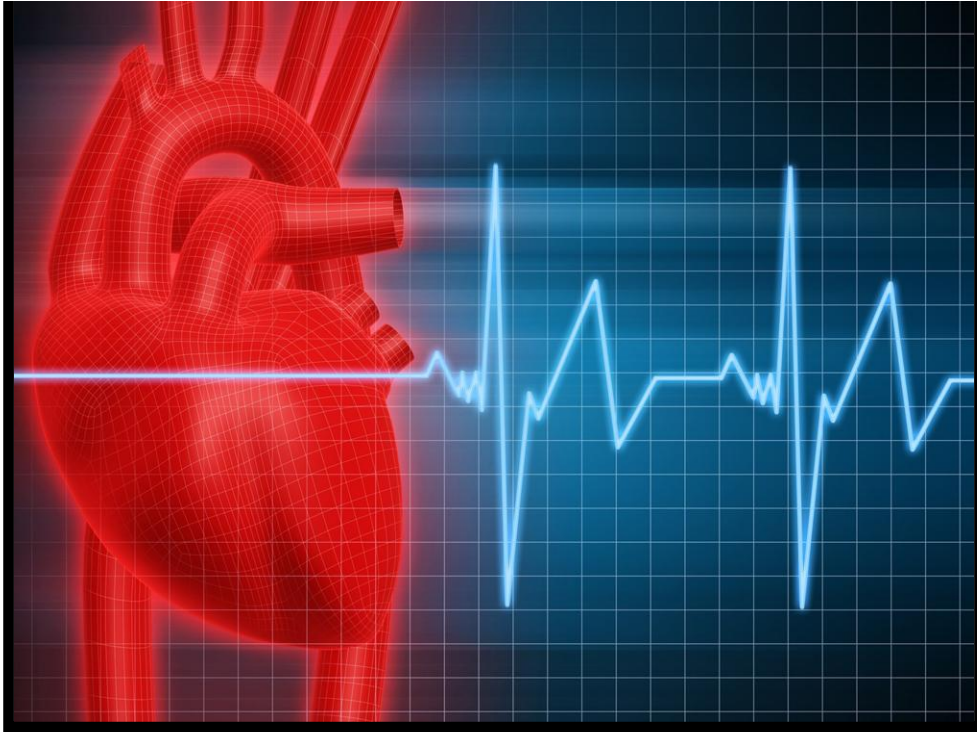# IPRO 319

New Technologies for Cardiac Arrest Victims

Team Members:

Jennifer John, Christopher Gazda, Julian Spinoza, Oksana Lasowsky, Albert Hutchful, Grant Austin, Bum Kyung Cho, Andrew Fournier, Stephanie Harmon

Advisors:

Francisco Ruiz and Ray DeBoth

Date: November 23rd, 2009

Due Date: December 4th, 2009

Table of Contents

IPRO Introduction

The Interprofessional Projects (IPRO®) Program at Illinois Institute of Technology: An emphasis on multidisciplinary education and cross-functional teams has become pervasive in education and the workplace. IIT offers an innovative and comprehensive approach to providing students with a real-world project-based experience—the integration of interprofessional perspectives in a student team environment. Developed at IIT in 1995, the IPRO Program consists of student teams from the sophomore through graduate levels, representing the breadth of the university's disciplines and professional programs. Projects crystallize over a one- or multi-semester period through collaborations with sponsoring corporations, nonprofit groups, government agencies, and entrepreneurs. IPRO team projects reflect a panorama of workplace challenges, encompassing research, design and process improvement, service learning, the international realm, and entrepreneurship. (Refer to http://ipro.iit.edu for information.) The New Developments in Cardiac Arrest team project represents one of more than 40 IPRO team projects for the fall 2009 semester.

Abstract

Due to the high rate of death associated with cardiac arrest, a prototype has been developed for on the scene response. The goals were to create a citizen-friendly device that would address various lifesaving technologies associated with cardiac arrest patients such as induced mild-hypothermia, controlled oxygen deprivation, and spinal-track oscillations. The product needed to be intuitive, portable, and fast so that it could be used before trained emergency response teams arrive.

Long standing research on cardiac arrest patients shows that individuals endure the most amount of brain damage as oxygen is rushed back to the brain after the patient's heart begins beating again. Studies by the American Heart Association show that cooling a person by 3 C decreases the amount of brain damage as long as the cooling is done within 24 hours of the original attack. Also, new research in pigs has shown that allowing a heart to not beat for 20 minutes while oscillating the subject along the spinal axis at 0.6g allows the subject to be revived without brain damage.

IPRO 319 has combined background research with realistic application goals to create an oscillating bed equipped with a phase change cooling system. Spring loaded wheels are used to drive the oscillation of the bed while cans of R152a release liquid coolant into a vinyl bed placed between the victim and the bed. This machine is low-profile and easy for standard by-passers to use in the event of a cardiac arrest emergency. The bed is designed for maximum use of 20 minutes, typical response time of emergency personnel is 10 minutes.

Background

Heart disease is the leading most cause of death in both men and women. Cardiac arrest is prevalent in all races, ethnicities, and creeds. Thousands of Americans die of sudden cardiac arrest originating from heart disease. Cardiac arrest is characterized is by the swift disruption of normal heart activity. This can include greatly increased heart rate which is tachycardia, greatly decreased heart rate- brachycranic, irregular heart rhythm which is arrhythmia, or irregular control of the pumping of the ventricles- ventricular fibrillation. Almost 95% of victims that suffer heart attacks and cardiac arrests expire before they are able to reach the hospital. Every minute a victim is not revived by CPR or defibrillation, their survival rate decreases by 7-10%. This percentage accumulates and increases drastically over just 10 minutes. Thus, it has been identified that immediate care after a cardiac arrest has began will help prevent brain damage, heart damage, and increase recovery and survival rate.

One of the first courses of action in immediate care for cardiac arrest victims is CPR which consists of checking their airway and breathing and administering a cycle of compressions and mouth to mouth resuscitation. An AED is an automated external defibrillator machine which is located in all public buildings, arenas, recreational facilities, work places, schools, and areas where large groups of people are present. A defibrillator sends electrical pulses to the heart to shock the heart back into normal function either because the heart has stopped beating or because there is ventricular fibrillation and different parts of the heart are contracting and relaxing based on their own pace.

CPR requires certification and in certain situations bystanders believe that are able to perform CPR themselves or those that are certified can cause injury to the victim if compressions are done to hard or in the wrong place. At the same time, if the cycle of compressions and breathing is not consistent and controlled, it could cause lung, heart, rib, or breathing damage not already present. In the same way, although the instructions and procedures in the use of an AED are very straight forward and easy to understand for

anyone, it is still only a machine that delivers electrical impulses based on calculations and thus cannot administer any CPR, check blood pressure or administer any blood thinners or medication like adrenaline to fasten the rate of blood flow.

In recent study and research in the past decade, it has been found that controlled cooling and generation of restrictive hypothermia to cardiac arrest victims within the 10-15min after the attack can help in starting and pushing the normal rate of blood flow in the blood vessels around the heart and throughout the body, especially to the brain. Much of the complications associated to cardiac arrest include neurological damage, as there will be loss of oxygen to the brain, injury to the heart and death of cardio muscle, damage to blood vessels to and from the heart, and etc. Oxygen loss over time increases death of muscle and body tissue as well. Induced controlled hypothermia is a way to steady cellular metabolism, reduce tissue damage, and prevent muscle injury by the time the patient is resuscitated successfully. Most hospitals are now equipped with hypothermia generating cooling systems that will decrease the body temperature of a cardiac arrest victim down to 32^0 C-34^0 C. The machines in the hospital are constructed for direct contact with the human body, and overall cooling of the body including the neck and head regions, and involved immediate cooling of the body as quickly as possible.

