

Human Respiratory Mechanics Demonstration Unit

Final Design Report

December 11th, 2007

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ABSTRACT

Human respiratory models help students visualize alveolar and intrapleural pressure changes that occur while breathing. However, several problems exist with current respiratory models: their life-spans are short, the scaling of parts is physiologically inaccurate, and the rib cage expansion is not demonstrated. Our goal is to design and build an adequate mechanical respiratory model for class instruction purposes. We developed three preliminary designs, and decided to construct the Rib Membrane Design using acrylic for the enclosure. This design utilizes a membrane flange mechanism and a piston to model rib and diaphragm expansions, respectively. Various elastic materials, including latex, Theraband[®], and gum rubber, were tested for maximum load and extension characteristics. The pure gum rubber had the highest maximum load and extension (3.2kg, 207.1mm), thereby making it a suitable material for use as the rib cage membrane. Tensile testing of RTV-sealed seams in latex and Theraband[®] materials revealed that Theraband[®] material is more appropriate for use as the lungs in the model. Our next steps for this design are to find a transparent rib cage membrane; develop an easily replaceable rib membrane and lungs; and integrate our device with BioPac[®] software, allowing for real-time visualization of pressure changes occurring during breathing.

BACKGROUND

Problem Statement

Our goal is to design and build an adequate mechanical respiratory model for class instruction. This model should demonstrate pressure differences between alveolar and intrapleural spaces. It must further demonstrate the expansion of the thoracic cavity from the rib cage as well as the diaphragm, thereby displaying a 3-D expansion. The size of the lungs relative to the size of the thoracic cavity enclosure should be scaled to represent the human anatomy. The lungs in the current model inflate to fill roughly 1/15 of the thoracic cavity. In actual humans the lungs inflate to fill nearly the whole cavity with the exception of the space occupied by the heart and major blood vessels [1]. The device must also be portable and small enough to use with a document camera.

Problem Motivation

Though simple homemade models and basic commercial Plexiglas[®] lung models are available, they have short life-spans and parts that are difficult to replace. For most models, when one portion of the model fails, the entire unit must be replaced; this is both inconvenient and expensive. Our clients had been using a basic lung model; however, since components wore out, their model was no longer useable. Furthermore, currently available models do not demonstrate rib cage movements or display pulmonary pressures, which make it difficult for students to visualize the forces driving gas exchange between the lungs and the atmosphere. Also, in current models, balloons used to model the lungs are much smaller than the thoracic cavity and are not scaled to reflect physiological conditions. Hence, a physiologically scaled model of the lungs which demonstrates the movement of the ribcage and diaphragm along with pressure displays would be a valuable teaching aid.

Respiratory Physiology

The main components of the human respiratory system are situated in the thoracic cavity. This space includes the ribs, heart, trachea, lungs, and diaphragm. When breathing, the alveolar and intrapleural pressures change, as shown in Figure 1. Alveolar pressure (P_{alv}) describes the pressure inside the lungs, while intrapleural pressure (P_{pl}) describes the pressure in the space between the lungs and the pleural membrane (intrapleural space). At rest, P_{alv} is 0 cm H₂O and P_{pl} is -5 cm H₂O [2]. When the diaphragm contracts, the intrapleural space increases and creates a negative pressure. This negative pressure expands the lungs and decreases the alveolar pressure, drawing air into the lungs from the atmosphere. During exhalation, the diaphragm relaxes and the pressures return to their resting states, forcing air out of the lungs.

These pressure changes affect the volume of air contained within the lungs. The difference between P_{alv} and P_{pl} in combination with the lung's elastic properties influence this volume. Contraction of the diaphragm and expansion of the rib cage by the intercostal muscles control the changes in these two pressures (Figure 2). Both the diaphragm and the intercostals function together during inhalation and increase the thoracic cavity space, which consequently causes P_{alv} and P_{pl} to become more negative.

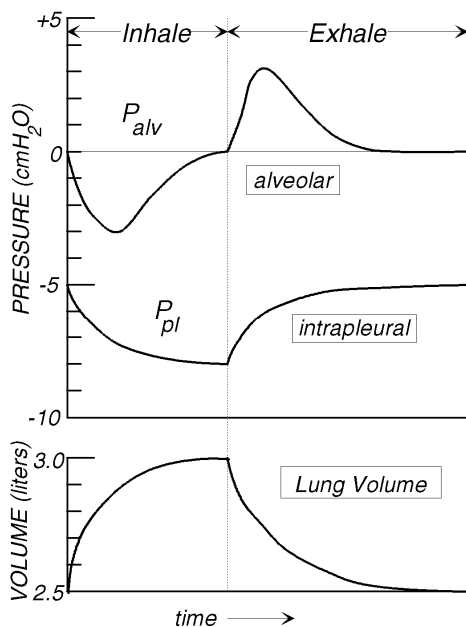


Figure 1. Changes in P_{alv} , P_{pl} , and lung volume during breathing [2].

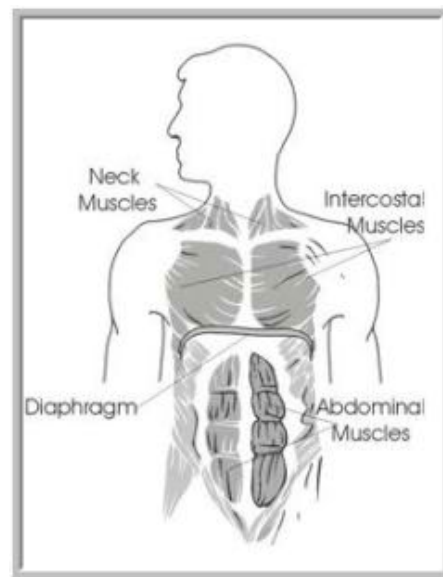


Figure 2. Locations of the human diaphragm and intercostals muscles [3].

Design Constraints

The final design should have considerations for use in a large lecture hall setting. This includes making the device operable by only one person and must be usable under a document camera. Hence, the device should be small enough to fit on a document camera (document camera bed is approximately 13x17in). Further, the container housing the lungs should be transparent such that the inner components of the model are visible. Additionally, the device

should weigh no more than twenty pounds, as a single person will carry it around campus. The parts on our device that tend to wear out quickly such as elastic membranes should be easily replaceable to increase the longevity of the unit as a whole. Finally, the cost of our device should not exceed our budget of \$500 for the 2007-08 academic year.

