Project Portfolio

Sillifoam Earbuds

Resonators of Sound

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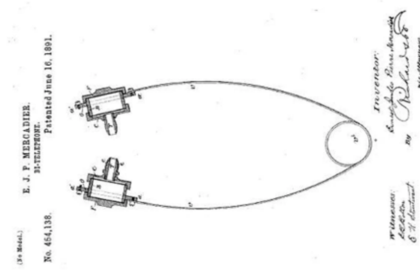
Element A

Problem Identification

Earbuds are a popular product; however, it is extremely difficult to find the right size. And due to the issues, that arise from having incorrectly sized earbuds – like the scratching of ears, infections, damage to eardrums, and tinnitus - it is even more important to find the right size for earbuds. However, this problem of size has existed since the beginning of their creation in 1891.



Earbuds were first invented in 1891 by Ernest Mercadier which he called the "bi-telephone," and some of the ideas he generated were like what modern day earbuds use. By suggesting using rubber for the earbud tips to prevent friction against the ears, and by making it as compact and lightweight as possible. Notable progress wasn't made again until the 1950s when a "private listening system" was created by Koss. This listening device consisted of a record player, speaker, and a headphone jack. It also started to improve the comfortability of the product by adding foam earpads to reduce any potential harmful aspects. It wasn't until 2001 that the introduction of an actual modern-day earbud would be developed – and it started with the iPods.

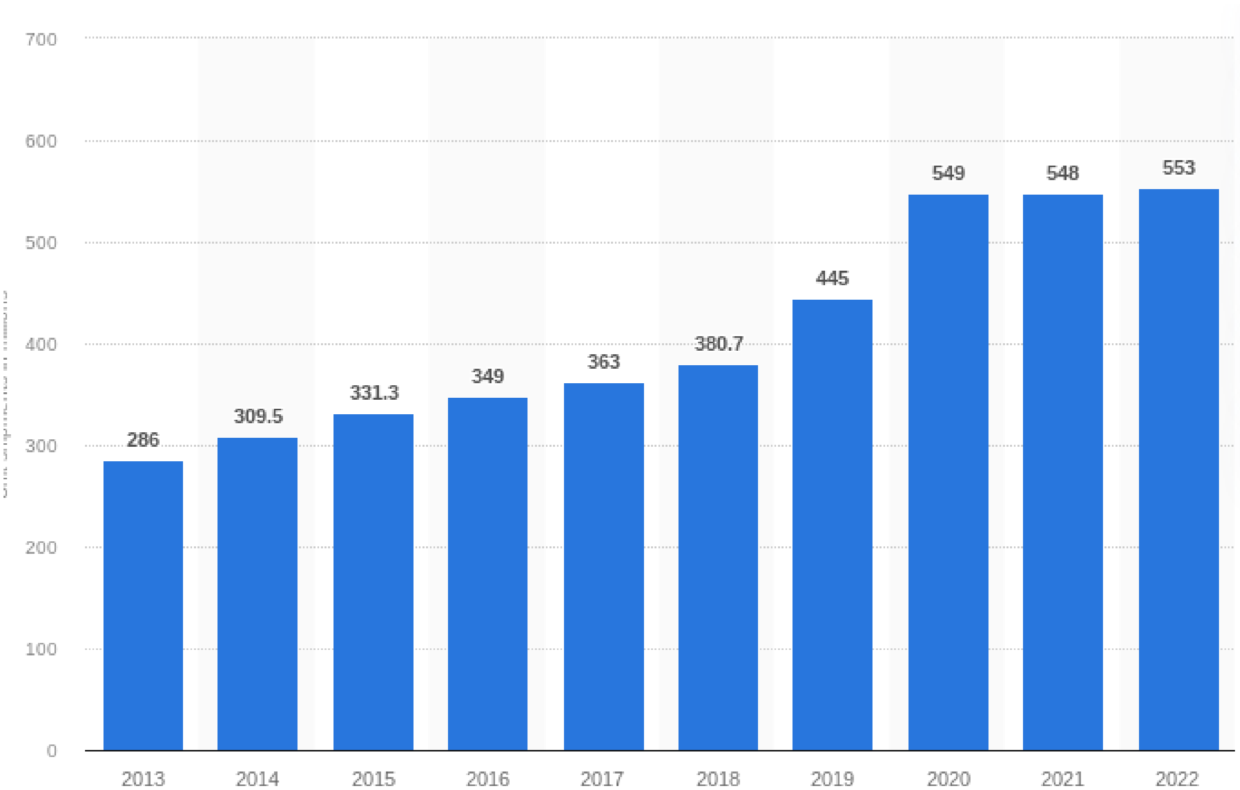
With the creation of iPods people had access to a way for digital music to be portable. This was again improved shortly after, in 2004 with the beginning of Bluetooth. In 2015 came the first pair of fully wireless earbuds with Bluetooth. Thus began the revolution of the wireless earbud brands we see today such as Airpods and Galaxy buds. And while most of these earbuds come with an earbud tip, which is the portion that goes into the ear usually made with silicon or memory foam, some of these earbuds are untipped – and many differences arise between them.

Tipped earbuds today usually come with multiple sizes of earbud tips to try and match the users ear size, however, the problem remains. Providing multiple sizes for earbuds tips can sometimes act as a solution, but more times than not, replacing the tip of the earbud will rarely fix the entire problem. Changing an earbud tip will only resolve some of the problems; the reason for this is primarily due to every person's ear being shaped and sized differently. One common problem is an earbud being too big, regardless of the tip, for one's ear – and this causes the earbud to be pushed out by the ear, which eventually will make the earbud fall out of the user's ear.

Untipped earbuds like air pods, or some forms of galaxy buds, are commonly made of hard plastic at the end. These types of earbuds, despite claiming to be "One-Size-Fit-All" usually once again depend on the person. Some people have even experienced burning/irritation after using these plastic tipped earbuds. However, others find them comfortable as they fit their ears perfectly, highlighting a perfect example of why finding the right size is incredibly important.

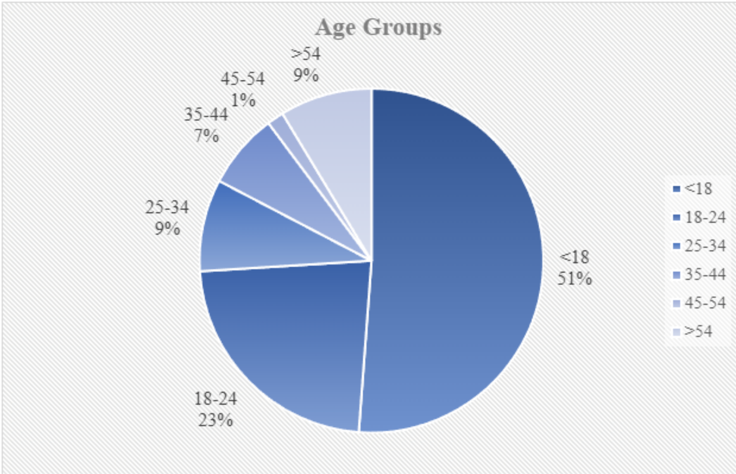
As of right now all earbuds, both tipped and untipped, have one common problem – they can only match the size of certain people's ears, meaning that most people will have incorrectly fitting earbuds. And considering that a vast majority of the population has phones and that over 90% of wireless earbuds users with phones use earbuds in their daily lives, it is important to attempt to mitigate the side effects of incorrectly fitting earbuds.

Market Research

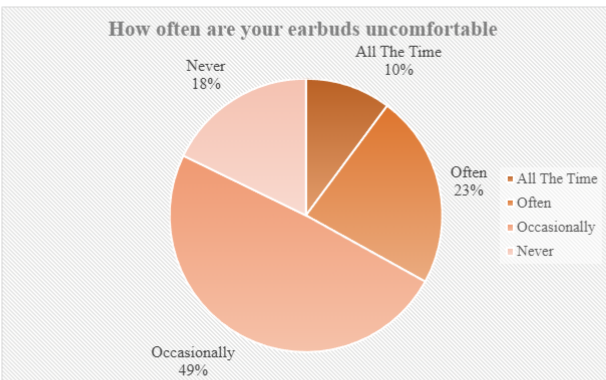


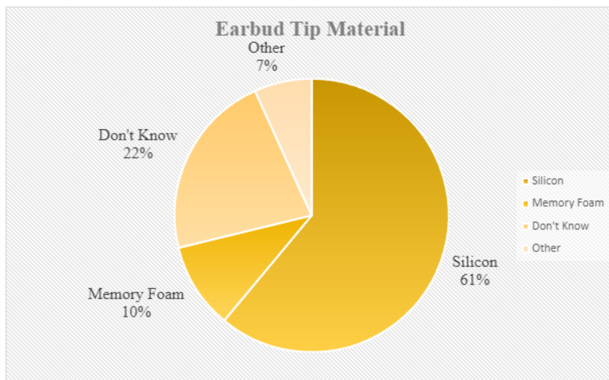
Audio technology has consistently risen economically, the sales of headphones alone achieved approximately 553 million dollars in revenue in 2022. Airpods alone have generated approximately 14.5 billion dollars in revenue in 2022 and have sold 150 million pairs in their total lifetime. Samsung has sold approximately 7.4 million pairs of their Galaxy buds in their time of selling. The market for earbuds is very large, but there are obvious flaws with the product.

A graph depicting the sales of headphones in millions from 2013 to 2022



Based on data gathered from a survey, about 93% of people, from the ages of under 18 to over 65 – as shown in the data graph, own earbuds. And over 61% of these 93% of people use earbuds frequently in their daily lives. When considering that earbuds have an estimated sale of over 550 million in 2022, and rising, these very similarly shaped earbuds will not be able to satisfy the shape of every person's ear. More data from the survey indicates that over 80% of people have found their earbuds uncomfortable while inside of their ear. So, it can be seen from the data that the current size for most earbuds do not match the size nor shape for comfortable use.

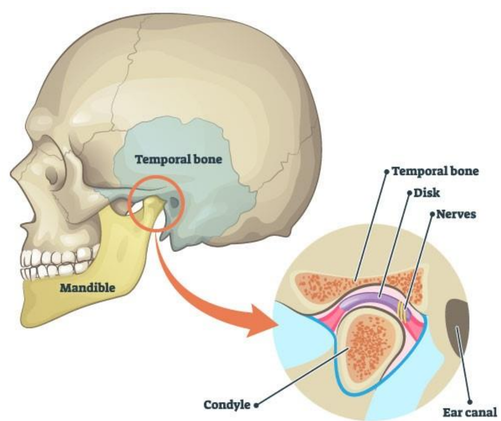




More info suggests that many people do not know the kind of material used for their earbud tip nor do they have a preference for the type of earbud tips. However, while most do not have a preference – most earbuds in present day are made of silicon or memory foam. Some earbuds are an exception with untipped being plastic; however, most earbuds are tipped. The following graph shows that most people do in fact know t material that the tip of their earbud is made of. This is important as the type of material can also affect the comfortability aspect of earbuds. Some materials provide better noise cancellation, sound quality, and how it fits into the ear of a person. All these factors make the material type of the earbud an important factor when attempting to find a properly fitting pair of earbuds. Another important note is that almost half of the people who buy earbuds - up to 44%, end up replacing them due to discomfort. This information highlights that improperly fitting earbuds is a very real problem and shows that many people replace their earbuds to not experience the side effects of wrong sized earbuds.

