Preliminary Report: Reducing Whole-Body Vibrations in Neonatal Transport

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BME 301

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Abstract

Transport puts extreme stress on neonates, who are often in critical condition, lowering their chance of survival [1]. Vibrational forces experienced by neonates during transport have been linked to an increased odds of severe brain injury. In particular, intraventricular hemorrhaging (IVH) can lead to neurodevelopmental impairment or death [2], [3]. However, there is no standardized device to mitigate vibrational forces during neonatal transport. To resolve this issue, a spring and damper combination is proposed to help mitigate the harsh vibrations. A total of 10 dampers are to be placed between the inner and outer trays of the transport isolette. Accelerometer and gyroscope data will be collected from within the isolette both with and without the dampers in order to quantify the effect of the dampers on the magnitude and direction of vibrations. As a proof of concept is established, continued improvements will be made to present the device as a marketed product.

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I. Introduction

Motivation

The quality of transport for critically-ill neonates to a Neonatal Intensive Care Unit (NICU) directly influences chances of survival or morbidity [4]. The critically-ill neonate is often the result of a preterm birth (< 37 full weeks of gestation) or underlying birth defects [5]. One in ten neonates need access to a NICU in the first week of life [6]. 1.3% of neonates are born *ex-utero* and must be transported to a NICU via ambulance or helicopter [7]. The current methods of transport expose a neonate to whole-body vibrations (WBV), translational and rotational motion, and excessive sound [8]. The effects of *ex-utero* transfer are well-documented in studies which conclude that transportation of a neonate significantly increases the odds of severe brain injury (odds ratio of 2.32) and significantly lowers the odds of survival without brain injury (odds ratio of 0.60) [2], [3]. One brain injury of concern is intraventricular hemorrhaging (IVH), which is closely associated with neonatal transport and can lead to subsequent neurodevelopmental impairment or death [9]. Therefore, reducing vibrations, mechanical forces, and excessive sound has the potential to significantly improve the outcomes of neonatal transport. There is no standardized vibration-reducing device used in neonatal transport, reflecting the need for a device that minimizes the environmental stressors transferred through the transport vehicle.

Existing Devices and Current Methods

The current methods of minimizing vibrations and mechanical forces by the UW Hospital's neonatal transport teams involve the use of a Geo-Matrix mattress, a five-point harness, various pillows, and suspension systems. The gel mattress in the incubator is placed directly under the neonate during transport. The five-point harness secures the neonate in place using straps across the shoulders, hips, and thighs [10]. The transport team uses additional pillows and blankets to manipulate the position of the neonate or support the head. The transport vehicle's suspension system as well as the built-in suspension system on the gurney act to reduce forces exerted by the ground.

These methods are insufficient in reducing vibrations and mechanical forces felt by the neonate, as whole-body vibration levels often exceed the recommended 0.315 m/s^2 in adults [11]. No standards have been developed for the recommended maximum vibration levels for neonates, but it can be reasonably assumed that it is significantly less than the level for fully-developed adults. The current method does very little to mitigate vibrations and features many rigid parts directly in contact with one another.

While no vibration-reducing device has been established as a standard for neonatal transport, several products have been created for this purpose. The first is the Quasi-Zero-Stiffness (QZS) Isolator (a1, Figure 1) which identifies and targets low-frequency components as the primary disturbing vibration [12]. This product modifies the incubator control box (a3, Figure 1), located directly below the incubator (a2, Figure 1) by adding four QZS Isolators in each corner of the housing. Each QZS Isolator has a pair of repelling ring permanent magnets (c4 & c5, Figure 1) that are connected in parallel to a coil spring (c9, Figure 1). The inner ring magnet (c4, Figure 1) is fixed to a central rod (c1, Figure 1), while the outer ring magnet (c5, Figure 1) is fixed on the sleeve (c7, Figure 1) that surrounds the rod. The concentric system of ring magnets mitigates the effects of rotational and translational motion and keeps the isolators aligned vertically, allowing the coil spring (c9, Figure 1) to take on most of the weight. Finally, a viscous damper (c10, Figure 1) is added inside the coil spring (c9, Figure 1) to help reduce vibrations and forces in the vertical direction. Although the concept of QZS Isolators is well supported, the design involves substantial alterations to the current transport setup, has a complicated design, and lacks experimental testing to verify its ability to reduce whole body vibrations.

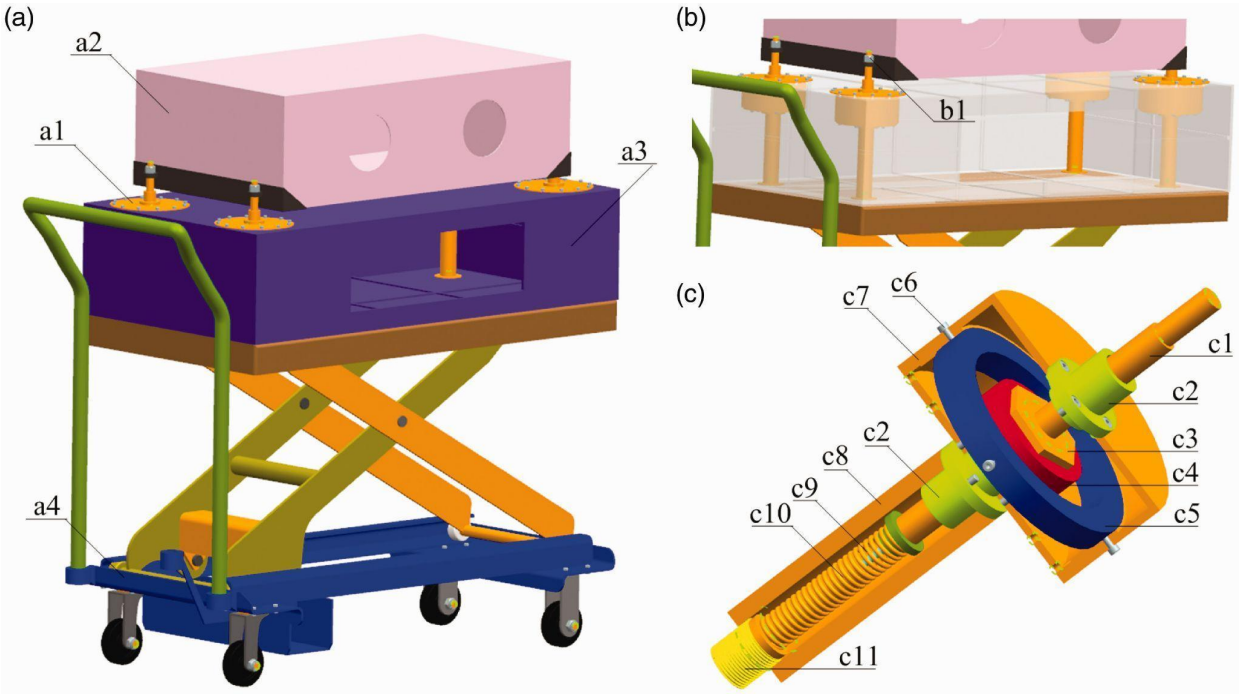


Figure 1: (a) an overview of the QZS vibration isolation system; (b) the installation view of the QZS isolators into the incubator control box; (c) the inside view of the QZS isolator [12].

A second design, referred to as an isolation device for shock reduction occupies the space between the isolette and the stretcher platform, and can be seen in Figure 2 [13]. The design features pairs of metal plates that serve as attachment points for gas or air springs. One plate is mounted to the top of the gurney while the other plate is mounted to the bottom of the isolette. Air or gas springs are fixed between the plates in order to provide dampening effects for the isolette. The pressure within the air springs can be adjusted to attenuate high or low frequencies of vibration. The design specifies that two air springs are placed in each corner and one is placed in the center. A patent application has been submitted for the use of parallel plates and air springs to reduce the transmission of kinetic energy between an isolette and support table (Application Number 11/540743). Similarly to the QZS Isolators, this design involves large modifications to the current transport setup. Additionally, it neglects the presence of the monitoring systems and

associated housing which are located directly below the isolette.

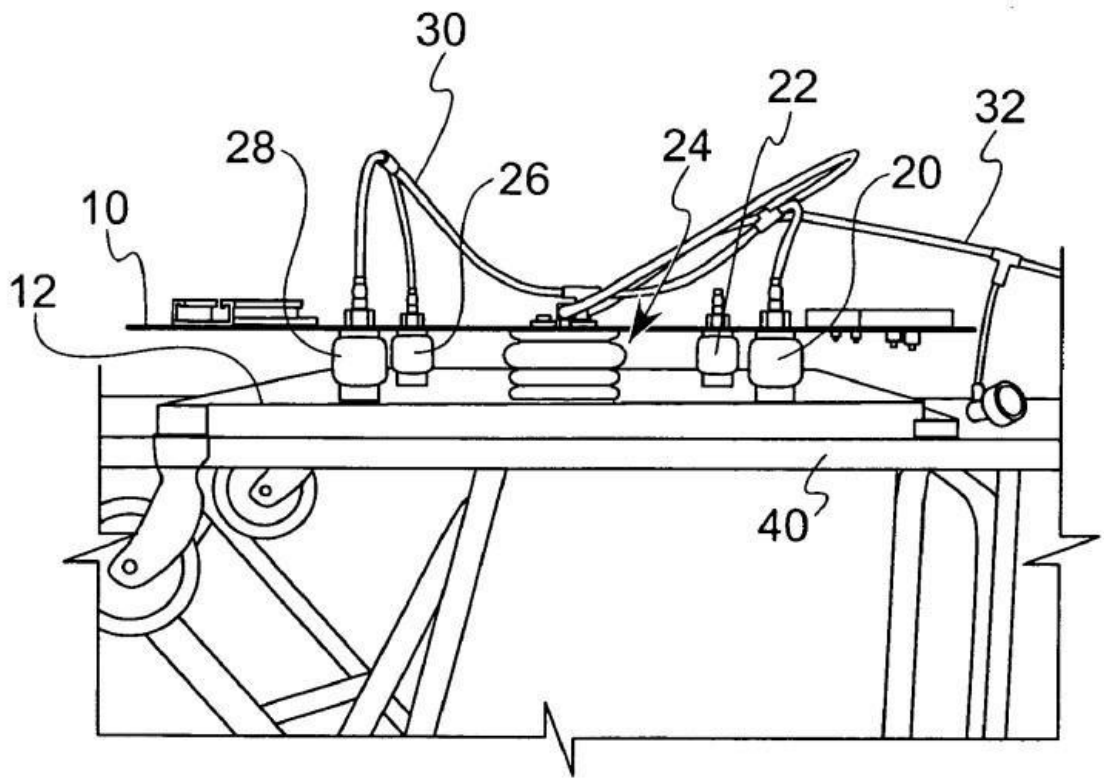


Figure 2: A side view of the isolation device for shock reduction in an operable position on the stretcher platform [13].

