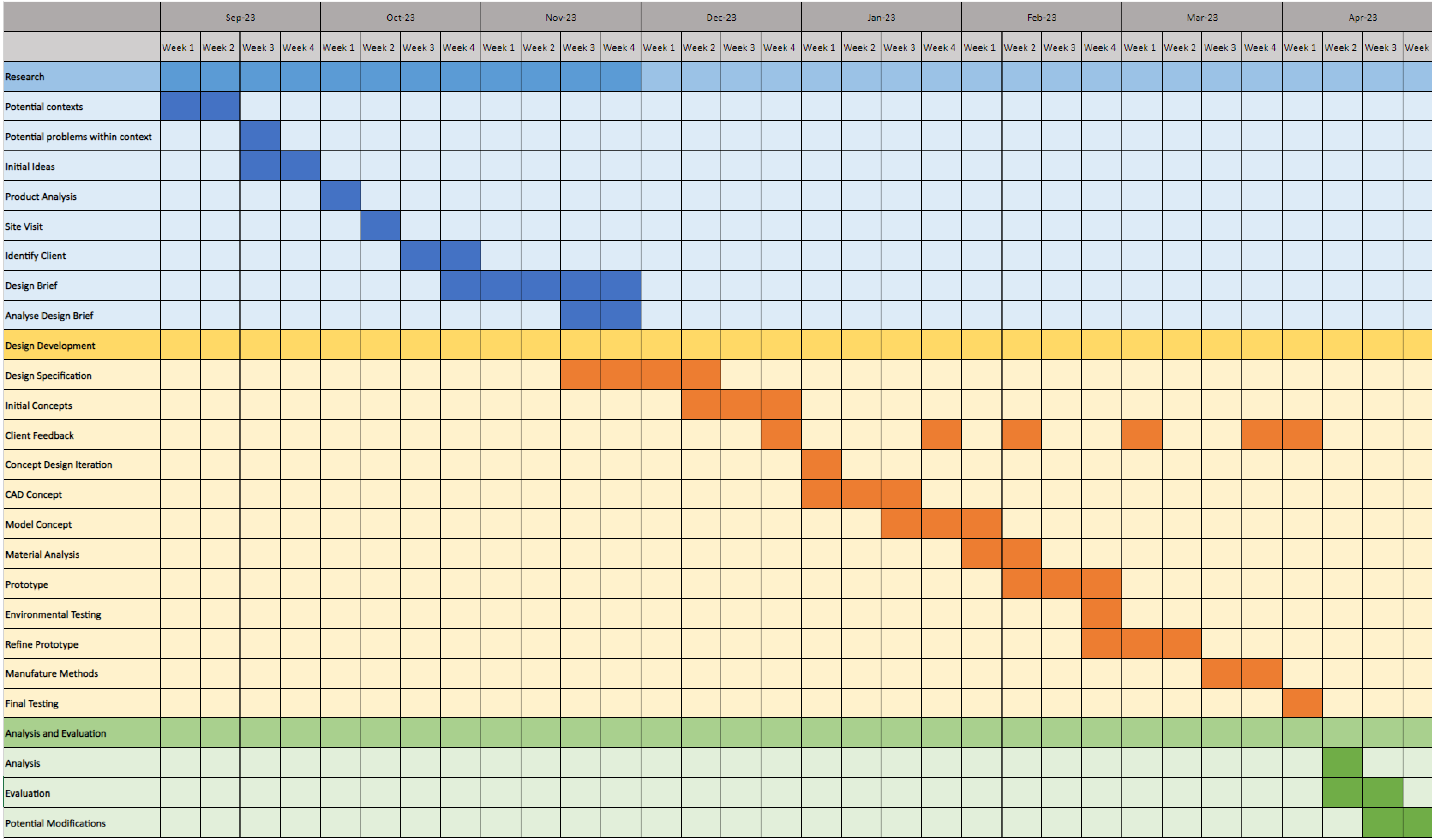
Leon Trowsdale

6358

Timeline



This timeline marks key parts of the project and when they are expected to be completed by. I will aim to follow this as closely as possible, however, as the project continues some parts may be added, removed or reordered to meet the desired outcome.

Some parts of the plan can be worked in conjunction with one another, these overlap on the timeline. Sections such as client feedback overlap as it influences the design development throughout. This is repeated multiple times so the client has an insight of the direction and current state of the product.

Conclusion

This has allowed me to organise my time frames effectively and keep track of different sections of the project. I can also provide this timeline to my client, so they know the design process and involvement throughout development, including when they expect to be contacted to provide feedback.

Initial Context Development: Potential Contexts

To begin the project, I needed to find possible problems that a product could solve. To do this I approached family and friends on issues they experienced in their day to day lives.

Of the problems mentioned during this process, four of them have been noted below to investigate further.

Client 1

“I often get woken up by my sister in the mornings which is not ideal, especially when there won't always be somebody to help. I have tried lights, alarms, haptics and all three together. I need a product that will solve this problem.”

Design Context:

Design and make a product that can help a consumer wake-up at a specific time if they often oversleep

Potential Solutions:

Water based
Electric based
Temperature based
Sleep longer

Client 2

“I’m tired of not being able to wear sunglasses on days where I don’t want to put contact lenses in. I have tried lots of glasses however all of them were either not wide enough to go over the other pair or there would be a gap between the two frames."

Design Context:

Design and make a product that allows consumers to have UV protection with prescription glasses

Potential Solutions:

Larger hollowed sunglasses
Apply to prescription glasses
Clip on

Client 3

“I enjoy flying drones as a hobby but have never felt comfortable with owning the batteries as they are known to cause aggressive fires”

Design Context:

Design and make a product that allow consumers to safely own lithium-ion batteries

Potential Solutions:

Extinguish fire
Contain fire
Safety/Handling information
Charging solution

Client 4

“Often when going on holiday, we buy inflatables to use in the sea, but when its time leave the country, the items are either too large or heavy to bring home and reuse another time so many have been left abroad.”

Design context:

Design and make a solution to portability of inflatable items

Potential Solutions:

Compacting solution
Lightweight inflatable

Conclusion

As a result of this exercise, I have decided to look further into the context of holiday waste as polymer disposal is becoming an increasingly prominent issue. On holiday I have had to leave products behind before, so it's easy to relate to the client's issue. A product descending from this context that positively impacts the environment would also give a sense of satisfaction during the process.

Initial Context Development: Holiday Waste

Client 4

"Often when going on holiday, we buy inflatables to use in the sea, but when its time leave the country, the items are either too large or heavy to bring home and reuse another time so many have been left abroad."

Design context:

Design and make a solution to portability of inflatable items

Potential Solutions:

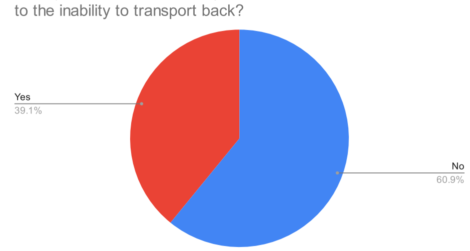
Compacting solution
Lightweight inflatable

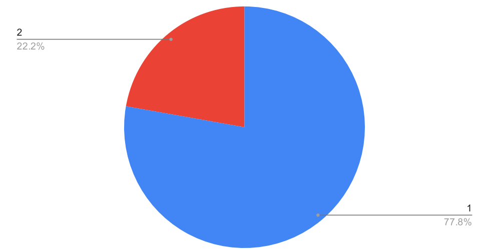
On many occasions when on holiday, we have purchased inflatables to be used while away. Unfortunately, due to the weight of these products many times we have had to leave them behind.

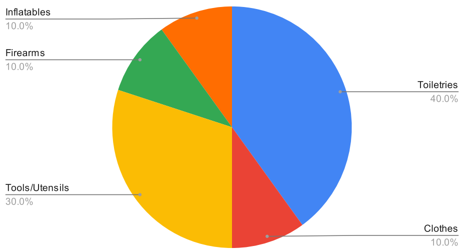
During my trip to Croatia, I noticed a considerable quantity of near-new items left on beaches. The pictures below are just a few examples of products that I found, I believe this could be due to the inability for people on holiday to take the items back to their home country since it would either make their luggage too heavy or there would be not enough space to accommodate them.

One item we found was a woven mat that we ended up using for a few days on the beach for comfort on the stones. Unfortunately, this also had to be left behind because luggage space was limited.

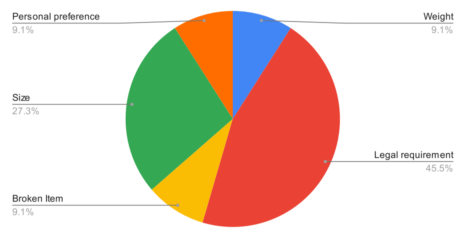
To further my research into this context I ran a survey around the topic. The survey had 23 responses (https://forms.gle/Q2hQZXyfQunnVMRL9). My hypothesis was that other people have had similar experiences to my own.

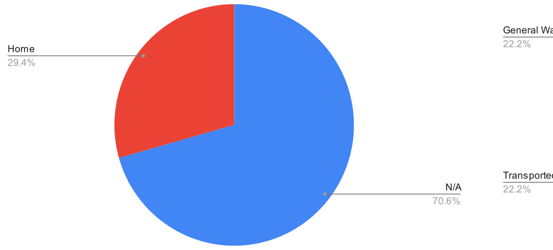


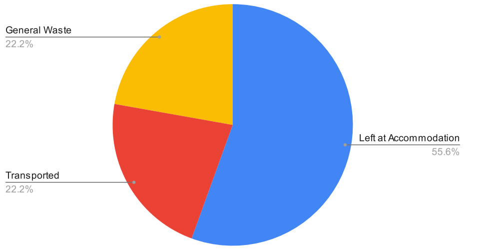




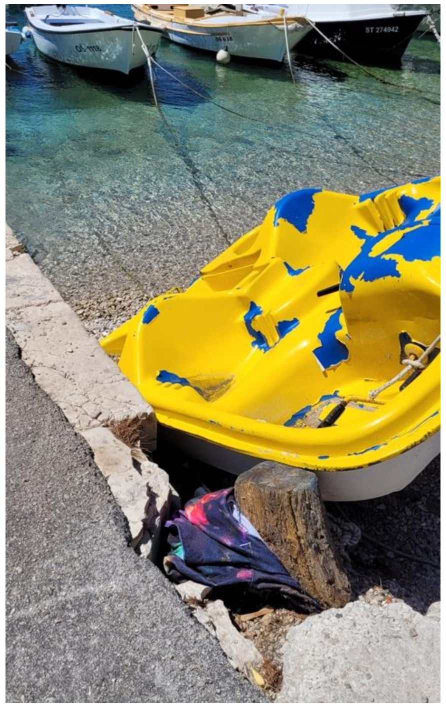
Overall, 40% of respondents, said they have left an item behind, and most have had this occur only once. The main item that was left behind happened to be toiletries which was a surprising result.

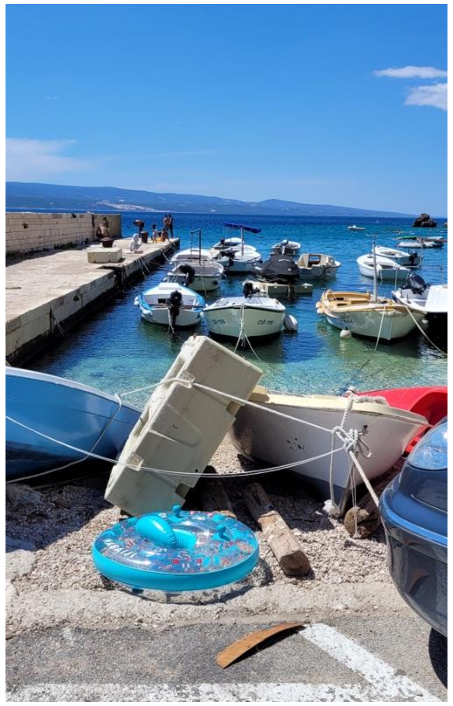


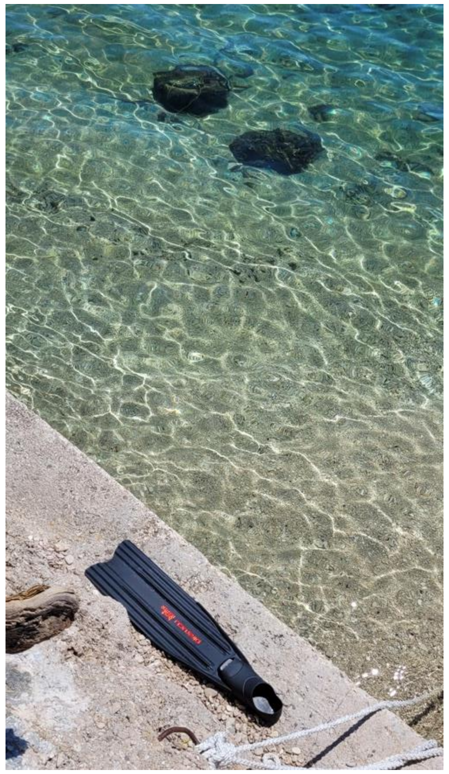




45% or respondents said their reason was legality related. Relating this to toiletries, most bottles of shampoo, soap, conditioner tend to be over 100ml in capacity. For safety reasons, airlines prohibit liquids over 100ml. This informed me that the issue I experienced is less common than expected,, however the other problem around airline regulation seems more prominent.







Conclusion

I have decided to not pursue this context partially due to the lack of demand to solve this problem, as well as the difficulty of creating a product around commercial airline laws and regulations. There are also existing companies that sell toiletries that contain under 100ml of liquid.

I am investigating Client 3's problem next, relating to lithium-ion batteries, because I also have an interest of drones which use similar batteries.

The Battery

Lithium batteries (LiPo/Li-ion) are a high energy density form of battery used in various small electronics like mobile devices and laptops. One specific use case for Lithium batteries are for drone electronics. The batteries designed for this use can provide the high discharge at a low weight and in small form needed for these electronics.

The battery packs are rated for different capacities (mAh) and voltage (V) indicated by how many cells are in the battery. These are used for different purposes depending on whether the user wants a longer battery life or higher power output. The capacity influences the battery life, and the voltage influences the power it can output.

Charging

To charge these batteries, you need a power supply and charger. The power supply provides the correct energy for the charger to operate. The charger is then set to the battery type and voltage then started. In most setups, only one battery can be charged at a time.

With typical chargers, when the voltage has reached the maximum, the unit will drop the current and indicate it has finished. These charger and power supply combinations tend to be large and heavy; this makes these inviable for travel. Since a lot of the drone market relates to filmmaking and travel, many need to transport to other countries. This will be investigated further.

Client 3

"I enjoy flying drones as a hobby but have never felt comfortable charging the batteries as they are known to cause aggressive fires"

Design Context:

Design and make a product that allow consumers to safely own lithium-ion batteries

Potential Solutions:

Extinguish fire
Contain fire

Thermal Runaway

Thermal runaway is the state of a battery when a current causes a rise in temperature, in turn, causing a rise in current and further rise in temperature in a repeating feedback loop. Thermal runaway can happen due to overcharging, overheating, physical damage or short-circuiting with most occurring during charging. The cells can burst, exposing the lithium to the air causing a chemical reaction. This reaction causes fluoride gas to be released which is then ignited during the reaction. This leads to a substantial fire up to temperatures reaching 500 degrees Celsius.

Existing Solutions

Due to the nature of these fires, they can be difficult to extinguish. The typical household will have a fire extinguisher however it's likely that it will be ABC class (rated for ordinary combustibles, flammable liquids and energized electrical equipment). Lithium fires require a class D extinguisher (rated for metal fires), designed to tackle combustible metals.

To combat this, lithium battery storage products are sold. These tend to be in the form of a bag though some more expensive solutions are made as a case. The purpose of these bags is to contain the fire. This is difficult because lithium battery fires emit a considerable amount of flammable fluoride gas. This causes a high-pressure buildup inside the bag meaning there must be a way for the pressure to be released. There have been reports of these type of products not functioning as intended, though further testing may have to be done.

Conclusion

This summary of the context has led me to think about certain aspects that need to be explored regarding the safety of lithium batteries, such as charger form, cause and nature of thermal runaway and the effectiveness of existing products.

Study on incident

A news article I read recently brought the issue into perspective for me.

The article recited the event of a fatal fire in East London that occurred on the 5th of march 2023. The fire started in a two bedroom flat in which at least eighteen people were living. The article outlined that a resident of the flat set the battery to charge before bed and a witness woke to sounds of spitting at 2:30am. The witness stated that neither blankets nor water would extinguish the reaction and said that it was “behaving like a rocket” and describing the “spurt of white and black smoke”.

Criminal investigation launched into fatal east London flat fire

One man died in fire on 5 March in two-bedroom flat where at least 18 people were living

The witness also mentioned, “Soon the whole flat was engulfed,” and, “Smoke was going in all directions. Everything happened in four or five minutes.” Sixteen people managed to escape the flat, however, one resident did not. The article states, “The moment we heard there was someone inside it was [awful] for all of us,” the witness said. “Especially the one whose battery it was. He was crying like crazy. His eyes were red. He was shaking.”

This, as a lithium-ion battery owner, puts into perspective how dangerous the technology can be, especially in a household environment with others around.

Other stories also resemble closely to the East London fire, the article also mentions two separate battery fire events,

In Merseyside in January, Rab Shearer and his son Gary were killed when an e-bike battery set to charge overnight caused a house fire. In South Yorkshire, a dozen fires since the start of 2020 have claimed two lives. Last September, Abdul Jabar Oryakhel, from Afghanistan, died falling from the top floor of a Bristol tower block after an e-bike started a blaze.

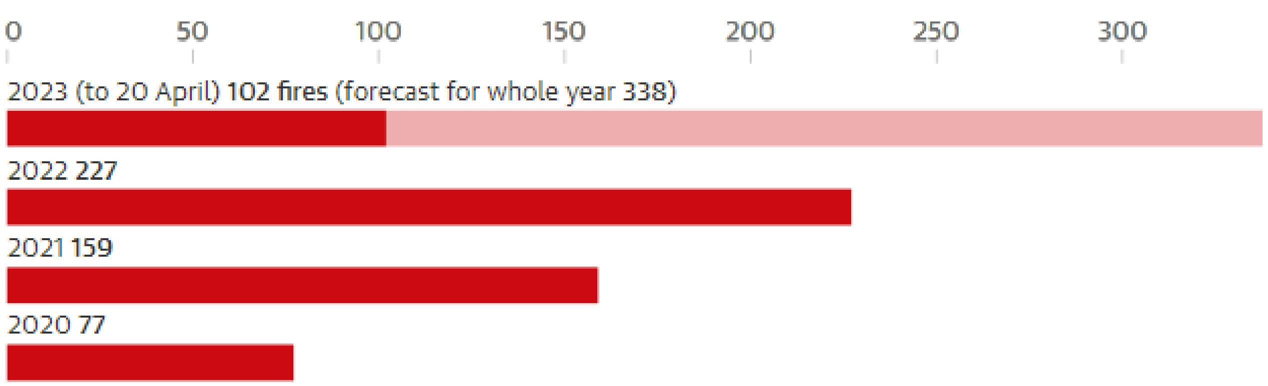
Information provided by the UK fire and rescue services show that the issue of battery fires is still increasing yearly.

From 2020 to mid-2023 the number of lithium-ion battery fires nearly quadrupled, and are 4x higher in Greater Manchester from 2020-2022, killing 6 people.

The fires typically occur due to low quality or incorrect chargers used on batteries, leading to overcharging or supplying too much current.

There have been 102 fires associated with e-bikes and scooters so far in 2023, with a forecast of 338 for the whole year

E-bike and e-scooter fires recorded by 38 UK fire and rescue services who responded to a Guardian freedom of information request



The crowded two bedroom flat before the fire occurred

https://www.theguardian.com/society/2023/mar/14/criminal-investigation-launched-into-fatal-east-london-flat-fire
https://www.theguardian.com/news/2023/may/02/e-bike-e-scooter-battery-fires-uk-data

Conclusion

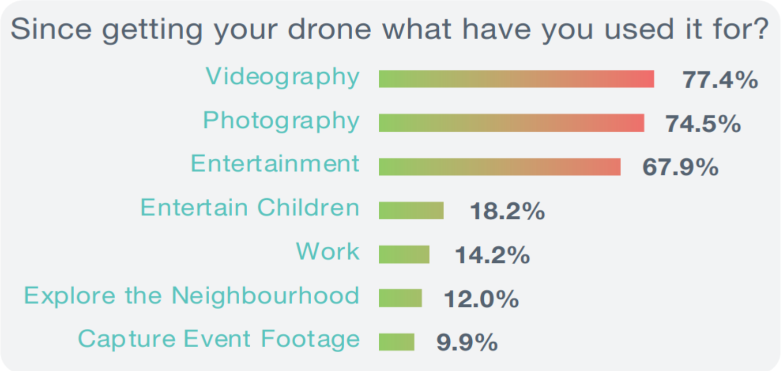
This information indicates that battery fires are a significant issue and a real problem, to the point people are losing their lives to the devices.

A product that can provide safety when charging the batteries would provide a positive contribution in the scene of lithium-ion safety.

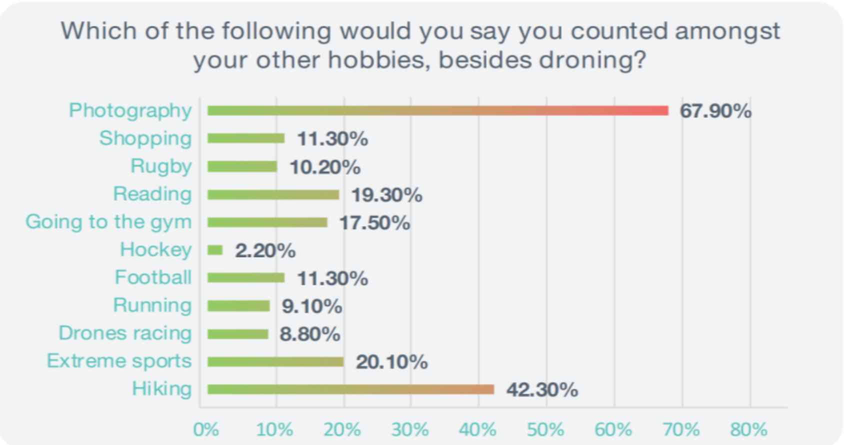
Initial Context Research

DronesDirect.co.uk (https://www.dronesdirect.co.uk/files/pdf/dronesreport.pdf) ran a survey on the drone market in 2016. Lots of data gathered by this survey has relevance with the target market of the product.

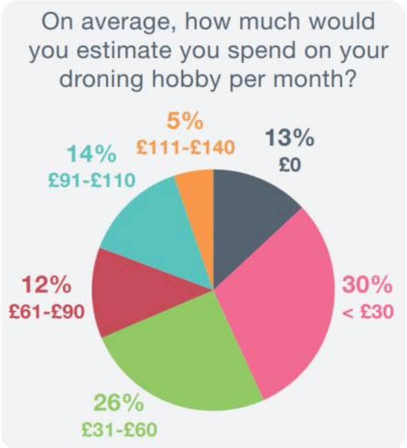
The survey outlined that the majority use-case for drones related to media of any kind (videography and photography)

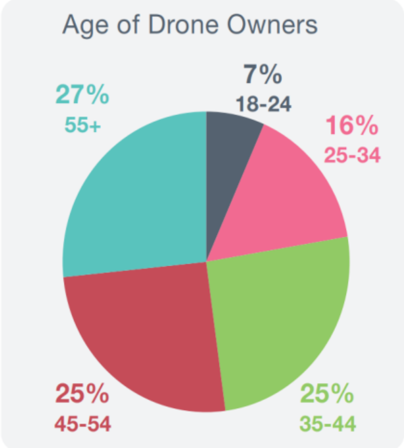


This correlates well with the alternative hobbies that drone owners have alongside flying, the majority being photography. The fact that hikers are also a large percentage of the sample could imply that the two go hand in hand. Hikers may bring their drone hiking for media purposes.



The survey also covered spending habits of the hobby, with 57% of drone owners estimated to spend upwards of £31 per month, with a smaller population of 19% that estimate spending upwards of £91 per month. The results of this show that the target market of this hobby is predominately people with a reasonable disposable income. This is also supported by the majority age demographic of drone owners being 55+, likely to have stable, higher earning jobs.





Further supporting the need for travel with reference to drones, many areas of the UK fall within restricted airspace for quadcopters and other UAV's.

The main rules state:

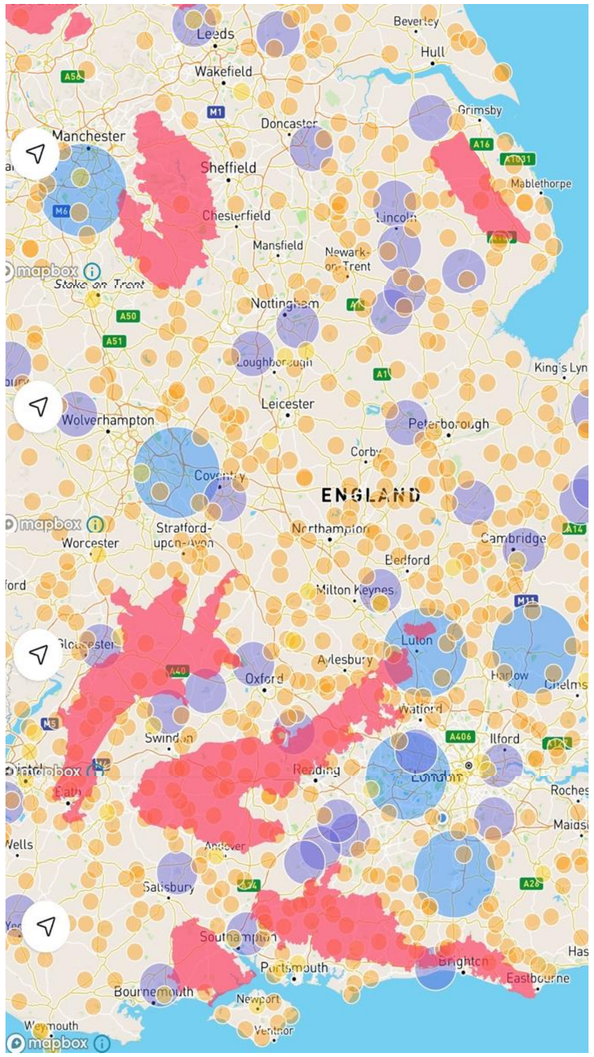
- No flying 50 meters from property
- No flying 50 meters from uninvolved persons
- No flying over crowds
- No flying 150 meters from residential, recreational, commercial and industrial sites
- No flying 5km from airports

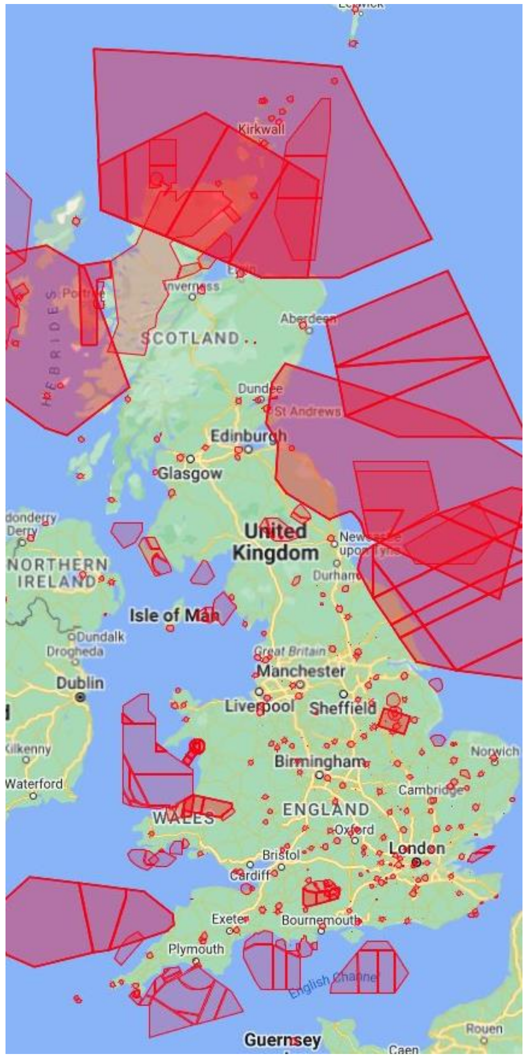
Restricted areas such as prisons, military, royal and government-controlled airspace are also no-fly zones.

The UK is also covered in SSSI (Sites of Special Scientific Interest) sites which are usually large open areas that would otherwise be ideal for flying, however they are restricted also.

These regulations around the devices also make it difficult to find places to fly, particularly for to those that enjoy or work in filmmaking with drones as they would be required to fly in scenic locations of which many are restricted. This could result in pilots travelling internationally for locations to fly, further supporting the need for portability.

The maps below shows areas where the airspace is restricted for flying UAV's





Conclusion

The result of this research has led me to pursue portability as a main factor of this design as travel covers a large area of the context. Since hikers also would use this product, it should be small and lightweight, preferably pocket-sized.

This research has also informed me that the price range of a product in this hobby should fall between £50-£100 justified that consumers are willing to spend £30 per month and the product is a one-time purchase.

Initial Context Research: Combatting Battery Fires

Lithium battery fires can be referred to as a highly exothermic reaction rather than a fire because they can continue to react even with absence of oxygen. This means they cannot be extinguished by conventional methods. There have been occurrences of battery fires such as those in electric vehicles where 30x the amount of water is required to extinguish compared to a conventional car fire. This leaves water to be insufficient for fires of this nature.

There are generally 2 methods to combat this form of fire. Using a Class D extinguisher or letting the battery combust in a controlled environment.

Class D fire extinguishers tend to be a specialist product for industrial use and come at a cost upwards of £500, this price-point would be greater than most consumer/hobbyist budgets. They contain a sodium chloride dry powder to create a thermal barrier between the heat and its surroundings. Not only are these extinguishers expensive but they typically come in a large capacity with masses upwards of 9kg.
https://www.fireprotectionshop.co.uk/p/fireshield-fire-ext-metal-spm-pyro-9kg-ms-sp-red.html?srsltid=AfmBOorIsAMVJcqPkdNraMIe1QRrkFMpoCfdeIFhk8ADoRuBTUNxIkeLl8A

Conclusion

The main issue with fire extinguishers is the lack of portability due to size and weight. This would not suit the context which involves travel.

Continuing the project, I will focus more attention on protection against the effects of thermal runaway instead of methods to extinguish it.

The other method for safely fighting the fire is to let it combust in a controlled environment. This is what the battery bags are designed to do. The battery bag below is the bag I have been using to store my Lithium-Polymer batteries. It has been used many times so is considerably worn.

This bag uses woven fibreglass as its fire-retardant material. It works well in this product since woven fibreglass is very flexible. Contrary to many other woven cloths, fibreglass does not ignite so cannot spread the fire. It also has a melting point of 1500 degrees which in theory should contain the fire for a suitable time.

The top corner of the bag contains an opening. This is a multifunctional design choice, to release pressure and to let the wires out when charging. The opening does seem to be too small to release the required pressure, however this will be revealed in the testing. A problem with this opening is the risk of flames being able to exit the bag, some solutions use a filter to combat this which will be looked at further into the project.

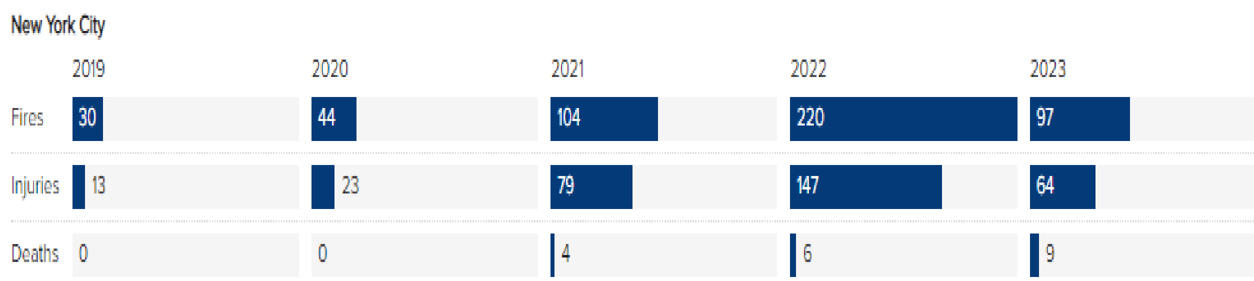
Another disadvantage to this product is the woven fibreglass. fibreglass is known to be aggravating to skin, microscopic fibreglass splinters cause itching and rashes. The material will have to be researched and tested for both fire retardance, flexibility, safety and weight.

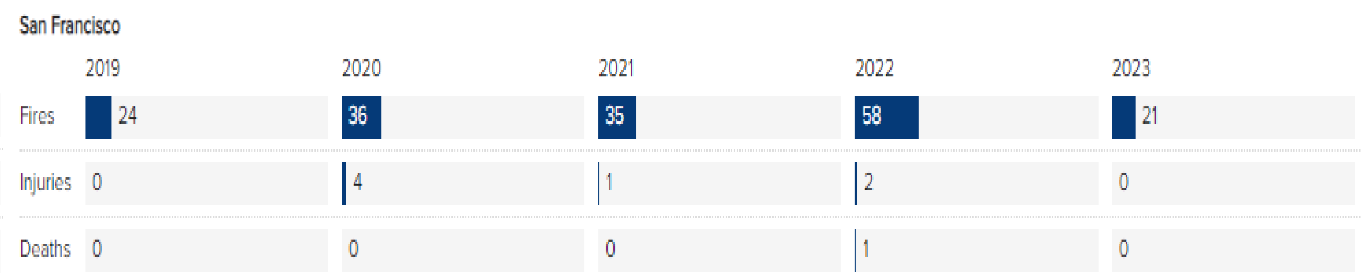
Initial Context Development: Problems

Scale of problem:

Worldwide, the demand for Lithium based batteries is projected to reach 4.7 terawatt hours by 2030 with the market valuing £205 billion. The insurer, Zurich, released data showing the number of fires caused by lithium ion batteries in the UK increased by 150% from 2021-2022. Since this market is increasing so rapidly, the demand for products that contribute to the safety of these batteries are increasing similarly. Methods to store commercial grade cells have been developed for larger products such as EV (Electric Vehicle) batteries, however, at a consumer level there aren't many options. It seems that battery safety is advancing much slower than the battery technology itself. The London Fire Brigade were called to 246 battery-related fire incidents between 2020-2022, and once every 2 days in 2023, with 119 reported by June.

