# Adjustable Wave Tube Stand for Acoustic Reflection Technique

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**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 information from medical imaging studies. The current protocol for Acoustic Reflection Technique 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 in an effort to improve accuracy and repeatability of scans. Several designs were considered and evaluated. The final design incorporates a miniature adjustable boom stand attached to a custom high density polyethylene base that is used to hold the wave tube device. This design also features rubber strapping and a silicone lining to firmly hold the wave tube in place. Further development of this device may include modifications made to improve the range of possible test subjects as well as a counterweight system to prevent tipping under all circumstances.

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**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

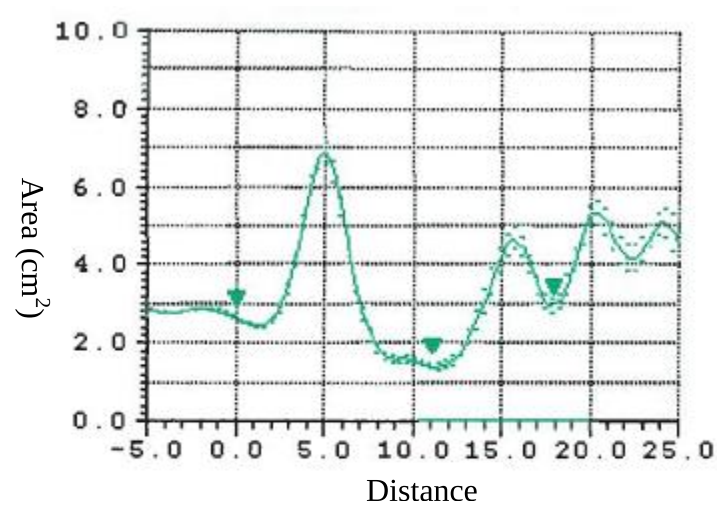


**Figure 1** – Acoustic Reflection Technique Echogram

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.

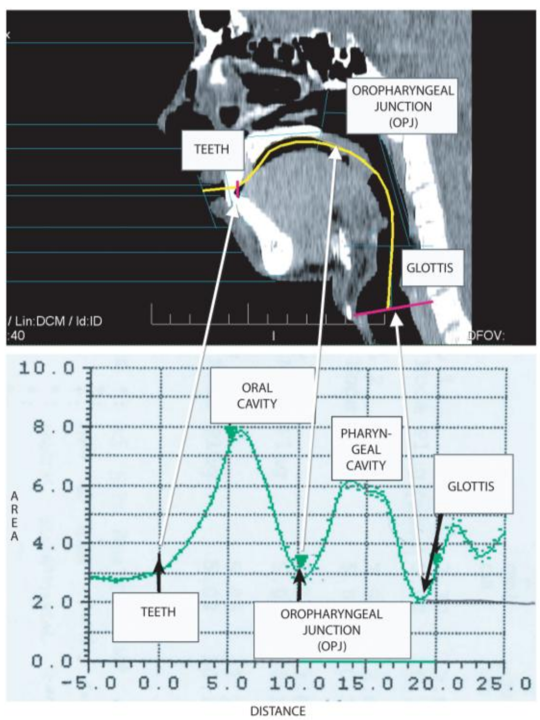


**Figure 3** – Acoustic reflection technique compared with imaging studies

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 necessary. These orientations should be easy to calibrate 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 Vocal Tract 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 provide an adequate range. The early conclusion was reached that it would be necessary for the stand to range from approximately 14 inches to 20 inches 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 wipes. 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 be 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 Vocal Tract 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 easier to use than medical imaging 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 be very intimidating. A large, restricting or otherwise threatening stand can place undue stress on the patients and defeat the advantages that ART presents. By meeting these requirements, it is 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 design ideas would be to analyze them by component rather than create three entirely different designs. Each individual component contained multiple ideas which were analyzed with a design matrix to choose the best solution. The final design utilized 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 to all the necessary alignments while providing a stable base for the interface to be attached to. These areas were then divided into five separate components by which they were independently analyzed. The overall design matrix shows all of the components and the ideas that were analyzed for each idea.

| | **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 ideas consist of some material wrapping or clasping device which exerts force downward 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 a loose fastening mechanism 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 while exerting 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 construct to the set specifications, creating less than ideal security for the wave tube. Ideally, the chosen component would be pre-made and 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 provided by the surface. With an ample normal force applied from the fastening straps, a material with a 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 to upright 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, which promotes friction and compressibility, may have 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.