Problem Statement

Whole-body vibrations, translational forces, rotational moments, and excessive sound from a medical transport vehicle can cause brain injuries to critically-ill neonates that lead to neurodevelopmental impairment or death. Mitigating these physiological stressors has the potential to drastically improve transport outcomes including increased survival rates and decreased brain injury. The current transport setup neglects the effects of the stressors aforementioned by including a collection of rigid parts and only a single mattress to dampen vibrations. Thus, the client has tasked the team with developing a vibration-reducing device with mitigating mechanical forces and sound as secondary foci. The device must reduce each physiological stressor, so the neonate does not sustain injury, must fit within the dimensions of a standard ambulance and helicopter without interfering with the movement of the transport team,

and must be compatible with current incubator setup or include all the associated functions and equipment (**Appendix A**).

II. Background

Relevant Physiology and Biology

The neonate brain is highly susceptible to injury due to its underdeveloped nature and lack of structural support systems. A neonate's brain is very soft (often compared to unset gelatin) and as a result very vulnerable [14]. Within the brain, neuronal-glial precursor cells make up a vascularized region called the germinal matrix [15]. This region is particularly vulnerable for infants due to weaknesses in the blood-brain barrier in the first 48 hours of life. Moreover, premature infants struggle with cerebral autoregulation, which is the ability of cerebral vessels to keep constant cerebral blood flow (CBF) regardless of changes in arterial blood pressure. The smooth muscle cells and pericytes responsible for minimizing variations of CBF are not fully developed. A fluctuating CBF is associated with pressure passivity in regards to cerebral circulation. Additionally, the neonate's central nervous system is at a very immature stage and is constantly undergoing organizational changes [16]. These changes, combined with physiological instability, limit a neonate's ability to coordinate autonomic and self-regulatory responses towards environmental stressors.

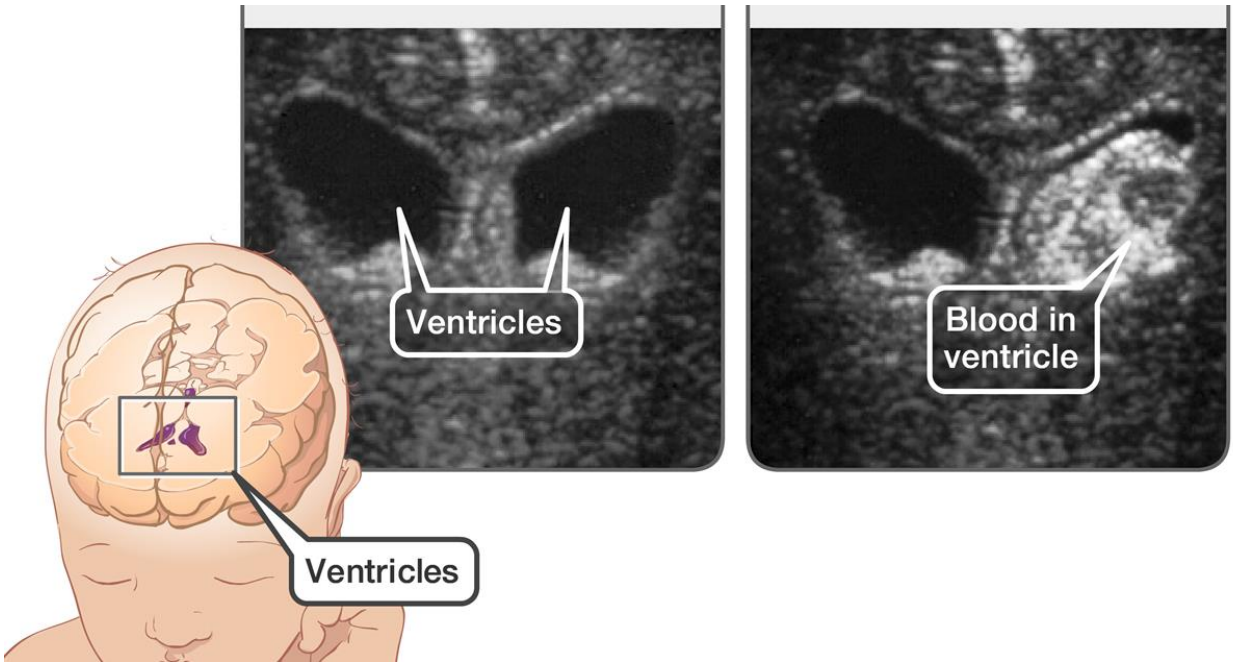


Figure 3: Healthy and IVH CT scans of the neonate ventricles with an anatomical reference on the left [17].

The fragility of a neonate brain described above increases susceptibility to intraventricular hemorrhage (IVH). The capillaries of the highly vascular germinal matrix are especially vulnerable to rupture when the neonate experiences whole-body vibrations [15]. Whole body vibrations can trigger IVH through a cumulative process beginning with cerebral vasoconstriction, increased free radicals, decreased nitric oxide, decreased cerebral blood flow, and repeated reperfusion injury [8]. These characteristics describe the progression of germinal matrix hemorrhage [15], as shown in Figure 3. Furthermore, there is a proven link between fluctuating cerebral blood flow velocity, commonly found in premature neonates, and higher chances of IVH. The nature of ground or air transport in conjunction with the neonate's unstable condition reveals the susceptibility of neonates to brain injury.

Relevant Design Information

The prospective design must function in conjunction with the preexisting setup. Understanding the organization of the transport setup is crucial to understanding design ideas and constraints. Descriptions of the setup are based on observations made from the transport incubator at UW Health, which is International Biomedical's Voyager model [18]. Regardless of

the model, all transport incubators follow the same general structure. The setup includes an incubator (also known as an isolette) which encloses the neonate during transport. A removeable, inner tray supports a mattress and fixes on to a permanent, outer tray on the bottom of the incubator. Below the incubator is metal housing for the incubator's control systems in order to regulate the environment of the incubator (e.g. temperature). This housing, with the incubator latched on top of it, is latched to a transport platform (also known as the deck). Also attached to the deck are a variety of support systems (e.g. oxygen tanks). The deck is then secured onto the gurney for transport.

Client Information

Dr. Ryan McAdams is the Neonatology Division Chief for UW Health and a professor for the UW School of Medicine and Public Health. Dr. Joshua Gollub is a fellow at the University of Wisconsin School of Medicine and Public Health specializing in neonatal medicine.

Design Specifications

The client has tasked the team with developing a device to reduce whole-body vibrations which can cause stress to a neonate during transport in an ambulance. The client requires that the device satisfy several identified problems, which guided the requirements for the project as elaborated in the Product Design Specifications (**Appendix A**). The device must minimize vibrational forces below 0.315 m/s^2 for the entire duration of the transport [11]. The device must mitigate the effects of translational and rotational motion so that the neonate does not sustain injury. The device must attach to the current incubators or include all the associated functions and equipment. Finally, the device must fit within the dimensions of a standard ambulance while allowing efficient movement of the transport team. Due to the constant nature of vibrations and motion during transport, the design should provide continuous functionality without disrupting the support systems and monitoring equipment. In terms of ergonomics, the device should be relatively easy to install and remove and require no additional manipulation once installed. The goal was to create a pilot model (i.e. functional prototype) that can be tested in mock ambulance transports and be implemented as part of the standard transport equipment.

III. Preliminary Designs

The team brainstormed several solutions to address the problem of reducing whole body vibrations to provide neonates with an improved chance of survival. The team decided on three designs to be formally illustrated and evaluated, each with distinct properties and methods to reduce vibrations.

Metal and Gel Composite Continuation

The first design considered was a damping system that consisted of metal and gel concentric layers. The goal of the damper design was to reduce the magnitude of varying frequencies of vibrational forces that are exerted on the neonate during transport. The forces the neonate would have experienced are then dissipated and applied to the tray inside the isolette. This design consists of four inserts that are placed in between the inner and outer trays of the isolette, as shown in Figure 4. There are two side dampers, which are placed in between the two trays and can be seen in Figure 5. These act to reduce the side to side motions and vibrations experienced. There are also two L-shaped dampers, which are placed through a small opening of the inner tray and rest between the two trays. These help to reduce the forwards and backwards motions and vibrations experienced. All four inserts are placed on the neonate accessible end of the trays in case of a medical emergency, such as the need to intubate the neonate during transport. The reason the dampers are placed on the accessible end of the trays is for easy removal and so the dampers reduce vibrations closest to the head of the neonate.