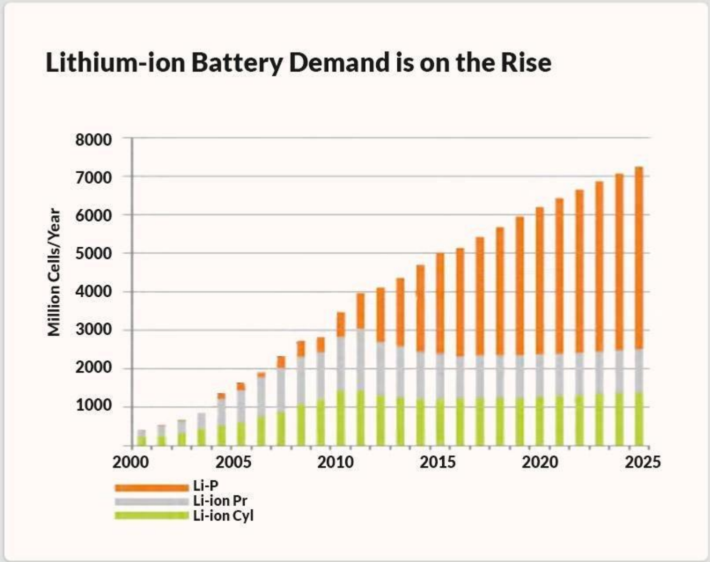
From 2019 to mid 2023 in New York City and San Francisco, the cities responded to at least 669 lithium-ion battery fires, ultimately causing at least 20 deaths and more than 300 injuries.





References:

- https://www.bruker.com/en/products-and-solutions/mr/nmr-epr-battery-research-and-manufacturing/structure-and-behavior-of-lithium-ion batteries.html#:~:text=Moreover%2C%20the%20global%20demand%20for,rising%20popularity%20of%20electric%20vehicles
- https://www.zurich.co.uk/media-centre/e-scooter-fires-caused-by-lithium-batteries
- https://www.london-fire.gov.uk/news/2023/august/new-record-high-of-e-bike-and-e-scooter-fires-in-london/
- https://www.cbsnews.com/news/lithium-ion-battery-fires-electric-cars-bikes-scooters-firefighters/
- https://www.techinsights.com/technical-capabilities/overview/markets-served/batteries
- https://www.researchgate.net/figure/The-global-lithium-ion-battery-market-size-is-estimated-to-touch-nearly-US-Dollars_fig1_336799279



Problems:

- Due to the options for consumer-based thermal runaway protection being slim, many hobbyists have resorted into creating their own methods of containment. A popular solution the problem is using ammunition cans as shown in Figure 1. The issue with this is the lack of airflow. If a battery were to set alight, the pressure buildup may cause the container to explode.
- Correctly treating the batteries can be complicated and overwhelming for new users. You must consider charging current, maximum voltage, minimum voltage, battery type, cell count, balancing, temperature, discharge rate, etc... If a battery user does not understand/follow the correct procedures for using the batteries, they risk their product entering thermal runaway, potentially causing harm.
- A large use of lithium batteries relate to drones which are often used for photography. Filmmakers and photographers tend to travel to sets or scenic locations as a large part of their hobby/job. Conventional methods of safely charging batteries are not portable enough to take abroad on a plane.

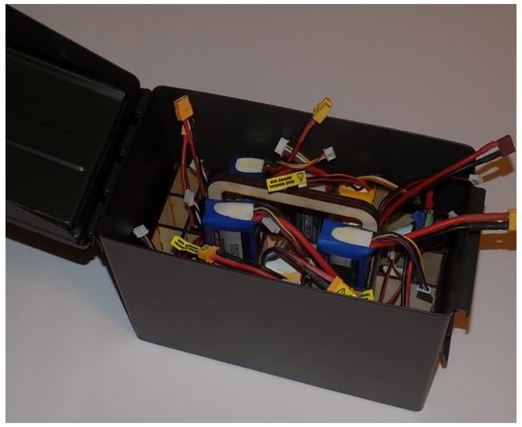


Figure 1

Conclusion

This research has led me to identify some key issues that the context involves. Throughout my project, I can focus more of my attention towards these specific problems, aiming to solve them will help structure my project so I achieve the desired end goal.

Design Brief

Brief

I am focusing my A-level design and make task on the safety of lithium batteries. These batteries are key aspect of drone designs, and many have never completely trusted the safety knowing the damage they can cause during thermal runaway. I will research and develop a safe method to reduce the damages lithium batteries can cause during thermal runaway.

- The product must be able to contain the fire from the battery so the surrounding area cannot ignite, potentially damaging property.
- The design must be portable, this includes keeping size and weight to a minimum. Ideally the product should fit a regular pocket.
- The design must be easy to use, especially for those that have little to no experience with these batteries.
- The design must be sized appropriately to contain at least one battery and have a form factor that can accommodate multiple shapes and sizes.
- Finally, the product must also include clear safety instructions on procedures in case of fire and methods to prevent it from occurring.

Analysis

I will need to investigate how lithium batteries react during thermal runaway including the temperatures and pressures that are created so the product can correctly contain the energy. This will involve making sure the materials used have a high enough melting point and are dense enough to stop the flames from escaping. This material or a separate materials should withstand the temperatures but also let air escape to release pressure.

Another aspect covered by the brief is portability involving the product being small and lightweight. Consequently, the materials used must be lightweight and possibly flexible if the design pivots that direction. Keeping the product portable is important due to the nature of the hobby as informed on slide 7.

To keep the design easy to use, it shouldn't add any complexity to the charging process. The product should also be quick to setup for charging, as easy as plugging in without the product. If the product has moving parts the mechanisms should be simple and smooth, especially for the large demographic of 55+ year olds who may have physical disadvantages.

Most occurrences of thermal runaway happen to be while the battery is charging and most chargers can only charge one battery at a time so only one battery is required to fit in the product. If the design leans more towards long term storage, larger designs need to be considered. Batteries are manufactured in many cuboid forms with some wider or longer than others, the design will have to reference different battery forms and ensure it can accommodate all of them.

The safety instructions must be clear. The user should be able to know what to do in the event of a fire, even during combustion. This likely means large text/images and bright colours. How to correctly charge, store and treat the batteries should also be indicated to prevent a fire. Information on maximum and minimum cell voltages can help the user when choosing the correct settings to enter on the charger before charging.

Conclusion

The points brought up here will influence a research plan used to identify further aspects of the project than need to be investigated. It will go into further detail and include the methods I will use to gather the information needed for the project.

This and the research will also contribute to the design specification when made later in the project.

Research Plan

Primary Secondary Primary and Secondary

Aim	Task	Source	Collection Method	Evidence	Conclusion
Identify potential problems/challenges in relation to lithium batteries	Look into potential issues that come with combating thermal runaway including safety risks and care information	From my initial context exploration, I can identify areas to focus my research into	Context analysis Online research	Slide 9	This research led me to identify the issues of consumer options, battery care, and portability.
Find general specifications of lithium batteries	Find typical sizing, standard connector types and battery cell count/capacities to set a maximum rating for the product	Product analysis on lithium batteries of varying sizes and brands designed for various uses	Product analysis	Slide 12	The minimum dimensions of the container must be 110mm by 35mm. Maximum rating of stored battery aimed at 50Wh.
Contact experts in the field	Get an insight into the issue from an expert in the field of lithium battery fires	Online research to find experts. Use refferals from other experts. Gather information using emails	Email	Slides 15, 16, 31	The experts provided valuable information regarding the nature of a fire, and the materials some products use.
Test an existing battery safety solutions	Analyse and evaluate how lithium battery bags perform during thermal runaway	Testing practically in a safe and controlled environment	Product analysis Case study Photographs	Slides 13, 14	Design flaws such as material choice and ventilation methods became apparent.
Commercial viability	Research the market of the product	Online research of sales, demographic, budgets	Online research Surveys	Slide 7	This research aided in justifying the need for portability, it also informed about the wealth of the target market.
Run a focus group session	Present my initial conceptual drawings in front of a group to obtain specific feedback	I can gather a group of the target market and get them to provide specific or general feedback about the initial concepts and other questions	Interview Drawings Questionnaire	Slide 26	The focus group provided feedback on the first prototype, leading to considerable design changes.
Ergonomics/anthropometrics	Research the target markets anthropometrics to create a size and shape that will be ergonomic for the market	Get the target market to use the product and give specific feedback about its comfort to use	Measurements Photographs moulds	Slide 38	The ergonomic research led me to settle on a circular design due to comfort and handling
Material research	Explore what materials are relevant to use in the project and how their properties can affect the functionality	I can test and prototype using the material by simulating the damages it would acquire during use	Online research Prototyping Stress testing	Slides 18, 45, 46, 48	I have settled on woven fibreglass for the flexible material, and mesh gauze for a filter. The main body will be aluminium.
Product analysis	Perform research on an existing solution for thermal runaway safety	Analyse how the product releases pressure, the materials it uses, its functionality and portability.	Online research Product evaluation	Slide 17	The Raclan box analysis provided information on base material and informed that extinguishing agents will not be used.

Lithium Battery Specifications

These are some examples of batteries that are made for hobbyist consumers. They range in size depending on the capacity and voltage of the battery but do have some universal properties.

Dimensions

All the batteries have a main power cable. The 3 larger batteries have an XT60 connector, and the smaller battery designed for micro quads has a 2pin JST connector. Some batteries use a XT90 connector for power delivery so this may be something to look at for universal use. Due to the larger batteries have multiple cells, they must also have a balance lead so the cells charge with even voltage. These use a JST connector, one being the positive cable and one ground connection out per cell.

Both the power and balance cables are around 10cm long. This must be considered when designing so the cables can reach a charger.

Capacity and Cells

All batteries have their specific capacities and cell counts. The higher the capacity, the more energy a battery can store, this would result in a more violent reaction during thermal runaway (this is further supported by the expert interview with Paul Christensen on slide 15). Capacity usually ranges between 450mAh and 4000mAh while cell count varies from 1 cell to 6 cell battery packs. To easily compare these different combinations of capacity and cell count, these batteries can also be measured in watt hours (Wh). When looking at lithium-ion polymer batteries, the typical voltage per cell lies at 3.7V, so a 3s battery would be 11.1V and a 4s battery would be at 14.8V. Because Power = Current x Voltage, if we multiply mAh and Voltage we get mWh, by dividing by 1000, we can get Wh. 1 Wh is also equal to 3600 Joules.

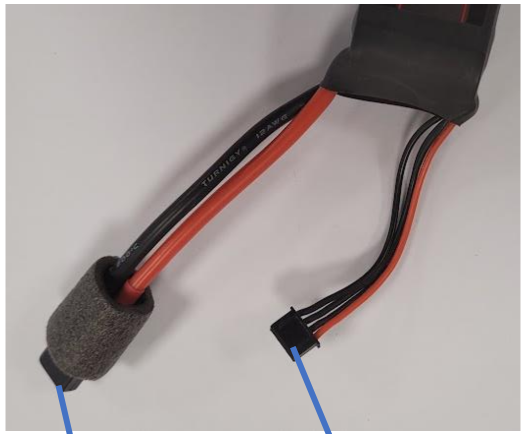
This consumer drone battery is rated 3500mAh at 11.55V so would contain 40.42Wh or 145530J.

The longest battery that will be considered throughout the project is a 3 cell Li-Po battery, measuring 110mm in length.

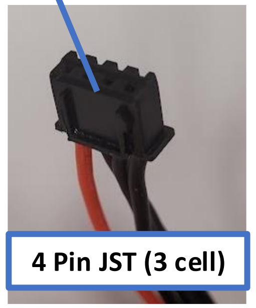
Longest

The widest battery that will be considered is a 4 cell Li-Po battery, measuring 35mm in width

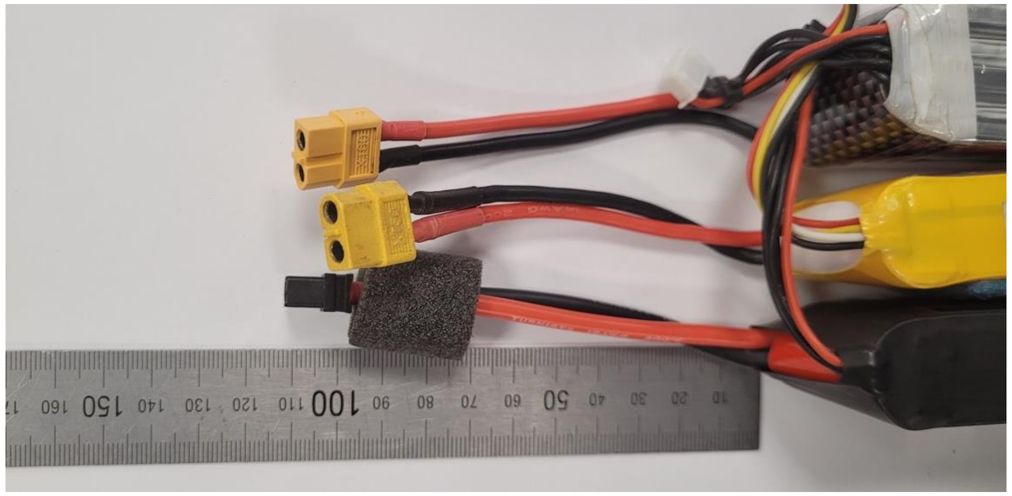
Widest



XT60



4 Pin JST (3 cell)



Conclusion

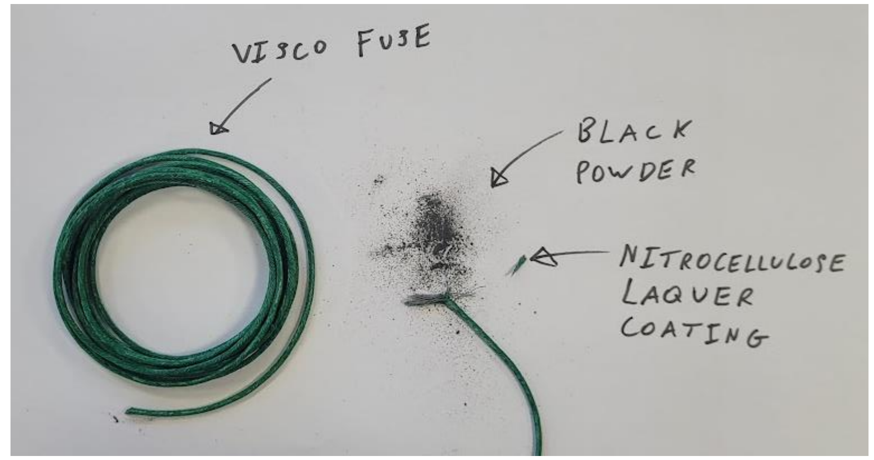
This battery research informed me of the dimensions a typical lithium battery has. The minimum length of the container must be 110mm and the minimum width must be 35mm. The length of the wire is relatively small so a method of extending the wire could be developed. It has also led me to set a maximum rating of battery that can be stored inside to be 50Wh.

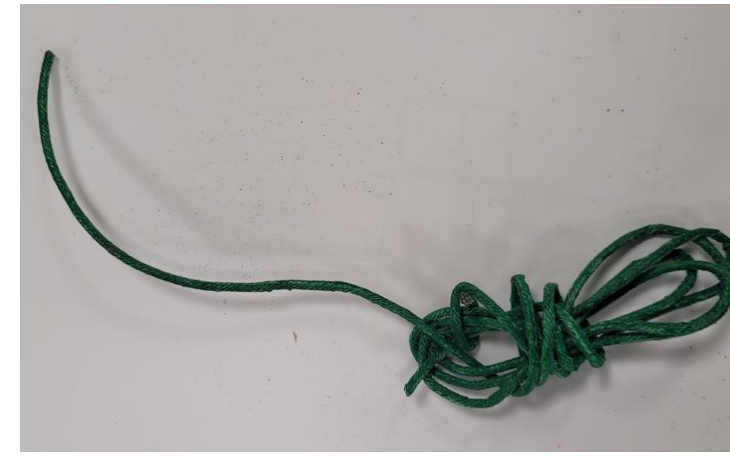
Destructive Testing: Battery Bag

To justify the validity of this problem, I tested an existing storage solution, a generic Li-Po bag.

Using a lithium polymer battery to perform this test would be a better representation to the performance of this bag, but due to the uncontrollable nature of the batteries it would be unsafe to do so. As a substitute to this, I used slow burning Visco fuse.

This the wound-up fuse can simulate both the high temperatures and combustion time which made it suitable for the testing. The burning is also very consistent so can be controlled safely.

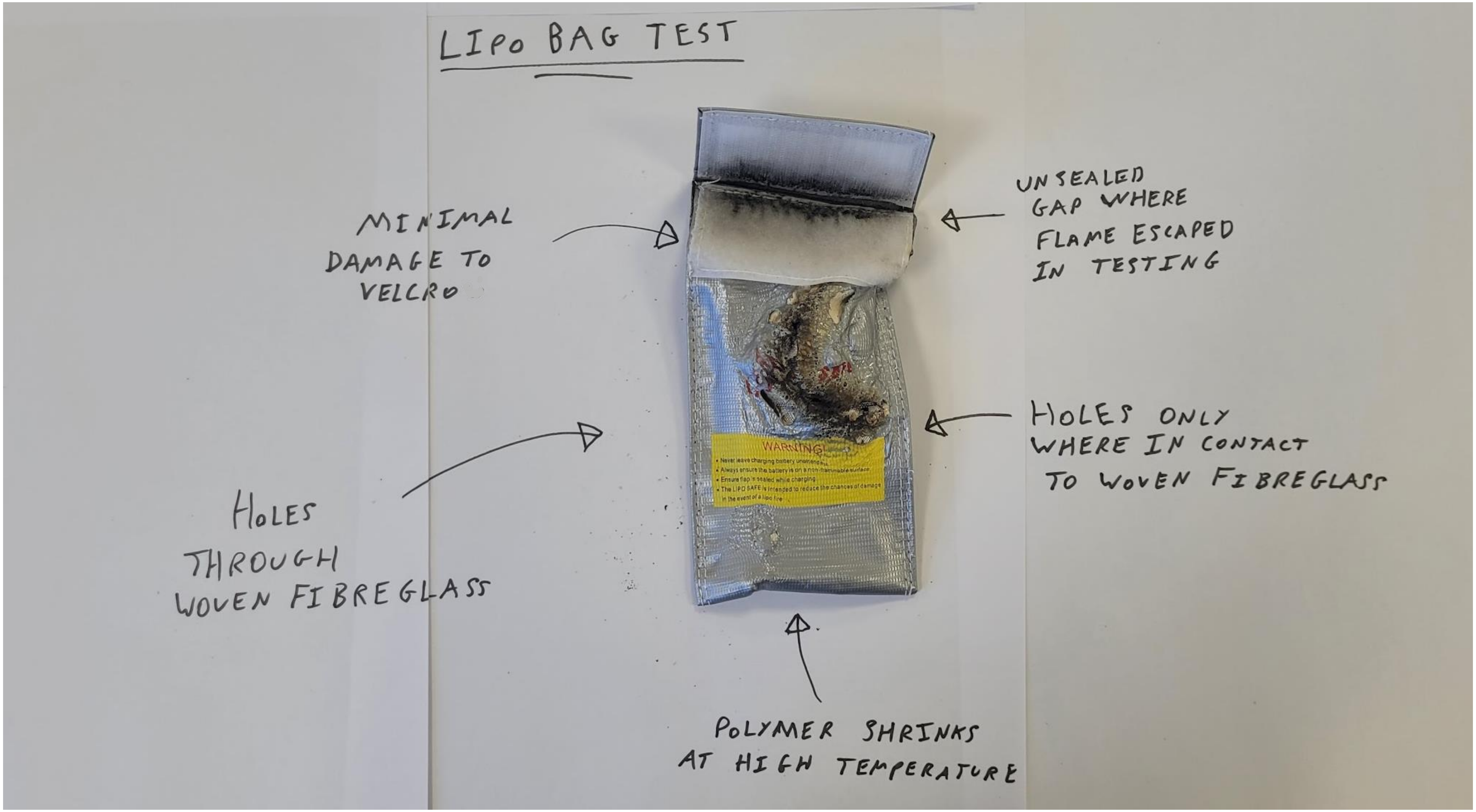




The testing resulted in many holes being made through the bag. As seen in the second picture, an open flame under high pressure escaped the bag which caused it to spin. If this were a lithium battery fire in a typical environment, it's likely the damages to the bag would have let open flames out from the bag for long enough to ignite a nearby item.

Overall, the testing was successful to show the storage solution is inadequate for the purpose of protecting against a battery fire

Destructive Testing: Battery Bag



Conclusion

Various issues with this design became apparent during the destructive testing. Although the material used to line the bag is woven fibreglass which has a melting point greater than 500 degrees, the material used is very thin. Due to this, holes were created in the bag.

Another issue with the bag is the method of pressure release. There is no obstruction for fire in the vent so flames are visible. A product like this should contain some sort of flame arrestor.

There is also a lack of safety information visible which could prevent thermal runaway in the first place.

Expert Interview – Paul Christensen

To gain a better insight on material choice and ventilation methods I contacted Paul Christensen, an Electrochemistry Newcastle University Professor. We had a voice call, transcript can be seen below:

MY EXPERIENCE

I am the Senior Advisor to the National Fire Chief's Council and a member of the BEIS Energy Storage Health & Safety Governance and BEIS Storage Safety – Fire Service Working Groups, and Derbyshire Police Electric Vehicle Safety Group. I advised Nissan on all aspects of lithium-ion safety during the construction and commissioning of the battery plant in Washington, UK.

I am a consultant on emerging risk to companies in diverse markets.

Member of the Cross-Government Technical Steering Group for EV Safety

https://lithiumionsafety.co.uk/experience/

Paul Christensen

Conversation

Leon: Hi Paul, thanks for finding the time for a call with me.

Paul: Hi Leon, nice to meet you, I presume this is for lithium-ion batteries.

Leon: Its between lithium-ion and lithium-polymer batteries .

Paul: Well lithium polymer is lithium ion, they have exactly the same chemistry.

Leon: Okay that's great to know thank you.

Paul: Next question is what rating cells will the product aim to contain. You're going to be storing the maximum rating in terms of the charge stored, which is in ampere hours, and you know that I times T is charge, so an ampere hour is 3,600 coulombs. You either have a rating in ampere hours so a typical powerful cylindrical cell would be about two to three ampere hours or you have it in energy stored which is in watt hours. Watt hours is the charge times the average voltage because energy is V times I times T. So have you got a feel for what you're going to be storing, how big these are going to be or are you going to set the limit yourself.

Leon: I'm looking more towards small hobbyist batteries, mainly used in drones.

Paul: This will be 2 ampere hours for that so all you're really going to be worried about is fire because for two ampere hours you'll get around four liters of gas if it goes into thermal run away without ignition. Now four liters of gas is not much so you're more concerned about if that gas immediately ignites and what you've got is a blow torch coming out of the back. Next question from you this time.

Leon: For the ventilation I'm not quite sure what I'm looking for, I've been seeing solutions like flame arresters which will allow gas through but stop the flame or prevent from igniting on the other side. The problem with those is that they are typically industrial products so its difficult to get my hands on one them.

Paul: What you might want to do, you know that air that all aircraft carry bags now for lithium-ion batteries so you could try contacting your local friendly airline and ask them what they use, and they may even give you a sample. They all have them for mobile phones and small battery packs.

Leon: The last part is the product material is a lining that is not porous, so just something to hold the heat for the duration of thermal runaway.

Paul: Well what I would do is contact fireblanket.com, David Smyth, it's a company in Ireland that I've had a lot of contact with, David's a lovely fellow, they produced fire blankets which do exactly that, so you ask him about the materials they use, mention my name.

Leon: Another company I found is called cellblock fcs I'm sure you've heard of them, I think they're a big company. Would they be worth looking into?

Paul: Yeah you got to be a bit careful because they use like glass beads and things so possibly it's not quite thing for you

Leon: Great, thanks Paul.

Paul: No problem Leon, good luck with your project.

Conclusion

From this research I found that roughly 4 litres of gas is produced from a battery of this scale during thermal runaway. I wil contact David Smyth from FireBlanket to find more information regarding material choice. Unfortunately, after contacting an airline, they never replied, I will have to gather this information from secondary sources.

Expert Interview – David Smyth

After receiving the recommendation from Paul Christensen to contact David Smyth, Managing Director at https://VehicleFireBlanket.com, I sent him an email regarding material choices in their products. The emails can be seen below:

David Smyth

Leon Trowsdale <leon.trowsdale.uk@gmail.com>
to info

Fri, 22 Mar, 10:44 (3 days ago)

To David Smyth,

I'm a student in the UK currently studying for my A-Levels. For my product design course, I have chosen to do a project around the safety of small lithium-ion hobbyist batteries that range up to 4s 4000mah capacity. The project has led me to design a small, portable container to place the battery while charging. The product should be able to mitigate all damages to potential surroundings outside of the container should the battery experience thermal runaway.

I've just gotten off a call with Paul Christensen, a professor at Newcastle University and he mentioned your name to get in touch with.

Since thermal runaway causes a significant amount of gases to be released, during testing of a typical Li-Po storage bag, the pressure caused flames to escape the vents. For my product, I will have to find a material that can release pressure from the container yet also prevent flames from escaping. Do you happen to know of any materials/components that work for this?

For the main body of the product, I will also need a flexible fire retardant material since the design is collapsible. The generic storage bags online are made from woven fiberglass however I've come across other materials that suit the same function such as silica fiber, refrasil cloth and PTFE fabric. Do you have experience in any of these materials for further insight into their suitability? It would be great to understand the composition of the fire blankets you manufacture.

Vehicle Fire Blanket
to me

11:52 (2 hours ago)

Hi Leon,

Thank you for your interest in our products.

We are working with a German company and selling products specifically for Lithium Battery Fires.
Have a look at https://fisacon.com/ & https://lithiumbatterybox.com/.
Also check out their LinkedIn posts. See below link to one of their recent LinkedIn posts, they have included a video of products that claim to contain battery fires but cannot.
https://www.linkedin.com/posts/fisacon-gmbh_lithiumbattery-lithiumionbattery-batteries-activity-7175051046833037313-vJlV?utm_source=share&utm_medium=member_desktop
You can see from this demo the energy contained and the difficulties involved with your project.

See also attached the spec sheet for the standards car fire blanket & Pro X fire blanket material & temperatures.

Kind Regards,
David

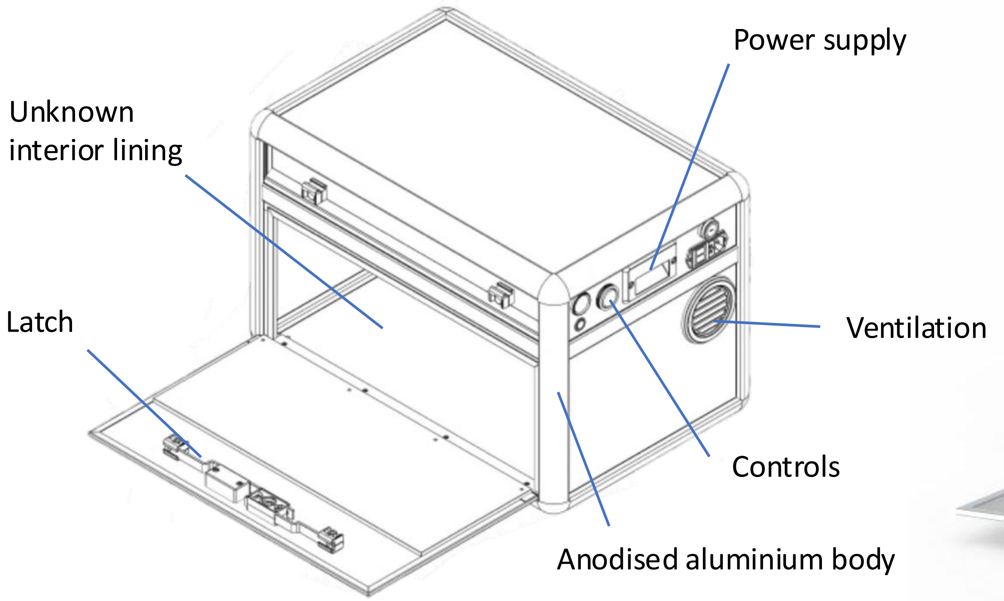
Conclusion

From looking at both companies David sent me, it seems lithiumbatterybox.com is a distributor for the first company, FISACON. I will perform a product analysis on one of their products to identify what methods they put in place, and whether there's any possibility of integrating any ideas into my own project. The specification sheet sent over will be referenced when looking into material choices.

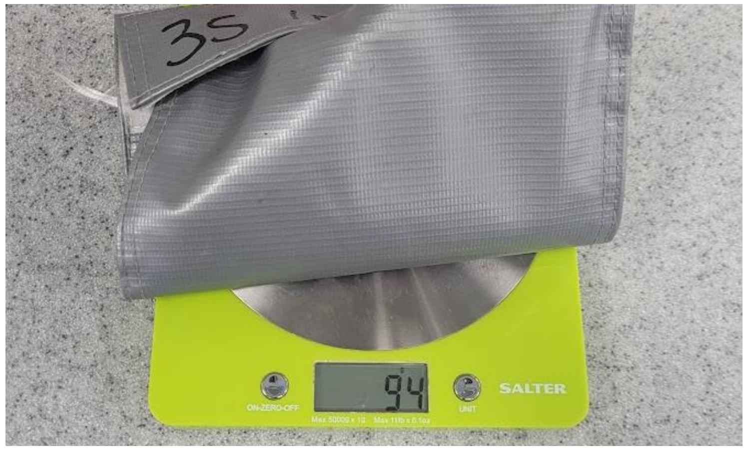
Product Analysis - FISACON

As mentioned in the expert interview with David Smyth, a company called FISACON (https://fisacon.com/) sells products that achieve the same function of protecting against thermal runaway dangers. To get a better understanding of the standards they use to ensure safety, I will look at the materials, methods of pressure release and form factor.

Their top product is the Raclan Box. This case is design for home use when charging larger batteries for power tools/E-Bike batteries. The battery and its charger is placed inside with the lid closed, and power is plugged into the box itself. The product can monitor the conditions inside such as temperature and smoke, setting off an alarm if these reading indicate thermal runaway. The Raclan also contains an extinguishing agent which is also released when triggered by thermal runaway.



The product dimensions are 580x380x380mm and weighs 24.7kg. At this scale, the Raclan cannot be considered a portable solution. For comparison, the cheap battery bag weighs 94g.



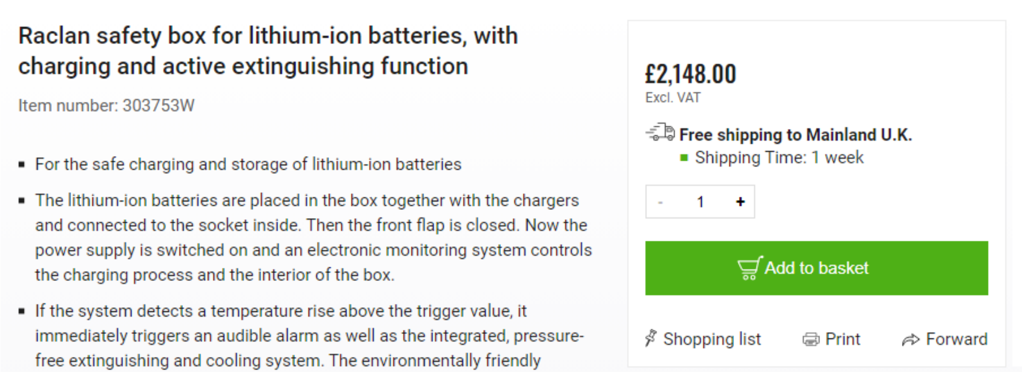
The case is rated for 1750Wh, much larger than the aim of 50Wh for this project. It seems the Raclan is widely used on boats/yachts for electronic water sports equipment or used by companies who need to store and charge large quantities of lithium-ion batteries

Materials

The box is stated to be made from an undisclosed “fire-proof and explosion-proof composite” however another product page mentions a main material being anodised aluminium. This seems reasonable since aluminium has a high melting point and is a relatively lightweight material. Little research has been done of the emissions of lithium battery fires but those that have reveal many forms of hydrogen compounds which can cause harm when exposed to, the ventilation aims to reduce harmful chemicals being released however there is very minimal information on the technical specifications.

Price

Unfortunately a quote is needed to obtain a price for the product however 3rd party sellers have listings reaching upwards of £2000. This is far from a hobbyist consumer’s budget so would not be a suitable product.

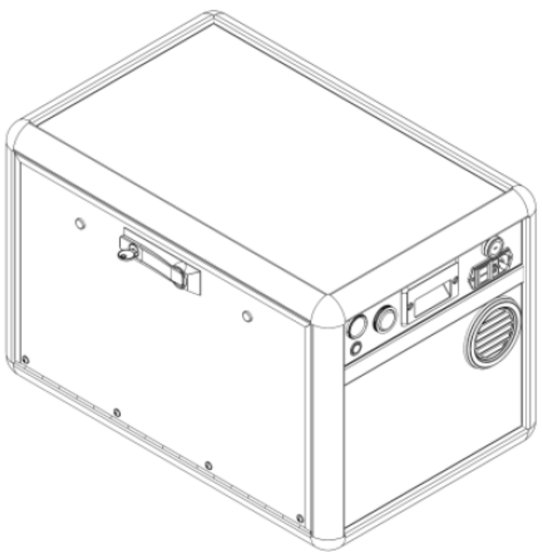


Raclan safety box for lithium-ion batteries, with charging and active extinguishing function

Item number: 303753W

- For the safe charging and storage of lithium-ion batteries
- The lithium-ion batteries are placed in the box together with the chargers and connected to the socket inside. Then the front flap is closed. Now the power supply is switched on and an electronic monitoring system controls the charging process and the interior of the box.
- If the system detects a temperature rise above the trigger value, it immediately triggers an audible alarm as well as the integrated, pressure-free extinguishing and cooling system. The environmentally friendly

£2,148.00
Excl. VAT
Free shipping to Mainland U.K.
Shipping Time: 1 week
- 1 +
Add to basket
Shopping list Print Forward



Conclusion

The Raclan box seems to be a great solution for large scale batteries for companies to use or for use on boats, however in the context of small consumer batteries it lacks portability and comes at a very steep price. When looking into materials for manufacture, aluminium will be considered as it seems to work as intended for this product. To keep portability low, the mechanisms responsible for distributing extinguishing agent won't be possible in this project.

https://www.denios.co.uk/raclan-safety-box-for-lithium-ion-batteries-with-charging-and-active-extinguishing-function-303753/303753

Material Research

David Smyth from vehiclefireblanket.com sent over the specification for two of their products. Both are large fire-blankets used to extinguish both engine and electric vehicles fires.

