Adjustable Wave Tube Stand for Acoustic Reflection Technique

Ryan Carroll – Team Leader
Benjamin Engel – BSAC
Andrew Bremer – BWIG
Jeremy Glynn – Communications

Client –Erin Douglass MS-CCC-SLP
Vocal Tract Development Lab – UW Madison

Dr. Willis Tompkins, Ph.D.
Biomedical Engineering Department – UW Madison

Table of Contents

Abstract

Acoustic reflection technique is a non-invasive method of measuring vocal tract anatomy. It is useful in studying a number of conditions including sleep apnea and speech disorders. Current studies at the Vocal Tract Lab of the University of Wisconsin seek to compare acoustic reflection technique data with data from medical imaging studies. The current protocol calls for the wave tube device to be held in the hands of a researcher throughout the duration of the scans. This is inducing variability in the data. For this reason it has been proposed to design an adjustable stand for the acoustic reflection wave tube device. After the development of design ideas, a system of matrices was devised to evaluate them by component. A design consisting of the five best ideas for the five different evaluated components will be pursued and built in the remainder of the semester.

Background Information

Acoustic reflection technique is a non-invasive method of measuring vocal tract anatomy, more specifically the volume of the human vocal tract. The underlying principle of acoustic reflection technique is rather simple; however it relies on a number of assumptions as well as difficult computational algorithms. As sound waves propagate through an enclosed tube and come across changes in cross sectional area, part of the sound is reflected while the rest of the sound continues to propagate until it comes in contact with a surface. Acoustic reflection technique takes advantage of this physical property of sound by measuring certain characteristics of sound waves emanating from a human vocal tract. The process of acoustic reflection technique requires a patient to exhale into a device known as a wave tube. This wave tube contains a mouthpiece that prevents loss of sound waves to the outside environment. The tube is also equipped with a sensitive microphone capable of measuring the amplitude of both incident and reflected sound waves that it receives. This information, coupled with the speed of the sound pulse, as well as the amount of time it takes for the wave to travel, allows for the computation of a series of cross sectional areas along the length of the human vocal tract. Often these cross sectional areas are plotted against their distance from a

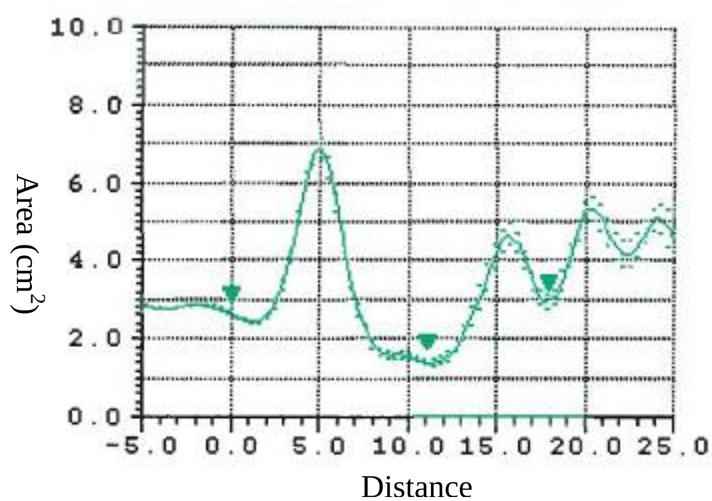

Figure 1 – Acoustic Reflection Technique Echogram

fixed point on the human body, most often the teeth or inlet of the mouth. This representation is known as an airway echogram (Figure 1). These cross sectional areas are then combined along the length of the vocal tract to gain information about the volume of the vocal tract [1].

Difficulty in computing the cross sectional areas arise due to the occurrence of multiple reflections and multiple arrival times. Fortunately a number of studies have addressed this issue, as the propagation of waves had incredible implications in many other devices. One of the major assumptions made with the acoustic reflection technique is that there exists a rather uniform gas composition within the human vocal tract; this is not always the case. Since acoustic reflection technique is based partially off of the speed of sound there exists error within the method because computation of the speed of a propagating wave depends on the gas composition within the vocal tract. Under normal conditions it had been shown that this error is negligible. Another assumption made with acoustic reflection technique is that the propagation of sound waves is one dimensional. That is to say that as sound emanates from a source it travels as a planar wave front. In measuring the human vocal tract, it is safe to state that this assumption is withheld throughout the tract due to the fact that the diameter of the tract never exceeds a critical value. This value, however, is exceeded between the cheeks. For this reason, special mouthpieces are used to prevent signal destruction [2].