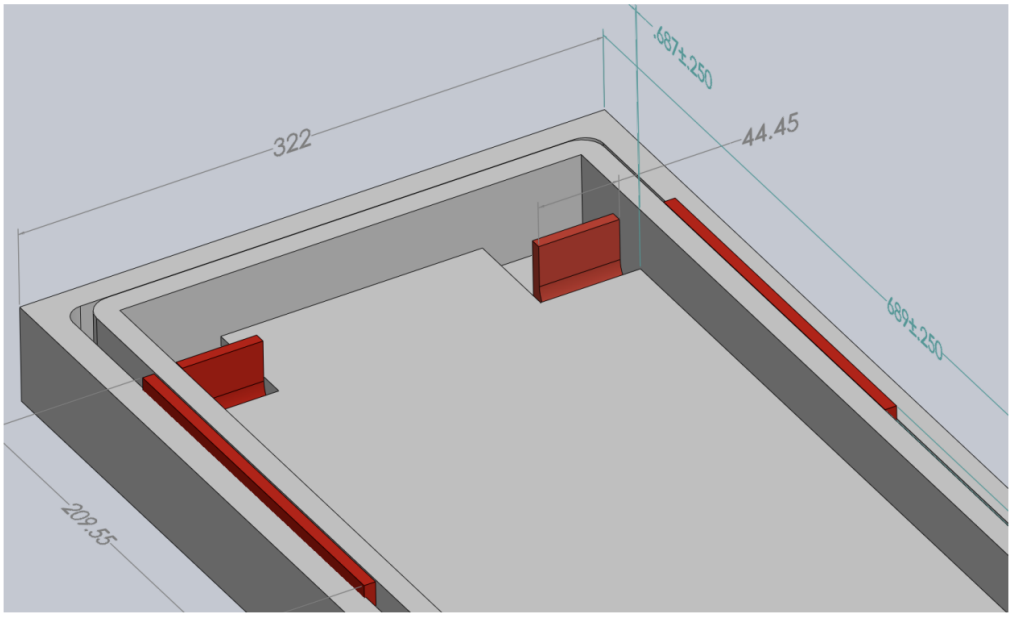


Figure 4: A SolidWorks model of the Metal and Gel Composite Damper placed in the isolette inner and outer trays. Dampers are outlined in red. All dimensions are in mm.

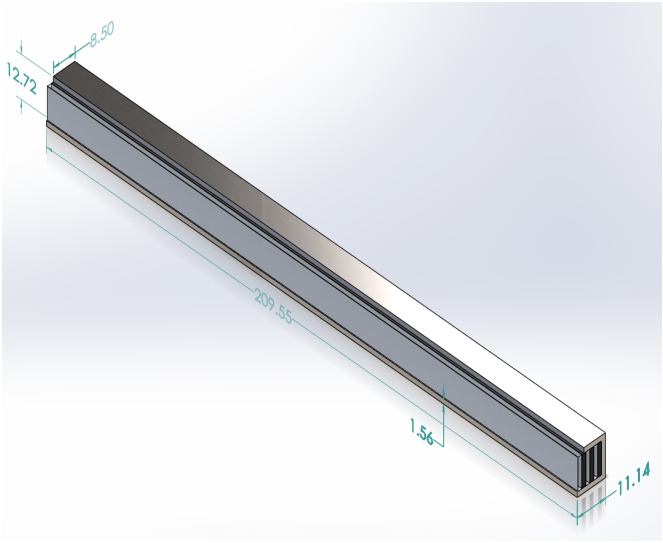


Figure 5: An individual SolidWorks model of the side Metal and Gel Composite Dampers. All dimensions are in mm.

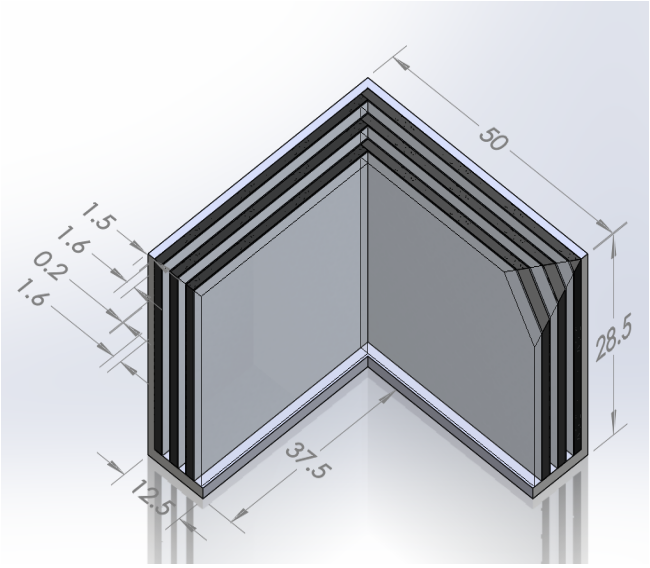


Figure 6: An individual SolidWorks model of the corner Metal and Gel Composite Dampers. All dimensions are in mm.

Each damper is composed of a total of four materials in the same repeating order. There are three repeating layers of foam, aluminum, gel, and aluminum, all enclosed by a single layer of stainless steel. The rationale behind these choices was based on the ability of the layered materials to mimic the unique and natural vibration-reduction properties of a woodpecker's head structure, as shown in Figure 7 [19]. Woodpeckers have a unique layering of bones in their head that enables them to exert significant vibrational forces on their beaks without those same forces having an impact on the brain.

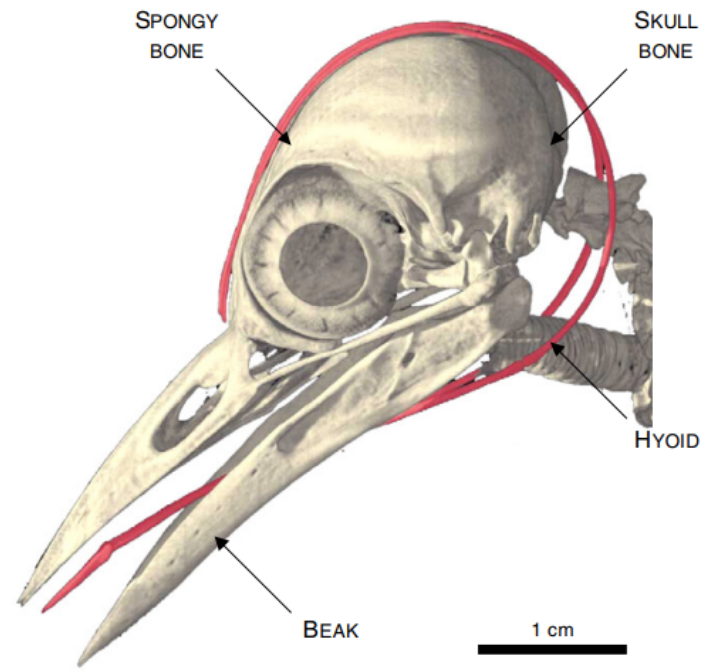


Figure 7: Four key vibration-reducing features of the woodpecker head structure are shown: the beak, the hyoid, skull bone, and spongy bone [20].

There are four main components to the head structure of a woodpecker, including the hyoid, the skull bone, the spongy bone, and the beak, as shown in Figure 7. Each of these components have various functions. The hyoid provides structure to the tongue and the skull bone with cerebrospinal fluid. Each of the four components of the overall head structure of a woodpecker were correlated to man-made materials in the work of Biju et. al (Table 1), who utilized the natural vibration reduction properties of woodpecker anatomy to construct and test shock-absorbing structures.

Table 1: The materials that were correlated to anatomical features of the woodpecker are shown below [19].

Woodpecker	**Layered shock absorbing structure**
Beak	Metal (steel) enclosure I
Hyoid	Viscoelastic layer (foam)
Spongy bone	Metallic Beads
Skull bone with CSF	Metal (aluminium) enclosure II

This experimental study formed the basis of the Metal and Gel Composite Damper design. The foam layer represents the hyoid, aluminum represents the skull bone with cerebrospinal fluid, gel represents the spongy bone, and the stainless steel outer layer represents the beak. The materials chosen for this design had similar material properties to those shown in Table 1 and can be visualized in Figure 8. The first layer is foam, which is thicker than the other layers included in the damper. This layer of foam is surrounded by a single, thin layer of aluminum, which is then covered with a layer of silicone gel. The gel is covered with a second thin layer of aluminum. Once repeated three times, the damper is enclosed in a single stainless steel layer, forming a medical-grade exterior that is easy to sterilize.

Dampening curves from Biju et. al showed promising results for vibration reduction of this composite material, which can be seen in Figure 10 [19]. Application of this damper for vibrations in an incubator has the potential to be immensely successful.