Competition & Current Devices

The current devices available to model the human respiratory system vary widely in complexity and anatomical accuracy. Simple models to demonstrate lung volume change can be made with balloons, soda bottles and straws. More complicated models incorporate an elastic membrane to act as a diaphragm, creating a negative pressure to induce lung volume changes. The most common model used to replicate respiratory function for student instruction consists of a dome shaped Plexiglas® container (Figure 3). An elastic diaphragm extends and contracts from the bottom of the container to alter internal pressure, similar to the anatomical action of the diaphragm. Two balloons inside the dome container represent the lungs. In such models, however, the ratio of container size to balloon size is much greater than the actual physiological ratio.



Figure 3. Example of current respiratory model [4].

Computers allow for more sophisticated models of the human respiratory system via interactive animation. Because of the specific guidelines set during animation, the online representations are more anatomically accurate than physical models. However, such models are limited by specific software requirements and do not provide the hands-on learning valued by instructors and students.

Currently, no physical models illustrate the expansion of the rib cage. Though most of the lungs' volume change is due to the diaphragm's contractions, the rib cage movement contributes between 5 and 42 percent of the lung's total volume change [5]. A more anatomically correct representation of the lung size compared to the thoracic cavity size should demonstrate the respiratory movement more accurately for students.

ALTERNATE DESIGNS

General Design

All three designs are based on a common structure with variations in rib and diaphragm volume displacement methods. This common structure is the main component of the model, representing the ribs and chest wall. It will consist of an eight inch diameter acrylic tube with acrylic sheeting covering the open ends. The back section of the tube will be removed and replaced with a flat sheet so that the model can be placed securely on a document camera as shown in Figure 4. Acrylic was selected for its clarity, scratch resistance, and strength. The lungs will be enclosed inside the acrylic tube that has an opening through the top. Pressure changes inside the tube created by the rib and diaphragm mechanisms will cause the lungs to inflate and deflate. It is important that this enclosure remains completely sealed and does not leak under the pressures that will be generated.

The lung design is also similar in all three preliminary designs. Two lungs will be constructed of various elastic membranes by sealing together two pieces in the shape of a lung. The lung openings will be clamped onto a Y-fitting fed through a rubber stopper. The rubber stopper will seal a hole in the top of the thoracic cavity. Different elastic materials will be used to represent various pulmonary diseases such as emphysema.

The alveolar and intrapleural pressures will be measured using analog pressure gauges with NPT fittings capable of measuring both positive and negative pressures. These will be used because they are cheap and easy to integrate into the model. The intrapleural gauge will be attached using a tapped hole through the acrylic. The alveolar pressure will be read by feeding a small tube through the rubber stopper and into the lung.

Hinged Door Design

The hinged door design simulates rib expansion by moving two hinged sections of the chest wall tube. The front section of the tube would be cut into two panels and fixed by hinges so that they open outward as shown in Figure 4.

An elastic membrane would be secured to the inside of the doors and the surrounding tube wall to make the chest enclosure airtight while still allowing movement of the panels (not shown in Figure 4). Knobs would be attached to each hinged panel for easier operation. By opening and closing the doors, the outward expansion of the ribs and the subsequent increase of the intrapleural space can be demonstrated.

Diaphragm function would be demonstrated using an elastic membrane stretched over an opening in the bottom of the chest enclosure. It would be secured using a hose clamp for easy replacement. This membrane can then be pulled to expand the intrapleural space and lower the pressure as shown in Figure 4. As discussed earlier, this diaphragm membrane design uses the same mechanism as many of the current models.

Advantages

The elastic diaphragm has a similar movement to the diaphragm muscle in the body. This elastic diaphragm may make it easier for students to visualize it as an actual muscle. The hose clamp sealing the membrane around the tube bottom also makes the diaphragm easily replaceable. The hinged doors show the outward expansion of the ribs and are easily differentiated from the diaphragm mechanism.

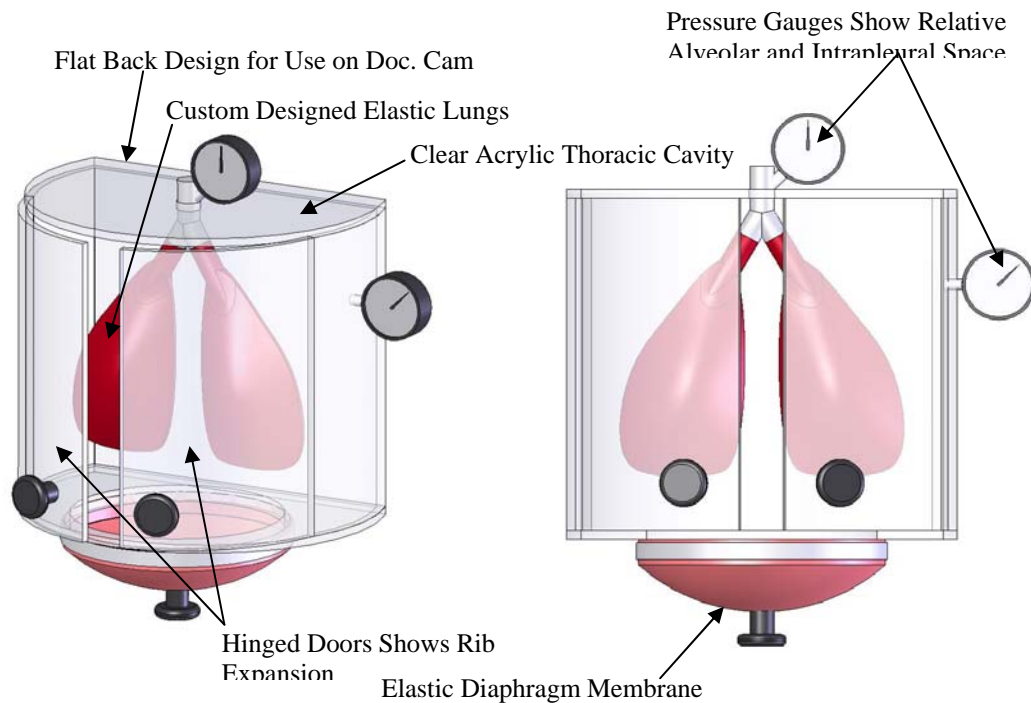


Figure 4: 3D Image of Hinged-door Design.