There are a number of applications of the acoustic reflection technique as it relates to the study of the human vocal tract. Acoustic reflection technique has been used to show that both pharyngeal structure and function of patients with obstructive sleep apnea differs from those who do not suffer from the condition. This corresponds to a decrease in pharyngeal volume as well as an increase in the variability of this volume. Acoustic reflection technique has also been used to study the anatomy of the pharynx and its relation to snoring, indicating that people who snore have similar pharyngeal volumes as those who suffer from sleep apnea. Acoustic reflection technique has also been used to find that the growth rate of the trachea differs from the growth rate of the lung. In addition these structures grow differently in men and women [1]. Research has also been conducted to understand the relationship between the developmental changes in the vocal tract and changes in speech acoustics [4]. Finally, acoustic reflection technique has been used to identify patients with difficult airways in clinical studies. This is important information during surgical procedures that require a patient to be ventilated, as difficult airways often cause obstruction during the process.

Problem Statement

The current protocol used by researchers at the Vocal Tract Lab of the University of Wisconsin requires the wave tube for acoustic reflection technique to be held in their hands while the patient exhales into the mouthpiece (Figure 2). It is exceedingly difficult to hold the wave tube at a fixed angle throughout the duration of the studies, which are often significantly long. This protocol is, therefore, inducing a great deal of variability in data. Not only is it difficult to achieve repeatability during each trial with the same subject, but also to achieve repeatability across a number of different

Figure 2 – Current protocol for acoustic reflection technique

subjects. Therefore, it has been proposed to develop an adjustable stand capable of holding the wave tube for acoustic reflection technique in a fixed position in an effort to decrease variability in data. Hood Laboratories, the company that makes acoustic reflection technology reports that they will not be offering an adjustable stand for the wave tube at this time or in the near future.

Motivation

The goal of the current study at the Vocal Tract Lab of the University of Wisconsin-Madison is to compare vocal tract anatomy measurements acquired through acoustic reflection technique, to those acquired through medical imaging procedures (Figure 3). This study is being carried out to determine whether or not acoustic reflection technique is indeed accurate enough to replace medical imaging in studies of the vocal tract anatomy. Thus far, measurements taken using acoustic reflection technique and CT were comparable, but not entirely accurate [5]. These researchers hope to improve the quality of the acoustic reflection technique measurements through the use of the adjustable wave tube stand. Using this technique as an alternative to medical imaging for anatomical data acquisition presents a number of benefits. Acoustic reflection is a much less expensive method than medical imaging.