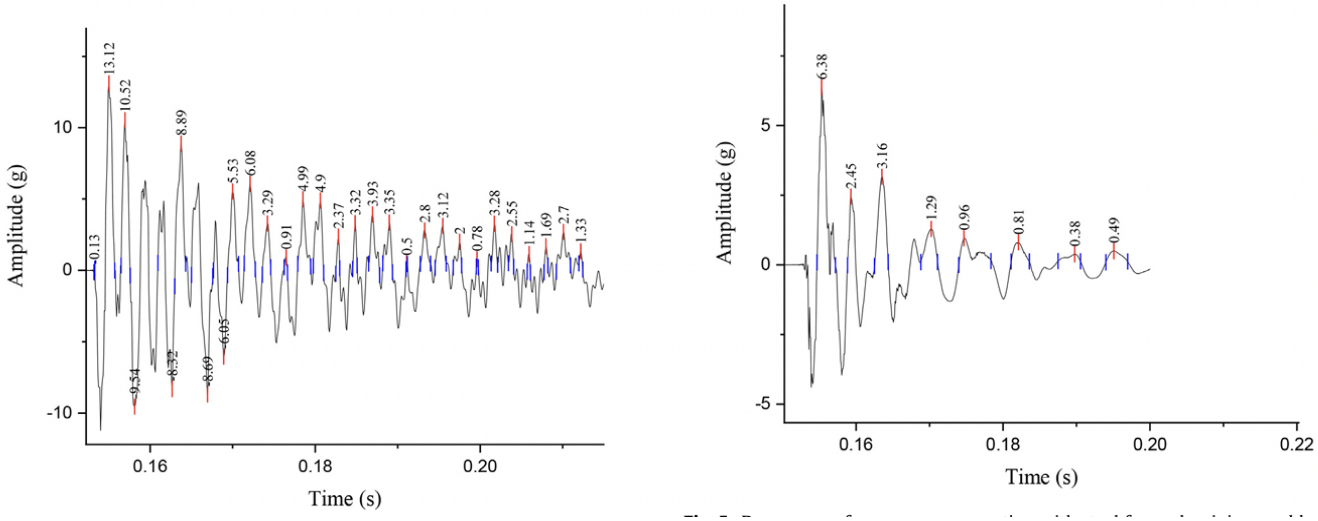


Figure 8: Damping curves for solid stainless steel (left) and the composite damper (right) [19].

Testing was conducted for this mechanism. Results can be seen in **Appendix B**.

Spring Viscous Damper Design

The second design considered was inspired by damper-cable systems used to protect buildings from seismic activity. In these systems, pre-stressed steel cables are connected in series with spring viscous dampers (Figure 9). The cables aid in providing a restorative force after the structure experiences vibrations while the dampers provide energy dissipation capacity [21]. In

buildings, the bearing-end of the damper is connected to the bottom corner of one face of the structure. The connected cable runs horizontally to the opposite corner on the same face of the building. A second damper-cable component is attached in the same fashion to the two remaining corners, creating an “X” shape on the wall of the structure. The damper-cable components in this geometric configuration, as shown in Figure 10, have been found to reduce deformations caused by vibrations.

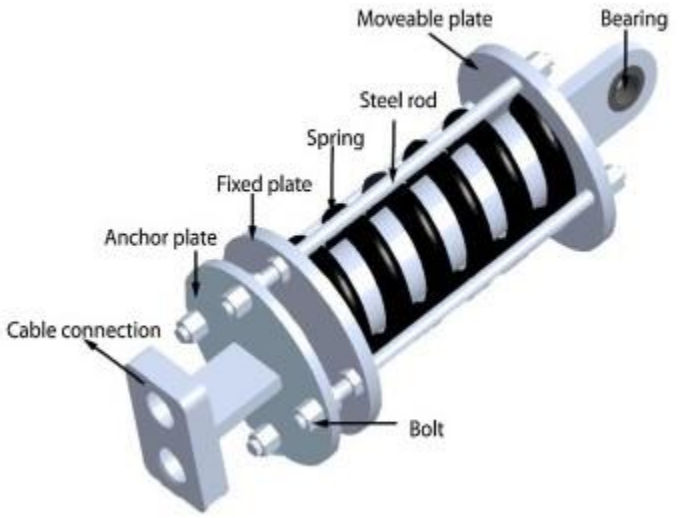


Figure 9: CAD model of the Spring Viscous Damper used in the damper-cable system [21].

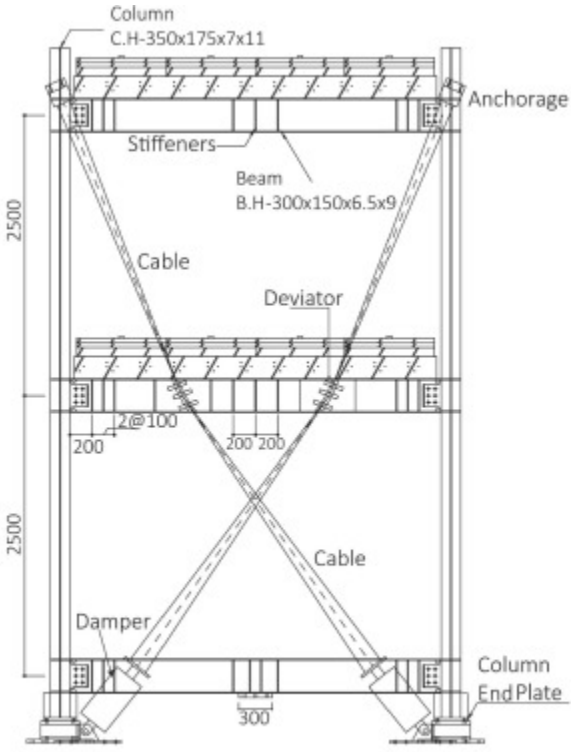


Figure 10: Diagram for implementation of the damper-cable components on a steel structure [21].

In earthquake-resistant buildings, the use of spring-viscous damper systems has been shown to reduce the lateral displacement of the building by up to 70%, and the acceleration of the building by up to 50% during a seismic event [22]. Additionally, spring-viscous damper systems can be designed to have a specific response to different types of earthquakes, making them an effective solution for seismic protection in a variety of locations. By utilizing a similar concept, spring-viscous damper systems in the design of neonatal transport incubators can help absorb and dissipate the vibrations, providing a smoother ride and reducing the risk of injury to the neonate.

The configuration of the damper-cable system aforementioned can be implemented similarly in the incubator transport setup (Figure 11). On one end of the viscous damper, the bearing is connected directly to the deck at each corner of the control box (i.e., there are four total damper-cable parts). The attached cable runs diagonally across the lateral face of the control box and attaches to a preexisting hole at the opposite corner. Two damper-cable components are utilized on each lateral face in order to create an “X” shape.

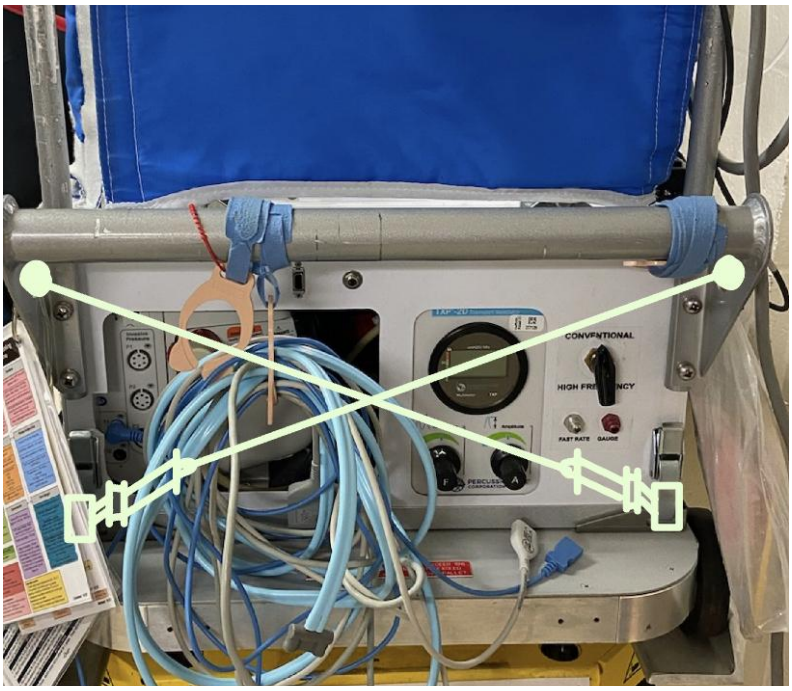


Figure 11: Geometric layout of the damper-cable system on one face of the incubator control box.

Compared to the rigid-nature of the latching mechanism, the Spring Viscous Damper allows for the control box and incubator to move with incoming vibrations via the viscous damper. This flexibility eases the intensity of vibrations felt within the incubator.

Spring and Damper Design

The Spring and Damper design incorporates both a spring and a damper into one system, as shown in Figure 12. The spring component has no internal damping (ideal springs) but stores the energy from vibrations as elastic potential energy [23]. Additionally, the springs provide a restorative force in order to keep the system in the same position that it started in (i.e. zero net displacement). The damper component dissipates the energy stored by the spring and created by the movement from the vibrations. Air or magnetic dampers are both effective solutions for this aspect of the design. Both the spring and damping constants can be tuned to target the disturbance frequency in order to effectively attenuate vibrations [24].

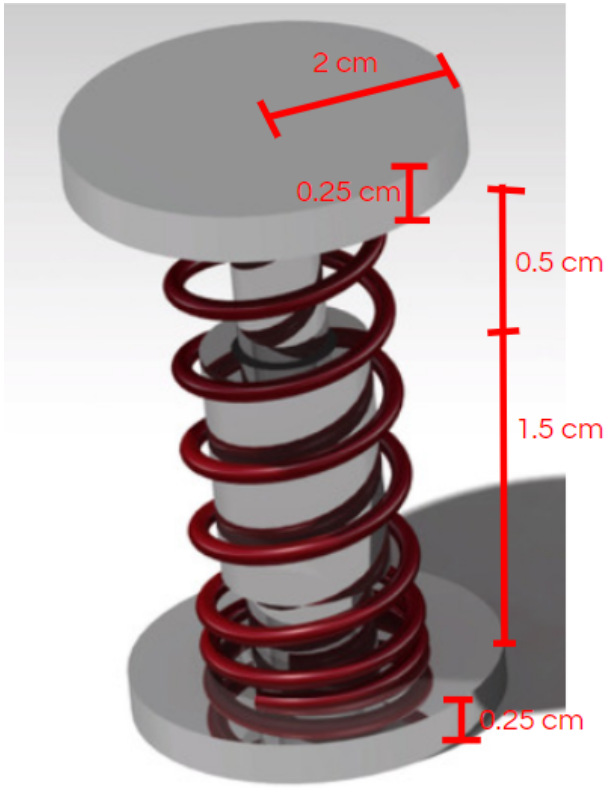


Figure 12: CAD model of the Spring and Damper Design [25]

Similar designs are used in car suspension systems to function as shock absorbers as seen in Figure 13. Irregularities in the road can exert forces to the wheels of a car, causing them to move up and down perpendicular to the road's surface. Therefore, a system is needed to absorb this energy such that it is not transferred to the frame causing the wheels to lose contact with the ground [26].

