Industrial Design Engineering Report

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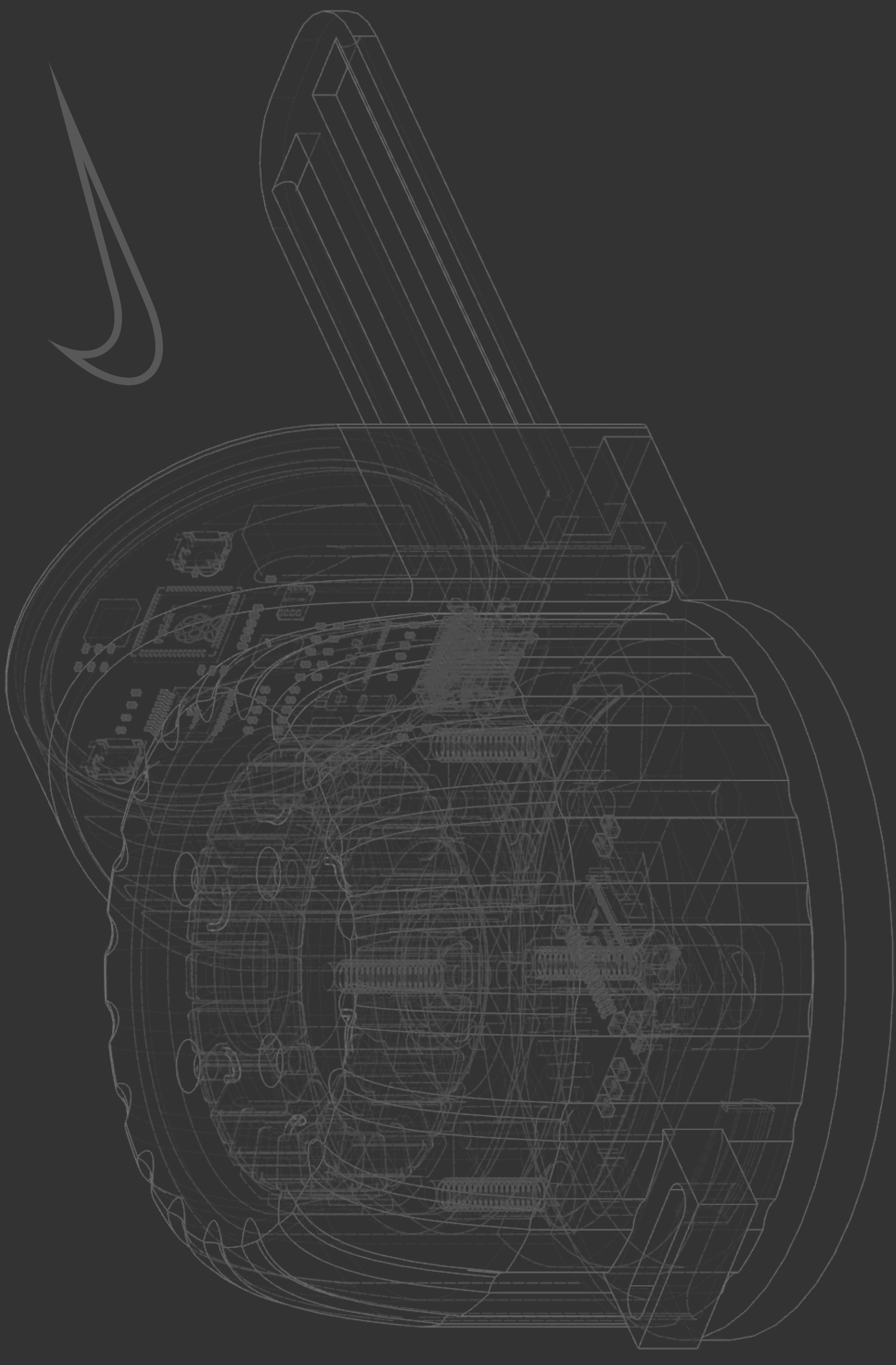
DX-4



Product Opportunity Statement

The chosen product opportunity statement is patients in recovery pre-operation and post-operation from ACL injuries. These people often feel uninvolved, low-motivation, and depression due to the often sudden change in their life style from highly active, to completely stagnant during the recovery which can take as long as 9-12 months after surgery.

User Interview Insights

There were 2 main focus groups when acquiring information about ACL injuries. The first was the patients themselves, the people who tore their injury to be able to provide a first hand experience on their recovery. The second focus group was industry experts on the science of the injury and recovery so that we can best understand the situation and provide better assistance to the users.

The interviews with our direct user group, Carys Ward, and one of our own group members Callum Hargrove, gave us first hand info on their experiences. The three key points that we recovered from these interviews was the following:

1 LACK ENDORPHIN RELEASE WHICH WAS PREVIOUSLY CREATED BY PLAYING SPORTS

2 WANTING A PRODUCT THAT WON'T DRAW ATTENTION TO THEIR INJURY

3 WANTING TO IMPROVE INDEPENDENCE AFTER SURGERY AS WELL AS SELF CONFIDENCE

Our interviews with a physical therapist, Ben Wilde, and surgeon, Prof Adrian Wilson helped lead us to focusing on adolescents and they had three key insights which were the following:

1 MISINFORMATION ABOUT QUICK RECOVERY TIMES WHICH LEADS TO DISAPPOINTMENT

2 TIME SPENT RECOVERING CREATES SOCIAL BARRIERS FOR KIDS

3 ISSUES WITH LACK OF MOTIVATION TO MOVE AND BEING ON CRUTCHES AFTER SURGERY

Target User Group

Given some of the insights, specifically the **mental battle** and **lack of motivation** from our interviews, the chosen target group within ACL patient recovery is:

"REGAINING INDEPENDENCE AND TACKLING MENTAL HEALTH FOR THE YOUNGER GENERATION WITH ACL TEARS"

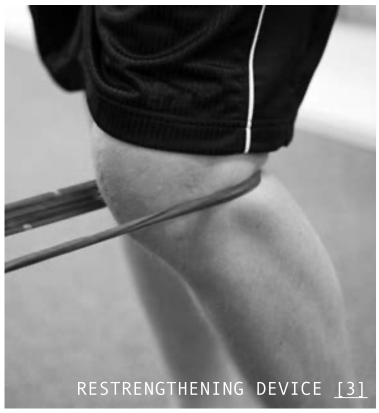
By specialising in the younger generation, we inferred 11-20 year olds (pre-pubertal, or older athletic people). This is because they likely undergo **iliotibial band tendonesis surgery** [1] - a non-invasive procedure where the patient's IT band is wrapped around the ACL to increase knee stability, hence preventing re-injury. This procedure does not require drilling through the bone, therefore being ideal for children and athletes as an additional procedure to ACL reconstruction surgery. By targeting this age group specifically, rehabilitation programs can provide tailored interventions that address not only the physical recovery but also the emotional and psychological aspects of the injury. This holistic approach can help minimise anxiety, depression, and other mental health issues, ultimately aiding in their overall well-being and quality of life of the patient throughout the process. Additionally, the younger generation tends to be more receptive to innovative and technology-driven approaches to healthcare, as well as allowing for implementation of preventive measures and educational initiatives to reduce all ACL injuries, primarily in school team sports with the highest rate of injury.

Existing Product Analysis

We decided to look at existing solutions to determine range of motion, increase range of motion and provide resistance for early stages of regaining strength in the knee joint. A **goniometer** is a protractor like instrument commonly used by physiotherapists to determine the range of motion. It provides a simple, affordable, yet highly inaccurate way to measure range of motion. It's non-trivial to use and, as a result, is often neglected by physios, who opt for a visual judgement due to inaccuracy and difficulty to use. Other devices can be used, for example a digital goniometer, yet these devices share the same issue of being cumbersome as well as being inaccessible for NHS clinics, and lack sufficient utility for ACL patients to purchase themselves. Hence, combining this device with a resistance device would be ideal commercially and for the patient.


RANGE OF MOTION MEASURING DEVICE [2]

Resistance bands are commonly used as restrengthening tools, accessible and used in a vast number of applications. The offer several benefits, providing controlled and adjustable form of resistance, allowing patients to gradually increase the intensity of their exercises as they progress through their recovery. Also, they allow for targeted exercises that focus on the specific muscles involved in knee stability, and offer a low-impact and joint-friendly alternative to traditional weights or machines.


RESTRENGTHENING DEVICE [3]

Concept Selection and Development

The following two pages address the justification behind initial concept selection and refinement. User research was then consolidated from previous reports to manufacture metrics with which to assess all development decisions.

Initial Selection, Evaluation and Refinement

A feasibility study was conducted to assess the technical, financial, and market viability of each of the four product concepts. This study guided the selection of the most promising concept for development and addressed the shortcomings by incorporating successful aspects from other concepts. The study was balanced with consideration of the project brief. The key findings are outlined below.

- Concepts centred around a knee brace lacked the market feasibility as a result of the competitive landscape and relatively short product life cycle.
- Tracking progress in ROM over the course of recovery provides a unique value proposition and does so for a longer proportion of the recovery process.
- Thomas and Lucas's concepts offered different approaches to tracking ROM. The simplicity of Thomas's design offered greater financial feasibility. However, ensuring consistent placement and alignment of the product brought technical challenges that would be difficult to overcome.
- Lucas's concept allowed the user not only to track the angle achieved over time but also to add resistance as they moved through their recovery. This prolongs the product lifecycle increasing market feasibility. The introduction of resistance also better aligned the product with the project brief.
- To further improve and refine Lucas's concept, we needed to improve the financial feasibility of the product by minimising manufacturing costs and considering a bold marketing strategy.

Brief Product Description

The selected concept consists of a dial positioned at the knee joint. The product is positioned by adjustment of two removable straps on the shin and lower thigh. The dial contains an OLED display and a brushless DC motor with encoder. This allows the angle achieved by the user to be measured, tracked and displayed on the OLED whilst the motor can provide resistance allowing for training.

Concept Development Approach

USER NEEDS (RESEARCH DEFINED)
PRODUCT REQUIREMENTS
USER FEEDBACK

It was important that previous work in defining user needs and research insights was carried through every stage in the design process and as such a metric was established in order to assess iterations and design considerations. At each stage, design decisions were evaluated based on user needs (derived from previous primary and secondary research), product requirements, and issue-specific user feedback.

User Needs

From previous research, the most important user needs were compressed into the following list:

- QUANTITATIVE ENGAGING MEASURES OF PROGRESS OVER TIME
- INDEPENDENT OPERATION
- CLEARLY INDICATED TO THE USER HOW THEY SHOULD FEEL DURING USE
- EXAGGERATES SMALL MARGINS OF PROGRESS
- DOESN'T DRAW OVERT ATTENTION TO THE USER
- INSPIRES THE USER TO ENGAGE WITH THE RECOVERY PROCESS

Product Requirements

The group arranged the following points as necessary product requirements to be considered during each design iteration.

- ACCURATELY MEASURES MAXIMUM ANGLE ACHIEVED BY THE USER
- TRACKS MAXIMUM ANGLE ACHIEVED OVER THE COURSE OF THE RECOVERY PROCESS
- LIGHTWEIGHT AND COMFORTABLE TO WEAR FOR PERIODS OF UP TO AN HOUR
- PROVIDES INTUITIVE PLACEMENT ON THE JOINT
- GIVES REALTIME FEEDBACK TO THE USER
- PROVIDES VARIABLE RESISTANCE TO THE USER

Integration Considerations

Key Function

It was imperative to solidify the user interaction right at the beginning of the design process. The most important consideration with this device is to encourage the user to reach as great a range of motion as possible within the first 3 weeks post surgery as this is the best predictor of avoiding re-injury. However, in order to be market feasible, the product must provide value over the entirety of the recovery process. The device doesn't aim to replace resistance training but rather serve as a means to track progress. Once the user has achieved full range of motion with no resistance provided by the device, they have the ability to add resistance to once again challenge them to extend their leg.