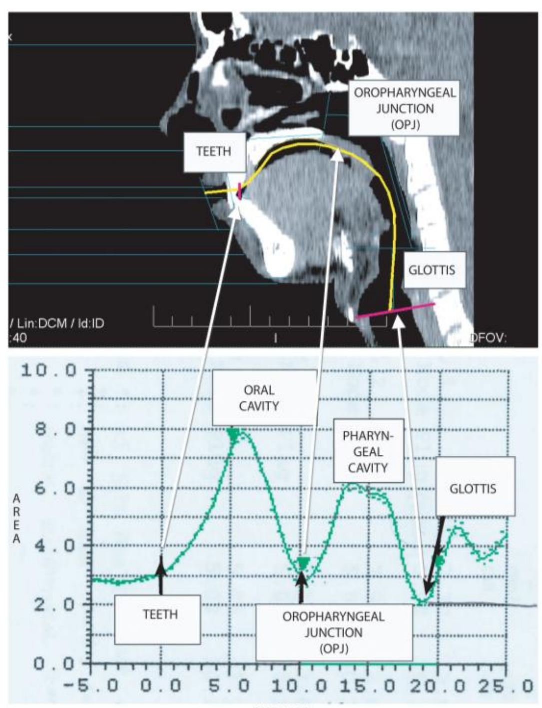

Figure 3 – Acoustic reflection technique compared with imaging studies

In addition, researchers hope to broaden the range of subjects they are able to study. Oftentimes carrying out medical imaging studies on pediatrics or individuals who suffer from developmental disorders such as Down syndrome can be next to impossible. Also the portability of the acoustic reflection technique makes carrying out studies in the privacy of a patients home a possibility, something that medical imaging cannot offer at this time. For these reasons, researchers at the Vocal Tract Lab of the University of Wisconsin-Madison hope to improve acoustic reflection technique methods through the use of the adjustable wave tube stand.

Client Requirements/Design Specifications

To ensure the product is fully functional in the Vocal Tract lab, and potentially other similar labs, the product must fulfill some specifications given by the client. First, the product must be able to achieve a standard alignment for both the upright and supine testing positions. While the subject is in the upright position, the stand should hold the wave tube at a perfectly horizontal position, and in the supine position a perfectly vertical alignment is needed. These orientations should be easy to properly calibrate with a patient as well as easy to switch between vertical and horizontal alignment.

The second customer requirement is that the product should have a large range of adjustability. The VT lab has subjects ranging from children to full-grown adults, and it is important that the stand be able to accommodate that patient diversity. After visiting the lab, it was observed that the chair in which patients sit is adjustable, but the product must still have adequate range. The conclusion was reached that it would be necessary for the stand to range from approximately 14 in to 20 in tall to accommodate all subjects.

In order to achieve the exact alignment described above, it is important that the product has the ability to make fine adjustments. If the patients have to alter their posture to compensate for a poorly adjusted stand, the ART data can be severely flawed, eliminating the usefulness of the stand. This adjustability is required in both the vertical and horizontal directions for the wave tube to achieve necessary orientation in both the upright and supine positions.

Because the wave tube is placed in the subject's mouth, and to satisfy the sanitary requirements of a lab environment, it is important that the product be easily disinfected. The current method of disinfection is a thorough wipe down with a disinfecting cloth. The product must be easy to clean in this manner and be able to hold up to the chemicals used to disinfect.

The client also stressed that portability is key in the usefulness of the product. The stand should be able to easily compact for travel, as well as easily realigned for proper testing. Weight also becomes an important factor in the design and should be considered when choosing materials for construction.

Finally, due to the fact that many of the subjects at the VT lab are children or developmentally challenged, it is critical that the product be non-invasive to the patient. A major advantage of ART is that it is functional for patients who are physically or mentally unable to deal with the stress caused by standard imaging techniques, such as an MRI or CT scan. For many of these patients, simply being in a lab setting can also be very intimidating. A large, restricting or otherwise threatening stand can place undue stress to the patients and defeat the usefulness of ART. By meeting these requirements, it can be certain that the product will fully satisfy the needs of the client.

Design Evaluation by Component

After brainstorming ideas for the product, it became apparent that the most effective way to evaluate the design would be to analyze it by component rather than create three entirely different designs. Each individual component would have multiple ideas which would be analyzed with a design matrix to choose the best solution. The final design would utilize all of the highest scoring components, creating a product that consists of the best of the ideas.

Overall, the product was divided into two areas, the first of which is the wave tube interface. This part is essentially trough-shaped holder cut to fit the wave tube and is responsible for securely holding the wave tube in all of its positions. The second major area is the stand, which is responsible for adjusting all to the necessary alignments while being a stable base for the interface to be attached to. These areas were then divided into five separate components by which they would be independently analyzed. The overall design matrix shows all of the components and the ideas that were analyzed for them.