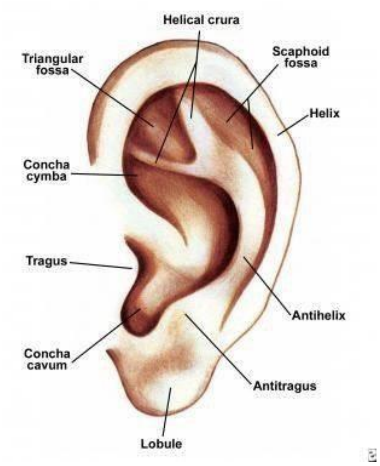
Academic Justification

Many people are not the same, even when it comes to their ears. Ear canals are a big part of whether earbuds fit or not. Ear canals are the pathway connecting the outer ear to the inner ear or the ear drum. The shape and size of the ear canal can vary from person to person but on average it is 2.5 cm in length and 0.7 cm in diameter[1]. Younger people usually have smaller ear canals and adult men usually have larger ear canals. The angle of the ear canal varies as well, making it difficult to find the right fit of earbuds. There are many different sizes, shapes, and material of earbud tips, some earbuds don't even have a tip. It could be troubling to find the right size for your ear and earbuds.



Improperly fitting earbuds are most commonly due to the wrong size of earbud tip. If the earbud tip is too small, it wouldn't have anything to sit against and would easily fall out. If the earbud is too big, it would be pushed out of the ear canal[1]. If the angle of your ear canal is incompatible, you would need to change the shape of your earbud tip, and in the worst-case scenario, change the earbuds itself. Another problem that can cause improperly fitting earbuds is earwax. Surprisingly, it is a type of sweat that cleans your ears and protects your skin despite being seen as disgusting. A buildup of earwax can cause earbuds to slip out of your ears as it coats the earbud in a waxy substance. The ear is very close to the jaw as well and small movements could cause the earbud to fall out if not fitting properly. Movement of the jaw can cause the ear canal to temporarily change shape and shift the earbud, even with properly fitting earbuds[1].

Improperly fitting earbuds are not just an issue of comfort but also health. Having improperly fitting earbuds can cause scratches in your ear and potentially infections. Shoving the earbud into your ear so that it can fit can scratch your ear and push earwax into your ear, causing an infection and hearing problems[1]. At that point, for some, it wouldn't even be worth it to put the earbuds back in again until it clears up. Another issue of improperly fitting earbuds into your ear is developing hearing problems. Some may blast music due to the earbuds not fitting properly to hear it clearer. Getting properly fitting earbuds that get closer to the ear won't make it worse as there is no need for the music to be as loud to hear it.

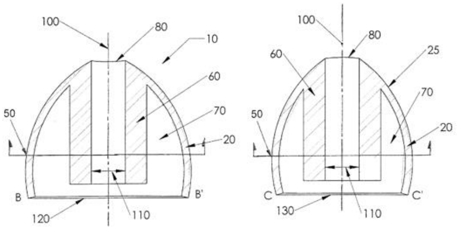


Getting properly fitting earbuds is mainly a case of trial and error in the few varieties of tips usually included with the earbuds itself. If the angle of the ear is incompatible, you would have to search for some earbud tips online or get tips with multiple flanges that can bend. They also provide better sound insulation but can be seen as intrusive as it goes deeper into your ear. You may also like memory foam earbud tips that are usually more comfortable and provide premium sound-isolation, but they are usually not washable and not as durable as the regular silicon tips. It can conform to the ear shape better but can be expensive to buy repeatedly. Some earbuds do not have tips and are usually plastic. These can scratch the ears and have difficulty providing sound isolation while also having the ear conform to the earbud. There are wingtip earbuds that rest on the triangular fossa to provide a more stable fit which are usually used for workout earbuds. Some people may order custom earbud tips, the problem is that it could cost from $150 to $250(2). Finding the right earbud tip can be very difficult. Creating a product that will easily conform to most ears while providing premium sound quality would be difficult but possible.

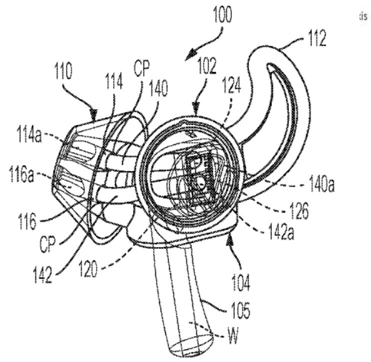
Element B

Benchmarking of Competitive Projects

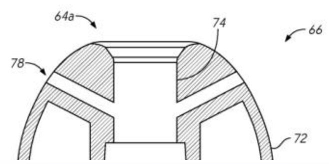
The following 4 designs were previous solutions attempts which have all accomplished solving a similar problem. These designs will be compared in terms of comfort, side-effects, reproducibility, effectiveness, and durability to develop an understanding of where current solutions are viable or fall short. The designs are shown below.



Solution 1:
This solution was designed to create a more comfortable tip for the earbud. Using an elastomer polymer material of the ear tip to maximize comfort. It also was made tto adjust the angle to fit the user's ear.



Solution 2:
This solution was made to try to configure the shape of the earbud tip through a sensor that detects physiological changes/shapes of the inner ear canal. It was made to accommodate the motion of the person using it, and to improve the shape and size of the gel depending on the person.



Solution 3:
This earbud tip was made to detect pressure changes and when a seal is broken between the ear and earbud, it is made of silicon however it has downsides being hollow on the inside.

Solution 4:
This is a foam earbud tip sold in many different sizes and materials to help users of earbuds find a more general size and shape that fits their ears the best.

Each one of these solutions was evaluated using the comparison points above. These comparison points were graded based on the data available through patent research, customer reviews, product specifications, and outside research. Each product will be compared objectively without relation to the other solutions – after this objective comparison all products will be compared against each other to find what each solution excels in, or what each product has problems with.

Comparison Tables

The solutions will be scored from 1 to 5 – the meaning of each comparison factor will be defined in the next section – Comparison Points.

Solution 1	*Score*	*Annotation*
Comfort	3	An elliptical shape may allow it to fit better into the user's ear as currently it penetrates too deep into the user's ear.
Side-Effects	3	Earbuds being pushed too deep into ears can cause issues – defined in comparison points
Reproducibility	4	Elastomer Polymer material allowing for good mass production

Effectiveness	2	The side-effects may cause more harm than good
Durability	5	Durable material

Solution 1 provides a good understanding of how attempting to focus on only making a product to fit a user's ear maybe come with downsides which overall reduce the effectiveness of a product. If not for the side-effects, of the earbud tip going too deep into the ear, it would be an effective solution as it is reproducible and very durable with its material.

Solution 2	*Score*	*Annotation*
Comfort	4	The sensor may mess with size and or awkwardly move if not fitted properly while earbud is in use
Side-Effects	1	Unless the sensor malfunctions, the possibility of side effects are very low
Reproducibility	2	The use of a sensor may make it difficult to mass produce as easily as other earbud tips
Effectiveness	4	Since the sensor will allow the earbud tip to accommodate the user based on motion – it will act as an effective solution
Durability	4	Sensor

Solution 2 provides a unique view of fixing earbuds falling out during motion – this type of solution may target a specific audience of people who may use earbuds during exercising, running, or other forms of physical activity. Overall, it may be used in daily life for those who travel a lot or like to use earbuds while participating in physical motion.

Solution 3	*Score*	*Annotation*
Comfort	3	A hollow earbud tip may shift around too much to allow for proper fitting
Side-Effects	2	Depends on pressure and seal detector
Reproducibility	5	It being hollow allows for better use of materials
Effectiveness	1	Detecting pressure changes to know when the seal is broken still requires manual fixing from the user not providing the right kind of solution
Durability	3	Being hollow decreases the durability and makes it more likely to break

Solution 3 is another unique solution that doesn’t quite accomplish the task at hand. The main issue is to fix users needing to constantly manage how earbuds sit within their ear. This solution would at best make it easier – notify the user when they need to fix it, rather than be a complete solution that would require zero input from the user.

Solution 4	*Score*	*Annotation*
Comfort	5	Based on customer reviews, many users seem to be satisfied with the comfort these custom tips provide

Side-Effects	1	May not fit the earbud of the user
Reproducibility	3	Because of it being custom made it will be a little bit harder to reproduce easily
Effectiveness	4	Based on customer reviews, it seems to be effective as it is the general solution for most types of earbuds
Durability	5	The use of usual earbud tip materials which are normally very durable

Solution 4 takes the general solution most companies have, which is to provide multiple sizes for their earbud tips and increases the scale of it. By providing many different sizes and materials for users it has a very high target audience as it allows many people to find the right type of material, size, and shape. While this solution works, it is not something companies can integrate into their marketing, meaning it is an external solution that users will have to find after purchasing earbuds.

Comparison of Total Scores of each Solution:

Comparison Factors	*Solution 1*	*Solution 2*	*Solution 3*	*Solution 4*
Comfort	3	4	3	5
Side-Effects	3	1	2	1
Reproducibility	4	2	5	3
Effectiveness	2	4	1	4
Durability	5	4	3	5
Total	11	13	10	16

The comparison chart above shows that solution 4 provides the best balance between all the products. Also, all solutions other than solution 2 are likely to be reproducible meaning that most solutions will not have too many limitations on materials or cost. All solutions are durable with the material used and do not have too many factors that cause it to break. The majority of the difference comes from the comparison factor side-effects as each solution tackles the problem in a unique way, however, some have more side-effects than others.

Element C

Project Proposal

Our primary stakeholders will be people who primarily use wireless or wired earbuds to help them with listening to music. Following evaluations from the results of our survey, we determined the relevance of the issue and concluded that a substantial group of people would be willing to buy a product to help them with preventing ear buds from falling out. Once the data was properly recorded, we split up to research different patents and previous products developed to counter the issues. From this research, we then began to identify the problems that we would mostly focus on and then develop a product.

Product Design Constraints

1. *The solution will be safe and not cause injury to the user's ears.*

This is a disqualifying specification, meaning that any solution that doesn't adhere to this requirement cannot be considered viable. All disqualifying specifications will automatically discount any brainstormed ideas that may be presented. Injury that could possibly occur would cause damage/rupturing to the eardrums.

2. *The solution can be made within the time constraint.*

This constraint is necessary because the most important factor in the entire project is time. If the product is too complex to be made, then it cannot be made. The complexity of the product is dependent on the features added to the product and what the product is made of.