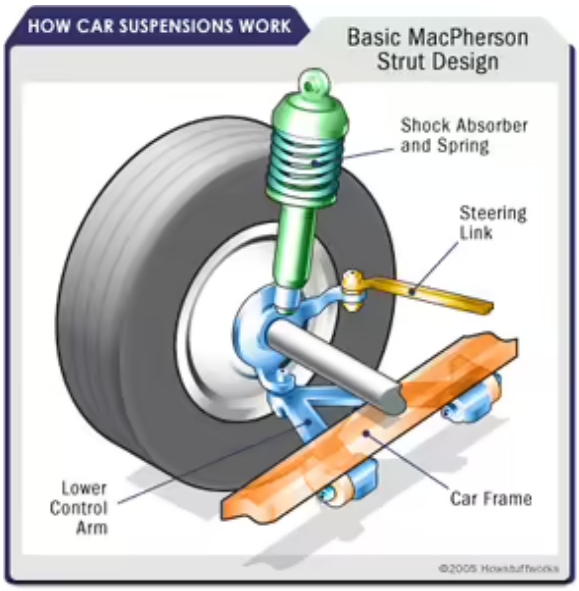


Figure 13: Illustration depicting common strut design, which is a common dampening structure in a vehicle's wheels.

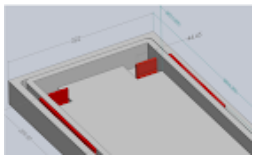
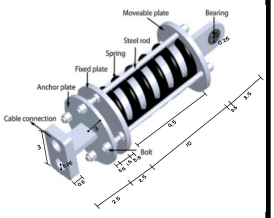
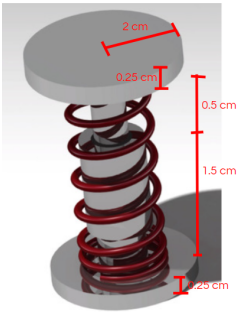
The stiffness of the spring determines how the car responds to the energy, either providing a smoother or bumpier ride. In other words, they absorb energy. Dampers are the component that then dissipate this energy, stopping the spring from bouncing at its natural frequency until all the energy put into it is used.

In the transport setup, these dampers would be placed in between the inner and outer trays on both sides of the tray, as well as underneath the inner tray. The purpose of this placement is to reduce vibrations and absorb shock in the x, y, and z planes. The spring damper system would need to be small enough to fit in between these trays, and the spring coefficients would be based off of the vibrations experienced in each of the three directions, meaning that the coefficients would likely be different for each location they are placed in. If it is not possible to find or fabricate spring damper systems small enough, redesigning the entire tray would be a potential solution to proceed with this design.

IV. Preliminary Design Evaluation

Design Matrix

Table 2: The design matrix and affiliated criteria used to evaluate the preliminary designs, featuring the Gel Composite Continuation, Spring Viscous Damper, and Spring & Damper designs.

		Metal and Gel Composite Continuation		**Spring Viscous Damper Design**		**Spring & Damper Design**	
							
	Weight	**Score**	**Total**	**Score**	**Total**	**Score**	**Total**
Efficacy of Vibration Reduction	25	3	15	4	20	5	25
Accessibility to Neonate	20	4	16	5	20	4	16
Compatibility with Equipment	20	5	20	3	12	4	16
Ease of Fabrication	15	4	12	2	6	3	9
Safety	10	5	10	4	8	5	10
Cost	10	5	10	3	6	4	8
TOTAL	**100**	**83**		**72**		**84**	

Efficacy of Vibration Reduction:

In order to reduce whole body vibrations in neonatal transport, the product needs to be designed to effectively attenuate or dissipate vibrations. This can involve the use of specialized materials, shock-absorbing mechanisms, or other design features that mitigate vibration. As specified in the Product Design Specifications, an ideal prototype will be capable of reducing vibrations to below 0.315 m/s^2 [11]. Additional factors to consider would involve identifying the specific vibration characteristics that are most harmful to neonates, such as frequency and direction, and then designing the product to address those characteristics. This category was given a weight of 25 and ranked as the most important category since any device that does not meet the performance requirements will not only fail to solve the issue presented but could potentially pose additional risk to the neonate.

Accessibility to Neonate:

Accessibility to the neonate is possible through several hinged doors located around the incubator. It is vital that access to these doors are not restricted or compromised so that the medical team can react and treat the neonate throughout the entire duration of travel. This category is weighted slightly lower, with a score of 20, than the reducing vibrations category because reducing vibrations is the primary focus of this project. A device that successfully reduces vibrations would still have the potential to cause harm to the neonate if medical professionals did not have immediate access to the neonate to provide emergency care while in transport. This explains why accessibility to the neonate is the second most important category, as this device should not increase risk to the neonate in any capacity.

Compatibility with Equipment:

The product needs to be compatible with other equipment used in neonatal care, such as oxygen tanks, ventilators, and monitors. This could involve designing the product to attach securely to existing equipment, or to work seamlessly with other products in a neonatal transport system. The device should be simple and require little to no effort for medical professionals to use. Ideally, the device would not require any significant modification of the existing transport system. This category similarly received a weight of 20 because the device should be able to be used in travel incubators within their daily operating environment of an ambulance or helicopter.

Ease of Fabrication:

Ease of fabrication is defined in this context as the level of difficulty to create a working prototype of the design within the constraints of accessible materials, machinery, and time this semester. This could involve designing the product to be modular, or to use materials that are readily available and easy to work with. Although the focus of this category is on small scale preliminary fabrication, the complexity of manufacturing on a larger scale can also be factored into evaluation of this category as well. This category was given a weight of 15 because feasibility is an important consideration to ensure a testable prototype can be created, however producing a device that effectively minimizes whole body vibration is the ultimate goal and performance should be prioritized over simplicity.

Safety:

The safety category assesses the potential for the device to cause harm or damage. This could involve designing the product to be impact-resistant, easy to sterilize, or to include fail-safe mechanisms that prevent injury or harm in the event of failure or misuse. Any mechanical, electrical, or chemical elements of the device must not harm the user and should be reliable to use on trips that may last for several hours. This category received a weight 10 since it is expected that all of the evaluated designs should comply with the numerous medical standards and practices that exist to protect patients and healthcare workers.

Cost:

This category is scored based on the expenses of the materials as well as the production cost to make the final product. All levels of prototyping should remain less than a total of $500. The score for this criteria is less significant to the client compared to the emphasis on safety and projected performance, and is willing to discuss a budget expansion if it is necessary to do so. The main goal is to have a successful prototype that can reduce the level of whole body vibrations experienced by the neonate. Any disposable components of the device should also be considered so that replacing parts of the device regularly does not become a financial burden for the hospital.

The aforementioned criteria have been used to assess the following three designs.

Metal/Gel Composite Damper Design

The Metal/Gel Composite Damper Design is a damper made of a layered material; the inner layer is composed of three repeating layers of a hard foam material, aluminum, silicone gel, and aluminum, all enclosed in a single layer of stainless steel. The damper is fabricated in two L-shaped pieces fitted in the corner under the inner tray and two straight pieces fitted under the lips of the inner tray parallel to the head of the neonate, each inserted between the outer tray and inner tray of the incubator on which the baby is placed during transport.

The material for the damper is modeled after the work of Biju et al., who were inspired by the anatomical characteristics of a woodpecker that mitigates vibrations reaching the brain during rapid pecking motions. They developed a layered material consisting of an inner layer of silicone gel, followed by an aluminum layer, a foam layer, and a final outer stainless steel layer. The damping curves from their tests showed that this layered configuration was successful in mitigating vibrations, so our design attempts to apply their idea to an accessory that can be attached to neonatal transport equipment [19]. The goal of this semester would be to change the materials used and/or the way the device is inserted in between the trays to attempt to increase its efficacy.

This design scored a 3/5 on the efficacy of vibration reduction category. As currently designed and tested, the gel composite damper lacks a spring component which is necessary to dissipate the energy from the vibrations. Since a damping component alone, which just reduces magnitude of vibrations, will not be as effective, this device did not score as high as the others. Additionally, testing results from last semester revealed that this design did not reduce acceleration values within the incubator to be below 0.315 m/s^2 [11].

This design scored a 4/5 on the accessibility to neonate category because the only evident issue is the increase in height to the inner tray system. Since the internal height clearance of the incubator is very low and the hand-holes for accessing the neonate have an even lower height clearance, it is important that the inner tray is not raised a significant amount. Raising the inner tray by 1 cm should not cause any issues with accessing the neonate, but any larger adjustments could jeopardize the ability to treat the neonate during transport.

This design scored a 5/5 on compatibility with equipment since it will not hinder access to the oxygen tanks, monitors, or ventilator systems that may be necessary during transport. Additionally, the materials and components of the device will not damage the inside of the

incubator and should not require any interference once attached to the system. There are no adjustments to the device that the MedFlight Team will need to make to the device, allowing for a seamless transition towards the incorporation of the design.