Available in the market currently are many machines and devices that also aim to reach this type of cooling capacity. RhinoChill, sponsored by BeneChill, uses a nasal catheter that is inserted non-invasively and injects coolant into the nasal cavity of the individual for cooling therapy. Sun gel pads, sponsored by Medivance, consist of 6 pads of hydrogel coating that have adhesive so that close contact with the patient's body can be maintained. The cooling pads are connected to a machine system that will regulate temperature, in a constant range, over all the pads. This method is non-invasive and uses a very efficient transfer of heat from the body to the atmosphere. This system is being used currently in hospitals around the country and is a very effective technique to initiate controlled hypothermia to recommence blood flow in a cardiac arrest victim.

At the same time, there has been a study performed at the Mount Sinai Hospital in New York where the blood flow of pigs was stopped for 20 minutes and periodic pGz-axis acceleration was induced as the pigs were laid down on their backs as opposed to normal CPR. The pigs were placed on a controlled machine oscillator that stimulated an acceleration of .6G. The pigs had less perfusion injuries, less blood-related damage to the body, and overall recovered faster and in better condition than normal CPR administration.

Objective

This project aims to design, construct, and assess a prototype system that will be used as a first step response method when an individual undergoes a cardiac arrest and increase their survival rate. The goal of this team was to develop a non-invasive cooling system that will reduce body temperature in a quick and efficient manner and to construct an oscillating table for Z-axis acceleration while still maintaining a simple complex for the average bystander to use both apparatuses.

The main goal of the semester for our IPRO 319 group was to create a model prototype of device to be used in the case of a cardiac arrest emergency in place or in conjunction with current CPR and AED protocols. This significantly changed the organization and approach from typical IPRO groups involving continuing projects because the scientific research behind this project plan is cutting edge and isn't readily available but the goal of the project is to make a prototype, not continue or build from current research. The group decided to organize the semester into specific milestones, set guidelines for practicality of the design, then sift again through past research, design a prototype that fits both project guidelines and is in sync with current scientific knowledge and research, and finally test this prototype for efficiency in it's design.

It was decided amongst the team that the guidelines for any such prototype must include the following: ease of use for an individual with seemingly no first-aid training, mobility and accessibility for individuals at the scene to obtain and use the device, the device must accommodate for individuals of all ages and sizes, both patient and rescuers. The next step of prototype production was to both research and plan different designs that would accommodate previous semester's advice and/or work as well as our specific vision for the project. While studying the final reports of semesters past, a common goal surfaced that many of the previous IPRO groups ended up somewhat inconclusive in their reports, usually due to the lack of time or funding to do the extensive research that was required to prove one method (cooling, shaking, or air-mask) was necessarily better than another. For example, previous groups did not have the necessary funds to properly test the effects of the shaking method with blood circulation in the heart. Also, groups were

unable to find the proper levels of atmospheric gases for the mask system to control Oxygen to the brain because the adverse reactions to the Oxygen levels vary on an individual level. And finally, all groups had the problem with funding cooling devices within the budget that would reach maximum cooling potential to lower a patient's body temperature by 3° C.

Ethics

In IPRO 319, our design was to assist with the resuscitation of a person undergoing cardiac arrest. In assessing the ethical aspects of our design the seven steps as indicated by the IPRO department were followed. The steps were to State the problem, to check the facts, to state the specifications, to develop a list of five options, to test the options (harm test, publicity test, defensibility test, reversibility test, virtue test, professional test, colleague test, organization test). Finally, to make a tentative choice and a final choice. The conflict of interest that existed was what the role of our project would be in terms of usability in the bigger scheme of the current CPR process (ie. how could we feasibly test our project, when the cause of resuscitation had not been established in animal models). Diversity of specialization moderated each team members conceptualization of the purpose of the machine. Through extensive communication, a final project was established to meet the mutual needs of the group.

IPRO 319 had team members that had different understandings of what could be accomplished within the semester's time that was granted. Some members believed that research should be accomplished to further understand why the animal models worked to resuscitate the heart, and then to establish the differences between the animal models and the human application. These members also wanted to devise ways to make the machine testable. Other members wanted to construct a device that would be able to replicate the shaking pattern of the animal model without actually testing it on a subject. Finally there was a third group that wanted the project to address the applications of an ideal machine that would resuscitate a person. Everyone had the opportunity to explore a tiny fraction of their interest and integrate the ideas into a workable mock up for the end of the semester. Ideas that conflicted with others required checking background information.

The second step as outlined by the IPRO office was to check the facts. Research from previous semesters, patents, as well as published research was obtained. It was found that with our research there were no tests that had been conducted on people in the same manner as the animal tests had been. We were left to make assumptions, and build

based on the frequency specifications by the research, and the weight measurements of a grown adult. Given the financial constraints of the IPRO, a platform and a cooling unit were constructed. Finally, instead of trying to build a bed that would be for a human, testing on a turkey would yield its own results that could be used by future researchers. We decided that we could create ideal situations where the bed could be utilized, as a suggestion, should the bed be found effective in humans in the future. Our end product is geared towards medical researchers first, with the capability for modification in the future for everyday use.

The third step was to state specifications. The bed would be utilized by medical researchers for human participants. We built our bed based on the weight and the height of the average person. The mattress was based on the temperature of the average person and the conductance was made in that regard. The functional test was specified for a turkey model that is similar to a human in terms of cellular material. Due to the NIH specifications, we were not allowed to conduct human or animal experiments.

If the project were progressed, the ethical consequences would be discussed only after extensive in lab research with the actual human subjects. This is the most important aspect of the project. It isn't possible to project its usability if it is unknown if its beneficial or detrimental to cardiac arrest victims. Further specifications could be made so that good Samaritans would be able to utilize the machine.

Approach

After researching different techniques to improve current cardiac arrest treatments the group decided to move forward with a design prototype that would include methods that seem to have a positive effect on the patient's survival rate: shaking and cooling. Ideally the shaking would start as soon as the patient enters cardiac arrest and would continue until paramedics arrive. This is also true for cooling of the patient, except the cooling mechanism would be detachable so that the patient could be cooled in the ambulance on the way to the hospital. This puts the patient in our cooling device for approximately 20 minutes, 10 before paramedics arrive and 10 on the way to the hospital. It is impossible to cool the human body by three degrees in 20 minutes without causing serious health problems such as frostbite, hypothermia, or even death. It was found that it will take 15 minutes submerged in freezing water for the human body to drop one half degree, meaning that our device would at most drop the patient's body temperature by 1/2 degree in 20 minutes. Even though this is far short of the goal of 3 degrees, it was decided as a group that this cooling process could still benefit the patient's survival probability because this is less net-body cooling the hospital cooling devices need to achieve.