One of the next most important considerations from our research was that progress needs to be tracked in an engaging and quantitive manner. Which is why we decided that the maximum angle achieved at each resistance level be tracked daily in the Nike Training Club app. The user will then be able to have a visual indicator of progress across each of the three resistances.

The device will be strapped to the leg in two positions (the lower thigh and mid shin.) Once the device is secured, the user will turn it on at the battery pack. A button located on the side of the screen itself will loop through three resistances (low, medium and high.) The maximum angle achieved by the user for each resistance setting will be sent to their phone via the bluetooth module on the microcontroller.

Issues arising and their Resolutions

The team came across various limitations during the prototyping process. Decisions were made according to the metrics discussed above as well as in consultation with 3 users (currently recovering from ACL surgery) and two physiotherapists. The following examples outline the iterative process for just a few of the many developments made over the course of the project.

Battery Position

Project limitations concerning cost and timeframe restricted how small we could make the battery unit. Initially, the battery was designed to sit on the other side of the knee in a compact ergonomic casing. With the inclusion of custom PCBs and more expensive batteries, we would hope to achieve this. Our solution involved a separate battery pack that could sit beside the user or hook to the user's belt.

Microcontroller limitations

In absence of a custom PCB, we set about trying to find an appropriate microcontroller, the necessary requirements were to contain a bluetooth module, have the correct number of PWM and GPIO ports and aim of minimise the footprint of the module. Having designed prototypes around Arduino nano and raspberry pi RP2040, we finally settled on an esp32. The implications of this were that the microcontroller sit inside the battery casing housing and there cables had to be drawn from the dial to the battery housing.

Strap location and Implications

Ergonomics played a key role in the positioning of the dial on the leg, It was essential that the straps were able to be positioned away from direct swelling. This posed design complications in extending the dial away from the strap. In addition, after prototyping we discovered that simply having one strap on the shin didn't support the motor enough to hold it in place and as such a secondary strap was added closer to the knee joint.

Screen Position

The initial design featured the round display on the top face of the dial for aesthetic reasons however, after rapid prototyping and user testing, it was determined that the position which the user would have to adopt to get a good view of the screen would become uncomfortable during longer training periods. As such, the screen was integrated into a separate housing facing towards the user.

Prototyping Plans

After selecting and refining our concept, the next step is to both digitally and physically prototype the product to test for size, fit, comfort, ergonomics, and practicality.

Prototyping Components Map

There are six key components to this product that need to be individually prototypes and tested when combined together because integration of all the different system can often be the source of most error.

1 EXTERIOR DIAL
The exterior dial is the main visual part of the product. The dial houses the motor and motor driver and is the main part that connects the motor to the leg to provide resistance.

2 MOTOR DRIVER HOUSING
The motor driver housing is located inside the dial and plays a pivotal role in housing the motor driver, providing a base to the screen and housing, the platform to the leg, and connection points for the strap.

3 LAG ATTACHMENT SYSTEM
The leg attachment system is composed of two parts. The first is the strap connected to the motor driver housing and the second is the beam and strap connected to the dial.

4 SCREEN HOUSING
The screen housing is connected the the motor driver housing. It holds the screen in place and protects it from impact damage.

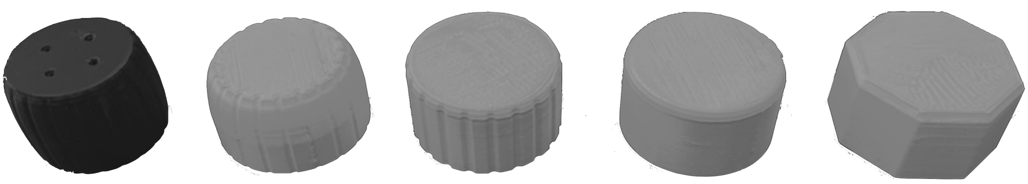
5 BATTERY HOUSING
The battery housing will hold the batteries, battery charging module, microcontroller, and will contain and protect them.

6 ELECTRONICS
The battery housing will hold the batteries, battery charging module, and voltage step down module, and will contain and protect them.

Exterior Dial

When prototyping the exterior dial, there were 2 key requirements that were considered. The first and most important requirement was the designs ease of machinability. That requirement was tested through virtual prototyping as it saved time and money compared to performing physical prototypes. The machinability requirement is also gone into more depth in the DFMA section of the report where it is more relevant.

The second important requirement is the ergonomics, feel, and look of the dial. This requirement has been tested with 3D printed physical prototypes which allow us to feel and see in real light how the dials perform. The initial concept had dial shape number 1 as seen in the image below. Shapes 2-5 were also tested to compare to the initial design. Design 1-3 were decided as the best options to proceed forward as they felt best to spin with the grooves. The final decision will made based on ease of machining and preference of look.



1 2 3 4 5

Motor Driver Housing

The main requirement being considered while prototyping the motor driver housing was that the FOCMini motor driver fitted compactly inside the housing. The initial design with smaller tolerances didn't initially fit the FOCMini and since the wires and the wire bend take up a considerable amount of space the casing had to be redesigned. Wiring Chanel's were added throughout which was a necessity as the final design had 14 wires running through it.

With such small spaces the wire gauge had a big impact on fit. Larger diameter wire has a lower AWG rating and but it it also has a much higher current capacity [1]. That means that for out final product, when we are lookin for thinner wires to fit in between the channels in the motor driver casing, we need to ensure that the wire can support the loads of our wires. At a minimum, the wire would likely experience a high of 1 amp as that is the max current of the motor. It would be much safer to chose a wire which can handle a larger current than that which also includes a safety factor. Wires with overloaded current can potentially overheat and melt.

During the digital prototyping of the motor driver housing, careful consideration was also put into ensuring enough gaps were left open to keep the motor driver at a safe operating temperature. An additional gap was added on the opposite side of the motor and encoder wire to increase airflow and also increase symmetry. Having more gaps in the frame allows more airflow through the system which keeps all of the electronics at a lower temperature which is important for not damaging the electronics or the user. Further analysis of this electronics cooling will be completed in the next component load section.

Leg Attachment System

While designing and prototyping the leg attachment system, the critical questions that we were trying to answer was whether it was comfortable to the user, and whether all the components stayed properly in place. It was important that the dial be placed right on top of the side of the knee as that is where point of rotation occurs so it is necessary for the dial to be there to capture an accurate angle. The initial design which had the strap go directly under the knee and attached directly to the circular base of the bottom motor driver housing was not only uncomfortable due to being right under the knee, but also constrained the knees movement. Because each persons knee and knee cap are different shapes, the dial also kept on sliding around over the knee. To prevent this while also keeping the dials centre of rotation directly over the knee, the strap has been moved up closer to the thigh where leg shapes are more symmetric, and generally softer which makes for easier strapping, and therefore the strap is more comfortable and keeps the dial secure in place. Another way that we have increased the comfort of the strap, and reduced its movement during use is by placing a thin foam pad below the motor driver. This greatly increased the comfort as it was no longer a hard plastic directly against skin but instead a soft foam. The foam also helped to prevent rotation due to greater friction and fit against the knee.

Screen Housing

The initial questions that we wanted answered while prototyping the the screen housing was what size did the housing need to be to protect the screen from damage and to prevent it from moving around while the user moves. It was an important optimization question to make it the right size. It was also important to prototype to test whether the cable holes were large enough for all the cables we needed to go from our motor driver, encoder, button, and screen to the microcontroller. In total there was 20 wires coming out of the main device assembly which is a lot for a small wearable device. To help overcome this in addition to the channels routed into the motor driver housing, was to use 28 AWG wire. As discussed about higher AWG wire has a lower current carrying capacity but 28 AWG wire should be safe for up to 1.5 Amps Based on the motor specifications and other electronic components, the highest current should not be higher than 1A so 28 AWG wire is safe. This allowed many more wires to fit into the same space as compared to more typical 24AWG wire. Another issue encountered during the initial prototype was the the housing was too small to fit the screen as the CAD model online was not an accurate representation of the real dimensions which is critical reason to prototype.

Battery Housing

The questions that we were looking to answer while prototyping the battery housing was how to make all the components inside packed as efficiently as possible to minimize the size of the casing and testing connection methods so that the users doesn't have easy access to potentially harmful LiPo batteries. The initial battery housing design was located on the inside of the knee however after initial prototyping attempts that idea was scrapped and instead that battery and microcontroller housing was moved to the waist. That is because the battery requirements for our project mean that we need large batteries which would be awkward and uncomfortable to wear on the inside of the knee. We test the battery housing to attach the the waist with a clip that could attach to a belt or the waist beam of your pants. To keep the battery case safe and closed, deep bossed self taping screws are used which means you would need a long screw driver to take apart the batteries which reduces the likelihood of accidental opening.

Electronics

The electronics are by far the section where the most prototyping and testing occurred. The main question being investigated while testing the electronics was whether each system worked individually, and more importantly whether each system worked together once integrated. There are 3 key electronic components that need to work for our device to function which are the motor, the encoder, and the screen. During initial testing we were using a Pi Pico microcontroller because it was integrated into the display which would've meant that we wouldn't need a separate microcontroller. This solution didn't work because each of the controllers only has 1 SPI communication bus port however both the encoder and the screen needed those ports which meant that we couldn't communicate with both at the same time. The next attempted solution was to use 2 Arduino Nanos which also only have 1 SPI communication port but to solve this port the encoder data from one Arduino to the other Arduino and have them communicate between each other which would allow for enough ports. This solution also didn't work so that final solution that worked was to use an ESP-32 WROOM-32D which has both 2 SPI communication bus ports but also has integrated wifi and bluetooth modules which means we don't have to add a bluetooth module to the battery casing.

Power and Component Load Calculations

Battery Sizing

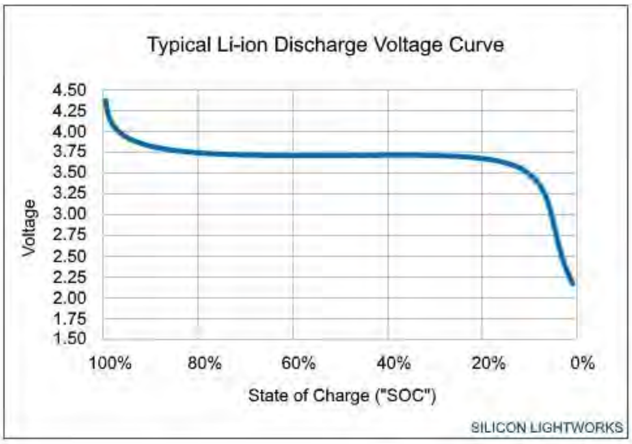
Several important considerations need to be taken into account when sizing a battery. Priority one should be understanding the device's power requirements. Analysing the average and peak power usage during various operating modes. Estimating the necessary battery capacity, taking into account usage patterns, such as frequency and length of use, as well as any power-intensive activities. Achieving a balance between capacity and the size, weight, and mobility of the device is crucial when determining the ideal battery life. To make sure the battery fits inside the available space, especially its form factor, must be taken into account. The decision of battery capacity is also influenced by the accessibility and ease of charging alternatives. Another critical factor is ensuring that the battery complies with safety norms and standards to ensure safe and dependable functioning.

ESP32 - 10-200 mA
Screen (8.3 cm^2) - 2uA (micro-amps) per cm^2 (will use 4uA)- 0.03 mA
Motor at stall current - 800 mA

Total Peak: 200+ 800 + 0.03 = 1000.03 mA
Total Idle: 10 + 170 + 0.03 = 180.03mA

A detailed analysis of the energy used during a single training session revealed a total consumption of 1000.03 mAh for peak usage. We debated the appropriate battery capacity keeping in mind our desire for the device to survive for a week without requiring a recharge. We came to the conclusion that a 3300mAh battery would be the optimum choice. This capacity ensures that the DX-4 stays lightweight and portable without compromising its lifetime by striking a balance between high power storage and retaining a small form factor. We can reliably guarantee extended usage without the need for regular recharging by selecting a battery with such capacity, enabling uninterrupted and effective training sessions.