This design scored a 4/5 on ease of fabrication. The design consists of materials that should be simple to source and is conceptually easy to understand. The most difficult part of the fabrication process will be cutting the material into even thinner sheets since the UW Madison TeamLab does not have the appropriate tools to cleanly work with materials as specified in the design. However, final assembly will be a quick process since attaching the various layers will require a simple spray adhesive.

This design scored a 5/5 on the safety category, because it does not greatly interfere with the incubator and stays out of the reach of the neonate. Since there are no complex mechanical, electrical, or chemical components to this design, it is predicted that the gel composite damper will not pose a threat to the patient or health care provider.

This design scored a 5/5 for cost. This design is small and does not require a large volume of material, given that the proposed thickness is less than one centimeter. Additionally, scrap material from last semester is available to remodel this design which would allow the team to use the rest of the budget on exploring testing devices.

Overall, this design scored a 83 on the design matrix. This design takes into consideration the effectiveness of dampers in absorbing shock as well as the limited amount of space within the incubator to intervene with any kind of accessory. The inspiration behind this design came from the anatomy of a woodpecker, which will be incorporated into the material used in the damper [19]. Although this design was superior in the majority of categories, its inability to effectively reduce the vibrations in the incubator meant that it would not be a suitable option to continue this semester.

Spring Viscous Damper

The Spring Viscous Damper design utilizes cables connected in series with a viscous damper to replace the latches which connect the incubator control box to the deck of the stretcher. On one end of the viscous damper, the bearing is connected directly to the deck at each corner of the control box (i.e., there are four total damper-cable parts). The attached cable runs diagonally across the lateral face of the control box and attaches to a preexisting hole at the

opposite corner. Two damper-cable components are utilized on each lateral face in order to create an “X” shape. Compared to the rigid-nature of the latching mechanism, the Spring Viscous Damper allows for the control box and incubator to move with incoming vibrations via the viscous damper. This flexibility eases the intensity of vibrations felt within the incubator.

The Spring Viscous Damper design scored a 4/5 for its efficacy in reducing vibrations because it works to minimize vibrations from the isolette externally rather than between the two trays. As a result, the device would not as effectively target the specific vibrations experienced by the neonate, but rather by the structure as a whole. However, the viscous damper would still allow for shock absorption and stability.

For a similar reason, the design scored higher in the accessibility to neonate category. The external focus of the design means that nothing regarding the isolette or how the neonate is treated within it would be affected by the device.

In contrast, the viscous spring design scored a 3/5 for compatibility with equipment, losing the category. This is because the device relies on metal cables that are connected to clamps on the isolator to strap the components together. These locations for attachment might not be present on other brands of incubators, making the design extremely specific in nature.

Due to the complexity of the damper component, this design scored a 2/5 for ease of fabrication. The damper consists of a collection of metal parts such as discs, rods, and connectors. Since some of the components are likely not available to buy, fabrication of the damper would require complex machining or possibly welding. For this reason, the Spring Viscous Damper scored the lowest of the three designs in this category.

While all the designs were created with safety as a focus, this design received a 4/5 for this category because of the tension in the cables that connect the device to the incubator. If these were to snap, it could be hazardous both to the healthcare providers in the ambulance and the neonate.

Finally, the design scored a 3/5 for cost. The design is largest by nature, therefore requiring the most materials. If the device were to eventually be commercialized, it would also likely cost more in production and labor.

Spring and Damper

The Spring and Damper design incorporates both a spring and a damper into one system.

These dampers would be placed in between the inner and outer trays on both sides of the tray, as well as underneath the inner tray. The purpose of this placement is to reduce vibrations and absorb shock in the x, y, and z planes. The spring damper system would need to be small enough to fit in between these trays, and the spring coefficients would be based off of the vibrations experienced in each of the three directions, meaning that the coefficients would likely be different for each location they are placed in. If it is not possible to find spring damper systems small enough, redesigning the entire tray would be a potential solution to proceed with this design.

The Spring and Damper design scored a 5/5 for efficacy of reducing vibrations because it includes both a damping component and an oscillating (spring) component. Both components are necessary for maximum reduction of vibrations. Additionally, these spring and damper components can be placed on the bottom and sides of the incubator, reducing vibrations in the x, y, and z directions. It is also possible to interchange both the spring and damper components to accommodate different frequencies should these values vary.

This design scored a 4/5 for accessibility to the neonate. While the spring dampers chosen will be as short as possible while still providing the desired vibration reduction effect, they will ultimately lift the inner tray toward the top of the isolette slightly, resulting in less space for medical professionals to reach the neonate. There will still be sufficient room to care for the patient, but this slightly reduced space led to a lower rating in this category compared to designs that do not reduce space inside the isolette.

This design scored a 4/5 for compatibility with the equipment. Pursuing this design would not require a full remodeling of the incubator, but the inner tray in the isoletter may need to be modified depending on the height of the spring dampers. Additionally, this design would not alter the functionality of any other equipment in the ambulance or helicopter, so it would be able to be used with said equipment. Consequently, this design received a good rating, but not the highest possible score.

This design scored a 3/5 for ease of fabrication. As previously mentioned, this design may require a redesign of the inner tray in the isolette which could include altering its dimensions and redesigning the track that allows it to be pulled out of the outer tray. Also, spring dampers that are purchased would likely need to be modified once calculations are completed to determine the desired resistance of the damping portion. Another reason this category received a

lower score is actually connecting the spring damper into the inner tray. If the inner tray material is too brittle to simply screw the spring damper into, a different approach will be required to integrate the spring dampers into the tray system.

This design scored a 5/5 for safety, as the design does not introduce any additional risks to the patient or the current procedure of transporting neonates. This design should be compliant with current medical standards. There are no electrical or chemical components to this design, decreasing potential safety risks.

The design scored a 4/5 for cost. The prices for spring damper systems vary based on size, material, damping type, and spring coefficients. Spring dampers in general are relatively cheap and would fit within the budget; however, potential modifications will likely need to be made to adjust these components, which could increase the price.

Proposed Final Design

After evaluating several proposed designs, the team has decided to proceed with the Spring and Damper design as our final solution for reducing vibrations during neonatal transport. This design incorporates both a damping and oscillating component, and can be placed in multiple locations to effectively reduce vibrations in all three directions. It should also be safe and compatible with existing medical standards, making it a viable option for neonatal transport. While this design may slightly reduce space for medical professionals and require modifications to the inner tray and spring dampers, the team believes that these trade-offs justify the prospective efficiency in vibration reduction. In comparison to the Metal and Gel Composite Design and the Spring and Viscous Damper design, the Spring and Damper design proved to be the most effective and promising solution.

V. Fabrication/Development Process

Materials

The major materials needed for the design are for the spring and damper components. The springs will be made from carbon steel to maximize durability while minimizing cost, given

that they are less expensive than stainless steel springs [27]. Additionally, the springs will be made from flat wire or in a nested conformation. This will allow for smaller compression of the spring, minimizing the vertical raise of the inner tray and thus mitigating any additional complications that could arise while providing care to the neonate during transport.

A magnetic vibration absorber with an adjustable natural frequency will be used as the damping component of the design. The magnets will be arranged with the same poles facing each other, creating a repelling force that acts like a spring constant [28]. The magnets will be placed on opposing ends of the spring, compressing it as the force of the movement of the neonate pushes them together. The repulsion between the magnets will support the elongation of the spring afterwards. Most permanent magnets contain iron, nickel, or cobalt [29] and can be purchased at local hardware suppliers.

The plastic coating of the damper will be made from a synthetic polymer such as high density polyethylene (HDPE). This will allow the entire component to be covered in a material that can be sterilized like the rest of the equipment without being susceptible to corrosion over time.

Finally, it may be necessary for the team to recreate the inner and outer trays of the isolette to work on component arrangements in between visits to the hospital. This will allow us to prepare for these valuable visits and best use the time that is afforded there. As such, household items such as cardboard or recycled plastic may be used to create rudimentary recreations of these items.

Methods

After obtaining the materials described in the Materials section, the spring will be attached around the magnetic damper. The top flat piece of the damper will secure the spring in place and provide a flat surface for the inner tray to slide across when the tray is being pulled in and out of the incubator. Mounting brackets will be attached to the inside of the outer tray to provide a method of attachment for the spring dampers. These mounting brackets will be screwed into the bottom tray of the isolette. Next, the spring dampers will connect to the mounting brackets with a clamp. Alternatively, epoxy glue can be used to secure the spring dampers to the inside of the outer tray.

There will be a total of 10 spring dampers used in this design. Four will be evenly spaced under the inner tray, and the remaining six will be placed on the three sides between the inner and outer trays of the incubator (two on each side and none on the side where the inner tray can slide out of the isolette).

In the case where the spring dampers are larger than the space between the inner and outer trays, the inner tray will be redesigned and fabricated. This simple redesign will reduce the width and length of the inner tray by the minimum dimensions necessary to fit the spring dampers. The sliding mechanism that attaches the inner and outer tray will be readjusted on the inner tray to line up with the outer tray as well. For the purposes of testing this semester, this inner tray will be fabricated with cardboard according to steps in **Appendix C**.

Final Prototype

The materials listed above and the fabrication protocol described in the Methods section are currently being developed and organized so that a final prototype will be created within the next four weeks (**Appendix C**). This will allow the team enough time to continue into the testing phase and conclude whether the product has met the specifications described in **Appendix A**.

