The Audio Dome Project

From: Tunes on the Go

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1 *Introduction:*

1.1) Objective

This report aims to give an overview of the design, research, and experimentation process which went into developing The Audio Dome. More specifically, it will look at the market, prototype designs and their failures, as well as the final design and future steps of the project.

1.2) Preliminary Information

To understand the project, it is important to start off by looking at the structure of the development team. Our team consisted of four individuals from various educational backgrounds. Each week the team was divided into engineering roles to have each member get their hands on all aspects of the design process. These roles ranged from being the project manager to the electrical and marketing engineers. The team met regularly once per week, increasing this on an "as need" basis. The meetings usually consisted of assigning the week's tasks, evaluating any physical models we may have, and writing the progress report for the coming week.

1.3) Problem Statement and Design Goals

When developing our initial goals for the speaker, our team decided that the problem with current speakers is their portability. The speakers found in the market were usually one dimensional with either one single-use attachment or none at all. We wanted to make a speaker that you could take anywhere you went and was easy to transport. This led to the problem statement: How can we make a speaker that is versatile enough for someone to use at any activity? Through this problem statement we were then able to generate the following initial goal rankings.

Rank	Goal
1	Ease of Use
2	Portability
3	Cost
4	Sound Experience
5	Reliability
6	Durability

2 *Background:*

2.1) Consumer Demographics

In the initial brainstorm, the Audio Dome was intended for anyone being active. This included bikers, people at the gym, hikers, etc. Through community outreach, however, this demographic shifted slightly to be more aimed at teens to people in their early twenties who are looking to use a speaker while being active. This was mainly due to the fact that in our surveying pool, this was the main demographic which received questioning; Therefore, their ideas and requests were implemented. While the product is still usable by anyone and everyone, it was designed to suit the needs of younger, more active individuals.

2.2) Use Environment and Design Specs

As previously stated, the Audio Dome is intended to be used by people pursuing an active lifestyle. This could take a variety of forms from the mountain on a hiking trail, to the streets on a long-distance biking trip, to the athletic field. The possible environments are endless. With this in mind, it was vital that we make our product just as versatile as these environments are. This meant making it light weight, compact, durable, and easily attachable to any kind of surface. To accomplish this, our speaker required a variety of different attachments including carabiner loops, wrist loops, suction cups, magnets, and hooks of varying sizes. It was also required that the speaker be under 4 pounds, able to survive a drop test, and under a 512 cubic inch volume. While being compact was a vital design feature, we were constrained by the dimensions of the speakers. Because of the size of the speakers obtained from our amazon speaker, the diameter of our speaker was constrained to a minimum of 4.5 inches.

2.3) Initial concept and competition

We began our thinking about our design options by first looking at the market and competitive designs. Our search was able to find multiple designs with carabiner/hook attachments, so this became our main competitor design. Figures 1 and 2 are examples of speakers we viewed as competitors.

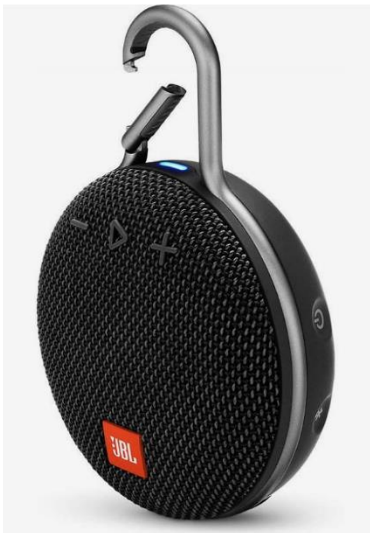


Figure 1

Figure 2

Once the standard had been set by the competitor's designs, our team was able to begin conceptualizing our own model. We wanted to set ourselves apart from these one-hook speakers, so through brainstorming, circle sketches, and mind maps, we were able to create a model which we believe surpasses these competitive designs. The mind map was the first model developed. It consisted of six initial design ideas which we encompassed our design goals. This mind map is shown in figure 3. From this mind map our team was able to abandon designs which we didn't like such as the multiple attachment design in the top left of figure 3. Ultimately, we had settled on the dome design circled in figure 3. With this we moved on to the circle sketch seen in figure 4. This circle sketch consisted of independent design concepts from each member of the team