After deliberating and deciding to include both mechanisms in the design, the entire group began drafting prototype plans. Each group member submitted at least one design and then after a week of debating and voting the group came to a consensus of using spring-loaded torsion wheels to drive the shaking oscillations and diflouroethane 152a as a cooling agent. Each spring needs to be able to move freely through 180^0 rotation as well as bear the load of 100kg person while also providing a torsion force to accelerate the bed from one amplitude maximum to another. Diflouroethane was chosen as a cooling agent also because of its environmental friendliness. This is essential to any cooling agent that was to be used in this project because either gas or chemical cooling products would in some way be released to the environment. In the case of R152a it is safe to directly let the gas into the atmosphere as long as the room is well ventilated. The next page provides a detailed figure of the oscillation system.
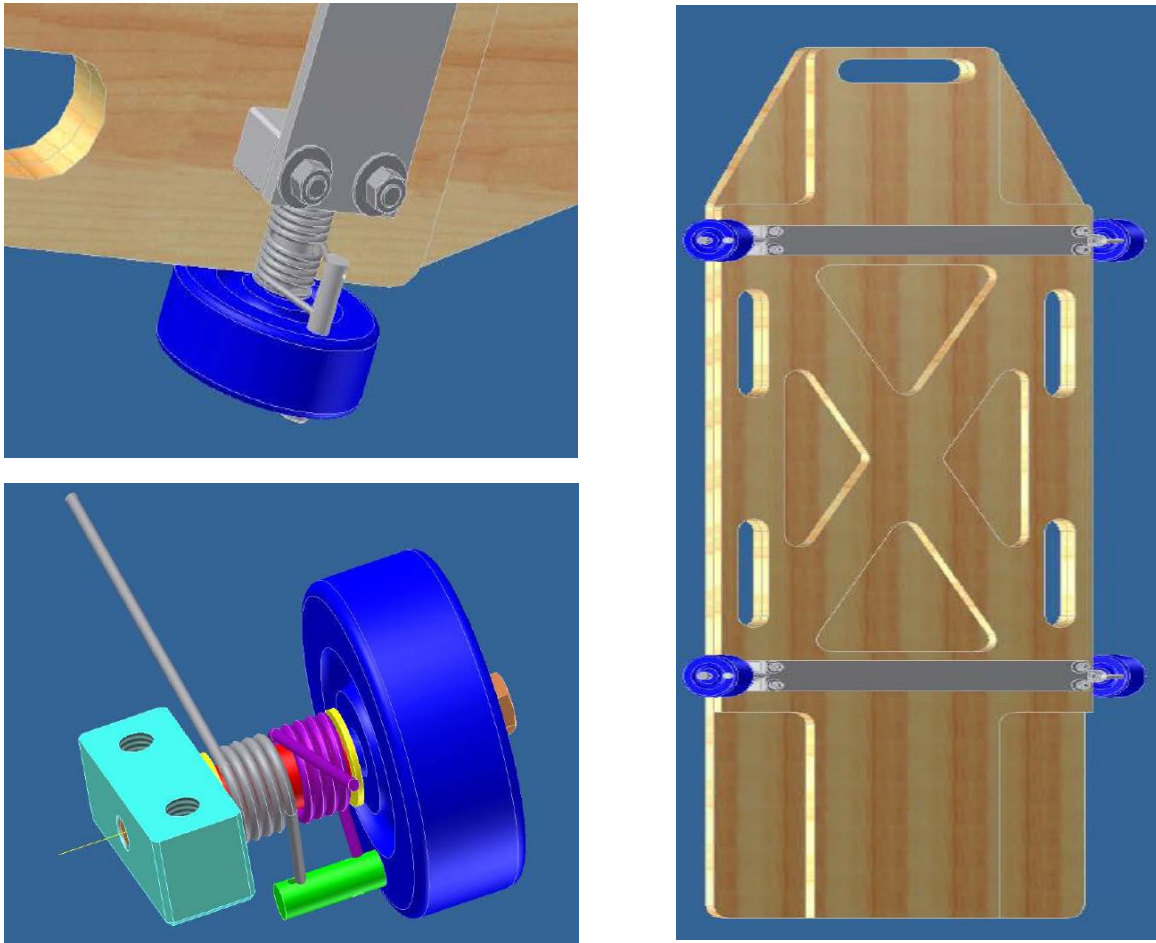
Fig. 1. Above shows the basic layout of the oscillation bed with spring loaded torsion wheels.

Method

COOLING

The cooling design also ran into the problem of being compact and mobile when the group began drafting ideas of chemical reaction cooling versus phase change cooling. Chemical reaction cooling could be achieved via an endothermic reaction between Barium Hydroxide Octahydrate and Ammonium Nitrate,

$$Ba(OH)_2 \cdot 8H_2O_{(s)} + 2NH_4NO_{3(s)} \longrightarrow Ba(NO_3)_{2(s)} + 2NH_{3(aq)} + 10H_2O_{(l)}$$

but we found that we would need 40lbs of materials per trial of these chemicals to achieve any reasonable cooling and this was unacceptable in terms of our prototype guidelines. The group decided to use diflorouethane 152a instead and capitalize cooling from the phase change of liquid to gas cooling. The liquid would be pumped into a bed that the patient is laying one, once the liquid obtains enough heat it will phase change to gas. The bed used in this prototype is a typical pool floating device made of vinyl, this bed was modified from its original design as to exclude the headpiece and to separate the chambers that air and liquid are contained in. The vinyl was particularly difficult to reseal after modification, creating a set of extra experiments involving the best sealing method. The group tested the vinyl's strength after being sealed by four different glues, Pliobond, Gorilla Glue, super glue, and caulk, along two different heat sealing devices: a food sealer and a hot-iron heater. Once the bed was correctly sealed the pressure capacity of the bed could be tested via testing involving different release valves connected to the foot of the bed. It is important to achieve maximum air flow within the bed without compromising the inflated volume as well as cooling capacity of the liquid. Te heat needed to cause liquid-gas phase change in the bed is preferably from the patient's direct body temperature. By continually pumping liquid in and the gas products out, we can efficiently cool the skin and therefore body temperature of the patient. The 152a liquid was obtained via compressed cans that are available commercially for cleaning purposes; by turning the cans upside down and releasing, the liquid was released from the canister and was transported into the inflatable bed by means of one tube that split into four

separate tubes, one for each section of the inflatable bed. Calculations for choosing diflouroethane along with its cooling capacity can be found in the next section of the report.

Cooling Capacity Testing Protocol

A 22.72-lb frozen turkey was purchased form a local grocery store. The turkey was in an 8% solution which consisted of 22% salt and starch. The turkey was thawed and measurements of width, height, of total body were taken. Also, adipose, muscle and connective tissue thickness were measured. The diameter of the internal body cavity was taken and internal organs were removed from their containing bag.

Part of Turkey	Measurement (cm)
Total Length	37.5
Total Width	30.0
Total Height	19.0
Neck Diameter	5.0
Length of Neck Cavity	15.0
Organ Cavity Diameter	9.0
Adipose Tissue Thickness	0.5
Body Cavity Muscle Tissue Thickness	0.5
Connective Tissue Thickness	0.2

The turkey was heated in a vacuum oven (no vacuum was induced) to 98.7 F to simulate body temperature. Once the turkey reached this temperature, it was placed on the cooling bed. The bed was activated using one 12-oz can of 1,1-diflouroethane flowing into its 5 separate channel.

OSCILLATION

This prototype had to accommodate different details for the two mechanisms. The shaking design uses spring-loaded wheels instead of a motor to drive the oscillations

because we are interested in making the final prototype as mobile as possible, something a motor does not accommodate very easily. As previously stated the goal of this project was to also include simplicity, a motor relying on outside power was not in the group's best interests. Also, the spring-loaded wheel design conserves the system's energy excluding the effects of frictional losses, which can be accommodated by means of a driving force, motors, solenoids, etc. This oscillating bed also needed to be low to the ground while supporting individuals of all shapes and sizes, it is because of this we needed relatively small wheels and a relatively large bed. The bed is 6feet x 2feet, with wheel sizes of three inches and six inches. The calculations involving wheel size can be found in the next section of the report.