CAR PRO X

EXTREMESERIES	For professionals
Size:	± 6 x 8 meters (48 m²)
Weight:	± 28 kg
Core material:	340 gsm graphite
Coating	± 160 gsm silicon polymer (Flames may occur during first time use) In fires with high levels of conduction heat, flames may appear from the coating of the blanket. This will not alter the purpose of the blanket.
Edge of blanket:	Eyelets every meter for when using the fire blanket as a fire sail
Car sizes:	Handles normal size vehicles up to SUVs such as Land Rovers, XC90 etc.
Main usage:	• As fire blanket: Cover any object to quickly block fire • As fire sail: Put vertically on any object to block spread of fire
Smartbag:	Airtight bag. Smartbag car and maintenance: Use silicon grease on the zipper to keep the bag airtight and smell free.

Technical Specification

Core Fabric			Unit	Tolerance
Yarn	Warp Weft	396 396	Tex Tex	± 5 ± 5
Yarn count	Warp Weft	4.5 4.0	Ends/cm Ends/cm	± 5 ± 5
Tensile strength	Warp Weft	3000 3600	N/50mm N/50mm	≥ ≥
Area weight	-	340	G/m2	± 10%
Thickness	-	0.32	Mm	± 5%
Weave pattern				4H satin
Service temperature on core fabric	Melting point ± 2500 °C Working temperatures ± 1500 °C			

TECHNICAL SHEET

CAR STANDARD

For First Responders	
SKU:	101251
Size:	± 6 x 8 meters (48 m²)
Weight:	± 28 kg
Core material:	380 gsm pyroxene
Coating	± 120 silicon polymer (flames may occur during the first-time use). In fires with high levels of conduction heat, flames may appear from the coating of the fire blanket. This will not alter the performance of the fire blanket.
Car sizes:	Handles cars up to normal SUV size like Land Rover, XC90 etc.
Main usage:	• Fossil fuel vehicles • Electric/hybrid vehicles
Smartbag:	Airtight bag. Smartbag care and maintenance: Use silicon grease on the zipper to keep the bag airtight and smell free.

Technical specification:

Core Fabric			Unit	Tolerance
Yarn	Warp Weft	300 165	Tex Tex	± 5%
Yarn count	Warp Weft	8.0 8.0	Ends/cm Ends/cm	± 5%
Tensile strength (typical)	Warp Weft	3200 N/cm 2500 N/cm	N/50mm N/50mm	≥
Thickness	–	0.40	Mm	± 5%
Weave pattern	–	Plain	–	–
Service temperature on core Fabric	Short Term **± 1600 °C** Long Term **± 800 °C**			

BridgeTech™

Car Fire blankets

Car Pro X

The core material for the Car Pro X specifies 340gsm graphite. Gsm (referring to grams per square metre) relates solely to fabric and paper, however after further research looking into this material, I cannot find any results for graphite in the form of fabric or paper. There are however forms of fibreglass fabric which are coated with a layer of graphite. The composite is stated to have an 800 degree continuous working temperature

Graphite Coated Fiberglass Cloth 1000°C

★★★★★ 1 REVIEW

S-G/CL/GRAPH

Graphite Fiberglass Cloth. Incorporating graphite with the glass fibre increases the short term temperature resistance to 1000°C short-duration working temperature/ 800°C continuous working temp. Has excellent abrasion resistance. Suitable for making heat proof quilts and welding defenders.

Please input number of metres required (50M per roll)

Qty − 1 +

Car Standard

After looking for the 380gsm pyroxene used in the Car Standard fire blanket, no results of any fabric form or composite exist that include pyroxene as on of their constituents. The only results that appear relate to this company specifically. Possibly it's a material specifically developed by vehiclefireblanket.com. Pyroxenes are a very common group of minerals that are naturally formed.

THE PYROXENE GROUP OF MINERALS

Conclusion

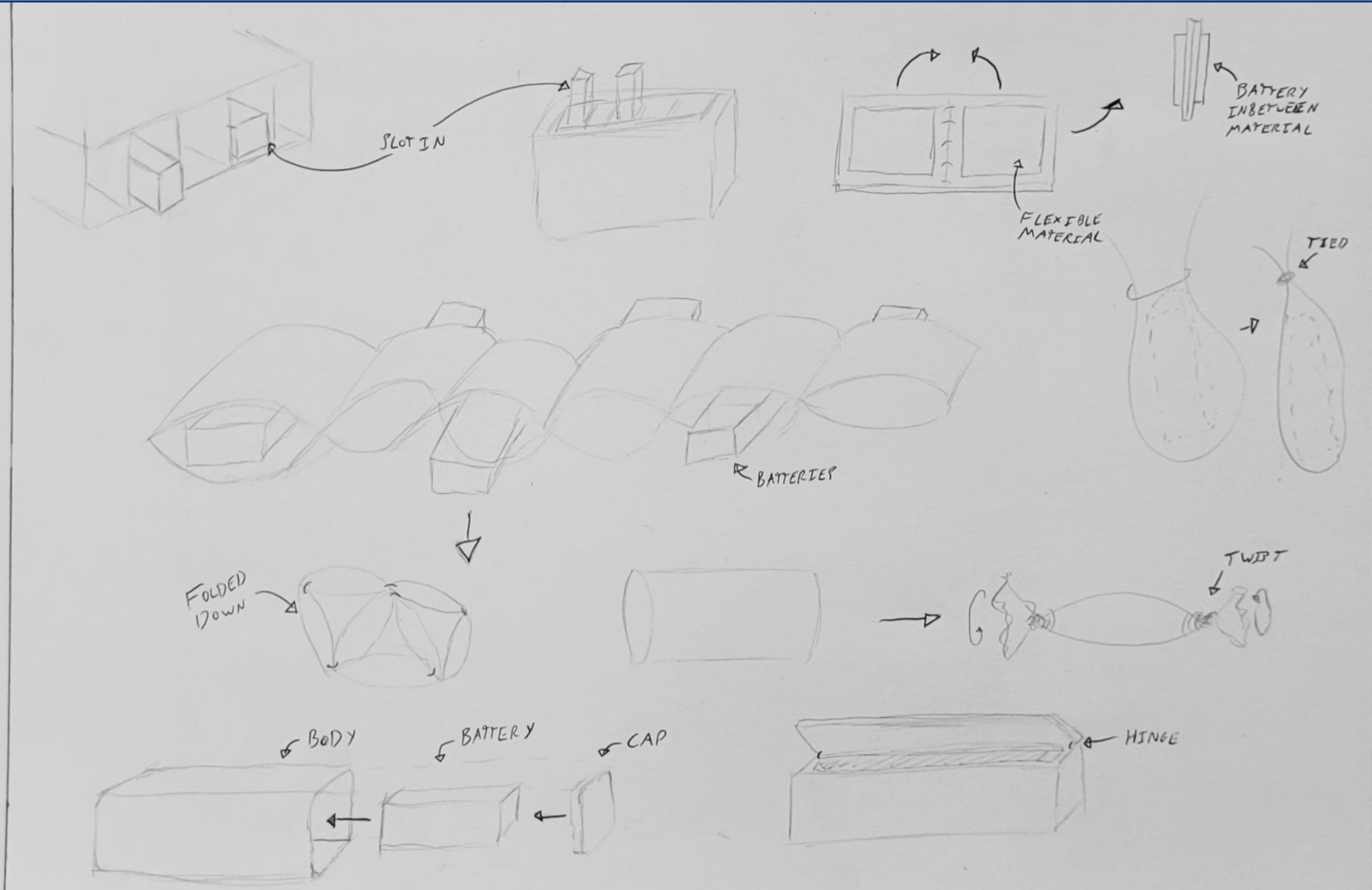
The majority of woven fibreglass fabrics seem promising in terms of temperature resistance so will be looked into further on in the project. Unfortunately, the obscure material used in Car Standard made it difficult to retrieve any useful information regarding material choice.

https://shop.vitcas.com/graphite-fibreglass-cloth.html?gad_source=1&gclid=CjwKCAjwt-OwBhBnEiwAgwzrUoG9KPnHo70OfGJbce38H3ASplxMdK1xN7GhEOl26feZHi8SPGBuLhoCj9EQAvD_BwE

Design Specification

Criteria	Justification	Solution	Evidence	Conclusion
Must mitigate the effects on a fire from a lithium-based battery experiencing thermal runaway.	There have been reports of these fires causing house fires, sometimes resulting in injury or death. Containing the fire is crucial to prevent this.	A flexible fire-retardant material, resistant up to 500 degrees C will be used to contain the temperatures produced.	Slide 46	Woven fiberglass resulted in being the preferred material due to its ideal flexibility and thermal resistance.
Must release pressure from gas release.	Lithium-based batteries release gas during thermal runaway. In a sealed environment, pressure increases rapidly, possibly causing an explosion. Some sort of ventilation is needed to prevent this from occurring.	A semi-permeable material is needed that air can pass through, yet flames cannot. Materials such as metal-based foam or gas filters would suit the purpose. The material should also be lightweight, as stated by the next criteria.	Slide 48	Mesh gauze has been decided on for the filter material as it is lightweight, inexpensive and can filter out flames.
Must be portable in both size and weight.	Many pilots, especially those who fly professionally, travel to scenic locations for filmmaking. These areas can be far from where they live, sometimes abroad. The design must be able to be taken on carry-on luggage under airline restrictions.	Designing a way for the product to compact into a smaller form factor than the battery itself. This could be through compression or folding. The product should also only use materials that are lightweight and avoid unnecessary material use.	Slide 33	In Prototype 4 I decided to integrate a large diameter spring into the design so the product can compress into a smaller, more portable form factor.
Must be able to accommodate one battery of ranging types.	Lithium batteries come in many shape forms. Some of the largest are high-capacity Li-Po batteries. The product only needs to contain one because lithium batteries are most volatile while charging, other batteries that are not charging can be stored with a less secure, alternative solution.	Research the range of sizes and connectors that lithium-based batteries are sold in. The maximum and minimum sized battery should be recorded so the product can be sized appropriately. The product should also have the correct ports or sized holes for various types of lithium batteries.	Slide 36	Prototype 5 introduces an increase in diameter to comfortably fit a larger 6 cell battery.
Must include appropriate method for charging to occur.	For the battery to charge while in the enclosure, there must be the ability for the wires from a charger to enter the product, where the battery can be found. It's important to consider the compromises a hole in the product may have on its overall seal.	Either a hole or internal wiring can be a solution to this. A hole could introduce issues regarding its fire containment so wiring the product could be a viable solution. The product would have its own XT60 male port on the interior and XT60 female port on its exterior. This could also prevent damage to the charging unit.	Slide 43	In Prototype 9, the design finalised the XT60 mounting port with a large lip and correctly sized holes for the wires to exit the product.
Must be priced appropriately for target market	Drone flying is becoming an increasingly expensive hobby due to fast advances in its technology. Due to this many hobbyists/professionals have decent disposable income. Since battery safety is necessary purchase, the product can be priced steeper.	The aim for this product's price is £60 which is priced just under the cost of a battery. This price is easily justifiable relative to the cost of damages if a battery fire were to occur. The cost also needs to be considered while choosing materials and parts used for manufacture.	Slide 7	The price has been set as £60 due to the demographic being higher earning on average.
Must include safety information regarding Li-Po care.	It's important that the user of the battery is aware of the danger's lithium batteries are capable of and how to prevent thermal runaway. These batteries can be very safe if treated correctly.	The information should be presented clearly on the outside of the product in large text and/or infographics. Bright colours may be used to attract attention. Information such as ideal temperatures, warnings of puncture. Maximum, minimum, and storage cell voltage could also be referenced here too.	Slide 49	An infographic has been made to inform the user of important voltage ranges and charging settings to avoid thermal runaway from starting during charging.
Possibly a method of alerting the user of a thermal runaway occurrence.	If possible, it would be beneficial if the user could be alerted by the product if a battery undergoes thermal runaway. This could give the user a chance to perform appropriate measures to ensure minimal damages occur, possibly referenced on information mentioned in the previous criteria.	Due to rapid production of gasses, a whistle could be used at areas of concentrated airflow alerting the used via sound. Methods such as light detection can be explored however it would involve electronics, adding to the complexity of the project.	Slide N/A	See manufacturing specification

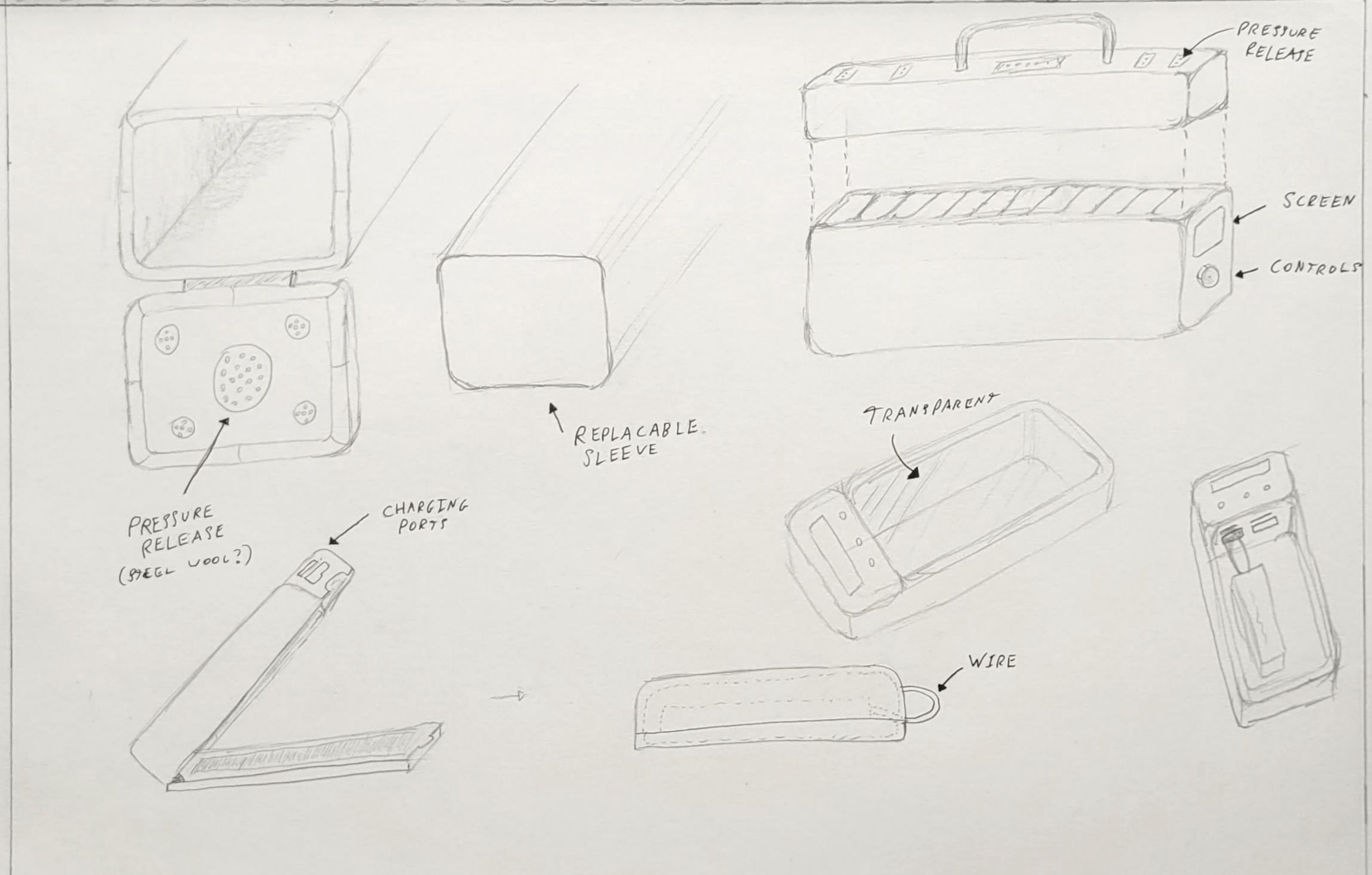
Concept Sketching



Conclusion

To begin the design process, I sketched a range of possible ideas to identify ideas to identify some worth developing further. These ideas ranged in size, quantity of batteries stored, and with different lid mechanisms. Some designs took a solid approach however flexible materials have also been explored.

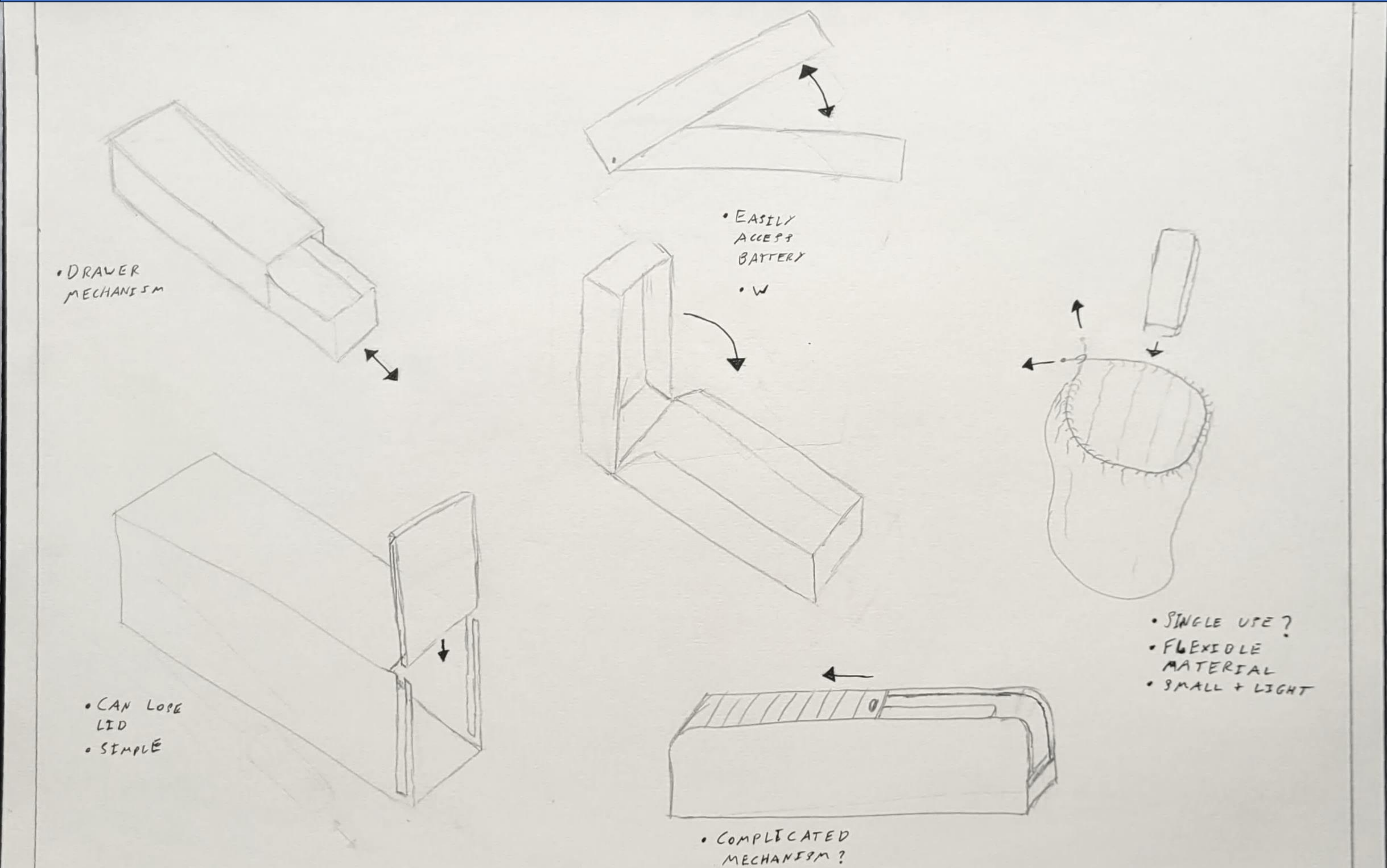
Initial Ideas - Development 1



Conclusion

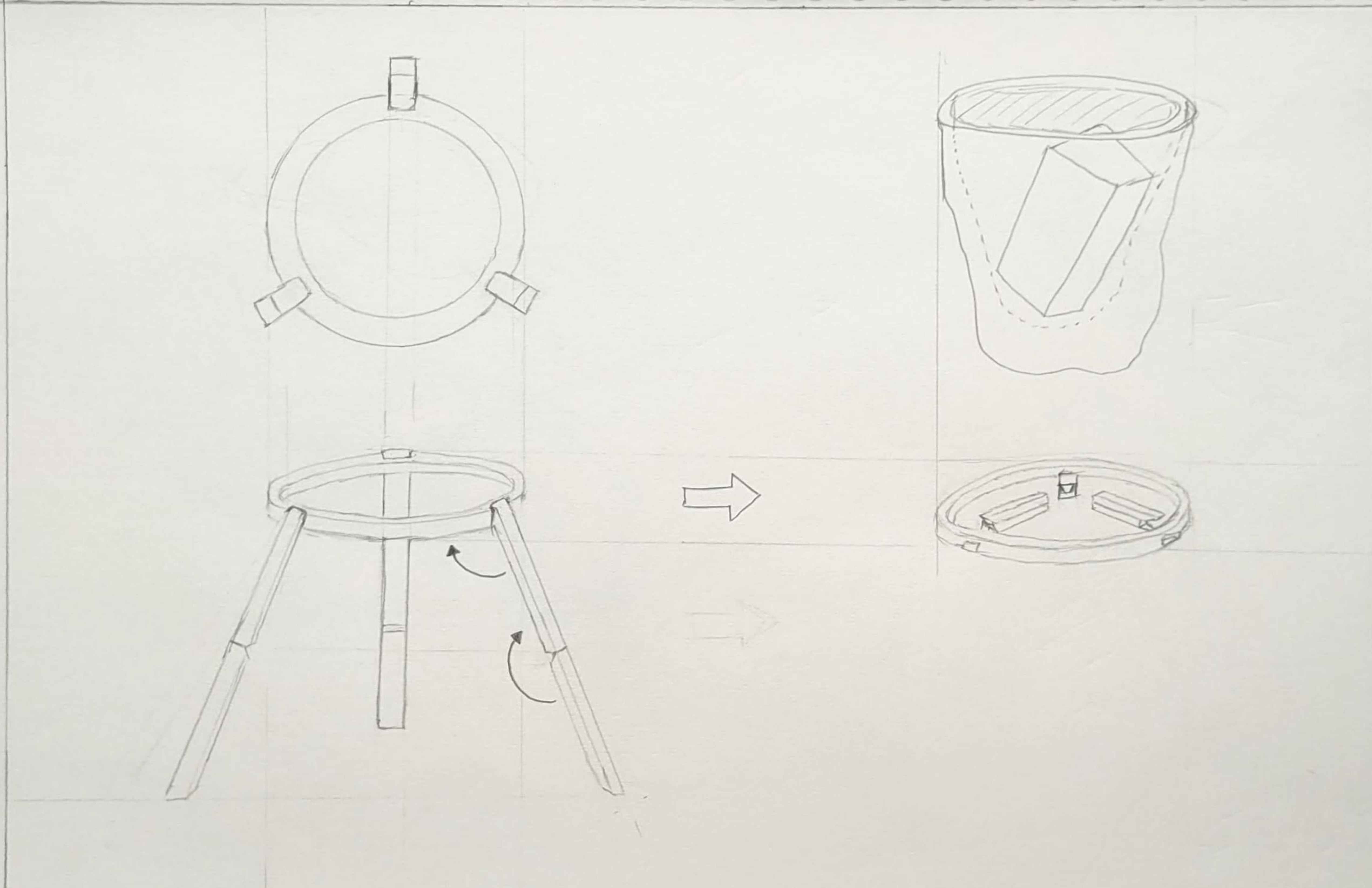
A rectangular form seemed to stand out most as it closely resembles a battery's form. Some designs contain an integrated charging circuit, the idea of the battery plugging into the interior of the container seemed promising to keep a consistent seal. Having a transparent surface on the product would allow the user to monitor the battery while charging.

Initial Ideas - Development 2



Conclusion

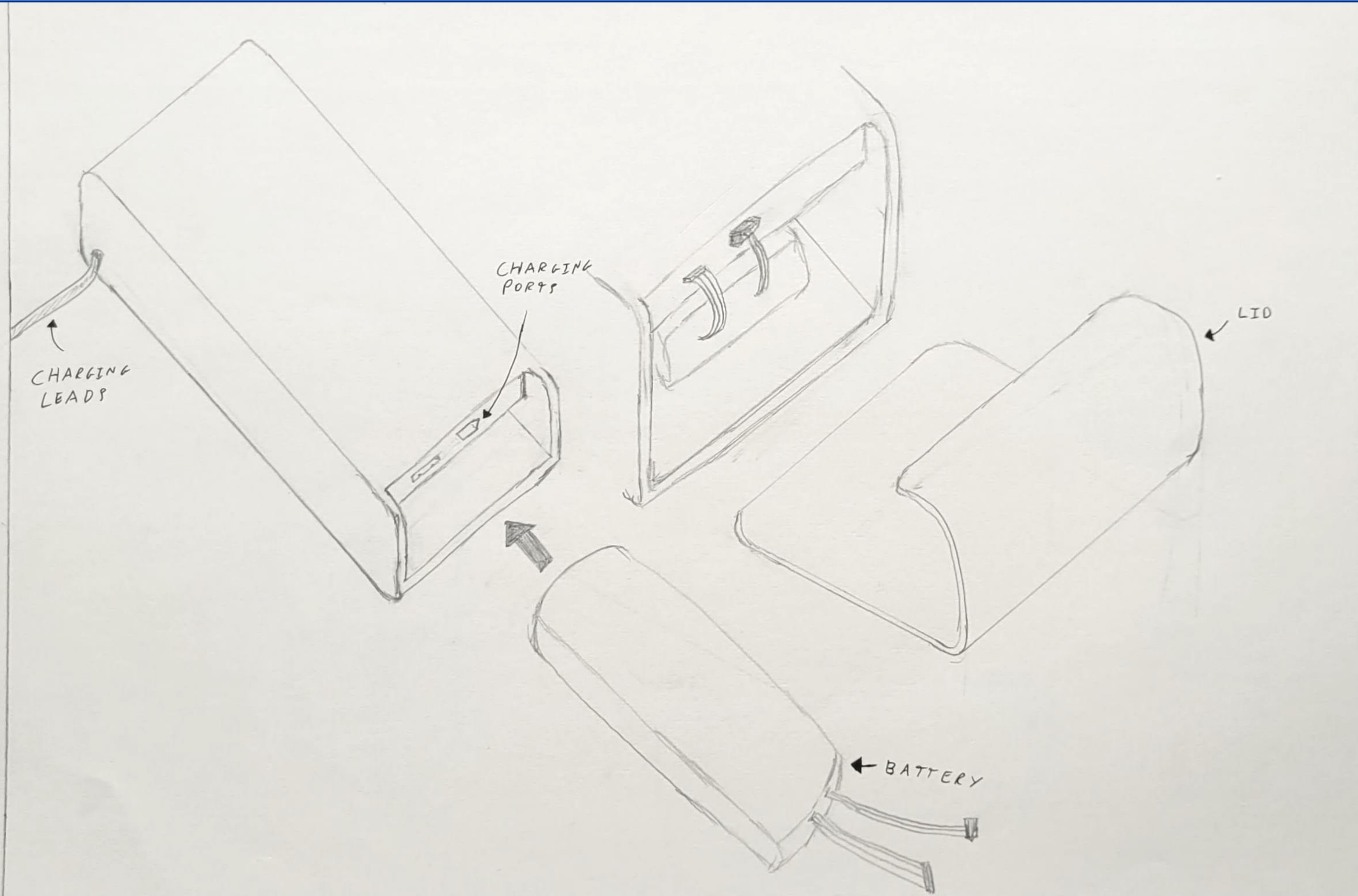
For the second page of initial ideas, I followed the rectangular design while looking at different ways a battery could enter the product. Another idea involving a product purely made from fabric to keep size and weight to a minimum, I will develop upon this and another sketch.



Conclusion

Following on from the fabric-based design, I started to develop on the design with a solution to suspend the battery away from the fire-retardant fabric, using air to insulate against the heat produced. The folding legs ensure the design is portable. The design does not have a way of sealing the hole where a battery would enter, and the legs seem very fragile.

Initial Ideas - Development 2

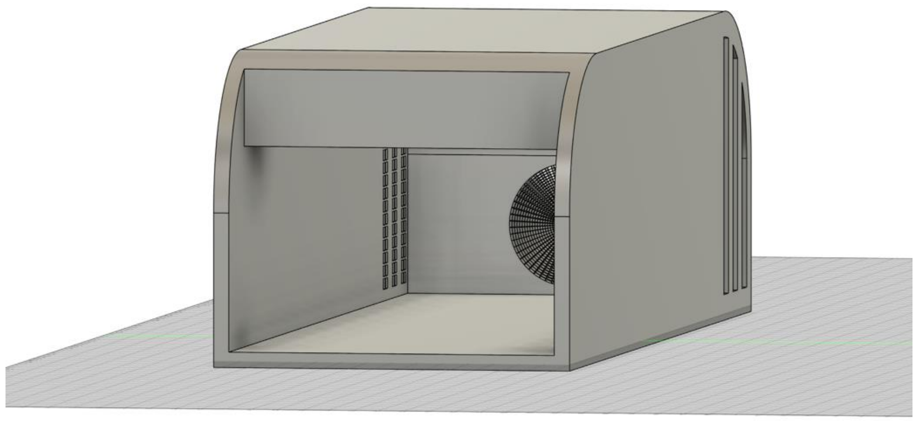


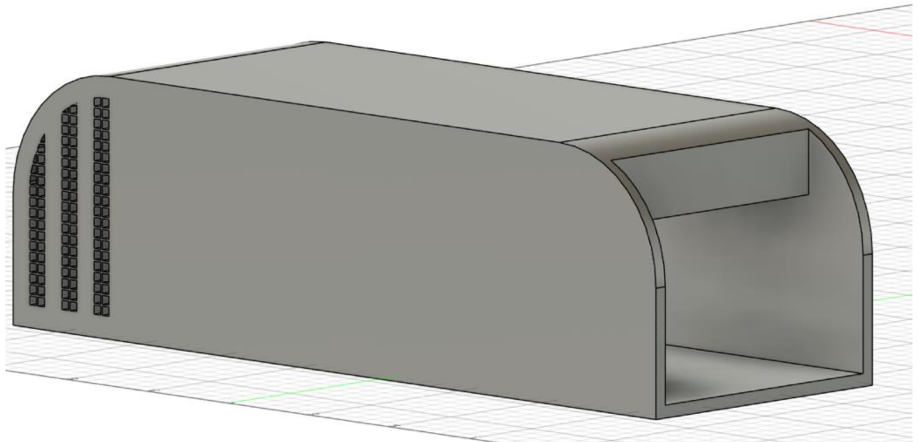
Conclusion

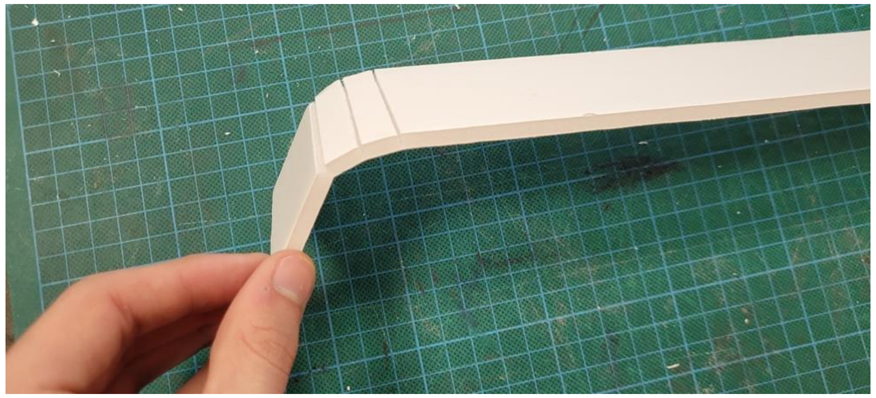
I decided to develop on the rectangular design, the battery would plug into the interior and a lid would be placed over the opening. The battery cable would be re-routed towards the back of the container. This idea seemed more appealing compared to the previous development however it lacks ventilation, this will be developed upon further.

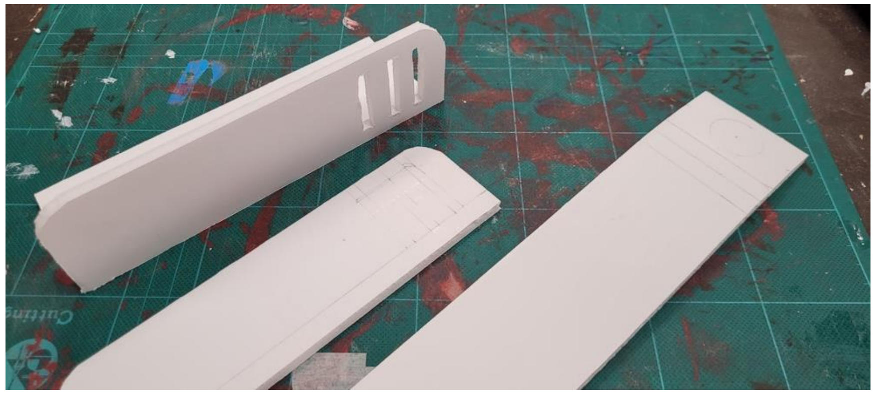
Prototype 1

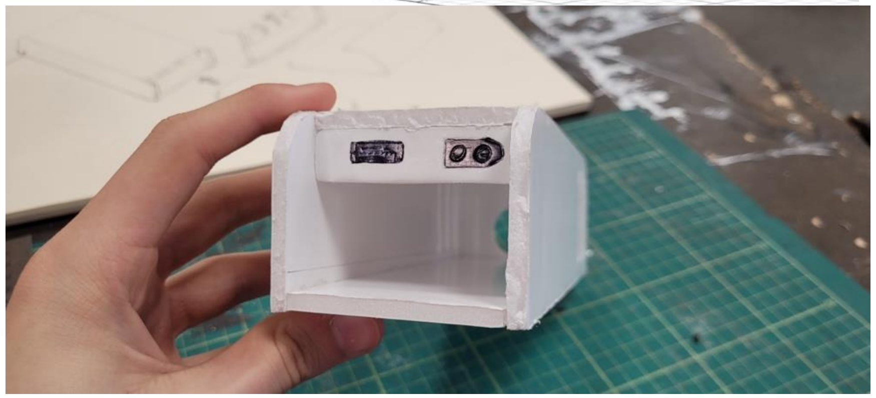
Before making the first prototype, I decided to develop on the design using CAD. This also helped me visualise the product and the parts I would need for the prototype. The design needed vents to release pressure so I added 3 slits on each side and a circular vent on the back end. They are all positioned towards the back of the product since it would be the side furthest from the user if thermal runaway occurs. This would reduce the quantity of gas they would be exposed to.