Testing

To measure the strength of the vibrational forces within the resting area of the isolette, the team plans to use an accelerometer system that will be capable of collecting data in the x, y, and z directions. To ensure accurate data collection, the accelerometer system used for testing should have a sampling frequency of at least 100 Hz, and the data should be collected and stored for at least one week. To collect the data, the team will set up the accelerometer system along the backside of the incubator opposite of the neonate's head position. Acceleration data will be collected both with and without the Spring and Damper prototype in order to determine the statistical significance of including the proposed solution.

A Power Spectral Density (PSD) plot will be created in order to evaluate the randomized vibrations that occur during transport. A PSD plot is a representation of the frequency concentration of a random signal. It shows the power of the signal as a function of frequency, allowing the team to determine the strength of the vibration experienced by the neonate [30]. The

shape of the PSD curve can define the mean acceleration of a random signal at any frequency which is important for evaluating the randomized vibrations that occur during transport.

The primary test that the prototype must pass is to reduce the vibrational accelerations felt by the neonate to be below the recommended 0.315 m/s^2 [11]. An analysis of the Acceleration vs. Time graphs and the PSD curve will allow the team to determine whether the whole body vibrations have been successfully reduced below this threshold. If this test is passed, a proof of concept has been established and the team can move forward on addressing other components of the Product Design Specifications (**Appendix A**) such as the size and weight of the prototype to better compete as a commercialized product.

VI. Discussion

Implications of Results

Testing will play a critical role both in the short term evaluation of the design's efficacy and the long-term commercialization goals for the project. The results of the accelerometer testing will influence the future direction of the design and what refinements will need to be made. Furthermore, the success or failure of a product in the market is heavily dependent on the reliability of the various testing it undergoes. Therefore, it is vital that it is completed properly and accurately according to industry standards.

Ethical Considerations

In the development of a new medical device, ethical considerations must be addressed in regards to research, patient safety, and inclusivity. First, ethics surrounding medical research involves acting on sufficient information and understanding and using that information to promote well-being [31]. The quantity and quality of research must be sufficient in providing an accurate, complete description of the problem and design variables in order to make informed decisions. Understanding of the research is just as critical as the team needs to act as experts in the identified field. A final focus of research ethics is reporting the research honestly and giving credit where it is due. Medical devices operate on the basis of the truth of the research done and will inevitably fail if research is falsified.

Secondly, medical ethics address the importance of patient safety and health through official device approval and testing. It is important to prove device efficacy prior to use to ensure that the device will function as intended. To do so, the device must comply with the standards set for Class II medical devices according to the FDA and receive approval prior to use (**Appendix A)** [32]. Additionally, the use of HDPE outer coating will protect existing equipment from the magnetic field generated by the magnetic damper while also allowing these components of the design to be easily removed and sterilized using an autoclave or ethylene oxide [33]. In regards to testing, it is important that results are reported transparently and all results are included. Omitting negative test results falsely informs clients and patients about device efficacy and can result in device failure during use.

Finally, inclusivity is an important ethical consideration which allows all patients to have the access and ability to use the device. Thus, religious, cultural, and economic considerations were taken into account during development of the final prototype. The chosen materials are permitted among all known cultures and religions which may forbid the use or interaction with certain substances. Finally, the cost of the device is kept low to allow accessibility to clients and patients regardless of economic status. Ethical considerations were taken into account throughout the design process and guided decisions to create a well-informed prototype.

Sources of Error

The team expects to combat potential sources of error in the testing process. For example, testing will be performed over the course of multiple consecutive days. This could lead to issues with data storage, inconsistencies in run time, and other related issues. As a result, careful analysis will need to be performed so the data is an accurate representation of the design's efficacy. Additional errors may arise if the device is in a position that is more or less representative of the vibrations the neonate may experience. Several comparisons will need to be made in order to determine whether placing the device near one end of the incubator will provide similar results to the middle of the incubator where a neonate's head is resting and most susceptible to intraventricular hemorrhaging.

VII. Conclusions

Critically-ill neonates are often transported via ambulance or helicopter to hospitals, and the ride could last several hours. The neonate undergoes significant stress due to forces the incubator experiences during transport. This could ultimately cause brain damage due to the delicate nature of the neonate during that time. The team was tasked with creating a device that could help to reduce the vibrations that are experienced by a neonate during transport via ambulance or helicopter to a hospital in order to lessen the chances of brain injury and to increase the chances of survival.

Prior iterations of prototyping with the Metal and Gel Composite Damper provided a start to solving the problem; however, the results were not significant enough to truly reduce the vibrations enough to positively influence the neonate. Because of this, the team proceeded to follow a different route and chose the Spring and Damper design to continue researching and prototyping in order to solve the task at hand. The Spring and Damper design utilizes a spring and damper intertwined into one system. They would be placed in between the inner and outer trays on both sides of the tray, as well as beneath the inner tray, in order to reduce vibrations in the x, y, and z directions. Incorporating a spring component into the design is a new addition from prior prototypes, and will hopefully produce the results that the team is looking for.

Future Work

Although significant progress has been made in the task to reduce vibrations that a neonate experiences during transportation, further research, prototyping, and testing needs to be conducted to see a bigger impact. The Spring and Damper Design will be the design that proceeds with the next phases in the design process. Specifically for this design, the team will be utilizing a magnet damper for the purposes of this project, but specific magnet materials and structures will need to be determined. Once all aspects of the design are finalized, the team will begin purchasing materials to prototype the design.

In addition to prototyping and testing the Spring and Damper Design, further research into accelerometers will need to be conducted. Having a viable accelerometer that produces trustworthy and reliable data is just as important to the success of this project, as that is what represents the effectiveness of the prototype. The team has had and will continue to have several

conversations with individuals who are experts in these areas in hopes of gaining any insight on how to proceed with purchasing an accelerometer. Once an accelerometer has been acquired, several rounds of testing will need to take place throughout the prototyping phases. Prior to testing the device in transport via ambulance, testing will be conducted to ensure the durability of the device to ensure it will be able to withstand the forces and environment of the ambulance. Then, testing will be conducted by measuring the acceleration within the incubator, with and without the Spring and Damper system, to determine how the values change and the effectiveness of the device. A similar route will be taken by the ambulance on all trials to avoid any confounding variables that would impact the results. The results will need to be compared to the results found from prior prototypes, as seen in **Appendix B**, to determine if the new and improved design is more or less effective than the prior prototype.

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IX. Appendix

A. Product Design Specifications

Product Design Specification

Reducing Whole-Body Vibrations in Neonatal Transport

Feb 10, 2023

Team Members:	Joshua Varghese	Team Leader
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Function:

Critically ill neonates, as a result of birth defects or other disorders, require transport to neonatal intensive care units (NICU) where specialized medical professionals and equipment increase their chances of survival. Transport in ambulances or helicopters, while necessary, induces physiological stressors which adversely affect the health of the neonates. In particular, whole body vibration (WBV) and excessive sound levels can induce head bleeds, leading to subsequent neurodevelopmental impairment or death. Minimizing the effects of mechanical vibrations and rotational and translational motion could improve outcomes during transport. The current transport incubator has ventilators, monitoring equipment, and temperature control mechanisms, but no control of the physical stressors aforementioned. The client, Dr. Ryan McAdams, tasked the team with developing a novel transport bed to minimize these issues. The new bed must ensure the safety and security of the neonate while maintaining the functions of current incubators.

Client requirements:

1. The device must minimize the vibrational forces within the incubator so that a critical neonate does not sustain injury.
2. The device must minimize translational and rotational forces enough to prevent injury to critical neonates.
3. The device must either attach to current incubators or include all the associated functions including ventilators, monitoring equipment, and temperature control mechanisms.
4. The device must be small enough to fit within a standard ambulance and allow the movement of the transport team.
5. The data collection method must meet industry standards and provide appropriate support to justify the damper design´s effectiveness at reducing whole body vibrations.

Design requirements:

1) **Physical and Operational Characteristics**

a) Performance requirements

i) The product must decrease the amount of whole-body vibrations to be below 0.315 m/s^2 as suggested by ISO standard 2631 regarding human exposure to whole-body vibrations [1].

ii) The product should allow the infant to maintain proper vital signs in a range appropriate for its size, age, and condition:

(1) A heart rate between 100 and 160 beats per minute [2].

(2) A respiratory rate between 30 and 60 breaths per minute [2].

(3) Blood pressure of no less than 30 mmHg systolic [3].

(4) An oxygen saturation level between 85% and 95% [4].

iii) The sampling frequency of the testing mechanism should be at least 100 Hz in order to appropriately cover the range of frequencies experienced within the incubator while traveling in an ambulance or helicopter [5].

iv) The testing mechanism should be able to continuously collect and store data for at least 1 week.

b) Safety

i) The transport bed, and any alterations made to it, must not inhibit the delivery of continuous treatment to the neonate.

ii) The device should not interrupt the functioning of the incubator, ventilator, or monitoring equipment.

iii) Any potentially hazardous components of the device (e.g. sharp edges, long cords, or small pieces) should not be accessible to the neonate while in the incubator.

iv) The device should be able to be decontaminated with a U.S. Environmental Protection Agency (EPA)-registered hospital disinfectant without degradation for the 5 year lifetime of the ambulance [6].

c) Accuracy and Reliability

i) The device should be able to effectively reduce the amplitude of vibrations with a frequency in the human sensitivity range of 3-20 Hz [7].

ii) The root mean square vibration exposure should fall below the 0.315 m/s^2 comfort limit specified in ISO 2631 [1].

iii) The device should not lose function or require maintenance over the course of its lifespan.

iv) The device should be functional when supporting neonates from 2.5-4.5 kilograms [8].

d) Life in Service

i) On average, ambulances have a lifespan of around 5 years and travel around 300,000 miles, assuming proper maintenance and standard operating conditions. The device should be able to withstand these conditions [9].