Li-ion Discharge curve



When comparing a Li-ion discharge curve, several arguments favor using Li-ion batteries rather than LiPo batteries in specific situations. The discharge curve's flat voltage plateau shows a steady energy production throughout a significant amount of their capacity and that lithium-ion batteries have better energy density. This quality makes them perfect for applications that require maximum energy storage yet have limited space.

Furthermore, Li-ion batteries exhibit voltage stability throughout their discharge cycle, providing a consistent and dependable power source. For applications needing a constant voltage output, this stability is essential. The discharge curve also shows that Li-ion batteries often have a longer lifespan with less capacity deterioration. They are ideal for devices that undergo many charge and discharge cycles because of their durability.

Li-ion batteries outperform LiPo batteries in terms of safety. Li-ion batteries are a safer option due to their more stable chemistry, decreased chance of swelling or puffing, and lower possibility of thermal runaway. Analysing the discharge curve makes it easier to control battery performance and efficiently reduce dangers.

Li-ion batteries are frequently utilised in consumer electronics, and analyzing their discharge curves provides faith in their suitability for various applications. On the other hand, LiPo batteries provide versatility in size and shape and perform very well in situations involving rapid discharge rates.

Examining a Li-ion discharge curve validates choosing Li-ion batteries over LiPo batteries due to their greater energy density, voltage stability, lifetime, safety profile, and application compatibility.

Battery Charging Time

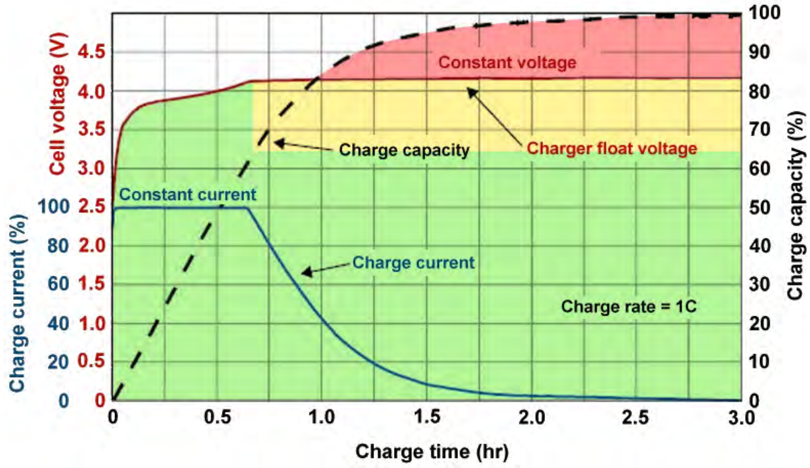
Calculations to get the approximate charging time for a battery with a capacity of 3300mAh charging at a constant current of 1A:

Battery capacity (in mAh) / charging current (in mA) equals charging time (in hours).

Battery capacity: 3300 mAh
Charging Current: 1000mA x 1A

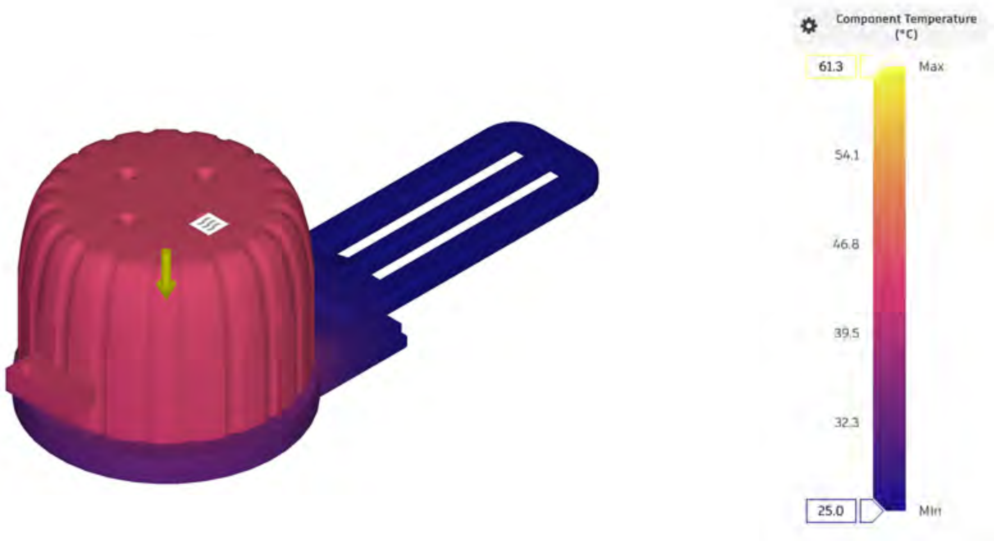
Time to Charge = 3300mAh / 1000mA
Time to Charge: 3.3 hours

Consequently, it would take around 3.3 hours to fully charge a 3300mAh battery at 1 A charging current. Note that this figure is based on ideal charging settings, and actual results may differ based on the charger's effectiveness, the battery's state, and other variables.



Electronics Cooling

One important consideration in any device that has electronics and batteries is the thermal loads of the components. If the temperature of the electronics or battery reaches too high of a temperature it can not only permanently damage the electronics but also risk burning the user. This is a serious consideration as our dial is a wearable device strapped to the knee. This was especially important as during prototyping of our electronics, the motor got especially hot during continuous usage to a point where it was painful to touch. To aid in the cooling of the motor driver, an additional channel was added into the housing so that a stream of air can pass over the hot chips. To test the estimated temperatures, a electronics cooling simulation was conducted. To set up the simulation each electrical component is given its maximum power output in Watts, and each component needs to be assigned its proper material. Since the motor is 12V and runs at 1A the power load of the component is 12W, in addition to the 12W for the motor driver. The simulation was also wet up with an ambient temperature of 25º C. The results of the simulation can be seen below:



Based on the results of the simulation, the temperatures are well within a safe operation temperature for both the electronics and for the user. For typical electronics chips, there is risk of damage above 100º C and this temperature aligns exactly with the glass transition temperature of the casing material, ASA. Ideally the temperature would be much lower than that which it is. The temperature analysis of the bottom of the mtoor driver casing where it would be in contact with the users legs shows a temperature of only 32.4º C which is completely safe for use.

Design for Manufacturing and Assembly (DFMA)

Following thr BS 8887 Design for manufacture, assembly, disassembly and end-of-life [1] process to make our product as cost efficient and environmentally friendly as possible. One thing that is important to emphasize through the entire design and assembly is the Poka-Yoke design theorem. The design theory is about designing methods that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred.

Design for Manufacturing

The first section that we will analyze for each component is their design for manufacturability which should ensure reduced cost, reduce the time frame, and increase the quality of the final product.

Exterior Dial

A final dial shape was not initially decided upon due to the uncertainty of the machinability of different shapes. An analysis was conduct on which shape would be easiest to machine by performing an accessibility analysis. Shapes 2 and 3 were both fully accessible from above however shape 1 since it had a full curve the lower part, was not accessible with the tooling bit. This however was not a factor in the decision as the biggest decision was whether the dial could be machined on a 5-Axis vs a 3-Axis CNC milling machine. Although there is not inherently a large difference between the 2, using a 5 axis machine greatly increases the cost and complexity of the manufacturing. Since the outside needs to be machined, and the inside needs to be hollow it would not be possible to machine in one 3-axis path as a minimum of 2 passes would be needed where the stock block would have to be flipped part way through. That is why the 5 axis machine was selected as then the part doens't have to be taken out of the vice. In addition the 5 axis machine is more readily available machine for access to the final prototype. Since all 3 dial shape options were on the table we made the decision based on the looks and feel which is why we went with the second dial option which had straight walls with a curve at the top. To confirm the machinability of our design we contacted a manufacturer, PCBWay, who does large scale CNC mill manufacturing who were able to confirm that the part could be made. By contacting the manufacturer we were also able to obtain a quote on the per unit price for 10,000 units.

One of the critical factor the the manufacturing of the dial is providing adequate dimensions, tolerances, and surface finishes through the engineering drawing so that the technicians can machine the dial to our specifications without increasing the cost by over tolerencing.

Motor Driver, Screen, and Battery Housing

The majority of the products parts that need to be specially designed and manufactured including the motor driver, the screen, and the battery housing all will be manufactured through injection moulding. Within injection moulding there are vast amounts of options and one of the most important ones is the material. There are lots of options for injection moulded plastics including ABS, ASA PC, Nylon, HDPE, POM, PVC, and many other options [2]. The issue with the majority of the plastics and why most of them will be eliminated is because they degrade or discolor in UV light. Since our product is a wearable device that will be outdoors this is a very undesirable material property. The 2 popular plastics that remain are ASA and HDPE however ASA was selected as the final material choice as HDPE can be highly flammable which is incredibly bad for wearable consumer products. ASA was developed as an alternative to ABS to be more resistant to UV and outdoor conditions and it is a great choice because it is easy to source, cost-effective, lightweight, low thermal and electrical conductivity, and great impact resistance [3]. It's major disadvantage being that is has a low melting point however that is not important for out application.

During the design, DFM was closely throughout the entire process because injection moulding comes with a specific set of rules that you must follow to ensure that it is physically possible to make. One of these important realization that we had while designing the motor driver housing and screen housing was the inability to have internally threaded holes. With injection molding it is possible to have exterior threads but not interior threads as the mold would be impossible to take out. This is why a snap fit was added the the motor driver housing and why large embosses with self tapping screw were implemented into the screen housing.

There are a few critical rules for injection that were followed throughout our design. The first is adding a draft angle of 1º to any vertical wall possible. This ensures that the parts can come out easily. The second was to reduce the number of sharp corners as sharp corners make the mold more difficult to fill and add increased stress concentration [4].

To further ensure that all of our parts would be injection moulding accessible, the first step was to perform an injection moulding analysis within Fusion 360. The key parameters that were set up for this simulation were the material and where the various plastic injection points were located.

The key findings from these simulations include plastic warping analysis, fill analysis, and cooling time analysis. Typically it is best to injection mould parts with uniform wall thickness to even cooling and reduce warping however our designed parts don't follow this suggestions. The results suggest that the warping that occurs due to the cooling is incredibly minimal. The fill analysis of the top motor driver housing can also be seen below. The process only takes a total of 0.31 seconds to fill however it takes a total of 41.56 seconds before the part can be removed from the mold.

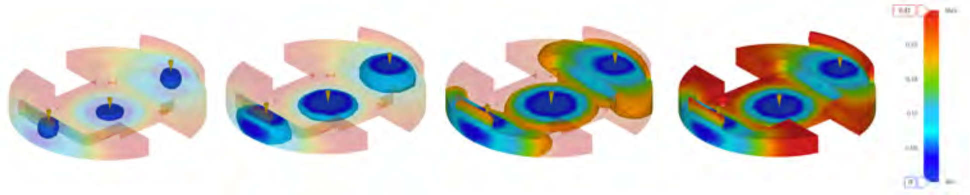


Table 1. Injection Moulding Analysis

Component	Time to Fill (s)	Total Time (s)*	Max Warpage (mm)	Maximum Pressure (MPa)**
Top Motor Driver Housing	0.31	41.56	0.11	8.3
Bottom Motor Driver Housing	2.43	128.88	0.29	33.2
Screen Housing	0.63	8.87	0.17	43.9
Button Cover	0.41	10.56	0.03	32.5
Top Battery Shell	1.36	12.25	0.41	47
Bottom Battery Shell	1.49	53.06	0.53	57.8
Leg Shaft Connector	0.31	36.13	0.11	42.4

This analysis shows that the injections molds are feasible in some respect. Through further analysis of the designed geometry, some of the parts with require 3 part moulds which allow for more complex geometry but increase cost and complexity.

