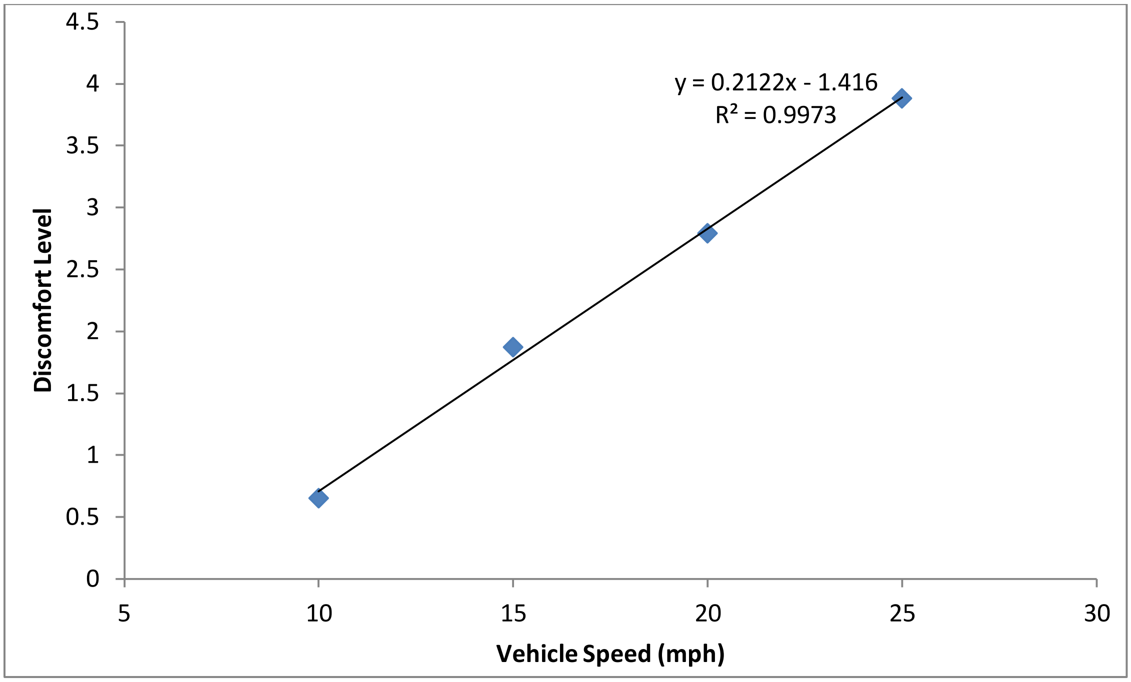


Figure 33: Average discomfort rating vs. vehicle speed.

Average discomfort ratings for all bump profiles at each speed with best fit line. The equation of the line and the R^2 value is also shown.

Intravenous therapy (IV) is one of the more difficult procedures an EMT may be required to perform and can be very uncomfortable for the patient. There are many devices used in intravenous therapy that are used for: feeding patients intravenously, blood transfusions, and devices used to hold and secure the intravenous apparatus. Intravenous therapy requires the needle, flow tube, and coupling to be attached to patient. EMS use medical tape to secure these components to the patient. This prevents the components of the IV from decoupling, twisting and/or pulling out of the vein. Using tape is the most common method of used to secure the IV, but, tape is often unsatisfactory from a patient discomfort point of view and from a functional point of view (Shapiro, 1989).

Removing medical tape is difficult to remove without causing pain and discomfort to the patient. The tape is used to apply pressure at the base of the needle and tube coupling into the flesh of the patient. This is not only uncomfortable but often bruises the flesh of the patient. When the adhesive tape is removed, body hair is typically removed from the skin and causes additional pain to the patient. Over extended periods of time, medical tape is known to cause tissue breakdown and other soft tissue damage, such as to the nerve network and various vessels in the skin. The use of adhesive tape may also lead to functional problems, which may include: inexperienced taping, gradual loosening of the tape due to patient movement, loosening and tape failure due to patient sweating. These problems will result in the loss of tape function and no longer keeping the needle, flow tube, and coupling suitably connected (Shapiro, 1989).

2.4.3 Comfort of Emergency Medical Technician

Professional drivers are constantly exposed to high vibrations for up to eight hours a day. Heavy vehicles, such as larger trucks, buses, or ambulances, have larger vibrations than the smaller traditional passenger vehicles. There are several reasons that large vehicles have more vibrations than smaller passenger vehicles. One of the reasons is that large vehicles are more dynamically active at lower frequencies caused by the articulation for maneuverability and frame flexibility for durability. Another reason is that large vehicle suspension systems possess increased levels of dry friction and transmit more road input to the vehicle. The driver also feels the vibrations amplified due to their location. The location of the driver is typically in the extremity of the vehicle, further away from the center of gravity, and thus vibrations are amplified. Truck and ambulance chassis suspensions are designed for a high load range and have heavier unsuspended masses (tires, rim, frame, axels, and brakes). When unsuspended masses hit a bump, energy is transferred to the vehicle body. Large, heavier vehicles will transmit more energy than smaller, passenger vehicles. The worst bumps are caused by potholes and frost heaves. These large shocks can deliver a compressive stress of over 0.5 MPa to the spine, which is considered a health risk by ISO standard 2631-5 (Granlund, 2008).

Long term exposure to whole body vibration (WBV), is not only uncomfortable, but has significant health risks. Studies have shown that link WBV and shocks to varying conditions in commercial truck drivers. These conditions include: lower back pain, premature degenerative deformation in thoracic and lumbar vertebrae cartilage, an increase in the risk of spinal abnormalities after 5 year, an increase in the prevalence of back pain in workers exposed to WBV above a threshold level, and an increase in spinal degeneration. Exposures to commercial truck vibrations were measured for various times. Measured accelerations were between 1 and 2 m/s^2 at 2 to 20 Hz. EMTs in the ambulance experience vibrations similar to these while in the ambulance. While no studies have yet been done to investigate the link between the WBV from ambulances to EMT back pain and other health problems, being exposed to similar vibrations for similar amounts of time should result in similar problems (Waters, 2007).

Most EMTs will travel and treat patients in the ambulance without the use of a seatbelt. Current seatbelt methods do not allow EMTs to perform their jobs properly and leave the EMTs feeling constrained. Seat belts will prevent EMTs from being thrown about the cabin in the event of abrupt stops, sharp turns, or collisions, but seat belts will not lessen the effects of low amplitude vibration (Wickens, 2004).

Whole or full body vibration (WBV or FBV), has detrimental effects on human performance in many physical tasks. WBVs cause major disruptions in any task that requires hand-eye coordination. Visual requirements are also disrupted by vibrations from the apparent blurred appearance caused by the vibratory motion. Vibrations oscillate everything inside the ambulance, including the EMT and the patient, and will disrupt an EMTs dexterity. Not only will these make it difficult for EMTs to function properly and perform their jobs, it can make the EMT very uncomfortable and place strain on the EMTs eyes (Wickens, 2004).

Acoustical noise is a less obvious cause for discomfort in the ambulance. These noises can occur over a range of frequencies. Healthy humans can hear sounds over a broad range of frequencies, spanning from 60 – 60,000 Hertz. Mechanical vibrations on the other hand occur at much lower frequencies, typically up to approximately 80 Hz (Wickens, 2004). Vibrations in the range of 0.5 to 80 Hz can cause resonance in the various parts of the body, such as: eye globes, head, spine, and organs in the body cavity (heart, lungs, liver, and stomach) (Granlund, 2008). A study from 1995, measured noise levels in the ambulance. The recorded noises ranged from 80 to 110 decibels, with an average of 100 db. This study showed that the ambulance is a very loud environment. Around 75 db is usually enough to disrupt sleep, and at a two hour exposure to 100 db, permanent hearing damage can occur. In addition to the many procedures that become disrupted from the loud sirens and cabin noise, these high sound levels are not only a discomforting nuisance, but often painful (Macnab, 1995).

CHAPTER 3: EXPERIMENTATION, DATA ANALYSIS, AND SOLUTIONS

Chapter 3 contains the teams and explanation of the experimentation done by Cotnoir and the several methods of data collection. This chapter also discusses the background to vibration and vibration analysis. The proposed teams solutions to roadway vibrations, additional suspension and stretcher modifications to dampen these vibrations, is also discussed.

3.1 Methodology

The main objective of this Interactive Qualifying Project was to investigate how the frequency, amplitude, and energy of vibrations due to road conditions affect the patient and Emergency Medical Technician in the moving ambulance. The vibrations have the potential to affect the quality and ease of patient care as well as the comfort and long term health of the patient and EMT. The team determined that the project will achieve the following goals:

1. Characterize the amplitude, energy and frequency of vibrations transferred to the ambulance cabin from the road under typical conditions and speeds.
2. Determine what care provided by medical personnel is affected by roadway vibration and to what extent. Further, determine how vibrations influence rider comfort.
3. Provide initial solution recommendations as a means for dampening roadway vibration transfer into the ambulance cabin area.

3.1.1 Background research

For the purpose of this project, the team needed to conduct background research in order to obtain both a broad understanding of the EMS profession and a focused understanding of the vibrations in an ambulance. The team started first and foremost by gaining comprehensive knowledge of the scope of practice of EMT's, or the skills they are trained to do, and of the history of the EMT profession. We felt it necessary to know both of these subjects in order to have a base knowledge able to aid in further research. Next, the team focused on what care is provided within the ambulance. Specifically, we were concerned with care that is provided, on a regular basis, while the ambulance was moving. This research allowed us to develop an idea of which tasks were affected by vibration. Tasks determined to be significantly affected by the moving ambulance included electrocardiograms, AEDs, intravenous therapy, blood pressure measurement and other vitals. With these cares determined, we now had target tasks to improve by dampening vibrations. Also connected with the affect of vibration on provided care is its affect on comfort. The group spent time researching case studies pertaining to the long term and short term effects of vibration on the body's physiology. The next topic to investigate was vibration. We utilized previous research done by other studies to familiarize ourselves with how vibrations are measured.

The team conducted further research into current suspension systems in use today. The consumer car market as well as other vehicle markets from commercial trucks to even military tanks have a variety of suspension designs to fit different needs and goals. We spent time looking into both suspension systems that are on current ambulances in the US as well as other viable options from other sources. By looking into current systems, the team meant to gain an understanding of the positives and short comings as well as the capabilities of what ambulances currently have installed.

3.1.2 Data Collection and Analysis

The team decided that an important starting point for the data collection and analysis was to determine the opinion of current EMT's working in the field. In order to accomplish this, a brief, written survey was created and distributed to the UMASS EMS Garage. The survey, shown in Appendix A, consisted of 8 questions. Each question was meant to give the team an idea of the magnitude and effect of vibrations and other disturbances experienced in the ambulance. The answers, asked for in scales from 1 to 10, give an indication of the relative importance/severity of each question. When completed, the surveys were returned and the results were compiled for analysis. The mean and standard deviation were determined for each value. The answers for the one question not involving number choices were tallied for display on a bar graph.

After determining the opinions of EMT, the team began analysis of Dr. Paul Cotnoir's Data. The data, taken using accelerometers and several ambulances, was used by Dr. Cotnoir to characterize the vibrations transmitted by the suspension from the road to the cabin and the patient. Throughout the course of the testing, four different ambulances were used, each of which met current standards outlined by KKK-A-1822 star-of-life standards. The first vehicle was a Type I model built by Horton. For reference, the "Type" of an ambulance describes the type of chassis the vehicle is based off of; I being a truck and III being a van. Its chassis was a 2005 Ford F450 (Figure 34 (a)) with a standard leaf spring and shock absorber suspension weighing a total of 16000 lbs. This vehicle was borrowed from UMASS. A second ambulance was borrowed from UMASS. This ambulance was a 2008 Chevrolet C4400 (Figure 34 (c)) from the body manufacturer Braun. This second vehicle was also a Type I model with a standard leaf spring and shock absorber suspension, although it only weighed 16500 lbs. The third vehicle was a 2001 Ford E450 (Figure 34 (d)) borrowed from Putnam, CT EMS, also with the standard leaf spring and shock absorber suspension weighing 14050 lbs. Unlike the two previously mentioned ambulances, this was a Type III. The final ambulance used for the testing was a Type III, 2009 Ford F550 (Figure 34 (b)) with an air ride suspension. This ambulance, weighing 17950 lbs., was borrowed from Woodstock, CT EMS.

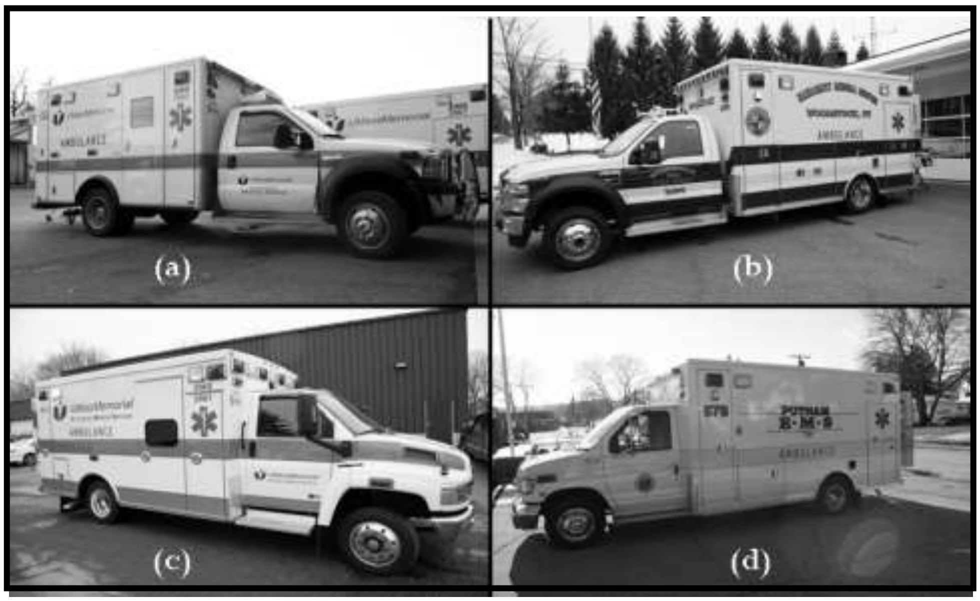


Figure 34 (a-d): Vehicles used in Dr. Cotnoir's study (a) 2005 F-450 Type I, (b) 2009 F-550 Type III, (c) 2008 Chevrolet C-4400 Type I, and, (d) 2001 Ford E-450 Type III

Using these four vehicles Dr. Cotnoir measured vibrations on varying road surface conditions and at varying speeds. Each vehicle was driven on four different road conditions characterized visually. From most vibration excitation to least, these conditions were unpaved road, paved secondary road, paved city street, and finally paved multi-lane highway. Although generally in that order, all roads contained random points of irregularity including potholes, frost heaves, speed bumps, and severely worn sections of road. The intent of the testing was to characterize each surface condition using the full range of velocities, but due to speed limits, only certain speeds could be tested on each road type.

Each roadway surface was tested using the maximum velocity allowed by law within the range in the experimental design, as well as the lower velocities in the design where possible. The velocities used were broken into three categories, namely ≤ 35 mph, 35 – 64, and ≥ 65 mph. Table 10 below includes the velocities used with each condition. The paved highway was tested with the entire range of velocities.

Table 10: Velocities used per surface condition

Road Surface	≥ 65 mph*	Speed 36-64 mph*	≤ 35 mph*
Highway	✓	✓	✓
Paved secondary road		✓	✓
Paved city street		✓	✓
Unpaved road			✓
Speed bump			✓

The provided velocities summarized above are relatively large and non-descriptive ranges meant as guidelines to remain within during testing.

During testing, an accelerometer was placed on floor of the ambulance approximately below the location of a patient's chest. The device, an Instrumented Sensor Technology EDR-3C-10 Shock & Vibration Sensor/Recorder, is capable of measuring and recording acceleration in three axis. To mimic accurate weight loading of the ambulance during a call, an anatomically accurate nursing trainer manikin was strapped to a stretcher, and put in position in the compartment. Each vehicle experienced 70, 10 s events distributed over the various conditions.

3.1.3 Solution Process

The problem of vibrations in the ambulance can be pursued in several different areas of the ambulance. In completion of the IQP project, the team utilized a simplified design process to determine a solution. To begin the design, the team brain stormed as a group by developing 5 ideas each. The ideas were drawn or described on concept sheets and presented to the rest of the group. The next step was to draw from other's ideas and further develop one of the ideas. The team then voted on the concepts based on feasibility, cost, ease of implementation, and effectiveness. The chosen solution was then further developed and a basic prototype idea was drawn in a computer aided design program.

3.2 The Physics of Vibration

According to the dictionary, vibration is the repetitive oscillation, typically in the unit of time, of some mechanical measurement about a central value or between two or more different states, about an equilibrium point. Most of the time, the vibration is undesirable by wasting energy, creating unwanted noise, or injury causing. For example, the vibrational motion of engines of cars can generate unwanted vibration to the passengers, and, after long term exposure, may result in back pain or chronic discomfort during transportation. Generally, there are two types of vibration, free vibration and forced vibration. Free vibrations occur when a mechanical system is set off with an initial input, and allowed to vibrate freely. The mechanical system will then vibrate at one or more of its natural frequency (at this frequency, even small periodic driving force can create large amplitude oscillations because of the systematically stored vibrational energy) and damp down to zero. Forced vibration, on the other hand, occurs when an alternating force or motion is applied to a mechanical system. In forced vibration, the frequency of the vibration is the same as the frequency of the force or motion applied, with the magnitude being dependent on the mechanical structure (Russell, 2012).

Most of the current suspension systems have a dampening system utilizing a spring. This is called a viscous damper and allows outputting a force that is proportional to the velocity of the object. This damping system is called viscous because of its equivalence to the viscous fluid model using a spring and dashpot. The first model of the system is a free vibration with damping, seen in Figure 35.