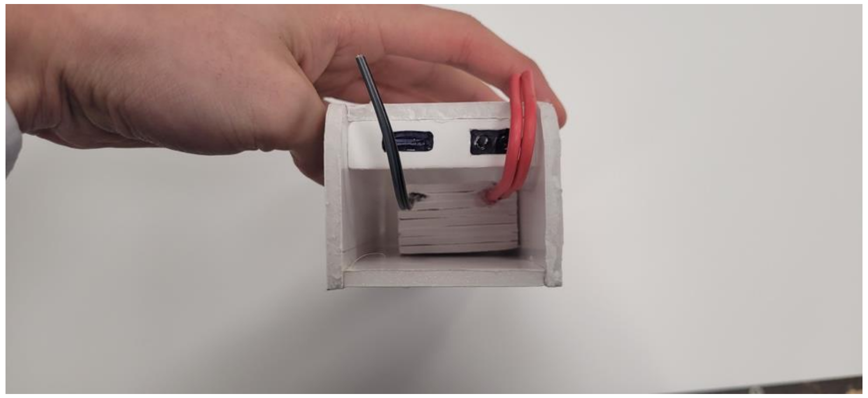


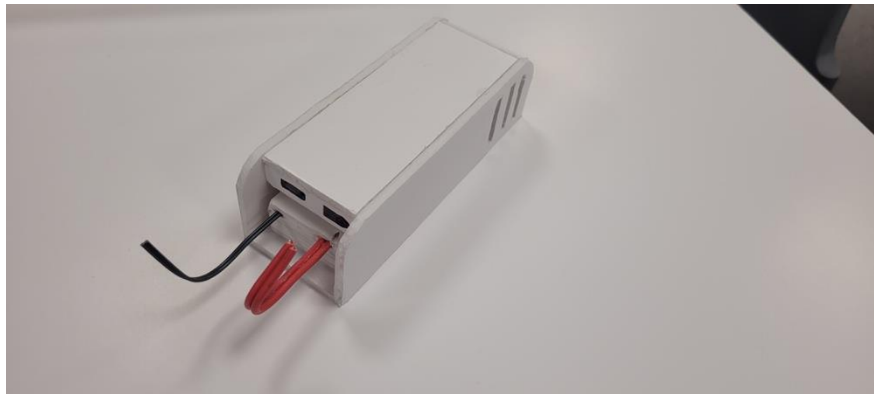






After marking the sides on the foamboard, cut the pieces out using a scalpel and safety ruler. The curved edge surrounding the top will be made by scoring the edge of the foamboard. Once the four sections were cut out I used hot glue to secure them all. Using foamboard for this prototype made it very quick and easy cut and glue all the pieces together. The XT60 and JST port positions have been marked on with permanent marker. To finish this model the lid was secured to the body, it was made using the same scoring method as the body yet also reinforced by hot glue. This was secured using two nails either side of the prototype and can be manipulated to open and close as intended. To help with visualising the product in use, I used a block of foam with the dimensions mentioned on slide 12 to simulate a battery.





Conclusion

The model resembled the CAD model and drawings very accurately and the model battery fits well in the prototype. For feedback on this design, I will approach a focus group with my drawings and model, this feedback will influence further designs.

Focus Group Feedback

To gain feedback on the first prototype, I ran a focus group with 5 individuals. In the focus group I presented the design sketches, prototype and asked the focus group various questions relating to the project. The group also had the opportunity to include additional comments As a result, some improvements and additions to the design presented were indicated as shown below:

Improvements

- Improve the form to make it more portable
- Switch to prevent charging when lid is open
- Spring hinged lid to close by default
- Angle the vents to direct smoke away from user
- Change design so cables fit in the product

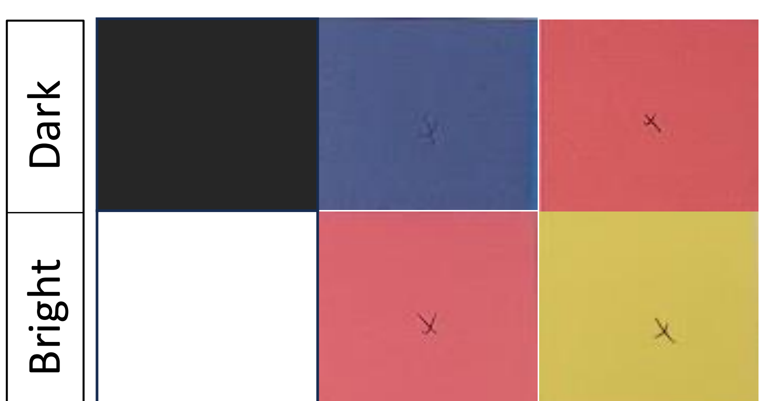
Additions

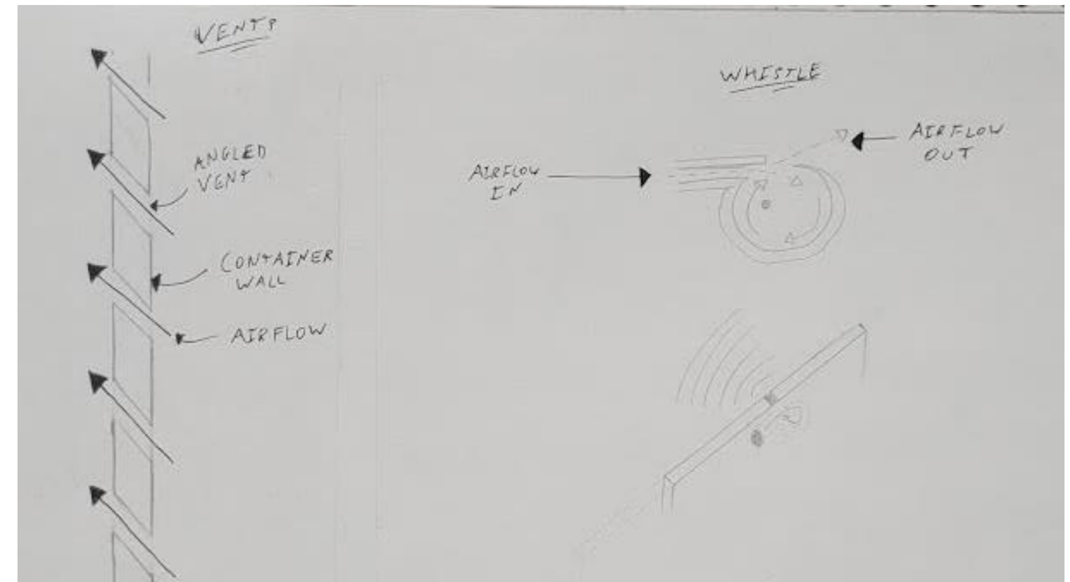
- Add method of notifying user of a fire
- Way to clip product onto body or bag
- Whistle built in to warn when gas is being released
- Test using smoke machine for airflow analysis and pressure testing
- Safety information should include large test using black and white contrast

Font and Colour

For information regarding the safety information, the focus group were also asked to decide on a font which stood out the most from a sheet of text. FF DIN PRO BOLD and FF DIN PRO BLACK were decided upon due to the thick text making the text easy to read. Italic fonts were avoided for the same reason.

A colour sheet was also presented to the group and 6 colours were indicated. The dark colours included black, dark blue, dark red and the bright colours included yellow, pink and white, with black and white being an overall preference due to the high contrast however yellow was the colour that caught the most attention.





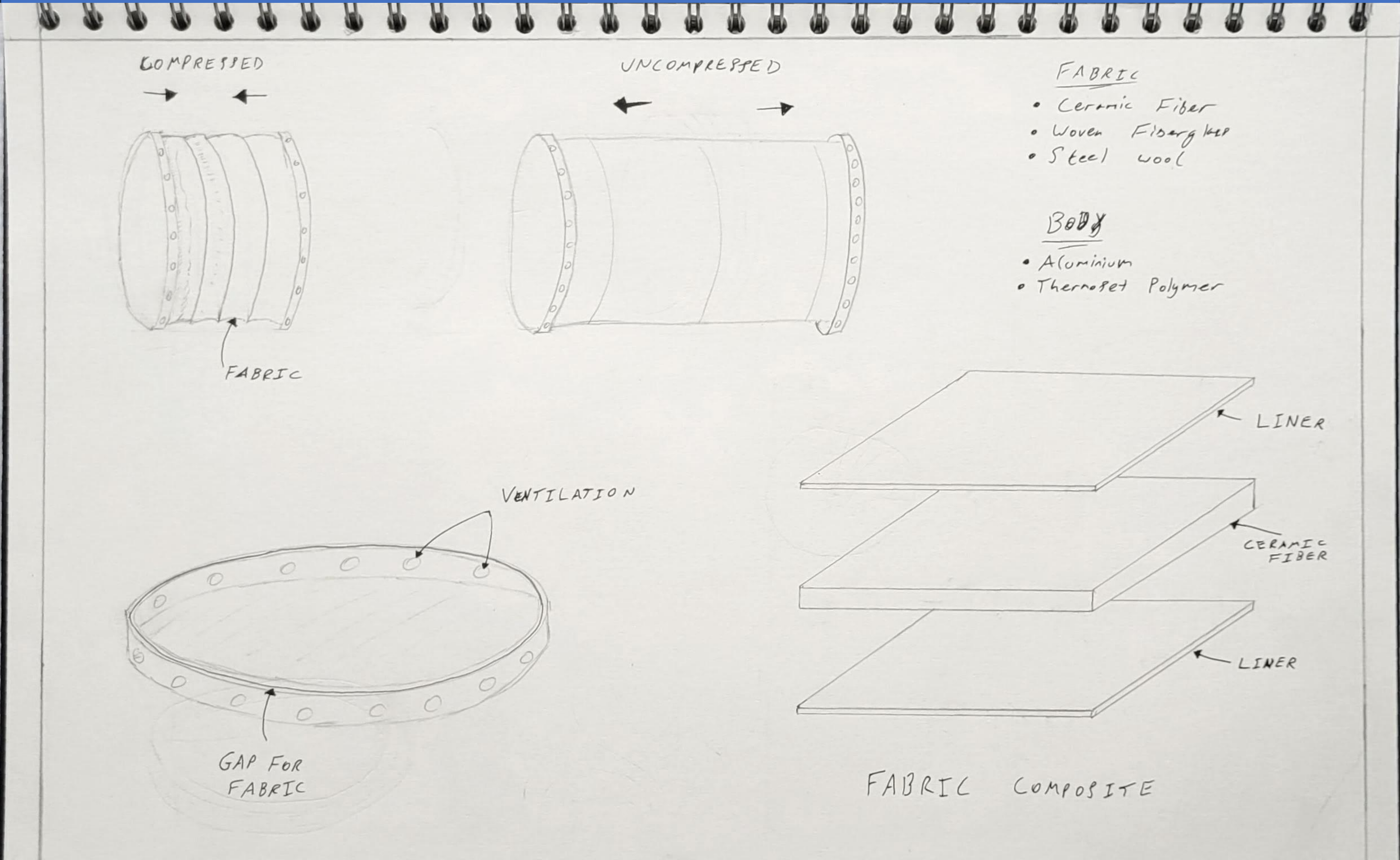
Sketches on airflow direction and whistle functionality

Conclusion

Some design decisions were made following the comments from the focus group:

- To make the form more portable, I will investigate collapsible designs that can change their size depending on what scenario will be used. In this case its desirable that the product is as small as possible while travelling but still contain a battery to charge when required.
- Instead of attaching the product to the user, for convenience, having the design pocket-sized would be better suited.
- When developing the safety information for the product, it will include high contrast colours such as black and white. Yellow caught the most attention so will be used also.
- The comments regarding electronic manipulation will not be pursued. This would increase the price, risk of error and possibly the safety of the device since electronics could interact with the charging battery.

Design Development

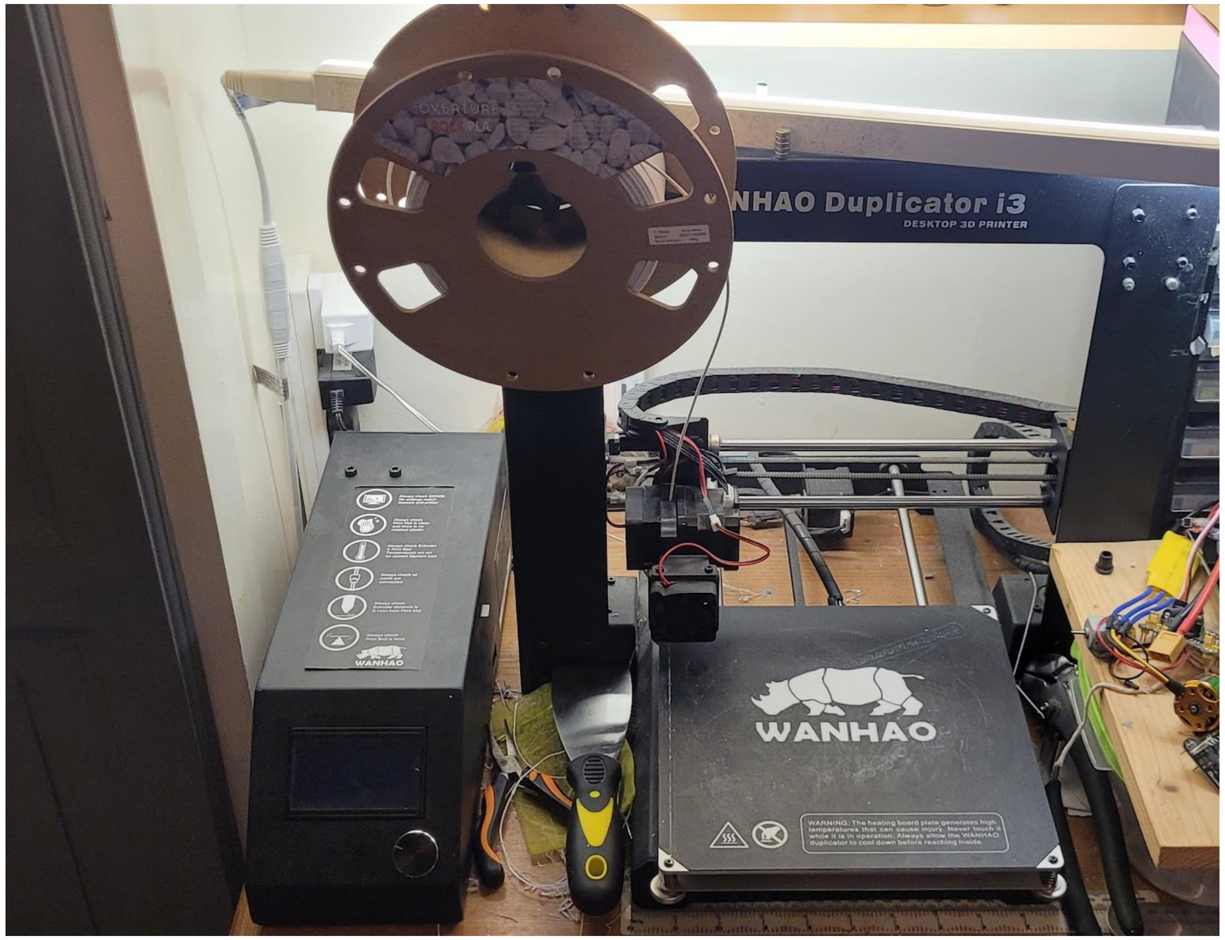


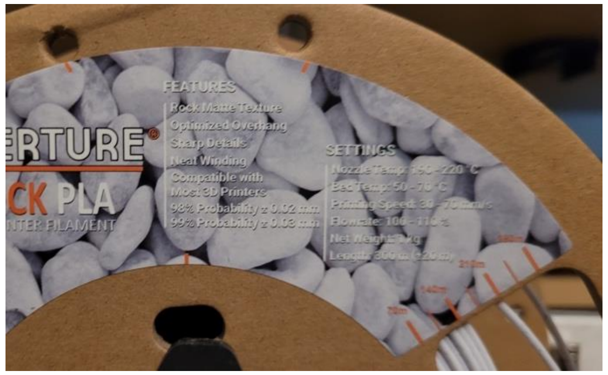
Conclusion

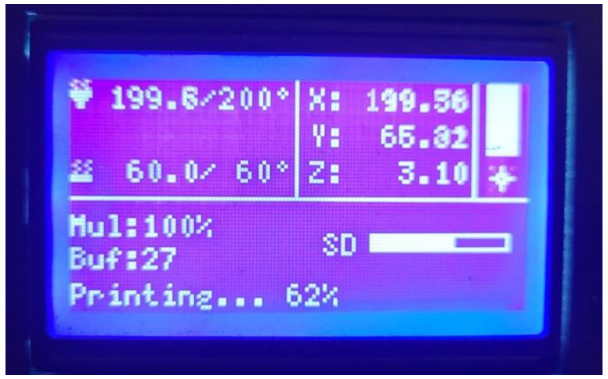
To achieve a pocket-sized design, the previous design had to change completely. This new concept uses a flexible material between two solid plates with vents to flatten down when transported. The fabric would slot into a gap made in each of the circular plates. At this stage I am unsure on how the battery would enter and exit the product. Possibly a zipper mechanism where the edges of the flexible material meet. A possible material mentioned here is ceramic fibre, the use of this material will be evaluated later on.

The prototype process in this project will rely heavily on CAD using Fusion360 and 3D printing. It will allow me to quickly i terate through prototypes with efficiency and accuracy. This means more time can be focused on the design itself rather than creating prototypes

The printer used for all the rapid prototyping is the WANHAO Duplicator i3. It can reach the temperatures needed for the filament used and has a print bed large enough for designs of this scale.







I am using PLA for the printing since it is easy to print and more environmentally friendly compared to other filament materials such as ABS. PLA is also relatively cheap, this is beneficial since many prototypes may be made during design iteration. This filament is rated for a nozzle temperature between 190-220 degrees C and a bed temperature between 50-70 degrees C. I am using 200 degrees C for the nozzle and 60 degrees C for the bed, falling within this range.

Quality

Layer Height	0.2	mm
Initial Layer Height	0.3	mm
Line Width	0.4	mm
Wall Line Width	0.4	mm
Outer Wall Line Width	0.4	mm
Inner Wall(s) Line Width	0.4	mm
Top/Bottom Line Width	0.4	mm
Infill Line Width	0.4	mm
Initial Layer Line Width	100.0	%

Quality Settings:

I am using a 0.2mm layer height for all the prints. A 0.1mm layer height would increase printing times significantly however the high accuracy is not required to that extent. A 0.3mm layer height would make for very quick prototyping however it would cause the small aspects of designs to lack detail. 0.2mm is the perfect middle ground.

Infill

Infill Density	100.0	%
Infill Line Distance	0.4	mm
Infill Pattern	Lines	
Infill Line Multiplier	1	
Infill Overlap Percentage	0.0	%
Infill Layer Thickness	0.2	mm
Gradual Infill Steps	0	

Infill Settings:

I am using 100% infill since the designs I am printing have a very small wall thickness. When the walls are thin, space for infill becomes negligible anyways so print time and filament usage changes a very little amount. The structural integrity is well worth the small compromise.

Support

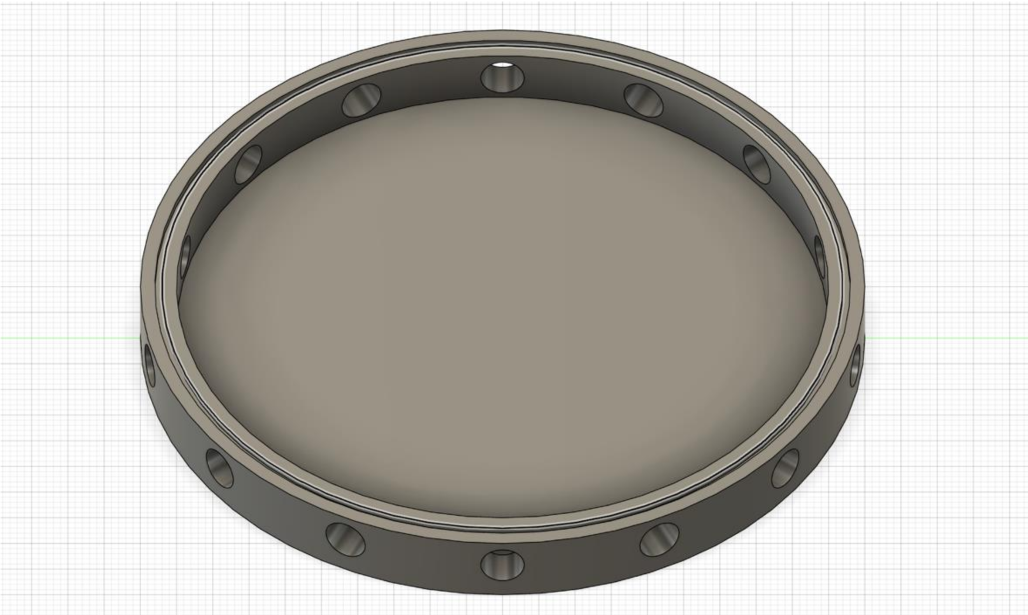
Generate Support	✔	
Support Structure	Normal	
Support Placement	Everywhere	
Support Overhang Angle	80.0	°
Support Pattern	Zig Zag	
Support Density	15.0	%
Support Horizontal Expansion	0.8	mm
Support Infill Layer Thickness	0.2	mm
Gradual Support Infill Steps	0	
Enable Support Interface	☐	

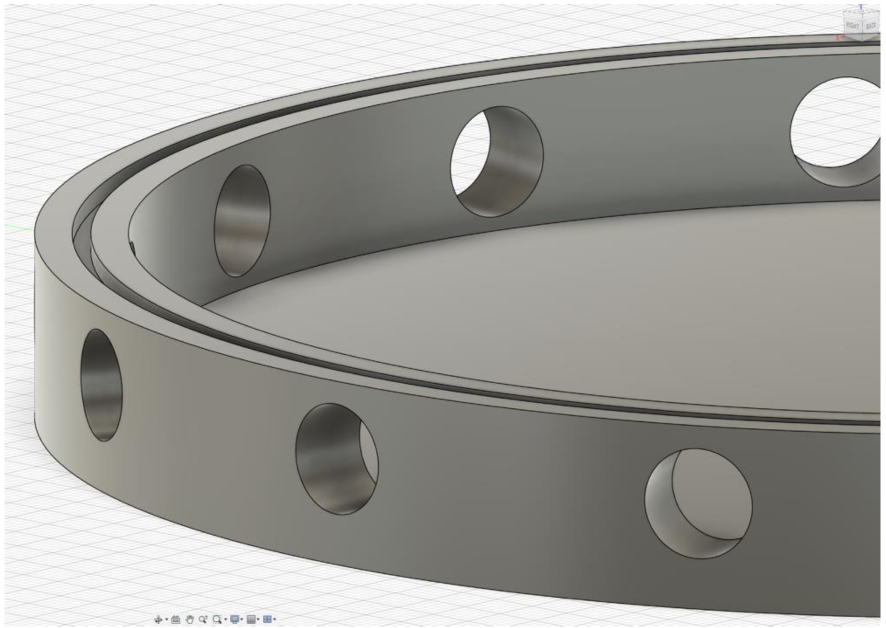
Support Settings:

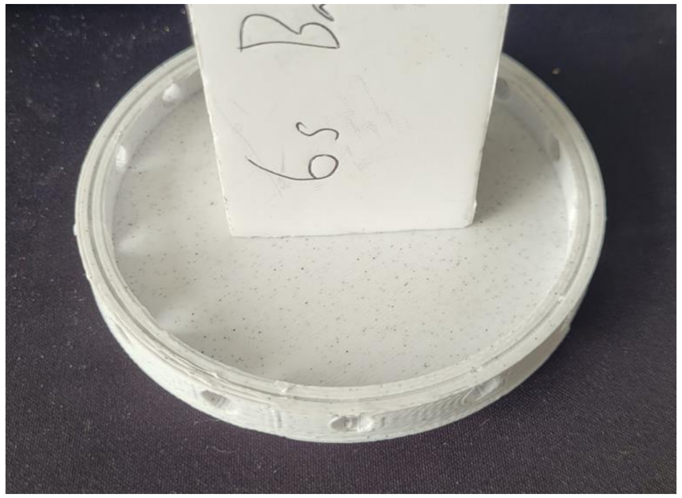
Support settings will have to be changed dependant on the design. If overhangs are too steep it may cause imperfections. Where possible, supports will be avoided. Some design s may require different support types. I expect to use a mix between Zig Zag and Tree support patterns to achieve the best quality print.

Prototype 2

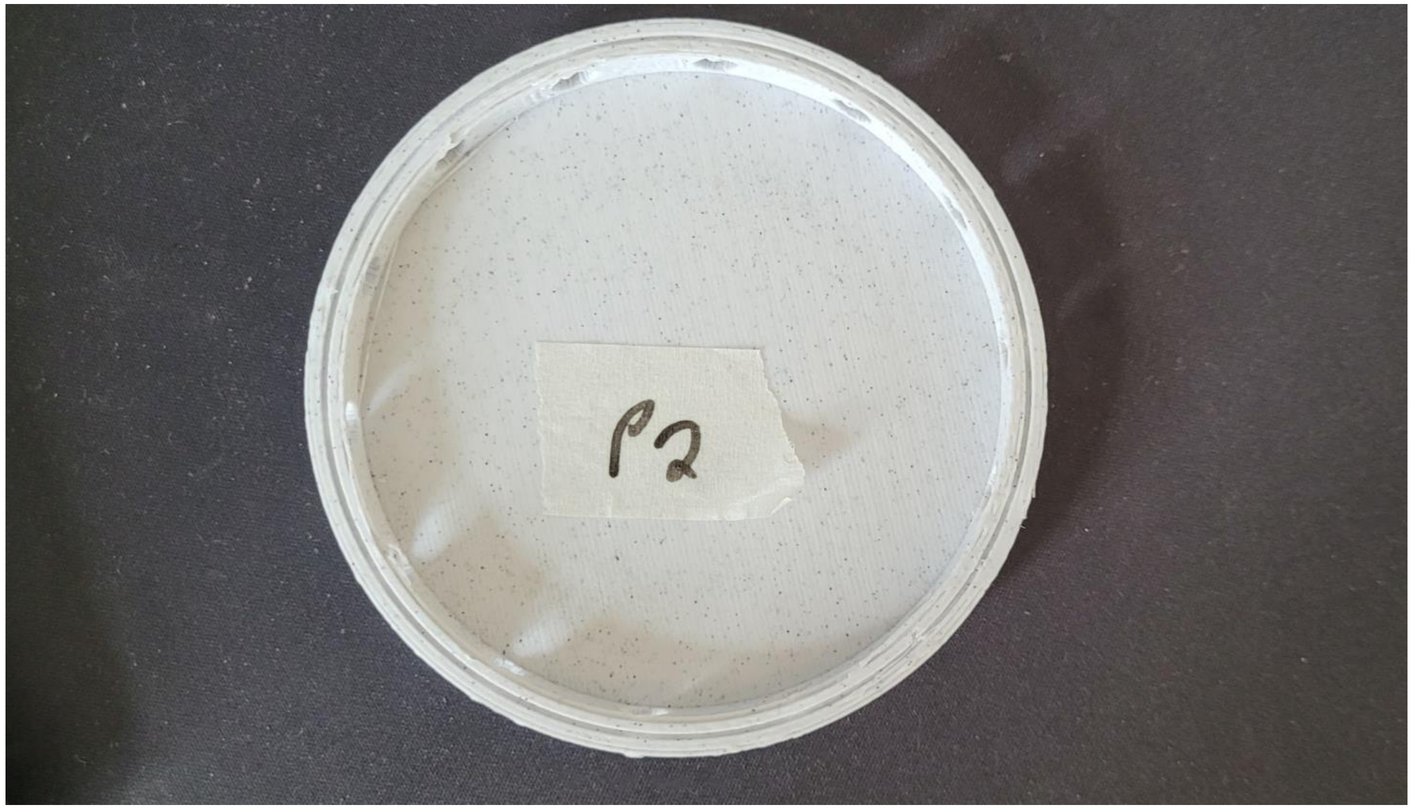
From the drawings of the design I made a CAD model and sent it to 3D print. This part managed to print without the need for supports so post processing wasn't necessary. The first issue I noticed with this prototype is that the gap designed for the flexible material to slot into is far too small and too shallow. In this case the vents would have to be redesigned as there is not much room to deepen the slot without interacting with the vents. Another issue is that there is still a very small area of ventilation, especially compared to the size of the part.

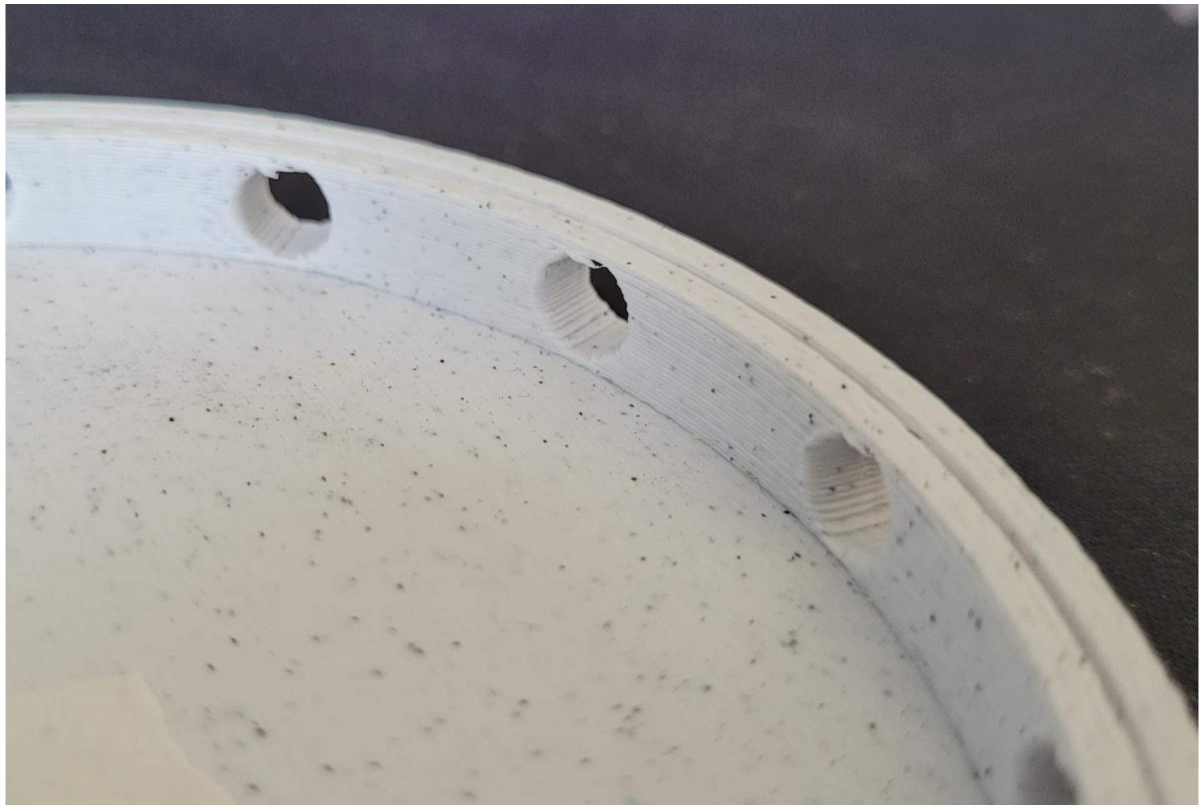






Comparing the new prototype to the battery, there is a lot of empty space so the product can be made even smaller.



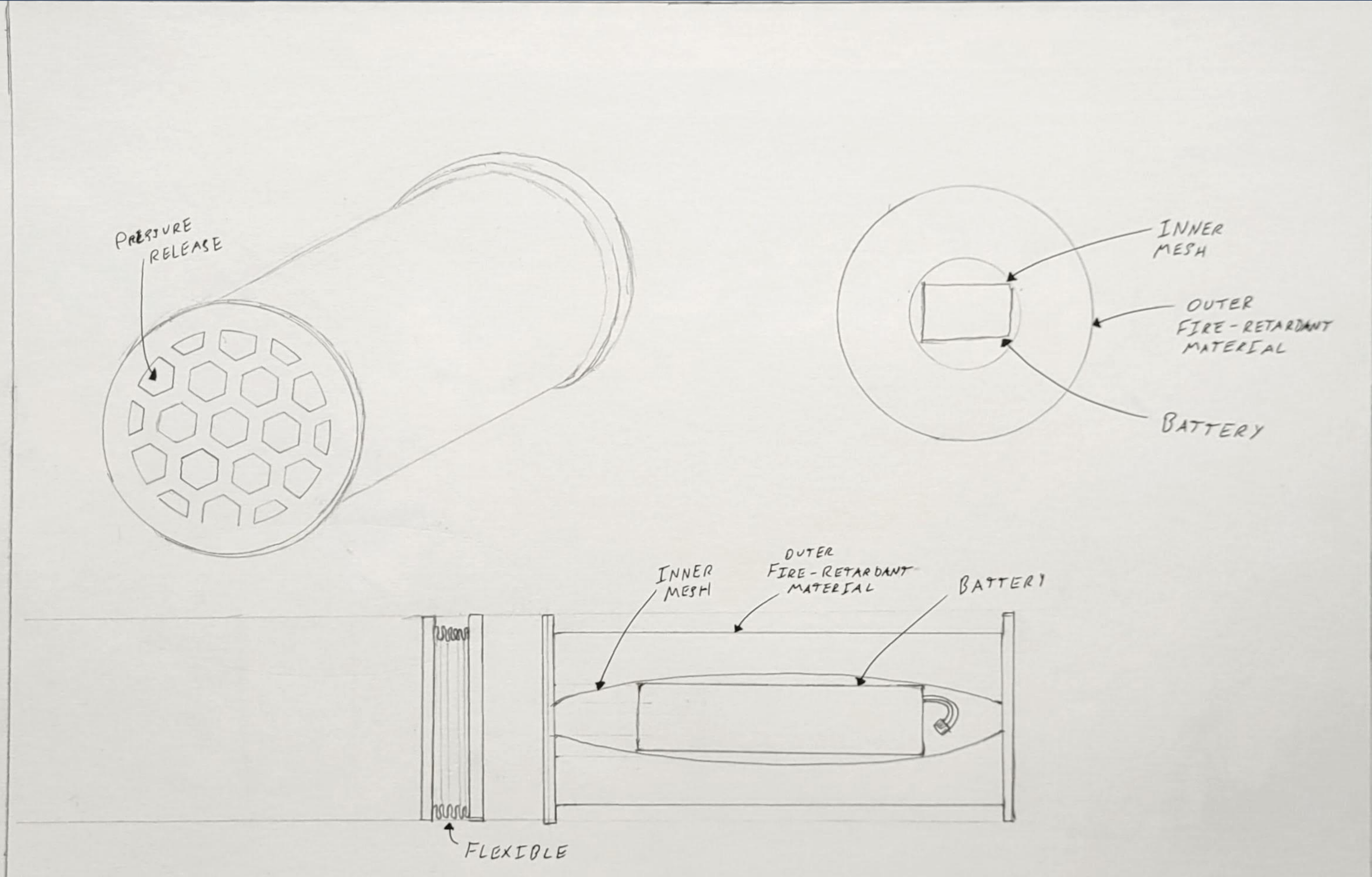


The part printed relatively quickly and with good accuracy, total print time below 1 hour, even at 100% infill. I also noticed that the flat plate could also be thinner to reduce weight and filament use

Conclusion

For the next design, I will maximise the area of ventilation whilst still ensuring structural integrity of the part. The slot designed for a fire retardant material must also be significantly widened and deepened since I greatly underestimated the scale of the feature during CAD development. Reducing filament use and weight would also be beneficial for further development.