Disadvantages

Due to the complexity of the gaps around the hinged doors, sealing them with a membrane may be fairly difficult and unreliable. The membrane would not get stretched evenly; thus some parts would most likely experience continual high strains, pinching, or folding, leading to quick failure. When the membrane fails, it would also be very difficult for the client to replace and would require use of an epoxy. Both membranes are likely to be the most replaced components on the model and having two membranes increases the maintenance needed. The mechanisms also do not cause large volume changes compared to pistons. Further, the model requires operating three different handles to demonstrate all the moving parts at the same time, which is disadvantageous if the lecturer wants to demonstrate it without help.

Rib Membrane Design

The rib membrane design uses a membrane-constrained panel to demonstrate rib expansion. A front part of the tube would be cut out and covered with a membrane. The cutout panel would then be attached to the center of the membrane, allowing the user to show rib expansion by pulling on the panel. This mechanism is shown in Figure 5, but does not show the membrane to make the image clearer. The membrane was held in place using a flange that was screwed into the acrylic tube.

A piston made out of acrylic tubing would demonstrate diaphragm movement in the model. Two acrylic tubes, one fitting inside the other, would be used. The inner tube used would have an end covered with an acrylic sheet. It would also have a groove cut into it to allow an o-ring to be inserted to insure proper sealing. The outer cylinder would be attached into a hole in the bottom of the chest enclosure with epoxy, and the inner piston could be removed for easy access inside the enclosure.

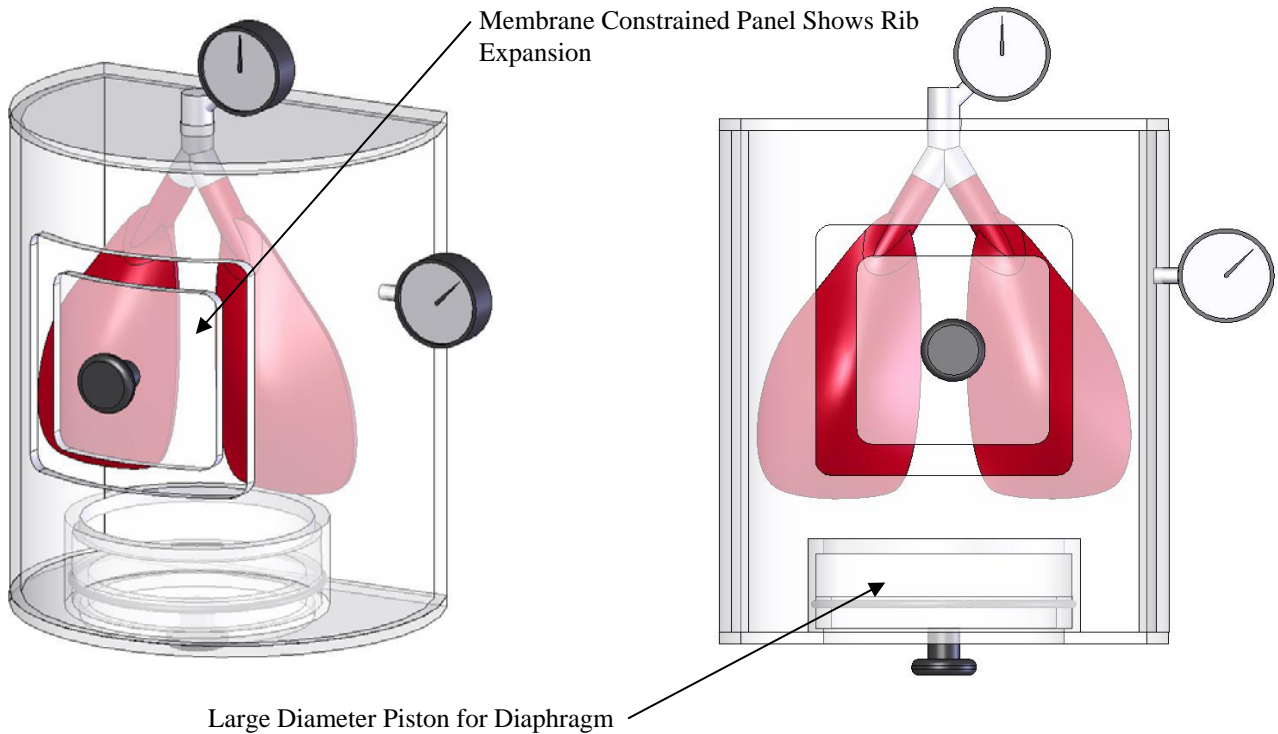


Figure 5: 3D Image of Rib Membrane Design.

Advantages

Compared to the hinged door design, the rib membrane in this design would be stretched evenly and thus would not be folded or pinched. This would minimize the wear on the membrane. The membrane flange mechanism is also removable should the membrane require replacement.

The piston is a very efficient mechanism and can provide large changes in volume unlike an elastic membrane diaphragm. It would also require little maintenance and would allow access to the inner enclosure if needed. Combined operation of the ribs and diaphragm only requires two hands and is easy for the client to operate alone.

Disadvantages

The elastic membranes will be the first to wear out. The rib membrane will likely need to be replaced several times throughout the lifetime of the device. Operation of the rib mechanism also requires the user to pull on the front of the device, slightly obscuring the lungs with their hand.

Quarter Section Design

The quarter section design has two mechanisms to simulate lung expansion from the ribs and diaphragm. To demonstrate rib expansion, two quarter sections would be created. The top half of the tube would be removed and cut into two halves. These quarters would be reattached to the main container and each other with an elastic membrane. The membrane would provide an airtight seal and allow the user to show the upward and outward expansion of the ribcage by pulling on the quarter sections (see Figure 6). The addition of knobs or handles to the quarter sections would allow the user to easily move them. This movement would increase the volume in the intrapleural space, thereby inflating the lungs.