The proportionality constant *c* is called the *damping coefficient* and has units of force over velocity.

$$F_d = -c * v = -c * \dot{x} = -c * \frac{dx}{dt}$$

where F=Force, c=damping coefficient, and v=$\dot{x}$= velocity of object

By summing the forces on the mass (See Figure 35) we get the following ordinary equation:

$$m\ddot{x} + c\dot{x} + kx = 0$$

where m=mass, c=damping coefficient, k=spring coefficient,

$\ddot{x}$ = acceleration of object, $\dot{x}$ = velocity of object, and x = position of object

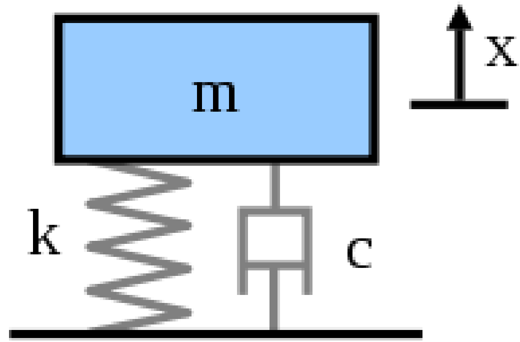


Figure 35: Mass Spring Damper Model. Image from (Russell, 2012)

The solution to this equation depends on the amount of damping. If the damping is small enough, the system will still vibrate, but it eventually will stop vibration over certain period of time. This case is called "under-damping." If the damping just increases to the point where the system no longer oscillates, it reaches the point of "critical damping" and if the damping is increased past critical damping the system has become "over-damped." The value that the damping coefficient needs to reach for critical damping in the mass spring damper model is:

$$C_c = 2\sqrt{km}$$

To characterize the amount of damping in a system, a ratio called the "damping ratio" is used, and is also known as damping factor or percent critical damping. This damping ratio is a ratio of the actual damping over the amount of damping required to reach critical damping. The formula for the damping ratio (ζ) of the mass spring damper model respect to damping coefficient (c) is:

$$\zeta = \frac{c}{2\sqrt{km}}$$

The solution to the under-damped system for the mass spring damper model is the following:

$$x(t) = Xe^{-\zeta\omega_n t}\cos\left(\sqrt{1-\zeta^2}\omega_t - \phi\right)$$

$$\omega_n = 2 * \pi * f_n$$

The value of x is the initial magnitude, ϕ is the phase shift, ω is angular velocity, and f is frequency of object are determined by the amount the spring is stretched.

Figure 36 shows a graph of a forced vibration system with damping. This covers the behavior of the spring mass damper model when it is added to a harmonic force. A force of this type could, for example, be generated by a rotating imbalance (Russell, 2012).

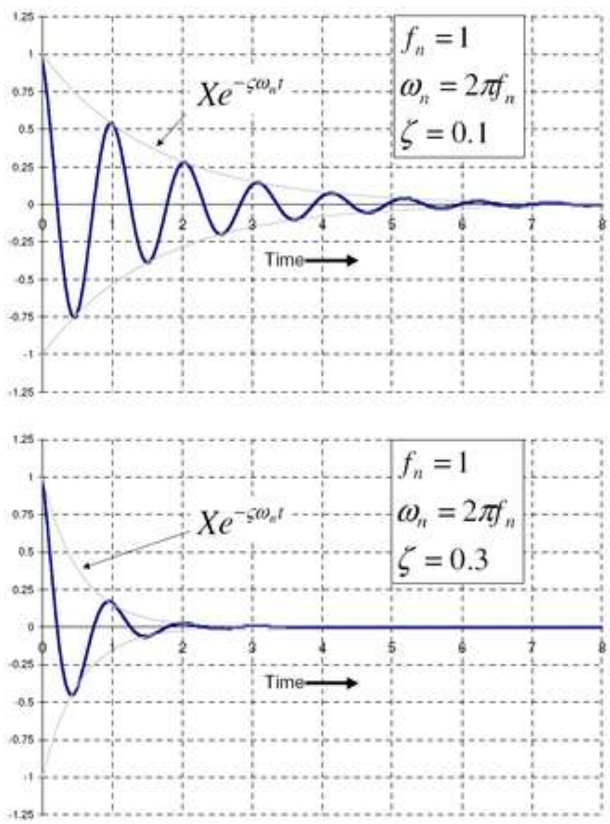


Figure 36: Graph of under-damped system. Image from (Russell, 2012)

Mechanical waves propagate through a material medium (solid, liquid, or gas) at a wave speed which depends on the elastic and inertial properties of that medium. There are two basic types of mechanical wave motion around the world: longitudinal and transverse (Russell, 2012).

When particle displacement is parallel to the direction of wave propagation, the wave is known as a longitudinal wave. Figure 37 shows a one-dimensional longitudinal plane wave propagating down a tube, the red lines in the tube show different crests in the wave. The particles do not move down the tube with the wave, rather the particles simply oscillate back and forth from their equilibrium positions in only one plane. The wave is seen as the motion of the compressed region, such as it is a pressure wave, which moves from left to right (Russell, 2012).

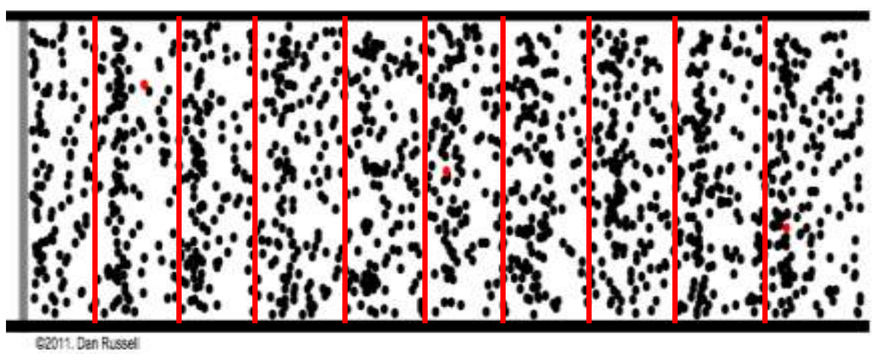


Figure 37: Longitudinal wave. The red lines show the crests this longitudinal wave. Image adapted from (Russell, 2012)

In a transverse wave the particle displacement is perpendicular to the direction of wave movement. Figure 38 shows a one-dimensional transverse plane wave as it travels from left to right. Rather than particles moving with the wave, the particles oscillate up and down. Similar to the longitudinal wave in the fact that both in both waves the particles move around and eventually return to their equilibrium location, but differ with respect to the direction the particles oscillate in. The particles do not travel with the wave, but simply oscillate up and down about each particle's individual equilibrium positions as the wave passes by (Russell, 2012).

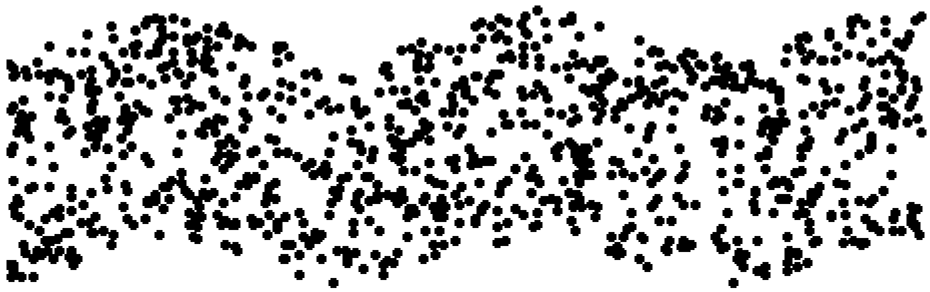


Figure 38: Transverse wave. Image from (Russell, 2012)

A water wave involves a combination of both longitudinal and transverse motions. As a wave travels through the waver, the particles travel in circles in both the x and y planes. The radius of the circles decreases as the depth into the water increases. Figure 39 shows a water wave travelling from left to right in a region where the depth of the water is greater than the wavelength of the waves. It is identified two particles in yellow to show that each particle travels in a clockwise circle as the wave passes. Notice how in the top yellow ball rotates around the origin (Russell, 2012).

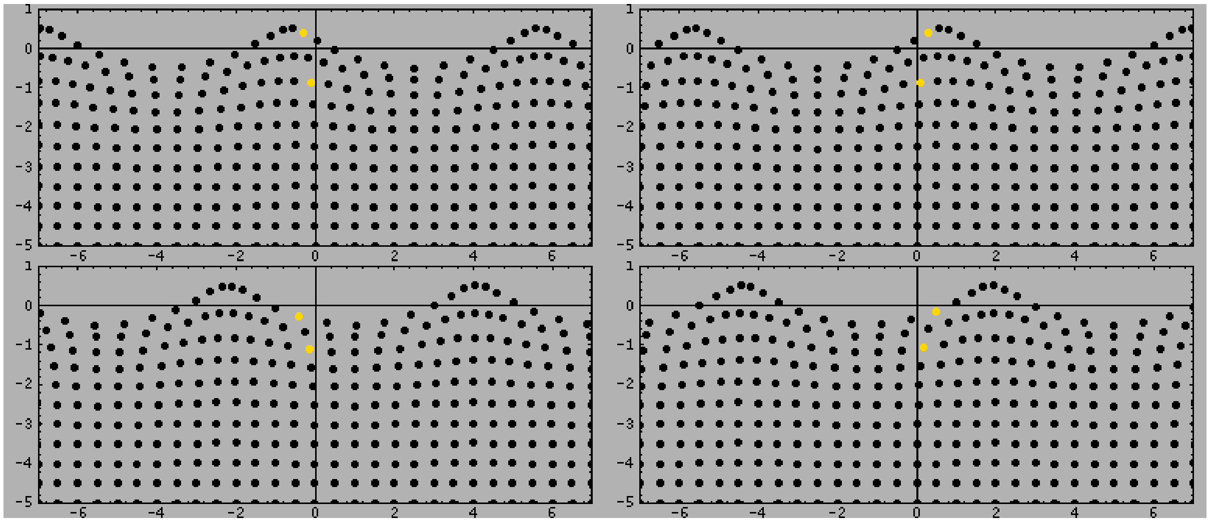


Figure 39: Water wave. Look at the images in a clockwise direction and see how the top yellow ball rotates around the origin, moving in both the x and y directions. Image adapted from (Russell, 2012)

Another example of waves which combine both longitudinal and transverse motion is found in solids as Rayleigh surface waves, named after John W. Strutt, 3rd Baron Rayleigh. The particles in a solid, through which a Rayleigh surface wave passes, move in elliptical paths, with the major axis of the ellipse perpendicular to the surface of the solid. As the depth into the solid increases, the width of the elliptical path decreases. Rayleigh waves are different from water waves in one significant way. In a water wave all particles travel in clockwise circles. However, in a Rayleigh surface wave, particles at the surface trace out a counter-clockwise ellipse, while particles at a depth of more than one-fifth of a wavelength trace out clockwise ellipses. In Figure 40, two particles are identified in yellow to illustrate the counterclockwise-clockwise motion as a function of depth (Russell, 2012).

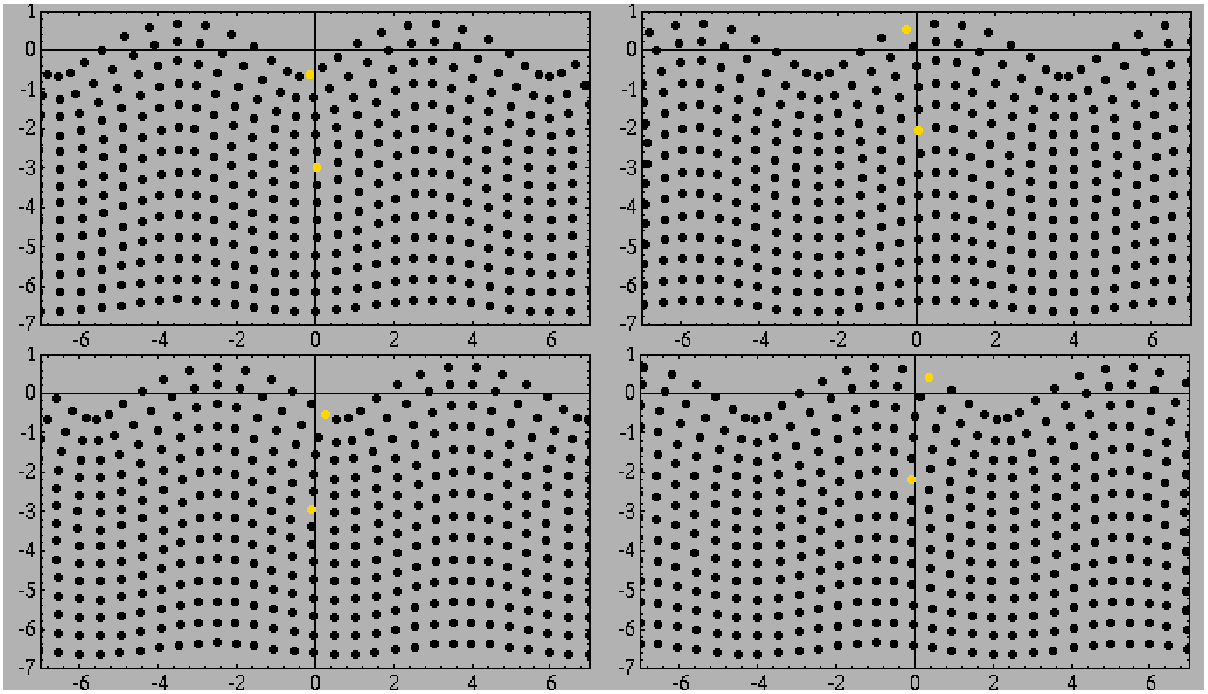


Figure 40: Rayleigh wave. Look at the images in a clockwise direction and see how the top yellow ball rotates around the origin, moving in both the x and y directions, similarly to the water wave. Image adapted from (Russell, 2012)

When an object, like a ball, is thrown against a rigid wall it bounces back. This reflection of the object can be analyzed in terms of momentum and energy conservation. If the collision between ball and wall is perfectly elastic, then all the incident energy and momentum is reflected, and the ball bounces back with the same speed. If the collision is inelastic, then the wall or ball absorbs some of the instance energy and momentum, and the ball does not bounce back with the same speed. Waves also carry energy and momentum, and whenever a wave encounters an obstacle, they are reflected by the obstacle. An example of this is shown in Figures 41 and 42 (Russell, 2012).

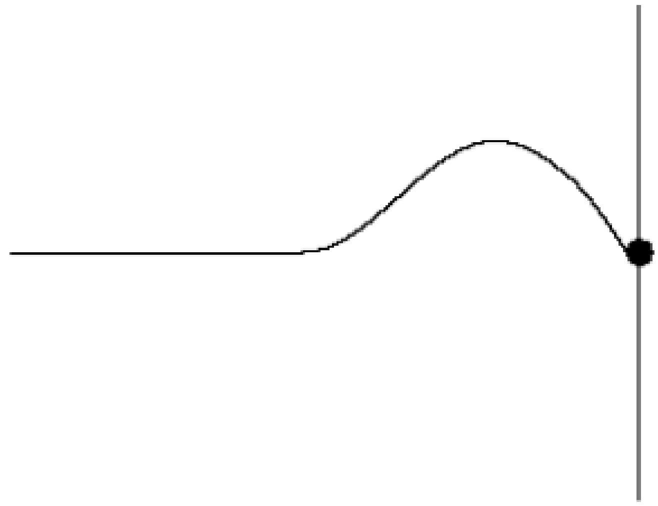


Figure 41: Before hitting the hard boundary. Image from (Russell, 2012)

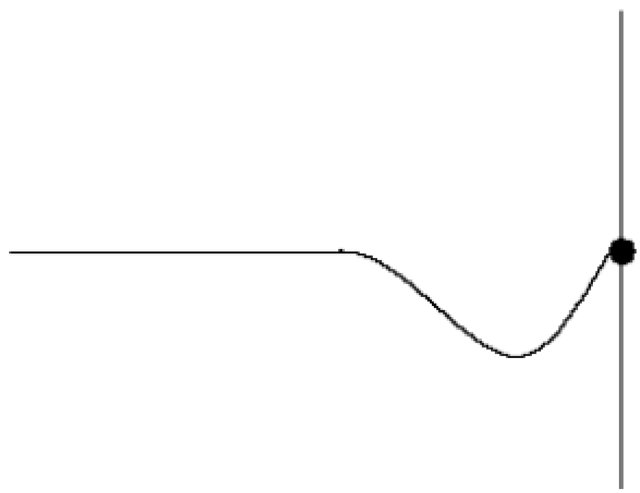


Figure 42: After hitting hard boundary. Image from (Russell, 2012)

Figure 41 and 42 show an example of this, where a rope is tired to a hook on a wall. When a whipping motion is preformed on the end of this rope, the wave travels to the wall (Figure 41). Once the wave traveling along the rope hits the wall, it cannot travel through the wall, and the energy cannot simply disappear, so the wave reflects off the wall and travels back along the rope (Figure 42). According to Newton's third law, the wall must be exerting an equal downward force on the end of the string. This new force creates a wave pulse that propagates from right to left, with the same speed and amplitude as the incident wave, but with opposite polarity. At a fixed boundary, the displacement remains zero, and the reflected wave changes its polarity. A change in polarity refers to when the wave undergoes 180^o phase change (Russell, 2012).

When a wave encounters a boundary which is neither rigid nor soft, but instead somewhere in between, part of the wave is reflected from the boundary and part of the wave is transmitted across the boundary. The precise development of reflection and transmission depends on the material properties on both sides of the boundary. One important property is the characteristic impedance of the material. The characteristic impedance (Z) of a material is the product of mass density (μ) and wave speed (C). If a wave with amplitude ξ_1. in medium encounters a boundary with different medium, the amplitudes of the reflected and transmitted waves are determined by the equation below equations (Russell, 2012):

$$\xi_r = \frac{z_1/z_2 - 1}{z_1/z_2 + 1}\xi_1 \qquad \xi_2 = \frac{2}{1 + z_2/z_1}\xi_1$$

In Figures 43 and 44 shown on the following page, two strings of different densities are connected so that they have the same tension. The density of the thick string is 4 times that of the thin string. If the speed of waves on a string is related to density and tension by:

$$c = \sqrt{\frac{T}{\mu}}$$

where c = speed of wave, T=tension on the object, and μ = mass density (Russell, 2012).