Design for Assembly and End of Life

Design for assembly (DFA) and design for end of life often go hand in hand. When designing for assembly there were 6 factors that were focused on to ensure a smooth assembly process. The first and most important one is that all the parts can go together in a feasible order. An example is that it is not impossible to join together 2 components because another component is in the way. This issue has been avoided by ensuring that everything is assembled vertically piece by piece. This means that it will be possible to join every component together.

The next important DFA principal which greatly reduces assembly complexity is reducing total part count. The less parts there are the easier and faster the device can be assembled. Our design attempts to achieve this by injection moulding complex components that might otherwise need to be several different components fastened together.

The third important DFA factor is using only 1 fastener head shape. This way during the assembly process only 1 fastening device is need which reduces assembly time. The shape that we decided upon was Phillips head. Phillips head are known for having a higher likely hood to strip however we are not using them in a high torque situation so that is not a concern. We are using Phillips head screws because of their large availability and their popularity among consumer goods items which means that the user can have easier access to our device if any repairs are necessary.

The 4th DFA factor that was followed for device was a modular design. There were 3 main modules one being the dial itself, another being the screen, and the third being the battery housing. These 3 components each being their own module means that the items can be simultaneously assembled and then combined together rather than all in a linear order. This means increased assembly speed.

The 5th DFA factor that was considered and already mentioned is Poka-Yoke as well as symmetry. Making sure each of the parts can only fit in the way their designed to or making it so that it doesn't matter greatly speeds up the assembly process. Poka-Yoke was done with with the snap fit in the motor driver house and symmetry was used in the battery casing.

The final design factor to meet the DFA requirements was avoiding any components that are too small. Tiny components make the assembly take longer due to the increased accuracy requried by the people assembling it. once it is too small it is no longer feasible for humans to assemble it and would require expensive machinery.

When designing for the end of life the ideally any parts can be reused and any parts that cant be reused should be recycled. To ensure that each part can go to its designated end of life destination each component needs to be separated into their respective materials. All of the aluminum components can be melted down and recycled, the injection moulded ASA parts can also be recycled, all of the stainless steel fasteners can be recycled.

Branding

To get an understanding of where our product fits in the market, we looked at three companies: Curovate, Teenage Engineering and Nike. We made a few **key messages** we want the brand to envoke:

- Highlight our cutting-edge technology and advanced tracking capabilities of the product, positioning it as a modern solution, using data-driven insights to optimise recovery and provide personalised progress reports.
- Position our product as a tool for young people and athletes aiming to enhance their performance and prevent future injuries by highlighting the importance of improving knee range of motion to reduce time out of sport.
- Promote the product as a dedicated companion that assists users in their journey toward re-entry to sport by emphasising the product's ability to track progress and provide visual evidence of improvement.

Curovate

About - Curovate [1] is a Toronto based digital healthcare platform that promises to transform physical therapy by giving individuals suffering from musculoskeletal injuries easy-to-access options. They provide a comprehensive range of tools and resources to assist efficient rehabilitation and speed up the recovery process of knee and hip replacements and ACL rehabilitation post operation by utilising technology. Curovate offers multiple features, with the aim to reduce the rehabilitation time for patients. Their primary product is the smartphone app which acts as a virtual therapist, guiding users through personalised exercise programs tailored to their specific injuries and recovery goals. By following thoroughly the instructions given in app and by testing benchmarks including range of motion (by using accelerometers in your phone), patients can safely and effectively perform exercises from home - reducing the frequency of in-person physiotherapy sessions.This is essential in the rise in ACL patients and their strain on [free] healthcare systems e.g. Medicare (Canada's publicly funded healthcare system) and the NHS (UK's alternative).

How would they fit our product and target market? - In their app, Curovate uses augmented reality (AR) technology to provide real-time feedback and guidance from healthcare professionals during physiotherapy sessions, utilising the device's camera to track and analyse the user's movements to ensure proper form and technique. This interaction enables immediate feedback, optimising recovery and errors in form. Our product could seamlessly fit into this interface, providing more accurate range-of-motion feedback and supplementing the next stage of progress by providing multiple layers of resistance for the user to choose and develop through. Furthermore, their tele-health system, where they connect patients to licensed physiotherapists who can remotely monitor each patient's progress, provide guidance and answer questions by message or video call, would ensure regular monitoring of progress and safe usage of the medical product. This warrants high-quality rehabilitation to be accessible to our 11-20 y/o target market regardless of their location or financial background.

POSITIVES

- The brand is ACL rehabilitation focused, hence our product would be well trusted in the community
- The app provides a pre-existing ecosystem ensuring correct form/progress via licensed physiotherapists
- Tele-health applications would fit the target users, as young people are often the most adept with mobile applications and technology products

NEGATIVES

- Since the brand is small and Toronto based, it does not provide much scope for the mass-market
- The brand's focus on providing a 'do-it-all' application could suffer with the introduction of physical products
- Misaligned with our position as a brand to be a tool for young people and athletes to prevent re-injury and tackle the mental health aspect. No 'gamification'.

Teenage Engineering

About - Teenage Engineering [2] is a renowned Swedish electronics company, garnering a reputation in the music production and design industry for its innovative and stylish approach. Founded in 2005 by Jesper Kouthoofd, David Eriksson, and Jens Rudberg, the company has become synonymous with unique and timeless products, somewhat in contrast to the current technology industry, that pushes the boundaries through its emphasis on user interaction, blending functionality with aesthetics. Their sleek aluminium mixed with vibrant colours and lines forms their distinct design language , making them stand out in a sea of generic consumer electronics, earning them several prestigious awards including multiple Red Dot Design Awards and Good Design Awards. They are primarily hardware based, releasing the OP-1 pocket synthesiser and workstation, yet have developed software interventions to keep their products up-to-date with current trends.

How would they fit our product and target market? - Teenage Engineering's design language would perfectly match our product, achieving a high build quality and timeless reputation by utilising aluminium and injection moulded resin-based polymers, like our aluminium dial and ASA polymer housing (similar to ABS yet highly resistant to UV with high impact resistance and rigidity). Furthermore, their user-group is young (albeit primarily music enthusiasts) people, with a passion for technology and timeless devices, immutable towards planned obsolescence. Moreover, Teenage Engineering's product base is ever expanding - recently developing the field desk - a recycled aluminium, double-sided formica birch plywood, modular desk. This extends their ecosystem from audio production devices towards the workspace and everyday. It would be a reach for them to develop a new product line towards ACL rehabilitation, yet they continue to produce high quality products in one market and are developing others and have done collaborations in others, for example the IKEA Frekvens [3], an audio lighting system or (more out of their current scope), a Panic collaboration - 'Playdate', a new handheld video game console, of which Teenage Engineering were credited to engineer the mechanical crank design.

continued

POSITIVES

- The brand is has a strong design language similar to our product, with a focus on well engineered parts
- Their pre-existing software systems keep products up-to-date, keeping products timeless and repairable
- Teenage Engineering's break-off collaborations and partnerships have lead to great success in other fields such as Nothing [4], IKEA and Off White [5].

NEGATIVES

- The brand is audio-engineering at heart, hence if we were to implement a specific product for a specific market it may be too dissimilar to their catalogue
- No real link except design language and user base, which is non-ideal since they do not cater towards athletes or injured people in addition to the youth.
- Expensive products infer big markups / inaccessibility

Nike

Nike [1] is a global sportswear and athletic company, founded in 1964, renowned for its innovative products, marketing campaigns, and commitment to athlete empowerment. They actively support sustainable development and community engagement initiatives, valuing social and environmental responsibility (despite their history of allegations towards workers conditions and rights, which have been amended since the early 2000s). Nike is primarily recognised as the industry leader in sports, ranging from football, basketball and tennis to winter-sports such as snowboarding. This reputation and global reach enables them to collaborate with many companies to produce more specific items, primarily trainers and basketball shoes (most famously) the Jordans with Michael Jordan. This relates heavily to ACL injuries, since the most common sports to injure your ACL are basketball, football and other high impact winter sports (and bouldering, a sport Nike are yet to compete in, with rival Adidas recently purchasing Five Ten [2] and developing a line 'Terrex' to compete in the outdoor garment industry against the industry standard Arc'teryx, Patagonia and North Face. Nike produces specific technology for their products, for example their accessible FlyEase trainers targeted to the disability community [3]. Furthermore, following the recent surge in ACL injuries in female footballers (where 5 of the 20 Ballon D'Or nominees this year are sidelined with ACL injuries! [4]), Nike developed their 'most meaningful investment yet' - the Phantom Luna [5]. This boot is centred around the female anatomy, incorporating three elements: the traction, fit and feel, featuring a tighter fit around the ankle and a new circular stud pattern to provide big touch zones to compensate for the smaller size of women's feet. This follows the stark research done by Dr Katrine Okholm Kryger of St Mary's University, Twickenham [6], who revealed how the likelihood of ACL injuries among others in women are highly elevated by use of unsuitable football kit.

How would they fit our product and target market? - This elevated research and development done by Nike in the sphere of ACL injuries could be a plausible avenue to get our product to market in collaboration with Nike. Their focus on athlete empowerment and performance aligns with the goal of ACL rehabilitation, which aims to support young people and athletes in recovering and excelling after injury. Moreover, leveraging their expertise in the industry of athletic sportswear and apparel could contribute towards the development of a range of products that specialise in providing necessary support, comfort and functionality for people recovering from ACL or other knee injuries. Their vast network of athletes, sports professionals and research facilities enables huge potential in potential partnerships and marketing in each industry. For example, their Phantom Luna Elite FC Boot specifically designed to address ACL injury risk in women playing football, reflects their commitment to player safety and optimising performance with a preventative measure. This represents their dedication in developing specialised products that cater to the specific needs and challenges of athletes in different sports and genders. Nike's Innovation Centre [7], in addition, is a highly relevant centre for high-level research and development - boasting excellent training facilities as well as the highest quality designers and engineers in the world. This 2016 recent development proves their strive towards innovation tailored towards more specific consumers of Nike products synonymous with innovation (most notably the Jordan line of shoes, Hyperdunk and more sustainable focused products). Hence, our product would fit with this notion of innovation and specialisation. In our research, we found that recovering from ACL injuries and other knee rehabilitation is a pressing issue that lots of young teens face with a range of sporting aspirations and range of abilities. One of the biggest difficulties faced was the prospect of not achieving what they had hoped and having a stunted sporting career. By attaching to Nike, we would draw an association between the everyday person hoping to recover from a really physically and mentally tough injury and high performance athletes doing the same, which aligns perfectly with Nike's inspirational outlook and brand identity. Most famously:

"JUST DO IT"

POSITIVES

- Nike's recent developments in specific ACL boots as a preventative measure for women's footballers proves that our product could fit their ecosystem
- Their combination of sport and technology and user group of young people and athletes is ideal
- Brand recognition and credibility - facilitating trust and adoption by users and healthcare professionals
- Nike's brand identity works perfectly with our user group to provide an inspirational outlook on recovery

NEGATIVES

- Competing priorities and resources. Since they are a large corporation with various ongoing projects, the focus on our ACL rehabilitation device may face challenges in receiving adequate consumer attention
- Financial and contractual considerations - in order to collaborate with a well-established brand like Nike, it may involve contractual obligations that need to be carefully negotiated and managed to ensure a mutually beneficial partnership.

HENCE, AFTER CAREFUL CONSIDERATION, WE CHOSE NIKE AS OUR BRAND TO COLLABORATE WITH NIKE AND NIKE TRAINING CLUB (AS A SOFTWARE IMPLEMENTATION WITH OUR APP TO TRACK DEVELOPMENT, RECORD DATA AND CONNECT TO YOUR FRIENDS OR PHYSIOTHERAPIST LIKE CUROVATE).