3. *The materials of the solution are acquirable within reasonable means.*

If the materials of the project cannot be acquired, the product cannot be made. The materials must be acquired at a reasonable cost, if they were too expensive, they could not be acquired. The materials must also arrive on time if they are delivered, because the product will not be creatable.

4. *The product can be made affordably*

The product must be made affordably, but profitably. The product must be cheap enough to be made without extreme cost to us, but quality enough to satisfy the customer. This solution must also account for the cost of labor.

5. *The product must not compromise sound quality.*

Although the product must provide a secure fit to the user's ear, the product must not lower the sound quality of the earbud. The product must not directly interfere with both the speaker and the sound isolation/canceling of the earbud without the product in use.

6. *The product must be made of material that is not irritating to the skin.*

The product must provide a secure fit, but must not irritate the user's skin, as this will cause the product to be consumed less. The material must be something that people are not allergic to and is not low quality.

7. *The product must be durable.*

The product must have at least a 1–2-year lifespan, as this is the average lifespan of earbud tips if used often. The material must also be resistant to force and weather as these factors may also decrease the lifespan of the product.

8. *The product must be modular to fit as many people as possible.*

To fit a wider consumer audience, the product must be able to fit as many types of people as possible. The product also may need to be sold in different models due to earbuds being extremely diverse in model.

9. *The product must be cleanable.*

If the product is not able to be cleaned, it may cause infection, which will cause consumers to be deterred from purchasing. The material must be durable enough to withstand the cleaning process, but soft enough to be comfortable.

10. *The product must be made from an environmentally safe material*.

In the event that the user loses one of both of their current gel tips, then the material be that of one that would not pose any threat to the surrounding environment.

11. *The product must be able to naturally reduce/muffle excessively loud noise*.

While the ability to control the noise of music and audio will primarily rest with the user, if they ever increase it to full volume, having a gel tip that can naturally muffle the sound would prevent excessive damage to their eardrums.

12. *The product must be able to be sold and appeal to a large variety of consumers*.

The main purpose of designing a new product is because the problem it is solving concerns a considerable number of people, and not just a single individual.

13. *The product must be an originally designed solution*.

Every invention or innovation is paired with a design patent that marks the specific idea as unique to the group or individual that made it.

14. *The product must ensure a tight, secure fit within or around the consumer's ear*.

Using earbuds in mobile activities generally causes them to become loosened or slightly dislodged from the ear canal.

15. *The product must be user friendly*

The product must be easy to use without many complications.

Element D

Preliminary Solution Design

To develop solution designs the previous research done was utilized to identify the main areas where earbuds could be improved. Each team member of the group was tasked with making 3-4 potential solutions based on the research gathered. The main points to improve are also available to know by comparing the previous solutions in element B.

The first task was to limit the solutions brainstormed by the team down to the top 3 possible/viable solutions. The following 8 ideas were all possible designs.

1. Clip-on earbud tips
    - The earbud will be combined with two miniature clips that can connect to the front and rear parts of the ear
2. Hooked earbud tip
    - The earbud will be attached to a semicircular hook that will attach around the back end of the ear
3. Suction earbud tip

- The earbud device will be combined with a cone that will simulate a plunger, compressing around the outside of the ear

4. Foam and Silicon earbud tip
   - A foam earbud tip surrounded by silicon skin to provide better durability and be able to be washed, combining both concepts of a silicon and foam tip earbud
5. Ear Canal Measurer
   - Needs a list of recommended sizes
   - Kind of like an air pumped tympanometer
6. Air pumped earbud tip
   - Air can get pumped into the earbud tip to inflate it to a custom size, allowing for the user to have a variety of earbud sizes in one
7. New Tip Mechanism
   - A sort of holster to put the earbud into then use that holster as the earbud to change size/shape of the tip
8. Ring Around Ear
   - A mechanism that clips to the wire or part that sticks out of the ear and warps fully around the outer side of the ear, could have a tighten and untighten mechanism

Before decision matrixes were used to decide on a solution to pursue the most viable solutions of these 8 were chosen. The solutions chosen were debated and deliberated in order to narrow down the possible solutions to a smaller number. Most designs involved a similar type of solution by adding an external portion to the earbud to either clip onto or use the outer parts of the ear to stay in place. These solutions were against the original standard the group had so most of the designs were dismissed.

Potential Solution Designs

The following 3 designs were the top three from the list above. These solutions were up to the standard the group set and seemed more capable of meeting the design requirements.

Constraints	*Air pumped earbud tip*	*Silicon-Foam Earbud Tip*	*Alternative Tip*
Safe for users' ears	11	16	17
Time Restriction	13	15	13
Affordability	14	13	16
Sound Quality	14	17	15
Durability	13	14	17
Reusability	13	17	17
Environmentally Safe	14	11	12
Sound Isolation	14	19	15
Compatible to many	17	15	12
Physical Appeal	12	18	12
Originality	20	16	16
Total	155	171	162

1. Air pumped Earbud Tip
    - Air can get pumped into the earbud tip to inflate it to a custom size, allowing for the user to have a variety of earbud sizes in one
2. Foam and Silicon Earbud Tip
    - A foam earbud tip surrounded by silicon skin to provide better durability and be able to be washed, combining both concepts of a silicon and foam tip earbud
3. Alternative Earbud Tip
    - A sort of holster to put the earbud into then use that holster as the earbud to change size/shape of the tip

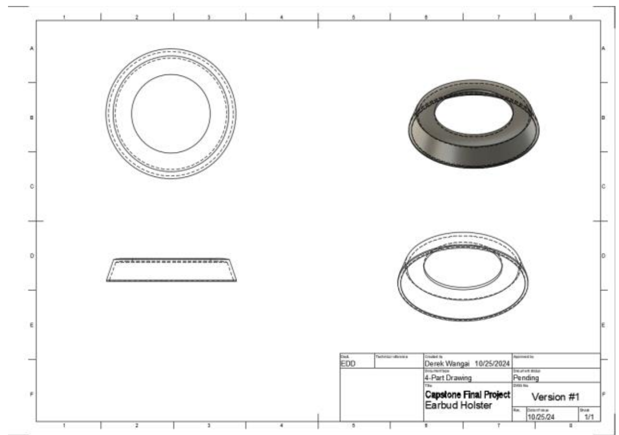
This decision matrix covers all main points of Element C design constraints and requirements. All 3 designs were scored by each member 1-5 for each comparison point, which is a design constraint, for a total of 20 points on each point – adding up to a maximum score of 220.

The matrix highlighted that the foam and silicon earbud tip was the design which fit all the design specifications the best, however, before a decision was made – another set of variables were considered.

Final Solution Viability

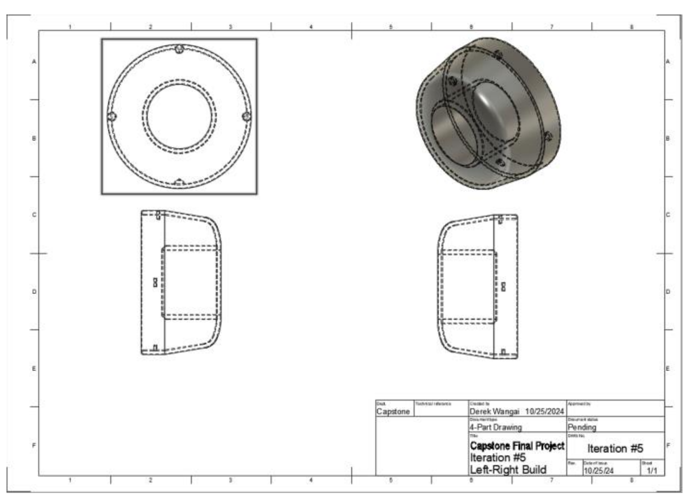
Refer to 3D Model/Designs for measurement

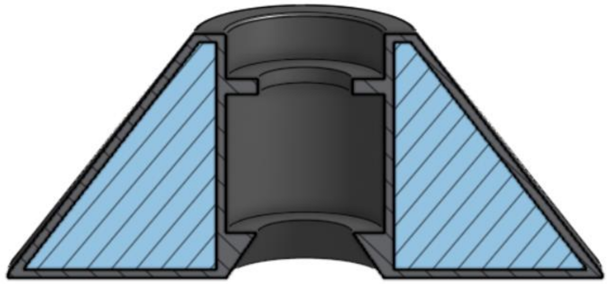
As a group, a consensus was made that the Alternative Earbud Tip would not be viable as it fails to encapsulate the goal of being compatible with as many people as possible. It also is a redundant solution as the current best solution is replacing the earbud tip with a new tip that fits the user's ear better. This solution of replacing the tip is one that already exists in a different manner and therefore is not a viable design as many other variations already exist.



The air-pumped earbud tip consisted of creating a special earbud tip that can be inflated to control the size of an earbud tip. The first problem with this solution was finding an easy method of measuring the ear canal of the user's ear, the current way to measure the size would be using a tympanometer; and even that does not provide the exact results we are looking for. Additionally, it would be difficult to design such a small object with a way to inflate it with accuracy. Furthermore, there existed a chance of the earbud tip rupturing it due to the amount of pressure within the tip creating a risk of injury. Considering these factors led to the conclusion that this solution is unviable with the amount of time available. Consequently, if rushed, the design has too many risks that may not be able to be negated. 3D Design is available to view below.

In this design the holes that are shown near the ends of the earbud are places where air would be pumped inside. Using this method the size of the earbud could be controlled to make a perfect sized earbud for an individual. However, as it is extremely small with the dimensions in millimeters this solution was deemed unviable as it was too difficult to produce within the allotted time limit – going against one of the main design constraints in Element C.



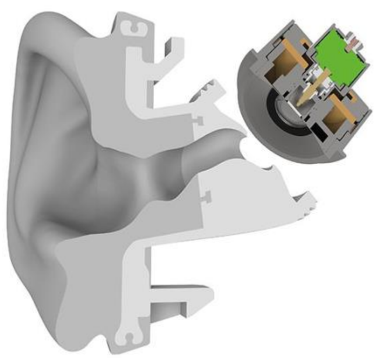


The blue portion of the design is memory foam, and what it is covered by is the silicon shell. The current idea is to utilize a reverse mold, 3D printed accurately, to create the silicon shell with the memory foam inside of the reverse mold.