Design Development



Conclusion

Working towards Prototype 3, I redesigned the ventilation approach with the vents on the flat plate instead of the sides. This provides more room to deepen the material slot and allows for a larger area covered by vents to maximise airflow. The new design also includes a way of suspending the battery for thermal insulation across the air gap however I would need more insight to verify this.

Expert Knowledge - Patrick Durham

While looking for experts on lithium battery technology, I came across a reddit post (https://www.reddit.com/r/spicypillows/comments/17kxxfl/ama_lithiumion_battery_fire_expert/) by Paul Durham (a mechanical engineer, firefighter, and fire instructor), offering his knowledge in the field. Below is the email trail with him.

Patrick Durham

Leon Trowsdale <leon.trowsdale.uk@gmail.com>
to stachedtraining
18 Mar 2024, 21:21 (7 days ago)

Hi Patrick,

I've come from a Reddit post of yours regarding Lithium-ion fires and figured you'd be a great guy to ask some questions,

I'm a student in the UK currently studying for my A-Levels. For my product design course, I have chosen to do a project around the safety of small lithium-based hobbyist batteries (mainly lithium-polymer and lithium-ion). The project has led me to design a small, portable container to place the battery while charging. The product should be able to mitigate all damages to potential surroundings outside of the container should the battery experience thermal runaway.

It would be great to hear your insight on some aspects of the project.

I understand that the chances of thermal runaway are significantly higher during charging/discharging in comparison to idle batteries so I'm looking towards a solution for a charging battery, not long-term storage.

Since thermal runaway causes a significant amount of gases to be released, during testing of a typical Li-Po storage bag, the pressure caused flames to escape the vents. For my product, I will have to find a material that can release pressure from the container but prevent flames from escaping. Would you happen to know any materials/filter types that would suit this function?

For the main body of the product, I will also need a flexible fire retardant material since the design is collapsible. The generic storage bags online are made from woven fiberglass however I've come across other materials that suit the same function such as silica fiber, refrasil cloth and PTFE fabric. Do you have experience in any of these materials for further insight into their suitability?

Upon testing a woven fibreglass bag, a hole was created in the material where the heat was in contact with the bag. A solution to this could be to suspend the battery in the centre of the cylinder, would the insulation due to surrounding air prevent this?

Patrick Durham
to me
20 Mar 2024, 17:54 (5 days ago)

The failure is extremely hot and I don't think suspending the device in the center of a container would prevent burning a hole in the material. You would need to find a material that can stand up to the abuse. The gasses being released are flammable. Most of the bags that have vents utilize metal vents with some type of screen to prevent molten metals from being ejected. Take a look at CellBlockFCS. They have systems like the one you are trying to design.

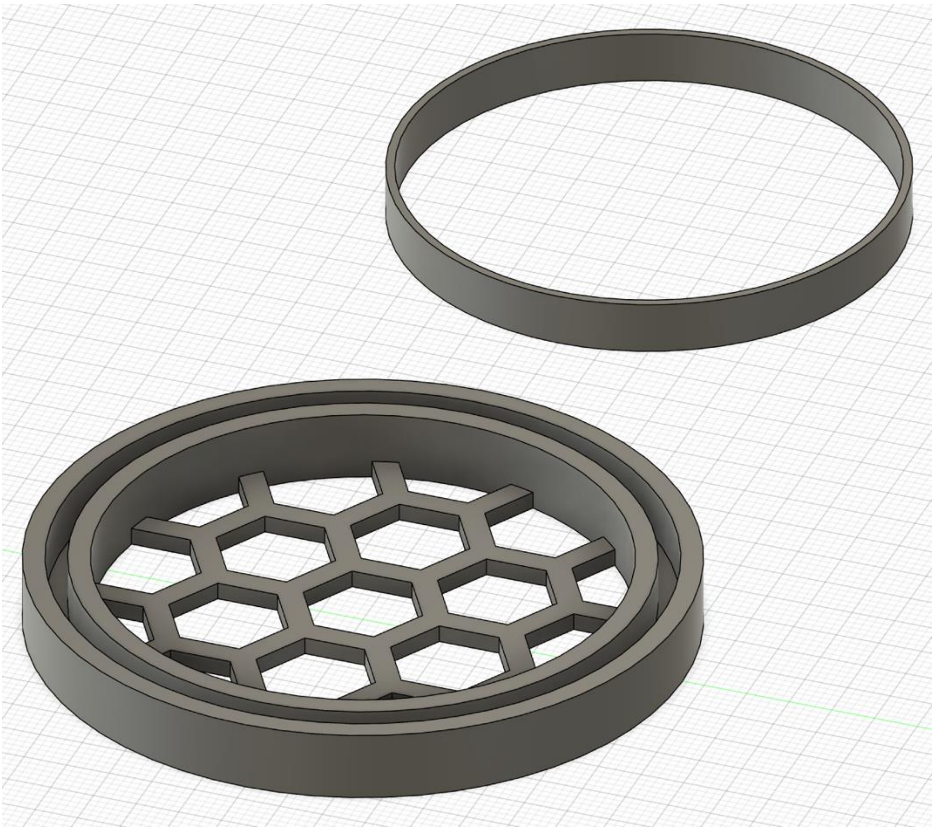
Patrick Durham
Website: StacheD Training
YouTube: @stacheDTraining

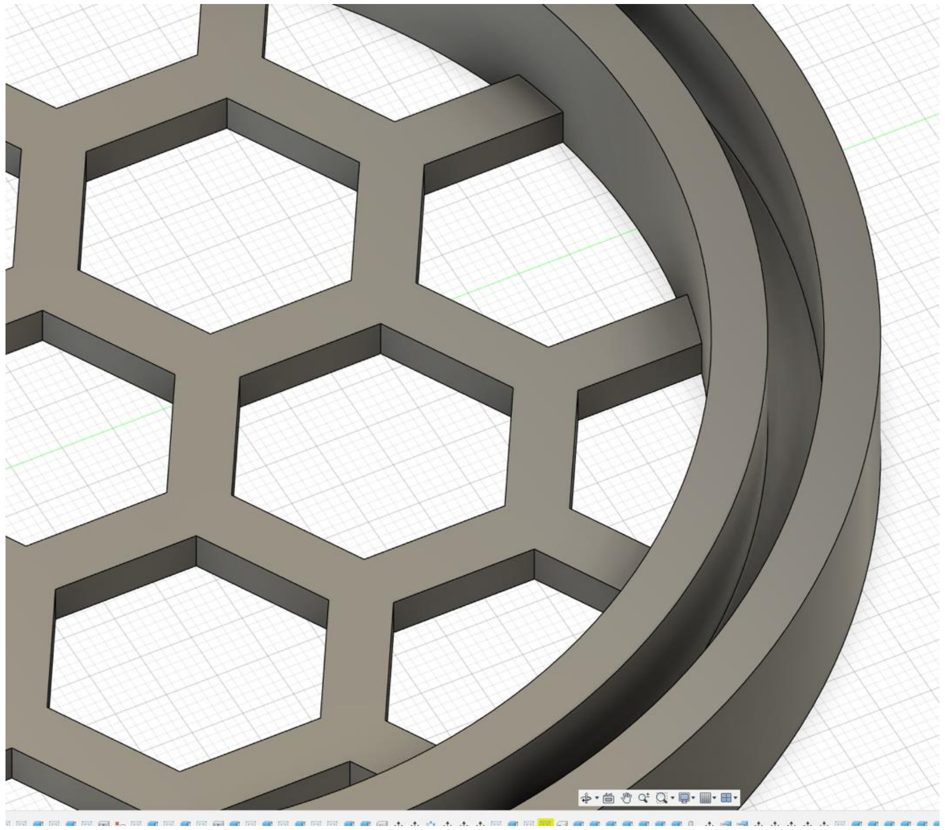
Conclusion

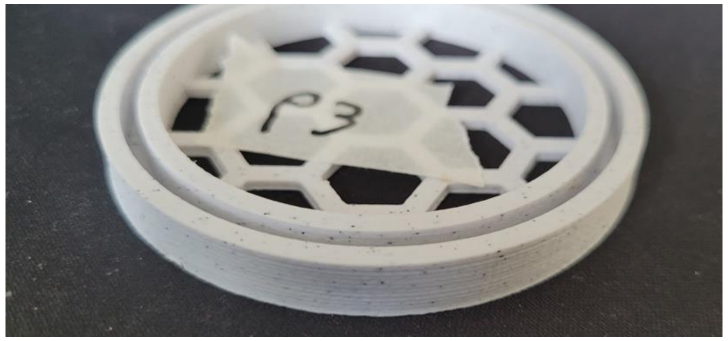
The response from Paul led me to discontinue the idea of suspending the battery to avoid direct contact with the material. He recommended a company called CellBlockFCS that seem to suit a similar function, however they are manufactured and priced suitably for industrial use. Earlier on, Paul Christensen provided insight on the same company and mentioned they often use glass beads to melt around the battery, this would not be suitable for my project in terms of weight and portability.

Prototype 3

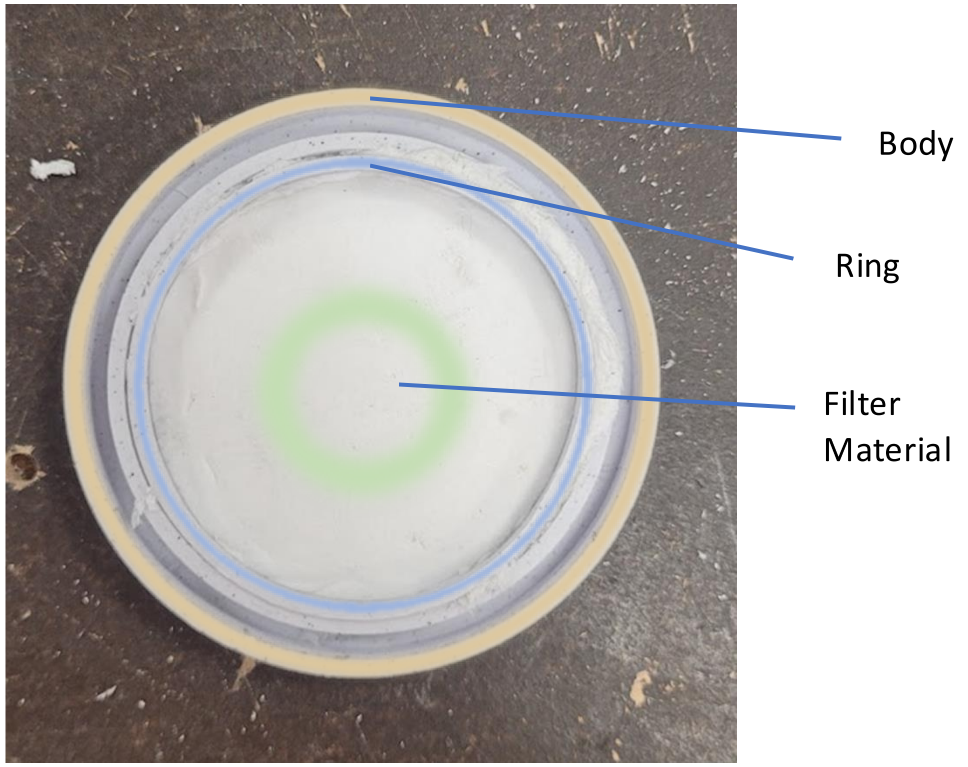
Prototype 3 closely resembles the previous design development page however there is also a new circular ring part designed to hold the filter material in place.







I'm very happy about the aesthetic of the hexagonal pattern that make up the vent shape, they blend surprisingly well with the circular design. Compared to Prototype 2, this Prototype is much smaller, lighter, more ventilated and has a better aesthetic. One feature I don't like about this design is the sharp edge along the bottom, for the next prototype I will add a bevel. This prototype did not carry across the suspending battery mechanism for the reasons mentioned in the previous slide.



Conclusion

Continuing through the design process I will keep the hexagonal aesthetic and keep the product circular as it fits in the pocket comfortably with no sharp corners.

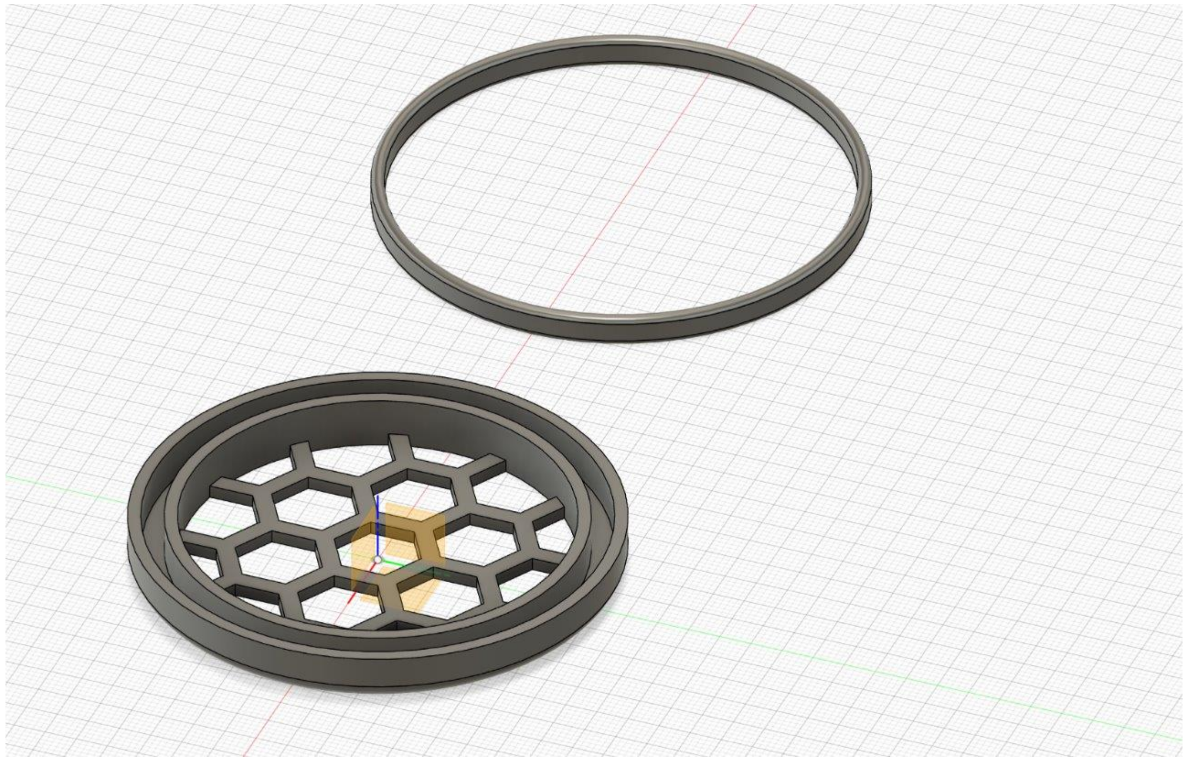
The method of securing the filter seems to work well in the short term, however this will have to be tested longer term to ensure it is secure.

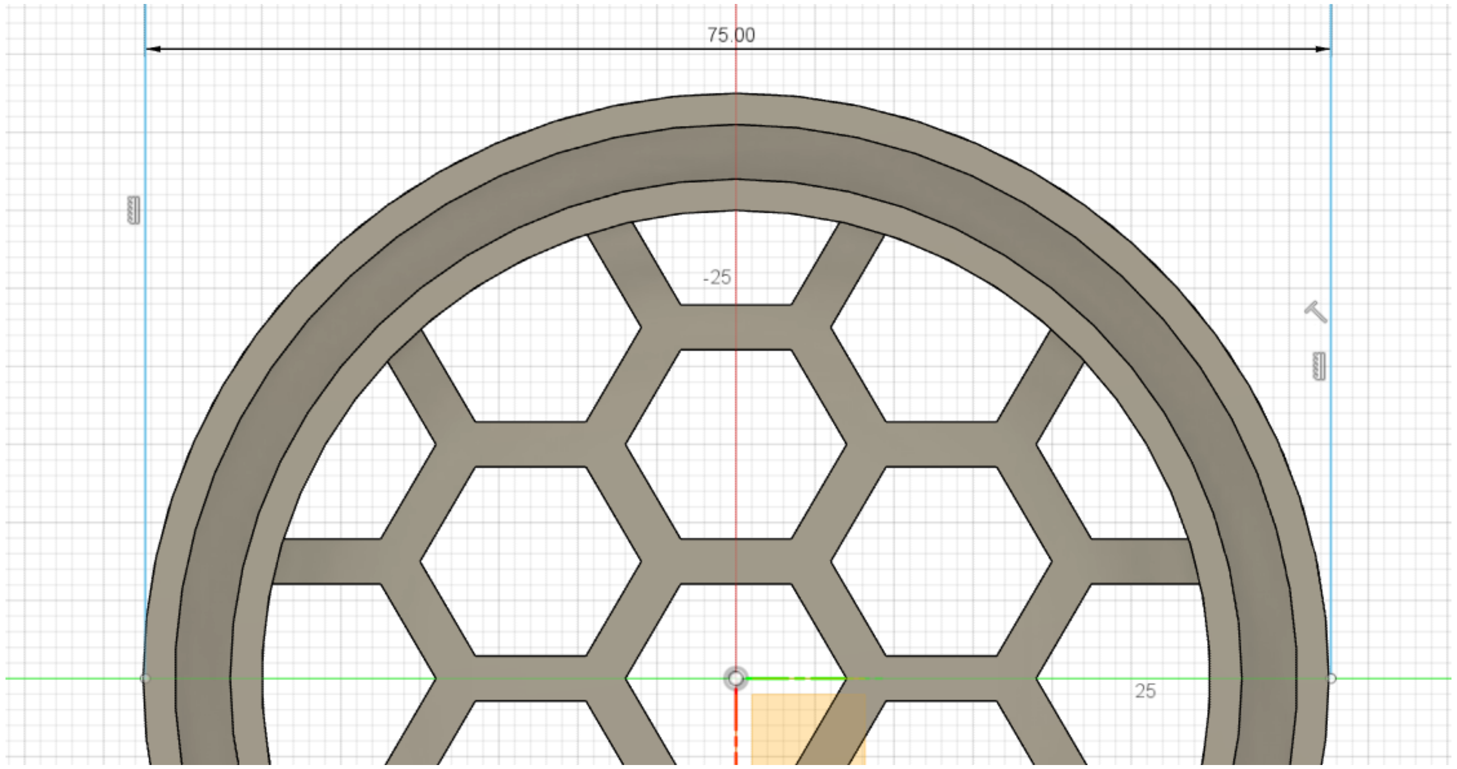
To improve the feel of the product I will bevel the bottom edge but leave the top, this is so the two plates still connect flush together.

Since the two parts are secured together only by a flexible material, there is no rigidity holding the two together. A possible solution to this could be including a large diameter spring around the inner circumference of the parts. This will be considered when designing the next prototype.

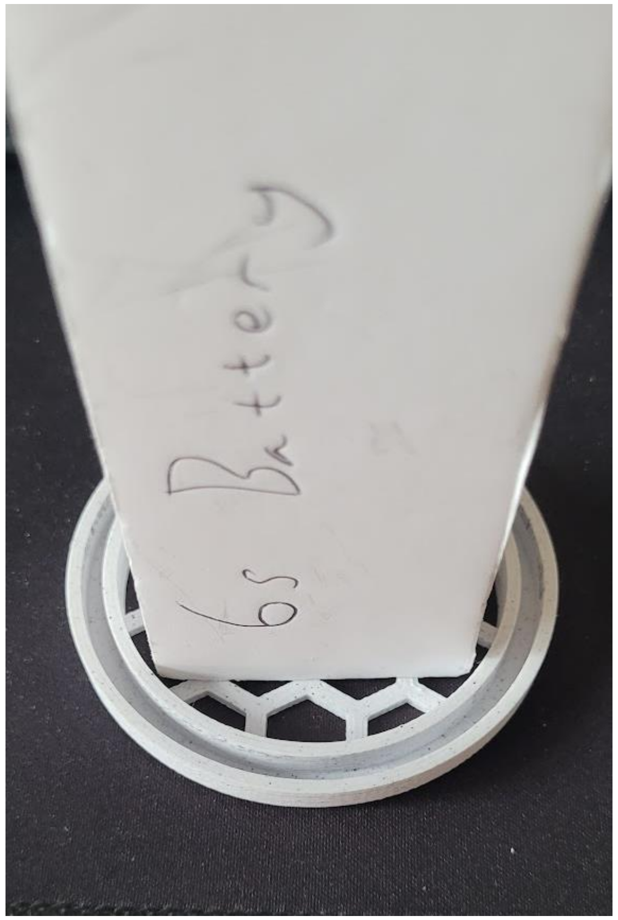
Prototype 4

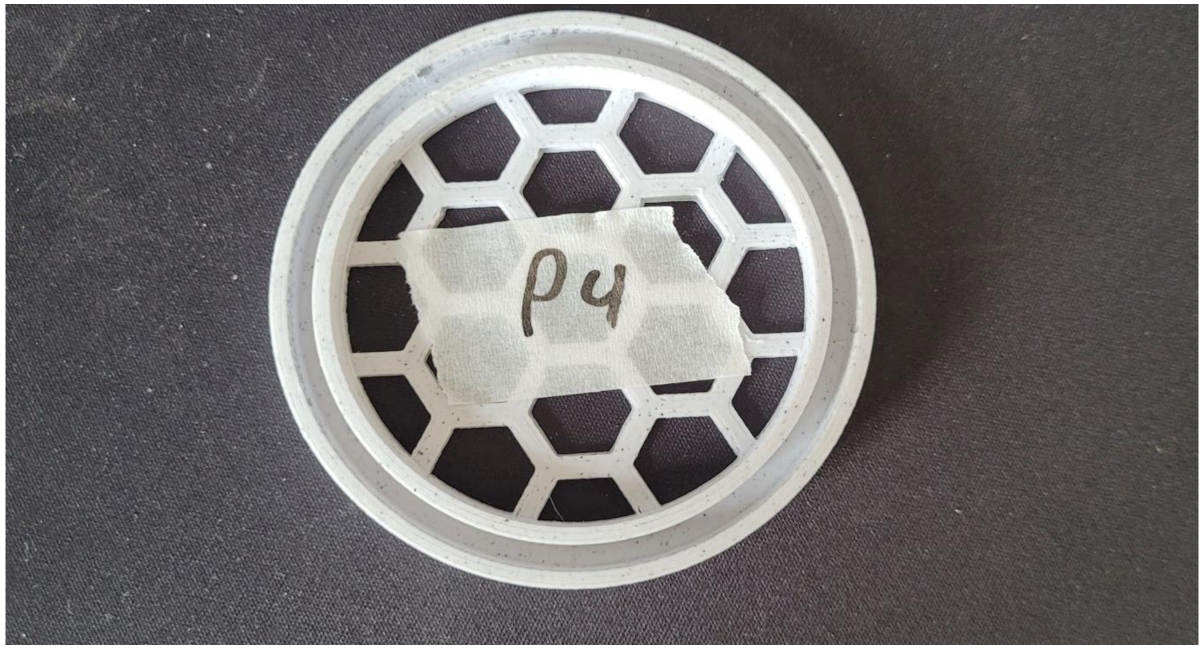
Prototype 4 now includes a bevelled edge on both the body and the ring as shown in the cad below. The new designs will be involving springs, so I've also widened the gap to accommodate the fire-retardant material and a spring made from 4mm diameter aluminium in the same space.





Since the gap has been widened, the space for the battery has gotten smaller and now does not fit comfortably inside the product. For the next prototype I will increase the diameter larger than 75mm. Even with the bevel included, the part still managed to print without supports, saving filament and time.





Conclusion

The bevelled edge makes the product more comfortable to handle and use so I will be keeping this feature for future prototypes. The next prototype will have a larger diameter to fit the battery better.

Spring testing 1

The first material I am testing for the spring is raw aluminium in a rod form. When manipulating the material in the hardware store, the metal seemed to spring back to its original form well. The rod was also very easy to manipulate and lightweight which is suitable for the product.

To create the cylindrical spiral spring shape, I decided on creating a mould to spin the rod around. This mould will be slightly smaller in diameter as the inner circumference of the spring slot so when it sprigs back after forming, it will be the correct diameter.

The mould I'm creating will be made of pine and cut on the lathe. To cut the mould correctly I created a guide with the desired diameter. This will be referenced in intervals while carving the piece.

To secure the aluminium rod in one place while wrapping it around the mould, I drilled a hole I the side of the wood (as seen above) to feed the rod through.

Conclusion

The aluminium was very easy to wrap around the mould by hand to create the spring shape, however, the aluminium deformed significantly under extension, changing the length of the spring in the process. Unfortunately, this makes the material unsuitable for the function of a spring.

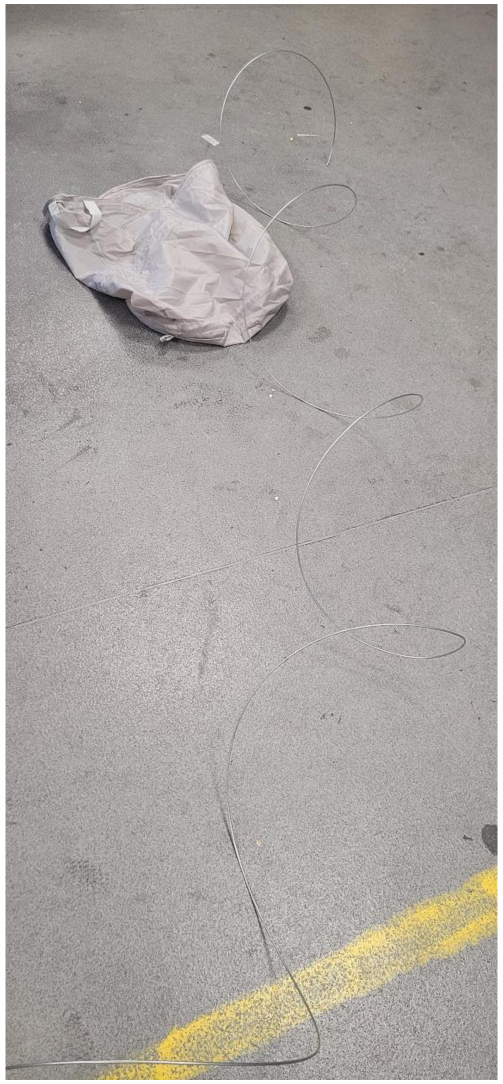
A material with a higher elasticity and preferably a smaller diameter would be ideal In this situation.

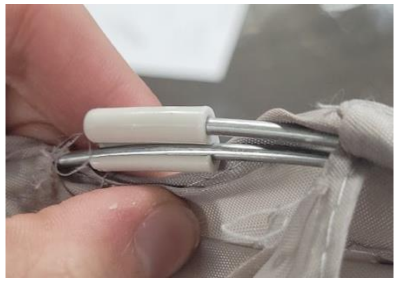
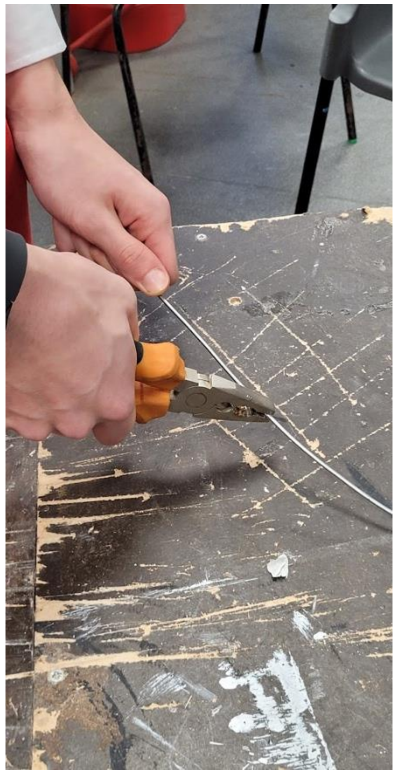
Spring testing 2

A product very similar the form I am trying to create is a collapsible laundry basket, its large and cylindrical when expande d but portable and flat when folded down. The material inside the basket seems ideal for the product I am designing as it should have high elasticity.







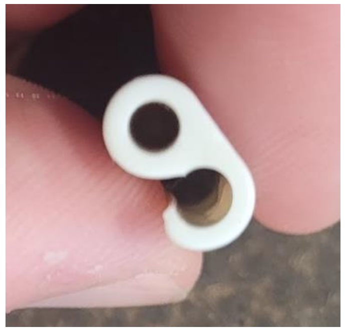



Although there is no documentation on the material of the wire, I assume its spring steel, known for its high elasticity.

It uses small polymer part to hold two sections of wire together, joining the loop making up the top and bottom of the basket.

Since the laundry basket is a much larger product than the design in this project, the diameter need to be changed.

To manipulate the wire a similar way to aluminium, ill wrap the wire around the mould. Unfortunately, since the wire is already curved, it had to be straightened first. Using pliers and a vice I managed to get it straight.

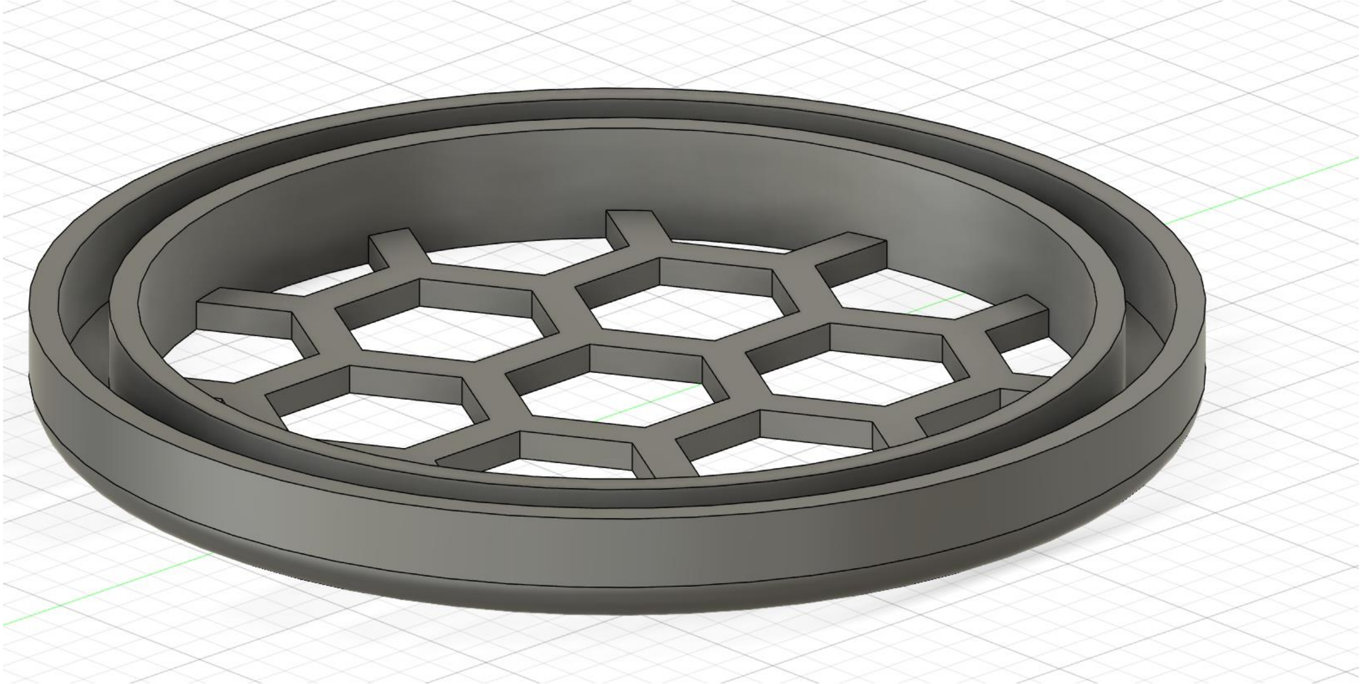

Conclusion

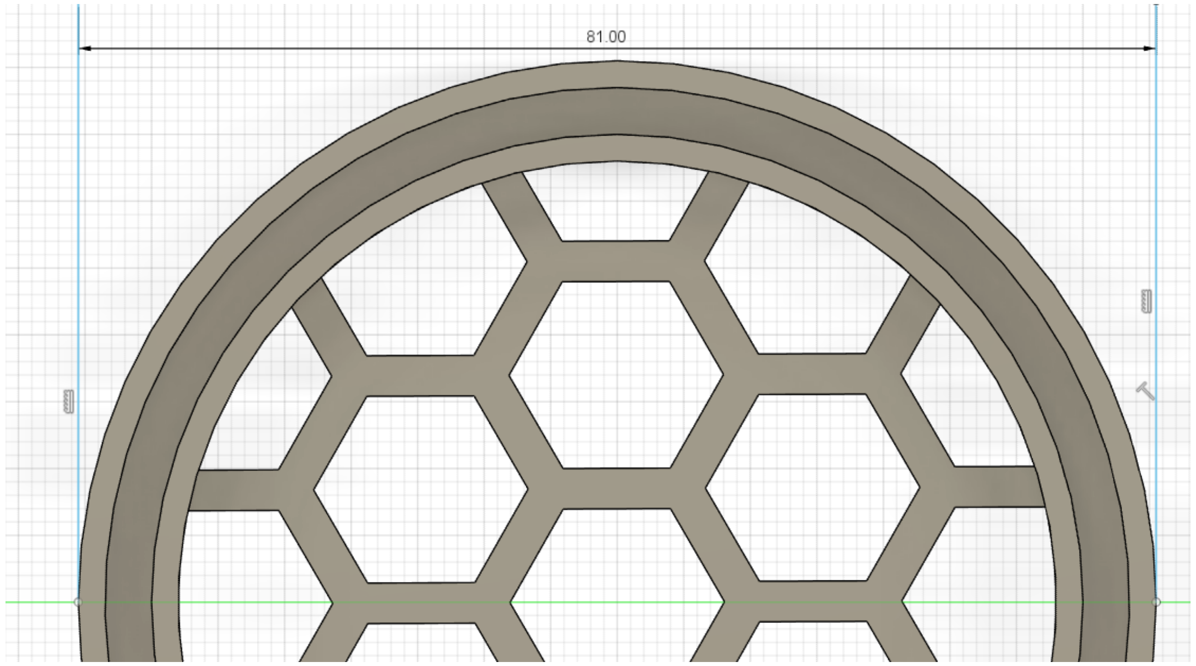
Although the elasticity of the wire is preferable, this wire was much harder to manipulate compared to the aluminium.