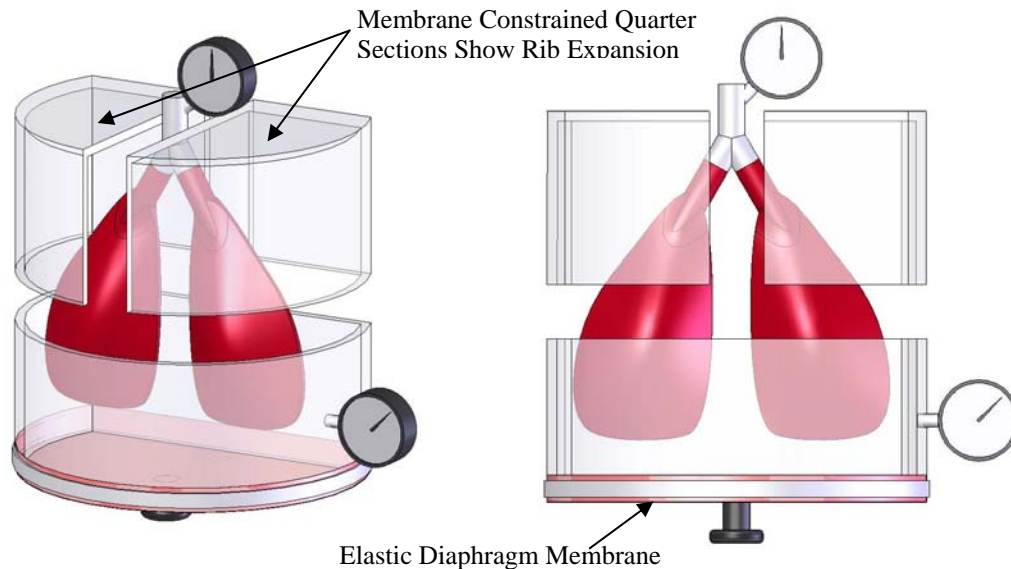


Figure 6: 3D Image of Quarter Section Design with Diaphragm Membrane.

The diaphragm movement would be demonstrated in a similar way as the hinged door design. An elastic membrane would be stretched over the bottom of the chest container, and would be attached with a hose clamp. This would allow for easy replacement. To show the movement of the diaphragm muscle, the membrane could be pulled by the user to increase the volume in the intrapleural space and inflate the lungs (see Figure 6).

Advantages

The quarter section design mainly has advantages from a physiological standpoint. The ability of the quarter sections to move upward and outward provides students with an accurate model of ribcage movement. Also, the movement of the diaphragm membrane is similar to the human diaphragm movement. This membrane would also be easily replaceable because of the hose clamp attachment.

Disadvantages

The attachment of the elastic membrane between the quarter sections and the main container would be difficult. The shape of the membrane would be hard to create, and would not be easily replaceable. There would be no easy way to attach the membrane without using adhesive. Because the membrane is the only way the quarter sections are attached to the main container, the membrane would wear out easily and need to be replaced often. Also, the

movement of the quarter sections and the diaphragm membrane will not provide very large volume changes. This would make it difficult to see the lungs inflate. Finally, this model requires a three-hand operation to show all the moving components at the same time. This is not ideal for a single user to demonstrate to a class.

DESIGN MATRIX/PROPOSED DESIGN

Each of the three designs was compared using the following design matrix. The criteria for the matrix were chosen based on the clients' requirements discussed previously. Ease of replacement and physiological accuracy were weighted the highest because these were the most important requirements for our clients. Based on the point totals for each design, the Rib Membrane Design had the highest score and was chosen as the final design.

	Design 1: Hinged Door	Design 2: Rib Membrane	Design 3: Quarter Section
Ease of Replacement (20)	10	20	15
Physiological Accuracy (20)	15	10	20
Ease of Use (15)	10	15	5
Durability (15)	10	15	5
Pressure Display (10)	9	9	9
Weight (10)	8	8	8
Cost (10)	8	8	8
TOTAL (100)	70	85	70

Figure 7: Preliminary design matrix.

MATERIALS

The materials that were used for the project involve various plastics and elastic materials. Cast acrylic was used for the main container of the prototype. This plastic provides both the clarity and strength needed for the prototype. Other materials such as polycarbonate and other acrylics were considered, but cast acrylic seemed the most appropriate because of its availability, transparency, and cost. A large diameter tube, small diameter tubes, and several sheets were needed to construct the final design.

There were two types of elastic polymers needed for the final design: a thicker, more durable elastic for the rib membrane, and a thinner, more compliant elastic for the lungs. Gum rubber sheets (1/32 inch thickness) were used for the rib membrane. Different elastomers were used to make lungs: latex and two types of Theraband®. These were each tested to determine their load and extension properties.

Epoxy and silicon adhesives were used to secure the acrylic pieces and also to seal the lungs. Screws, hose clamps, rubber stoppers, and rubber O-rings were some of the other materials that were needed to complete construction.

FINAL DESIGN

From the design matrix (Figure 7), the rib membrane model received the highest score, and was the design that was pursued during the semester. As described above, the rib membrane design consists of a moveable front panel to demonstrate rib cage motion and a piston to represent diaphragm muscle contractions (Figure 8). Sketches along with dimensions of prototype components are provided in Appendix B. During the construction phase of the project, we encountered some difficulty in machining acrylic tubing. We chose acrylic because of its clarity and scratch resistance. However, acrylic is brittle and is not very easy to machine. Several components had to be re-ordered that failed while we were trying to machine them. A detailed listing of ordered materials and their costs are provided in Appendix C. Although the constructed prototype closely follows the 3D sketches shown in Figure 5, the membrane used in the front panel is not transparent as described in the sketches. Since we were unable to find materials that were both elastic and transparent, an opaque elastic material, gum rubber, was