The shaker bed was assembled and tested with all eight springs, two on each wheel. The bed was very difficult to push and did not oscillate when released. Instead it simply returned to the equilibrium position. Analysis revealed that the system was acting as an over-damped system. Friction was determined to be the cause of the damping. The bed was reworked to improve its structural integrity, and four springs were removed to make it easier to push. Only four springs remained, two on each of two wheels. It was then re-tested using a string potentiometer to record linear displacement and an accelerometer for reference.
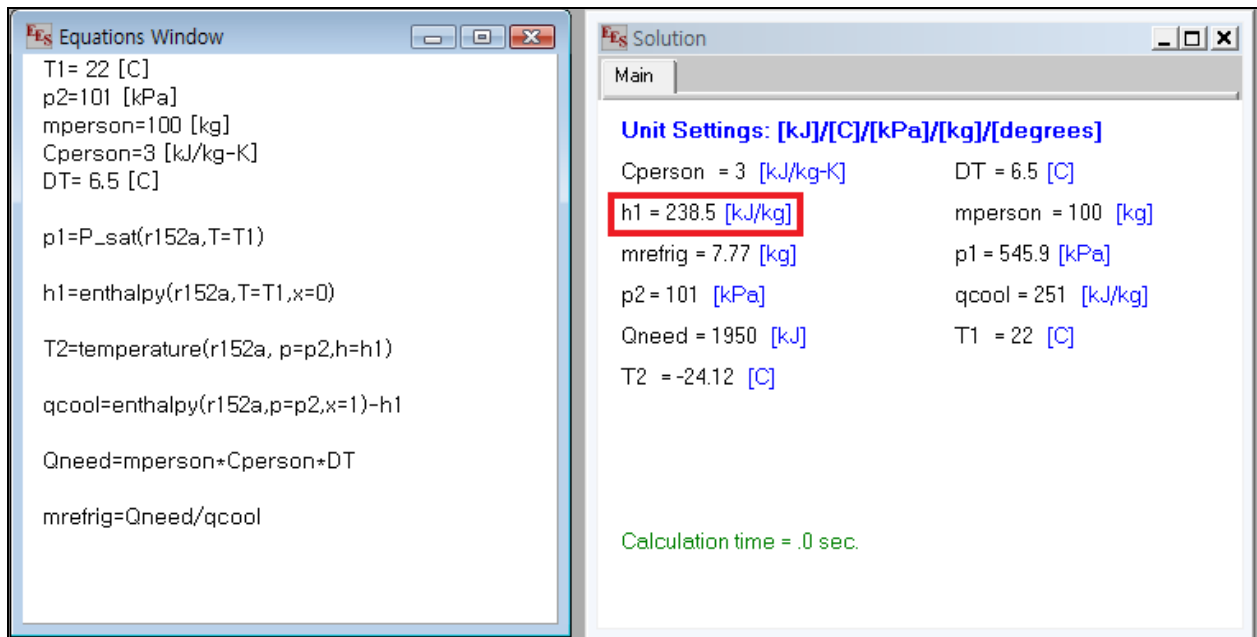
Results

COOLING

Figure 2. The cooling capacity when using R152A refrigerant calculated by EES

The left side of the figure shows how we formulated the equations for calculating the cooling of R152A using the EES. The right side of the figure presents the solution of the equations. From this calculation, the cooling of R152A was obtained as the value of **238.5 kJ/kg**. (As highlighted in Fig. 1 with a red box). The concept of the cold pack is to utilize the two powders that cause an endothermic reaction. From my research, thionyl chloride ($SOCl2$) and cobalt(II) sulfate heptahydrate could be used for endothermic reaction as well. However, thionyl chloride is not only nasty liquid, but also corrosive and toxic so that the ammonium nitrate and water reaction is considered much more reasonable and it is even cheaper when it comes to the cost.

The previous team does not give us the specific value of the cooling so that we calculated it on our own.

$$Ba(OH)_2 \cdot 8H_2O_{(s)} + 2NH_4NO_{3(s)} \longrightarrow Ba(NO_3)_{2(s)} + 2NH_{3(aq)} + 10H_2O_{(l)}$$
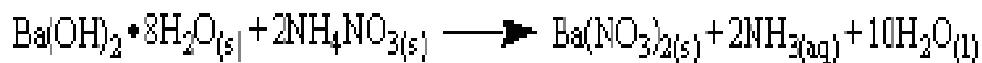
Component	Ba(OH)$_2$	2NH$_4$NO$_{3(s)}$	Ba(NO$_3$)$_{2(s)}$	2NH$_{3(aq)}$	10H$_2$O$_{(1)}$
ΔHf (kJ/kg)	-3342	-365.6	-80.29	-285.8	-992.1

Fig. 2. Shows the relative heat of formation for each of the separate components of the cooling reaction.

$$Q_{out} = -3342-365.6-2*(-80.29)-10*(-285.83)-(-992.07)=-62.25 \text{ kJ/kg (Endothermic)}$$

Thus, Q_{out} =-62.25 kJ/kg= **197.4 kJ/kg**. As seen in the results above, using R152A method is a better idea for mattress cooling system than using the previous team's idea since using R152A is more efficient cooling method (approximately 40 kJ/kg more cooling) and also easier to use.

The results for the turkey experiment were not very successful or helpful. The turkey experiment was conducted to obtain data about thermal conduction of the mattress portion of the bed. The turkey was heated to 115 degrees Fahrenheit. The control for the experiment was the cooling of the turkey without the presence of the mattress, while the variable scenario was the cooling of the turkey with the mattress. It was found, using a household cooking thermometer and an IR thermometer, that the temperature change between the two scenarios was not significant. In the control scenario, the turkey decreased by one degree over a ten minute period, while a comparable decrease also occurred with the cooling system. The experiment was not a loss however. Through the temperature acquisition portion of the mattress itself, we found that the underside of the mattress cooled quickly and with gross quantity compared with the top portion. The turkey was situated at the top. For future experiments, if the mattress containment of the cooling fluid were placed on top of the turkey, and due to convection , the hot air from the flesh could rise and the cooling portion that was pooled to the bottom could be used to make contact with the flesh. We also believe that there are better conducting materials that could be used in lieu of the air mattress. The optimization problem of a material that could protect the patient from frostbite, but cool at a faster rate could be examined.

Table 1 below shows the cooling for the control experiment while table 2 shows the temperature drop as a result of the cooling bed.

Time (min)	Temperature(F)
0	114.7
2	114
4	113.9
6	113.3
8	113.1
10	112.8

Table 1. Control temperature of turkey when it was not on the mattress

Time (min)	Temperature (bed) (F)	Temperature Turkey external (F)	Temperature Turkey internal (F)
0	50	94	112.4
2	57	81	112.2
4	62	87	112.1
6	60	86	111.7
8	63	85	111.3
10	64	85	111

Table 2. The data acquired from the turkey on the outside of the mattress.