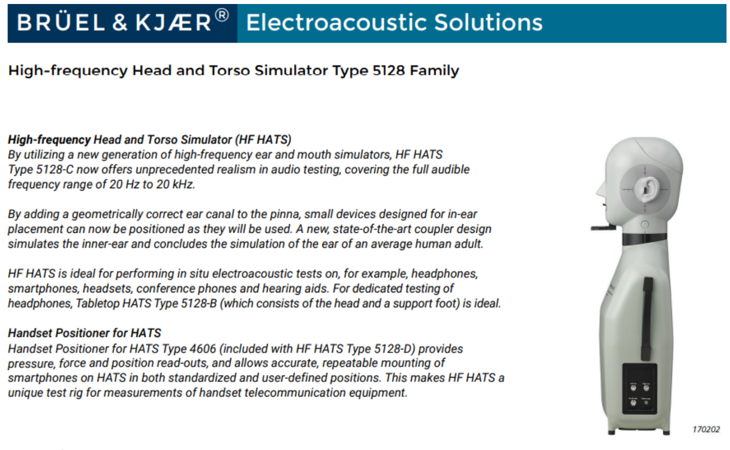
The solution with the highest score in the design matrix – the Silicon-Foam Earbud Tip, was the final chosen design. Not only did it meet the criteria of the design specifications the best, but it also has a reasonable design of an earbud tip made with foam and adding silicon coating on the exterior. Memory foam is the main chosen material as it provides more comfort and elasticity. This solution is viable as it combines two existing solutions by utilizing the elasticity of memory foam and the usefulness of silicon to reduce damage to users' ears. The 3D Design is shown above.

Element E

Application of the Engineering Design Process



The first phase of the project was to brainstorm potential problems that were either personal or problems within the community. Once a problem was identified, the group researched various primary and secondary sources that included relevant information on the problem and developed a means of testing the effectiveness of the prototype. One of such sources is SoundGuys, an online publication team of experienced journalists, reviewers, and audio engineers that review and test audio products. To test headphones, SoundGuys use the Bruel & Kjaer 5128 HATS. It is an audio testing dummy that uses a realistically shaped ear canal, using data from MRI scans of 40 people, as well as realistic simulations of tissue and bone. The Bruel & Kjaer 5128 HATS comes with the Handset Positioner Type 4606 which gives pressure, force, and position for accurate, repeatable testing.



BRÜEL & KJÆR® Electroacoustic Solutions

High-frequency Head and Torso Simulator Type 5128 Family

High-frequency Head and Torso Simulator (HF HATS)
By utilizing a new generation of high-frequency ear and mouth simulators, HF HATS Type 5128-C now offers unprecedented realism in audio testing, covering the full audible frequency range of 20 Hz to 20 kHz.

By adding a geometrically correct ear canal to the pinna, small devices designed for in-ear placement can now be positioned as they will be used. A new, state-of-the-art coupler design simulates the inner-ear and concludes the simulation of the ear of an average human adult.

HF HATS is ideal for performing in situ electroacoustic tests on, for example, headphones, smartphones, headsets, conference phones and hearing aids. For dedicated testing of headphones, Tabletop HATS Type 5128-B (which consists of the head and a support foot) is ideal.

Handset Positioner for HATS
Handset Positioner for HATS Type 4606 (included with HF HATS Type 5128-D) provides pressure, force and position read-outs, and allows accurate, repeatable mounting of smartphones on HATS in both standardized and user-defined positions. This makes HF HATS a unique test rig for measurements of handset telecommunication equipment.

170202

After the problem had been justified, group consultation was needed to design a solution. The design requires a bill of materials, blueprints (paper & CAD), material processing skills, and more. The solution design will be tested using various methods to identify the shortcomings and strong suites of the product. The results and process will be presented in a PowerPoint presentation in front of a panel of judges and engineers within the community. Gathering information through objective testing, which verifies product performance through controlled, standardized tests.

Application of Prior Classes

Material study was a factor of one of the classes taken in sophomore year at the school. The material decided on was narrowed down based on many of the qualifications taught in the class, including comfort, cost, and durability. 3D modeling was also taught in a class taken the year prior, which is needed to attain a better grasp of the prototype without physically designing it. Project documentation was also taught in the same class as 3D modeling, and this is done via an engineering notebook. The engineering notebook was the way that everything in class was recorded. Technical writing was taught in the 3D modeling class and is a requirement in the documentation of the project. Proper notation is indispensable when it comes to explaining the project ideas to others and retaining the information about it.

Application of Mathematical Principles

With all the measurements being done for each prototype, the amount of each material needing to be used would need to be found. This can be found via finding the volume of the earbud tip and converting that to silicon (for one prototype foam is needed).

(Volume of silicon part of the Silicon coated foam earbud is 355. 98172 mm^3)

3D Design of Silicon Coating

All dimensions used in the 3D Design are measured to accuracy using a dial caliper.

Application of Science Principles

Knowledge of physics and chemical properties are both needed to make the earbud tip as quality as possible. Physics knowledge is applied via understanding how much force the earbud tip can withstand and how much force it takes for it to be removed from the ear. Chemistry is applied by understanding the chemical properties of the materials such as heat tolerance, effects on skin, and conductivity of electricity.

Application of Technological Principles

The focus of our problem revolves around a technological premise. Earbuds are used within technology from computers to the phones carried around by people daily. Not only is the focus of this project on a piece of technology, but many other kinds of technologies are also being utilized in the design making process. The solution will be planned out and designed using CAD 3D modeling software, specifically Onshape. For any physical constructions or fabrications that need to be utilized, we will also have to be conscious about any safety procedures when working with those specific tools. The 3D printer will be used to create a prototype and a mold which will be used to make the actual product.

Application of Primary Research Principles

For the research phase of our project, we first investigated any relevant organizations in the surrounding Savannah-Pooler area that dealt with issues related to our problem. We eventually came across audiology departments, which are healthcare specialists that are responsible for evaluating, treating, and documenting any issues or diseases surrounding ears. One person from our team was tasked with going to a couple audiology departments across Savannah and documenting any valuable information, while attempting to respond to our questions. The locations that were selected was a hearing aid dispenser organization and an audiologist center. At both locations, a leading member was sought out to be interviewed regarding what they do, how they perform their responsibilities, and how their knowledge and practices could be implemented into our own project.

Element F

Tangible Design

To justify the viability of the solution the following 3 areas will be explored: Dimensions and Sizing, Material Importance, and Building Processes. The dimensions and sizing are important as one of the most important factors is for the solution to be compatible with as many users of earbuds as possible. The material must be chosen carefully as it cannot cause any harm or irritation to user's ears nor compromise sound quality/other factors that previous earbud tips have established as a baseline. The building processes answers how the solution will be built, and or what is needed for it to be built.

Dimensions and Sizing

First a reference was needed to gain an understanding of a large size and small size for earbud tips. The earbud tip used as a reference is an extra-large size earbud tip Raycon Everyday Model RBE725 and was measured using a dial caliber. The table below highlights what was measured and the sizes of those portions.

Extra Large	*Diameter* (⌀)	*Height*	*Outer (Middle)* ⌀	*Inner (Middle)* ⌀	*Outer (Top)* ⌀	*Inner (Top)* ⌀	*Middle Height*
Measurements (mm)	19	8	6	5	6	4.5	5

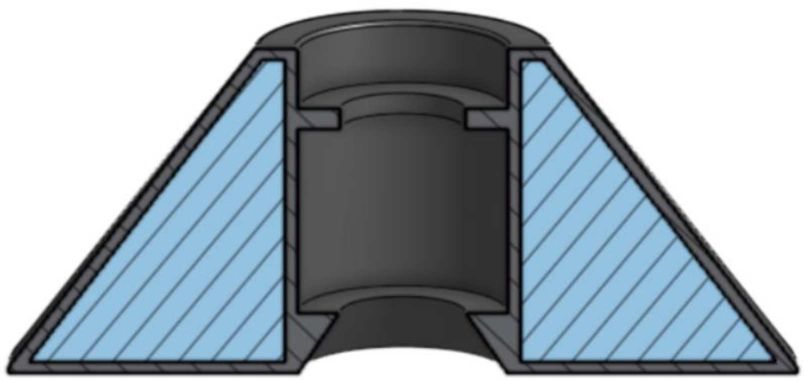
This data will act as an upper limit to the sizes of the earbud; the next data table will contain the measurements for a small sized earbud tip.

Small	*Diameter* (⌀)	*Height*	*Outer (Middle)* ⌀	*Inner (Middle)* ⌀	*Outer (Top)* ⌀	*Inner (Top)* ⌀	*Middle Height*
Measurements (mm)	11	8.5	6	N/A	4	N/A	6

Sony Wired Earbuds were used to measure the small earbud tip, while the build of it is different from the Raycon it provides the important measurements required to make a comparison. This data will act as a lower limit to the sizes of the earbuds. Using both datasets will allow us to identify a middle ground where this earbud tip will be able to fit the greatest number of users for the earbud tip.

The shape chosen for the final earbud is a trapezoidal shape. As we lack the devices and or certification required to make earbud tips with the regular circular curves with precision, a trapezoidal shape will be used to circumvent that problem. Another reason for this shape is that it complements the memory foam material being used better as it allows for better elasticity.