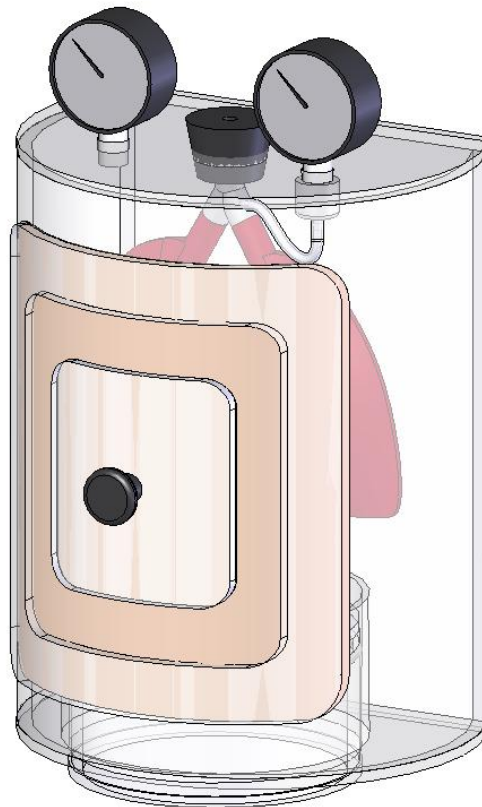


Figure 8: Solid Works image of final design.

used in the model. The opaque material obstructs the front view of the lungs, so this will be modified in the future to provide a clearer view. Moreover, the two analog pressure gauges used in the design to display pulmonary pressures are insensitive to the small pressure changes produced within the model. Therefore, more sensitive gauges that display both positive and negative pressures are needed to demonstrate the alveolar and intrapleural pressure changes.

TESTING

Material Strength

Rib and lung membrane materials were tested using the Instron 1000 tensile test machine to determine maximum material strengths. 2"x3" pieces of latex (n=3), black Theraband® (n=2), red Theraband® (n=2), pure gum rubber (n=3), and pure gum rubber with a 1/8" hole centered approximately 1/2" from the edge were tested (n=3). The hole was added to simulate the attachment of the prototype's rib cage membrane by a screw. To test these samples, a hook was secured in the upper clamp of the machine, and the material was placed on this hook with its bottom edge secured in the lower clamp. Sample sizes for all tests were small due to limited materials.

Maximum loads and extensions of each sample were measured and averaged within groups (Figure 9). Loads handled by materials from highest to lowest were pure gum rubber at 3.2kg, black Theraband® at 2.95kg, red Theraband® at 1.99kg, and latex at 1.43kg. Both the black Theraband® and pure gum rubber have similar loading characteristics. Unlike pure gum rubber, the black Theraband® started tearing at the friction clamps during testing. Therefore, we decided to further test the pure gum rubber for use in the rib cage mechanism by testing the material's strength with a hole. Pure gum rubber with a hole handled the same maximum load as the pure gum rubber without a hole of 3.2kg but only extended 105.6mm. Maximum extensions of the other materials from largest to smallest were pure gum rubber (207.1mm), black Theraband® (202.1mm), red Theraband® (134.3mm), and latex (108.4mm). Since the pure gum rubber withstood the greatest load and greatest extension, this material is appropriate for handling the force applied by the user when demonstrating rib cage expansion and improving the life of this mechanism.

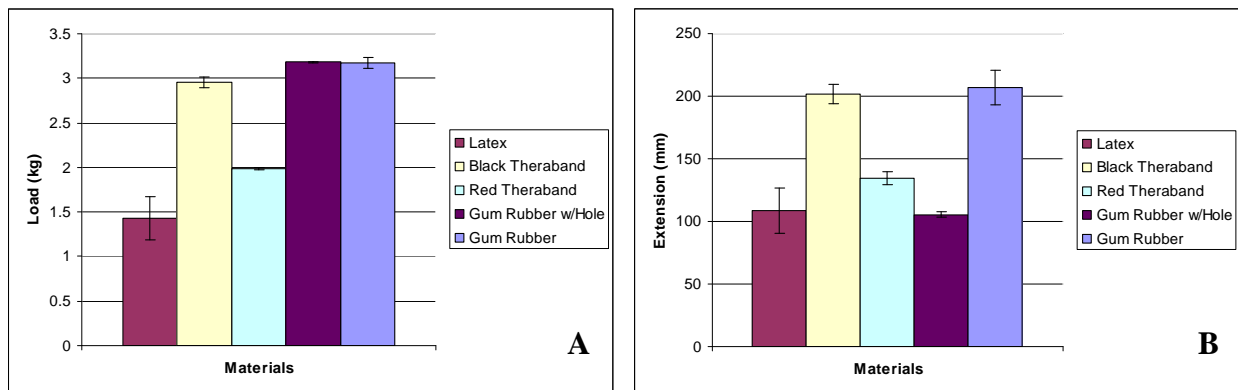


Figure 9. Maximum load (A) and extension (B) characteristics of latex, black Theraband®, red Theraband®, pure gum rubber, and pure gum rubber with a hole (+/- 1SE).

Seam Strength

The same procedures used to test material strength were implemented to test the seam strength of potential lung materials (latex and both Theraband® materials). The ends of two 2"x3" pieces of each material were sealed 1/4" together at one end using room-temperature vulcanizing sealant (RTV). The maximum extension of each material from largest to smallest was 50.2mm in the red Theraband®, 35.4mm in the black Theraband®, and 32.7mm in the latex (Figure 10). Maximum loads were also measured for these materials; however, the machine we

used was very old and not very sensitive to the small loads generated from testing. Since the Theraband® materials withstood greater extensions than latex before failing, these materials are more suitable for modeling the lungs in our prototype.