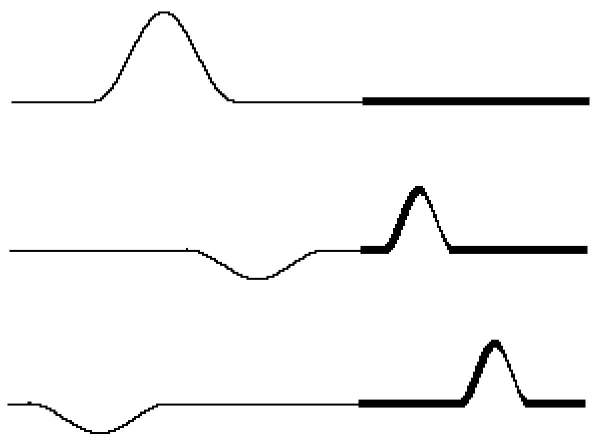


Figure 43: From high speed to low speed (low density to high density). Look at the images from top to bottom and notice how one larger wave is incoming and is split into two smaller waves. Image adapted from (Russell, 2012)

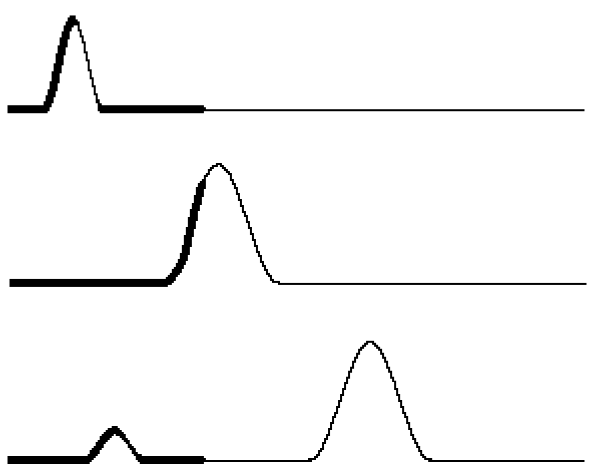


Figure 44: From low speed to high speed (high density to low density). Observe these images from top to bottom and notice how one small wave is incoming from the thicker rope, but once it hits the smaller string, it transfers to the smaller string and reflects back through the thick string. Image from (Russell, 2012)

A wave can be described as a disturbance that travels from one location to another. This disturbance can be expressed by a wave function. The wave function is dependent on both space and time. An example sine function wave would be expressed by the following equation:

$$\Psi(x,t) = A\sin(\omega t \pm k x)$$

Where A is the amplitude of the wave, ω is the angular frequency of the wave, and k is the wave number. The negative sign is used for a wave traveling in the positive x direction and, the positive sign is used for a wave traveling in the negative x direction (Russell, 2012).

Any room or enclosed space has resonant frequencies, at which occur depend on the shape and dimensions of the room. At a resonance frequency, the response of the room will be divided into antinodes, where the pressure is at maximum, and nodes, where the pressure is zero. In a room with hard walls, the pressure will always be at maximum at the wall or in a corner when the room is driven at any of its resonance frequencies. If the source is located at antinodes for a given resonance frequency, the room response will be greatest. If the source is located at a pressure node for a given resonance frequency, the room will not respond no matter how loud the source is (Russell, 2012).

In order to illustrate the effect of source location on room response, the equation is a simple one-dimensional model with a rigid walled tube of length L, which is closed at both ends with a rigid end caps. The rigid ends ensure that pressure reflects without a phase reversal, so that an incident and reflected pressure wave have the same phase at the wall and thus add together constructively to produce a maximum.

The resonance frequencies for our 1-D room are given by:

$$f_n = n\ c\ /\ 2\ L$$

Where *c* is the speed of sound in the room, *n* is an integer (*n*=1,2,3,4,.....) and L is length of the object (Russell, 2012).

In the Figure 45, the red dot represents the source as it moves from the left wall (at *x*=0) towards the right wall (at *x*=5). The sine curve in the different pictures represents the amplitude of the pressure wave as a function of position in the room. The complicated part of understanding wave motion is recognizing the differences between the time and space behavior. The top part of Figure 45 shows a sinusoidal wave pulse traveling from left to right. A red dot has been identified to highlight the time behavior of a point at a specific location (Russell, 2012).

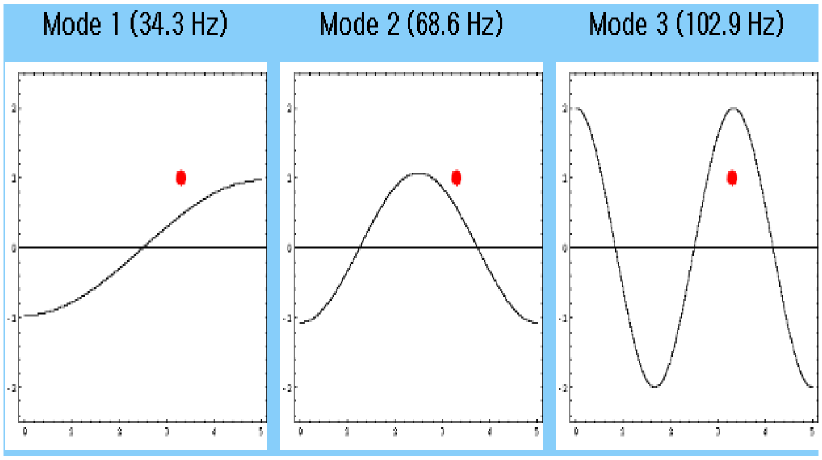


Figure 45 driving the room at a resonance frequency. The different frequency has different amplitude according to its specific location with time behavior of point. Image from (Russell, 2012)

As the source moves along the length of the room, the resulting room response is a maximum when the source is located at antinodes for that given frequency. When a system is being driven at a resonance frequency the pressure amplitude is always greatest at the walls of the room and the maximum pressure is twice the source amplitude. This is because the incident and reflected waves are in phase at the wall boundaries. When the source is placed at a node for that frequency standing wave pattern, the maximum room response drops to zero at that frequency (Russell, 2012).

Standing wave patterns only occur when the room is being driven at a resonance frequency as seen in Figure 46. At all other frequencies, the pressure waves radiating outwards from the source are reflected from the walls, but do not combine to produce a standing wave. The pressure at the walls goes to zero because there are no nodes and antinodes. As a result, maximum pressure will never exceed the source level, and the location of the pressure maximum is constantly moving with the source.

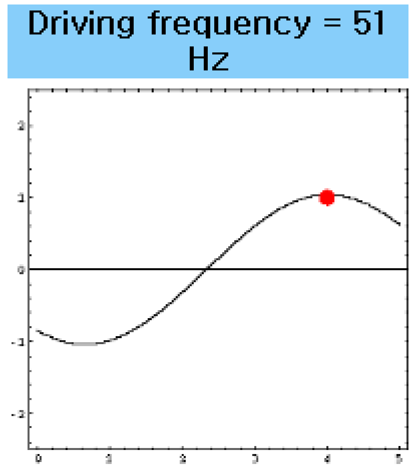


Figure 46: Driving the room at a frequency which is not a resonance frequency. The graph shows the highlighted location for specific time behavior with the specific non-resonant frequency. Image from (Russell, 2012)

3.3 Data Analysis

The purpose of Paul Cotnoir's ambulance experiments was to determine: the amplitude of vibrations, the frequency of the vibrations, and the energy of a typical ambulance ride. All of the data analyzed in this experiment was gathered by Paul Cotnoir in his 2010 study. The team has determined a correlation between the amplitude, frequency, and energy of the ambulance vibrations and the different physical impacts on ambulance passengers, patients, and EMTs.

3.3.1 Frequency and Energy Content Analysis

In Cotnoir's study, Instrumented Sensor Technology Dynamax was used to collect and analyze the vibration data. The data that was gathered and inputted into the Instrumented Sensor Technology Dynamax software that could simplify the vibration amplitude data as a time domain function. The Dynamax was used to calculate the Power Spectral Density (PSD). The PSD function outputted the frequency domain data as a function of power versus frequency. The graphs of the PSDs identify the frequencies where most of the vibrational energy is concentrated. A Fast Fourier Transformation was used to express functions of time as functions of frequencies.

The figure on the following page, Figure 47, shows an example of the data collected during a typical event. The upper graphs of the figure show the vibrations in the x, y, z directions, and the resultant versus time. The lower graph is the PSD graph for 10 seconds. In this example, ambulance 3 was driven on an unpaved road at speeds less than or equal to 35 mph. Various examples of the data collected, by road type and speed are listed in the Appendix C.

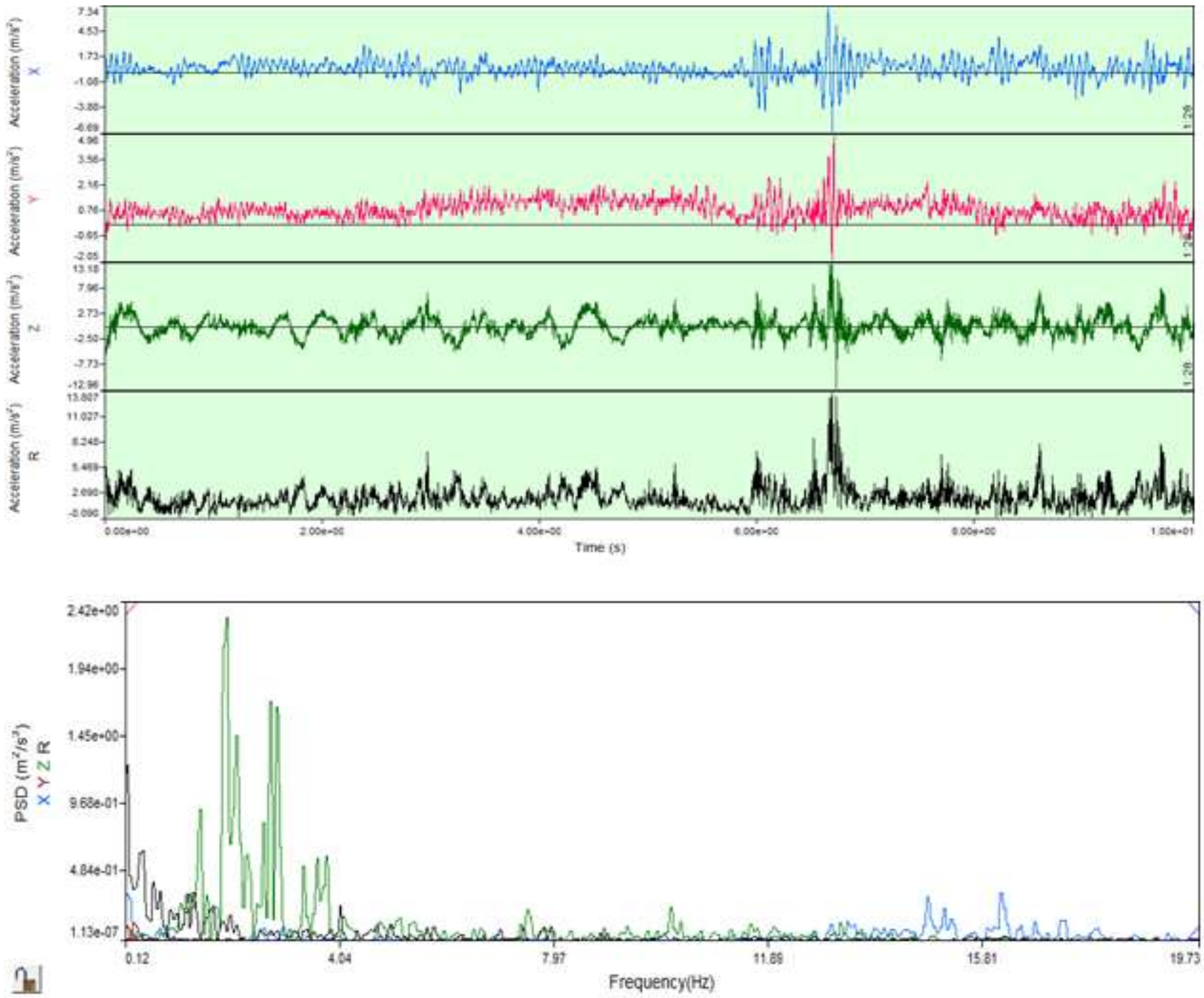


Figure 47: Typical data collected during experimentation. The upper four graphs are the multi-axial directions and resultant. The lower graph is the PSD of the x, y, z, and resultant for 10 seconds.

From the data collected there was a general trend that no matter the road condition, the speed of the ambulance, or the different ambulance, all of the frequencies were typically in the range of 0.12 to 6 Hz. The z-axis vibrations that were tested in the ambulance were concentrated in the sub 6 Hz range. The highest vibration peaks were around the 10 Hz area, high vibrations in addition to the high frequencies will have the greatest health ramifications. While all directions of vibration are relevant, z axis is the most important in this study and is the only direction that is shown in the graphs. Figure 48, shows the typical data with a multi-axis vibration time history and PSD graph for a 10 second measurement event, the ambulance driven in this event was ambulance #3 at 65 or greater mph on a highway road surface.

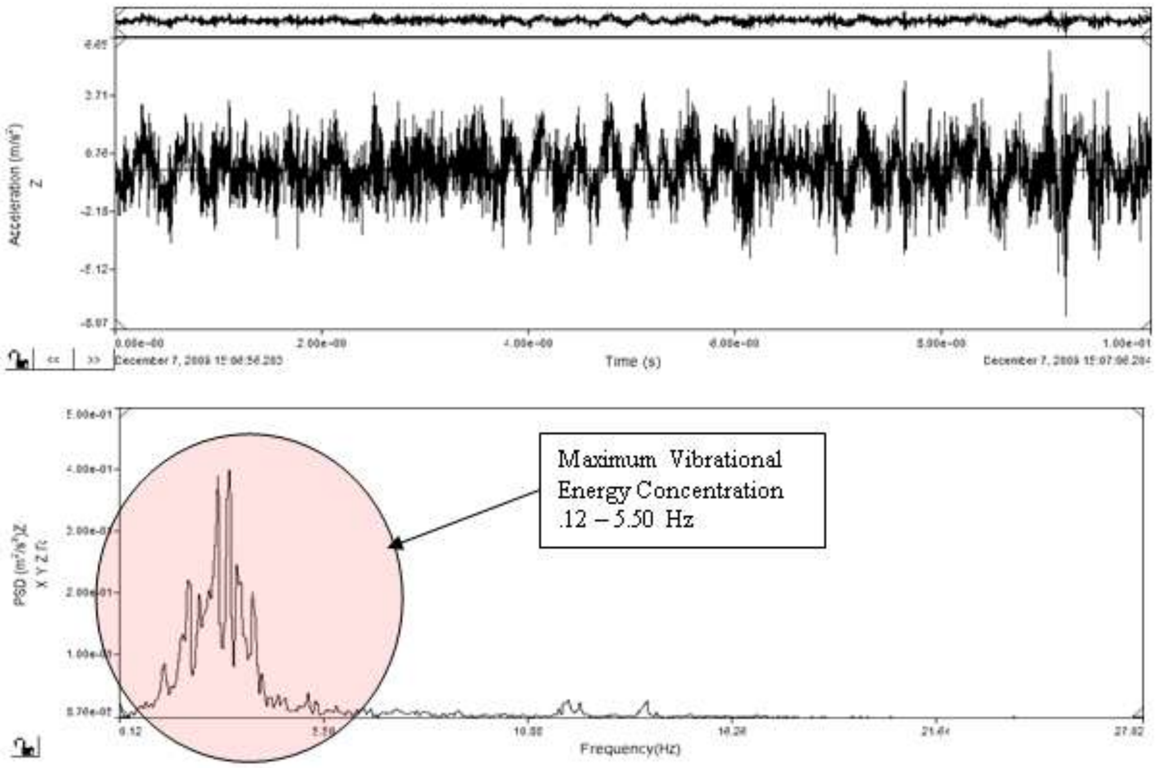


Figure 48: Graph of z-axis vibration time history and power spectral density, Ambulance. #3, speed of 65 or greater, Highway road surface.

3.3.2 Analysis of Patient Safety

From Cotnoir's data, the average vertical vibrations (z-axis) for a typical ambulance ride has an acceleration of between 0.46 and 2.55 m/sec^2 with a frequency of 0.1 to 6 Hz. Table 10 shows some natural frequencies of different body parts and organs. Table 11 shows a summary of the resonance frequencies of human body parts and the effect of experiencing vibrations similar to the resonance frequencies. As you can see there is an overlap between the frequencies measured and the resonance frequencies of major structures in the human body. These vibrations have negative effects on the patient whose health is already compromised, and also the EMTs experience long term exposure to these harmful vibrations. In Figure 49, the event data is from ambulance #3 traveling at 65 mph or greater on a highway road. The graph shows the PSD and vibration levels. There is a clear overlap in several areas with the natural frequency of the respiratory system, motor skills, brain and heart. Some of the other areas could be affected by the ambulance vibrations as well, but not from the vibrations in this particular event.

Table 11: Natural frequencies of human body parts. An asterisk (*) indicated a seated posture. Data from (Paschold, 2008)

Study authors	Natural frequency (Hz)	body, part or organ
Randall, Matthews & Stiles, 1997	12	Whole body, standing
Brauer, 1994	4-6	Whole body, seated
Brauer, 1994	3- 4	Whole body, supine
Wasserman, 1996	4- 8	Whole trunk, vertical
Kroemer and Grandjean, 1997	4*	Lumbar vertebrae
Brauer, 1994	20-30	Head, relative to body
Kroemer and Grandjean, 1997	5-30*	
SafetyLine Institute	20- 30	
Mansfield, 2006	20	Eyes
Kroemer and Grandjean, 1997	20- 70*	
SafetyLine Institute, 2007	20- 90	
Kroemer and Grandjean, 1997	5*	Shoulder girdle
Kroemer and Grandjean, 1997	3- 6*	Stomach
SafetyLine Institute	4- 5	
Kroemer and Grandjean, 1997	4- 6*	Heart
Kroemer and Grandjean, 1997	10-18*	bladder

Table 12: Summary of resonance frequencies of body systems and physiological effects. Data from (Bellieni, 2004).