Product Assembly Process

The product assembly process analysis includes the bill of materials research for the commercial off the shelf components (COTS) and the custom manufactured components to get an initial understanding of the cost. Then an analysis of the assembly steps to get a time estimate to be able to calculate labour costs.

Scale of Manufacturing

The first step to understanding the assembly process and the costs of the components is to determine the scale of manufacturing. This is due to economies of scale as one-off manufacturing will have drastically different per device cost than mass manufacturing. The more units we produce, the lower the cost per unit. There are 2 big groups to consider which are the total addressable market (TAM) and the Serviceable available market (SAM) [1]. TAM is an estimation of everyone that might consume our product while SAM are the people in the TAM that could feasibly reach or purchase our device. To find the TAM we will use our initial research to see how many people tear their ACL every year. Our initial research suggested that 2 million people tear their ACL annually however the SAM is much smaller [2]. The design of our product includes several expensive electronic components and quality material which likely wouldn't be available for the majority of the world population. Roughly 5% of the people tearing their acl will either make above $75,000 dollars or they will be directly part of a family that does. This leaves around 100,000 people in our SAM and with another rough estimate of 10% of those 100,000 people being interested in our product and wanting to purchase that leaves our realistic number of sales per year for our desire at around 10,000 units. We therefore assume 10,000 units when determining the price of each component.

Bill of Materials with Cost*

Table 2. COTS Bill of Materials

COTS

Component	Quantity per Device	Price per Unit ($)**	Price per Device ($)
GM3506 with AS5048A Brushless DC Gimbal Motor	1	15[3]	15
FOCMini Motor Driver		3.88[4]	3.88
1.28inch Round LCD		3.66[5]	3.66
ESP32-WROOM-32D Bluetooth + Wifi		4.43[6]	4.43
3S Lipo battery with BMS + switch		1.40[7]	1.40
Mini Momentary Button		0.01[8]	0.01
38mm ⌀, 1mm thick glass panel		0.66[9]	0.66
2.2 × 12.5mm Phillips counter sunk self tapping screw	6	0.009[10]	0.054
M2.5 × 4mm Phillips counter sunk bolt	4	0.008[11]	0.032
M3 × 8mm Hand Threaded Bolt	1	0.63[12]	0.63
			29.756

Table 4. Cutsom Parts Bill of Materials

Custom Manufactured

Component	Manufacturing Method	Material	Price Per Unit ($)***
Exterior Dial	5-Axis CNC Mill	6061 Aluminum	6.66
Top Motor Driver Housing	Injection Moulded	ASA	1.68
Bottom Motor Driver Housing			2.76
Screen Housing			1.92
Button Cover			0.18
Top Battery Shell			2.17
Bottom Battery Shell			2.56
Leg Shaft Connector			0.96
Leg Shaft	Water Jet	6061 Aluminum	0.64
Foam Base	CNC Vinyl Cutter	Polyurethane Foam	0.20
			19.73

* Small low cost items such as electrical wires, solder, glues, heat shrink, and others have been excluded in the bill of materials as their costs are insignificant compared to the other items
** Each superscript is the citation to the item which the pricing was based on. For real production the price per unit would likely be even lower as economies of scale would bring down the cost.
*** Price per unit and price per device are joined together as 1 column as each custom manufactured component only has a quantity of 1.

To determine the pieces per unit for the injection molded and the CNC Milled parts we contacted an overseas manufacture PCBWay to get a better initial cost estimate. This is important because when milling the dial ourself, the materials and manufacturing cost added up to roughly $35 however after reaching out to PCBWay and giving them the specific material and CAD file, the cost per unit came out to $6.66 which is roughly an 83% percent decrease in price. The same process was applied for each of the injection moulded pieces where ASA was specified as the material, SPI-B1 surface finish so that the plastic is smooth (important for CFM of our product), and each CAD model was uploaded to their service. These quotes were double checked with injection moulding pricing guidelines to ensure they are within a real realm.

Another important note for consideration in the injection moulded parts pricing is that as more units are need, their prices will be much lower than the specific per unit price as a majority of the price for injection moulded parts is the initial setup and tooling cost of making the mould. This means that in the future when more unit will be produced, their per unit cost will be drastically lower as the setup cost has already been payed for. This meansas the life of the product extends, it can possible get cheaper.

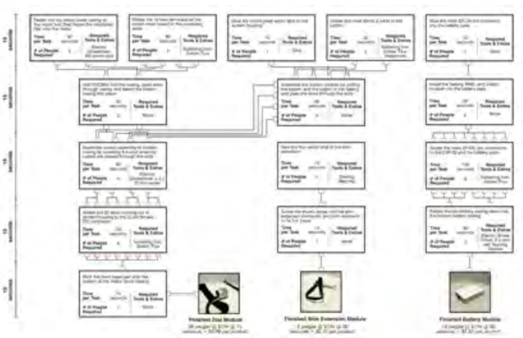
Materials Cost Caluculation

Now that we have the rough costs for all of the COTS and the manufactured parts we can add them up to get an estimate. The total for the COTS components is $29.756 and the costs for the manufactured components is $19.73. That brings the total to $49.486 per product. That is just the material and manufacturing costs and so the other 2 major cost considerations that will be calculated is the shipping cost and the labour costs. A typical 20ft shipping container from China to the UK, costs on average $2000 [1]. We are looking at manufacturing in china as it is where the majority of the worlds electronics manufacturing and assembly occurs. The main part of our product which is the gimbal motor is manufactured in China so it makes sense that the assembly takes place there and then would be shipped to the UK.

A 20ft shipping container has an internal volume of 32.6 cubic meters and when we calculate the volume of our packaging we find our packaging has a volume of 0.00243 cubic meters. From these 2 values we can find how many boxes would fit into the shipping container. 32.6 / 0.00243 = 13,415 units. Although the shipping container could fit a maximum of 13,415 units, that figure assumes a 100% packing efficiency which it would't be. Since our product has large filleted edges at the top this would reduce the packing efficiency. The packing efficiency will further reduce because the packing wont be placed directly into the container. The boxes will most likely be bundled together in a bunch of 100 or so. This would mean another cardboard box around it. After these factors, a packing efficiency of roughly 80% will be used. 13,415 * 0.8 = 10,732 units. With this figure in mind, since we are only producing 10,000 units, it means that all of the manufactured products could fit into one 20ft shipping container.

If we split the 2000 dollar shipping cost over the 10,000 units we get: 2000 / 10000 = 0.2. This means that for each device and packaging, the rough shipping cost to ship it from china to the UK will be about $0.20. In reality the shipping cost would be higher as there is also the shipping costs from the factory to the shipping port and the shipping port in the UK to the customer, service centre, or store. Therefore for the shipping we will use a cost estimate of $0.50.

Labour Cost Calculation



To calculate an accurate labour cost estimate a detailed factory and assembly systems diagram has been created. This diagram can be seen on page 12 of the portfolio section. The way that this diagram functions is that it takes into account how long each assembly process take and depending on how long it takes it assigns more or less people to it. For example for task that takes 15 seconds by a person 1, they could complete that task 4 times in 1 minute. Whereas a task that takes a full 60 seconds, person 2 could only complete that task 1 time in a minute. That means if the part that was assembled from the short task was going to the person 2 performing the longer task, there would be a pileup of parts coming from person 1 to person 2. To offset this difference 4 people could be assigned to the longer task which means that after 1 minute the task has been completed 4 times. This then creates a balance between the shorter and longer task and prevents any buildup of parts. This same logic has been applied to the entire assembly process to create the systems diagram as seen in page 12 of the portfolio. Since the shortest task is 15 seconds and all the tasks are in time increments of 15 seconds we can use 15 seconds as the base time and increase the number of people per task so that each manufacturing step can be completed every 15 seconds. This can be visualized in the diagram where fro the main dial assembly where the entire thing would be assembled in 75 seconds (excluding travel time from 1 assembly step to the other). The benefit of this system is that each person is only performing 1 small task which maximizes the efficiency and optimizes the process. One of the benefits of our design is the high level of modularity which means that several components can be assembled simultaneously and then joined together which speeds up the overall speed time. There are 3 separate final assemblies which are the main dial, the shin extension, and the the battery module.

From this diagram we can calculate the total labour cost and how long it would take to manufacture all of the devices. In total there are 41 people working in this diagram and they are all paid $7 per hour. For the dial module, there are 26 people working and it takes 75 seconds to finish 1 product which means that it costs $3.79 in labour to make the dial module. The same math can be applied to the shin extension module which costs $0.12 per product, and the battery module which has 13 people working so it would cost $1.52 in labour. That means the labour cost for the whole device is $5.43. Since the longest task is 75 seconds, and we need to produce 10,000 units, it would take 52 24 hour days to produce all the units. It would take 156 8 hour days to produce all 10,000 units

Total Cost Calculation

The total cost of the product includes the materials, transport, and labour cost. This total comes out to 49.49+ 0.5 + 5.43 = $55.42. Normal profit margin for products is around 40-50%. That means a realistic price for our product would be $100 which seems reasonable for a high quality, luxury finish product.

Product Compliance

The product compliance research shows all the relevant regulations, standards and compliance specifically for products but we also touch upon organisational compliance. Going over key standards and markings for sale of products in the UK and EU.

ISO Compliance

The International Organisation for Standardisation, or ISO, establishes and distributes global standards to guarantee effectiveness, safety, and quality in a variety of businesses. When a new standard is determined to be necessary, the procedure starts. A working group of specialists draughts the standard after developing a proposal that, if accepted, is produced. The draught is subsequently made available for public discussion, amended as necessary, and submitted for vote to ISO member organisations. The standard is published after approval and its applicability is assessed every five years. Despite being optional, ISO standards frequently end up being included into international laws and regulations.

On the product side, it's essential to confirm that the DX-4 abides by a wide range of performance and safety regulations. The specific ISO standard that may be relevant is ISO 13485, which outlines the specifications for a quality management system where an organization needs to show that it can consistently supply medical devices and related services that fulfil customers' expectations and applicable regulatory requirements. ISO 13485 can be used even when the equipment is not a medical device to show a commitment to quality and safety.

UK Radio Equipment Regulations

The UK Radio Equipment Regulations (UKRR), similar to the EU's Radio Equipment Directive (RED), require Bluetooth devices to be compliant in the UK. To guarantee they follow the applicable rules, businesses must successfully complete a Conformity Assessment. Specific technical requirements relating to emissions, power outputs, and frequency ranges must be met by these devices. They must also not endanger the users' health or safety. They must also clearly display the UKCA logo and give specified information, such as user manuals and safety information. Bluetooth equipment typically complies with the ETSI EN 300 328 standard.

CE and UKCA markings

While the UKCA (UK Conformity Assessed) marking is a new UK product marking used for items being placed on the market in Great Britain, the CE mark signifies a product's conformity with European health, safety, and environmental protection regulations.

The Machinery Directive (2006/42/EC) is one such directive that makes sure the tool won't threaten people or animals. Conducting a risk analysis, putting safety precautions in place, and finishing the relevant technical documentation are all possible parts of complying with this requirement.

Compliance with RoHS and WEEE

Both the RoHS (Restriction of Hazardous Substances) Directive 2011/65/EU and the WEEE (Waste Electrical and Electronic Equipment) Directive 2012/19/EU are essential for product compliance.

The WEEE programme promotes the collection, handling, recycling, and recovery of electronic equipment that has reached the end of its useful life. Producers are now expected to pay for these initiatives. For consumers to return used equipment and for proper disposal or the recycling process, the business should have a mechanism in place.

The use of specific hazardous compounds in electronic equipment is restricted by RoHS. It makes sure that goods entering the EU market contain no trace of certain elements like lead, mercury, and cadmium that might be hazardous to both human health and the environment. Products must pass a conformity evaluation, and producers must create an EU declaration of conformity and attach the CE marking to the item.