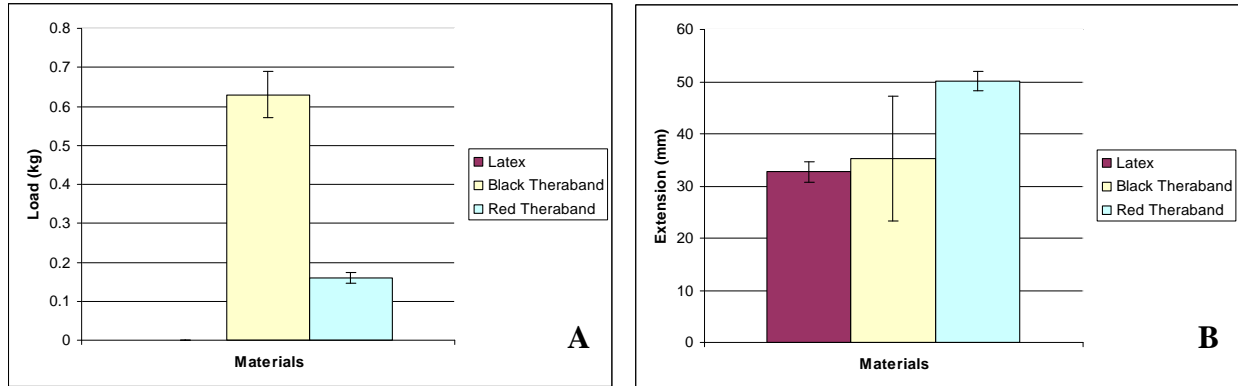


Figure 10. Maximum load (A) and extension (B) characteristics of seamed latex, black Theraband®, and red Theraband® (+/- 1SE).

FUTURE WORK

Additional testing is required to ensure that the operation of the device creates the relative pressure differences during respiration. Since the analog gauges used on the device do not detect the small pressure changes produced by the model, more sensitive gauges should be used in the model. Further, pressure readings for various diaphragm displacement and volume changes will need to be measured to ensure that relative inhalation and exhalation pressures correspond to physiological trends. Based on testing results, alterations to the design will need to be made.

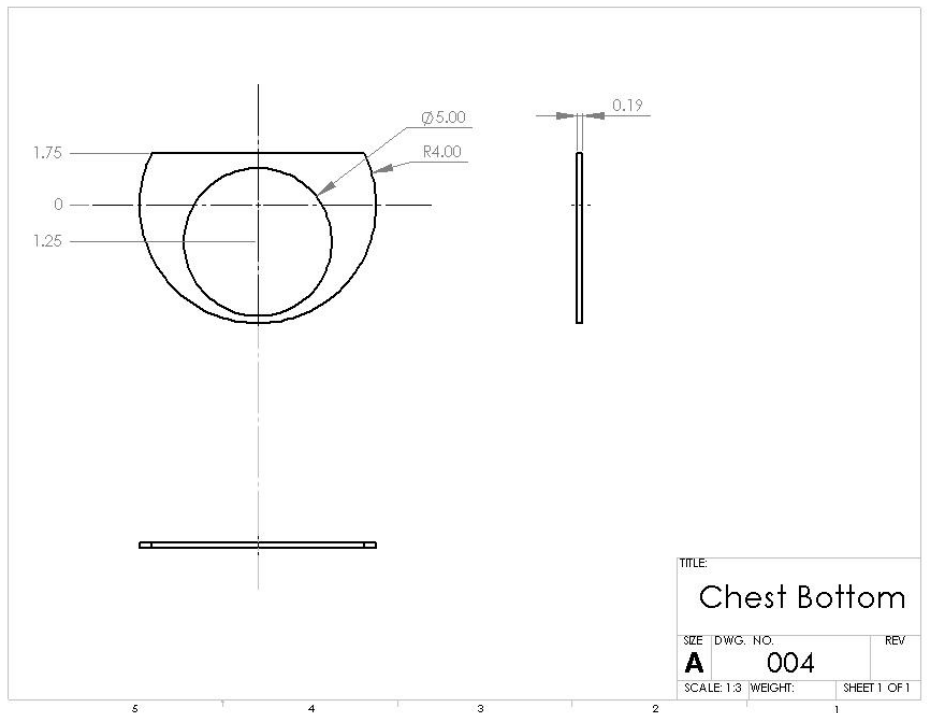
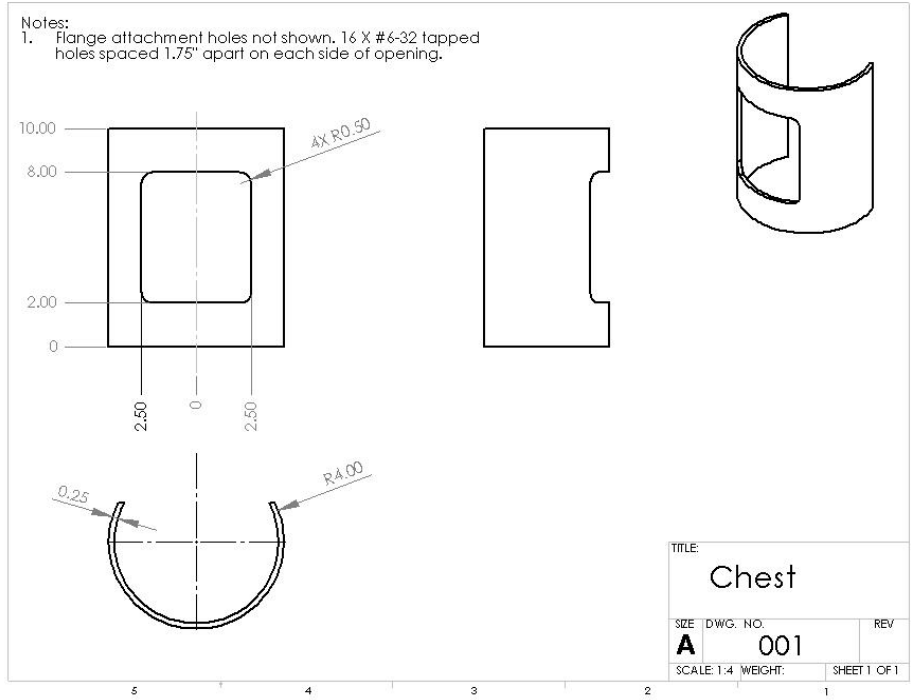
Further, a clear membrane could be used in place of the currently used gum rubber to increase visibility of lung mechanics. It would also be beneficial to include a stop to prevent unintentional removal of the diaphragm piston. Moreover, lung replacement could be facilitated by providing a removable back panel rather than the current access through the piston.

Following the completion of the physical model, it will be integrated with BioPac® software to produce graphs of alveolar and intrapleural pressure changes in the lungs. Pressure transducers and analog-to-digital converters would be needed to relay the pressures produced within the physical lung model to the software program. Hence, during the second semester, research on software integration and other electronic parts will be necessary.