OSCILLATION

It was decided that oscillation of the human body should occur at a frequency of 1.5Hz with a maximum amplitude of 0.6g in the head-to-toe direction. It was also decided that the shaking apparatus would have a mass of approximately 10kg and that the average mass of a person suffering cardiac arrest is approximately 100kg. Thus the design criteria are:

linear frequency of oscillation, $f = 1.5Hz$

magnitude of acceleration, $A_a = 0.6g \left(\frac{9.80665\,{}^m/_{s^2}}{1g} \right) = 5.884\,{}^m/_{s^2}$

total mass undergoing oscillation, $m = 10kg + 100kg = 110kg$

From these criteria, the necessary wheel diameter was determined as shown below:

angular frequency, $\omega = 2\pi f$

$$\omega = 2\pi(1.5Hz) = 9.4248\ ^{rad}/_s$$

displacement as a function of time, $x(t) = A_x \cos(\omega t)$

velocity as a function of time, $v(t) = \frac{d}{dt}x(t)$
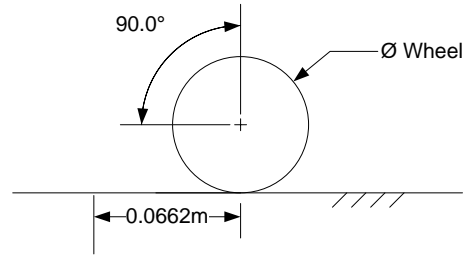
$$v(t) = -A_x(\omega)\sin(\omega t)$$

acceleration function, $a(t) = \frac{d}{dt}v(t)$

$$a(t) = -A_x(\omega^2)\cos(\omega t)$$

$$A_a = A_x(\omega^2)$$

magnitude of displacement, $A_x = \frac{A_a}{\omega^2} = \frac{5.884\ ^m/_{s^2}}{(9.4248\ ^{rad}/_s)^2} = 0.0662m$

It was then assumed that the wheel would move through $90°$ of rotation past the equilibrium position in each direction. This is because the torsion springs to be used cannot exceed $90°$ of rotation in one direction.
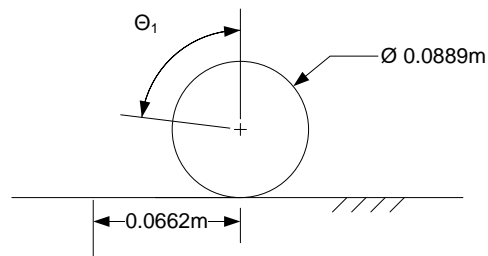
assume 90° of rotation, $\frac{1}{4}(\pi D_{wheel}) = 0.0662m$

target wheel diameter, $D_{wheel} = 0.0843m \approx 3.32in$

A commercially available wheel with diameter of 3.5 inches was selected and the actual angle of travel was calculated as shown below:

actual wheel diameter, $D_{wheel} = 3.50in \approx 0.0889m$

$$\frac{\theta_1}{360°}(\pi * 0.0889m) = 0.0662m$$

angle of operation (one direction), $\theta_1 = 85.33°$

The design also included all four wheels being spring-loaded, so as to spread the load across all four points of contact with the ground. This minimized the possibility of slippage occurring between the wheel and ground. The spring constant for each wheel was then calculated as shown below:
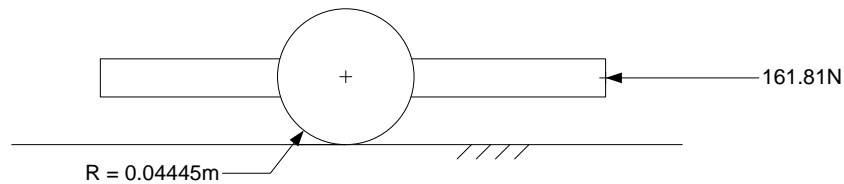
$$F_{total} = mA_a$$

total linear force required, $F_{total} = (110kg)\left(5.884\,^m/_{s^2}\right) = 647.24N$

linear force per wheel, $F_{wheel} = \frac{1}{4}(647.24N) = 161.81N$

The linear force which is opposed by the torsion spring acts through a moment arm with length equal to the radius of the wheel.

radius of wheel , $r_{wheel} = \frac{1}{2}(D_{wheel}) = 0.04445m$

R = 0.04445m

$$\tau = r \times F$$

torque (per wheel) at 85° of rotation,
$$\tau_{85°} = (0.04445m) \times (161.81N) = 7.192Nm$$

Commercially available 90° torsion springs are commonly rated by the torque generated at full travel (90°). The design requires only 85.33° of rotation and thus it was necessary to find the torque required at 90°.

torque (per wheel) at 90° of rotation,
$$\tau_{90°} = \frac{90°}{85.33°}(7.192Nm) = 7.586Nm \approx 67.14lbf\text{-}in$$

It was not possible to find commercially available 90° torsion springs with such a large torque rating. Thus it was decided to package two torsion springs in parallel. This solution required eight springs total. The springs chosen have a rating of 34.290 lbf-in.

A power spectrum analysis was performed on the displacement signal. This revealed the frequency of oscillation that occurred during testing. From that data, the effective spring constant of the shaker table (with 2 spring-loaded wheel assemblies) was calculated.

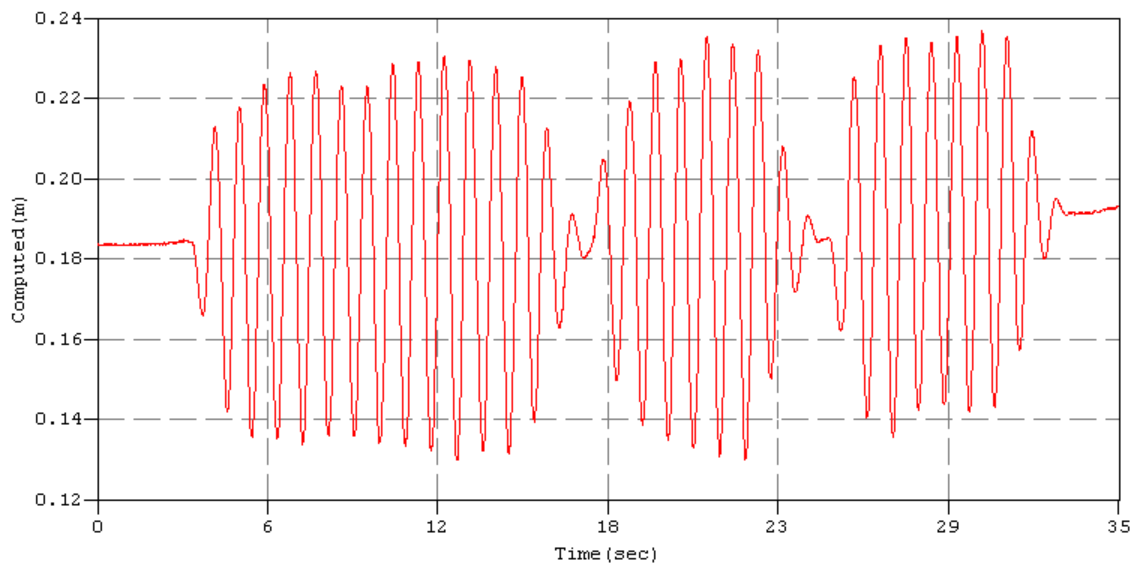**Linear Displacement vs. Time**

Figure 3. Here we are looking at the linear displacement vs time of the oscillation device for the four-spring system.

Figure 3 shows the linear displacement vs. time graph of the four-spring system. The pushing force to begin and maintain oscillation is an individual group member. Despite not having an accurate measurement of even force distribution the graph above shows relatively consistent amplitude throughout the experiment, this means that even the human error associated with uneven force on the system from a by-stander manually pushing the machine, it will operate near ideal. The breaks in the graph represent the behavior of the bed when the individual who is pushing lets go. The decrease in amplitude is characteristic of dampening forces caused from friction. These decays from

full motion down to the resting point can be fit to an exponential decay relation of the dampening coefficient of the system, which can then be later used to determine the necessary power of a motor supply to drive the bed to resonate at the ideal frequency.