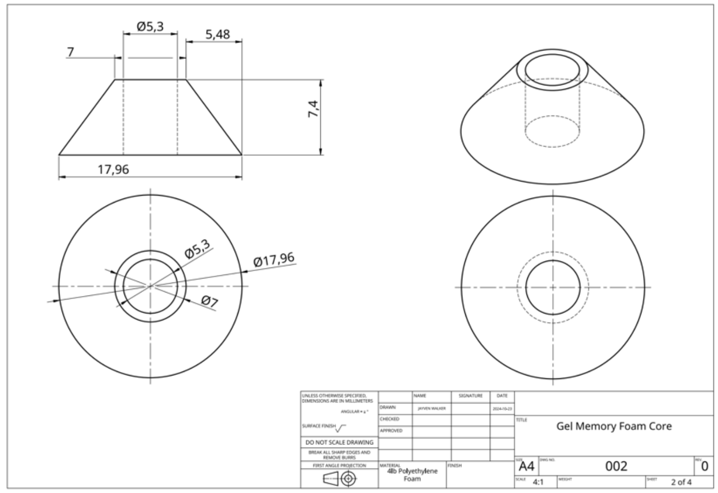
Choice of Materials

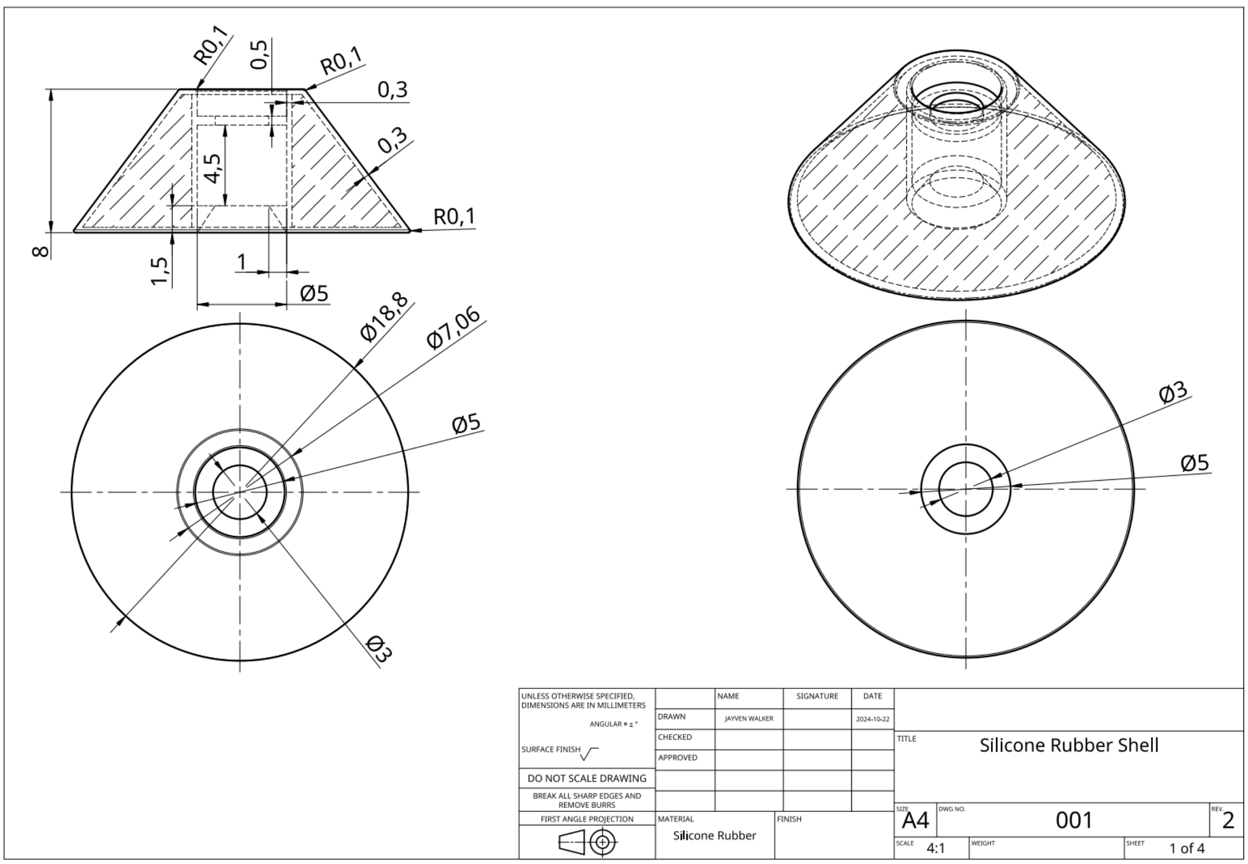


This is a representation of the first prototype design. The two main components used are memory foam and silicon. Each material will need to meet a criteria to be viable for usage. 3D Design showing both the Silicon coating and Memory Foam (Blue portion) assembled.

The first requirement of the memory foam is softness, second is to not cause irritation to the ear and finally to not compromise the sound quality. As one of the main problems of improper fitting earbuds is ear damage/harm, it is very important to find a kind of silicon that will not harm or irritate the ear. Next is sound quality, as earbuds are going to be used frequently in most people’s lives it is essential to not ignore the standards set by modern earbuds on sound quality. Earbuds are used for listening to entertainment to making important phone calls in public, so compromising the main premise with sound quality and being able to hear what is played through the earbud would be a disqualification of that material. The picture shown is a representation of how the memory foam would be shaped for use. As this is what the earbud portion responsible for relaying sound will be covered with, sound must be effectively captured.

This four-part drawing represents the important dimensions of the memory foam and how it is designed. It will be made smaller than the silicon outer shell to fit the memory foam inside the coating/shell made of silicon as shown in the picture above. The four-part drawing of the silicon can be found below.





The next material to consider is the silicon and its criteria. Being the outer portion of the earbud tip means it too will need to not cause any harm or irritation to the ear and also provide sound isolation. Since the inside portion is memory foam its role will be more for sound quality, however, as the silicon is on the outer side its role will be for sound isolation. So, the main factors considered for silicon will be durability, comfort, and sound isolation. The first picture above is the 3D design for the silicon shell placed around the memory foam. This picture slightly above is the four-part drawing which shows the important/relevant measurements needed for this silicon coating.

Building Processes

For this design to be viable it must be able to be made. For this reason, design/building processes must be examined to identify the best way to proceed into the building phase. The main method of construction currently is using a mold, made with either silicon or resin; via 3D printer. A mold allows for the construction of the product with precision and accuracy on shaping. As shown above, both of the main parts of the earbud tip have been designed and 3D modeled. Therefore, casting into a mold is the most realistic approach as it will be doable within the time constraint and also be cost efficient.

Element G

Prototype Description

During the planning phase of designing the CAD model of our prototype, our initial focus was on setting the criteria for the decision matrix and ensuring that it matched with the service that it would hope to provide. Most of the decision matrix criteria involved constraints about being user friendly, both health and function wise, as well as affordability. For the designs of the models, we included a whole scale view, an exploded view with each internal component, and 4-part drawings to simulate various viewpoints.

Bill of Materials

The bill of materials shows all of the parts needed to construct the earbud tip. It contains the quantity, cost, and amount that comes with each material. The total cost comes to $95.87.

Item	*QTY*	*Description*	*Cost*	*Notes*
Gel Memory Foam	1	24' x 14' x 4.5'/3.5'	$31.00	Will be cut into the general shape of the earbud.
Liquid Silicon Rubber	1	16 oz	$29.99	Will be poured and dried over the cutout mold.
Reverse mold V2	1	19.6mm ⌀ x 9.5mm	N/A	3D Printed
Silicon Release Agent	1	6 oz	$16.99	Used to make sure that the silicon does not stick.

Build Procedure

The construction phase of our prototype followed all components that had been constructed and printed. An assortment of tools, as seen in the tables below, were used during this phase. The steps may utilize hands-on construction, 3D printing, laser cutting, or scissors. Procedures for completing the design can either be completed consecutively or by handling one element at a time. Some precise skills are needed to design the product, but other than laser cutting and working with the box cutter, there should not be many other safety issues when creating the product.

Skills	*Where skill is coming from*
Laser cutting	Jayven
Using blades to cut foam	Jayven
Basic Assembly skills	Jayven
Ability with 3d printing	Jayven + Nuveesh
Ability to work with liquid silicon	Jayven

This table above highlights the skills required for the creation of this design and who is responsible for that skill.

The Laser Cutter will be used to make a general outline of the shape we need with the memory foam. Then, sharp scissors are used to shape the foam core. Safety goggles will be used as safety measures when handling liquid silicon and cutting memory foam. Finally, the 3D printer is for printing out the components to our design.

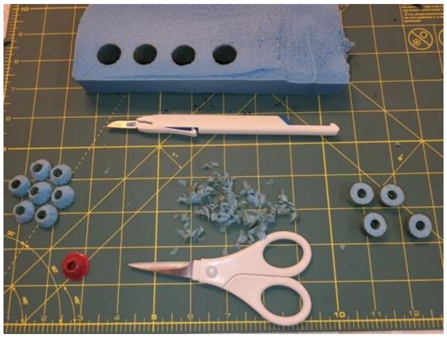
To make this prototype a mold will be used to create the silicone shell. The mold will be designed in a 3D Modeling space and 3D printed for use.

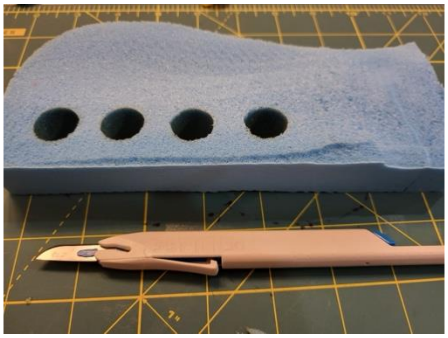
Procedure #1

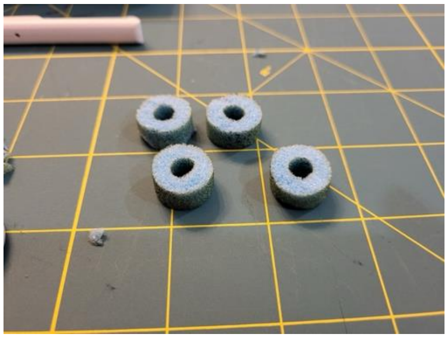
Creation of Memory Foam Core -

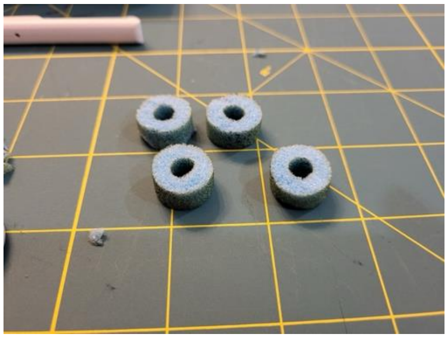
1. Cut out a piece of memory foam at least 2 cm in thickness, making sure that there is no “skin”
2. Put the foam into the M1 laser cutting machine that has been raised, and update the background image
3. Create a cutting path of 2 circles in X-Tool Creative Space. One circle 17.8 mm in diameter and a smaller circle in the middle of the other of 5.6 mm in diameter
4. Place the cuts along the background image of the foam
5. Put the cutting specifications at 70% power, 1mm/s, and 10 passes
6. Start framing and adjusting either the foam or the cutting path to be on the foam if it goes off the foam.
7. Once aligned, start the cutting and stay with the machine until it finishes
8. Once finished, take out the foam. You may need to cut with a sharp blade or thin sharp scissors to get the foam cores out

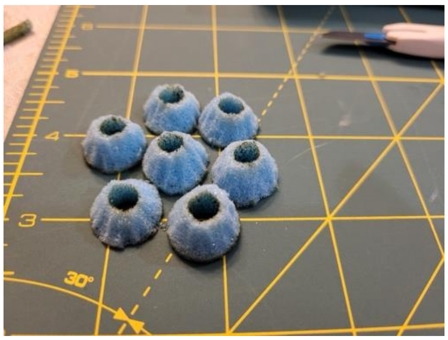
9. Using sharp scissors, cut out the angle from the bottom edge of the foam to the edge of the hole
10. Prepare the silicone and reverse mold v2 as well as a paint brush and a work space while wearing gloves
11. Mix Silicone Part A and Part B well in one direction, making sure to get every edge of the container
12. Use a paintbrush to coat one of the trimmed foam cores on all sides and the middle, then put the foam on a reverse mold v2, making sure there is enough silicone in the middle
13. Repeat for how many foam cores and reverse mold v2s you have in a quick manner.
14. Wait 30 minutes to an hour for the silicone to harden and use a sharp hook and knife to trim off the earbud from the reverse mold v2.
15. The earbud tip is complete

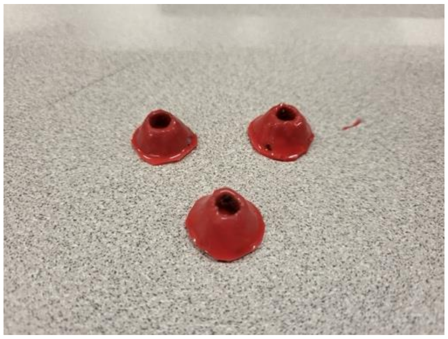












Testing Standards

The following tests will be used to examine the prototype solution and grade the design based off the design constraints listed in Element C. Out of the design requirements/constraints listed in the previous element, a total of 6 labs. Sound Quality, Durability, Cleanability, Sound Isolation, User Safety, and Fitability will all be tested to examine the effectiveness of the solution. For any of the tests that the earbud tip must be used, it must be attached to an earbud. The earbud tip must be undamaged at the start of each test. If the earbud tip breaks or causes a health-related issue, the test is terminated.