Furthermore, each of the materials considered were 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 research 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 of the listed materials. Silicone has the lowest durometer rating thus possesses 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 out of which the interface cup will be machined. A rectangular block of the desired material will be purchased with dimensions that are approximately the desired size. Using a band 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 tip 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 experienced Biomedical Engineering 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 determined 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 to accommodate a range of patients. Therefore, the height variability represents an important part of the design. For clarification, each of the candidates that were evaluated will be explained in depth. The perforated tube/pin design refers to a design that is often seen in crutches. There is a pressurized pin on the inside of a perforated shaft that snaps 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 used in 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, or have the ability to move much like the elbow joint.

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 be easily carried 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

## Final Design

### *Adjustable Stand*

As mentioned before, the purpose of the stand component of the design is to provide a safe, easy to use, and highly adjustable base for the wave tube holder. After much research and consideration it was concluded that a commercial microphone stand would fulfill these criterion. A microphone stand generally has an extremely high range of adjustability in order to achieve the best orientation for sound acquisition. They are easy to use and operate because that they are often operated on stage. Finally, they are structurally stable in that they don't tip over easily. However, the traditional size microphone does not adhere to the client requirements due to its extremely tall height and its spatial inability to be placed on a crowded table. Therefore, a smaller microphone stand, the Samson MB1 – Mini Boom Stand, was purchased to function as the base for the design.

This stand features a number of different aspects that work well with the design. First of all, the stand offers height adjustability by means of a twist-and-lock mechanism. This aspect is important so that the height of the stand can be varied to accommodate the different heights of the subjects in the Vocal Tract Lab. Furthermore, the twist and lock mechanism for height adjustment is easy and quick to use. This results in less set-up time for each scan, which then increases the throughput and happiness of the lab patients.

Secondly, the stand offers rotation around the central joint in the vertical plane. This allows for the stand to tip upwards or downwards. Rotation downwards about this joint allows the stand to easily become more compact and portable (Figure 4). In the portable configuration, the stand can be toted around with relative ease which allows for on site visits. Furthermore the stand decreases in spatial area by more than half so that it can be easily stored in an overhead cabinet or under a desk.

**Figure 4 –** Adjustable wave tube stand in compacted configuration

The horizontal boom arm allows for rotation in the z-plane or the plane that extends

**Figure 5 –** Adjustable wave tube stand in the supine configuration

out of the page. This allows for the wave tube holder to rotate 90 degrees downward from the horizontal upright position to the vertical supine position (Figure 5). With the stand in the supine position, the wave tube is vertical allowing for a patient to lie down on the ground or mat and perform the test.

*Stand Modifications*

Regardless of the stand's configuration (supine or upright) the boom arm of the stand needs to remain horizontal throughout the tests. Having the arm in the horizontal position insures that the patient's head is not tilted throughout the tests, an important point stressed by the client. Using a level on the top of the stand, the arm was placed in a horizontal position and locked down. A vertical mark was then placed on the stand and the joint that corresponds to this horizontal position. Therefore, the stand can be unlocked and the joint can be moved, but the horizontal configuration can always be attained without the means of a level.

Although the stand has a means of moving vertically to accommodate for the variety of patient heights without markings each person's specific height would have to be found every time they came in for a test. Therefore using a metallic marker, markings were placed on the vertical shaft of the stand in half inch increments. The same was done on the extending horizontal shaft of the stand although it will not be altered as much as the vertical component.

*HDPE Base*

A High Density Polyethylene base functions as the interface between the wave tube and the stand. With regards to patient safety, a concern of the client was the sturdiness of the stand and its ability to remain standing. This lightweight polymer minimizes the weight on the outstretched arm of the stand, minimizing the moment force created due to gravity and therefore reducing the risk of the stand tipping over. Another benefit of the HDPE is its ease of manufacturing. This material is easily milled, allowing a custom fit for the wave tube to be machined from a solid block.

To connect the HDPE base to the stand, slight modifications were made to the boom stand's original interface connection. A screw locks in place two L-brackets with a washer laid between them, with the top of the L-brackets both jutting up from the connection but pointing out in different directions. The HDPE base rests on top of the outstretched L-brackets, with screws locking it into place and holding the entire system together (Figure 6).