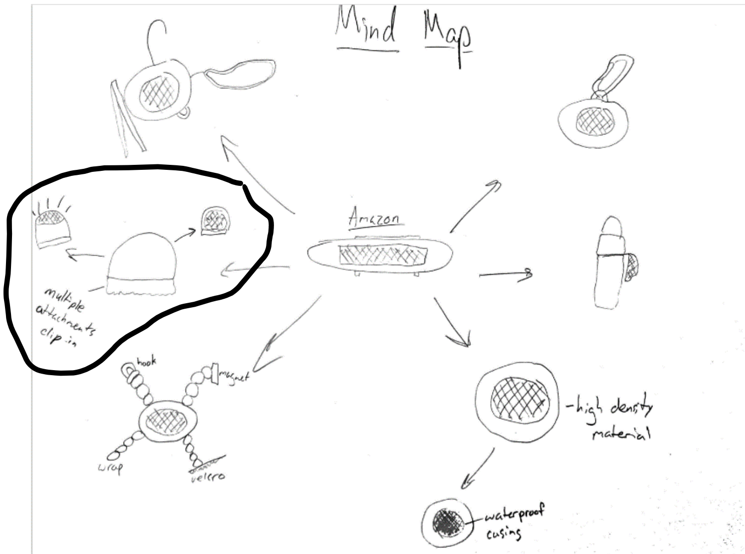


Figure 3) Mind Map 1

based off the design of the member before them. Our circle sketch refined our design and gave the team a conceptual goal to achieve. With the idea in place, we could now make CAD models and begin the design and test phases of our project.

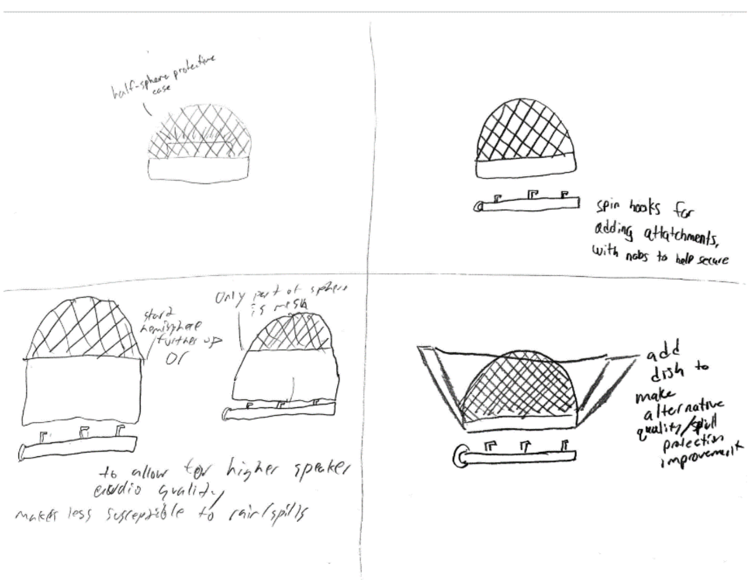


Figure 4.1) Dome design circle sketch

3 Comparison of Solutions:

3.1) The conceptual process

To begin the speaker design, the team first performed a circle sketch and mind map. These allowed us to get each other's ideas out on the table and gave us a base to grow the design out of. In addition to the mind map seen in figure 3 and the dome's circle sketch in figure 4.1, figures 4.2 and 4.3 show the circle sketches of the other promising design concepts.