APPENDIX A - References

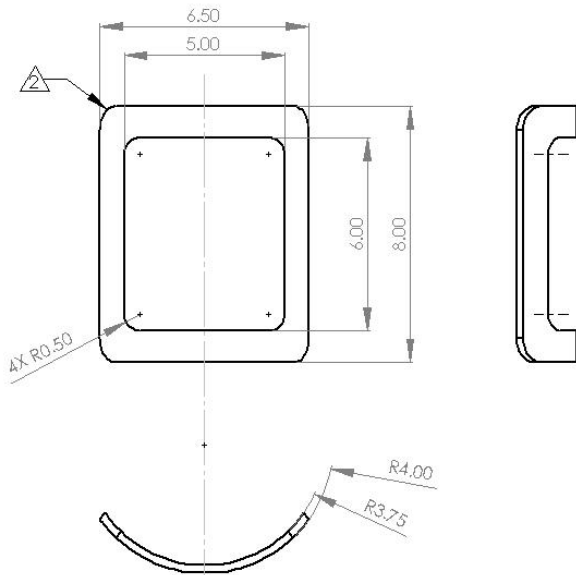
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APPENDIX B – Schematics of Final Design

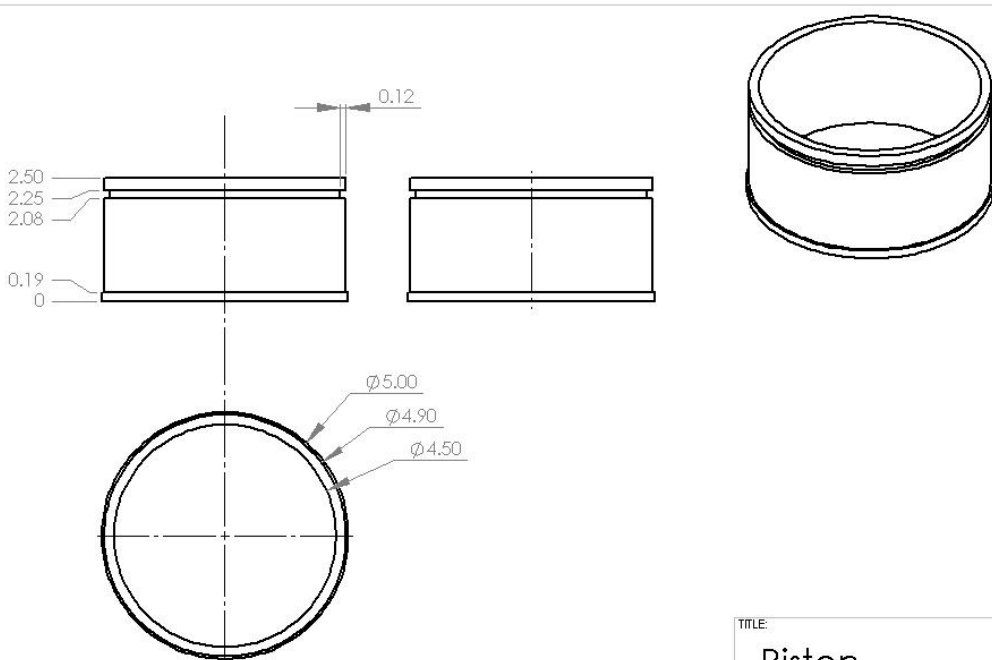


Notes:

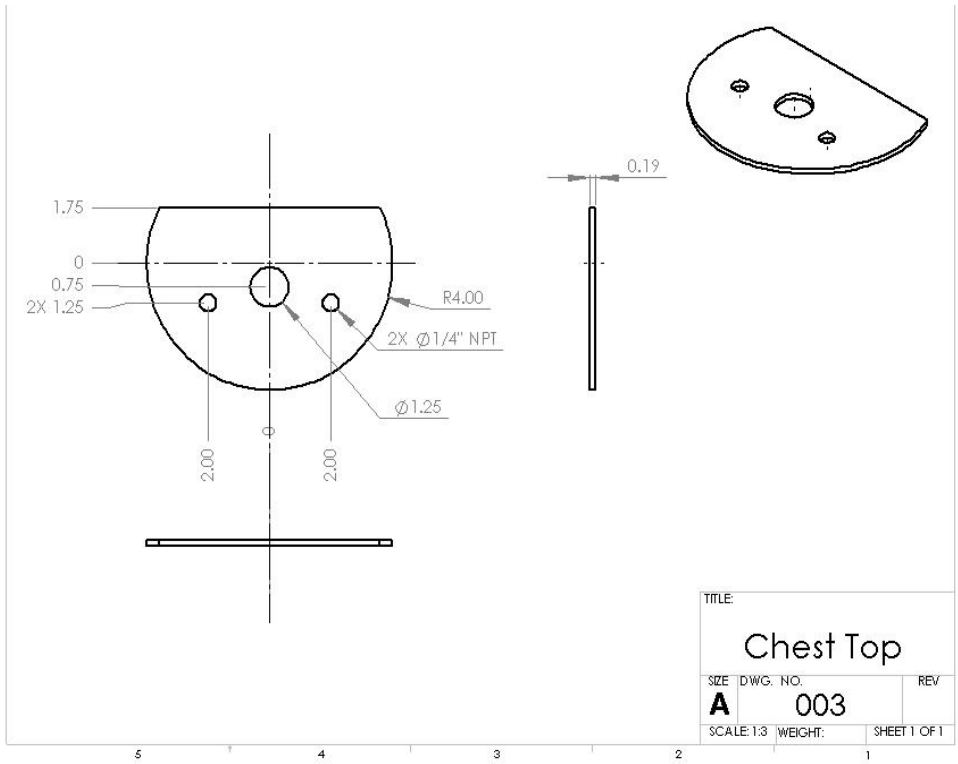
1. Attachment holes not shown. 1.6 X 0.11 ϕ " holes spaced 1.75" apart on each side.
2. 4X 0.5" R



TITLE:		
Flange		
SIZE	DWG. NO.	REV
A	002	
SCALE: 1:3	WEIGHT:	SHEET 1 OF 1



TITLE:		
Piston		
SIZE	DWG. NO.	REV
A	005	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