	Feature	**Ideas**			
Interface	Fastening Mechanism	Velcro	Rubber Strap	Latch	
	Gripping Mechanism	Silicone	Foam	Rubber	
	Base Material	HDPE	Delrin	Aluminum	LDPE
Stand	Method of Adjustment	Perforated Tube/Pin	Twist and Lock	Gear and Track	
	Joints	Rigid	Adjustable		

Table 1 – Matrix outline the approach for design component evaluation

Fastening Mechanism

The fastening mechanism is the component that would secure the wave tube in the interface. All of the ideas consist of some material wrapping or clasping down on the top of the wave tube, securing it to the bottom of the interface. For this component, the most important criterion is the security of the wave tube. This is the main function of the fastening mechanism, and is important in both protecting the wave tube from damage as well as keeping it stable during scans. The wave tube can be damaged both by falling out of too loose of a holder as well as being compressed by too tight of a restraint. Therefore, a device had to be considered that could supply maximum traction on the wave tube with minimal pressure. Materials with a tacky texture received high scores in this category.

To comply with the client requirements, the straps must be easily disinfected and resistant to chemical treatment. Patient health is the prime concern of the lab, and the product must be able to comply with their disinfectant process. Materials that would degrade over time, or lose some of their ability to secure the wave tube when moist, scored poorly in this area.

Although not as important as other criteria, the ease of manufacturing was considered in the design matrix. Components which required a high degree of skill to manufacture would result in a product that would be difficult to perfectly construct to the set specifications, creating less than ideal security for the wave tube. Ideally, the chosen component would be pre-made, easily modified and attached to the interface.

Cost received a low weight in this category because all of the ideas were similarly priced, and remarkably inexpensive. Because of its relative tackiness, and its ease of disinfecting and construction, the rubber strap achieved a score of 8.4, the highest for this component.

Criteria	**Weight**	**Velcro**	**Rubber Strap**	**Latch**
Security of Wave Tube	.4	7	9	5
Ease of Disinfecting	.3	2	8	9
Ease of Manufacturing	.2	8	8	3
Cost	.1	9	8	5
Total	1.0	5.9	**8.4**	5.8

Table 2 – Component matrix for evaluation of fastening mechanism

Gripping Lining

Much like the fastening mechanism, the gripping lining is another component to provide friction between the wave tube and the interface piece. A thin sheet of the lining material will be placed on the interior cup of the interface by means of a glue adhesive or provided adhesive backing. During the trials the wave tube will be strapped into the interface and cushioned by the gripping lining. Therefore, in addition to providing friction, it works as a security feature that protects the outside of the wave tube from scratches and dents that could result from direct exposure to the interface.

Furthermore, the lining plays an essential role in physically holding on to wave tube by means of the friction surface. With an ample normal force applied from the fastening straps, a material with a relatively sufficient coefficient of static friction will hold onto the wave tube and prevent slipping throughout duration of the trials and during the transition from supine and sitting configurations.

When looking at candidates a number of different criteria were considered. First and foremost, the gripping lining needs to be easily cleanable. The client stressed that the wave tube is primarily used in a clean laboratory setting. A candidate with a high porosity (to promote friction and compressibility) has a high potential to accumulate dust and pathogens over time. Client and subject health takes precedent over any other criteria in the study. Thus is the reason for the high weight of the criterion (.35).

Furthermore, each of the materials was researched to look for compliance with various chemicals. The online engineering website McMaster-Carr offers a table of "Chemical Resistance" for each of the materials however this scale was not extremely clear as items ranged from "Good" to "Excellent" [6]. Therefore, more research was conducted that specifically looked into papers dealing with degradation issues of each of the materials.

Relative tackiness of the material was compared using a durometer meter supplied online from McMaster-Carr [6]. The meter supplies hardness on a scale from extra soft to very hard and various numbers are supplied for all the listed material. Silicone has the lowest durometer rating thus it has the highest relative tackiness.

Finally, an inverse application of the durometer rating was used to evaluate the durability of the material. In other words, softer material was associated with lower durability. Therefore rubber, a harder material, would easily win this category. With a total of 8.2 out of 10 the rubber is the material that will be used for the design prototype.

Criteria	**Weight**	**Silicone**	**Foam**	**Rubber**
Ease of Disinfecting	.35	6	1	9
Relative Tackiness	.25	9	6	7
Durability	.25	6	2	9
Cost	.15	5	8	7
Total	1.0	6.6	3.55	**8.2**

Table 3 – Component matrix for the evaluation of gripping lining

Base Material

The base material component of the design refers to the material that the interface cup will be machined with. A rectangular block of the desired material will be purchased with dimensions that are approximately the desired size. Using a table saw, the block's dimensions will be further refined on all sides to accommodate the dimensions of the wave tube. Next a solid works rendition of the desired prototype will be crafted. The rendition will match the specifications of the wave tube so that there will be an exact custom fit. Finally, the design will be used to mill out the precise curvature using a programmable mill in the Engineering Centers machine shop.