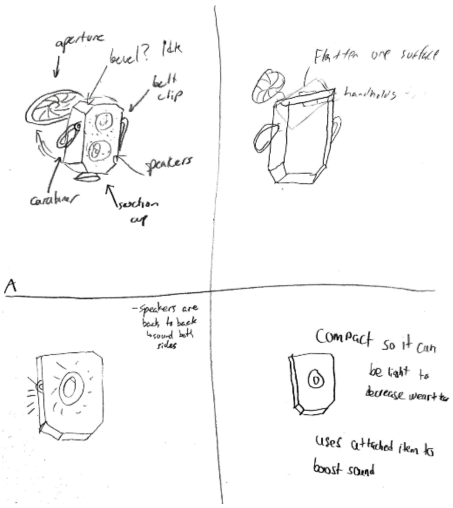
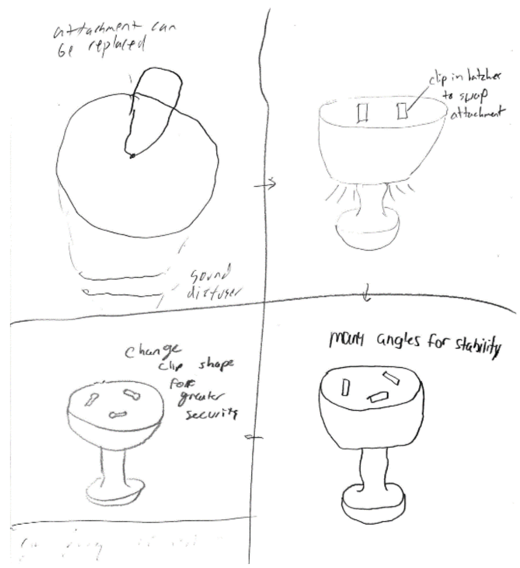


Figure 4.2) multi-attachment design circle sketch

Figure 4.3) chalice design circle sketch



Between the mind map's designs and circle sketches, the team had conceptualized enough material to begin refining and determine the design's necessities. This led the team to develop a Pugh matrix. This matrix (seen in figure 5) makes a direct comparison of the various designs to the "standard" speaker, across several design aspects.

	Lenrue Speaker “standard” speaker	Dome Design	Chalice Design	Multi-Hook Design
Design is Portable	0	+	+	+
Design is Convenient	0	+	0	0
Material is Cheap	0	-	-	-
Assembly is Cheap	0	0	0	0
Design is Safe	0	0	0	0
Audio Quality is Good	0	+	+	0
Design Looks Good	0	+	0	-
Design is Sturdy	0	0	-	0
Total	**0**	**+3**	**0**	**-1**

Figure 5) Pugh matrix

As seen in the Pugh matrix, the dome design, seen in figure 4.1, was believed to be optimal. Where it fell short in cost efficiency, it made up for in audio quality, appearance, and portability. This design incorporated a quick release attachment plate, dual speakers, and durable dome. These features all look to please the initial design goals of durability and convenience. The only other design which had potential to outdo the dome speaker was the chalice design. With its amplifying cone, the chalice design would have an increased audio range and, theoretically, a better audio quality than the standard speaker. While the dome model didn’t have this amplifying feature, it included an additional speaker to increase the audio quality.

3.2) Evolution of design and included features

The design of our speaker began by looking at the attachment side of the model. The team wanted to make portability the main focus, so naturally we began development on the attachment side. We began by looking at the attachment options and found a list ranging from a simple carabiner hook to an aperture design to fit on water bottles. With such a large variety of attachments, we knew that we couldn't attach them all to the speaker at once, so we decided on removable attachments. The simplest and most effective form of this we found was a twist-on, friction-fit attachment plate. These attachment plates could then be sold individually from the speaker to allow the customer to further customize their experience. With the attachment design finalized, the speaker simply had to be modeled to fit this attachment plate model. This was the point at which we were able to begin prototyping. The major assumption made with this design is that the friction fit between the attachment and base plates would be strong enough to hold the speaker throughout a variety of movements. Additionally, we assumed that the market would be open to purchasing additional attachments rather than having everything included in the initial purchase.

4 Final Design

4.1) Iteration process

To determine the optimal speaker size, we needed to first determine the effects of air volume on speaker quality. Through sweep tests of boxes with varying profiles and air volumes (results seen in figure 6), it was determined that above 20 cubic inches is the ideal air volume for speaker quality over large frequency ranges.