Figure 4 gives the power spectrum of the oscillation data. What we look for in analysis is a spike in the general exponential decay of the system as the amplitude (inches) is decreased and frequency (hertz) is increased, this spike identifies the characteristic frequency of the system. In other words, this gives the exact frequency that will give the maximized efficiency in amplitude.
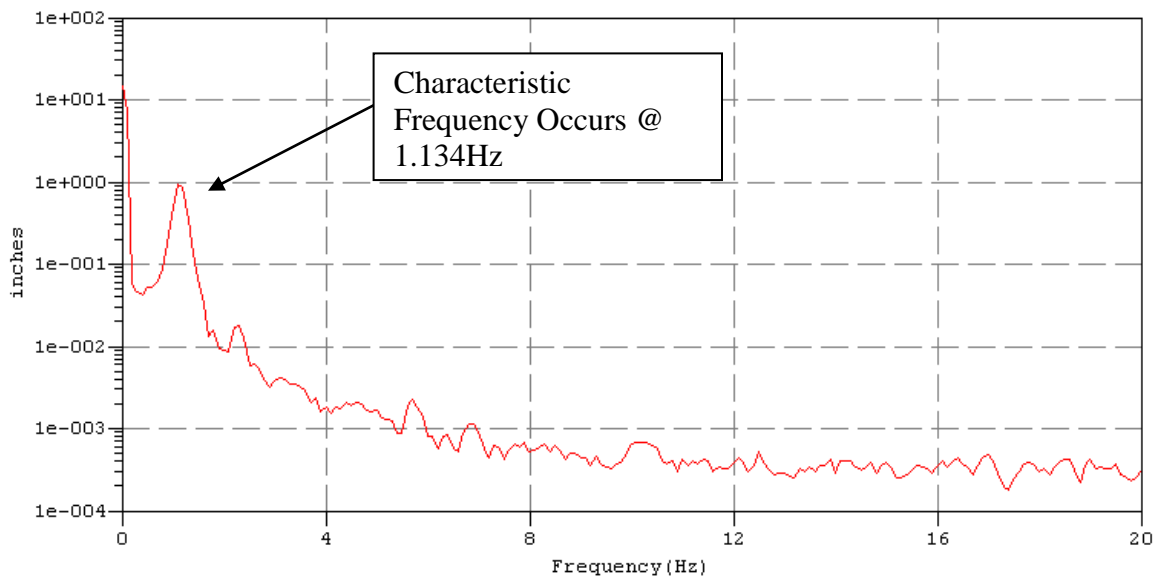
(Auto) Power Spectrum

Figure 4. Here we are looking at the power spectrum of the oscillation device for the four-spring system.

In an ideal system, the characteristic frequency of the system would be at 1.5Hz but as seen above, the characteristic frequency of our system lies at 1.134Hz. This means the bed is not hitting the target acceleration at each turn of the oscillation and thus our system is not operating at ideal conditions. We speculate that this is because the wheel sizes are too small to accommodate the amount of extension required to achieve 0.6g's in a 4-spring system. As a group it was decided that all 8 springs are necessary to achieve

ideal acceleration of the machine unless the wheel sizes are changed dramatically in the 4-spring system, below is the same data given above but for the 8 spring system set.

A power spectrum analysis was performed on the displacement signal. This revealed the frequency of oscillation that occurred during testing. From that data, the effective spring constant of the shaker table was calculated. As seen in Figure 5, the average amplitude of the bed has a much higher error rate than that of the four spring system, and it also appears to have a much higher dampening coefficient judging by how quickly the machine motion drops off after the pushing force stops momentarily.

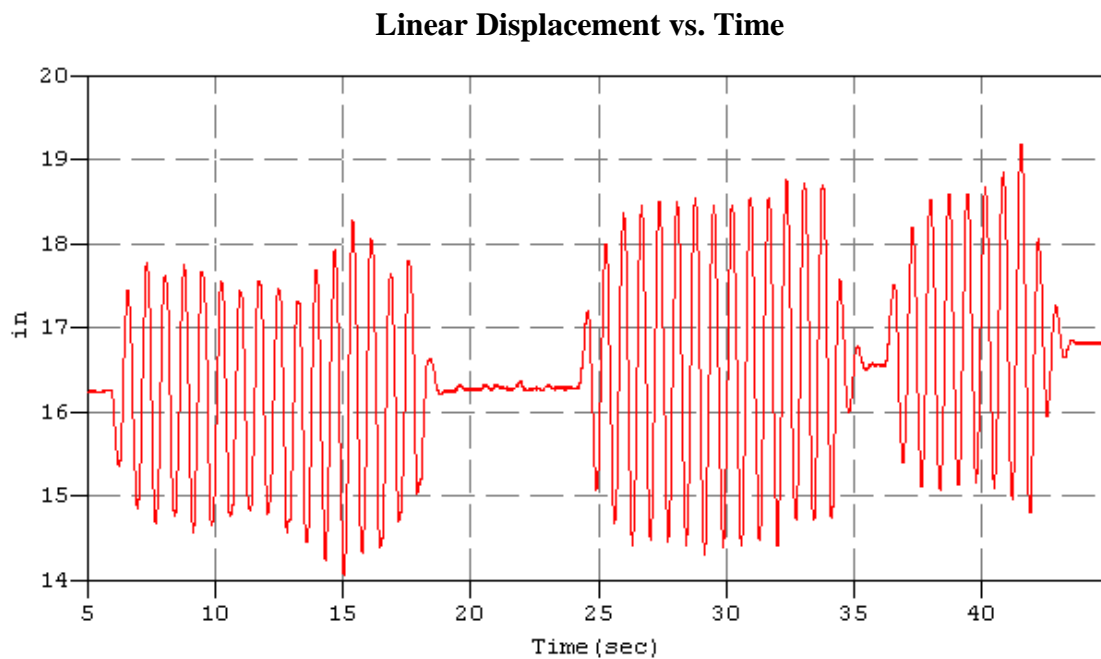**Linear Displacement vs. Time**

Figure 5. Here we are looking at the linear displacement vs time of the oscillation device for the eight-spring system.

Despite being much harder to push and also having a presumably higher dampening constant, the power spectrum analysis shows the characteristic frequency occurring at 1.417 Hz, this is much closer to the ideal 1.5 Hz and therefore has a more appropriate acceleration per oscillation.
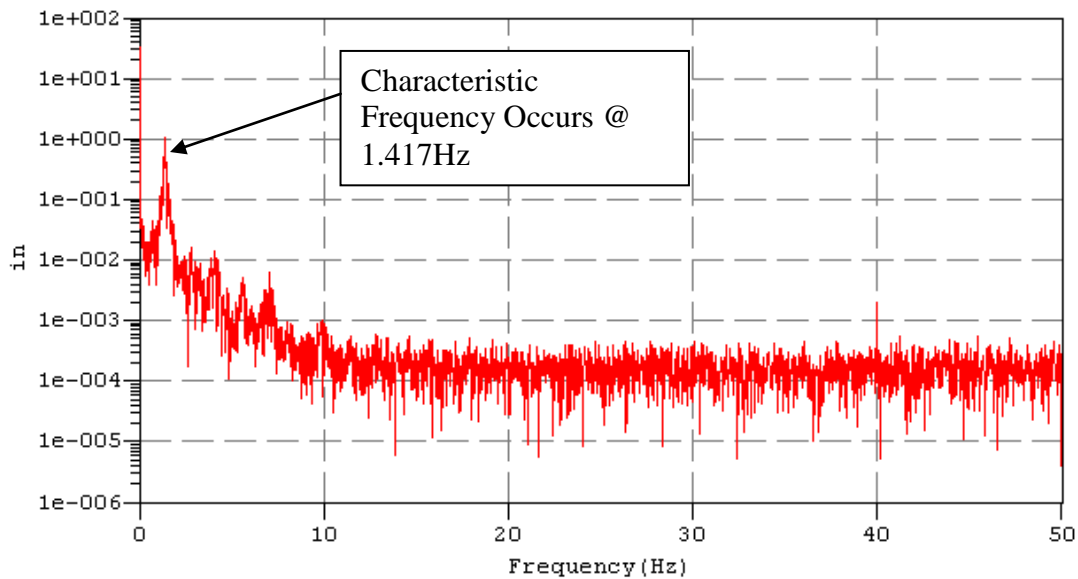
(Auto) Power Spectrum

Characteristic Frequency Occurs @ 1.417Hz

Figure 4. Here we are looking at the power spectrum of the oscillation device for the eight-spring system.