Resonant Frequency (Hz)	Body part, organ, or system	Physiological effect
.3	Inner ear	Motion sickness
1 – 4	Respiratory	Hyperventilation
2 – 8	Motor skills	Difficulty performing simple target tracking tasks, handwriting etc.
4 – 6	brain (cognition)	Fatigue, loss of concentration
4 – 8	Inner ear, heart	balance and sway problems
5 – 20	Speech	Difficulty speaking clearly
20 – 30	Spine	back disorders &, pain
10 – 20+	Vision	Diff. tracking objects, reading, blur

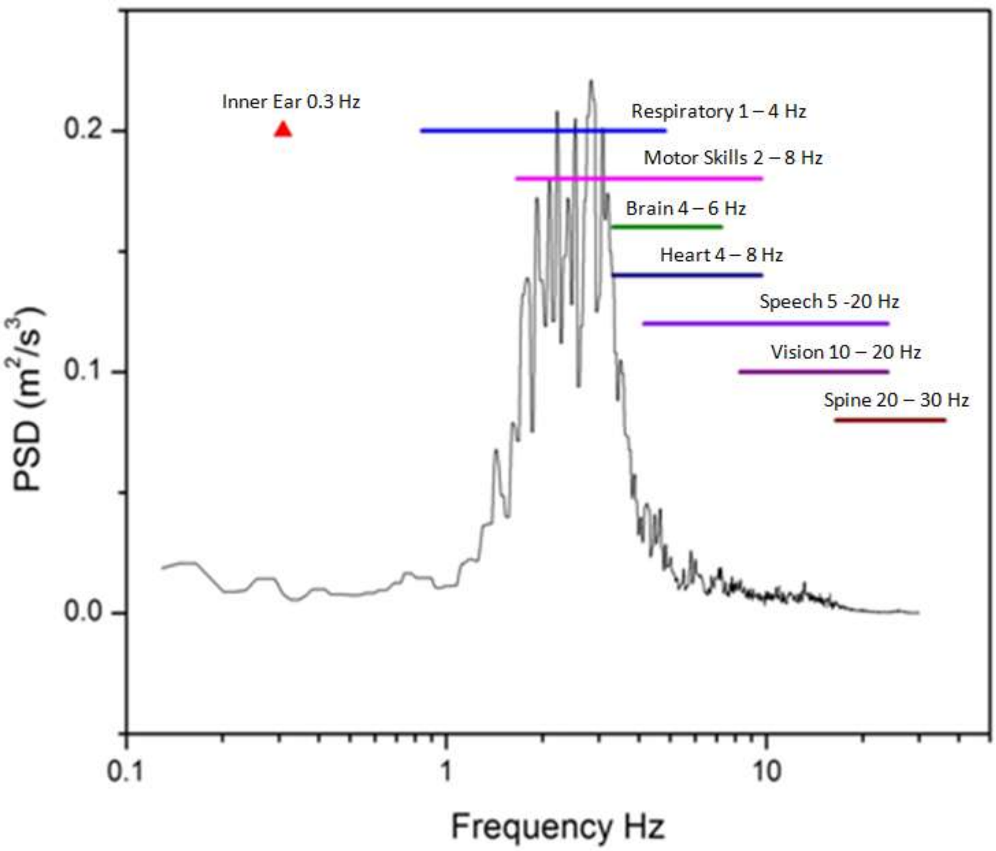


Figure 49: **Physiological effects of ambulance WBV. WBV frequencies superimposed on PSD graph of z-axis power spectral density, Ambulance #3, speed of over 64 MPH, highway road surface.**

3.3.3 Analysis of Patient Comfort

Comfort is a difficult quantity to measure, because is to very subjective. Pain and comfort depend on the feelings or perception of the patient; what may be agonizing pain to someone may not even bother the next person, while to most people it would seem slightly uncomfortable. A general agreement is that most people are sensitive to frequencies in the 4 to 8 Hz range, but there is not an universal standard to confirm this range. Figure 11 (on page 28), shows some approximated and generally accepted comfort ranges for acceleration magnitudes. This shows that almost all of the vibrations in the ambulance are considered uncomfortable.

New EMTs may consider the ambulance vibration uncomfortable at first, but after many ambulance rides, EMTs become used to vibrations and it bothers them less. Patients that ride in the ambulance once on the other hand will almost always find vibrations uncomfortable. The team conducted a survey of EMTs at UMASS in Worcester, where 75 % of the surveyed EMTs said that patients often/always complain about vibrations in the ambulance.

There have been two main studies on a frequency weighted vertical displacement tolerance. The two studies are SAE-J6a, and SAE-J670e, 1978 with ISO 2631-1978. The SAE-J6e investigates human tolerance to ride vibrations. The other two studies have evaluated human exposure to WBV with the SAE J670e and 1978 and ISO 2631-1978 studying the lower and upper tolerance limits, respectively. These later two standards are plotted below with the data from Cotnoir's study, in Figure 50.

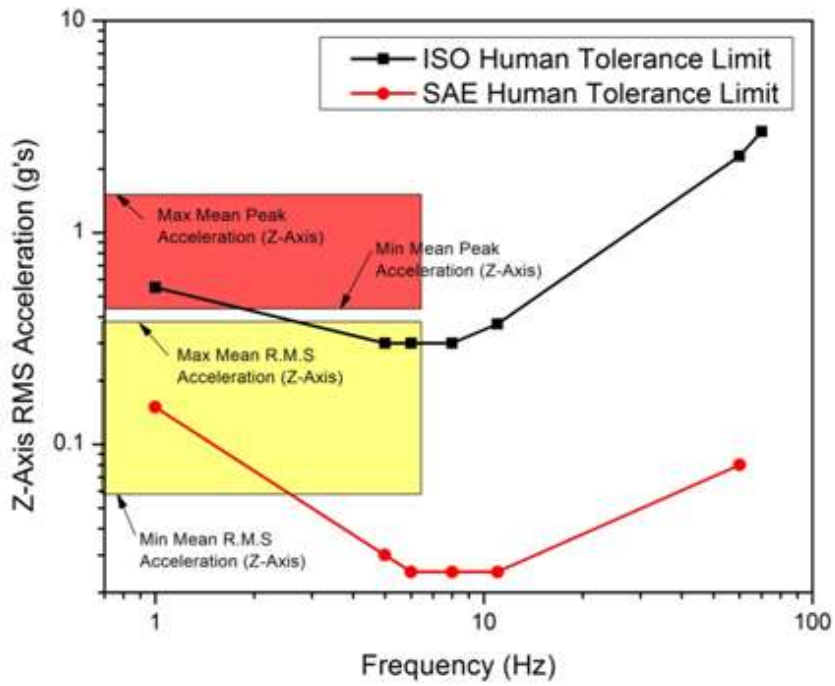


Figure 50: Human tolerance limits for vertical vibration. This plot includes the mean r.m.s. and peak z-axis accelerations measured in Cotnoir's study, plotted with the ISO and SAE Human Vibration Tolerance Limit.

The red box shows the mean peak data, with the top and bottom of the box representing the minimum and maximum recorded z axis accelerations. The yellow box shows the mean r.m.s. acceleration in the z-axis and like the red box, the top and bottom represent the maximum and minimum r.m.s. z-axis accelerations. Since the measured data is right around or above the ISO and SAE line, this means the measured vibrations in the ambulance would be considered uncomfortable.

3.3.4 Patient Care

Patient care can be greatly affected by vibrations. In the survey of Worcester UMASS EMTs, conducted by our team, EMTs were asked the following question, "How much does vibration affect the ease of patient care?" The response was on a scale from 1 to 10 with 10 being vibration greatly affects patient care. All of the responses were averaged and the mean (and median) response was 7, with a standard deviation of 2.83. This tells us that most of the EMTs surveyed think that vibration makes patient care more difficult. Many of the EMTs also wrote about how different vibrations affected care from case to case, depending on the condition of the patient and the skill of the EMT.

Vibrations can have an adverse effect on an EMTs ability to perform fine motor skills. Figure 51 on the following page, shows a graph of hand-eye tracking errors. The hand-eye tracking error test was performed by Lewis and Griffin in 1978. In this study, subjects were exposed to vibrations of varying z-axis amplitude and frequency. At the different frequencies and accelerations, test subjects were asked to perform a "simple zero order pursuit tracking tasks." In a simple zero order pursuit tracking task, the subject is asked to move his or her hand in a certain pattern; the error is how far off the patient's hand was. Cotnoir's data is represented by the yellow box. The yellow box is the mean r.m.s. (over the frequencies of 0.12 to 6 Hz) with the left side corresponding to 0.46 m/sec^2, the right side corresponding to 2.55 m/sec^2, and the dotted line is the overall mean r.m.s. z-axis acceleration of 0.99 m/sec^2.

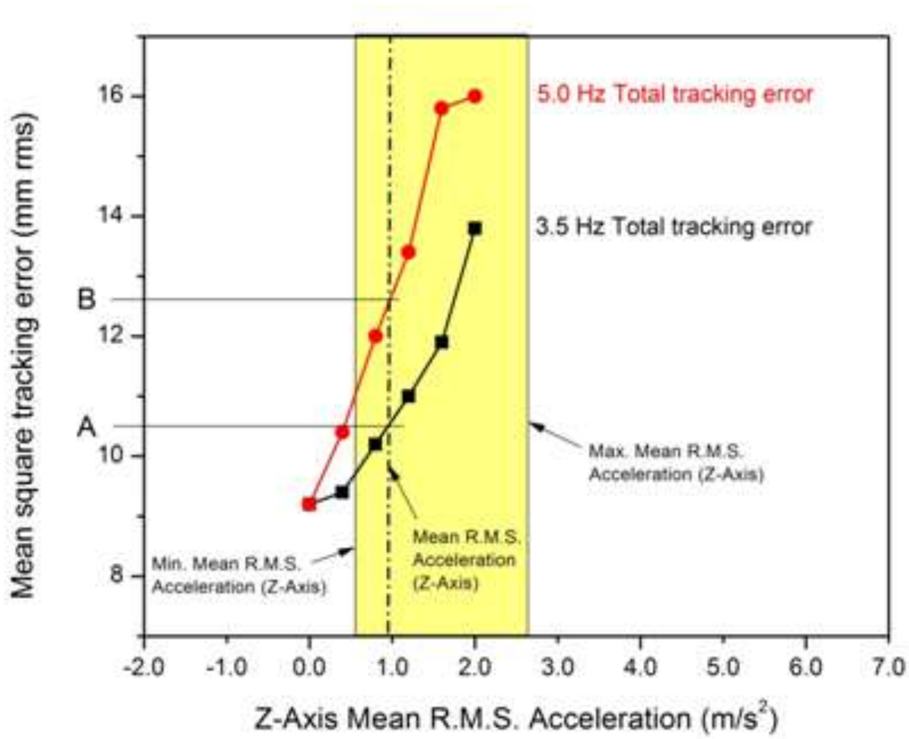


Figure 51: Average tracking error associated with whole body vibration. Z-axis accelerations were calculated from Cotnoir's data. The red and black line correspond the tracking error at 3.5 and 5 Hz respectably Where the dotted line and red or black line intersect is the average expected tracking error from a typical ambulance ride in Cotnoir's study (A = 10.5 mm and B = 12.5 mm).

The intersection points of the overall mean r.m.s. z-axis acceleration and the 3.5 and 5 Hz total tracking error correspond to the overall tracking error expected in any given ambulance in Cotnoir's study at the given frequency. Only the overall vibration was used, but if peak accelerations were used, you would expect a greater tracking error. At 3.5 Hz the tracking error is approximately 10.5 mm and at 5 Hz the tracking error is approximately 12.5 mm. The range of 10.5 to 12.5 mm is a large range of error for an EMT that may need to perform very precise procedures. Being off by as much as a 5 mm will have severe effects on several procedures such as: intravenous therapy, airway management, and inserting any tubes in the airway or nasal passages.

A study by Whitman and Griffin in 1978 investigated the spill percentage of test subjects holding a conical cup of water that were subjected to various vibrations. Spills could occur from three possible sources: (1) vertical vibrations transmitted by the hand, to the cup, and then to the water, resulting in a spill, (2) cross axial vibration from the hand, leading to shaking the water out of the cup, or (3) fluid excitation from resonance frequency. Once again the yellow box represents the mean r.m.s. from Cotnoir's data with the bottom side corresponding to 0.46 m/sec^2, the right side corresponding to 2.55 m/sec^2, and the dotted line being the mean r.m.s. z-axis acceleration of 0.99 m/sec^2. At 4 Hz, the spill percentage is the highest, indicating the maximum effect of the three factors: vertical vibration, cross-axial vibration, and resonance frequency. This data is shown in Figure 52 on the following page.

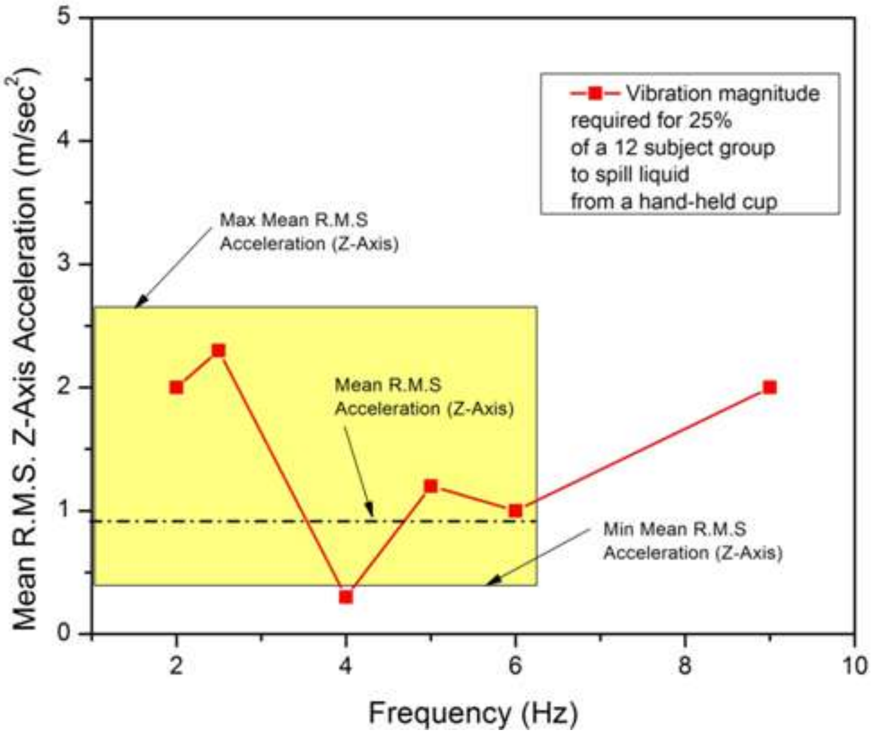


Figure 52: Amplitude of z-axis vibration required for 25% of the tested subjects to spill liquid from a hand-held cup with the mean r.m.s. z-axis accelerations measured in this stud superimposed. The spill data is from Griffin, 1990.

This shows that all of the areas that the test subjects had difficulty keeping the water in the cup are in the range of vibrations that were measured in the ambulance. If a device that an EMT is using to treat the patient is dropped from the EMTs hand, it could be a danger to the patient.

In 1986, Moseley and Griffin performed a study on the percent reading error when the reader is subjected to vibrations. In this study 1.1mm sized characters were placed 750 mm away from the reader. Both the reader and the characters being read were subjected to various vibrations at different amplitudes and frequencies. Figure 53 shows the graph of the percent reading error, the increasing z-axis vibration and increasing frequency. The increase in percent error with the increase in vibration amplitude is clearly visible. This can cause problems in the ambulance. In the ambulance, the EMT may be required to read many important passages, such as medication labels, medical equipment readouts like ECG readings, medical devices, and other essential information incorrectly thus, providing less than optimal care.

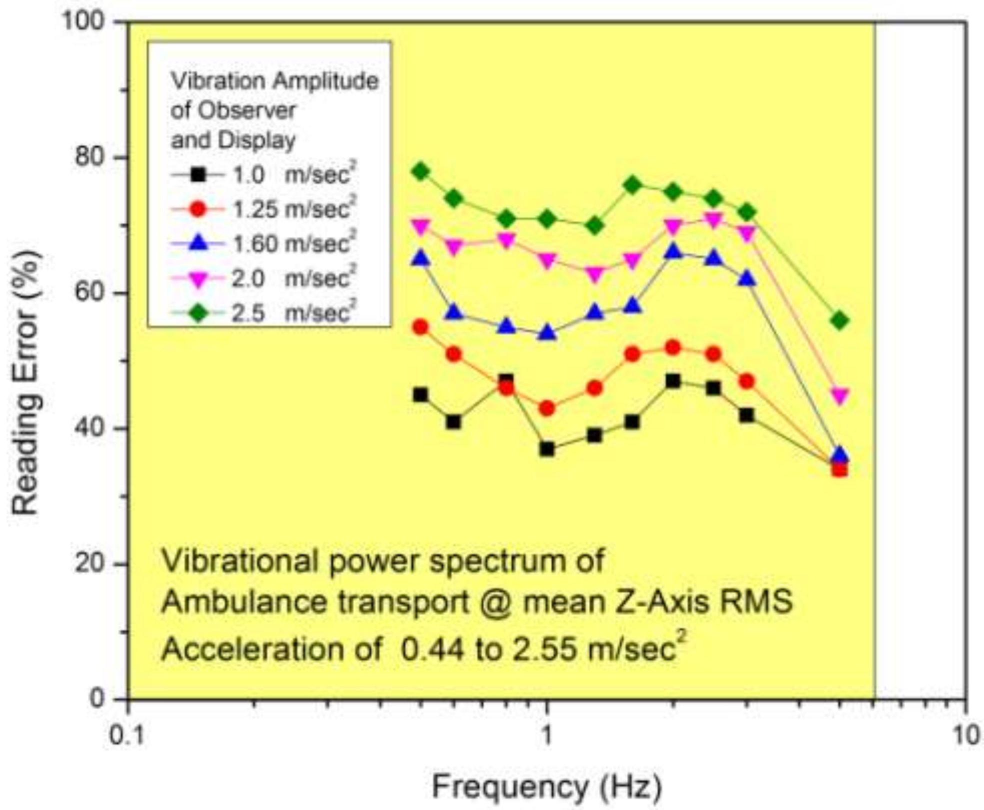


Figure 53: Vibration spectrum of z-axis excitation and associated reading errors. Both the reader and characters being read on display were subjected to the vibration amplitude and frequencies. Each different line represents different vibration amplitude and the varying frequencies are on the x-axis. Cotnoir's measured frequency ranges are in yellow. Data adapted from Moseley and Griffin 1986.

Figure 54 shows a simple writing test that was performed in a study by Griffin in 1990. It shows how as the z-axis vibrations increases, the writer has less and less control over their arm movement. The frequency was held constant at 4.5 Hz, as shown in the upper graph, and the lower histogram shows that all of the acceleration that were tested in the complex arm writing test. This data falls within the range of accelerations gathered by Cotnoir.