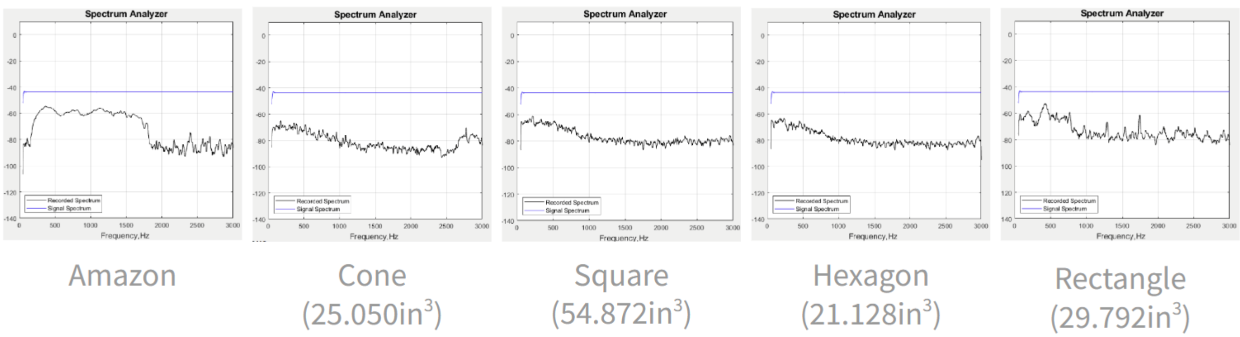


Figure 6) Air volume sweep test results

With this constraint in mind, the team began designing the first prototype. Through this initial prototype a variety of problems arose. The principal issue was the size of the model and the application of the resonance chamber. This model was much larger than was necessary; with only a 3-inch radius, the internal volume works out to be 56.5 cubic inches. Such a high internal volume was unnecessary and made the speaker bulky, reducing the level of portability. Secondly, the team's fundamental understanding of the resonance chamber was incorrect. As seen in figure 7, the speakers were positioned inside of the dome, resulting in virtually no resonance. This would mean poor speaker quality and an overall ineffective product.

Figure 7) Prototype 1 live model

With these flaws in mind, the team began to develop prototype 2. This model incorporated a solid dome with the speakers oriented on the face, as seen in figure 8. This allowed the dome to act as a resonance chamber, as it was initially intended. Additionally, it fixed tolerance issues between the attachment and base plates. This prototype was not printed because at the time, the team had consulted the TA and found additional adjustments to make and didn't want to waste time with printing.

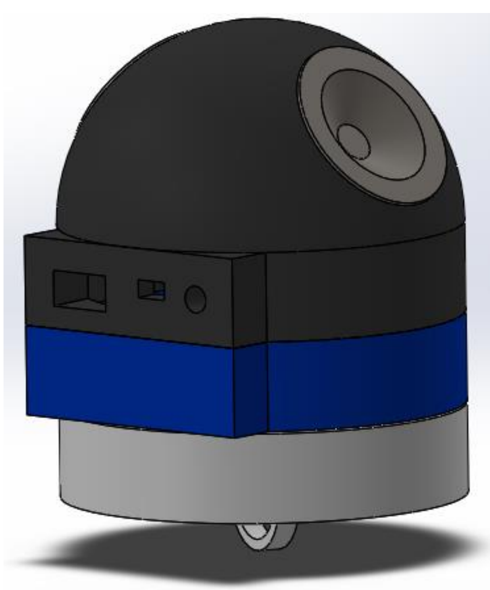


Figure 8) Prototype 2 CAD model

Before designing the final model, the team produced prototype 3a (seen in figure 9). This prototype incorporated a place for the PCB, battery, and reduced the material used in the printing process. By reducing the thickness of the attachment plate from an inch to 0.2 inches and shelling the base plate, the print times of these parts were more than cut in half and the amount of material used was greatly reduced. This model is where we were first able to see how the components all fit together. From this more issues were found, leading to the development of prototype 3b, the final product.