The base, or interface for the design will be located at the end of a horizontally extended arm. It is for this reason that the weight of the base material plays a large role in determining the optimal candidate. The horizontally extended arm acts as a rather large moment arm. Therefore, as weight at the end of the moment arm increases, the moment about the stand increases. A higher moment means there is more potential for the stand to rotate, ruin the alignment, or even falling over. All of these results either endanger the client and subject or affect the validity of the data. Therefore the weight criterion is the most important in this matrix. Furthermore, the weight of each material was compared using specific densities of each of the candidates.

Ease and quality of manufacturing refers to the fact that the finished product should be free of imperfections. Some materials have a potential to chip, break, or leave rough edges when subjected to milling, a perfect score in this category corresponds to a material where none of these imperfections are present. The values used to rate each of the materials were not found by quantitative means. Moreover, they are the result of an opinion of an advanced BME graduate, Christopher Westphal.

For clarification, of the candidates mentioned there are three plastics (HDPE – High Density Polyethylene, Delrin, and LDPE – Low Density Polyethylene) and one metal (Aluminum).After evaluating each of the materials, HDPE was decided to be the best and will be used in the final design.

Criteria	Weight	HDPE	Delrin	Aluminum	LDPE
Weight	.45	8	5	3	8
Ease/Quality of Manufacturing	.25	6	8	8	4
Cost	.3	8	2	2	9
Total	1.0	**7.5**	6.15	3.95	7.3

Table 4 – Component matrix for the evaluation of the base material

Method of Adjustment

The "Method of Adjustment" component matrix is used to determine the configuration for vertical movement of the stand. As mentioned previously the stand will have to change heights as the patient size increases. Therefore, the height variability accounts for an important part of the design. For clarification, the each of the candidates that were evaluated will be explained in an in depth matter. Perforated tube / pin refers to a design that is often seen on crutches. There is a pressurized pin on the inside of a perforated shaft that "pops" into position when a specific hole is reached. Twist and lock refers to an internal camming device on the interior of the shaft that can unlock and lock by physically twisting the shaft. Finally the gear and track option was inspired by the method of adjustment of old overhead projectors. As the gear is turned the height is varied by means of pushing a track up or down.

Repeatability and Fineness of Adjustment were the most important criteria for this matrix. Although a rod with a perforated tube/pin configuration will consistently go to the same placement each and every time, it has a finite range of adjustment. The number of holes or perforations in the rod dictates the number of different subjects that can be measured. However, the other two designs offer much more freedom than the perforated tube/pin. With the twist and lock and gear and track configurations the precise height can be achieved as there are an infinite number of placements for height, however, then repeatability becomes an issue.

The twist and lock configuration scored the highest in this design matrix. In order to overcome the issue of repeatability the shaft will be marked on the sides with many numbered markings so that the desired length can be recorded and repeated.

Criteria	**Weight**	**Perforated tube / pin**	**Twist and Lock**	**Gear and track**
Repeatability	.3	10	8	6
Collapsibility	.2	8	9	7
Ease of Use	.2	6	8	8
Fineness of Adjustment	.3	2	10	8
Total	1.0	6.4	**8.8**	7.2

Table 5 – Component matrix for the evaluation of the method of adjustment

Joints

The last component in the design is the configuration of the joint. The joint being referred to is the joint between the vertical shaft and horizontal arm in the stand. There are two options for the joint. The joint can be rigid and unmovable like an elbow joint. Or the joint could be freely movable and lockable such as the wingnut joint in the picture to the right.

Portability was a major factor in evaluating this component. The client stressed that the wave tube unit should be easy to break down and taken out of the lab if need be. Likewise, the client also noted that some of the scans are preformed at subject's homes. Therefore, the stand would need to be portable enough to easily carry between the house and lab. Since the adjustable joint has the potential of moving to an upward configuration or even unattached if need be, it is more portable and will be used in the final prototype.