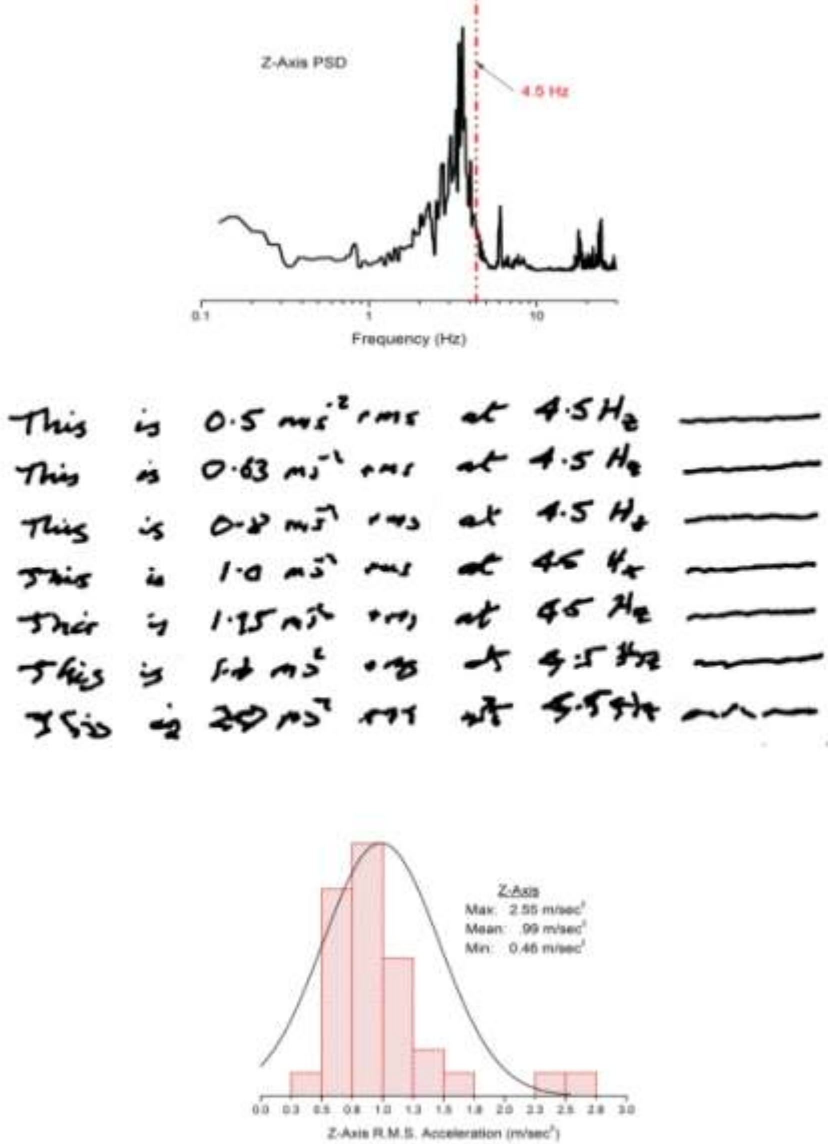


Figure 54: Amplitude and frequency of ambulance vibration and examples of associated handwriting performance. Data from (Griffin, 1990).

All of these mentioned tests show that vibrations can disrupt normal human movement. When an EMT is caring for a patient, the roadway vibrations transmitted to the ambulance can make it very difficult to provide the patients with the best possible care.

3.4 Our Solution

From the data collected in Cotnoir's study, it is clear that the vibrations have experienced in the ambulance can be harmful to the patient and the EMTs. Our team has proposed solutions of chassis alterations and stretcher mechanisms that will be eventually able to lessen the effects of vibration on the patient and EMTs in the ambulance. SolidWorks drawings of the ambulance and the stretcher can be found in Appendix D.

3.4.1 Additional Suspension

As discussed earlier in Chapter 2, Hydragas is a type of suspension system that uses a fluid or gas as opposed to the traditional spring and damper system. A Hydragas system is composed of a capsule of nitrogen gas, often referred to as the "nitrogen egg," that acts as the springing medium and a fluid. When a wheel goes over a bump, the fluid rises and the gas compresses resulting in no vertical displacement in the vehicle.

Our team proposed an additional suspension system to dampen the vibrations felt in the ambulance box. This suspension system will be placed between the ambulance chassis and box. The additional hydragas suspension will dampen the vibrations felt by the patient and the EMTs while not significantly changing the production and manufacturing of the ambulance. A hydragas system will be placed between the chassis and box to reduce vibrations because the hydragas system is simpler than yet just as effective at reducing vibrations as other non-spring suspension systems.

3.4.2 Stretcher Modifications

The stretcher in the ambulance is a major cause of the vibration felt by the patient. The locking mechanism that attaches the stretcher to the floor and the mechanism that compresses the stretcher to the folded state have mechanical give, amplifying vibrations transmitted from the ambulance. Our team came up with a modification for the stretcher which involves adding a system that can secure the stretcher to the ambulance and prevent additional z axis vibration. These modifications would ideally be used with the additional hydragas suspension discussed in Chapter 3.4.1.

The stretcher locking mechanism will be used to suppress any additional z axis vibration that was previously added by the stretcher. The current locking mechanism presents in the ambulance involves hooks toward the front of the ambulance that holds the wheels in place and a clamp that stops the stretcher from rolling or sliding. Our team proposes a system of that will use a series of straps to secure the stretcher to the ambulance floor. Most auto mobiles (and the ambulance box as well) have a seatbelt system that has two main components, the buckle and the insert. The buckle is attached to the seat and has the unlocking or releasing button on the buckle. The insert has a clip that locks into the buckle, an inertial reel that draws the excess belt, and a webclamp that locks the belt when after the inertial reel has drawn in all of the excess slack. The team's system includes attaching a six seat belt buckles to the stretcher (three on each side) and 6 inertial reels and webclamps that will be attached to the floor (three on each side of the ambulance). After the stretches has been loaded into the ambulance, the EMT will insert the clip into the each respective buckle and the inertial reel will draw in the excess belt while the webclamp locks the belt so no more belt can be pulled out. This system will secure the stretcher so vibrations will not be amplified by the stretcher.

Ideally, this seat belt securing system would be manufactured as a kit. As a kit, each ambulance company that purchases the kit can install the seat belt securing system in their ambulances without requiring the manufacturing lines of each company to install new mechanism. For this system, the buckle must be attached to the stretcher handles and the inertial reel, webclamp, and insert must be attached to the ambulance floor. Some potential ways to attach the buckle to the stretcher are: series of Velcro straps that would hold the buckle on the handles or a loop in the belt of the buckle that could secure the buckle on the stretcher, by threading the buckle through the loop around the handles. The simplest way to attach the "floor component" (the floor component consists of the inertial reel, webclamp, and insert) to the ambulance would be to screw or blot it onto the floor. The seat belt locking mechanism will greatly reduce, if not eliminate, the vibrations that would normally be amplifies and transmitted to the patient by the stretcher.

CHAPTER 4. CONCLUSIONS AND DISCUSSIONS

The objective of the project is to reduce the impact of roadway vibrations on the EMTs and patients. This objective is further divided into three major topics: efficiency of care, quality of care, and safety of care. Using Paul Cotnoir's thesis as background research, the team has investigated the issues with whole body vibrations and their effects on the human body. The random accelerations caused from the vibrations decrease the efficacious ability of performing medical treatments such as intravenous therapy, blood pressure measurements, and electrocardiograms. The vibrations have an average root-mean-squares acceleration of 0.99 m/s^2, which is fairly uncomfortable to the normal person, and even more so for a patient with severe injuries. And the long term effects of whole body vibration include lower back pain and loss in bone density. To improve the efficiency, quality, and safety of care, the group has developed possible solutions to resolve these issues by implementing new designs to the frame of the locking mechanism and applying an additional suspension system. The locking mechanism reduces the motion of the wheels of the stretcher while inhibiting the stretcher from coming off of the floor as the ambulance engages road perturbations while in transit. And a hydragas suspension system is applied between the chassis and ambulance box to reduce extraneous vibrations without compromising the handling of the ambulance. Some of constraints are the inadequate amount of time to fully develop the detailed solutions and a deficiency in budget that restrains the team from building the solution. These solutions could be further developed by future Worcester Polytechnic Institute Major Qualifying Projects under the supervision of MIRAD Laboratories.

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Appendix A: EMS Survey

The below text is the survey given by the team to the EMTs of UMASS EMS Garage. Results were returned to the team and complied for research purposes.

MIRAD Laboratory – we create and develop engineering knowledge structure, computation and technology to sustain our world

Defensive Surface Roadway Vibration Dampening Inertia Wave

Emergency Medical Technician Vibration Survey

1. How much vibration do you feel in the ambulance?

   1 2 3 4 5 6 7 8 9 10

2. How difficult is it to drive the ambulance with respect to the handling of the vehicle?

   1 2 3 4 5 6 7 8 9 10

3. How much does vibration affect the ease of patient care?

   1 2 3 4 5 6 7 8 9 10

4. How often do patients complain about vibration?

   Never Sometimes Often Always

5. How loud is it in the ambulance cabin?

   1 2 3 4 5 6 7 8 9 10

6. How much does the noise affect the ease of patient care?

   1 2 3 4 5 6 7 8 9 10

7. What is the closest speed (mph) to the average driving speed in varying priority transports?

High:	10	20	30	40	50	60	70+
Medium:	10	20	30	40	50	60	70+
Low:	10	20	30	40	50	60	70+

8. How interested would you be in dampening vibration in the ambulance?

1 2 3 4 5 6 7 8 9 10

Optional: **name** ________________________ **email** _____________________________

Team Contact: Spencer Coffin scoffin@wpi.edu

Project Advisor: Professor Fofana, PhD, e-mail: msfofana@wpi.edu

Appendix B: UK Department of Transport Data

Other road bump data and graphs from the 2000 study by Department of Transport in the United Kingdom.

Vehicles tested. A range of vehicles was used in the trials to assess discomfort, noise and ground borne vibrations. In each test the vehicle tested was driven over the 5 bump profiles: the 3.7 meter sinusoidal, 3.7 meter round-top, 5.0 meter round-top, 8.0 meter flat top sinusoidal ramp, and 8.0 meter straight ramp flat top. Several test subjects were used and drove over the bump and recorded a discomfort rating. The average discomfort rating was then averaged and graphed.

These included five different bicycle types, a small, medium and large car, five different buses, including a low floor bus, three different goods vehicles with steel or air suspension, a fire appliance and three different ambulances.

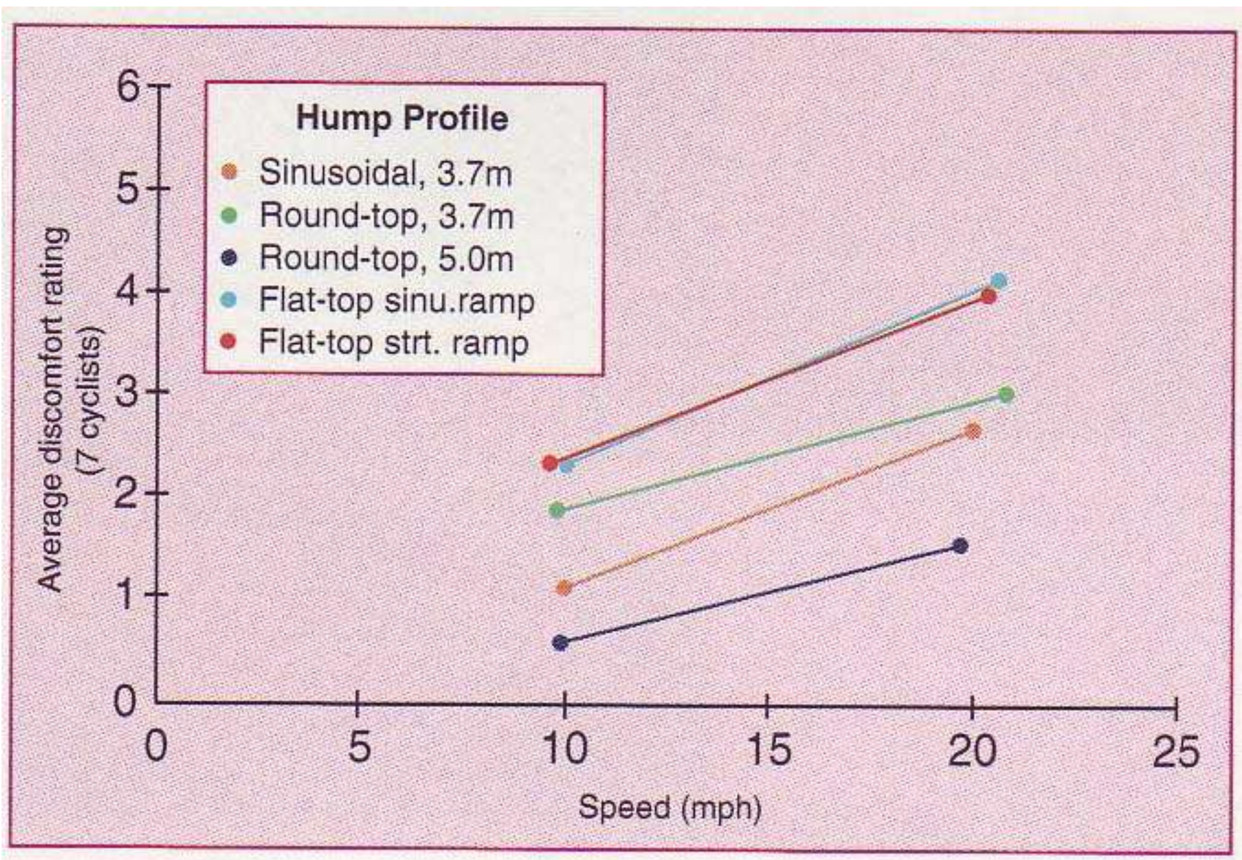


Figure B1 *Unladen cyclists*

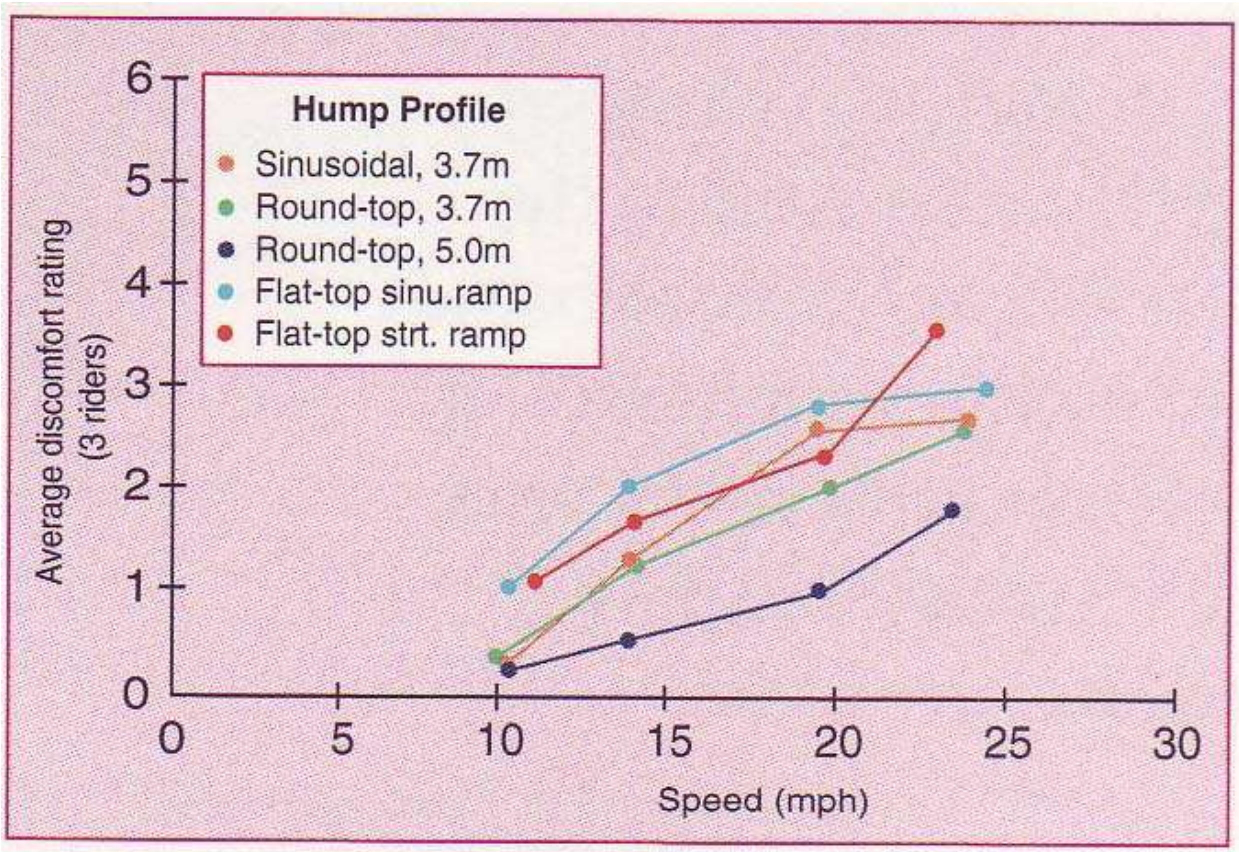


Figure B2 *Motorcycles - combined results from small, medium and large motor cycles*