This may make it difficult to wrap around the mould to create another spring.

Prototype 5

Prototype 5 resembles very closely to Prototype 4, the diameter has been increased from 75mm to 81mm and the gap has also been closed slightly. This change is to fit the mild steel found in the collapsible laundry basket mentioned in the previous slide.





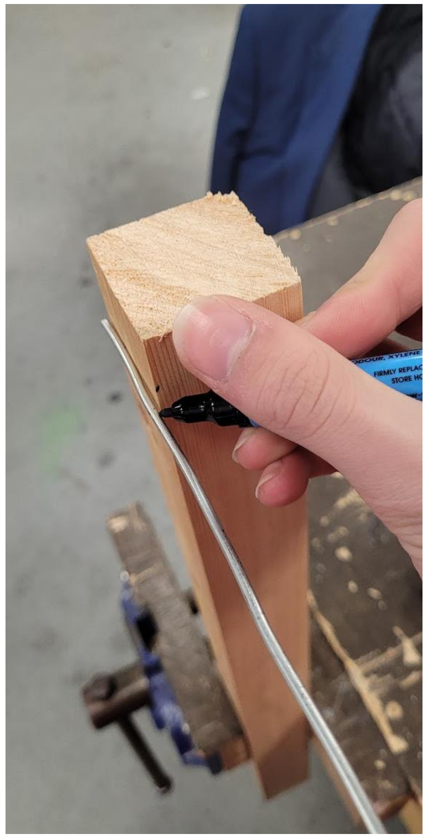
Conclusion

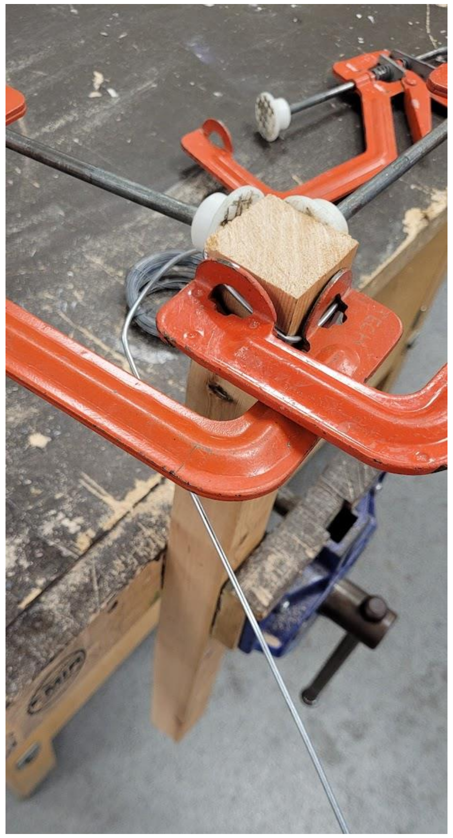
The larger diameter has fixed the sizing issue, however there is still no solution to how the battery will enter and exit the product, this will be developed upon in the next prototype.

The initial idea to open and close a hole in the material itself seems like it would create a vulnerability in its thermal resistance so another method must be found.

Spring testing 3

After trying to wrap the wire around the mould, it became apparent that the wire was too stiff to manipulate by hand. Instead, I tried other various methods of manipulation the wire, such as using clamps.





Since a circular arrangement would increase difficulty, I'm using a square section of pine. An example as to how a new design would look if pursuing the shape can be seen above.

By repeatedly bending a section of wire 90 degrees and clamping down the sections while moving around I would be able to form a square based spring. I quickly realised this would be too difficult given the amount of G clamps getting in the way.

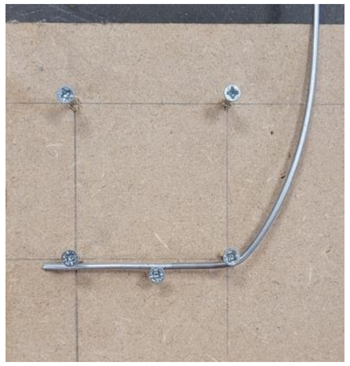
Unfortunately, this process did not work either. The bends would spring back significantly and form an undesired shape.

For the next method, I made a jig from an MDF base and some wood screws. The idea was to manually bend the angles however this was still too difficult.

Instead, by using a brazing hearth and heating the wire until glowing red, I was able to easily bend round the corners. Although this worked out much better than the previous clamping solution, the angles were still inaccurate.

This is partly due to the lack of accuracy the brazing hearth on a specific point, this resulted in very rounded corners. The parts where only a small section was heated turned out much better than the rest.

Another problem with this method is extending the spring after the corners have been made. Since the jig is 2D, the wire would have to be reheated and bent afterwards.



Conclusion

The wire used from the laundry basket has turned out to be a difficulty when manipulating into the desired shape. It would save time and effort switching to a new material. It would also allow the previous circular design to continue, which is the preferred shape for ergonomics.

Ergonomics

Although a squared shape was mentioned on the previous slide, I will continue to pursue a circular design. The most recent prototype, Prototype 5, has been tested in various scenarios the product could be encountered with.

One common scenario is being placed in a pocket. During my own evaluation, I found the product very easy to slide into the pocket as there is nothing for the circular shape to catch on, a square may encounter this issue. The combination of diameter and width did not cause any discomfort, even when walking around.

To research grip, I tested the product with two different hand sizes. One in the 80th percentile (Candidate 1) and another in the 25th percentile (Candidate 2). The candidates were given both Prototype 5 and Prototype 2.

https://multisite.eos.ncsu.edu/www-ergocenter-ncsu-edu/wp-content/uploads/sites/18/2016/06/Anthropometric-Detailed-Data-Tables.pdf Page 20

Both candidates said they preferred Prototype 5 due to the bevelled edges. Candidate 2 mentioned specifically that Prototype 2 was difficult to hold due to the size, and uncomfortable holding at the base which has sharp edges.

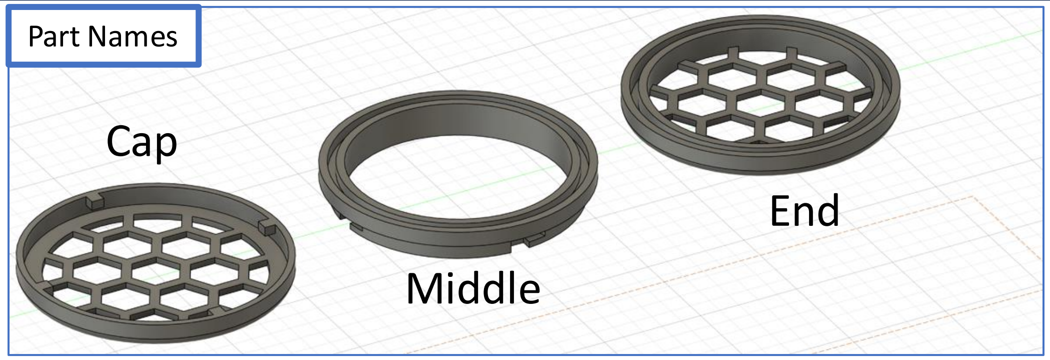
One issue that was indicated by the candidates after holding the prototypes was the risk of a finger getting caught in the ventilation holes. This will not be a problem with the final assembly due to a filter material covering the holes.

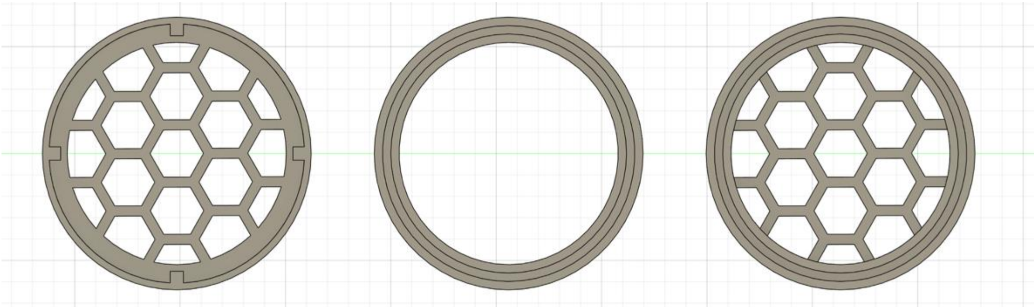
Conclusion

The circular design seems to be far superior compared to a squared form. The product is comfortably sized for a pocket, can be picked up with one hand and has no sharp edges.

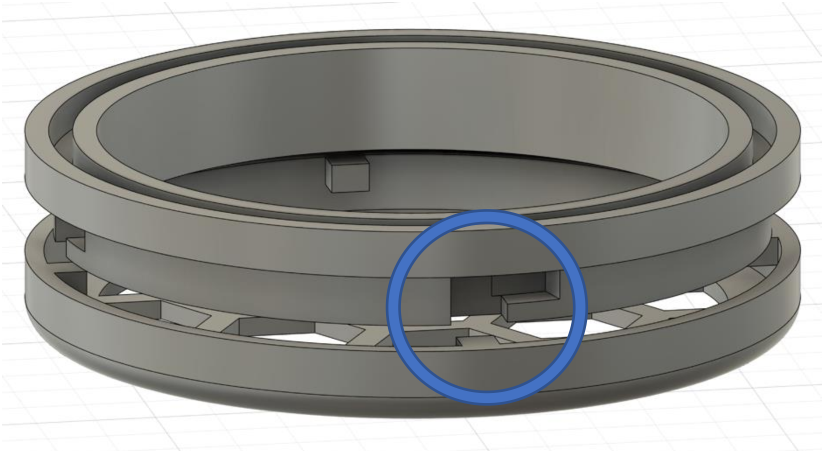
Another ergonomic issue may be the force required to close the product, acting against the force of the spring. It could be the case that the elderly or physically disabled may find the task a higher difficulty. If this is an issue, the strength of the spring can be modified.

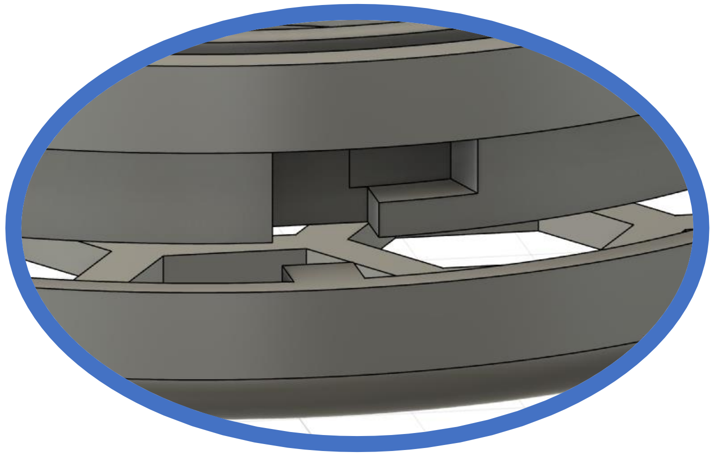
Prototype 6





Prototype 6 introduced two new parts, a middle part and cap part. The middle and end are connected with the spring and flexible material, with the cap securing to the middle with a twist-lock mechanism. Both the middle and cap parts have overhangs so after 3D printing, support material has to be removed and the surface sanded to ensure the twist-lock mechanism works smoothly. This part required lots of sanding around the outside circumference of the middle so the cap would fit over. To avoid this next time, I will decrease the diameter of this surface.





Prototype 6 Development

Prototype 6 Development fixed the twist lock tolerance issue, so the locking mechanism doesn't have friction issues, however, there is no way of securing the cap shut when secured. If the product were to get shaken or knocked, the cap could easily fall off

Conclusion

Prototype 6 and its development introduced a functioning solution to open and close the battery without compromising on safety.

The next prototype will aim to solve the problem of the cap falling off. An idea that seems appealing is the use of magnets.

Spring testing 4

The next material I'm testing to form into a spring is copper. This material specifically is a filler material for brazing but after coming across the rods, they seem suitable for the use.

The rods are very small in diameter and lightweight, ideal for portability. Most importantly, the material is easy to manipulate and does not deform as easily as the aluminium.

The mould does have to be smaller for this material as it springs back more than the aluminium, this was an easy fix referencing vernier callipers periodically.

Wrapping around the mould was very easy and the diameter fit the current prototype accurately. Because the wire is very thin, the entire spring fits inside the prototype when closed.

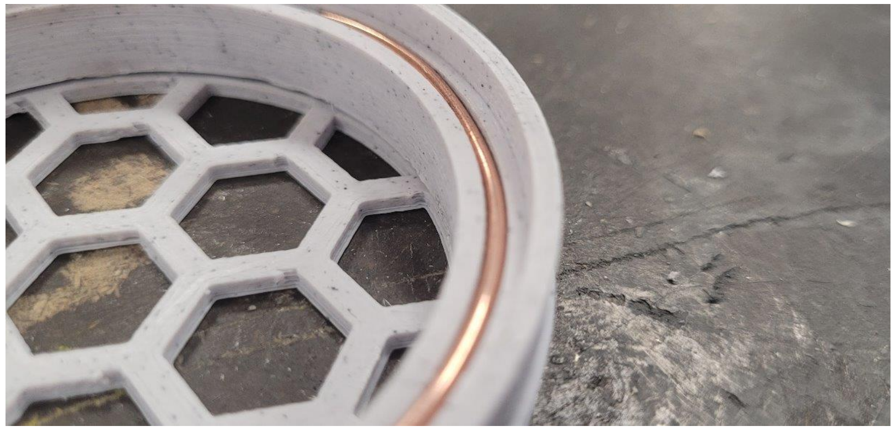
Now the spring sits in the prototype, I've noticed there isn't much space left in the slot for the flexible material to sit. This will be fixed in the next prototype

Conclusion

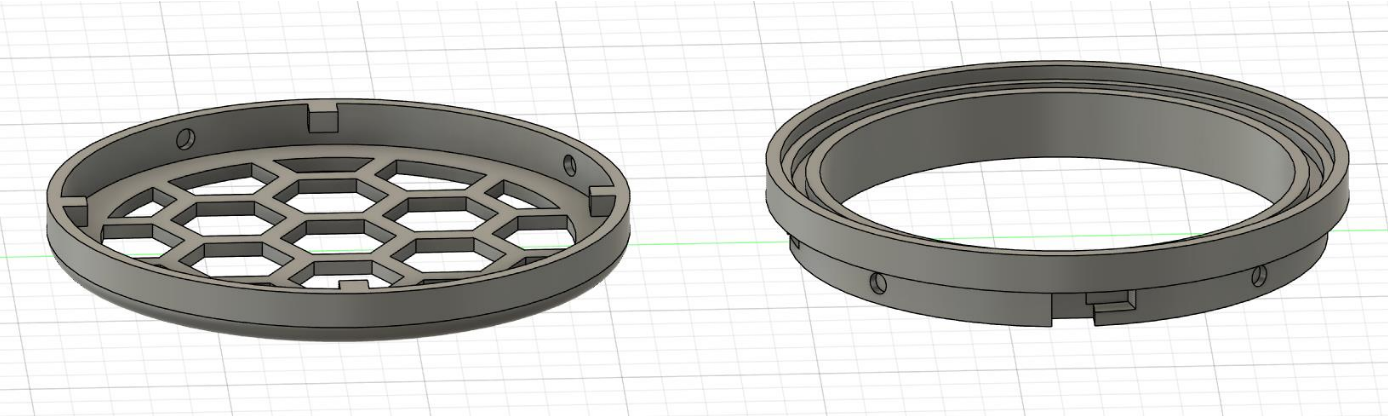
This material of spring works much better than the others tested and will continue to be used for future prototypes.

The design will need to be modified for the spring and fabric to sit in the middle and end piece. One solution to this could be to separate the spring and fabric into two separate slots so they don't restrict movement.

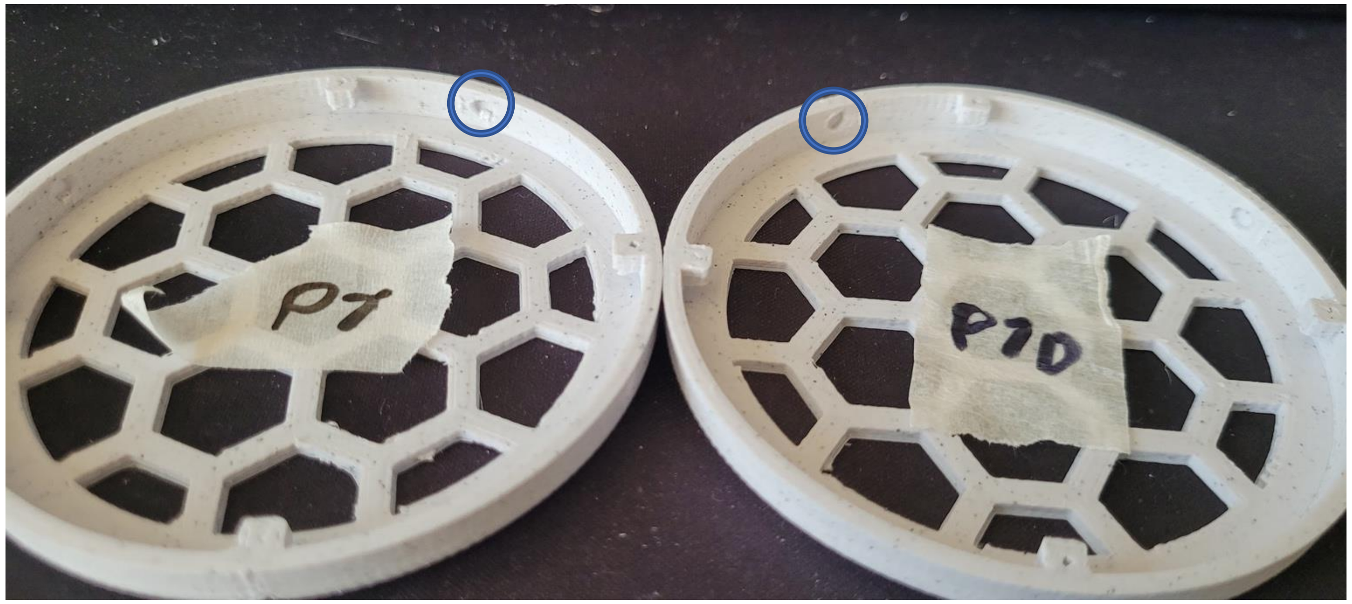
Prototype 7



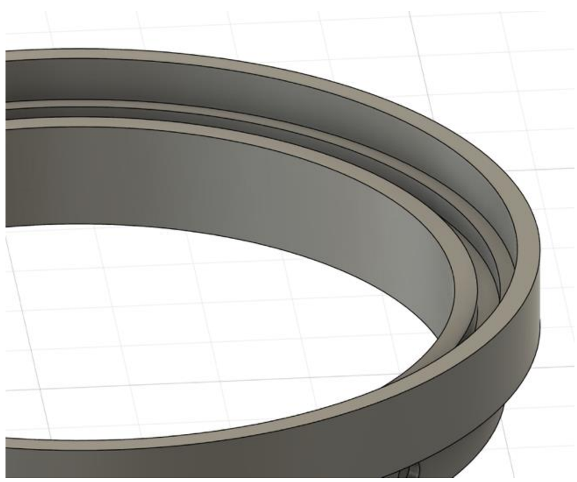
For Prototype 7 the section to slot the spring and material in has been changed. There is now a slot specifically for the spring, and the fabric will sit on the outside of the spring. Another change is the additions of holes to for magnets to be secured inside, the holes are on both the middle and cap piece. The magnets should align when the twist lock is rotated shut to secure them locked in that position. After printing I realised the magnet holes were in the wrong position and didn't align, this will be fixed in the next print.

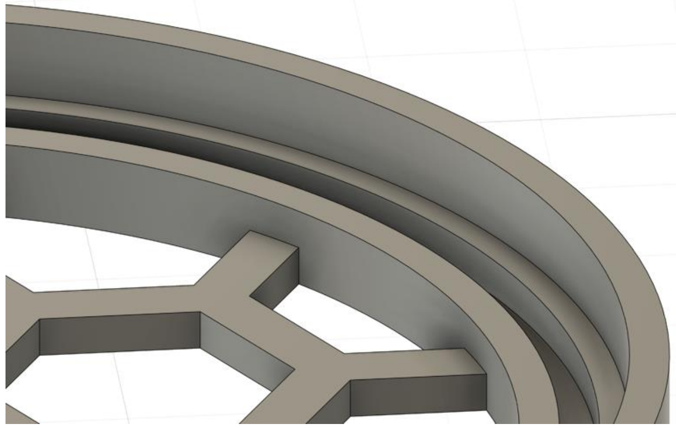


Prototype 7 Development



For Prototype 7 Development, I fixed the alignment of the magnets and added a larger lip to both the end and middle so the flexible material has more space when the product is closed.



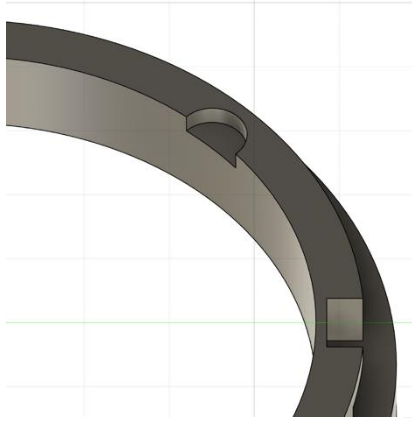


Conclusion

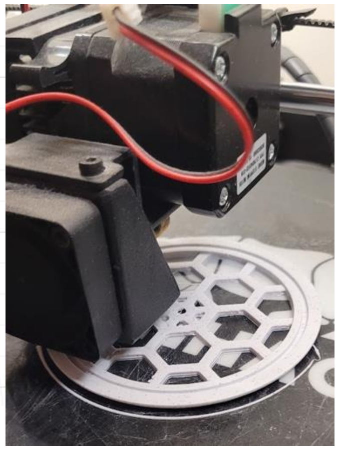
Prototype 7 and its development have solved the issue of the cap falling off, the magnets give a noticeable force when closing the product's cap which would inform the user that the lid is secured. The next incomplete aspect of the product is securing the product in a closed position. Since the spring will always push against a compressive force, a relatively robust method of securing the middle and end shut is needed.

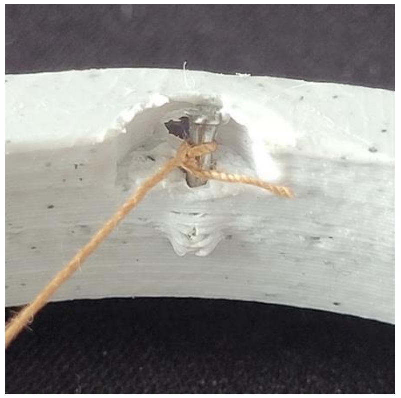
Prototype 8

The idea for Prototype 8 is using string to hold the middle and end a set distance apart. The string would then be pulled to close the two ends together. The string is secured at four points on the middle section and is fed through a hole on the end.

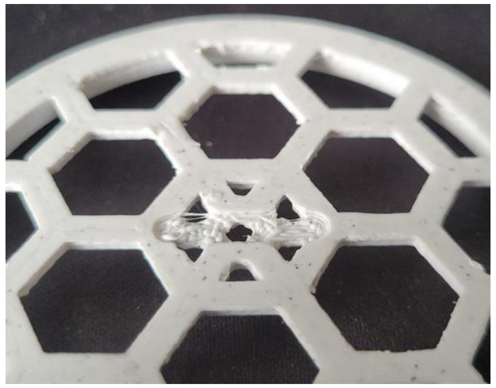




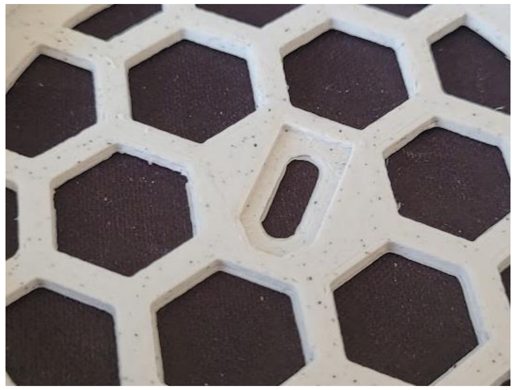


The string is tied to a short nail that's attached to the middle section. A problem with this is there is no hole so the nail displaces the plastic, breaking the part. To fix this a hole for the nail will have to be printed with the design or drilled out. Since more prototypes will be printed, I'll modify the design to include the hole.



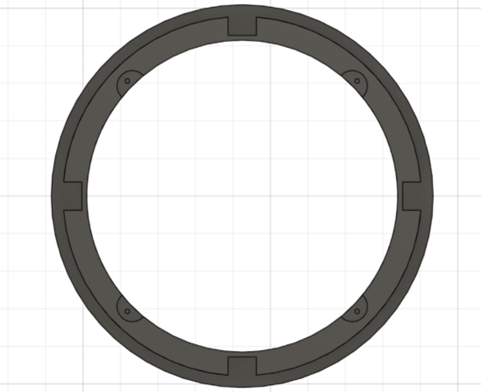
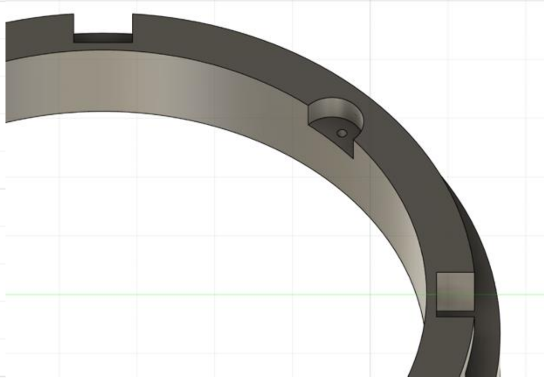
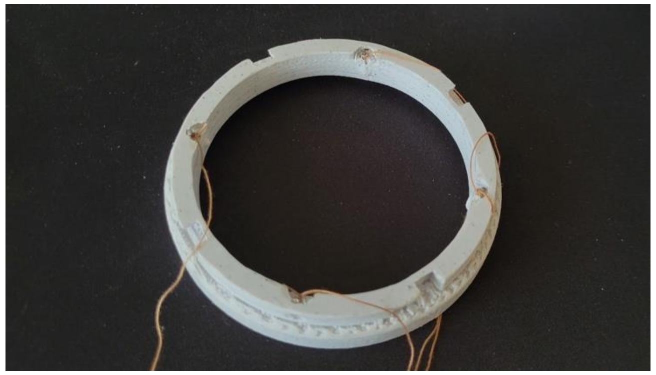
At the bottom of the end there is also a cut-out for a small cylindrical handle where the four strings would attach. It would also be the part you would pull to close the product.



The cap has also been modified with a designated slot for an XT60 extension lead to be attached. This is to route the battery cable to the charger without creating an open gap in which flames could escape.

Prototype 8 Development

For the development of the design, I fixed the issue of the nail damaging the print by including designated holes. The photos below also show the assembly with the string. The user would pull the string at the end, this pulls the middle towards the end, compressing the string.


Conclusion

After assembling Prototype 8 Development, I noticed some issues.

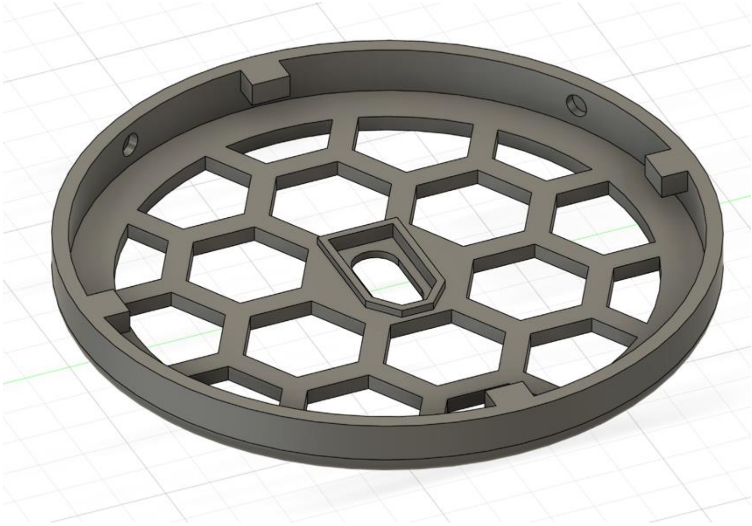
When the product is open and the string collects into one point, it creates a conical shape which would obstruct the battery. Having multiple holes on the end section for the four strings would solve this.

Another issue regards the xt60 mount. The dimensions are slightly too small and the indent created is not large enough to secure the plug in position.

Prototype 9

The end section in Prototype 9 now has four holes for the string to feed through instead of one. This means the tensioned strings will position around the battery instead. One problem with this design is that the string cannot connect to a handle as they are all separated. I will have to design a solution to collect the strings back to a singular point.

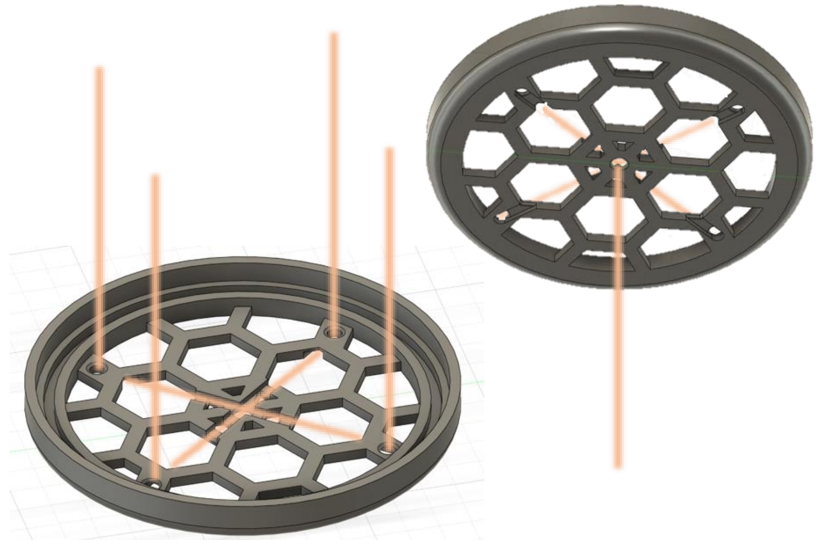
The other modification is to the XT60 mount on the cap. The dimensions have been increased for a better fit with the cable and there is now a lip for a more secure hold.

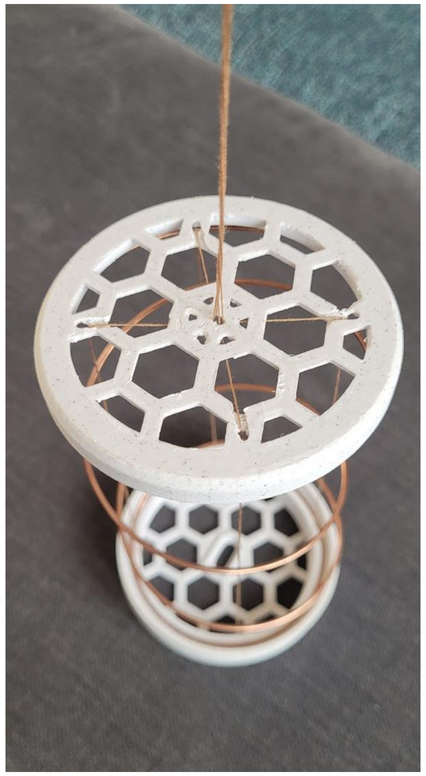


Prototype 9 Development

Prototype 9 Development introduces some valleys to the end piece so the string is redirected to one point. This allows the handle to attach.

The string enters the piece through the four holes at the bottom of the end piece, wraps over and back to the bottom where it can be fed back through a hole in the centre. All of the edges that the string passes over have been bevelled to reduce friction and wear over time.



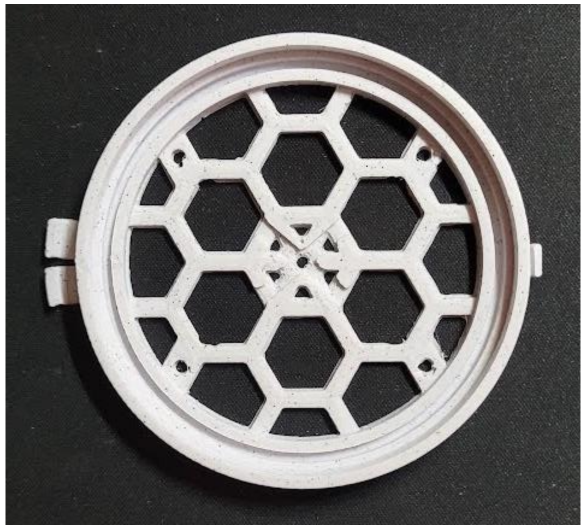


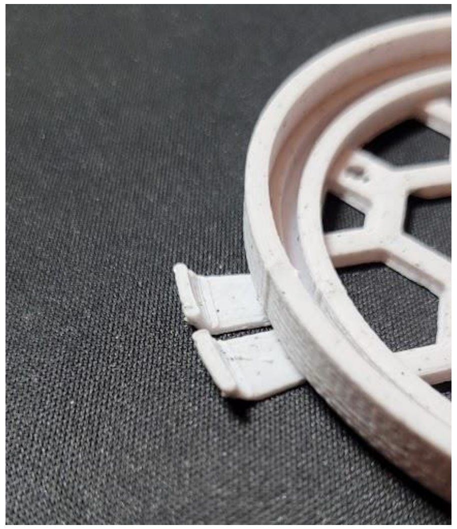
Conclusion

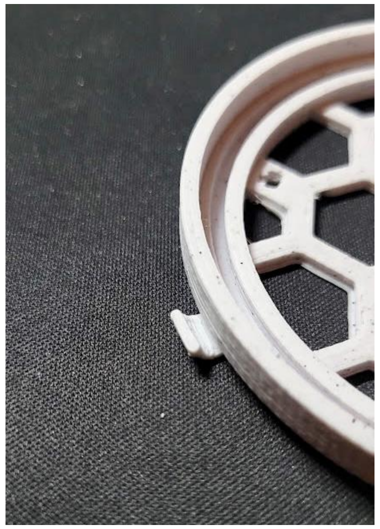
Now the handle can be attached, the product needs a way of staying in a closed position. By applying constant tension on the string while closed, the string itself will pull it shut.