Criteria	**Weight**	**Rigid**	**Adjustable**
Ease of Use	.2	9	6
Portability	.4	3	9
Repeatability	.4	9	8
Total	1.0	6.6	**8.0**

Table 6 – Component matrix for the evaluation of the joints

Future Work

The remaining time of the semester will be spent building and testing a working prototype that follows the results of the design matrices. Once the prototype is completed, testing of the stand will be done as well as any necessary modifications to better the design.

The first step in constructing a working prototype is to purchase the materials needed. For the stand's interface, this includes the HDPE base, the rubber gripping lining, as well as the rubber straps to secure the wave tube. For the base of the stand, a Samson MB1 mini boom stand will be purchased and modified (Figure 4) [7]. This boom stand combines the essential parts of the design as outlined by the design matrices, incorporating the twist and lock method of adjustment and adjustable joints. All of these materials can be purchased at a minimal cost and can be easily found on the Internet.

Figure 4 – Samson MB1 mini boom stand

http://www.woodbrass.com/images/woodbrass/SAMSON+PIED+MICRO+MB1.JPG

Once all necessary components have been obtained, construction on the prototype can begin. The first step in building the stand will be to fashion the base of the interface out of the HDPE. This includes milling out the space where the wave tube rests and creating a site on the bottom where the interface will attach to the base of the stand. Once this is complete, the rubber gripping lining and the rubber straps can be assembled onto it (Figure 5).

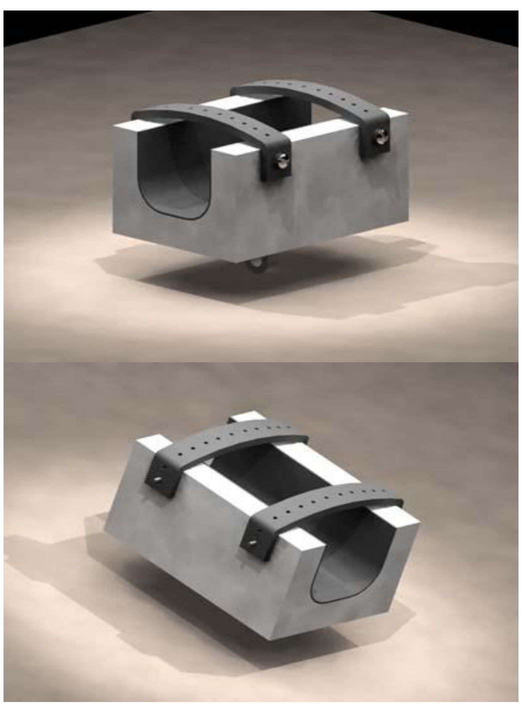

Figure 5 – 3D representation of proposed design

The final step in building a prototype will be to add slight modifications to the boom stand. In order to comply with design requirements, markings will be placed on the boom stand. These markings will provide ease of use as well as repeatability to the stand. They will allow the client to use exact heights and angles each time the stand is used, no matter the patient and no matter the study conducted. The second and final modification will be to convert microphone holder on the stand into an attachment location that is compatible with the wave tube.

After the completion of the prototype, testing and analysis can begin. Self-testing will be done first, as proper approval by the Institutional Review Board on the Vocal Tract Lab's Human Subject Protocol is required before the lab changes its procedure for its studies. As time permits, modifications to the stand will be made as a result from the testing.

References

[1] Hoffstein, V. (1991).The acoustic reflection technique for the non-invasive assesment of upper airway area . *European* Respiratory Journal. *4*, 602-611.

[2] Rubinstein, I (1987).Effect of mouthpiece, noseclips, and head position on airway measured by acoustic reflection technique. *Journal of Applied Physiology*. *63-4*, 1469-1474.

[3] Vorperian, H. (2005). Waisman Center. Retrieved October 23, 2007, from Vocal Tract Lab Web site: http://www.waisman.wisc.edu/faculty/vorperian.html

[4] Ochroch, A. (2002).Clinical Application of Acoustic Reflectometry in Predicting the Difficult Airway. *Anesthesia and* Analgesia. *95*, 645-649.