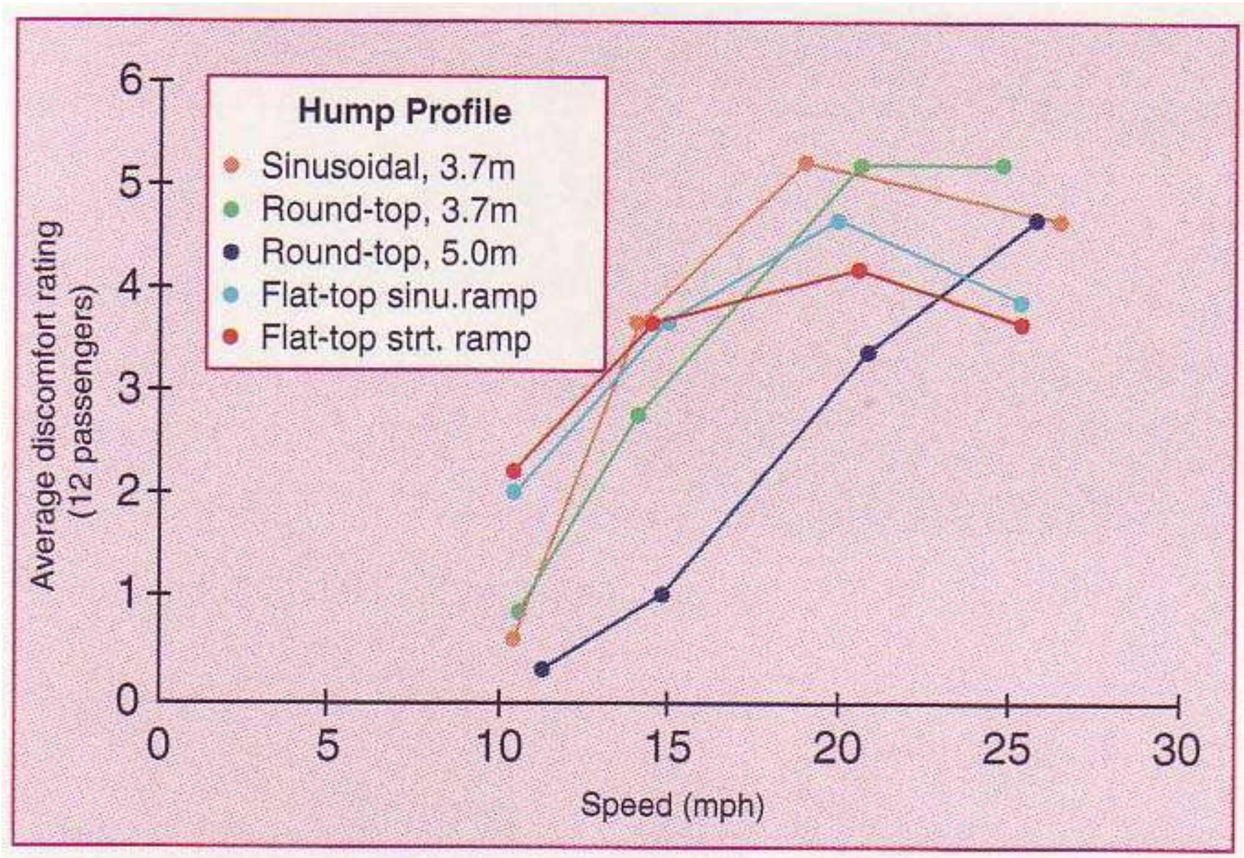


Figure B3 *Minibus (Optare City Pacer all passengers sitting)*

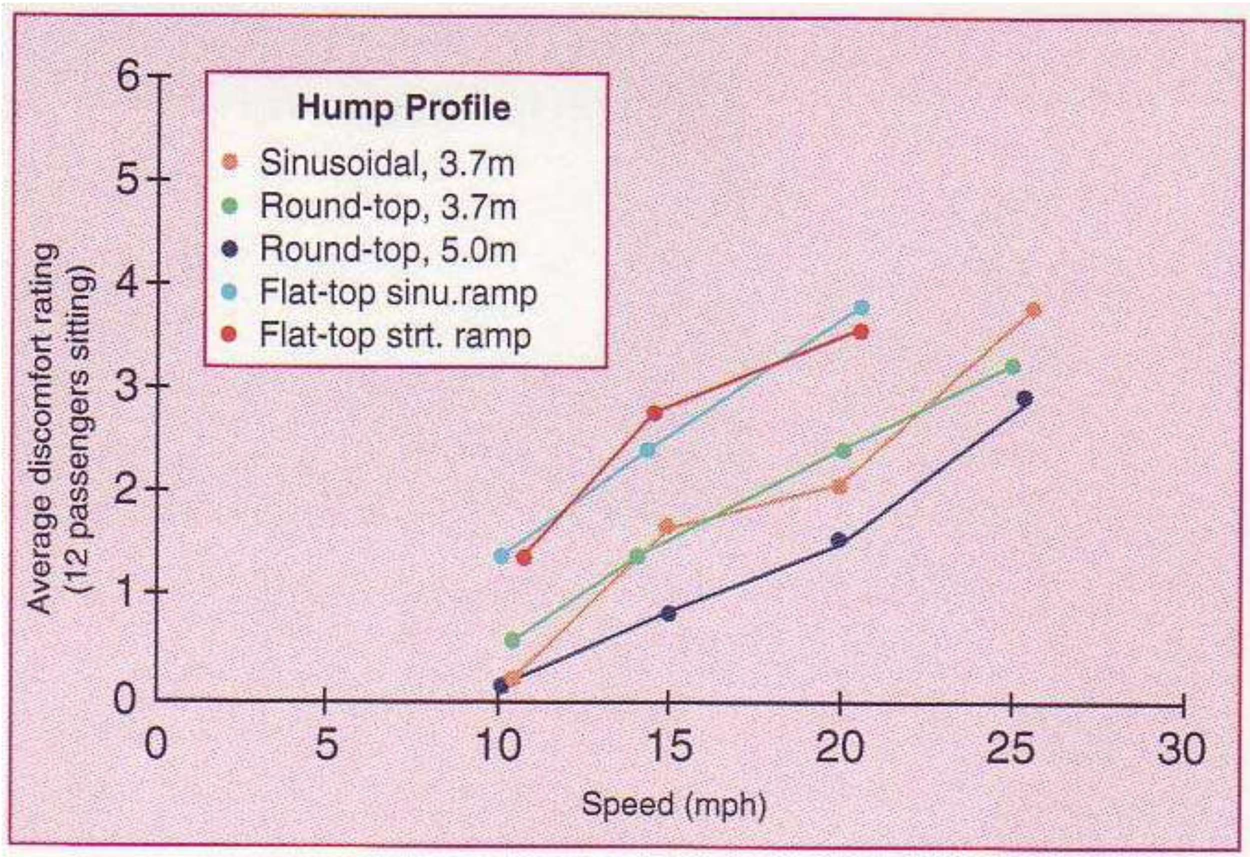


Figure B4 *Large single-deck bus (Optare Low Rider - Low floor bus)*

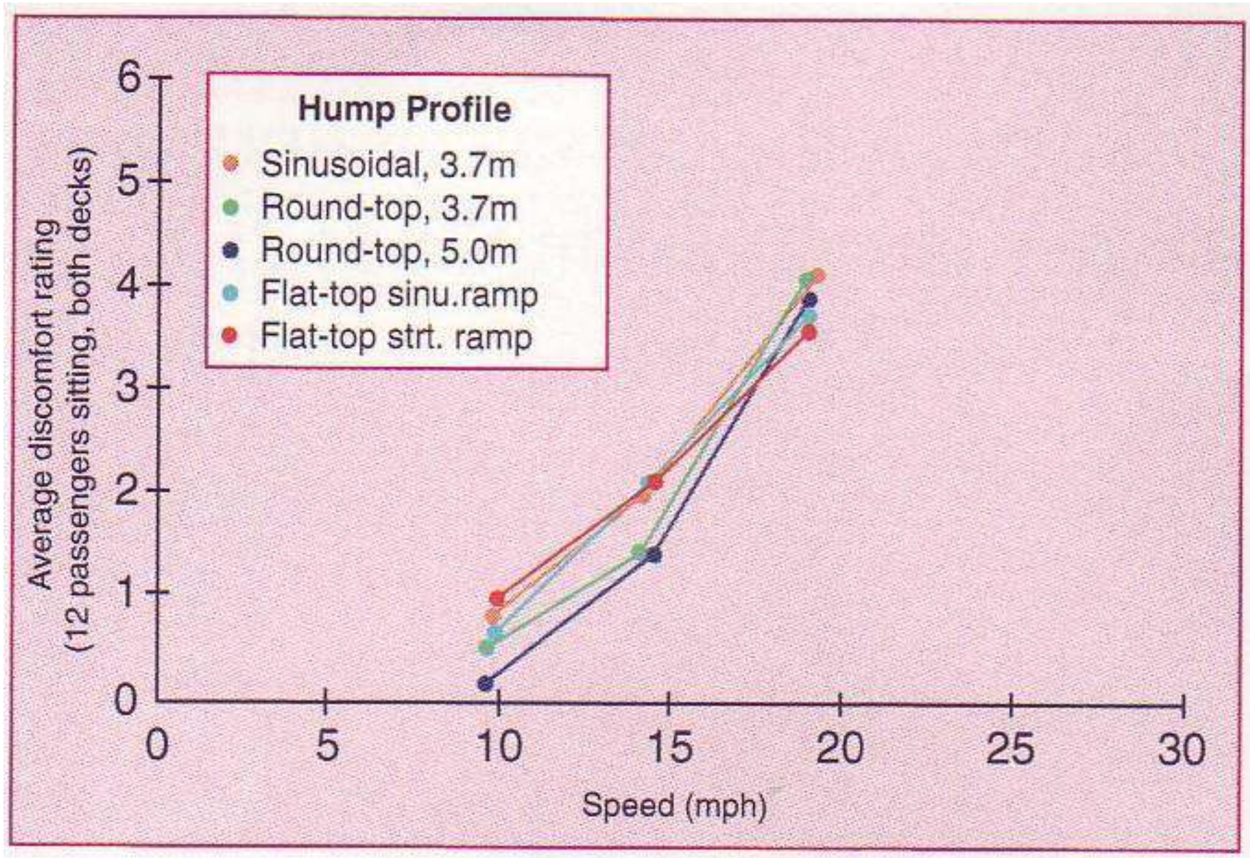


Figure B5 *Double-deck bus (Optare Spectra)*

Appendix C: Sample Data from Cotnoir

Sample vibration time history and PSD graphs

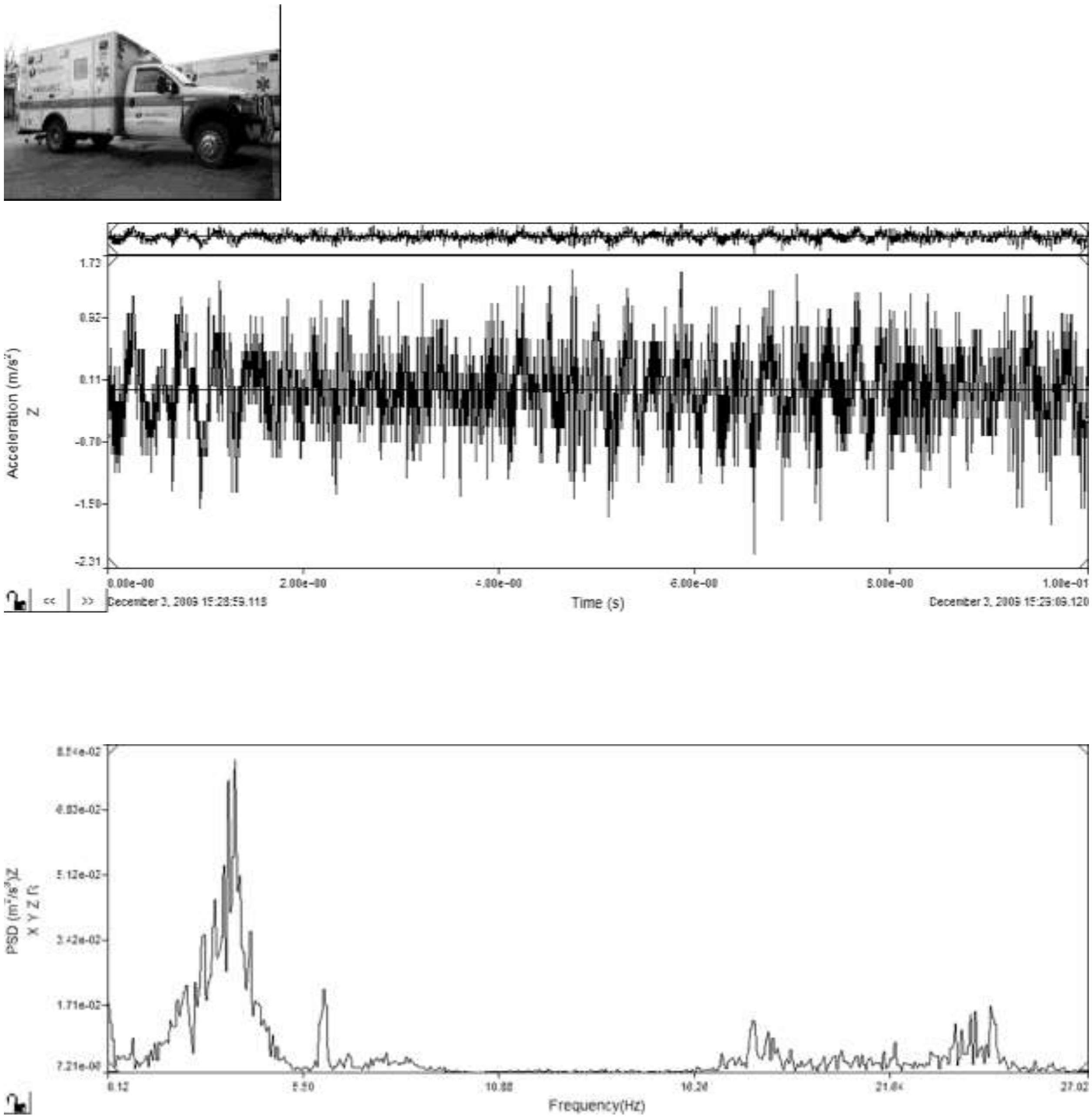
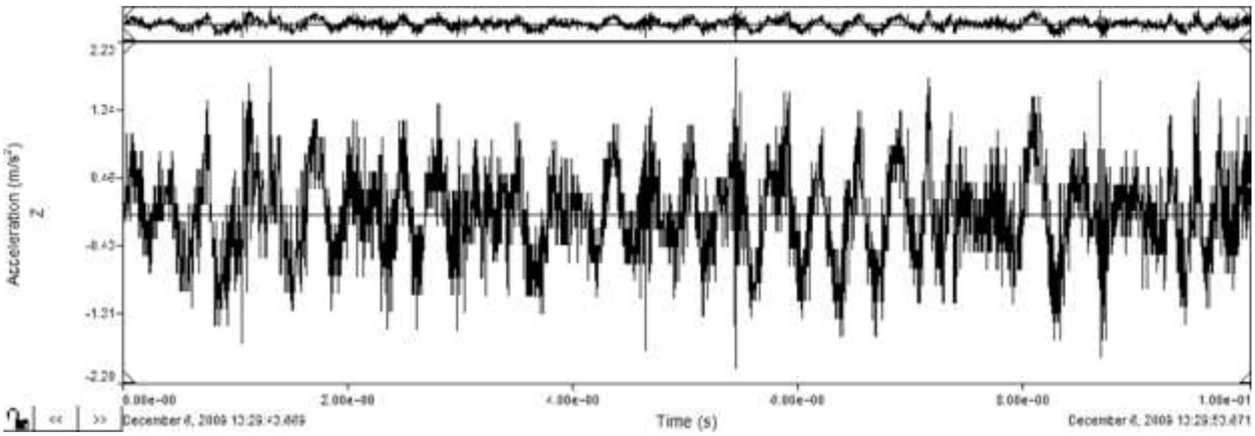


Figure C1. *Ambulance #1 – Highway, 35mph, Z-Axis R.M.S., typical 10 sec event interval*



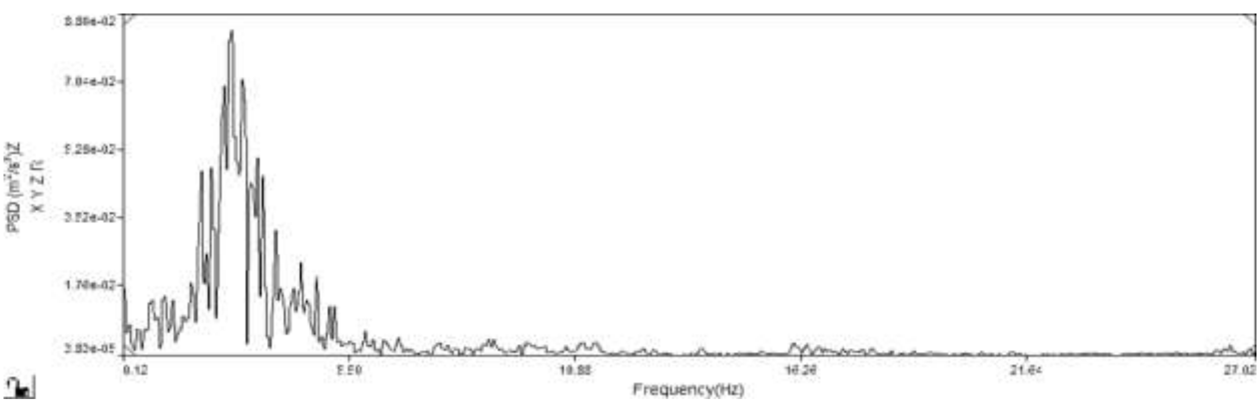


Figure C2. *Ambulance #2 – Highway, 35mph, Z-axis R.M.S., typical 10 sec time interval*