Sound Quality Lab

This lab determines whether the build of the product, materials and proportions, interferes with the sound quality of the earbud used for testing. For the design to pass, the user must experience a very similar quality of sound to the original earbud tip used. If the user experiences a worse quality of sound, then it is considered to fail the test.

Materials

1 Pair of the Silli foam Earbud tips

1 Pair of Earbuds

1 Pair of memory foam earbud tips

OR

1 Pair of Silicon earbud tips

Procedures

1: Materials are obtained, and initial conditions are met

2: Place either memory foam or the silicone earbud tip on the ear

3: Play audio that is sufficiently audible to the user

4: Document any notes on sound quality

5: Remove silicone/memory foam earbud tip from the earbud and place the untested/prototype earbud tip on the earbud

6: Play the same audio used for testing the first earbud tested

7: Record notes about sound quality

8: Place Silli foam earbud tip on the earbud tip after the one being tested is removed

9: Play the same audio used for the first 2 tests

10: Record notes about sound quality

11: Compare the sound quality between all 3 earbud tips

Sound Isolation Lab

The purpose of this lab is to determine if the product can properly isolate sound using other modern earbud tips as a standard. A pass for the design would be if the earbud tip isolates sound similar to or greater than modern earbud tips, and the product would fail if there was a significant difference in the sound isolation the earbud tip provided.

Materials

1 Pair of the Silli foam Earbud tips

1 Pair of silicone earbud tips

OR

1 Pair of memory foam earbud tips

Procedures

1: Materials are obtained, and initial conditions are met

2: Place earbud tips (Silli foam, memory foam, or silicon) in ear

3: Play a sound to determine how loud it is to the test subject (Record decibels of the sound and distance from subject)

4: Record observations about sound isolation

5: Remove tested earbud tips

6: Place an untested pair of earbud tips in ear

7: Play the sound at the same volume and distance from the subject

8: Record observations about sound isolation

9: Remove tested earbud tips

10: Place final untested earbud tips in ear

11: Play sound at the same distance and volume as the prior tests

12: Record observations about sound isolation

Durability Lab

The purpose of this lab is to test the materials durability and ability to be used for a long period of time. The design will be considered to pass the test if it shows that the product has sustained very little to no damage after the testing. If the product fails to pass the test, it cannot be sold as it will break far too easily.

Procedures

1. Collect Materials
2. Record current state of earbud
3. Place earbud tip between hands
4. Rub hands together for 15 seconds for trial 1, 30 for trial 2, and 1 min for trial 3
5. Record *State of Earbud* or if any damage has occurred
6. Repeat the process 1-2 more times for more data

Fit Test

This test will be run to determine the quality of the earbud tip's fit to many individuals. If all users are comfortable using the earbud tip, then the test will be passed. If the product fails the test, the sale will be difficult because comfort usually comes first when it comes to earbud tips.

Materials

1 Pair of the Silli foam Earbud tips

Safety Concerns

N/A

Procedures

1: Materials are obtained, and initial conditions are met

2: Place Silli foam earbud tips Silli foam in ear for 15 seconds while not moving

3: Record any discomfort and adjustments made during the trial period

4: Remove earbud tips from ears

5: Place earbud tips in ears, but moving at walking pace (Record distance)

6: Record discomfort and any adjustments made during the testing period

Health and Safety Test

This test is most likely the most important to the producer, and the least important to the consumer. The test is important to the producer because the test is one that will determine if the product can be sold at all. It isn't important to the consumer because safety is the baseline, and they will look elsewhere if the product isn't safe to use. The test is done to determine any health or allergy related problems.

Materials

1 Pair of the Silli foam Earbud tips

Safety Concerns

Allergic reactions

Eardrum damage

Inner ear pain

Procedures

1: Materials are obtained, and initial conditions are met

2: Place earbud in ear and leave for 15 seconds

3: Remove after testing period or if the Termination Conditions are met

4: Repeat testing 3 times per subject

5: Record any observations after each test

Cleanliness Test

This test is done to determine if the product can be cleaned and how clean it can get. If the product cannot be cleaned, then it has the potential to cause infection to the user. Which will cause the user to no longer use the product, which will drive down sales.

Materials

1 Silli foam Earbud tip

1 Bottle of soap

1 Sink

Procedures

1: Materials are obtained, and initial conditions are met

2: Drop Silli foam earbud tip into a patch of dirt/grass and immediately pick up (Ensure that the product is dirty)

3: Move to the sink and proceed to clean the earbud tip using soap and water

4: Record any damage and debris still on the earbud tip post cleaning

By testing the prototype of the silicon foam earbuds design in these labs, the team will be able to decide whether the product meets the design specifications/constraints and decide if the product is a success, or failure.

Element I

This document contains data collected from the labs described in Element H. These labs will justify whether the final product meets the design requirements from Element C and whether the product is marketable.

Sound Quality Lab Results

Audio	*Audible (Y/N)*	*Better or Worse?*	*Observations*
Left Earbud	Y	Similar	If earbud is not fully in, sound goes around the ear rather than fully in the ear
Right Earbud	Y	Similar	Same as above, Also the sound sounds slightly muffled but not enough to be considered a problem
Both Earbuds	Y	Similar	The muffled sound problem gets less apparent/goes away with both earbuds

A piece of audio, found at the bottom of documentation, was played for each ear, and then both at once, to identify if there exists any difference between the prototype created and the standard earbud tip. If the prototype is audible, similar to or better than the standard earbud, and had no negative observations, then the prototype is considered to pass the lab and successfully meets the design specification.

Sound Isolation Lab Results

Audio Level	*Sound Isolated (Y/N)*	*Better or Worse?*	*Observations*
Muted	N	Slightly Worse	Was able to hear more than what would be considered isolated
Low Volume	Y	Better	Was just barely able to understand words spoken
Safe Volume	Y	Same	Heard almost no audible words

For this test, three different levels of volume will be tested and observed to identify whether the sound isolation is sufficient for everyday use or use in public. The prototype would pass the lab if sound was isolated similarly or better than standard earbuds and no negative observations were made during the lab.

Durability Lab Results

Trial run	Time tested	Observations
1	15 sec	No observable damage
2	30 sec	No observable damage
3	1 min	No observable damage

This test is ran to determine if the earbud tip can withstand the wear and tear of frequent use. The prototype passes the test via not breaking under the testing conditions. Damage is acceptable, but not to an extreme point as to the earbud tip being unusable.

Fit Test Results

User/Trial Run	Time used	Observations
User 1 Left Ear	15	Must push in and hold earbuds in the ear to be properly used
User 1 Right Ear	15	Earbud Tip was slightly sticky and fell out when taking earbud tip out
User 1 Both Ears	15	If the earbud is left to rest in ear, it gradually falls out. However, despite needing to hold the earbud tip in, it was more comfortable than imagined
User 2 Left Ear	15	Too big, was not able to fit
User 2 Right Ear	15	Earbud tip adhered with force applied
User 2 Both Ears	15	Earbud tip adheres to both
User 3 Left Ear	15	Earbud sticks out of ear, but stays in ears
User 3 Right Ear	15	Earbud hovers outside of the inner ear but stays in that spot
User 3 Both Ears	15	Earbuds hover on the outside of the inner ear, but fit there
User 4 Left Ear	15	While only placed in the opening, remained firm and unmoved
User 4 Right Ear	15	While only placed in the opening, remained firm and unmoved

User 4 Both Ears	15	*Same results for individual left & right ear

The user will be given 2 earbuds and tested to see if it can be used for 15 seconds without pain/discomfort. The prototype will pass the test if there is little to no discomfort and no pain.

The earbud tip was able to fit multiple types of earbuds as each user was able to fit the earbud tip onto their own pair of earbuds.

Health/Safety Test results

User/Trial Run	Time used	Observations
User 1 Left Ear	15 sec	No safety Concerns
User 1 Right Ear	15 sec	Earbud tip popped out of earbud when earbud was removed from ear
User 1 Both Ears	15 sec	No safety Concerns
User 2 Left Ear	15	No safety concerns
User 2 Right Ear	15	No safety concerns+ no breakage
User 2 Both Ears	15	No safety concerns
User 3 Left Ear	15	Did not fit
User 3 Right Ear	15	Did not fit
User 3 Both Ears	15	Despite earbuds sticking out and not fitting fully, a decent amount of force was required for it to fall out of the ear
User 4 Left Ear	15	Ear remained intact, unstained; no visible scratches or irritation
User 4 Right Ear	15	Ear remained intact, unstained; no visible scratches or irritation
User 4 Both Ears	15	Ear remained intact, unstained; no visible scratches or irritation

Each user must not have an allergic reaction, or receive a severe injury after each test in order for the product to pass the test.

Cleanliness Test Results

Trial run	Time Cleaned	**BEFORE** Observations	**AFTER** Observations
1	10s	Earbud has some observable foam outside the silicon	Some of the silicon came off one of the earbuds and foam absorbed water

This test is run to determine if the earbud tip can be cleaned without sustaining damage due to dirty earbud tips having the possibility of causing infection. The test is passed if the earbud tip can be fully cleaned without damage.

***USED ON AN OLDER ITERATION.**

Final Prototype:

Trial Run	Time Cleaned	Quality Before	Quality After
1	5s	Slightly Shiny from silicon, sparse dots of dust across body	Dust has been removed;
2	10s	Same as 1st trial; bottom portion engraved with thinned silicon	Slight pieces of silicon rubbed off at top; slightly cleaner
3	15s	Same as Trial 2 after results	Same as Trial 3 before results

This table represents the data for our recent prototypes as of December 6th. This test is run to determine if the earbud tip can be cleaned without sustaining damage due to dirty earbud tips having the possibility of causing infection. The test is passed if the earbud tip can be fully cleaned without damage.

Critical Design Review

Overall Craftmanship

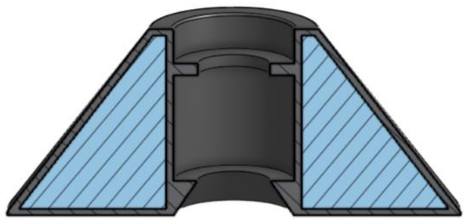
The earbud tip will mostly be handmade via hand cutting the memory foam and hand painting the silicon onto that memory foam, but there will be some aspects that will be automated such as a laser cutter being used for the hole in the middle of the earbud tip. The hand making of the prototype will create some margin for error, but that is easily manageable.