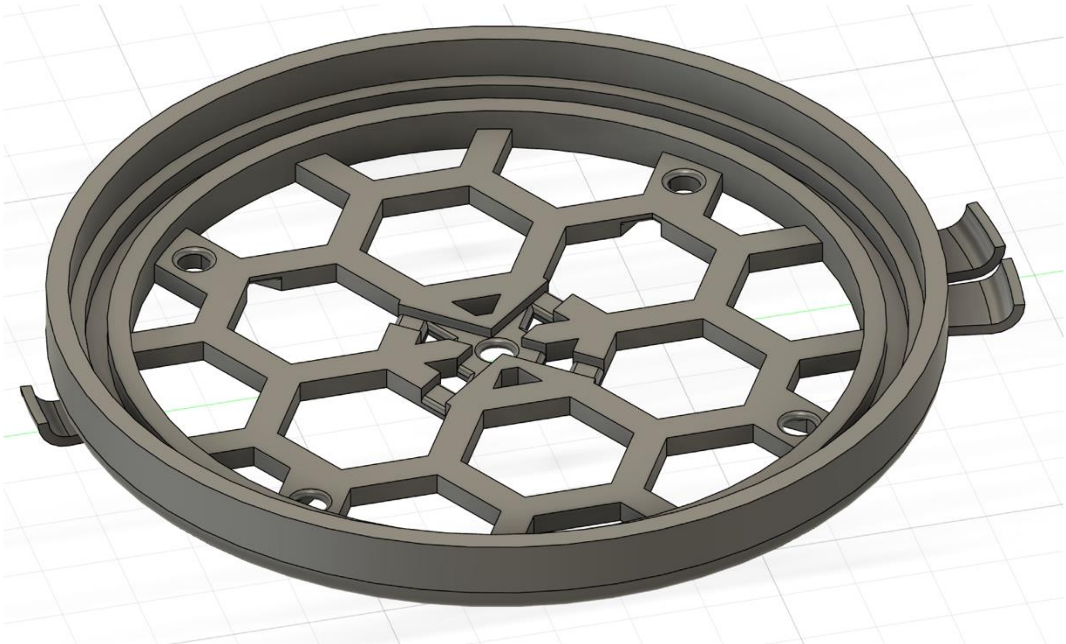
Prototype 10

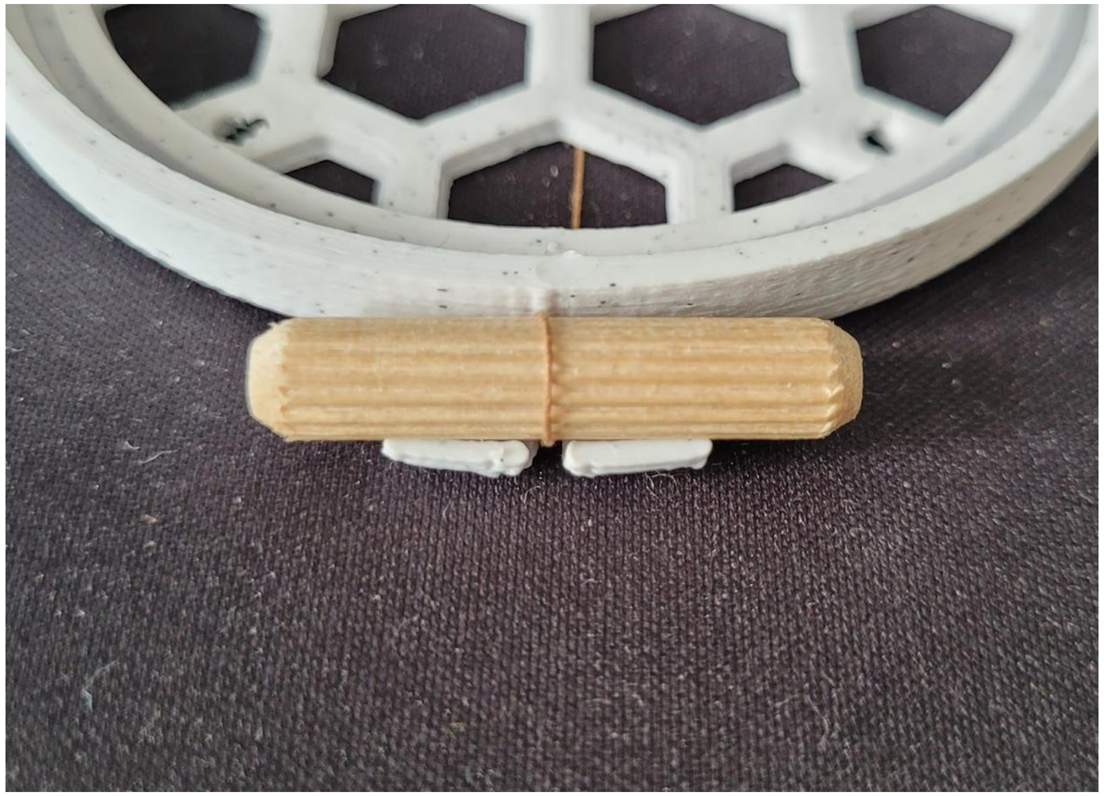
Prototype 10 adds adapts Prototype 9 Development by adding two hooks on the end piece. When closed, the slack string would wrap around the small hook and loop back to the large hook. Since the large hook holds the handle securely, the string cannot extend, restricting the spring from extending. This holds the product closed.

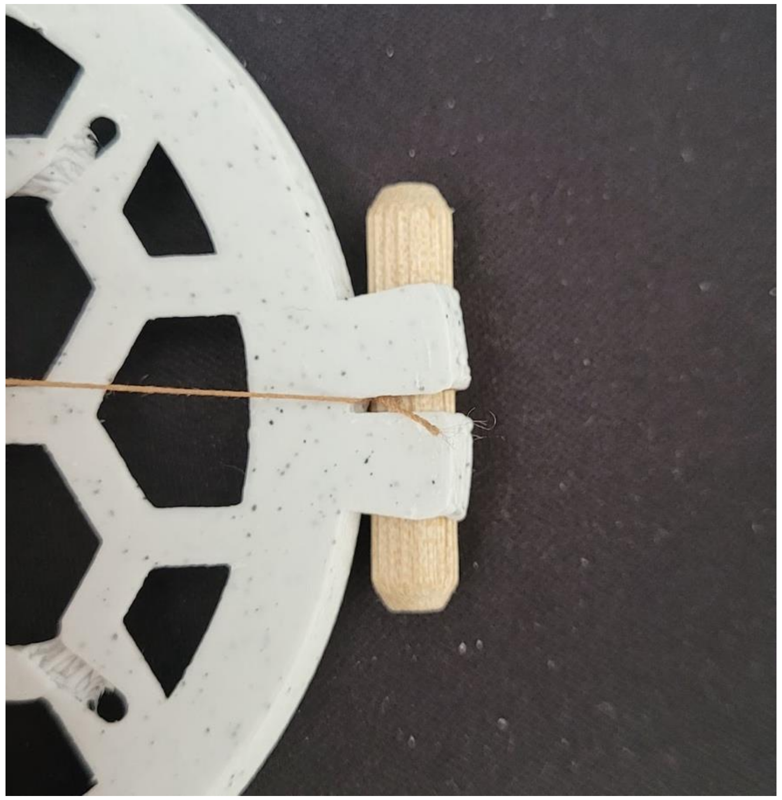












Conclusion

At this point of the process I'm happy with how the design has turned out. There are no issues that immediately stand out for another prototype to be necessary.

The next step in the process will be deciding what materials to use. For fire retardance the ceramic fibre turned out to be unsuitable for flexibility so another material I will look into is woven fibreglass. Thais material failed in the battery bag test however the material was very thin. A material must also be found to filter out flames exiting the vents.

Material Testing - Ceramic Fibre

After secondary research regarding various fire-retardant materials, I found Ceramic fibre to be suitable due to the thickness, malleability and fire retardance. The product I'm testing is 2mm thick, however they sell this form between 1mm and 3mm. Upwards of this the product is considered Ceramic Wool or Board.

The material purchased comes in A4 sized sheets and was very easy to cut with scissors. The first property of the material I tested was its fire retardance.

Using a kitchen blowtorch (Figure 1), the material was exposed to the heat for 10 seconds. After inspecting the results, there was no broken seal, the material didn't melt and didn't set alight. There was, however, damage to the structural integrity of the fibreglass. The layers of the sheet seemed very soft, and fibres tore apart easily.

Another test with the material related to its malleability. Since the material must suit a collapsible design, long term flexibility is crucial. The ceramic fibre managed to sustain 55 folds until tearing apart however damages started to occur within the first 10 folds.

The final test for this material involved 5cm of Visco fuse sealed between two squares of ceramic fibre (Figure 2). As seen below, the material held up well compared to the woven fibreglass in the battery bag testing where holes were made. The material after this testing also resulted in a much weaker fibre, very similar to the result of the blowtorch testing.

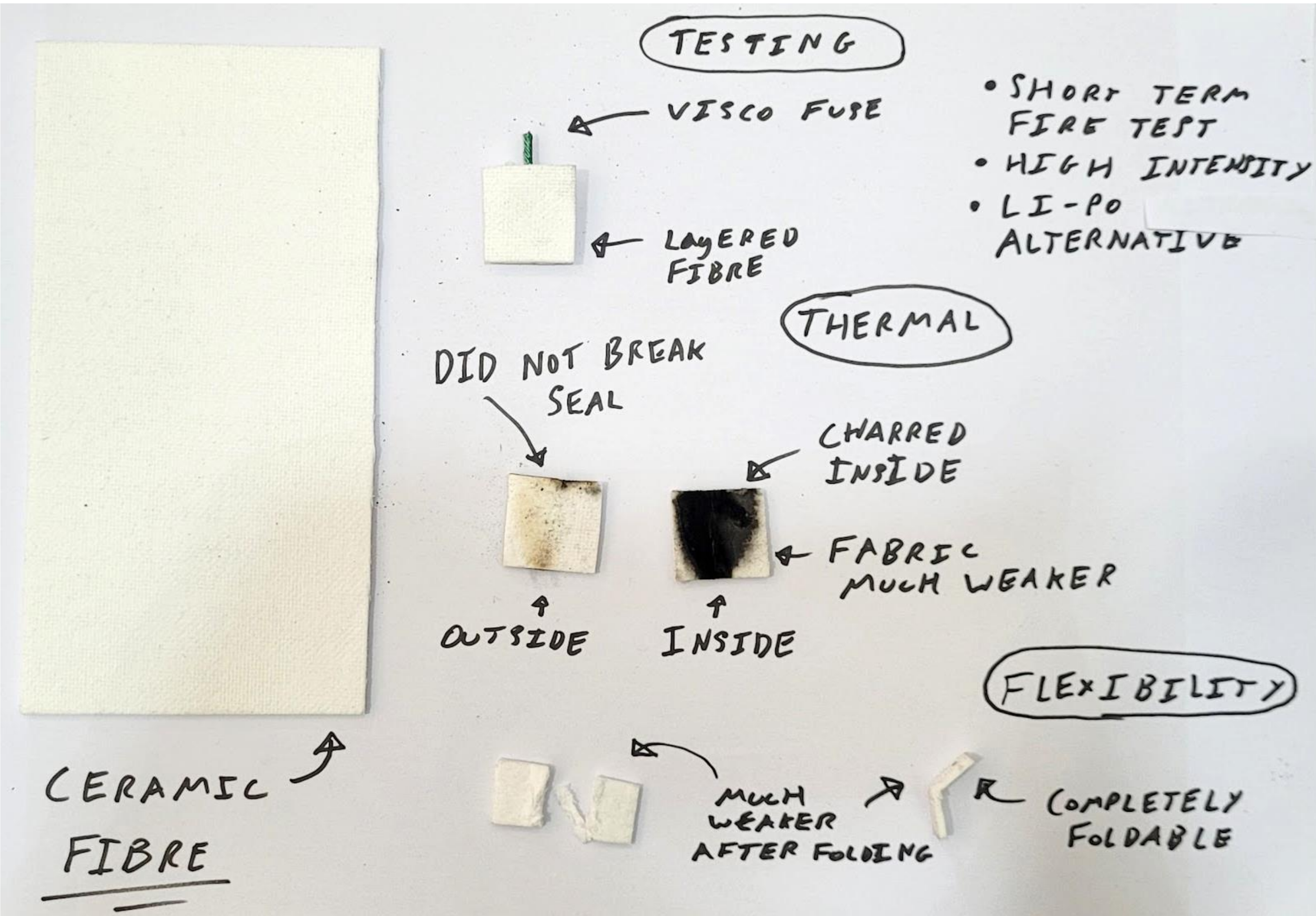


Figure 1



Figure 2

Conclusion

Though the material could withstand the temperatures required, due to the lack of structural integrity when being folded, this material will not work for its intended function. A similar material that can sustain malleability still needs to be found.

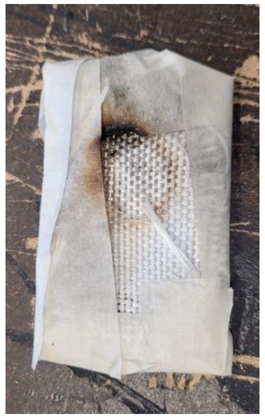
Material Testing - Woven Fibreglass

Since the ceramic fibre turned out to be unsuitable for this product, I am testing woven fibreglass as a possible material to use. This woven fibreglass was purchased in the form of a welding blanket and is relatively thick at 510 GSM compared to the estimated 200 GSM of the tested battery bag. For this testing, I will do 2 tests, one with a flat piece of wove fibreglass and another with the fibreglass wrapped around the fuse.

The flat section test involved a short section of visco fuse placed in-between a layer of ceramic fibre and a layer of woven fibreglass. A hole was made in the ceramic fibre to access the fuse.

The wrapped section involved a fuse wrapped around with the woven fibreglass and secured in a cylindrical shape using masking tape. I had access to the exposed fuse from one end.

No flames were visible during the testing or while performing a frame-by-frame analysis, the masking tape did not catch fire.



The material did not burn through, the outside only experienced discolouration. The physical properties did not alter either, the fibreglass did not weaken or stiffen due to the temperatures.

The fibreglass in the wrapped test experienced the same effects as the flat test. No major flaws were identified.

Conclusion

The woven fibreglass performed very well in the tests. The material did not melt, unlike the thin woven fibreglass in the battery bag, and since it is a fabric, flexibility is not a problem. This material seems a great fit for the fire-retardant lining around the spring. The only noticeable issue is the fraying edges. This will be fixed when secured into place on the product.

Filter Testing

To test ceramic fibreglass as a filter material, I have designed a small container in similar design to the prototypes. The bottom half is where the fuse will be placed, and the cap with filter material will be placed on top.

The filter is secured by the ring mentioned first in prototype 3, this is a good test for the durability of this mechanism. I mistakenly didn’t add a hole for the use to be ignited from in the CAD and print so I had to pillar drill a hole in the plate.

To allow air through the ceramic fibre, I used a pin to create small holes with the idea being the heat from the flames will be absorbed by the fibre and air can escape through the holes.

After testing it seems successful as no sparks or flames can be seen but after further analysis it seems most air is escaping through the hole at the bottom, towards the ground. This means the inside pressure is not correct, invalidating the test.

To fix this, I placed a sheet of ceramic fibre beneath the test to seal the hole. A clamp then put downwards pressure on the body. This resulted in a more accurate test showing the sparks did escape through the holes of the ceramic fibre. This is likely due to the high pressure inside, forcing air and heat out.

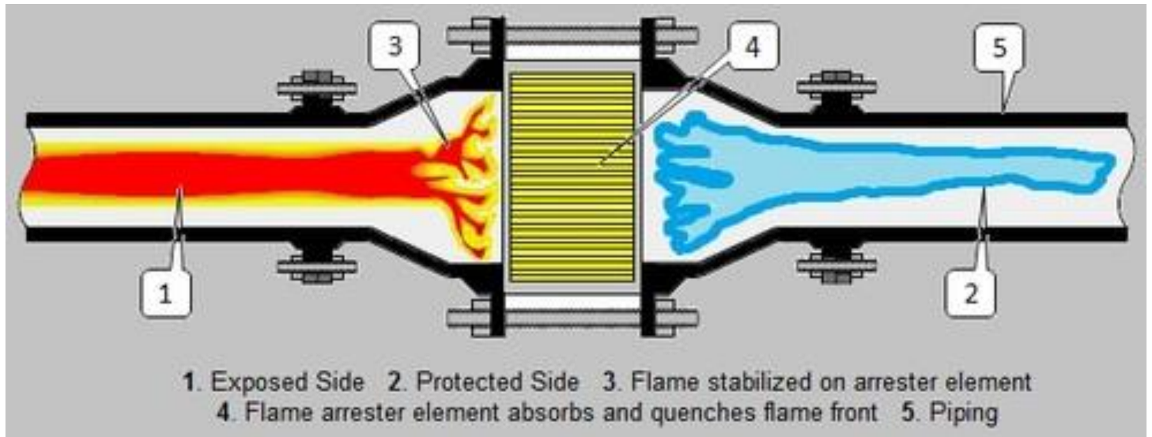
Conclusion

The ceramic fibre doesn't seem to be a good suit for this function. The felt-like material is not porous so to let air through, holes must be made in the material, letting flames out.

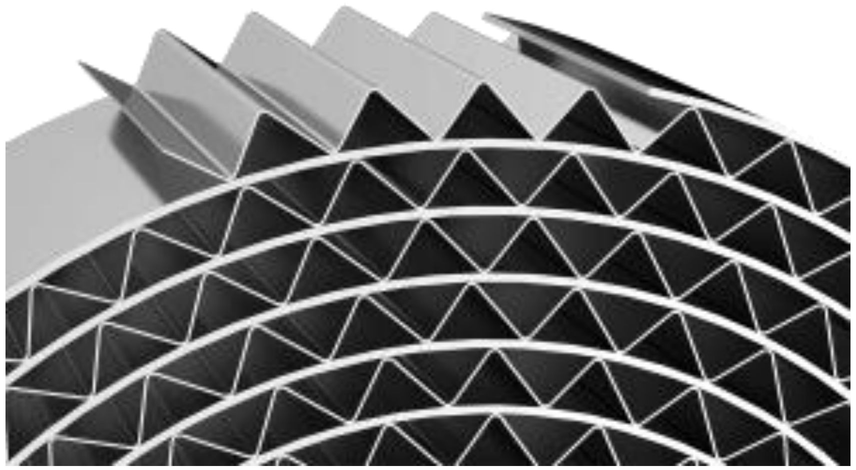
Filter Material

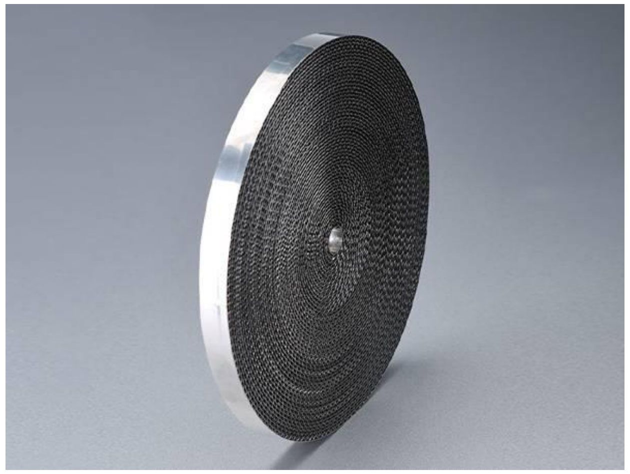
A filter material still needs to be found for the product since ceramic fibre deemed unsuitable.

Many industrial systems use a component called a flame arrestor. These function by absorbing the heat of the flame to below ignition temperature on the opposite side of the arrestor, therefore the fire cannot continue the opposite side. To absorb the heat, the gas is exposed to an element, this is made from metal strips wound in a corrugated arrangement to maximise surface area.



https://paradoxintellectual.com/how-flame-arresters-work.html



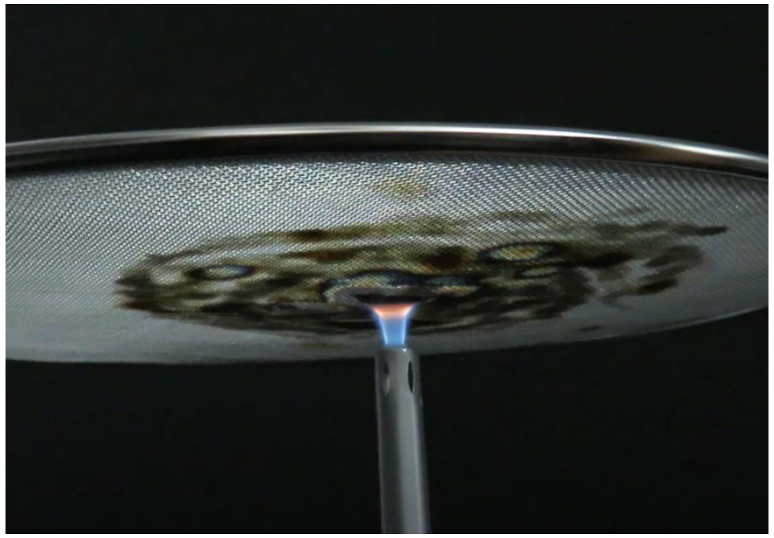


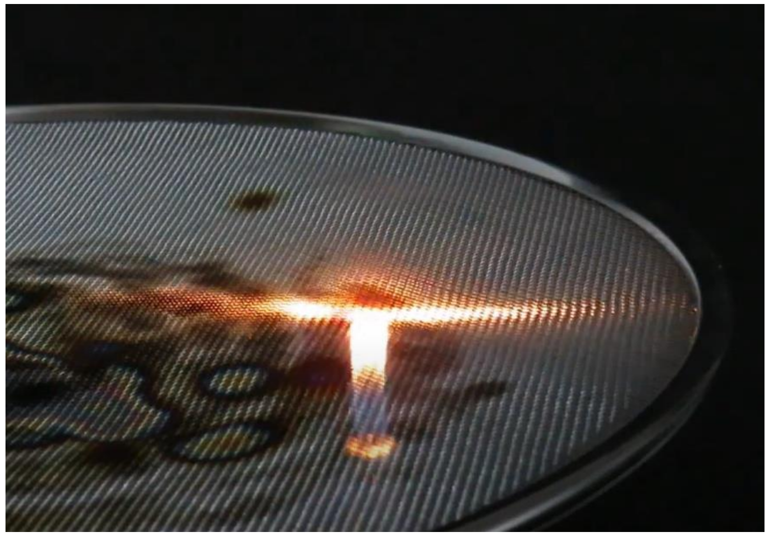
These systems perform the function required for the product's filter, but the size and weight of the standard products make it incompatible with the product.

Another component that forms a similar function is a flame screen. This solution is generally used for smaller applications and consists of wire woven fabric of very small mesh. Like the flame arrestor, they both aim to dissipate the heat of the flame so it cannot ignite on the opposite side.

An example of a flame screen is a wire gauze, typically found in schools for use with Bunsen burners to protect the glassware.

Since this solution is much cheaper and more lightweight, it suits the product much better. Due to the high pressures created in a battery containment solution, a wire with very small mesh must be used for larger heat dissipation.





Conclusion

The route of using wire mesh for the filter seems very viable. The material is accessible, lightweight, and since it is also inexpensive, the filter material could also be a replaceable component in the design should thermal runaway occur.

Safety Information

This safety information would be provided along with the product. It contains important information regarding lithium-ion battery safety, aiming to prevent thermal runaway from occurring in the first place.

IMPORTANT CARE AND SAFETY INFORMATION

Cells	1	2	3	4	5	6
Max Voltage	4.2	8.4	12.6	16.8	21.0	25.2
Min Voltage	3.0	6.0	9.0	12.0	15.0	18.0
Storage Voltage	3.7	7.4	11.1	14.8	18.5	22.2

Definitions

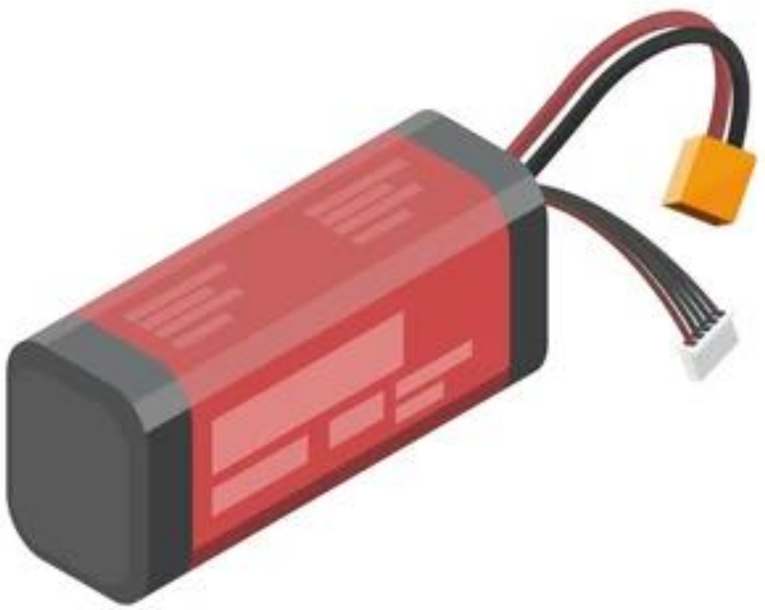
Cell Count: Number of cells in a battery, typically ranging from 1-6

Capacity: The mAh rating amount of energy the battery can store

Average voltage: The total voltage when cells are at 3.7v

WARNING

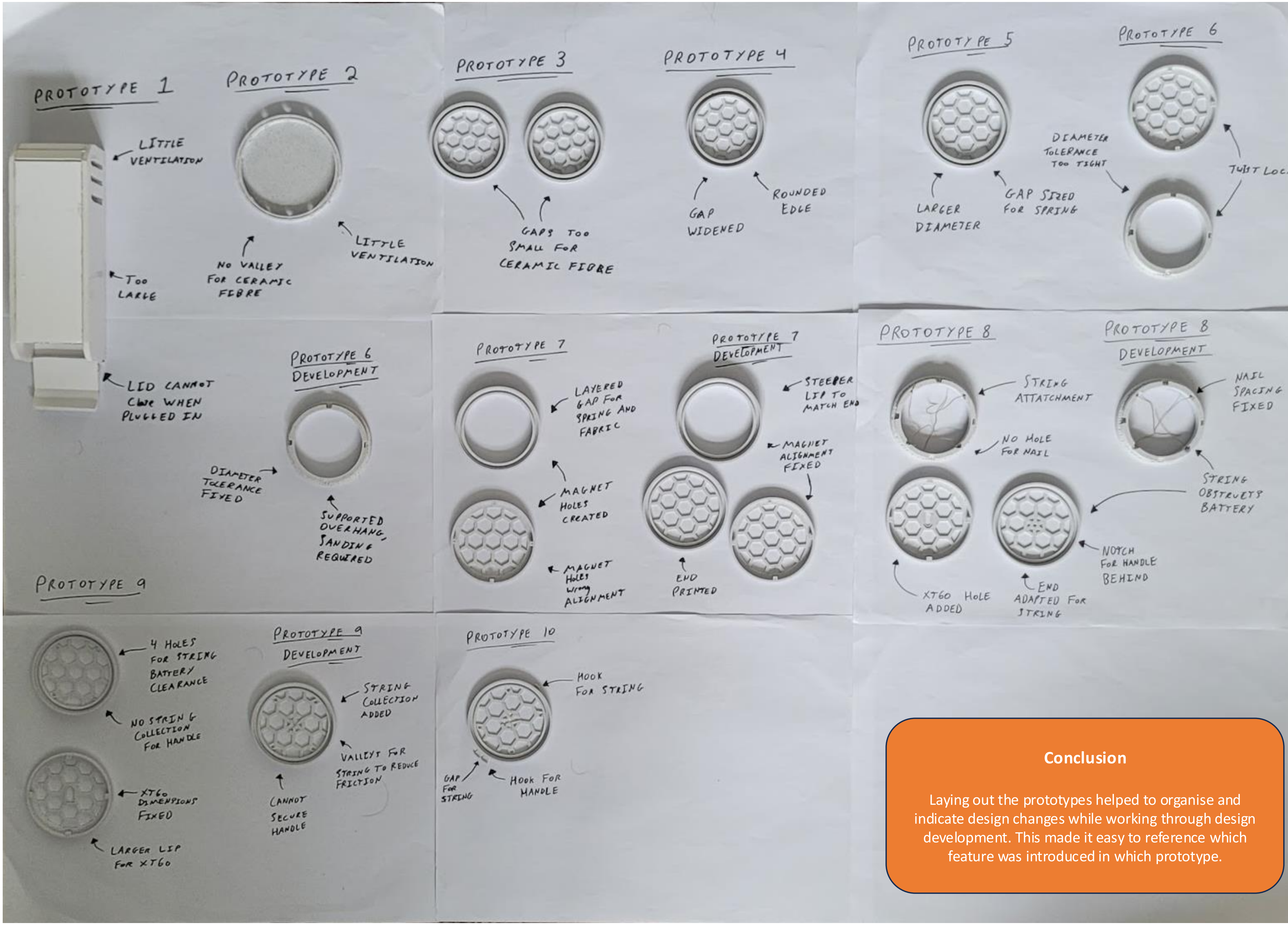
- Do not leave batteries fully charged for more than 2 days, for long term storage, reference the storage voltage.
- Do not charge battery while still warm after use
- Never use battery below -20°C and 60°C
- Check battery for physical damage before charging
- Never leave batteries charging unattended
- Keep batteries away from water
- Store batteries at room temperature
- Always dispose of "puffed" batteries
- Always charge at 1C: 1000mAh = 1A



Conclusion

As indicated by the focus group, the safety information uses contrasting colours such as black, white, yellow and uses a FF DIN PRO BLACK font. It contains detailed information in a clear and concise way.

Prototype Development



Conclusion

Laying out the prototypes helped to organise and indicate design changes while working through design development. This made it easy to reference which feature was introduced in which prototype.

Manufacturing Details

Part	Material	Process	Material Price	Reference	Part Price	Quantity	Total Price
Cap	Anodised aluminium	CNC milling	£1.96 per 100g	https://www.aqua-calc.com/calculate/materials-price/substance/aluminum	£0.44	1	£0.44
Middle	Anodised aluminium	CNC milling	£1.96 per 100g	https://www.aqua-calc.com/calculate/materials-price/substance/aluminum	£0.66	1	£0.66
End	Anodised aluminium	CNC milling	£1.96 per 100g	https://www.aqua-calc.com/calculate/materials-price/substance/aluminum	£0.53	1	£0.53
Spring	Copper	Winding	£4.23 per 100g	https://www.bes.co.uk/1-kg-phoson-brazing-rods-15995/	£0.71	1	£0.71
Flexible Material	Woven fibreglass >400GSM	Scissors	£1.71 per 100g	https://www.amazon.co.uk/dp/B09H7J8GSB?ref=ppx_yo2ov_dt_b_product_details&th=1	£0.86	1	£0.86
Filter Material	Wire gauze	Wire cutters	£0.52 per gauze	https://www.rapidonline.com/eisco-iron-wire-gauze-plain-15cm-pack-of-10-52-3568	£0.52	2	£1.05
						Manufacture Cost:	£15
						Net Price:	£19.25

Material

Though the prototypes were 3D printed, and therefore PLA, they cannot be used since the melting point of the material is very low (<150 degrees). The proposed material for the parts indicated in the technical drawings, will be anodised aluminium. Aluminium is an inexpensive, lightweight and has a melting point that exceeds 500 degrees. An issue with the metal is its conductivity, when working with batteries, high conductivity could result in a short-circuit, possibly causing thermal runaway. To combat this, the aluminium can be anodised, creating a non-conductive oxidised layer on the surface of the aluminium, preventing the risk of a short-circuit.

Process

When manufacturing the part, computer-controlled milling (CNC milling) would be an ideal process. The CAD file of the project paired with CNC would provide the precision needed to for a complex part with tight tolerance, needed for the design in this project. CNC milling costs around £40 per hour. I estimate the three aluminium parts in total will take around 20 minutes to manufacture, bringing the manufacturing cost to £15.

Type of Manufacture

From start to finish with an assembled product, I would estimate the process would take 25-30 minutes, this time scale makes it suitable for continuous manufacture. Just in time (JIT) manufacture would improve the efficiency of continuous manufacture. With multiple CNC milling machines running, the process would also be suitable for batch manufacture. Since the components/materials involved in this product tent to be sold in larger quantities than required for a single product, the process would benefit from lean manufacturing. To achieve this, appropriate tessellation for the woven fibreglass and filter material would be beneficial.

Conclusion

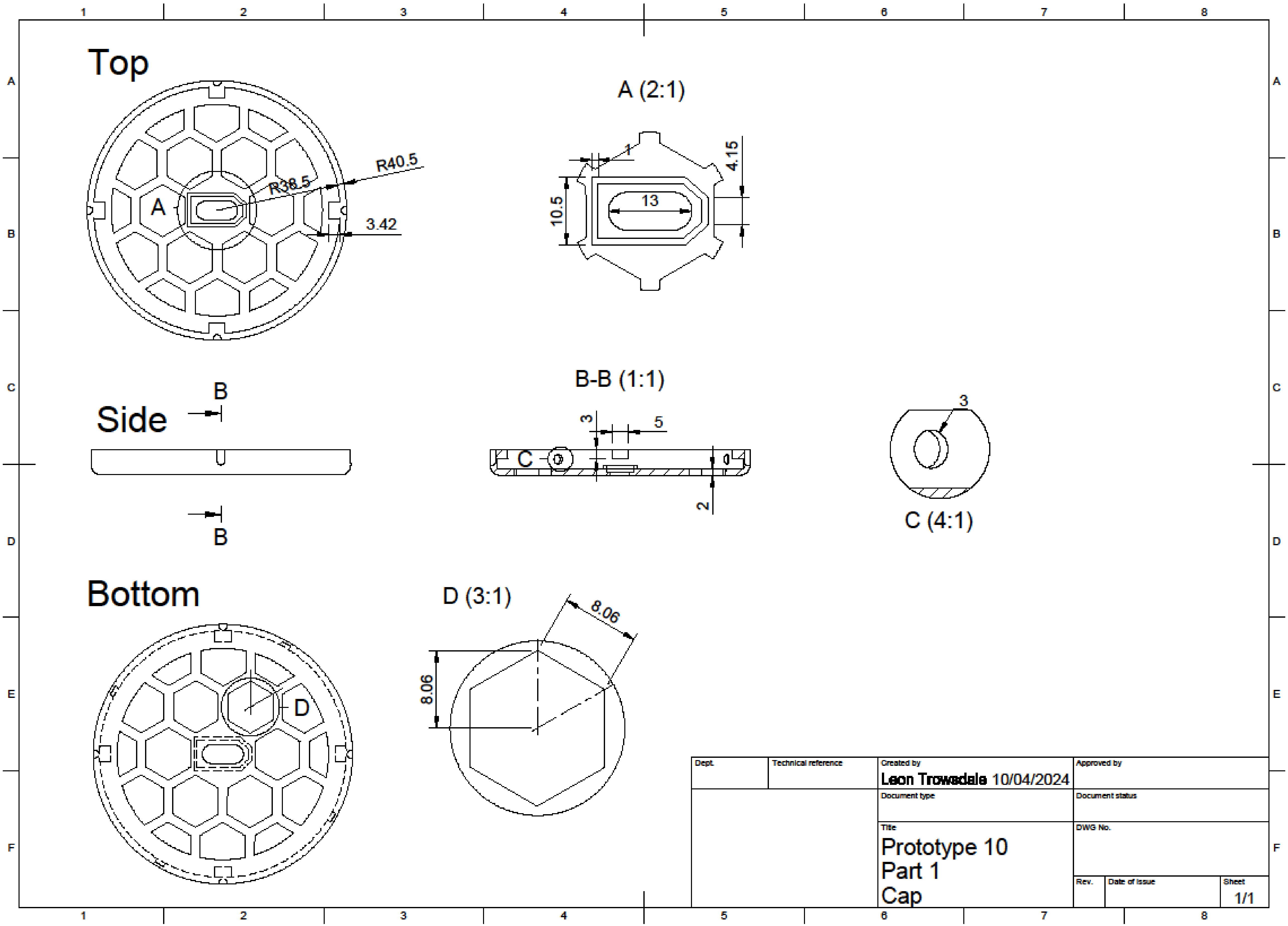
The price initially set for the product was £60, however the total cost of the product turned out to be lower than expected. A lower market price may make the product appeal to a wider demographic, possibly mitigating the issue of consumers compromising their safety to save money. The product being priced at £40 would still provide a large profit margin, at £20.75 per product.