**Figure 6 –** Apparatus used to connect HDPE base to boom stand

*Fastening Mechanisms*

The final components of the design are the gripping mechanisms. Laid inside the milled HDPE is a silicone gripping lining. Not only does this induce a more snug fit for the wave tube inside of the milled HDPE, it creates friction between the two. This helps to hold the wave tube securely in place. The use of silicone as the gripping lining strays from the mid-semester design matrices' results, in which rubber was chosen over silicone as the material to be used for this surface. However, upon further testing of the silicone and the availability of both materials, silicone was chosen as an appropriate material to be used.

Working in conjunction with the silicone gripping surface, two rubber straps fasten over the wave tube to lock it in place. On one side of the HDPE, screws are used to attach the straps to the base, with washers placed between the two to prevent them from tearing. The straps fasten on small pins located on the opposite side of the base. These pins are glued into drilled holes in the base and keep the straps firmly holding the wave tube in. The rubber straps are essential in preventing the wave tube from falling when it is tilted downward for the supine position. They also allow for easy insertion and removal of the wave tube, allowing both it and the stand to be disinfected with ease. The following figure compares the final prototype with the design idea drawn in the middle of the semester (Figure 7).

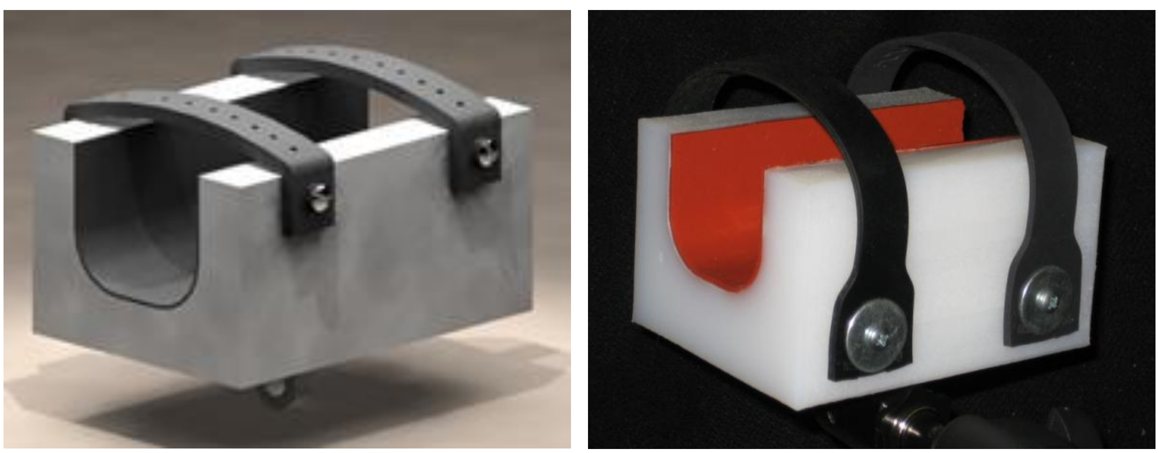

**Figure 7** – Drawing of design ideas compared with photo of final prototype

**Prototype Testing**

The first set of quantitative testing done was on the silicone lining. Because acoustic reflection requires patients to place the wave tube in their mouths, it is crucial that the lab maintain a very clean environment. Thus, all equipment involved in the scanning procedure must be disinfected in between subjects. Apparatuses that do not get placed in the patient's mouths, such as the stand, are wiped down with CaviWipes after each scan. To ensure the security of the wave tube, it had to be sure that the silicone lining would not become slippery when moist with the disinfectant and also that it would not degrade over time as a result of the chemical exposure. To test this, a sample package of CaviWipes was obtained from the VT lab and layered the wipes over one side of the lining for a long duration. During the testing, it was ensured that the lining was continually saturated with the solution. Afterwards, the characteristics of the treated side of the lining were compared with the untreated control side. It was found that the treated side did not deteriorate at all after the extensive chemical exposure, and that it actually was tackier than the control side. Both of these positive results solidified the confidence in the functionality of the silicone lining to secure the wave tube contrary to beliefs expressed in the design matrix for this component.