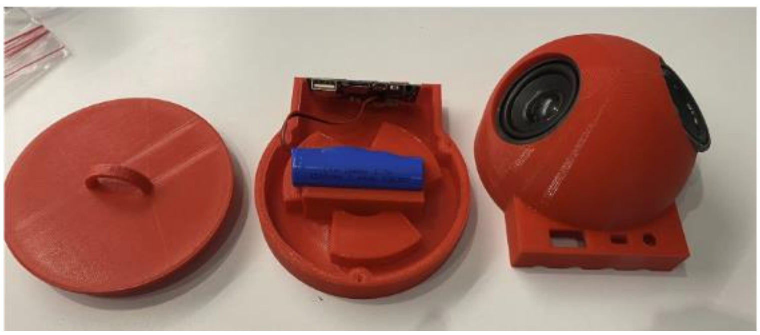


Figure 9) breakdown of prototype 3a

4.2) Final design

4.21) Mechanical design

The final design of the Audio Dome largely resembled prototype 3a, however, it greatly improved upon its ergonomics. The first major change included a 90 degree turn of the batter holder. As seen in figure 9, prototype 3a's battery sat parallel with the PCB. This caused issues with the installation of the speakers. As seen in figure 10, this has been fixed with a simple rotation of the battery holder. The other major alteration between models has to do with the PCB accessibility. This model includes the buttons, back supports for the PCB, and rearranged the holes for the plug-in ports. In all the prior iterations, the buttons were left out in case changes needed to be made. These buttons are independent of each other and are inserted upon assembly just before screwing the plates together. They consist of a simple "T" shape that stays pinched between the PCB and the face of the body.

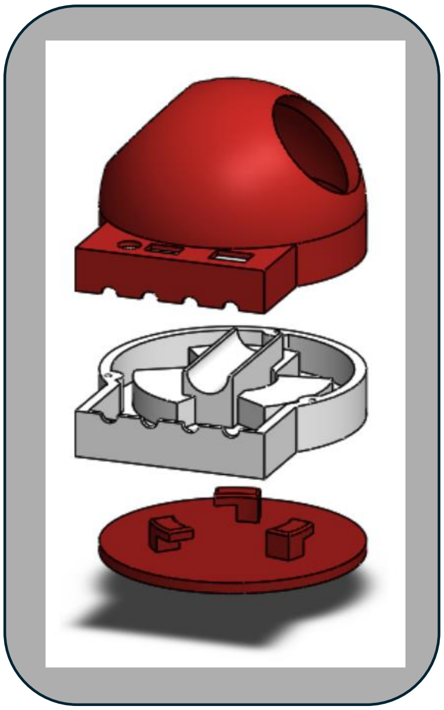


Figure 10) exploded view of prototype 3b

Figure 11) live prototype 3b

As seen in figure 9, the holes for the charging port, USB, and auxiliary cable have been inverted. When the top body for prototype 3a was modeled, these holes had been modeled backwards, putting the buttons on the inside of the speaker and the battery/speaker plugs facing outward. This was a simple fix, only taking time to print. Supports were also added to hold the PCB in place. These are simple ½ inch walls that sit in the top and bottom of the PCB block. The walls are positioned to hold the PCB with just enough room to have a tight fit with the buttons without depressing them. Finally, with this being the final product, the speakers could be glued into place.

4.22) Electrical design

With all the charging and auxiliary ports hardwired into the PCB, the electrical design of the Audio Dome is relatively simple. It consists of two speakers and a battery as seen in figure 12. The significant issues found with the electrical components were the soldering of the wires and the speakers. These connections were broken several times throughout the development of this product, requiring repeated repair.

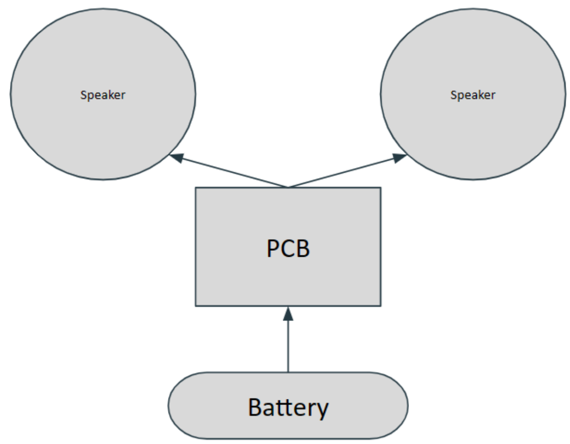


Figure 12) Block diagram of electrical components

Additionally, an issue arose with the battery. Just before the final presentation of the Audio Dome, our battery began malfunctioning, turning the speaker off and disconnecting the Bluetooth from the paired device. While the speaker was plugged into a charging source, however, this would not happen, and the audio experience was uninterrupted. Because of this, we were led to believe that there was either a poor connection to the PCB in the clip, or the battery taken from the amazon speaker was damaged. Without time to remedy this issue, we were forced to present the speaker while charging.