[5] Durtschi, R. (2007, June, 22). A Comparison of Measurements: Acoustic Reflective Technique vs. Medical Imaging. Retrieved October 13, 2007.

[6] Rubber and Foam Film. Retrieved October 11, 2007, from McMaster Web site: www.mcmaster.com

[7] Samson Audio. Retrieved October 18, 2007, from MB1 Mini Boom Stand Web site: http://www.samsontech.com/products/productpage.cfm?prodID=1681

Appendix A : Product Design Specification

Adjustable wave tube stand for Acoustic Reflection Technique

Team Members
Andrew Bremer: BWIG
Ryan Carroll: Team Leader
Ben Engel: BSAC
Jeremy Glynn: Communications

Problem Statement:
The Vocal Tract Development lab (VT Lab) plans to compare anatomic measurements secured from Acoustic reflection technology (ART)- also known as acoustic pharyngometry with measurements secured from imaging studies (MRI & CT). The data collection for ART is done by means of a wave tube. The wave tube has a mouth piece that keeps the subject's tongue in position not blocking the airway – and ensures that all exhaled air passes through it. Sounds waves are emitted and the system's microphone captures the acoustic reflections of the airway. Currently, researchers in the VT Lab need to hold the wave tube in their hands which is presenting variability in the data. It is difficult to hold the wave tube at the same angle during each trial within subjects and across subjects. Hood Laboratories, the company who makes AR technology, reports that they will not be offering an adjustable stand at this time or in the near future to keep the wave tube stable while testing in the upright and supine position. We are requesting for the BME team to design and build a steady stand for the ART wave tube. The stand should be adjustable so that it may be used by individuals of different ages -- young children to adult. Also, the stand must allow the patient's head to remain in a standardized position in the upright and supine position. Another important criterion is that the stand/unit should be easy to clean and disinfect.

Client Requirements:
• The unit should be adjustable so that it may be used by individuals of different ages – young children to adult.
• The unit must allow the patient's head to remain in a standardized position in the upright and supine position
• The unit should be easy to clean and disinfect.
• The unit should be non-invasive to the patients.
• The unit should be portable.

Design Requirements:
• The unit should be able to fit on a relatively small table.
• The interface between the unit and the wave tube should put little or no pressure on the wave tube.
• The unit should be fully adjustable to accommodate the upright and supine position

• The cost should be relatively low.

1. Physical and Operational Characteristics
a. *Performance Requirement:* The unit will need to reduce variability in results by holding a constant angle between the wave tube and the subject.
b. *Safety:* The unit will be stable on any surface it is placed. There will be no sharp appendages that have the ability of harming the subject or operator.
c. Reliability: Once put in a position, the unit will hold that position throughout the duration of the experiments.
d. Shelf Life: Shelf life will not be an issue with the unit.
e. Operating Environment: The unit will be in use in a mid-size lab where the wave tube is located. It will be placed on a table where the subject will be sitting and on the ground while the subject is lying down.
f. *Ergonomics:* The unit will have a simple interface to adjust the height. There will be position markers on the side of the unit for a reference for the operator.
g. Size and Shape: The unit will accommodate for the height of the subject. It will provide a lateral distance between the patient and base. This allows for the subject to be seated comfortably at a table throughout the experiment. The unit will also allow for the subject to be lying in a supine position.
h. Weight: The base of the unit will be heavy enough to keep it stable. However, the unit will be light enough to be portable and safe if dropped from a small distance.
i. Aesthetics, Appearance, and Finish: The unit will be non-intimidating for all subjects.
2. Product Characteristics:
a. Quantity: One unit that performs two tasks is required.
b. Price: The budget for the project is $500.00. Our goal is to make it for well under this price.
3. Miscellaneous:
a. Human Subject Protocol: The unit should meet requirements set by the IRB in regards to testing human subjects.
b. Customer: The unit should allow our client to obtain more accurate data using ART.
c. Patient-related concerns: The unit should not present any danger to harming the patient.
d. Competition: There is currently no unit available that adheres to the requirements set forth by the client.