Theoretical Spring Constant Calculations

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \text{where:} \quad \begin{array}{l} f = frequency \\ k = spring\ constant \\ m = mass \end{array}$$

$$1.5Hz = \frac{1}{2\pi}\sqrt{\frac{k}{110kg}} \quad \text{values from design criteria}$$

$$k_{theoretical} = 9771\ \frac{N}{m}$$

Experimental Spring Constant Calculations

Four-spring system:

$$1.134Hz = \frac{1}{2\pi}\sqrt{\frac{k}{96kg}} \quad \text{values from test data}$$

$$k_{experimental} = 4874\ \frac{N}{m}$$

$$\frac{4874 \frac{N}{m}}{9771 \frac{N}{m}} = 49.9\%$$

Eight-spring system:

$$1.417 Hz = \frac{1}{2\pi} \sqrt{\frac{k}{110kg}} \text{ values from test data}$$

$$k_{experimental} = 8720 \frac{N}{m}$$

$$\frac{8720 \frac{N}{m}}{9771 \frac{N}{m}} = 89.2\%$$

Thus, this design had exactly half of the theoretical spring constant, which is to be expected since the design was modified to only include four springs instead of the original eight for fear of the device being too hard to push on its own. The eight springs where put back on the original design after analysis via accelerometer data showed we were only achieving half of the targeted acceleration, this is because the wheels are too small to allow for the full amplitude of the desired oscillation parameters. The team debated over whether or not to increase the wheel size but after considering the cost and time constraints, it was instead decided to simply add the other four springs back on to ensure that the springs were applying the necessary force per wheel and thus the required acceleration was achieved.

The oscillation bed will also require some sort of motor to drive the motion of the bed to maintain resonate frequency. Motors were originally turned down as a source of oscillation because the team did not want to rely on outside power to move the bed. The power of the motor can be calculated by the previously mentioned dampening constant. The dampening constant is an inherent aspect of the system at hand. The force of dampening is given by a periodic function

$$F = f_o \cos(wt)$$

Where f_0 denotes the amplitude of the driving force divided by the oscillator's mass and ω represents the driving frequency, this is separate from the natural frequency of the oscillator, ω_0. Although these are independent frequencies, the ideal situation between a natural oscillator and a driving force is that the driving frequency is equal to the natural frequency, allowing the system to resonate at the natural frequency. This is especially important in this situation because the oscillating bed has such specific specs to follow in terms of acceleration and frequency of the system. Now, in any case the maximum amplitude of the driven oscillations is found by allowing the system to resonate at $\omega_0=\omega$ to find

$$A_{max}=f_0(2\beta\omega_0)^{-1}$$

Where β is the dampening coefficient of the system that is given by the exponential decay of the amplitude in an unobstructed, natural damped oscillator. This was found from the graphs above in Figure 3 and Figure 5 to find the amplitude of the driving force which was then used to calculate the required power of a motor to drive a damped oscillator, such as the shaking bed, to resonate at a natural frequency of 1.5 Hz. This power was found to be one-twentieth of a standard small car, quite large considering the use of the machine and the ideal that this design allows for easy mobility.

Problems and Suggestions

Different problems that arose throughout the project include: sealing vinyl, determining a wheel size, finding proper testing techniques, hazardous effects of releasing gases into a closed room, constructing proper release valves, compensating for the effects of friction, and maintaining a practical, simple design while also creating a device that appeals to the medical field. Perhaps one of the most time consuming issues we came across was the inability to successfully seal the holes we had cut for the tubing the vinyl bed material. We had tried Pliobond, superglue, gorilla glue, PVC glue, and heat sealing. The heat sealing techniques were successful, however very difficult because too much heat will ruin the material. We recommend that future IPROs find a more efficient material to host the refrigerant, as vinyl is both problematic and inefficient. The problem with determining the wheel size came up after the testing of the bed had already started. After analyzing the testing data, the team realized that the specs of the wheel size were not properly set and could affect the ability to reach full extension of oscillation, also affecting the ability to maintain peak acceleration. This problem was more prevalent in the bed with four torsion wheels instead of eight torsion wheels, and it was decided as a team that we would revert back to the bed with eight torsion wheels due to lack of time and funding to order and receive new, larger wheels. It may be necessary in the future to increase the wheel size and decrease the number of springs as to make the oscillation more manageable for passersby to use. We were also concerned with the possible harmful effects of releasing harmful gases into the air. The team researched the adverse effects of releasing R152a into the atmosphere of a closed room, the only major worries would be in a closed, confined space with no ventilation. This can be solved by a simple warning stick on the device so individuals operating know that they are doing so at their own personal risk.

Another issue the team ran across was compensating for the frictional problems previously mentioned and their adverse dampening effects to the system. A certain amount of friction is necessary for maintaining the proper oscillation conditions (i.e. no wheel slippage). A small motor to supplement the frequency and consistency of the device may be necessary to overcome these issues. A final problem that does not have an

explicit solution is the issue of keeping the needs of the industry in mind as the prototype progresses. Companies and research facilities will not be interested in using an inefficient device for their products and/or research set-ups. This issue will always need addressing in an IPRO project such as this because the needs of individuals and companies in society is constantly changing and this device needs to be feasible to either withstand or change within the proper spectrum.

The group also had significant issues with the turkey experiments. The turkey experiment was conducted to obtain data about thermal conduction of the mattress portion of the bed. The control for the experiment was the cooling of the turkey without the presence of the mattress, while the variable scenario was the cooling of the turkey with the mattress. It was found, using a household cooking thermometer and an IR thermometer, that the temperature change between the two scenarios was not significant. In the control scenario, the turkey decreased by one degree over a ten minute period, while a comparable decrease also occurred with the cooling system. The experiment was not a loss however. Through the temperature acquisition portion of the mattress itself, we found that the underside of the mattress cooled quickly and with gross quantity compared with the top portion. The turkey was situated at the top. For future experiments, if the mattress containment of the cooling fluid were placed on top of the turkey, and due to convection , the hot air from the flesh could rise and the cooling portion that was pooled to the bottom could be used to make contact with the flesh. We also believe that there are better conducting materials that could be used in lieu of the air mattress. The optimization problem of a material that could protect the patient from frostbite, but cool at a faster rate could be examined. The methodology of the testing protocol needs to be further examined as well. There was only one trial done for the control and one for the variation due to unforeseen circumstances. If the variation could be conducted more times(greater than 15) the experiment would have further statistical validity. Additionally, different turkeys or other fleshy materials could be utilized. We encountered many problems for standardizing the timing of the measurements. A computer program could be created to automatically read the temperature inputs. The probes for these readings could be placed in more locations on the turkey. This would give the experimenters a better understanding of how the cooling process of the flesh is distributed across the spatial area. In the future,

with NIH approval, testing within a real life scenario would be ideal. Utilizing patient consent, the cooling protocol could be implemented into the current CPR protocol. Over a long duration, exceeding 5 years, those patients could have a functional magnetic resonance image taken as a control of their brain. Then once the probable patients encounter cardiac arrest, observe how their brain image looks with the cooling mattress protocol.