4.23) Manufacturing

The manufacturing process of the Audio Dome is relatively straight forward. Printed out of mainly PLA, the body of the speaker can be printed on practically any 3D printer globally. The buttons were printed out of TPU which, while less common, is still very accessible on many 3D printers. Finally, the attachment plates vary in their manufacturing. For the majority of attachments, PLA is a fine material to print with. For specific attachments such as a suction cup or a shock absorbent flat plate, this material would need to be adjusted according to the application. As with all 3D printing, any supports must be removed before the assembly can begin.

With all the parts printed and cleaned, the assembly process can begin. The base plate and dome have three pilot holes built into the print, which align and allow for quick and secure attachment. Prior to this, however, the speakers must be put into the holes in the dome from the inside of the speaker and connected to the PCB. The battery can then be connected to the PCB and glued into place in its holder with the wires facing the PCB. From here, the buttons are set onto the base plate and the PCB is set into place fully connected. The dome can then be carefully set onto the base plate, ensuring the PCB is on the front side of the interior walls and that the buttons are correctly placed inside. With everything in place, 1-5/8” drywall screws are screwed through the plate and the dome to hold the speaker together. From here the speakers get glued in place, completing the assembly of the speaker.

The high-volume assembly could either be automated on an assembly line or done by hand manually. The automated assembly would take fine tuning to ensure proper, accurate assembly, however, could save a significant amount of time compared to a manual assembly.

4.24) Audio experience

Similarly to the air volume tests, a sweep test was run on the final prototype of the Audio Dome. The results of the Audio Dome sweet test are shown in figure 13a, and the results of the sweep test done on the standard speaker are shown in figure 13b.

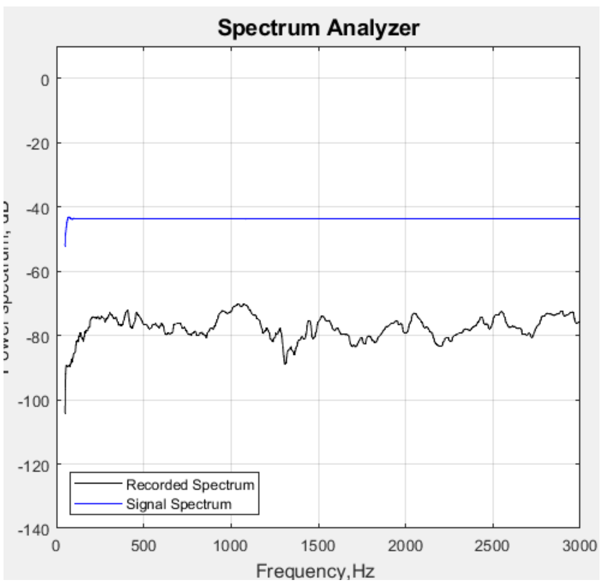


Figure 13a) Audio Dome sweep test

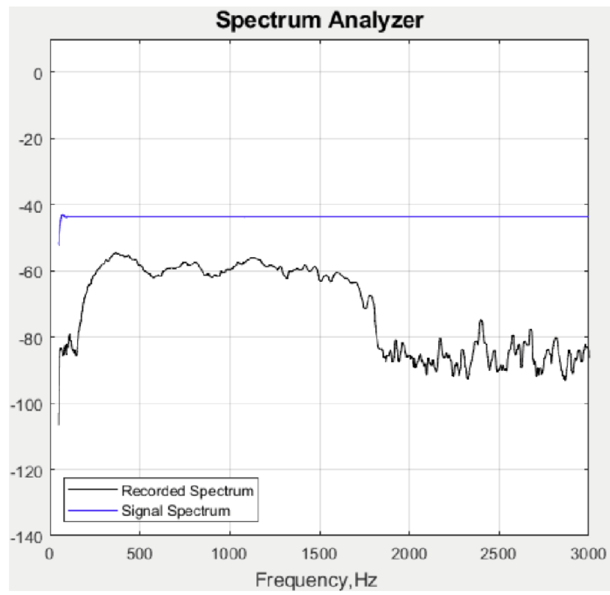


Figure 13b) Standard speaker sweep test

As seen in these figures, the standard speaker performs well at low to mid frequencies but has a significant drop in performance after 1700 hertz. The Audio Dome has a relatively steady curve across all frequency ranges. Audibly, this means the Audio Dome produces a more consistent, smoother sound than the competitor.