**Figure 8** – Adjustable wave tube prototype being tested for usability in the lab setting

In order to get a better understanding of the stand's usefulness in the lab setting, the stand was taken over to the Vocal Tract lab and ran through the scanning procedure. At this meeting, the clients set up the wave tube stand in both the upright and supine positions (Figure 8). During and after the testing, feedback was asked from the client about how the stand met their needs and also what improvements could be made. Through this investigation, it became apparent that while in the supine position, the stand held the wave tube approximately 4” too high, even in the lowest possible setting. In the upright position, the wave tube was also held higher than desired when the stand was placed on the desk. The wave tube was easily reached if the chair was raised, but this was not the lab’s preferred solution because they would like all subject’s feet to be touching the ground during the scanning. Another solution would be to place the stand on the ground and extend the boom arm to reach the patient’s mouth. This is also not the most ideal remedy because it requires many adjustments and is inconvenient for lab workers. The best improvement to the stand seems to be shortening the center shaft to give a range more appropriate for the lab’s needs.

While in the lab, the stand’s safety was tested; specifically, it’s resistance to tipping over was tested while holding the wave tube. We found that the stand was very secure when the boom arm was only extended a moderate distance, but when it approached the limits of its reach, the stand was very prone to tipping. Safety of the patients and researchers is a very serious issue, and this testing showed that the stand would need to be modified in order to ensure a safe scanning procedure.

Despite these shortcomings, the lab thought the stand did meet many of their criteria very well. The stand was extremely portable, easy to use, it gave them a very fine range of adjustment, and it is also very easy to clean and disinfect. Overall, the experience proved that the design was very practical for the lab, and will easily meet all of their requirements with some minor modifications. The feedback from this meeting very clearly demonstrated the places where the stand meets and also falls short of the lab's needs and gave a good direction for future work.

**Ethical Considerations**

The primary ethical consideration which was considered throughout the design process was patient safety. Overall, the prototype was designed in such a manner that held patient safety paramount. While some design flaws currently exist, they will need to be addressed before future testing can occur. Future human subject testing will require the researchers at the University of Wisconsin Vocal Tract Lab to prepare a new initial review protocol in order to gain approval from the Institutional Review Board. The new protocol will need to include descriptions of the wave tube stand and the ways that it will be used in research. In addition, it will need to be made apparent that the stand will be used in a new direction of research which seeks to determine if accuracy and repeatability can be improved through its use.

**Future Work**

The future of this project can be divided into two major subsections, prototype modifications and future testing. The current prototype has a few significant shortcomings that make the device less useful than desired. Primarily, after usability testing was carried out in the laboratory setting, it was determined that the stand was too tall to be used for small children in both the upright and supine position. This requires roughly 3-4 inches to be removed from the stand which will likely be carried out by cutting the vertical support and rethreading it to screw back into the base of the stand. It has been determined that removing this amount of material will not adversely affect the twist and lock adjustability mechanism. This should shorten the stand enough that it accommodates smaller patients, while still providing enough height for larger patients. Another future goal for this project is to fix or lock the joints where adjustability is deemed unnecessary by the client. Since the MB1 boom stand possesses such a large number of adjustable joints, locking those that are not being used may improve the repeatability of the results. One of the major client requirements was that the design cannot harm the patient in any way. Currently when the horizontal arm is extended significantly, and the wave tube is in place, the stand has a tendency to tip. It would be beneficial to develop a counterweight system that eliminates the possibility of the stand tipping and potentially harming a patient. Finally, after usability testing was carried out with the client, she indicated that it would be useful to equip the HDPE base with levels that allow for easy calibration to 90 degrees in both the upright and supine settings. Currently, the markings made on the stand allow for these settings to be achieved, yet it would be difficult to level the device if any other configuration were to be attempted.

The second major area of future work involves more advanced testing with the device. After the necessary modifications have been made to the prototype it would be beneficial to conduct usability testing once again to ensure the device is completely accommodating. The next step in testing would involve a rescan of those patients tested using the former protocol to determine whether or not using the stand actually improves the repeatability of data, or simply improves the ease of carrying out the test. Ultimately further testing which compares acoustic reflection technique data with medical imaging scans should be conducted to determine whether or not the stand improves the accuracy of the technique, thus justifying its use as a potential replacement of medical imaging in determining the anatomy of the human vocal tract.

## References


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## Appendix A: Product Design Specification

**Adjustable Wave Tube Stand for Acoustic Reflection Technique**

*Team Members*
Andrew Bremer: BWIG
Ryan Carroll: Team Leader
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### Problem Statement

The Vocal Tract Development lab (VT Lab) plans to compare anatomic measurements secured from Acoustic reflection technique (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.

**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.

**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.

**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.