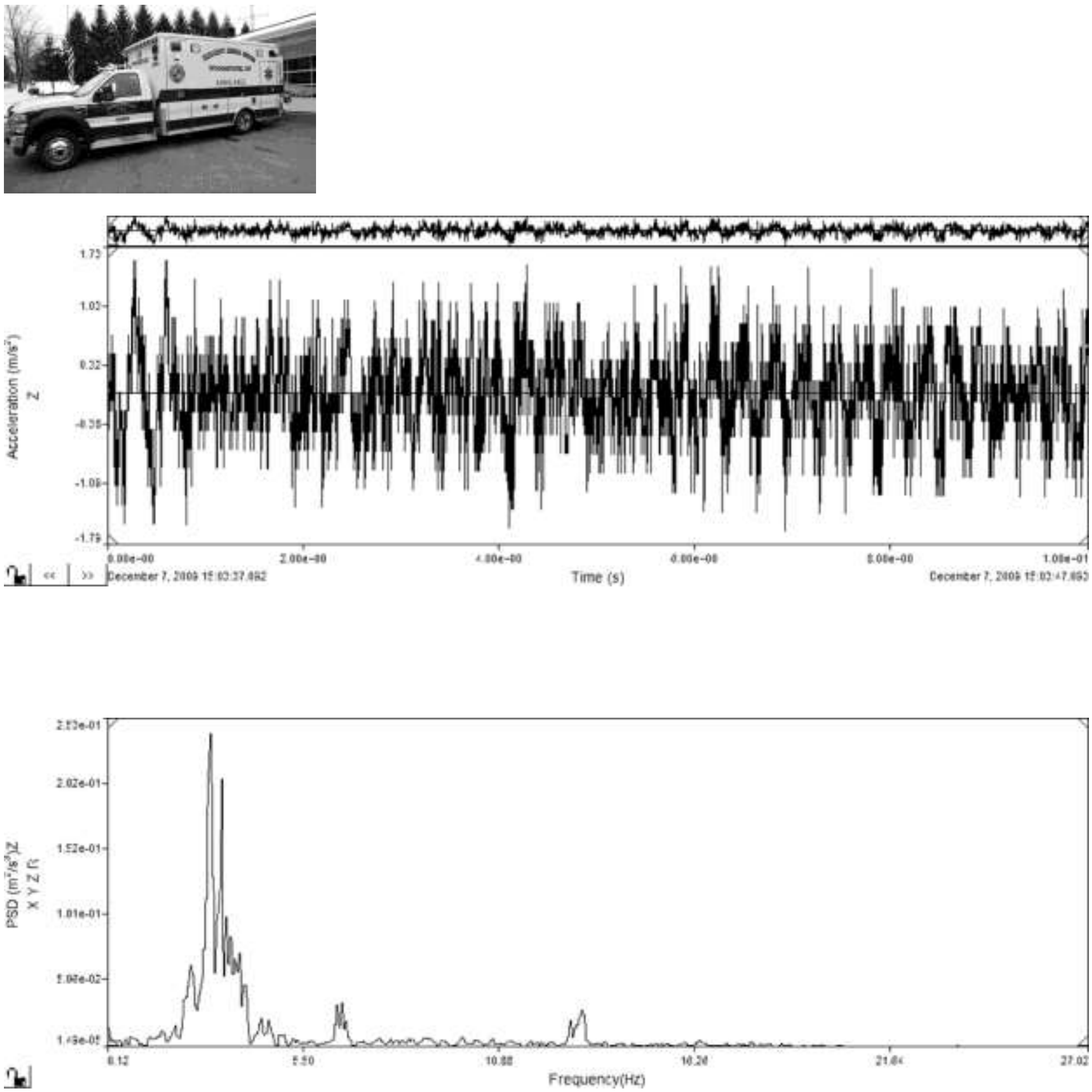


Figure C3. *Ambulance #3 – Highway, 35mph, Z-axis R.M.S., typical 10 sec time interval*

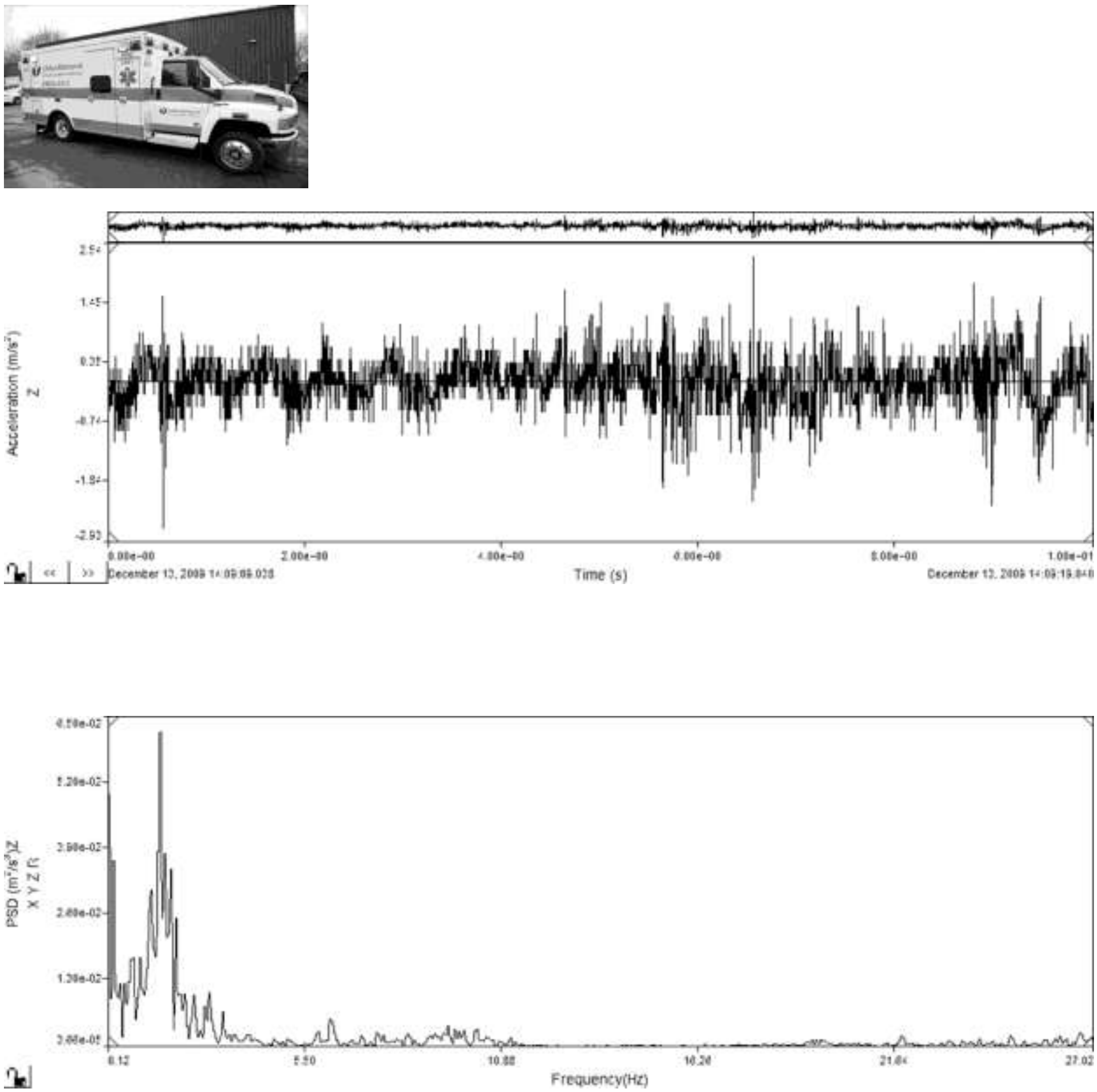


Figure C4. *Ambulance #4 – Highway, 35mph, Z-axis R.M.S., typical 10 sec time interval*

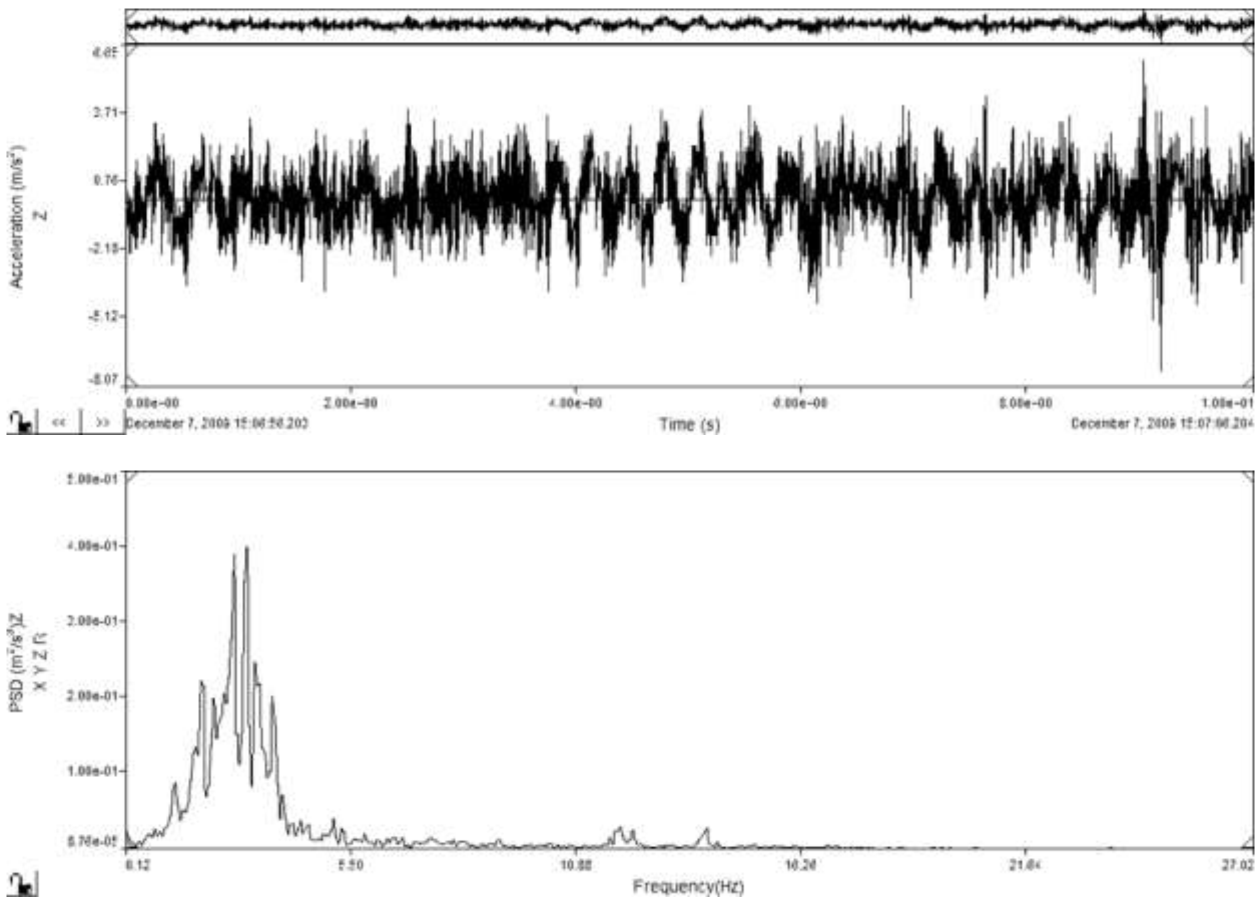


Figure C5. *Highway, Ambulance #3, Z-Axis R.M.S.,≥65 mph., typical 10 sec event interval*

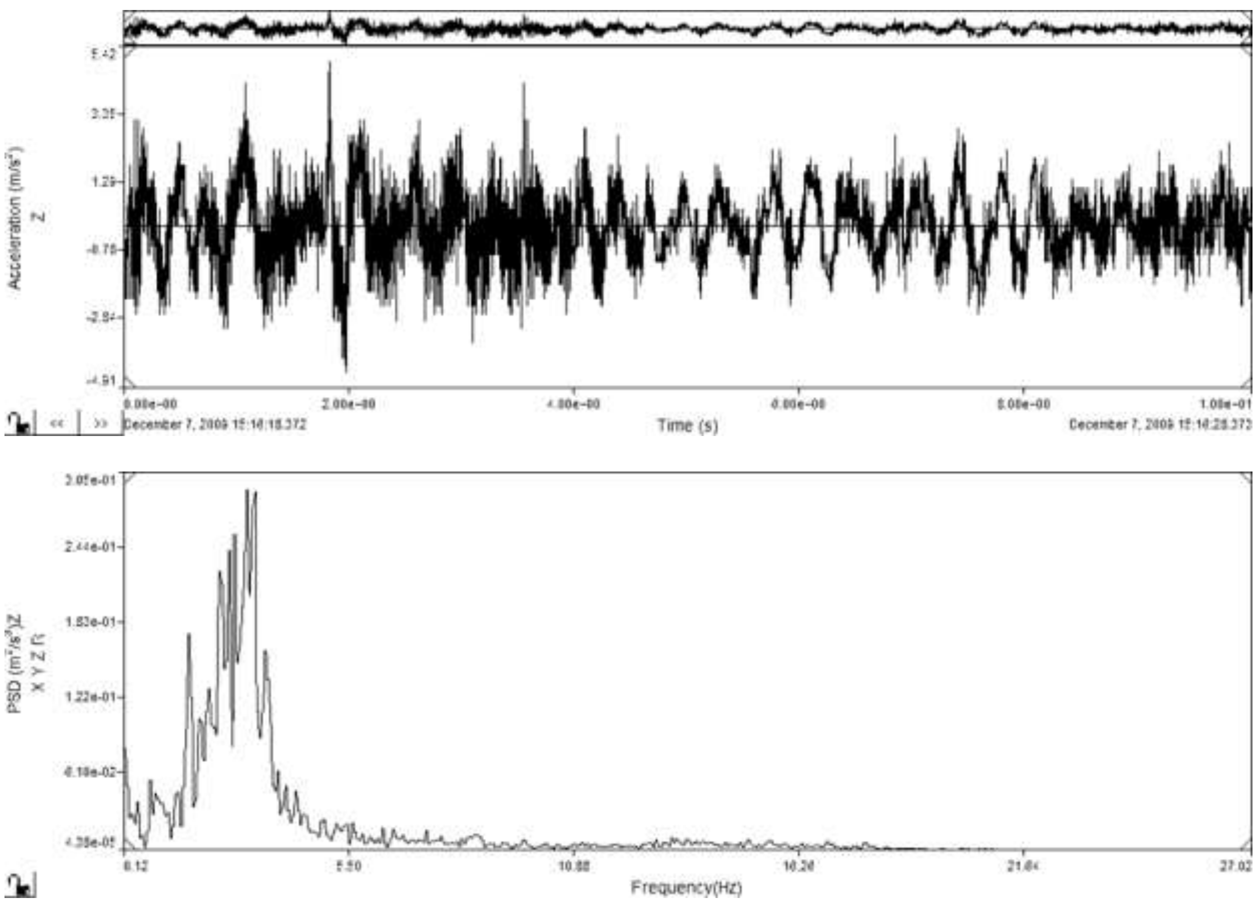


Figure C6. *Secondary road, Ambulance #3, Z-Axis R.M.S.,≤35 - 64 mph., typical 10 sec event interval*

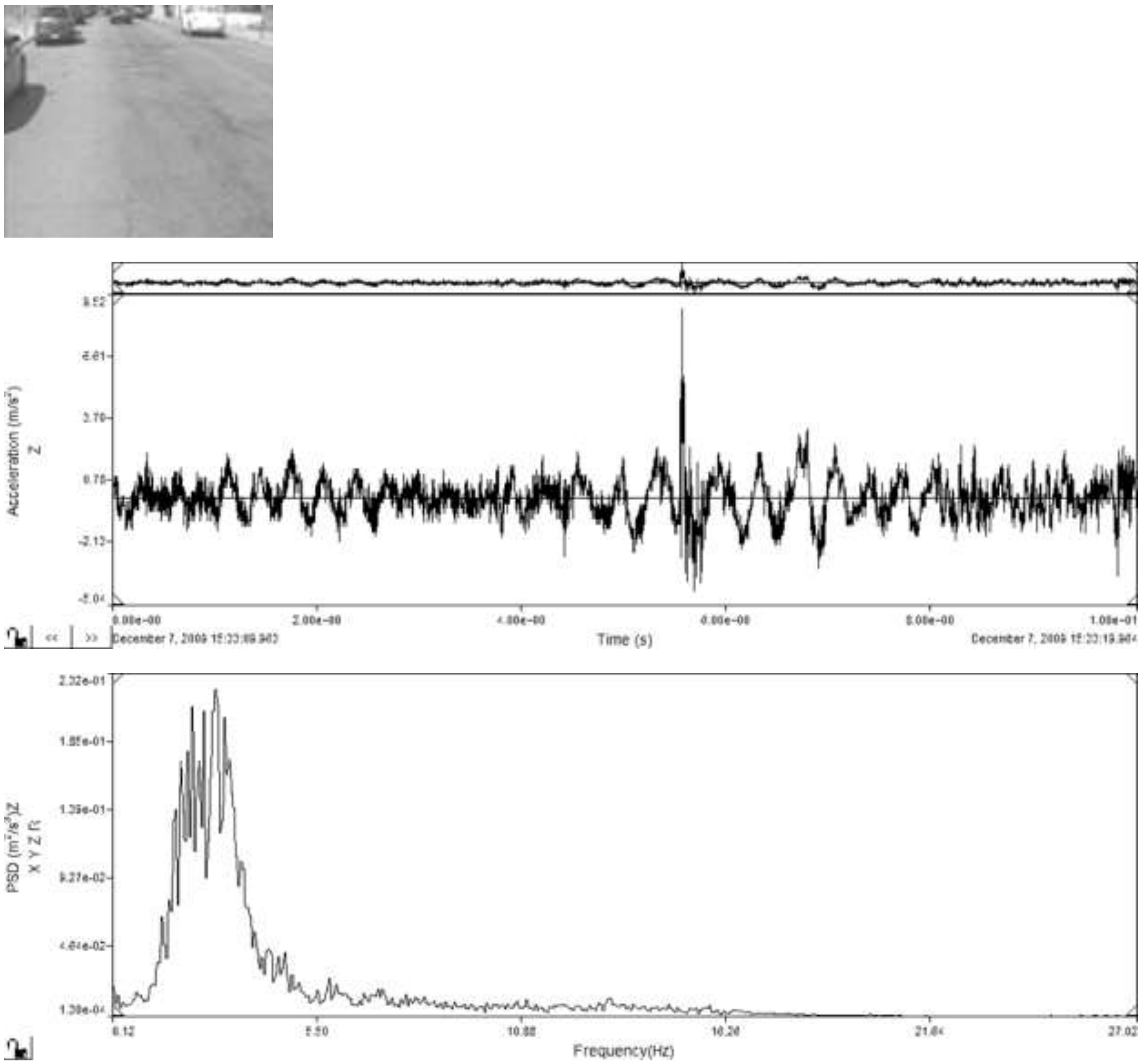
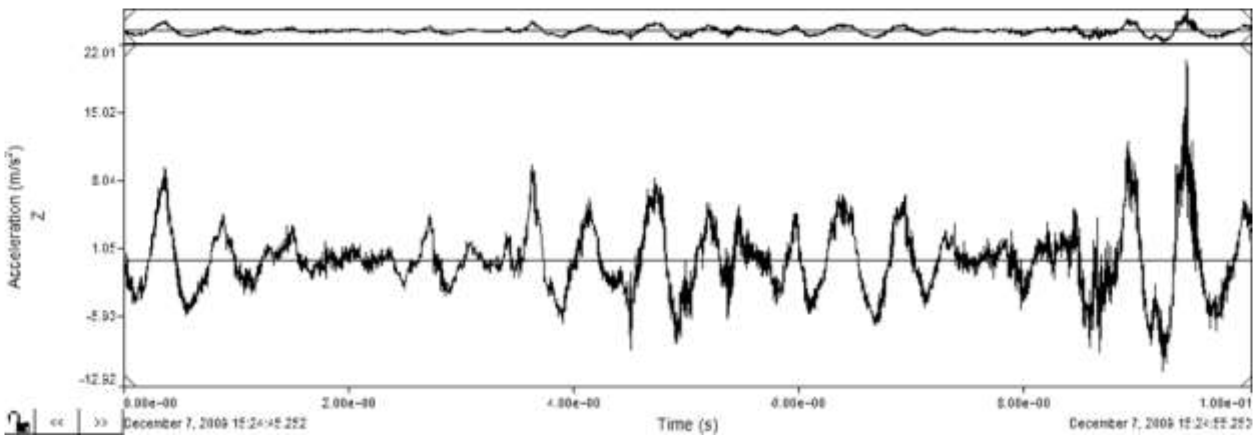