Regulations UN3481

UN3481 is pertinent since DX-4 has a lithium battery. Lithium-ion batteries found inside of equipment are covered by UN3481 and are categorised as Class 9 hazardous items for transportation.
In order to ensure compliance with UN3481, the item must be packaged properly for transit, the packing must be labelled properly, and the paperwork that goes with the package must be accurate. Additionally, the business should make sure that it only employs carriers qualified to transport Class 9 dangerous items and that it provides training to those engaged in setting up the device for shipping.

Organisational Compliance

The internal rules and practises that a business follows in order to uphold the legal, moral, and professional standards set by both external organizations and internal stakeholders are referred to as organizational compliance. Product safety, quality assurance, and environmental sustainability could be crucial elements of organizational compliance for any business.

The ISO 9001 standard is one example of a standard that could be organizationally applicable to our corporation. This International Organization for Standardization (ISO) standard talks about quality management. In accordance with legislative and regulatory standards specific to the good or service, ISO 9001 assists organizations in making sure that they satisfy the expectations of customers and other stakeholders.

ISO 27001

The International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC) have jointly developed ISO 27001, a standard for information security management systems (ISMS). This standard, formally known as "ISO/IEC 27001:2013," specifies the conditions for creating, putting into place, maintaining, and continuously enhancing an information security management system.

The objective of ISO 27001 is to assist organisations in enhancing the security of their information assets. By creating standards and basic principles for starting, putting into practise, sustaining, and enhancing information security management inside an organisation, it does this. The actual structure of information security is often determined by the requirements of various organisations and their unique goals.

BS EN IEC 62311:2020

The British Standards Institute (BSI), the European Committee for Standardisation (CEN), and the International Electrotechnical Commission (IEC) together developed the standard known as BS EN IEC 62311:2020. It describes how to determine if electrical and electronic equipment conforms with the safe levels of electromagnetic field exposure for people. In the UK, the entirety of the EU, and worldwide, the standard is accepted and enforceable.

Other relevant standards

EN ISO 20957-1: Stationary training equipment: For stationary training equipment, this standard specifies general safety standards. It comprises specifications for cardio, particular strength, and training equipment type strength.

IEC 60335-1: Safety of Household and Other Electrical Appliances, Part 1: Basic prerequisites: Electrical appliance safety is covered by this standard. This or a comparable standard must be followed if your gadget is electrically powered.

IEC 62368-1: Safety regulations for audio/video, information, and communication technology equipment, Part 1: Product may need to adhere to this standard if it includes any integrated audio or visual components or interfaces with information and communication technologies.

ISO 14971 recommends identifying, assessing, assessing residual risks, and evaluating control effectiveness, while advising producers to assess residual risks. For continued risk management, post-production data assessment is important. Manufacturers are expected to judge danger levels based on regulatory requirements and their intended use. The standard does not specify danger levels.

Product Labelling & User Guide

Labeling

The product labelling is laid out in detail in the portfolio slides. However, it is important to mention a few key details. The key points for user interaction are the red push button on the side of the screen housing which loops the device through three resistance settings. In addition the screen offers a key interaction point. The arc rotates through different angles to give a visual indication of how much range of motion has been achieved whilst the display shows in real time how the user is progressing.

User Manual

Since the interaction with the nike training app is such a key feature as it is the way the user is able to visually track their progress it made sense that the product didn't include a paper manual and instead pointed the user towards the app in order to ensure full functionality of the product. Here they are able to access videos and graphics walking them step by step through the set-up, calibration, training and charging processes.

The Nike Training Club app walks the user through a step by step process where they cannot progress before ticking off the tasks performed in advance. These steps include charging the battery and setting up the battery pack, connecting via bluetooth, selecting whether the device is going to be used on the left or right knee and answering questions such as height, sex and date of surgery.

The user is unable to progress to using the product without completing the checklist and reading how to correctly operate the device.

Calibration

Whilst the device comes calibrated, the position that the user chooses on their leg will differ depending on comfort. On these occasions when the user wants to provide more accurate measurements, they have the option to calibrate the device to true 90 degrees.

In order to calibrate, the user sits against on a 90 degree surface. Once the user is happy that the angle between their thigh and shin is 90 degrees they can calibrate by pressing a button on the app which resets the device to ensure that the new angle read is 90 degrees.

Legal Disclaimer

1. Safety Precautions: When operating DX-4, it is essential to follow all safety precautions and guidelines provided. Failure to do so may result in personal injury, property damage, or adverse effects on the device's performance.

2. Proper Usage: Use the device in accordance with its intended purpose and within the specified operating conditions. Misuse or unauthorized modifications to the device or battery can lead to safety hazards and void any warranties or liability from the manufacturer.

3. Charging and Handling: Only use chargers and accessories recommended by the manufacturer for charging the Li-ion battery. Follow proper charging procedures, including using the correct voltage and current levels. Avoid exposing the battery to extreme temperatures, physical impact, or excessive moisture.

4. Storage and Transportation: Store and transport the device and battery in a safe and appropriate manner, adhering to local regulations and guidelines. Prevent exposure to extreme temperatures, direct sunlight, or flammable materials that could compromise the battery's integrity.

5. Disposal: Follow proper procedures for the disposal or recycling of Li-ion batteries in accordance with local regulations. Do not dispose of batteries in household waste or expose them to fire, as they may pose environmental and safety risks.

Packaging

Packaging has 6 main functions: to inform, to preserve, to display, to protect, to transport and to advertise [1]. Hence, when designing our packaging, we opted for a more unique and Nike brand-aligned design.

Packaging design plays a crucial role in product presentation, protection, and user experience. In the case of the DX-4, which features a polycarbonate press fit top and a paperboard lower with pulp inlays, we have crafted out packaging to enhance functionality (by providing a multipurpose use storage case for portability), promote sustainability (using two widely recyclable materials) and aesthetics of the product

Design Inspiration and Methodology

Right is our primary inspiration for the packaging. The product is clearly shown and the branding comes through well - being shown on multiple sides whilst being minimal. Also, the two part design allows for some parts to be hidden/submerged in the paperboard. As a result, we decided to have our DX-4 product logo on the side of the product and have the Dyson School of Design Engineering x Nike on the top of the device. For the design on the back, we decided on a wireframe design based upon a design by Dime Mtl [3], a skate brand with a similar ethos to Nike SB. with a centred label with all the relevant information - referring to our app integration with Nike Training Club for the user guide.

NIKE CONCEPT PACKAGING REFERENCE [2]

Materials and Manufacturing

One key consideration is the choice of materials. We chose **Polycarbonate** for our upper housing since it is a durable and lightweight plastic known for its impact resistance and clarity. Its use for the press fit top showcases the product, distancing ourselves from other technology products on the market. Polycarbonate offers a sleek and modern appearance, aligning with contemporary design trends. Furthermore, this material is widely recycled - hence we included the relevant plastics recycling code for ease of recycling.

On the other hand, the **Paperboard** lower housing with **pulp inlays** serves multiple purposes. Paperboard is an eco-friendly paper based material that can be recycled or composted, emphasising sustainability and environmental consciousness. The pulp inlays provide cushioning and protection, ensuring that the product remains safe during transportation and handling. Furthermore, they provide a unique user experience by having filleted edges around the sides and around each product so you can easily access and put away each product which fits tightly into its shape indented space.

The manufacturing process for our packaging would be injection moulding for the frosted clear polycarbonate top and traditional paperboard production techniques for the lower portion. Injection moulding allows for precise shaping and production of the press fit top, ensuring a secure fit and maintaining the desired aesthetic. Paperboard manufacturing involves forming the material into the desired shape, such as a box, and integrating the pulp inlays. This pulp inlay would fit with our business model of producing 10,000 units in the first year - since each high quality mould can cost around 4000 USD [4], which is as precise that if we were to adjust the design by a millimetre or two, this would require us to produce another mould which would be expensive. Nevertheless, considering economies of scale, it would be completely worth it for aesthetic reasons to acquire the pulp-inlays on the paperboard to achieve a high-quality, durable packaging that would double as a case.

As for the wireframe design on the bottom of the packaging, we would use screen printing: a versatile technique used for printing graphics on paperboard. The manufacturing process consists of a fine mesh screen, coated with a light-sensitive emulsion and exposed to UV light through a film positive, creating a stencil. A sustainable ink compatible with the substrate is selected:a **water-based ink.** This is mixed, and applied onto the screen using a squeegee, transferring the wireframe graphic onto the paperboard. The printed packaging is then dried and cured, ensuring proper adhesion and durability. This process allows for quality control checks, ensuring accurate and neat printing - adhering to the existing modular manufacturing process, allowing for multiple processes to be happening at the same time (maintaining a low overall cost). Screen printing is a cost-effective method of printing graphics on paperboard, in which the water based ink is durable - ensuring the wireframe graphic maintains its visual appeal throughout the product’s lifespan.

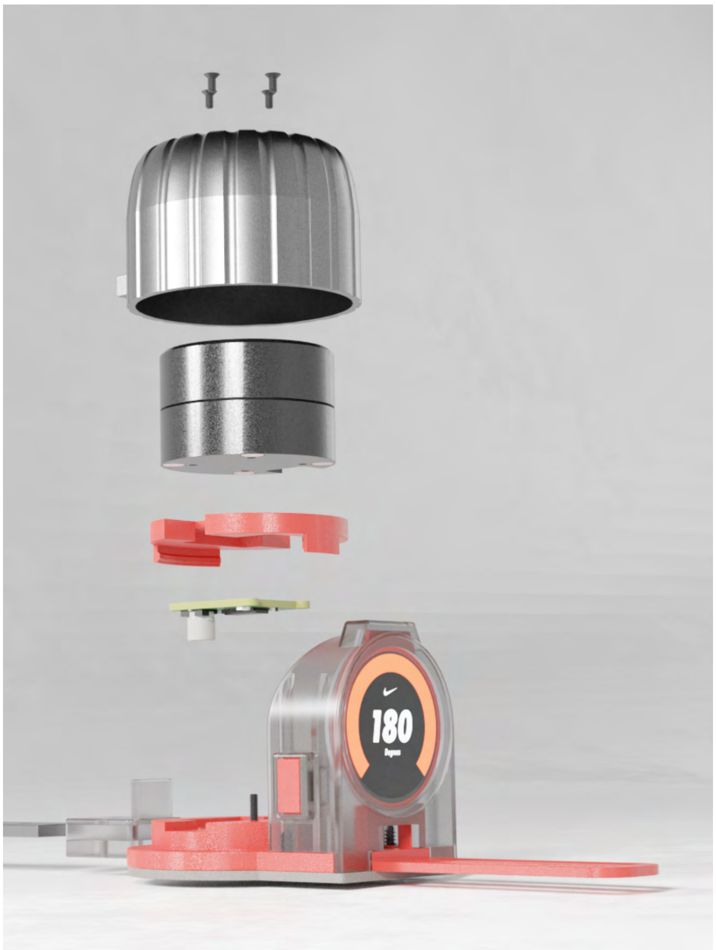
Omitted Items

In the packaging, we decided to omit a few items, in the aim to improve sustainability by reducing packaging, removing commonly household items and moving the user guide onto a pre-existing Nike Training Club application. We removed the three velcro straps which go around your knee, since these are very dependent on the person and need to fit well. Next, we removed, the Li-Ion battery charger, since this is a regular 12V 3A charger which can commonly be found in most households (power adapters, even laptop power adapters). Finally, we digitalised the user guide, as mentioned in the user guide section, removing paper from the packaging enabling us to use a simple two piece packaging design rather than requiring pull-up tabs and more paper below the other packaging with the user guides.