4.25) Market review

Through the market research, the design of the Audio Dome stands alone. The vast majority of Bluetooth speakers only have one attachment method, if any at all, and none have an interchangeable attachment system as this product does. This blue-ocean market allows for further development of the product and for the Audio Dome makers to really set the standard for the product line.

When reviewed by potential consumers, the Audio Dome was a great success and got positive reviews. From these reviews, what stood out the most was the simplicity and usability. Athletes on the football team said that they would be likely to use this product due to its ability to be used both on the field and in the weightroom. A reoccurring comment was that they would want a magnetized attachment to hook to a weight rack or to the bus wall. This would absolutely be feasible and would only take more prototyping to perfect.

5 Final Design Conclusions

5.1) Strengths and compromises

The major strengths of this product are in its usability and sound quality. The quickly interchangeable attachments are easy to use, are reliable, and allow for a variety of application environments. The nature of the attachment plates allows for endless possibilities in attachments and are relatively easy to manufacture. Surprisingly, the sound quality of the Audio dome outperformed the original speaker which the parts were taken from. While sound quality was only a midrange design goal, it turned out to be one of the major strengths of the speaker. In the Q&A following our oral presentation, one of the grounds asked our thoughts on the additional weight of having two speakers. To this we answered that the additional weight was offset by the increased audio quality brought by the additional speaker.

5.2) Additional/future changes

Moving forward with the product, the next steps would be to remodel the buttons as well as develop a larger variety of attachment plates. The buttons used in prototype 3b were designed as quick solutions to use for the demonstration. Given more time to work on the prototype, a more streamlined, visually appealing set of buttons would greatly improve the product and could additionally improve its appeal to the athletic community and the market. The attachment plates are the main attractive feature of the speaker, so the further development of these would be a necessity. As stated in the peer consultation, a magnet attachment would be extremely popular. Additionally, a suction cup attachment would be useful. Finally, a major step would be to waterproof the speaker. If people are using the product outdoors, it is inevitable that it gets wet. Adding a waterproofing mesh on the speakers and sealing the buttons/plugs would be a major step in this direction. There are a number of other changes and additions that can be made to the speaker to improve it, but these are some of the major ones.

5.3) Cost/profit margin

Overall, the Audio Dome has the potential to be a profitable design. While the overall cost seen in figure 14 is higher than the cost of the original speaker ($20), the vast majority of this cost comes from printing with PLA. The attachments along are printed parts along cost roughly $16, which is almost 70% of the overall cost. If this process were changed to PIM (plastic injection molding), this cost would be greatly reduced, allowing for a profit margin.

Item #	Description	Qty.	Weight (g)	Unit Cost ($)	Total Cost ($)
1	Battery	1	42	1.468	1.468
2	Circuit Board	1	10	0.49	0.49
3	Speaker (2in 5W 4Ohm)	2	111	0.86	1.72
4	Case (Dome)	1	119.64	4.79	4.79
5	Base Plate	1	110.15	4.11	4.11
7	Screws	3	0.1	0.25	0.75
8	Flat Attachment	1	68.04	3.02	3.02
9	Carabiner Attachment	1	68.04	3.02	3.02
10	Belt Attachment	1	86.94	3.48	3.48
11	TPU Button Covers	4	0.5	0.051	0.204
12	Port Plug	1	3.71	0.15	0.15
TOTAL					23.202

Figure 14) cost breakdown of Audio Dome

Additionally, if 3D printing remained the modeling process, the model walls could be narrowed further to reduce costs. Along with this, if shorter speakers were acquired, the overall profile of the speaker could be reduced. The required air volume is currently well surpassed, so in terms of audio quality there shouldn't be any drop off. The speakers are nearly touching within the speaker, however, so the current radius of the dome is a restraint, forcing the print to use a large amount of material.

6 Project Conclusions

Overall, this project was a success and met its goals. The team was able to produce a versatile and portable speaker that can be used in a variety of environments. The product has a large amount of growth potential through further prototyping and alterations, however, the product produced is at a competitive, marketable level. With no major competition in the attachable speaker market, our design stands alone in solving the problem of attaching speakers and reinvents the potential applications of Bluetooth speakers. For those who would look to continue work on this product, know there are several different avenues to further advance in. Looking back at the three major design goals of portability, cost, and ease of use, these should be the areas to improve. As stated in section 4.23 of this report, manufacturing, the printing takes up the bulk of the expenses. This is simply one example of improvements yet to be made. Through further research and development, the Audio Dome has potential to be a greatly profitable product.