ii) Incubators can last several years, but undergo significant stress due the vibrations and mechanical forces they withstand on a day-to-day basis and due to intense transportation (e.g., ambulance rides, cleaning, etc.). The device should be able to withstand similar mechanical stress to the incubator and last around a similar time frame [10].

iii) The device should not compromise the functionality or safety of the incubator throughout the lifespan of its use.

e) Shelf Life

i) If electrical components are involved in the design, the device should function for a minimum of 7 years [11].

ii) If no electrical components are included, the device should last for at least 12 years [11].

f) Operating Environment

i) The operating environment for both the dampening device and testing mechanism will be targeted for ground transport using an ambulance and the Voyager transport incubator by International Biomedical [12].

g) Ergonomics

i) No parts of the device will interfere with ambulance personnel or obstruct access to the neonate.

ii) For any electrical components, there will be a simple screen interface.

h) Size

i) The device will fit inside or under the Voyager transport incubator by International Biomedical with dimensions of 53 cm H x 48 cm W x 99 cm L [13].

i) Weight

i) The dampening device should be no more than 4 kg which is equivalent to 10% of the incubator's weight when empty [13].

ii) The testing mechanism should contribute less than 2 kg to the incubator system so that its weight will have a minimal effect on the vibrations experienced by the neonate [14].

j) Materials

i) The materials should be safe to use in a medical environment and be in compliance with federal EMS regulations [12].

ii) The damping device and testing mechanism should avoid using heavy metals or latex materials on portions of the device that may come into contact with a patient [15].

k) Aesthetics, Appearance, and Finish

i) The device should appear as a part of the incubator, but with distinguishing characteristics, such as color or material, that set it apart from the incubator as a whole. This will assist in removal, isolation, and cleaning of the device if needed.

ii) The color of the device should be either white, green, or blue, which all symbolize cleanliness. Color selection is important to provide confidence to the client and user that the product was professionally developed and is functional [16].

iii) Appearance and material considerations and choices should not ultimately affect the functionality of the device. FDA regulations surrounding material and color choices need to be carefully considered.

2) Production Characteristics

a) Quantity

i) A single functional prototype should be developed by the conclusion of the semester.

ii) A single testing device must be acquired to perform repeat testing on both the initial prototype and future developments.

iii) Design should be able to be mass produced for commercial use in the future.

b) Target Product Cost

i) The design should cost no more than $500 for preliminary development and testing.

3) Miscellaneous

a) Standards and Specifications

i) The dampening prototype can be considered a Class I or Class II device depending on the modifications that accompany the design. Either class will require compliance with sections 513(a)(1)(A)- general controls, 513(a)(1)(B)- special controls and specific risks, and potentially 510(k)- premarket notification [17].

(1) If the device modifies the incubator and replaces any components that are present in International Biomedical's Voyager, then it will require FDA approval and must meet requirements for a class II medical device

(2) If the device does not alter the incubator setup and presents a minimal risk to the patient, then it may meet the requirements described for class I devices.

ii) To ensure safety and efficacy, the device must follow the requirements under 21 CFR Part 820- Quality System Regulation [18].

iii) The device must comply with sterilization standards described in ISO 14937 [19].

iv) If the device directly alters the isolette, it must meet the standards in IEC 60601-2-20, which outlines safety and performance requirements for transport incubators [20].

b) Customer

i) The hospital requesting the device requires that the device is compatible with their preexisting transport setup.

(1) Alternatively, the design should include all the associated functions of a transport incubator including temperature control, ventilators, and monitoring systems.

ii) The design should fit within a standard ambulance and not hinder the mobility of transport teams.

(1) The maximum area for device implementation, as detailed for Type III Transport Ambulances, is 173 cm interior headroom and 124 cm aisle width [21]. It is important to note these are maximum size constraints while the functional design area may be limited further within this space for mobility and accessibility.

iii) The design must improve transport outcomes by reducing vibrations with no additional adverse effects on patient health.

c) Patient-related concerns

i) During use and transport, the device should not introduce any additional threats or risks to the neonate.

ii) The product should not come in contact with the patient in case of allergic reaction to the material.

iii) Thorough testing must be completed before testing on patients can occur to ensure comfortability, safety, and effectiveness. All risk management procedures must be fully and carefully analyzed.

d) Competition

i) The Quasi-Zero-Stiffness (QZS) Isolator is a proposed design which targets low-frequency vibrations via modifications made to the incubator control box [22]. The design primarily utilizes concentric magnets and coil springs to mitigate vibrations. However, the design requires extensive modifications to the preexisting setup and has not been experimentally proven.

ii) The isolation device for shock reduction is another proposed design which utilizes gas springs between the isolette and stretcher deck [23]. The design features variable pressures in the springs as a way to target various frequency ranges. The proposed design makes considerable modifications to the preexisting setup while failing to acknowledge the presence of monitoring systems.

iii) Magnetorheological (MR) dampers help stop vibrations in vehicles when driving on roads that have changes in smoothness and shape. The pneumatic suspension system can be set to be soft or firm, and the MR damper can be adjusted to different levels of firmness to work with the pneumatic suspension and reduce vibrations [24].

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B. Testing Results

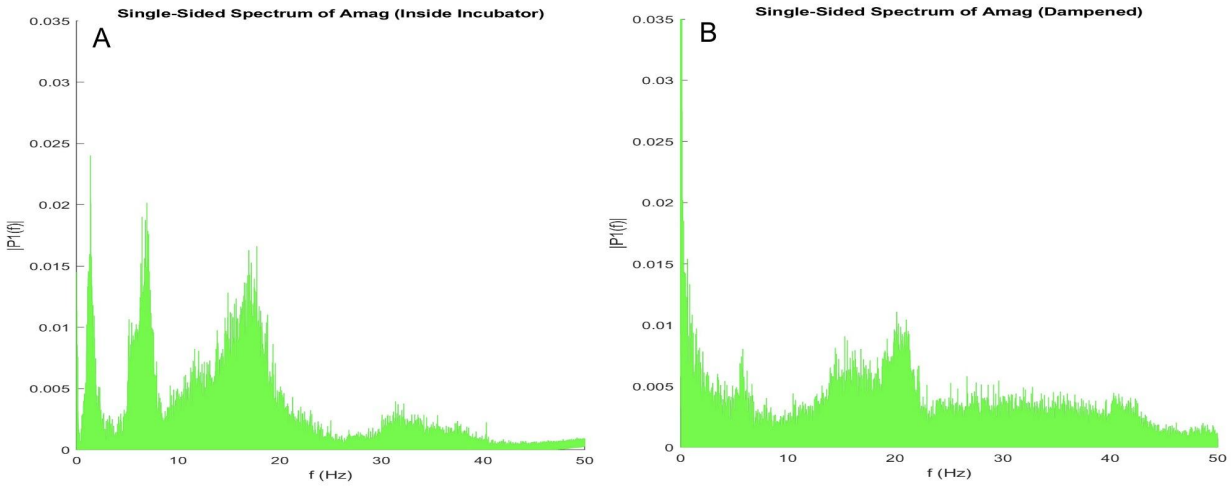

Figure 1: Power spectral density graphs for measurements (A) inside the incubator without the dampening prototype, and (B) inside the incubator with the dampening prototype.

The acceleration data acquired from the testing runs was uploaded to MATLAB drive. A Discrete Fourier Transformation was applied to the total magnitude of the acceleration data to gather the frequency information. An analysis of the frequency derived from the transform was done to provide information about the vibrations experienced by the neonate mannequin inside the isolette as well as the surrounding setup. The data was cleaned using the detrend function in MATLAB to remove the best straight-fit line. The sensors were grouped by location for analysis; the two sensors inside the incubator during undamped baseline testing were grouped together, and the two sensors inside the incubator during dampened device testing were grouped together. These groups were formed so that performance of the damper could be compared to vibrations experienced inside and outside the incubator during a standard transport trip. Power spectral density graphs were created for each of the three sensor groupings in Figure 1. Qualitative size comparison of the spectrums in Figure 1 (A) and (B) from baseline testing suggests that a large amplification of vibrations occurs inside the incubator within the 0 to 20 Hz range.

C. Fabrication Methods

After obtaining materials, the spring dampers were fabricated and attached to the outer tray of the isolette according to the following steps.

1. Attach the spring around the damper. The top flat piece of the damper will secure the spring in place.
2. Attach 10 mounting brackets to the inside of the outer tray using screws. These mounting brackets will provide a method of attachment for the spring dampers.
    a. Four mounting brackets will be spread evenly across the bottom of the outer tray and there will be two on each of the three sides of the outer tray (no brackets on the side where the inner tray needs to slide out).
3. Install four spring dampers evenly spaced under the inner tray by attaching them to the mounting brackets. The remaining six spring dampers will be placed on the three sides between the inner and outer trays of the incubator (two on each side).
    a. Alternatively, epoxy glue can be used to secure the spring dampers to the inside of the outer tray.
4. For fabrication of the redesigned inner tray, the width and length of the tray will be reduced by the minimum dimensions necessary to fit the spring dampers.
    a. Cut a 26 cm x 30 cm rectangle out of cardboard.
    b. Cut two additional cardboard rectangles that are 30 cm x 6 cm and two cardboard rectangles that are 26 cm x 6 cm to attach as walls of the fabricated inner tray with 2 cm below the bottom of the cardboard base.
5. Adjust the sliding mechanism that attaches the inner and outer tray. This mechanism will need to be readjusted on the inner tray to line up with the outer tray.
    a. Cut a rounded slit in the two walls of the cardboard inner tray in the 2 cm of cardboard that is below the base piece of cardboard. This will allow the tray to still slide in and out and will increase vertical space between the bottom of the inner tray and the bottom of the outer tray.