Final Design

Digital Prototype

Our digital render prototype was modeled parametrically inside of Fusion 360 to allow for easy changes to the design file. This was critical as many iterations were needed to achieve a working prototype. Constant small changes were made to fit our parts due to the warpage when 3D printing. The Fusion model was imported into blender to create the still renders in addition to the video animations. This was greatly beneficial as it allowed us to see a more realistic final product look compared to our final working prototype which worked and mostly fit the look, however due to limited resources, we were not able to make it look exactly as we wanted. The renders allow us the designers, and the consumers to get a good idea of the product. Our digital prototypes also allowed us to conduct simulations to ensure that the products are safe to use. In the future, it would be beneficial to add wires to the model as we struggled with determining spacing for wire channels, and wire in the CAD would've helped



Works Like Prototype

Our works like prototype was the final conclusion to the many prior looks like and works like prototypes. It had 70% of the functionality and 90% of the looks that we desired. Some of the main functionality that would ideally be implemented in future more refined prototypes would be the implementation of the button which changes the resistance and even more in the future would be to implement the bluetooth functionality of the ESP-32 to get it to connect to our phone. One thing in our works like prototype that wasn't as good as we had hoped was the resistance of the motor. The motor didn't provide as much resistance as we hoped and in the future it would be worth looking into motor which could provide more resistance. To make our works like prototype more visually similar to the desired final version similar to the render would be to make the screen housing and shin extension connector translucent and add color to the other injection moulded components. Other than those aspect, visually our product was very similar to the desired final design.

Project Plan

In reference to our Gantt Chart, the final page of our portfolio.

Week

1

ALL
Review project direction and develop opportunities, speak to new user. Lucas' chosen project.
Speak to target users to further develop idea to aid product direction and make changes to initial design

2

LUCAS
Begin CAD developments, additively manufacturing main components and testing different dial shapes

WILL, CALLUM, THOMAS
Microcontroller and encoder developments, taking turns with working on this or determining and wiring the 12V battery

3

ALL
Work together on electronics and wiring, discussing each part and finding the most cost-efficient solution

4

LUCAS
Begin dial machining, adjust main strap component to fit all straps, develop CAD

WILL
Wiring motor driver boards, step-down voltage systems and general soldering

5

THOMAS
Begin Blender renders, storyboard video and help programming electronics

CALLUM
Program ESC-32 electronics, begin packaging design, label and branding

6

ALL
Get feedback from users, provide feedback on additively manufactured parts, aid in electronics testing and wiring and make team decisions e.g. type of plastics used, battery placement, brand ideal, etc.

7

LUCAS
Complete dial machining, resin 3D print all parts, complete CAD

WILL
Wire battery to electronics, solder all parts, build final device, 20 pin connector J-tag

THOMAS
Finish Blender renders, complete video, help with electronics

8

CALLUM
Complete programming, packaging, branding and labelling

Insights

To choose between our concepts developed in the previous term, we focused on market, financial and technical feasibility instead of less commercially viable and more complex designs e.g. Leg exoskeleton. Hence, we picked DX-4.

Through our initial research and checking out more existing products, we found where to hone in our product: enabling easy-to-read range of motion and long term tracking of this to aid the mental journey of rehabilitation whilst being able to slowly increase resistance to improve restrengthening.

After our first additive prototypes, we found many issues. We had to compete with microcontroller limitations, hindering our progress due to the lack of SPI pins on the Arduino Nano boards, causing us to change to using ESP-32s with bluetooth connectivity (for ease of connecting to an app). We had initially hoped to use an rp2040 connected to a 1.28" LCD display but this did not have enough pins either.

Furthermore, we battled with the battery position - since the gimbal motor required 12V 1A stall torque (as well the other electronics, which ran off 5V). We went from placing the battery on the inside of the leg on the strap to clipping a larger battery pack onto a belt (increasing wire lengths and making soldering more difficult).

We also had to play around with the strap location to achieve a tight enough fit around the knee joint to ensure the highest resistance possible. This affected the screen position among other 3D printing problems such as reducing the size of the slot for the strap and the slot snapping, and changing filament type (before we used resin) and this causing tolerance issues.

We fried more motor driver boards and resistors whilst working on a step-down voltage system as well as not accounting for back emf on the gimbal motor, where we would spin the motor to retrieve the angle back in the range of the dial on the screen (0-180 degrees), which accumulated to fry the motor driver. Once this was done, we began coding a master file to combine our two Arduino programs: running a motor at constant voltage and using the magnetic sensor to measure the angle of the gimbal motor when moved manually.

For the branding, our initial idea of Curovate was quickly shut-down due to their limited reach and brand reputability, as was teenage engineering since their brand was not relevant enough to our product despite their design language being ideal. Therefore, we settled with Nike - due to their advancements in ACL preventative technology and wearable technology.

Rendering our final product, we designed the packaging which aligned with our brand identity, as well as our CAD and renders / product animations. We adjusted our initial colour scheme to match Nike's vibrant colour palette in our renders.

Assembling our final product proved very difficult, requiring lots of re-soldering, utilising a ribbon cable, 20 pin connector, rewiring the battery and fitting the cables through the small holes and channels in the design through some sheath.

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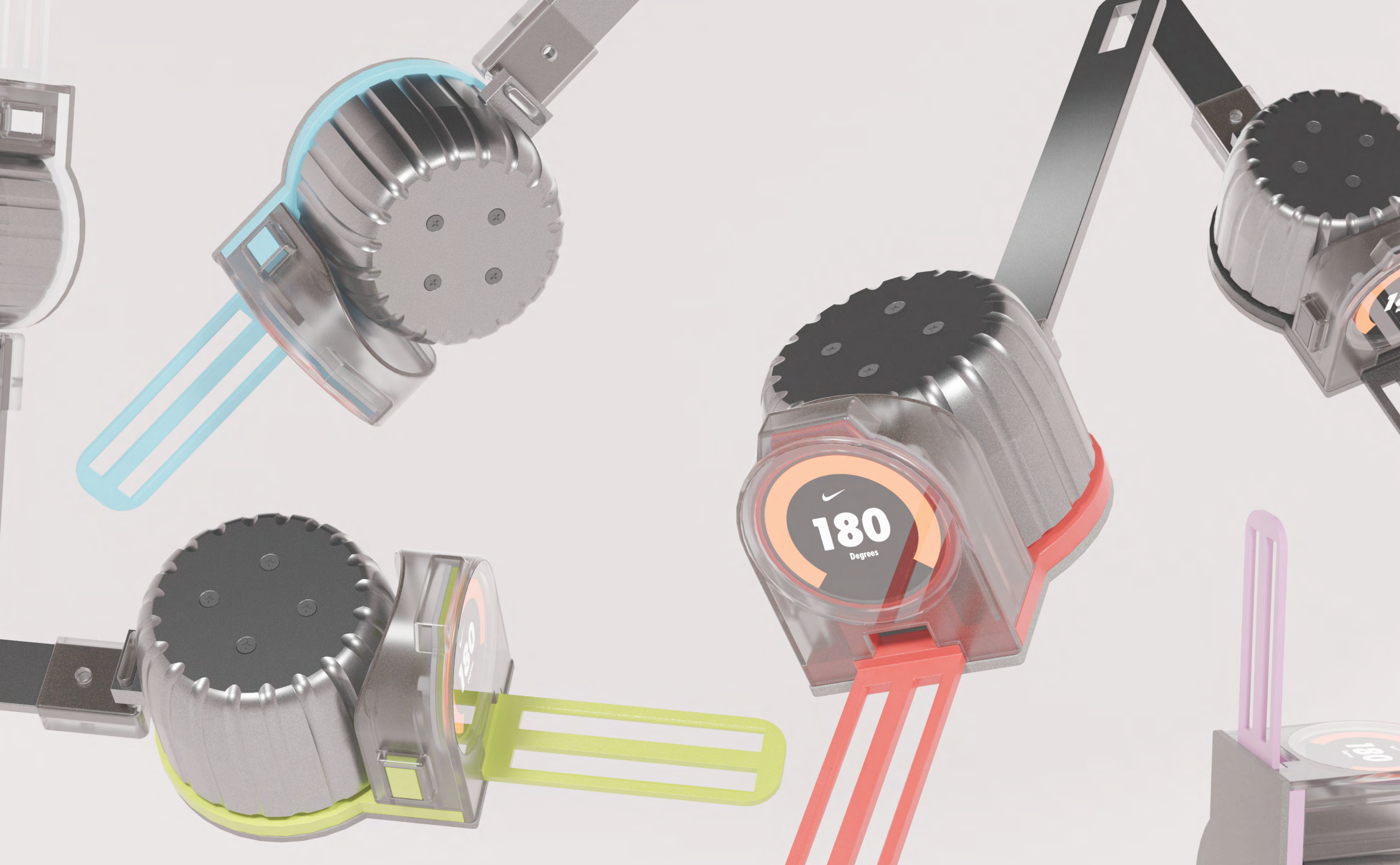


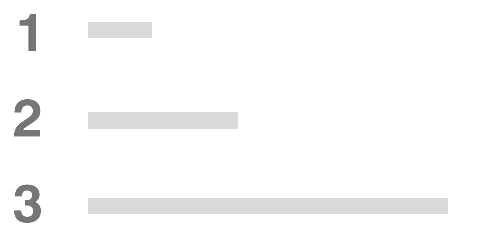
Industrial Design Engineering Portfolio

Dyson School of Design Engineering x

Concept Selection

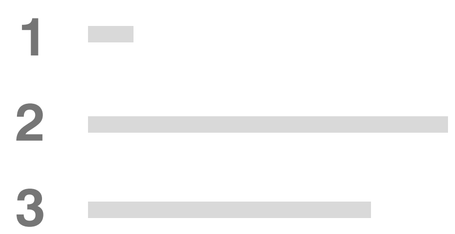
Market Feasibility

Market Feasibility was largely differentiated by differences in product lifetime. By adding extra resistance in ROM tracking, concept 3 has the greatest lifetime. Concept 1 was deemed to be significantly less feasible due to the density of competition within the knee brace



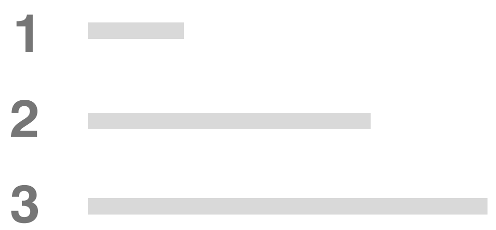
Financial Feasibility

The simplicity of concept 2 and associated manufacturing costs led to a feasible design, the additional complexity and inclusion of the motor in concept 2 scored it slightly lower and the expensive materials of concept 3 led to a low score.



Technical Feasibility

Both concepts 2 & 3 are technically feasible. Concept 3 is probably more so since there isn't the need to calibrate the device before every use.