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Jack Thompson stated, “I can see myself using this for field workouts” (personal communication, April 20, 2024)

Thomas McGraw said, “It [the Audio Dome] would be awesome to use in the gym” (personal communication, April 19, 2024)

Appendix A:

Functions or Goals	Option 1	Option 2	Option 3	Option 4
Shape	Hemisphere	Box	Sphere	Tube
Sound Quality	Low	Medium	High	Fantastic
Cost	~$10	~$15	~$20	~$30
Material	Extrusion	Metal	Resin	Plastic Casting
Size	~20 cubic in.	~40 cubic in.	~80 cubic in.	~160 cubic in.
Weight	~0.5lb	~1lb	~3lbs	~5lb

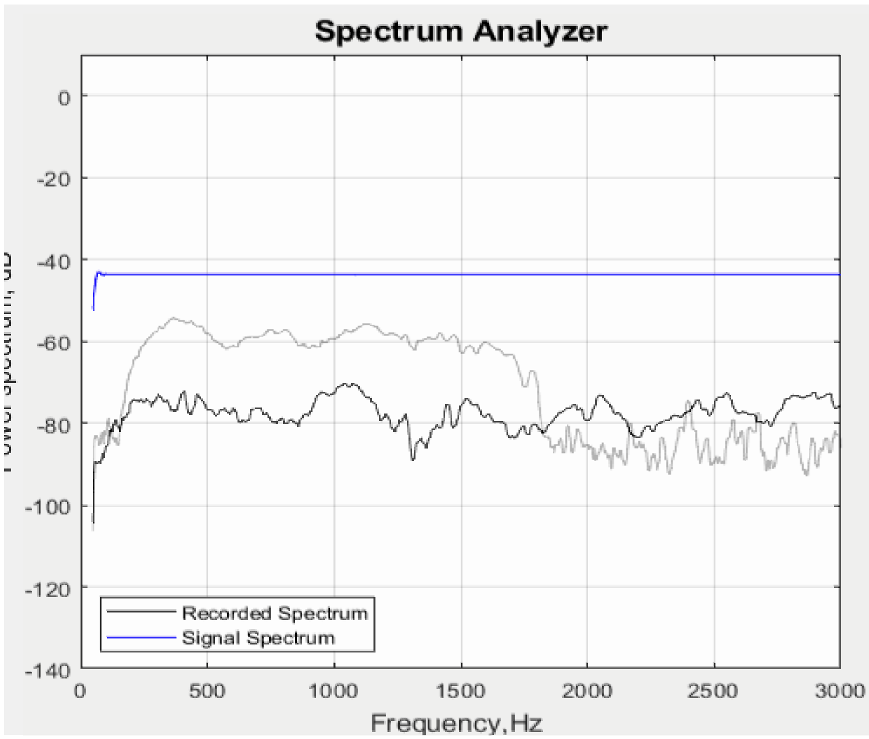
Morphological chart made during initial ideation process

The above morphological chart was developed during the ideation process and helped to determine the design model of the Audio Dome. It compares 4 design models over 6 categories. From this chart, it is seen that options 1 and 2 (dome and box models) are the top designs. Between this chart, the circle sketched, and the mind map, the dome design was decided on, leading to the final product.

Appendix B:

This image depicts the size comparison between the first prototype (right) and prototype 3b (left). It was initially stated that the first prototype was much larger than intended, however, this puts that statement into proportion. The original prototype had a diameter of 6 inches, giving the dome section alone a volume of 56.5 cubic inches. The final prototype was reduced to a diameter of 4 inches. This seemingly minor change reduced the volume of the dome to only 15 cubic inches, making the speaker much more compact and portable.

Appendix B:



This graph shows the sweep test results from the amazon speaker (lighter curve) vs. the Audio Dome (bold curve). This direct comparison shows the just how much more consistant the Audio Dome is across the frequency ranges. When examining the sweep test results, one must realize that the height of the curve isn't as important as the flatness of the curve. The flatness represents the overall consistancy and "smoothness" of the audio quality while the desible height can simply be controled by the speaker's volume.