Testing plan

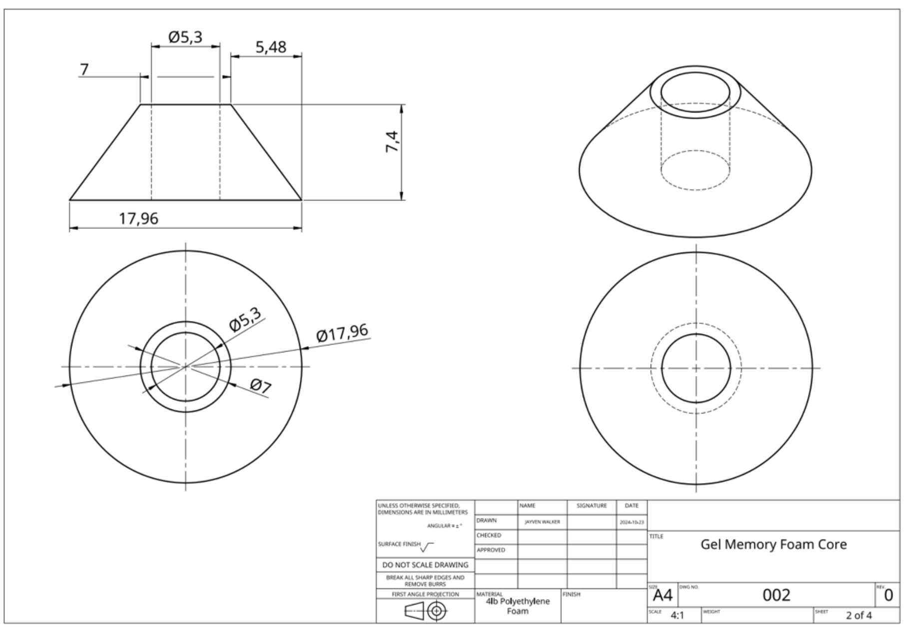
The group will internally test the product and will do so by adhering strictly to the testing procedures. 6 tests have been designed to either prove or disprove the quality of that iteration of the product. The documentation of the results will be objective, and all observations will be recorded to guarantee the most accurate results.

Visuals of actual product

Internal view of product



4 Part drawing of product



How safety is addressed

Safety is addressed by the first of the 6 tests being conducted the safety test. This test shows that the earbud will not harm, nor cause irritation to the user via the materials. During other tests, the testers will be adequately protected to ensure that no harm comes to them via the earbud tip.

Choice of materials

The silicon was chosen because that material is the most used, and most comfortable for designing the exterior of the earbud tips. The silicon also boasts high durability and adheres to the user’s ear fairly well. The memory foam was chosen to for the sound isolation properties, and the malleability of both the silicon and memory foam will not contradict each other to create a faulty product.

Opportunities for modification

At first, the product was supposed to be fully automated, the laser cutter was meant to cut the earbud tip fully, and the silicon was supposed to use a reverse mold. The modification opportunity came up when the original manufacturing plan failed and the handmaking procedure turned out to be more efficient.

Testing Analysis

Sound Quality

The sound goes around the ear, and not directly into the ear for both ears. This is likely due to the shape of the hole in the middle of the earbud tip, and the lack of the screen on the earbud tip. Sound is described as muffled for the individual earbud tests, but when used in conjunction with the other earbud the issue goes away.

Sound Isolation

When no sound was playing from the earbud, sound was able to be heard and understood and was worse isolation than the standard earbud tip. When the sound was at a low volume, the sillifoam earbud tip had better sound isolation than the standard earbud tip. When sound was played at a higher but safe volume, both earbud tips had the same level of sound isolation, and no sound was let in.

Durability

The durability test was passed phenomenally, and the earbud tip had no observable damage for all of the tests performed.

Fit

For user 1, they had to hold the earbud tips in place but stated that the feel was quality. User 2 stated that the earbud tip was too big, but adhered to the spot that they were in. User 3 stated that the earbud tips hover on the outside of the inner ear. User 4 reported that the earbud tips hold on the opening of the inner ear for all tests.

Health and safety test

All users reported no damage, irritation, or allergic reactions.

Cleanliness test

For all trials, the earbud tip wasn't damaged, and the debris was removed.

Element J

Outside Group Reflections

The group decided to take the opinions of potential investors of the product, to determine potential faults and good qualities about the product. This opinion gathering also serves to gain a baseline on the quality of the current iteration of product made at the time. In addition to the consumers, the group also decided to gain the opinion of an expert to further enhance the quality of data gained from the gathering. In total, 15 consumers were interviewed for their opinion of the product. The consumers were asked to rate the product on a scale of 1-5 and to offer a comment on the product.

- Consumer 1
    - Rating- 4.5
    - Stated that the product feels nice
- Consumer 2
    - Rating-3
    - Stated they believe that product wouldn't go far enough into the ear, but would use if it did
- Consumer 3
    - Rating-3
    - Stated that the earbud doesn't fit, but is a fan of the material and enjoys the feel
- Consumer 4
    - Rating-4
    - Stated that the fit is nice despite the size, and enjoys the material
- Consumer 5
    - Rating-4.5
    - Gave the recommendation to use heat to reshape the earbud tip more accurately
- Consumer 6
    - Rating-4.5
    - Stated that they would use the earbud tip
- Consumer 7
    - Rating-4
    - Believes that the product would conform to the user's ear too much over time, causing the product to become unusable
- Consumer 8
    - Rating-4

        - Stated that the product is possibly too squishy, but that could help with the fit
- Consumer 9
    - Rating-5
    - Found no immediately observable faults, but would need to use for an extended period to confirm
- Consumer 10
    - Rating-4
    - Stated that the product is comfortable, but is not a fan of the look
- Consumer 11
    - Rating-4
    - Stated the product feels nice
- Consumer 12
    - Rating-4
    - Stated that the product feels nice, but isn't a fan of the look
- Consumer 13
    - Rating-4
    - Stated the product feels sticky
- Consumer 14
    - Rating-4
    - Stated that the product is agreeable
- Consumer 15
    - Rating-4
    - No comment

The average rating for the consumers was a 4.03 overall, and a majority of the comments are about the quality feel or the look being off. The rating is high for a first iteration product and can easily be higher with time for adjustment/progression. The fit issue can be fixed by making multiple versions of the product or creating a more precise product.

Expert 1 Information

Tools + Equipment used in examinations

Otoscope

Audiograph --> tests for responses & feedback from patients when trying out hearing aids

Avg. Patient age range: >65

Rough % with issues resulting from headphone/earbud problems (frequency of high intensity volumes): 25%

Common materials used in hearing aids

Acrylic

Polyethylene

Silicon molds

Vinyl

*JB3000: Compound made from acrylic and silicon molding

*WESTONE: company in Georgia that currently works to develop compound solutions that are better equipped for long-term, reusable hearing aid/listening devices

Expert 2 Information

Factors/Causes of Hearing Loss

Noise-Induced responses --> less common

Genetic/inherited issues --> more common/severe (leads to other diseases)

Presbycusis --> proportional loss of hearing with increasing age

Conductive --> temporary loss of hearing

Audiologists

Identify specific factors

Take measurements of patient’s inner, middle, and outer ear

Refers patient to a type/brand of hearing aid

Hearing Aid Dispensers

Custom fit and testing of hearing aids

Types of hearing aid tests

Tympanometry --> looks for desired pressure and flexibility of hearing aid in relation to ear

Pure-tone Air test --> evaluates how freely air can move through the ear

Sound Isolation test --> evaluates for the point at which sound can be detected through added insulation

*BAHA device

Current Solutions to Permanent hearing loss

Antibiotics

Cochlear implants

Element K Problem Validation

The problem validation was the first three Elements - A, B, and C. Element A began with identifying our problem, that being the issues arising from improper fitting earbuds, and condensing our research down. This research about earbuds helped focus our problem down into our problem statement: *Earbuds are a popular product; however, it is extremely difficult to find the right size. And due to the issues, that arise from having incorrectly sized earbuds – like the scratching of ears, infections, damage to eardrums, and tinnitus - it is even more important to find the right size for earbuds. However, this problem of size has existed since the beginning of their creation in 1891.*

Once we identified our problem, a survey was conducted to see if this was a problem that persisted within our community, and the results said that yes it did. 49% of the people who took the survey occasionally found earbuds uncomfortable and over 20% often found earbuds uncomfortable. This information gained by the survey allowed us to justify the problem through market research. Also, because the shape and size of people's ears vary from person to person, and because another tool like earbuds - hearing aids - also faces the same issue it was able to be justified by academic means.

After justifying the problem through market research and academic means, previous solutions were examined, and it was found that creating a custom sized earbud was currently the best solution to this problem. The comparison factors used were comfort, side-effects, reproducibility, effectiveness, and durability. Comfort was based on the material used and the shaping of the earbud. Side-effects were counted as negative points, meaning that the lower the score the better. This comparison factor looked at the potential risks or faults of the product. Reproducibility was how easily the product would be able to be remade for marketing, and effectiveness was how well the design solved the issue at hand of improper fitting earbuds.

Once these solutions were compared, design specifications/requirements were identified, using what was learned through comparing previous solutions, to set a goal on what the product/solution design created should accomplish. Three categories were created for Element C – Design Elements, User Elements, and Construction Elements. Design elements were overall goals that the solution should reach based on standards set by previous solutions. User elements were specifications that are for the benefit of the user allowing for marketing of this product. Construction elements were more focused on the time limit, budget, processes being used, etc.

Reflection

The problem identification was initially difficult as we all had ideas that seemed either too difficult to solve or too specific – meaning that it would only apply to a few people and be difficult to justify as an issue. As the problem of improper fitting earbuds was one that all group members had encountered before, this was chosen as the issue. One of the topics we thought would be the hardest was academic justification as this mostly seemed like an issue that could only be justified by marketable means. However, we were able to find a connection with the issues which were caused by improper fitting earbuds, and how the shapes and sizes of peoples' ears were different. The surveys provided more results and information than initially thought by the team

The previous solutions were also difficult to find information on and thus most of the ones examined were patents regardless of whether they were successful or not. More solutions could probably have been found to help with the solution design process, and by accomplishing more on this element less redundant solutions could have been brainstormed in the next section of solution design. Also, examining the process in which these previous solutions were made could help with the prototyping/building process.

While there were not that many issues coming up with design constraints, it just was that some of them began to overlap. Because of this overlapping of constraints/specifications we decided to split up the specifications into different categories and attempt to combine any overlapping ones into one big specification. The result was one that we believe covers the greatest number of specifications for a viable solution.

Solution Design

The solution design is elements D, E, and F. The initial start of this component was brainstorming solutions, and the team came up with around 5 solutions each. Out of these 20 total solutions the ones that were similar were disregarded and a total of 8 solutions were chosen to be considered. After further discussion on what the project was going to accomplish and a little bit of comparison to the design constraints, 3 final potential solution designs were chosen. All 3 of these solutions were compared using a decision matrix which contained all of the design specifications as comparison factors. Out of these 3 the one found to be best was the silicon foam as it received the highest score when compared in the decision matrix. Following the decision matrix, a rough design was made using Fusion 360 and Onshape for each potential solution to examine what an actual prototype would look like. Only once the 3D designs were examined did the team decide to choose the silicon foam earbud idea as the final solution idea.