Figure C7. *City Street, Ambulance #3, Z-Axis R.M.S.,≤35 - 64 mph., typical 10 sec event interval*



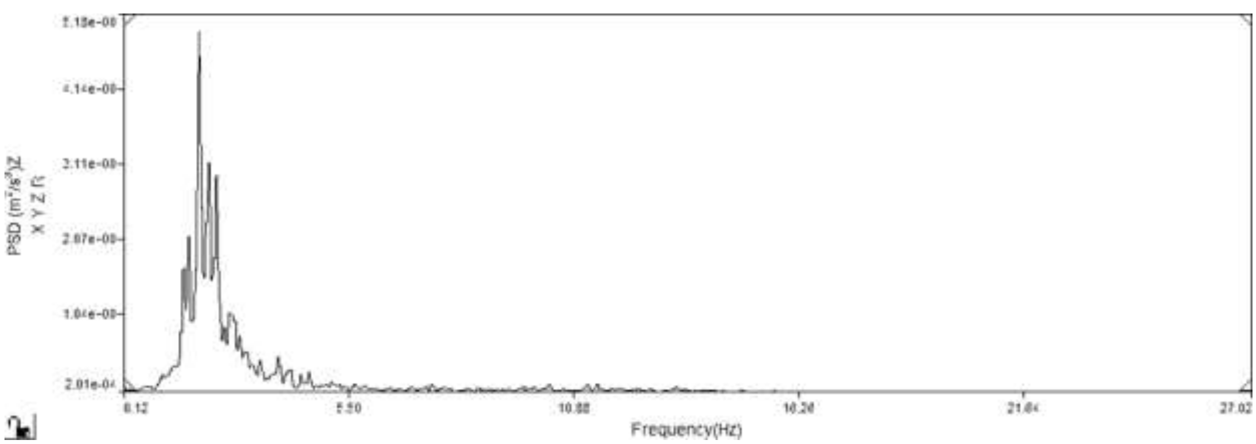
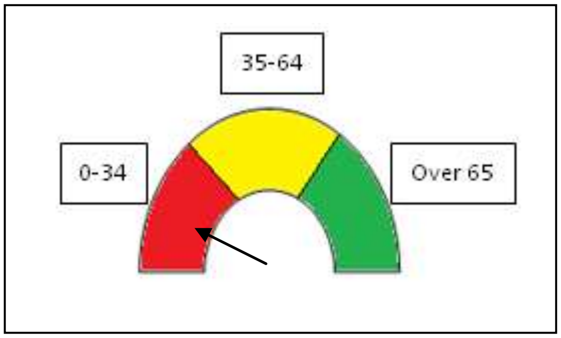


Figure C8. *Unpaved Road, Ambulance #3, Z-Axis R.M.S. ,≤35., typical 10 sec event interval*



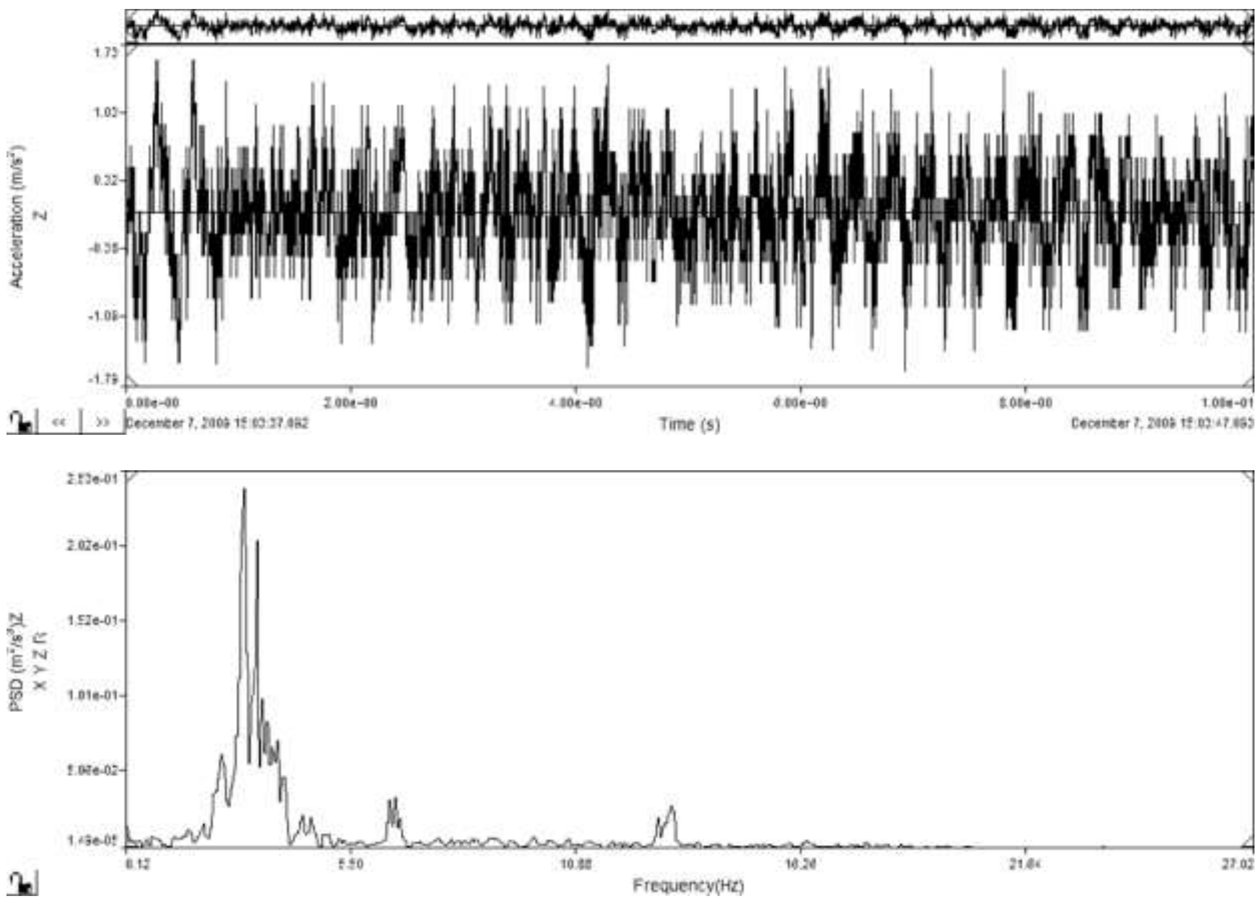
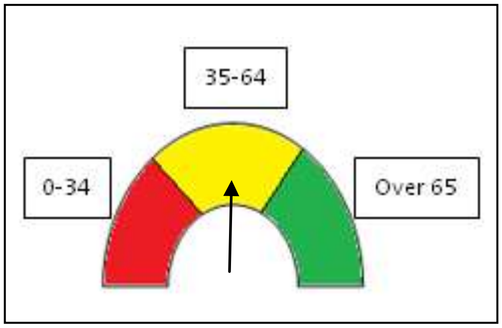


Figure C9. *≤35 mph, Highway, Ambulance #3, Z-Axis R.M.S., typical 10 sec event interval*



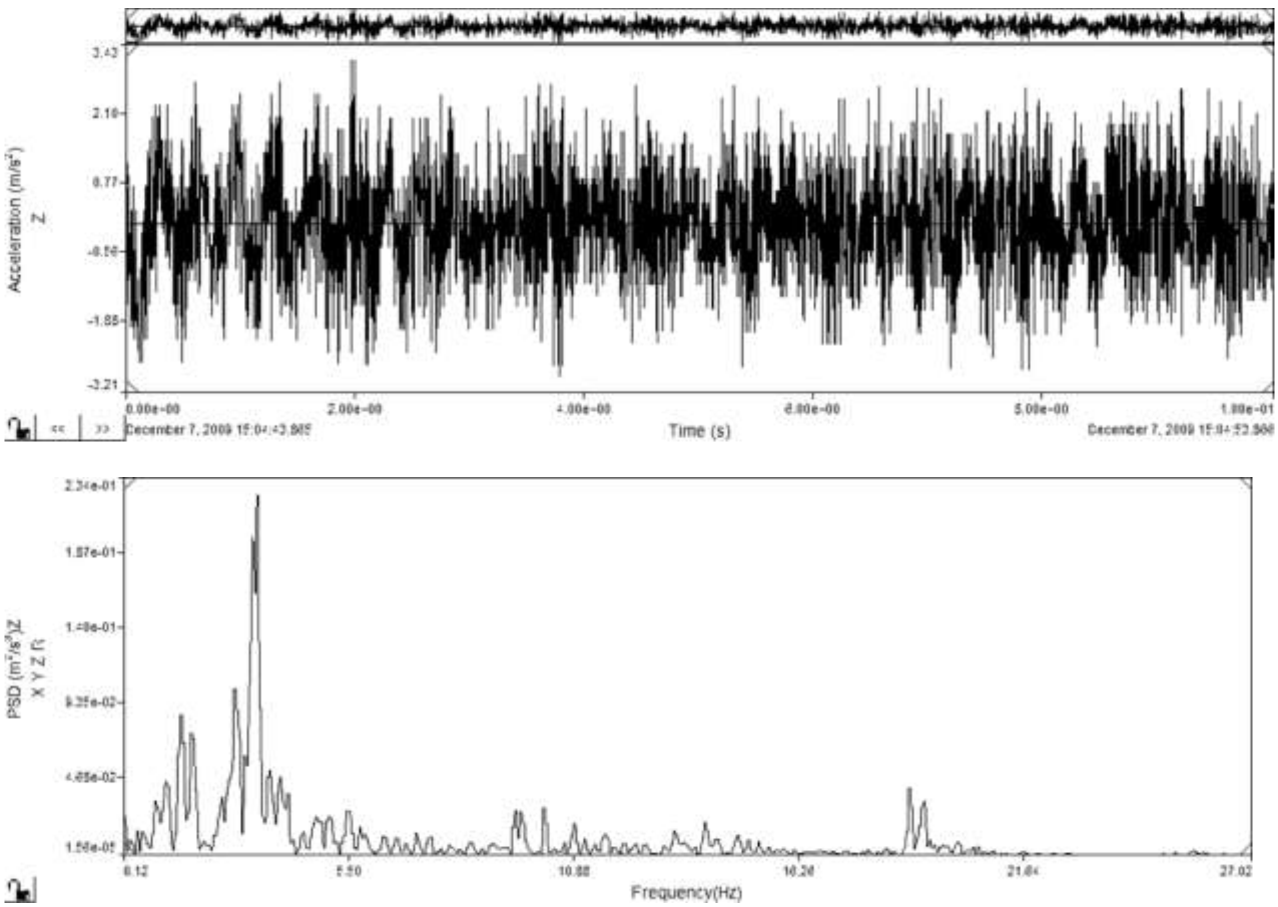
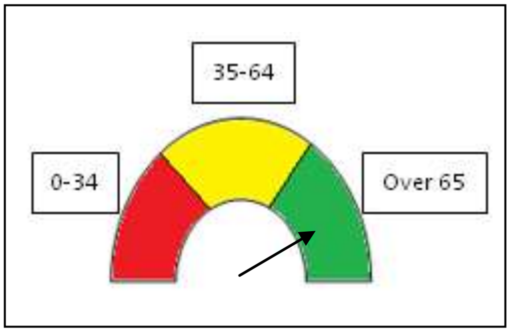


Figure C10. 36-64 *mph, Highway, Ambulance #3, Z-Axis R.M.S., typical 10 sec event interval*



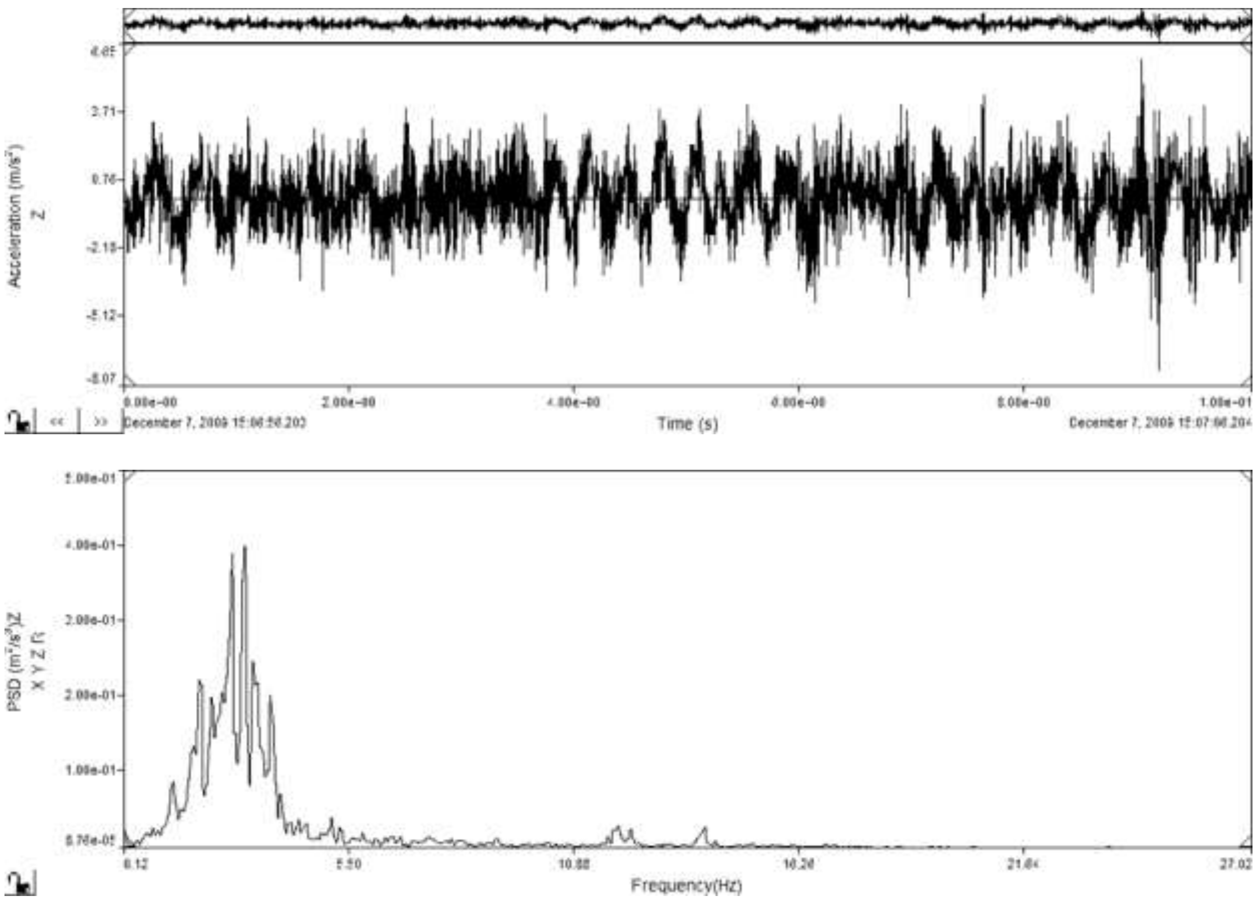


Figure **C**11*. ≥65 mph, Highway, Ambulance #3, Z-Axis R.M.S., typical 10 sec event interval*

Appendix D: CAD Drawings

SolidWorks drawings of the stretcher and the ambulance.

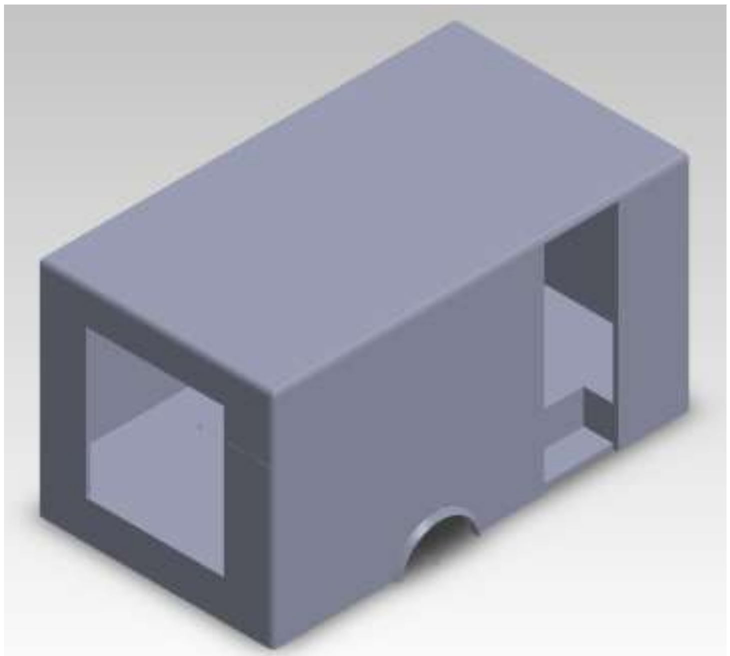


Figure D1. *Ambulance Box*

Figure D2. *Stretcher, opened, dimetric view*

Figure D3. *Stretcher, opened, side view*

Figure D4. *Stretcher, folded, dimetric view*

Figure D5. *Stretcher, folded, side view*