APPENDIX C – Bill of Materials

Description	Manufacturer	Part Number	Qty	Price (each)	Price (Tot)
8" outer diameter acrylic tube (thickness= 3/16")	McMaster-Carr	8486K837	1	\$41.40	\$41.40
5" outer diameter acrylic tube (t= 1/4")	McMaster-Carr	8486K583	1	\$25.65	\$25.65
5" inner diameter acrylic tube (t= 1/8")	McMaster-Carr	8486K582	1	\$21.35	\$21.35
Silicone Adhesive (3.0 oz)	McMaster-Carr	7587A37	1	\$3.37	\$3.37
Epoxy Adhesive (1.7 oz)	McMaster-Carr	7467A55	1	\$13.55	\$13.55
Hose clamps: (7/32")	McMaster-Carr	5388K14	1	\$4.68	\$4.68
Tube-to-tube Y fitting (3/8")	McMaster-Carr	53415K241	1	\$14.29	\$14.29
12"x12" Acrylic Sheet (t= .177")	McMaster-Carr	8560K211	4	\$5.05	\$20.20
O-ring (diameter = 5")	McMaster-Carr	9452K352	1	\$4.90	\$4.90
Rubber stopper with through hole (13/64"), size 7	McMaster-Carr	9545K33	1	\$11.05	\$11.05
Compound Pressure Gauge 0 to -30"Hg/0-15psi	McMaster-Carr	3941K53	2	\$9.37	\$18.74
Natural Latex (t= .008") by yd.	McMaster-Carr	85995K13	2	\$2.31	\$4.62
8" diameter acrylic tube (thickness= 1/4")	McMaster-Carr	8486K597	1	\$51.13	\$51.13
polyurethane tubing: inner diameter 3/8" (t=1/16")	McMaster-Carr	5108K56	2	\$0.92	\$1.84
helicoil (insert length =.138" thread #6-32)	McMaster-Carr	91990A219	2	\$6.36	\$12.72
button head socket cap screws #6-32	McMaster-Carr	92949A146	1	\$6.53	\$6.53
metal knob (1/4" -28 threads)	McMaster-Carr	6079K32	2	\$4.54	\$9.08
Piston O-ring (inner diameter = 4.125")	McMaster-Carr	9452K193	1	\$9.45	\$9.45
1/32" pure gum rubber sheet	Small Parts, Inc	PGRS-0031-F	1	\$8.55 + shipping	\$13.45
12"x12" Acrylic Sheet (t= .177")	McMaster-Carr	8560K211	4	\$5.05	\$20.20
Total					\$ 308.20

APPENDIX D – Product Design Specifications

Respiratory Demonstration Device

Janelle Anderson, Malini Soundarrajan, Chris Goplen, Lynn Murray, Kristen Seashore
December 3rd, 2007

PURPOSE & DEVICE FUNCTION:

Currently, a basic balloon and latex membrane model is being used to represent the lungs, and diaphragm, respectively for classroom instructional purposes. While they demonstrate respiratory mechanics, the models have a short lifespan and do not display alveolar and intrapleural pressure changes. Further, current models do not accurately depict the anatomical scaling of the lungs with respect to the thoracic cavity.

Our goal is to design and build an adequate mechanical respiratory model for class instruction purposes. This model should demonstrate pressure differences between alveolar and intrapleural spaces. It must further demonstrate the expansion of the thoracic cavity from the rib cage as well as the diaphragm, thereby displaying a 3-D expansion. The size of the lungs relative to the size of the thoracic cavity enclosure should be scaled to represent the human anatomy. The lungs in the current model inflate to fill roughly 1/15 of the thoracic cavity, when in actual humans the lungs inflate to fill nearly the whole cavity with the exception of the space occupied by the heart and major blood vessels [1]. The device must also be portable and small enough to use with a document camera.

CLIENT REQUIREMENTS:

- Long-lasting, easily replaceable parts
- Portable
- Displays alveolar and intrapleural pressures
- Scales lungs, thoracic cavity, and diaphragm correctly
- Operable by one user

DESIGN REQUIREMENTS:

1. Physical and Operational Characteristics
 - a. Performance Requirements
 - i. Reusable. The unit will be used about four weeks per year, so the pieces should be durable.
 - ii. Easily replaceable lungs and diaphragm.
 - iii. Operable by a single user.
 - b. Safety
 - i. Non-toxic and non-absorbing materials.
 - ii. Durable. The device should withstand regular usage.
 - iii. No sharp edges. Edges should be rounded to prevent any cuts or scrapes from being incurred by the demonstrator or students.
 - c. Shelf Life
 - i. Approximately 30 years.
 - d. Operating Environment

- i. Lecture hall and laboratory instructional settings.
 - ii. Between room temperature and temperature of document camera (25°C-30°C).
- e. Size
 - i. Must fit on a document camera for lecture demonstrations (11" x 13").
 - ii. Portable such that a professor or lab instructor can lift the device to transfer it easily to and from classrooms.
 - iii. Device should be small enough to fit in a standard cabinet or storage closet for easy storage.
- f. Weight
 - i. The device should weigh less than 15 pounds so that it can be transported around, when not in use, without inducing excessive stress on the lab instructor's arm and back muscles.
- g. Pressure Measurement
 - i. Must display alveolar and intrapleural pressures relative to each other.
 - ii. Analog gauges only.
 - iii. Pressure measurements should be easily readable using lecture document camera.
- h. Aesthetics
 - i. Transparent container to better visualize lung mechanics.
 - ii. Red colored lungs to enhance physiological representation.
 - iii. Cylindrically shaped container to model the thoracic cavity.

2. Production Characteristics

- a. Quantity: 1 unit
- b. Target Product Cost: under \$500

3. Miscellaneous

- a. Competition:
 - i. Acrylic model with latex diaphragm and balloon lungs



[2]

- b. Ethics:
 - i. Model could replace use of animals in teaching students.

References:

[1] <http://www.lib.mcg.edu/edu/eshuphysio/program/section4/4ch2/asidpg28.htm>. Thoracic Cavity Volume.

[2] http://www.xecu.net/kiireenza/anatomy/resp_models.htm. *Picture of current model.*