Manufacturing Specification

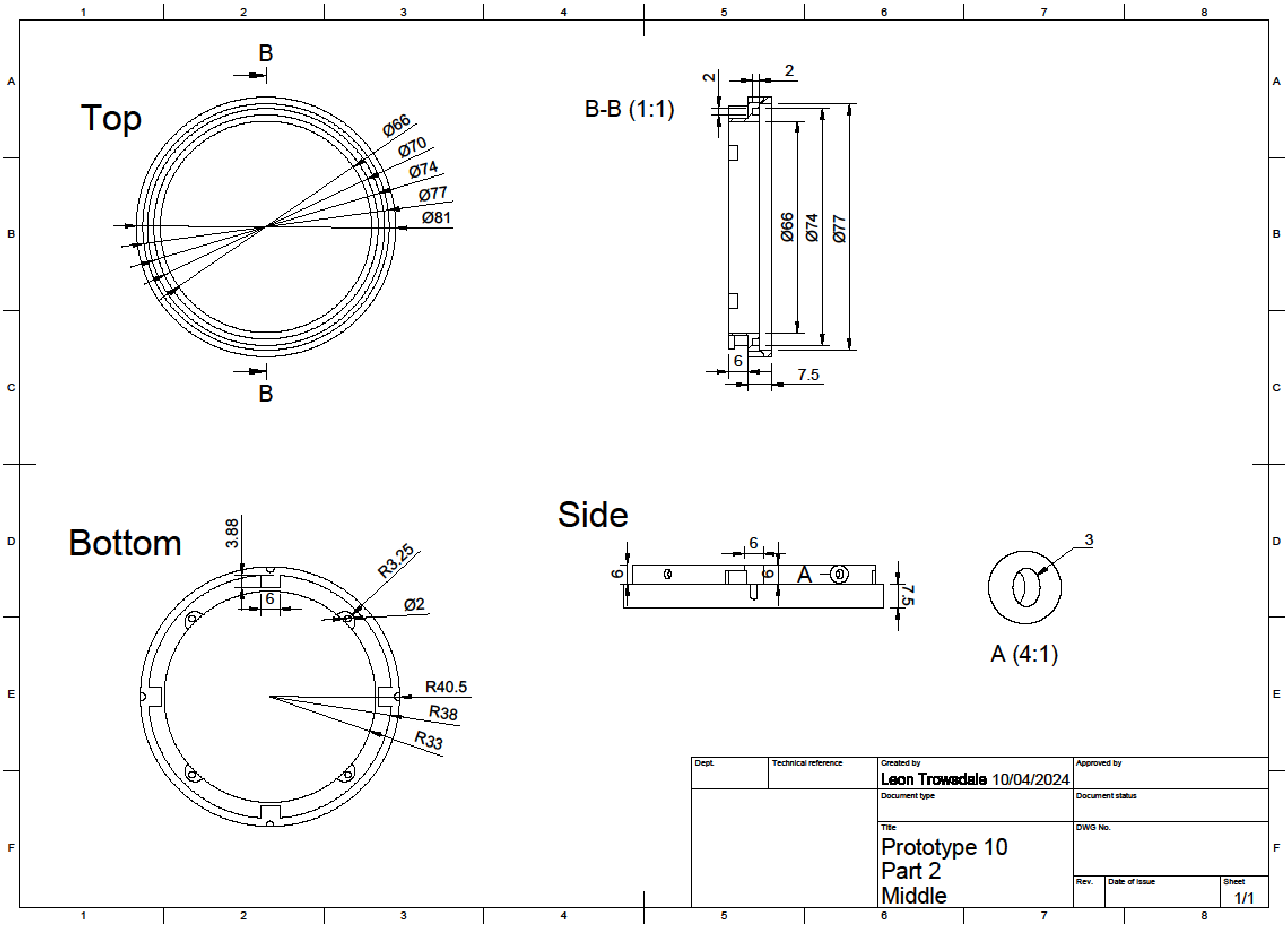
Throughout the design process, I have identified some changes that need to be made to the specification, these will be indicated here. The changes to the specification have been highlighted yellow.

Criteria	Justification	Solution	Evidence	Conclusion
Must mitigate the effects on a fire from a lithium-based battery experiencing thermal runaway.	There have been reports of these fires causing house fires, sometimes resulting in injury or death. Containing the fire is crucial to prevent this.	A flexible fire-retardant material, resistant up to 500 degrees C will be used to contain the temperatures produced.	Slide 46	Woven fiberglass resulted in being the preferred material due to its ideal flexibility and thermal resistance.
Must release pressure from gas release.	Lithium-based batteries release gas during thermal runaway. In a sealed environment, pressure increases rapidly, possibly causing an explosion. Some sort of ventilation is needed to prevent this from occurring.	A semi-permeable material is needed that air can pass through, yet flames cannot. Materials such as metal-based foam or gas filters would suit the purpose. The material should also be lightweight, as stated by the next criteria.	Slide 48	Mesh gauze has been decided on for the filter material as it is lightweight, inexpensive and can filter out flames.
Must be portable in both size and weight.	Many pilots, especially those who fly professionally, travel to scenic locations for filmmaking. These areas can be far from where they live, sometimes abroad. The design must be able to be taken on carry-on luggage under airline restrictions.	Designing a way for the product to compact into a smaller form factor than the battery itself. This could be through compression or folding. The product should also only use materials that are lightweight and avoid unnecessary material use.	Slide 33	In Prototype 4 I decided to integrate a large diameter spring into the design so the product can compress into a smaller, more portable form factor.
Must be able to accommodate one battery of ranging types.	Lithium batteries come in many shape forms. Some of the largest are high-capacity Li-Po batteries. The product only needs to contain one because lithium batteries are most volatile while charging, other batteries that are not charging can be stored with a less secure, alternative solution.	Research the range of sizes and connectors that lithium-based batteries are sold in. The maximum and minimum sized battery should be recorded so the product can be sized appropriately. The product should also have the correct ports or sized holes for various types of lithium batteries.	Slide 36	Prototype 5 introduces an increase in diameter to comfortably fit a larger 6 cell battery.
Must include appropriate method for charging to occur.	For the battery to charge while in the enclosure, there must be the ability for the wires from a charger to enter the product, where the battery can be found. It's important to consider the compromises a hole in the product may have on its overall seal.	Either a hole or internal wiring can be a solution to this. A hole could introduce issues regarding its fire containment so wiring the product could be a viable solution. The product would have its own XT60 male port on the interior and XT60 female port on its exterior. This could also prevent damage to the charging unit.	Slide 43	In Prototype 9, the design finalised the XT60 mounting port with a large lip and correctly sized holes for the wires to exit the product.
Must be priced appropriately for target market	Drone flying is becoming an increasingly expensive hobby due to fast advances in its technology. Due to this many hobbyists/professionals have decent disposable income. Since battery safety is necessary purchase, the product can be priced steep.	The aim for this product's price is £40 which is priced just under the cost of a battery. This price is easily justifiable relative to the cost of damages if a battery fire were to occur.	Slide 51	The price has been set as £40 due to the markup being too high initially. The manufacturing costs were overestimated previously.
Must include safety information regarding Li-Po care.	It's important that the user of the battery is aware of the danger's lithium batteries are capable of and how to prevent thermal runaway. These batteries can be very safe if treated correctly.	The information should be presented clearly on the outside of the product in large text and/or infographics. Bright colours may be used to attract attention. Information such as ideal temperatures, warnings of puncture. Maximum, minimum, and storage cell voltage could also be referenced here too.	Slide 49	An infographic has been made to inform the user of important voltage ranges and charging settings to avoid thermal runaway from starting during charging.
Possibly a method of alerting the user of a thermal runaway occurrence.	If possible, it would be beneficial if the user could be alerted by the product if a battery undergoes thermal runaway. This could give the user a chance to perform appropriate measures to ensure minimal damages occur, possibly referenced on information mentioned in the previous criteria.	Due to rapid production of gasses, a whistle could be used at areas of concentrated airflow alerting the used via sound. Methods such as light detection can be explored however it would involve electronics, adding to the complexity of the project.	Slide N/A	This will not be included as part of the final design since it could risk causing a battery fire due to electronics being involved. The whistle functionality will not be pursued due to only 4 litres of gas being produced, as specified by Paul Christensen on slide 15.

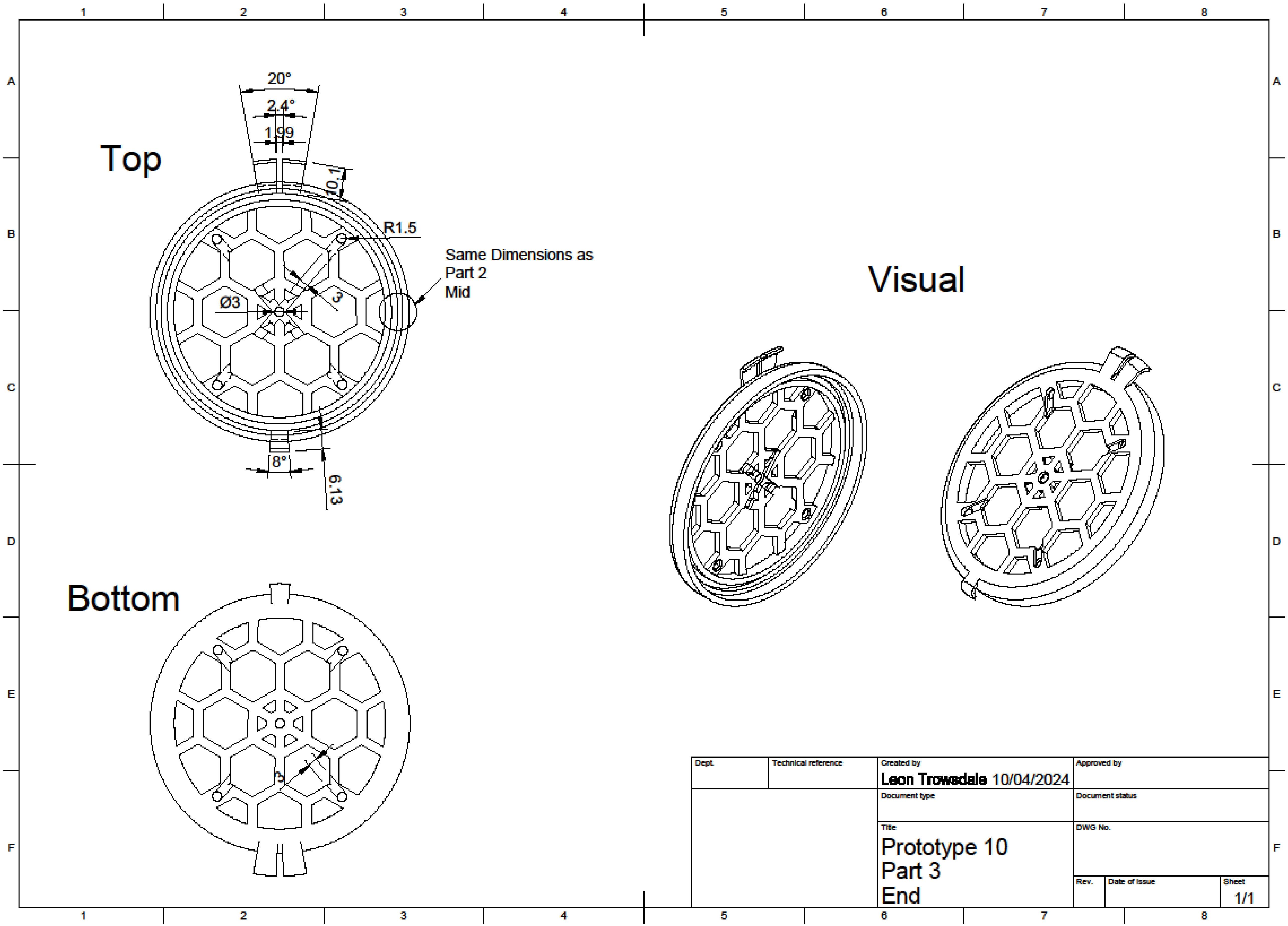
Technical Drawing - Cap



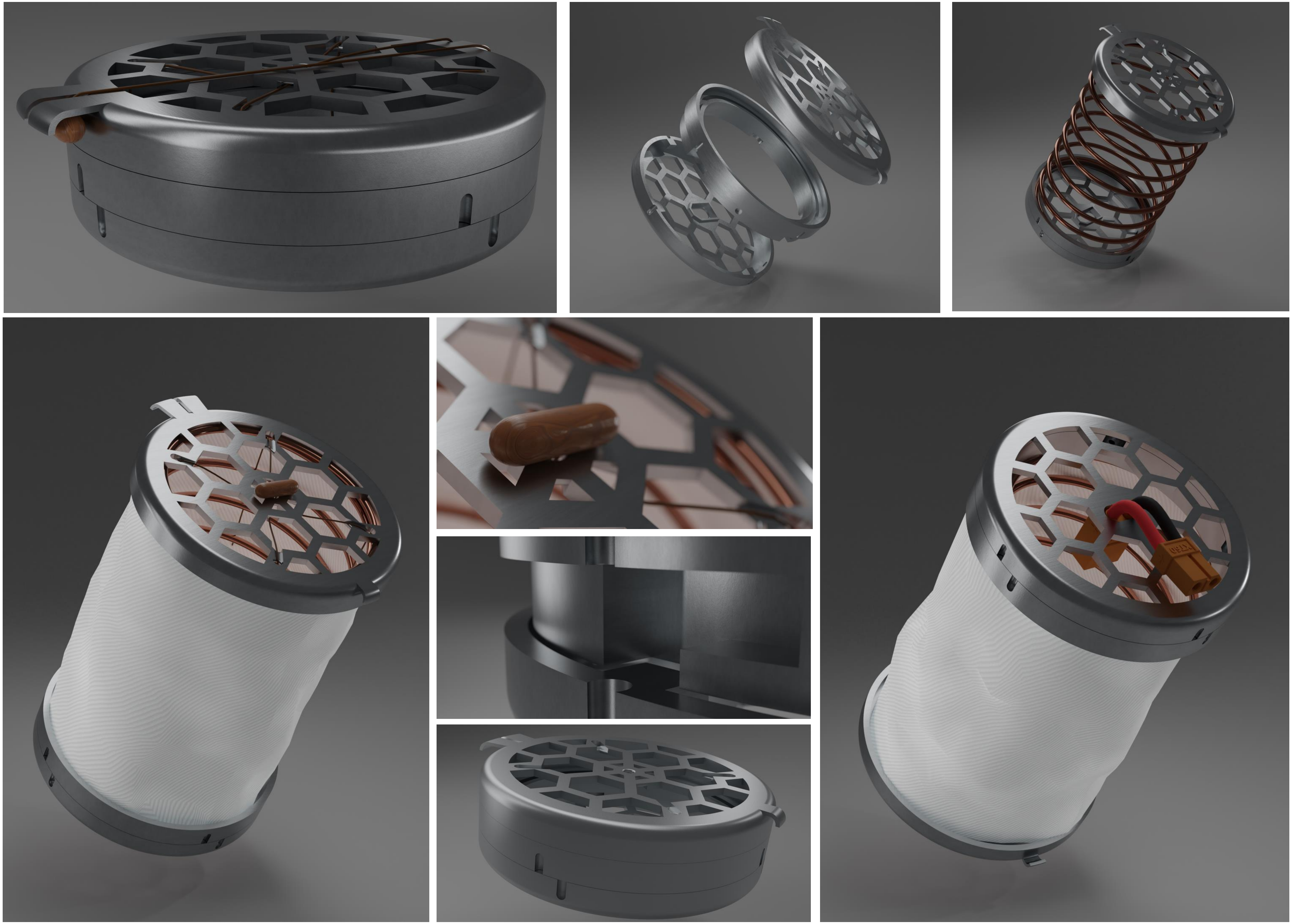
Technical Drawing - Middle



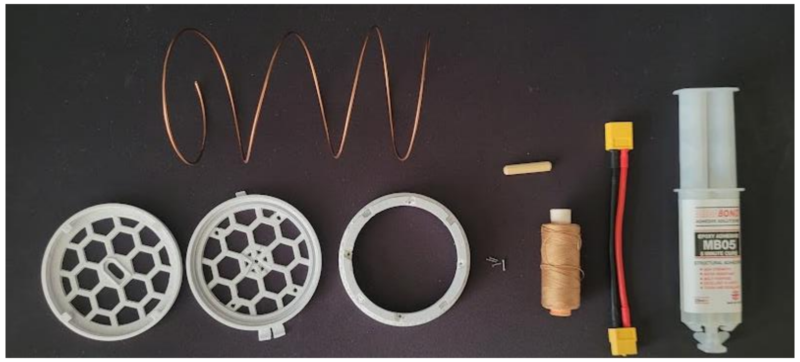
Technical Drawing - End

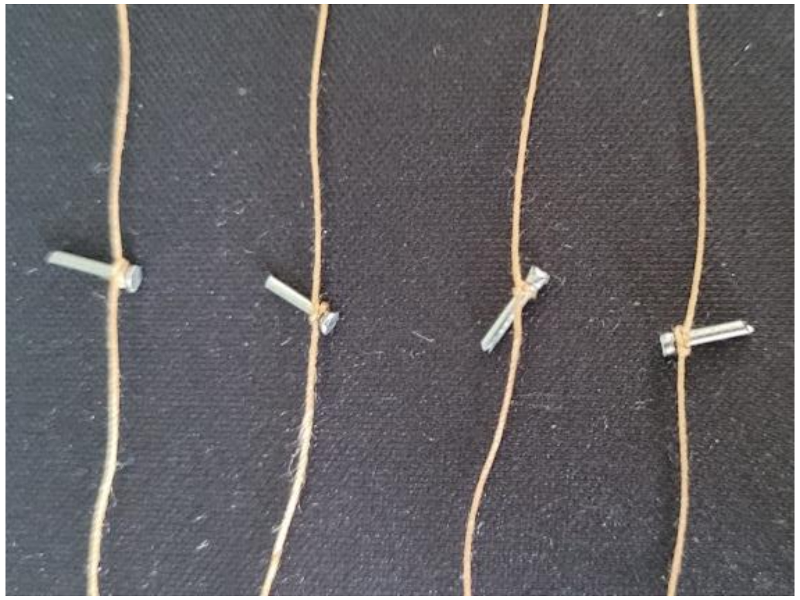


Final Design - CAD Render



Final Assembly





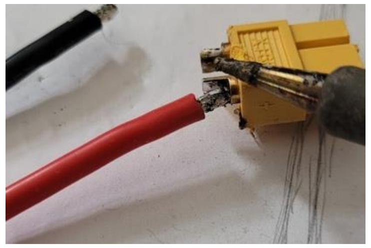
For my assembly, I will combine the parts developed throughout the project into a final prototype. The prototype will include the cap, middle and end sections, joined with the spring, with the cap and middle parts both including embedded magnets. Thread, nails and a small dowel will make up the handle assembly. The XT60 cord will also be attached to the design.

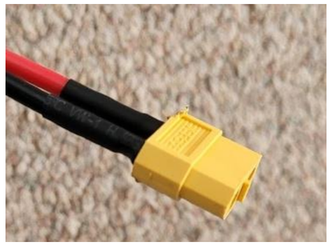
I'm using two-part epoxy as it is capable of securing metal and polymer parts together, unlike many adhesives, however I will also use the epoxy to join the XT60 and magnets to the PLA parts. The epoxy I am using is purchased in a syringe form which allows for equal extrusion of resin and hardener.

To start the assembly, I tied the thread to four shortened nails, these were then inserted into the holes of the middle section and secured in place with epoxy.

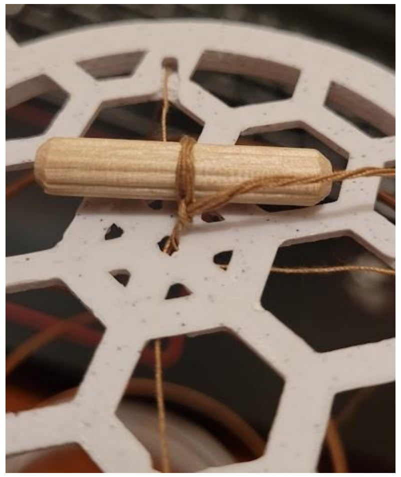
After the thread was attached, I fed the thread through the holes and cutouts in the end section, typing a knot in the four threads on the other side to ensure the threads stay together.

The spring was then also attached with epoxy however the wire had to be held in place for 5 minutes to allow time for the resin to set.



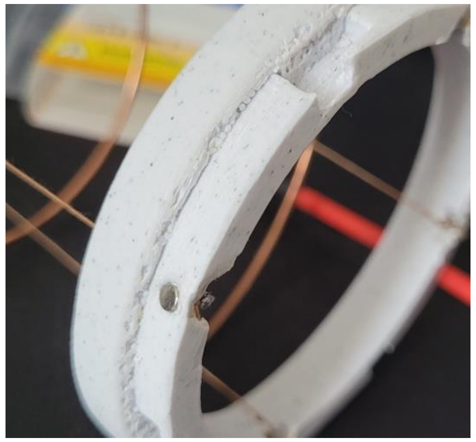


To attach the XT60 lead, the resoldered in position. I used a soldering iron at 300 degrees to separate the connector and wires, with a heat sink in-between the wires to prevent the risk of a short circuit. The male connector was then secured with epoxy to the cap.



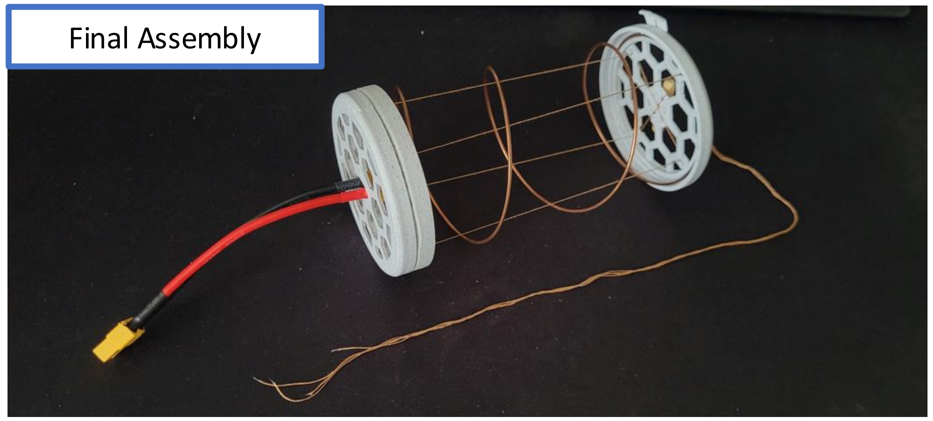
The handle was tied to the end next, since the spring has a slight curve, to keep the middle and end parallel, some strings had to have higher tension than the others, this was particularly difficult as the thread is very easy to lose track of, especially working while under tension due to the spring.

It was important to keep in mind the distance so the handle can still be secured using the hooks on the end section when closed.



Finally the magnets where secured to the cap and middle sections, again, with epoxy. This process required some cleaning up on the magnet holes so they would fit since the 3D print wasn't perfect. In the end the mechanism seemed to work smoothly and held the cap in position.

Final Assembly



Conclusion

The final assembly turned out to be very successful, the product closely resembles that of the renders and is fully functional (minus temperature resistance). The design and assembly will be compared against the specification later on to evaluate the success of the project and any potential changes.

Specification Evaluation

On this slide I will evaluate the final design against the updated manufacturing specification to verify that it has met the conditions I set at the start of the project.

1 Must mitigate the effects on a fire from a lithium-based battery experiencing thermal runaway.

Due to the thorough research and testing on various materials and testing, the product is perfectly capable of containing and controlling the temperatures and flames, confining them from exiting the product.

2 Must release pressure from gas release.

After testing and research, I settled on mesh gauze to confine flames yet also allow air to escape the lightweight form most suits the product and its portability needs

3 Must be portable in both size and weight.

A main aspect of the design is its large diameter spring which provides support between the end and middle sections. This allows it to compress from 150mm in length to 23mm, an 85% reduction in length. Its weight totals at roughly 100g, considering these aspects, the product could be considered portable.

4 Must be able to accommodate one battery of ranging types.

The product managed to contain the largest specified battery, mentioned at the start of the project, 110mm by 35mm. The battery cable still managed to connect with the cap cable.

5 Must include appropriate method for charging to occur.

An XT60 extension cable has been attached to the cap of the product to allow for the battery cable to be redirected outside the product with no open hole for flames to potentially escape from.

6 Must be priced appropriately for target market

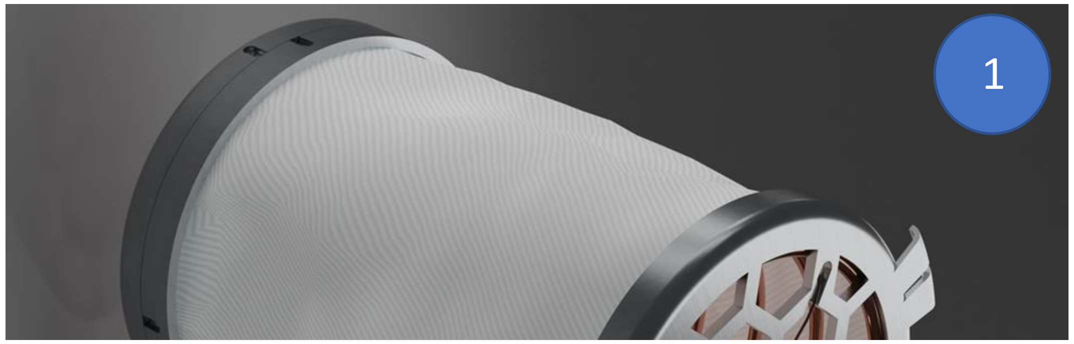
The demographic and product costs have been evaluated to land on a final price of £40, this is completely affordable for the target market yet also priced high enough according to other products in the hobbyist market.

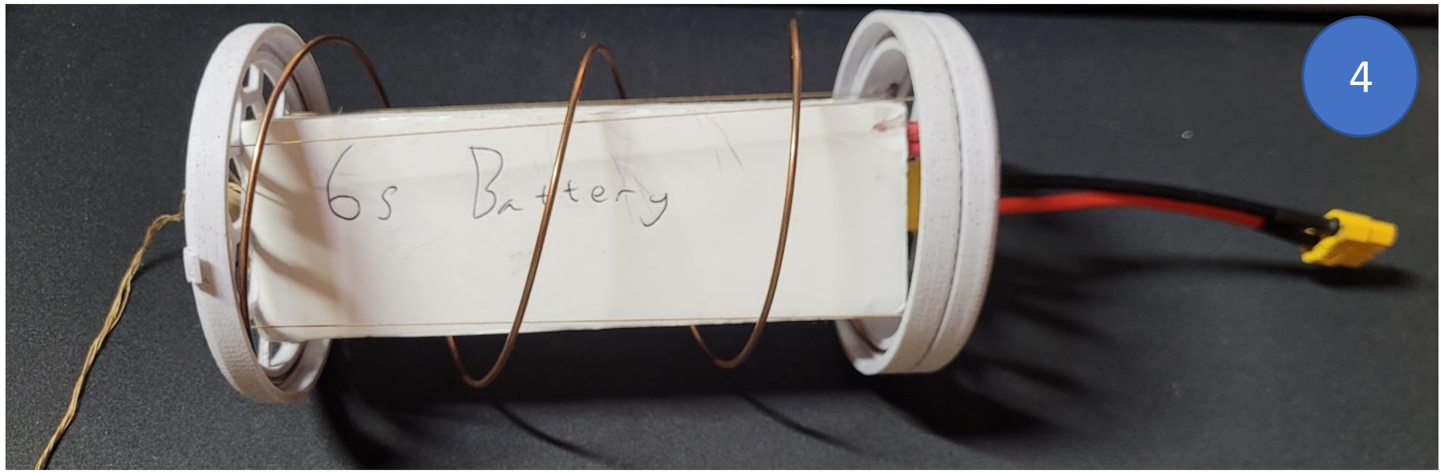
7 Must include safety information regarding Li-Po care.

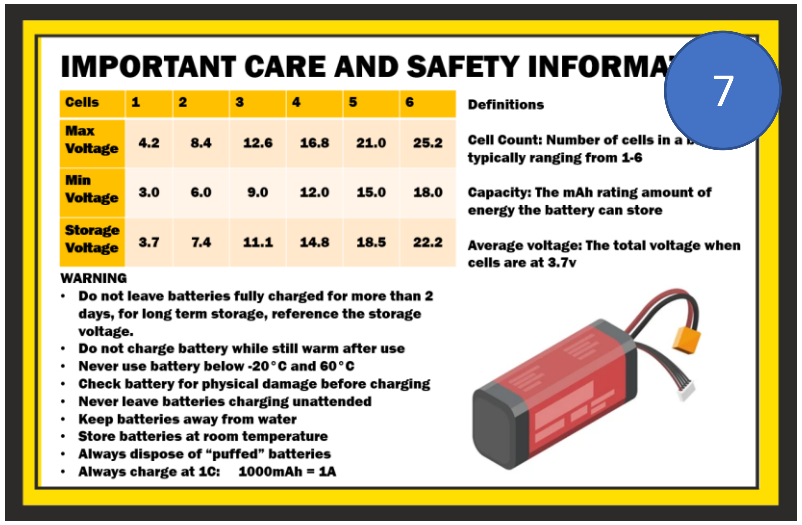
Included with the product will be a safety information sheet to inform of battery care, charging and storage. The information aims to prevent the fire from occurring as the first line of defence.

Conclusion

Overall the design has met all of the conditions outlined by the specification, rendering the project a success, however there are some changes I would make to improve the design even further if more time was spent on the project.







IMPORTANT CARE AND SAFETY INFORMA

Cells	1	2	3	4	5	6
Max Voltage	4.2	8.4	12.6	16.8	21.0	25.2
Min Voltage	3.0	6.0	9.0	12.0	15.0	18.0
Storage Voltage	3.7	7.4	11.1	14.8	18.5	22.2

Definitions

Cell Count: Number of cells in a b typically ranging from 1-6

Capacity: The mAh rating amount of energy the battery can store

Average voltage: The total voltage when cells are at 3.7v

WARNING

- Do not leave batteries fully charged for more than 2 days, for long term storage, reference the storage voltage.
- Do not charge battery while still warm after use
- Never use battery below -20°C and 60°C
- Check battery for physical damage before charging
- Never leave batteries charging unattended
- Keep batteries away from water
- Store batteries at room temperature
- Always dispose of "puffed" batteries
- Always charge at 1C: 1000mAh = 1A

Improvements and Modifications

Although the product met the design specification, there are some modifications I would include in future designs, should the project be continued.

Spring Adaptation

The first change to make would be modifying the spring to have a closed, flat loop at each end. This would allow the spring to stay upright without unnecessary and uneven tension. I would also enable a larger surface area of string to be secured by epoxy resin to the middle and end sections.

Thread Material

Another change I would make is to the thread material. On the current design, the thread is very thin so after constant use, it has potential to break over time. A better option would be to use a nylon thread as it has a much higher tensile strength and better temperature resistance.

Handle Adaptation

To enable more flexibility, it would be beneficial to have the maximum spring extension independent to the handle-hook configuration. To do this, a separate piece could be added to the spring which maximises spring extension, but the handle is still secured with the hook.

Hood Adaptation

Since the rest of the design is completely circular, it breaks the smoothness and symmetry by having two hooks sticking outwards from the end section. A method of folding them down or a separate mechanism to apply tension on the string would greatly improve both aesthetics and ergonomics.

Friction Reduction

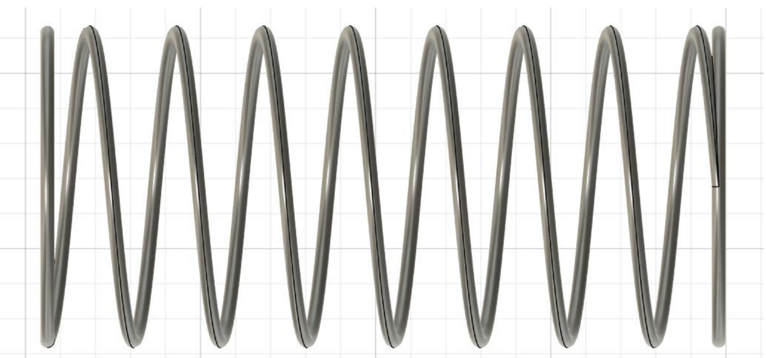
One noticeable issue with the current design is an abundance of friction between the thread and 3D printed parts. Although this would be reduced by using aluminium and potentially nylon, the product could be improved by having PTFE, also known as Teflon (a material with a very low coefficient of friction), grommets around all of the holes the thread goes through.

XT60 Holder

The XT60 cable cannot be secured anywhere in the current design which leaves it to sway around when not plugged in, this reduces the portability slightly. To fix this, a securing system either on the side of the product or on the cap itself may help.

More Safety Information

To increase visibility of the safety information, some simplified safety and care information could be integrated into the product itself. The most obvious way to do this is have the information printed directly onto the woven fiberglass. This would force ignorant users to be exposed to the information needed for safe use.



Closed end spring

Conclusion

If the project were longer, these modifications would be a great addition to the design, creating a product that would be completely ready for the market.

This project has greatly improved my research, CAD, prototyping, and manufacturing skills that will prove very valuable when continuing with engineering through university.