This project had utilized every field in STEM so as for relevance it was just putting them together. For science we needed knowledge of the physical and chemical properties of the materials we were combining and how they would feel/react with skin. For math we needed volume measurements to allow us to pour the right amount of silicon for the memory foam to coat it. Technology is arguably the biggest portion of our project, not only our product for a technological piece – a lot of 3D printing and CAD design was used to make the building processes easier. The project followed the engineering design process while combining what was learned from previous classes- such as material study, documentation, and the 3D design that was heavily used - to help with all portions of this project.

Element F's goal is to prove the viability of the solution and highlight its environmental impacts. To identify how tangible the solution is to create, 4 areas were examined. The building processes, dimensions and sizing of the earbud, the choice of materials, and the product lifecycle. The dimensions and sizing of the earbud are required to design the 3D model and for the actual building of the prototype, also the size of the product could affect the type of materials used. The choice of materials depends on the dimensions and sizing and will affect the building processes as certain materials utilize certain processes for building. The building process could change the effect on the environment caused by the product and or the product's life cycle. Thus, every area examined builds on another area only being fully viable when all 4 areas can find a middle ground.

Reflection

The beginning of coming up with solutions was a hard task, most of the solutions that were thought up by the team were similar and didn't seem to fully accomplish what we had wanted. Once the team had chosen the top 3 solution designs it was obvious that after comparing it with the decision matrix that the team would only be able to successfully accomplish one of the chosen 3 and reach the goal of solving the problem best we could. The silicone foam earbud was chosen with some discussion, and we moved on to problem viability. It was difficult thinking of how the other 2 potential solutions would appear in actual design so making the 3D designs of them was harder than envisioned.

With relevance in pretty much every field of STEM it was difficult to understand what to write about on this element. It seemed like a little of every field and the biggest with Engineering and Technology as that was the premise of the project. We were, however, able to find relation to the previous engineering classes we have taken along with some relation to the math and science principles portion. Also, more information regarding technology existed than we first thought so more relation was able to be documented.

During the initial process of writing Element F, we had forgotten to research the product life cycle and so better materials could have been chosen if the process was correctly followed. Going through the building and prototyping process has made it clear that more research should have been done on the building processes to prove design viability. This research regarding design viability would have allowed for an alternative method for coating the earbud in silicone than the route of 3D printing as what we were working with is incredibly small. If other building processes were examined, less time could have been spent figuring out how to shape and coat the foam while building – which in turn would have given more time for testing and redesigning.

Prototyping and Testing

This part of the project included Elements G, H, and I. Element G focused on the steps which were going to be taken to build the prototype. The first iteration of building was split up into 2 processes – shaping the memory foam and coating the foam in silicone. In this first iteration the original plan to shape the foam was to utilize a laser cutter and do any other precise changes with a utility knife or scissors. The second procedure was coating the foam in silicone, for this procedure a 3D design of a reverse mold was made. A reverse mold, as the name suggests, is the reverse of an actual mold, it will allow the silicone to go around the memory foam rather than creating a mold. The problem with this design was our inability to create the reverse mold correctly and also having issues shaping the foam as a laser cutter could not be used.

The second iteration had the same two procedures – shaping the foam and coating the foam, however, in this iteration the product would be made 5 times the original size. This would allow us to gain a better understanding of the building process and make the building of the actual prototype easier. Making the product 5 times the size fixed the sizing issues allowing for the original written instructions to be easily followed. The problem then became pouring the silicone into the reverse mold as little holes on the top part of the reverse mold were not big enough to allow the silicone to pass through it easily. To fix this a funnel was added to the reverse mold and all the silicone was passed through the funnel.

The third iteration requires the use of a laser cutter in the possession of one of the team members. The laser cutter in question is the X-Tool M1 10W. It was used to cut the general shape of the foam into a circular shape. Then it was trimmed using thin and sharp scissors to get the angle of the foam. Afterward, the silicone would be mixed and brushed on the foam using a paint brush. The use of the second reverse mold would create earbud tips that would hook onto common earbud brands. Initially, the second reverse mold was not used, allowing the creation of an earbud tip but no ways to use it. Having the second reverse mold allowed the silicone in the middle of the foam to be shaped to the desired shape while also not impeeding the overall shape of the product. Another issue it solved was the lack of holes when it came to coating the middle of the foam as silicone would settle at the bottom of the hole and would be impossible to out accurately.

To make the prototype first the memory foam was bought while deciding on the type of silicone to use and the shaping of the earbud began. Initially it was difficult to figure out how to cut the foam, however, through testing of some tools, the best two methods of cutting the foam were found to be an electric serrated blade, and tightened scissors. Using these 2 tools a larger scaled version of the prototype, specifically 5 times bigger, was made. This was done to ensure that the team understood the actual process of making the real prototype and that we would learn from any mistakes. Once this phase of building was finished, the team began building the real prototype making many smaller sized earbud shaped foam cores to cover in silicone.

Element H was based on the design requirements/constraints of Element C. The 6 labs that were made – cleanliness, durability, health and safety, fit test, sound quality, sound isolation – were each accomplishing the task of proving whether the product/prototype made would meet the constraints written in Element C. The sound quality/isolation and safety lab focus on the build of the product, materials and proportions, interferes with the sound quality of the earbud. The durability lab tests for the longevity of the product, and the fit test is how effective the product is at solving the problem.

Element I was the data collected by the labs run in Element H. For the sound quality lab, different users were given regular pairs of earbuds and then asked to compare it with our product/prototype. A similar approach was done for sound isolation, and for durability the damage was recorded with times 15 seconds, 30 seconds, and a full minute of sustaining damage. The fit test and health/safety test were done similarly to the sound quality and isolation. All 4 labs – fit test, health and safety, sound quality, sound isolation – had left ear, right ear, and both ears as a separate testing trial.

Reflection

The hardest part of this project has been the building process. Each iteration had issues and was harder to accomplish than we thought. The first iteration, utilizing the reverse mold, became a failure due to the issues that occurred when trying to print something as small as that. Also, the plan to shape the foam immediately had to be changed because of the laser cutter being unable to cut at an angle.

The second iteration was our attempt to see if whether the reverse mold was worth continuing or not, which the second iteration did prove that it had the ability to work. One of our other concerns was the silicone coating as we had originally assumed that we didn't pour enough silicone for the material to harden around the earbud, it actually was due to the misuse of the product. The silicone came with 2 bottles, and both had to be used for the silicone to harden properly, due to the misreading of instructions, only one of the bottles was used.

Both Element H and I were very similar with our problem, be how the results were going to be compiled. In the end the best form of testing and data collection was observations and subjective reasoning. Thus, to prevent bias, multiple users were used for testing with many different earbuds. One surprising factor was that the earbud tip made by our product was able to fit many kinds of earbuds and still work properly. Because of this reason, I believe that with some changes, the product made would be marketable.

Project and Process Evaluation

Each team member will complete a personal evaluation using a rubric containing 5 different points - Conceptual understanding, Strategies and Reasoning, Equipment and Materials, Work Habits. The data tables below contain the scoring of each member below. A description of each point/element will follow the scores.

Group Member 1

Elements	Weight	Score

Group Member 2

Elements	Weight	Score

Conceptual Understanding	1	4
Strategies and Reasoning	1	4
Equipment and Materials	1	4
Work Habits	1	4
Total		16
Average		4

Conceptual understanding	1	4
Strategies and Reasoning	1	4
Equipment and Materials	1	3
Work Habits	1	5
Total		16
Average		4

Group Member 3

Elements	Weight	Score
Conceptual understanding	1	3
Strategies and Reasoning	1	4
Equipment and Materials	1	4
Work Habits	1	4
Total		15
Average		3.75

Group Member 4

Elements	Weight	Score
Conceptual understanding	1	3
Strategies and Reasoning	1	4
Equipment and Materials	1	4
Work Habits	1	3
Total		14
Average		3.5

Element L

Future Improvements

- The method for applying the silicon to the outer portion of the memory foam core could've included additional or refined elements
- 3D printing of the reverse mold
  - Finding an accurate and effective structure for the supports
  - Don't have the printing preset of forming a baseplate onto the actual design
- *Material Study
  - Having an overall team understanding of how different materials interact with each other, with special regards to the project materials
- *More attention to design specifications/dimensions
  - Taking note of the initial constraints and features of each presented solution and adhering to them during modeling/construction

Prior to any physical modeling and construction of a solution, there were a couple of issues presented from the research and planning phases, namely with material study and design specifications/dimensions. After our group had come together, we each came up with 3 feasible problems that could be solved, then after deciding on one, we each designed 5 possible products to counter the problem. Once a solution was decided on, we split up to research materials to be implemented into our product. However, there was some slight confusion and misunderstanding when researching the desired materials, more specifically for their interactive properties with other materials.

Following all the construction and testing with our prototype, there has been a decent mix of positive and negative outcomes resulting from collective evaluations. One of the primary concerns that was highlighted was the issue of properly and efficiently pouring the silicon resin into the body of the reverse mold. In the earlier attempts, we would just try to pour the resin manually without assistance from a funnel. Expectedly, there was too much silicon that spilled around the outer portion of the reverse mold and couldn't get where it needed to. When considering a new solution or strategy for future processes, the best course of action would most likely be to either prebuild a funnel design onto the component's model or widen the entry point on the model to allow for effective use of an external funnel. The method we went with in the end was to create a different version of the reverse mold without the top cover. This allowed us to use a brush to coat the foam in silicone.

Another point in the project that presented significant challenges was when we had to 3D print the reverse mold of the silicon shell. At one point during the printing process, we decided to invert the orientation of how the reverse mold would be printed on the pad. This then warranted the need to decide on what kind of supports we would use to help keep it upright until it finished. One of the first support types that we chose was a root system that funneled downward into a single branch. This, however, did not end up working as a viable solution because as the 3D printer moved up the design, the root support's top-heavy design caused it to easily topple over and fall, leading us to halt the rest of the printing process and start over from the beginning. When considering a new solution or strategy for future processes, the best course of action would most likely be to incorporate angled supports, like we did in our project, that align closely with the main body of the component.

Along with the issue of being temporarily unable to find effective printing supports for the internal cross beams, our team encountered a slight dilemma when deciding on whether or not to use the default baseplate that is printed underneath each part/component. While the baseplate would provide a rigid base for each component to be built on, the process of removing the completed components from the baseplates often resulted in excess tears and shatters from separating the two. Eventually, though, we were able to utilize pliers and other hand-held gripping tools to precisely pry off the two components. While this did present a significant issue regarding the effectiveness of our printed components, it doesn't essentially warrant the need for recommending future design instructions.

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