Future goals that IPRO 319 has for other groups to consider include creating a smaller bed that has a closer liquid-skin interface for cooling. Gel conduction may be a possible solution to this issue. We are ultimately hopeful that this prototype, or an updated version, can be used to duplicate and test the Mt. Sinai pig results in humans and then can also be introduced to the industry as a possible replacement of CPR with the added benefits of an on-site cooling system for cardiac arrest victims.

Conclusions

      Overall the team was successful in designing, building, and testing a prototype aimed to increase survivability of a cardiac arrest victim. The team first decided upon an objective statement that would include a list of goals that the prototype should encompass: This project aims to design, construct, and assess a prototype system that will be used as a first step response method when an individual undergoes a cardiac arrest and increase their survival rate. The goal of this team was to develop a non-invasive cooling system that will reduce body temperature in a quick and efficient manner and to construct an oscillating table for Z-axis acceleration while still maintaining a simple complex for the average bystander to use both apparatuses. After testing and calculations were done on premature models of the prototype, the team was able to decide on finalized designs of the cooling and shaking equipment. The primary cooling of the patient is done by the phase-change process from liquid-phase R152a diflouroethane to gas-phase at the interface of the skin to liquid surface. The shaking aspect of the bed is powered by manual pushing and eight torsion springs connected to four separate wheels. The bed held up well in oscillation and acceleration testing, showing its ability to achieve near-perfect results in the expected 0.6g and 1.5Hz criteria. The cooling aspect of the bed did not prove very efficient but further improvement of the material design of the bed may increase productivity and cooling of the device without changing the chemical cooling process.

Appendix A

Budget

Cost ($)	Item Description
13.26	Compressed Gas Canisters
18.09	Neck Brace
92.19	Springs
10.36	Screws and bolts fit to the wheels
23	Dead Turkey
120	Compressed Gas Canister Holder
120	Wood, Wheels, Bolts
13.26	Compressed Gas Canisters
30.98	Compressed Gas Canisters
441.14	**TOTAL**

As seen above, most of the budget was spent on the building of the oscillation device, specifically the special-ordered springs and wheels. The compressed gas canister holder was an expensive purchase because it too was custom-made from the MMAE department machine shop, but is invaluable to the design and simplicity involved in the cooling aspect of the device. Most all other expenses went to the cost of gas canisters for testing purposes of the cooling bed.

Appendix B

Team Members

Team Member	Respective Position
Andrew Fournier	Cooling Design and Construction
Bum Kyung Cho	Cooling Design and Oscillation Construction
Chris Gazda	Oscillation Design and Construction
Grant Austin	Cooling Design and Construction
Jennifer John	Cooling Construction and Organizational Management
Julian Spinoza	Oscillation Design and Construction
Oksana Lasowsky	Ethical Research and Implementation
Stephanie Harmon	Cooling Design and Oscillation Analysis

Although each individual was assigned their own portion of the project to specifically work on, the small size of the group allowed all major decisions to be made as an entire group. Many individuals were dynamic in the group, working on specific aspects of both the cooling and shaking components. We believe is this crucial to our success as a team because the very specific objectives that this semester's team had in mind could only be reached with everyone working on the same page. The first two weeks of the semester were spent deciding as a whole group which technologies we would pursue in our design as well as creating preliminary designs. The next few weeks the team was split into separate groups for the design and construction of different aspects of each component. Later on in the semester many individuals completely changed pace and began working on another side of the project as our testing and analysis phase began.

Appendix C
Project Plan - IPRO 319: New Technologies for Cardiac Arrest Victims (Fall 2009)

		AUGUST		SEPTEMBER				OCTOBER				NOVEMBER				DEC
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
		24 25 26 27 28	31 1 2 3 4	7 8 9 10 11	14 15 16 17 18	21 22 23 24 25	28 29 30 1 2	5 6 7 8 9	12 13 14 15 16	19 20 21 22 23	26 27 28 29 30	2 3 4 5 6	9 10 11 12 13	16 17 18 19 20	23 24 25 26 27	30 1 2 3 4
TASKS	Discuss Technologies															
	Design Prototype															
	Order Parts															
	Receive Parts															
	Construction of Prototype															
	Testing and Debugging															
	Modification of Prototype															
DELIVERABLES	Project Plan		Due 11-Sep													
	Midterm Reviews							5-Sep to 15-Sep								
	Ethics Reflective Report					Due 11-Nov										
	Final Report (1st Draft)											Due 20-Nov				
	Abstract/Brochure													Due 30-Nov		
	Poster													Due 30-Nov		
	Presentation															
	Final Report															
	IPRO Day															

Denotes IIT holidays

Appendix D

Sources

A. Boles., Boston : McGraw-Hill Higher Education, c2008.

Adams, A. Jose. "Cardiopulmonary resuscitation (CPR) using periodic acceleration (pGz) in an older porcine model of ventricular fibrillation." Resuscitation. 60. 327-334, 2004.

"Arctic Sun." Medivance. http://www.medivance.com/html/products_arcticsun.htm

Babbs, F Charles. "Biophysics of cardiopulmonary resuscitation with periodic z-axis acceleration or abdominal compression at aortic arch resonant frequencies." Resuscitation. 69.3, 2006. pp 455-469.

Bernard, Stephen A. "Treatment of Comatose Survivors of Out-of-Hospital Cardiac Arrest with Induced Hypothermia." The New England Journal of Medicine. Volume 346:557-563, (2002)

Bonifield, John. "For young mom, new CPR beat back death." CNN news. Wed. October 14, 2009. www.cnn.com/2009/HEALTH/10/14/cheating.death.harden.cpr/index.html

Cardiac Arrest. Retrieved February, 2009, from American Heart Association. <http://www.americanheart.org/presenter.jhtml?identifier=4481>

Cengel, Yunus A. Thermodynamics : an engineering approach / Yunus A. ðCengel, Michael

Cimbala, John M. Essentials of fluid mechanics : fundamentals and applications / John M.

Cimbalak, Yunus A. Cengel., Boston : McGraw-Hill Higher Education, c2008.

Fries, Michael. "Neurocognitive performance after cardiopulmonary resuscitation in
pigs." Critical Care Medicine. Mar2008, Vol. 36 Issue 3, p842-847

Incropera, Frank P. Fundamentals of heat and mass transfer, New York: Wiley, 1990.

Nolan, J.P. "Therapeutic Hypothermia After Cardiac Arrest." Circulation. 2003; 108:
118-121.

"Statistical Fact Sheet—Miscellaneous: 2009 update." American Heart Association. 2009.
<americanheart.org>.

Sudden Cardiac Arrest Key Facts. Retrieved February, 2009, from Heart Rhythm
Foundation http://www.heartrhythmfoundation.org/facts/scd.asp

Taylor, John R. "Classical Mechanics." University Science Books. c2005. Ch. 5, Sec. 5.
pg. 179-187.