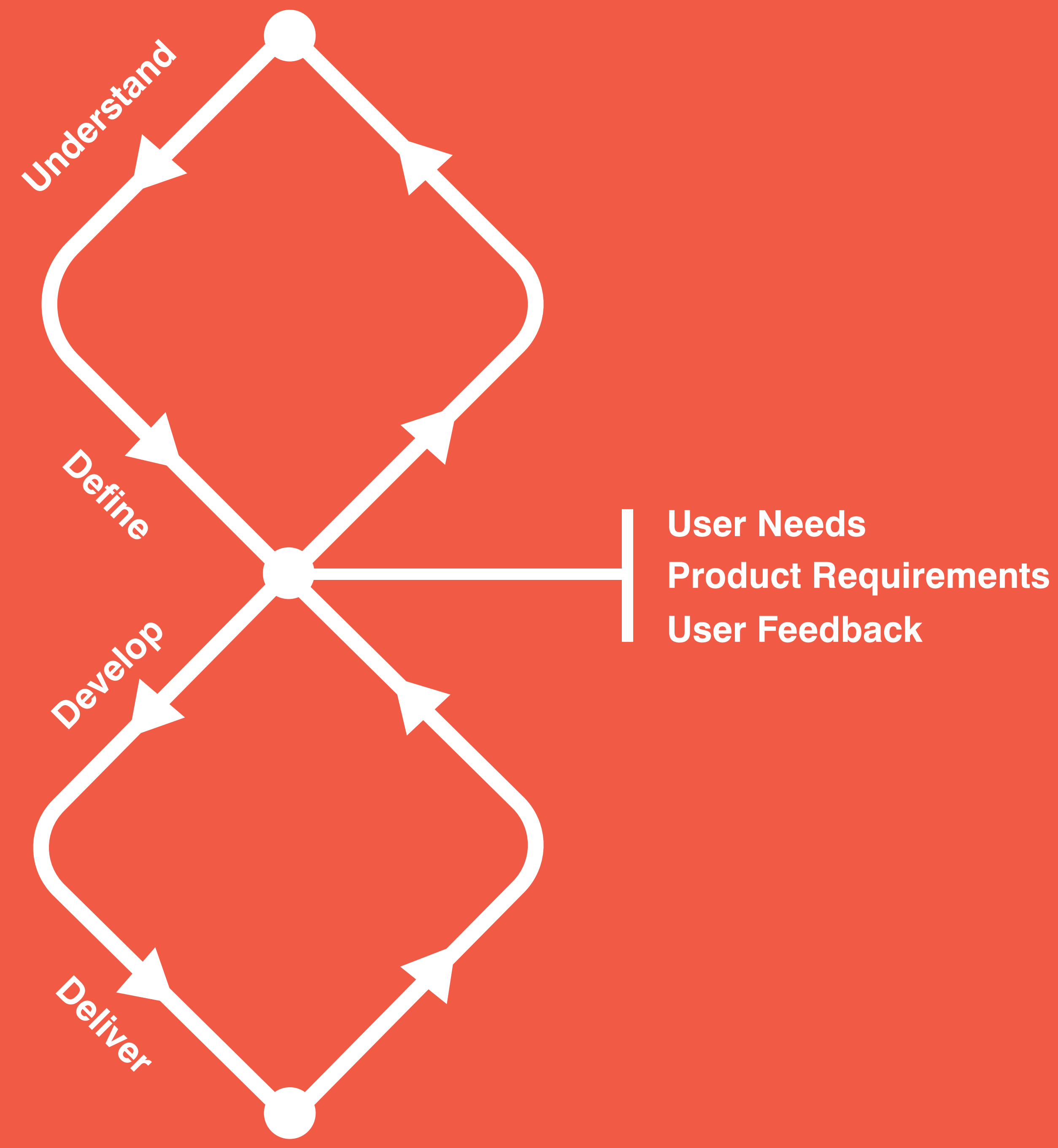
Concept Development Approach

User Needs

- Quantitative engaging measures of progress over time
- Independent Operation
- Clearly indicated to the user how they should feel during use
- Exaggerates small margins of progress
- Doesn't draw overt attention to the user
- Inspires the user to engage with the recovery process

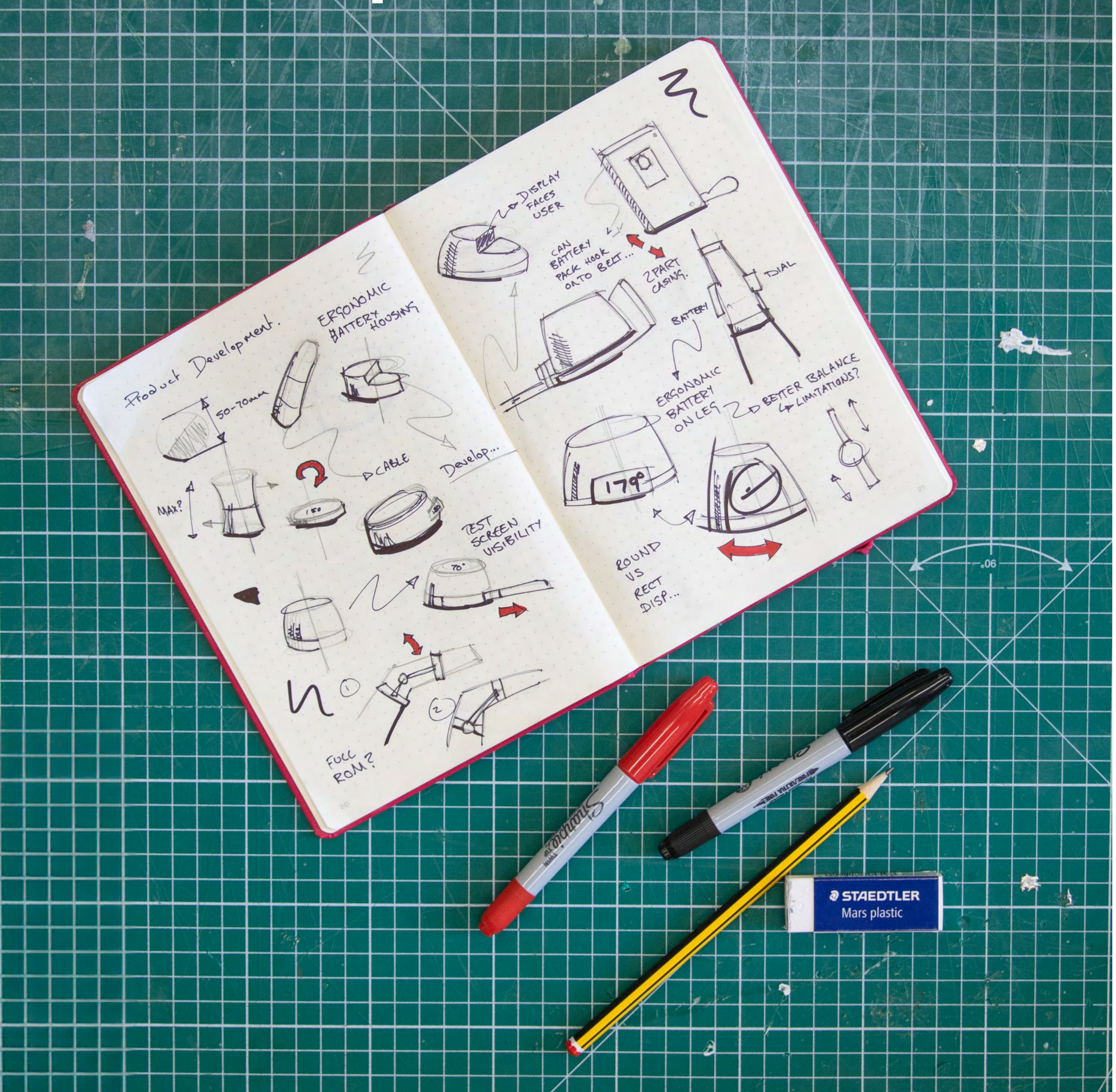
Product Requirements

- Accurately measures maximum angle achieved by the user
- Tracks maximum angle achieved over the course of the recovery process
- Lightweight and comfortable to wear for periods of up to an hour
- Provides intuitive placement on the joint
- Gives realtime feedback to the user
- Provides variable resistance to the user



At every stage in the development process, decisions were made based on metrics derived from user feedback, an assessment of product requirements as well as in conjunction with user feedback

Concept Selection & Development



Key Developments

Ergonomics & User Centred Design

Ergonomics played a key role in the positioning of the dial on the leg, It was essential that the straps were able to be positioned away from direct swelling. This posed design complications in extending the dial away from the strap.

Battery Limitations

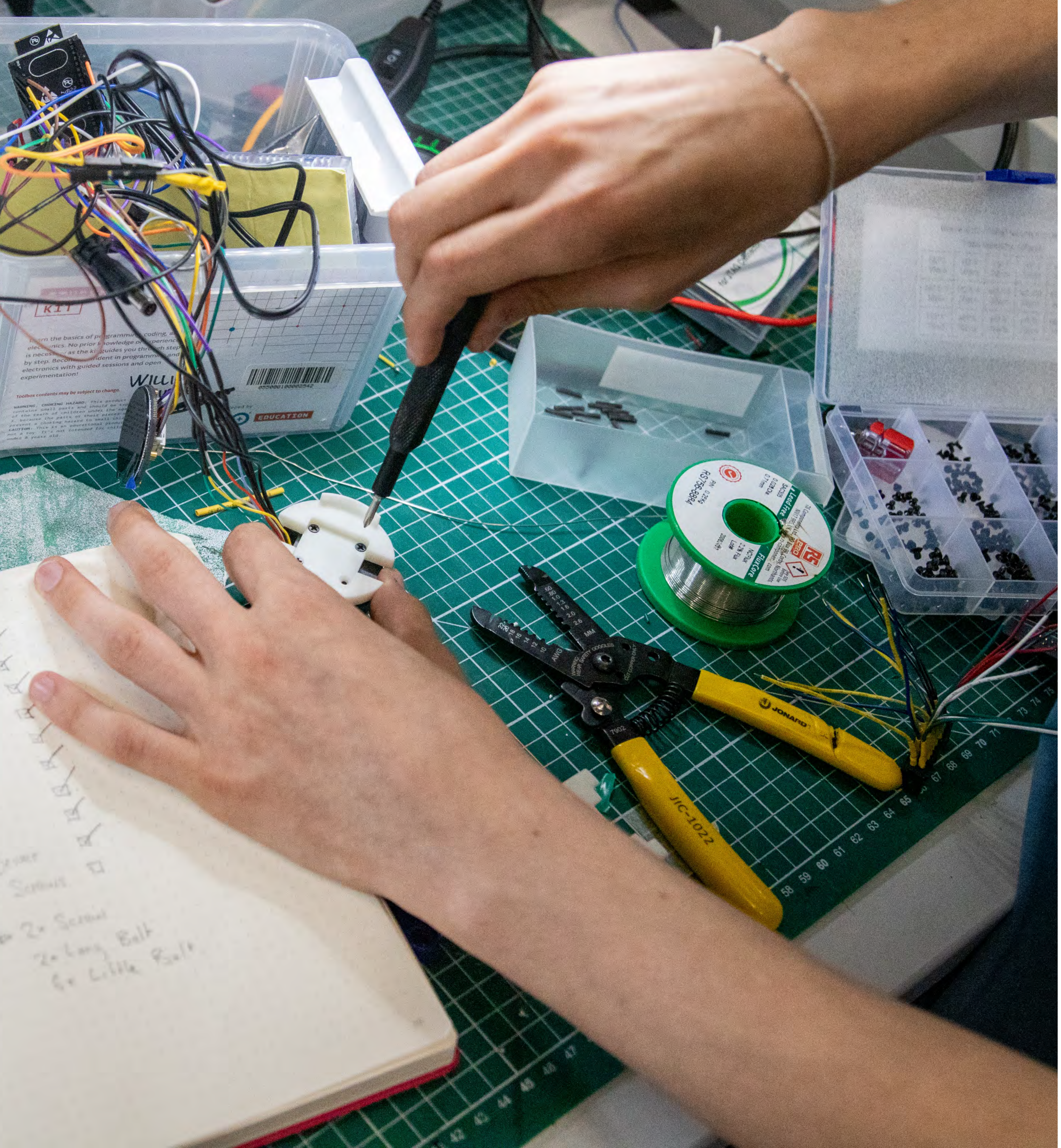
Project limitations concerning cost and timeframe restricted how small we could make the battery unit. Initially, the battery was designed to sit on the other side of the knee in a compact ergonomic casing. With the inclusion of custom PCBs and more expensive batteries, we would hope to achieve this. Our solution involved a separate battery pack that could sit beside the user or hook to the user’s belt.

Colour, Material & Finish

The product is available in a range of colours, colours were decided to fit in with the nike brand including a “volt” yellow. Materials were also chosen to fit with the nike brand including a translucent SLA housing for the screen and machined aluminium 6061 dial drawing inspiration of the Apple Watch in collaboration with nike.

Physical Prototyping

Large amounts of physical prototyping was undertaken to test the shape, fit, form, comfort, and size before a final design was decided upon. The primary manufacturing technique that was used was 3D printing where FDM printing was used for our rough prototypes and SLA resin printing was used for the final prototype with its higher tolerances.



Electronics Prototyping

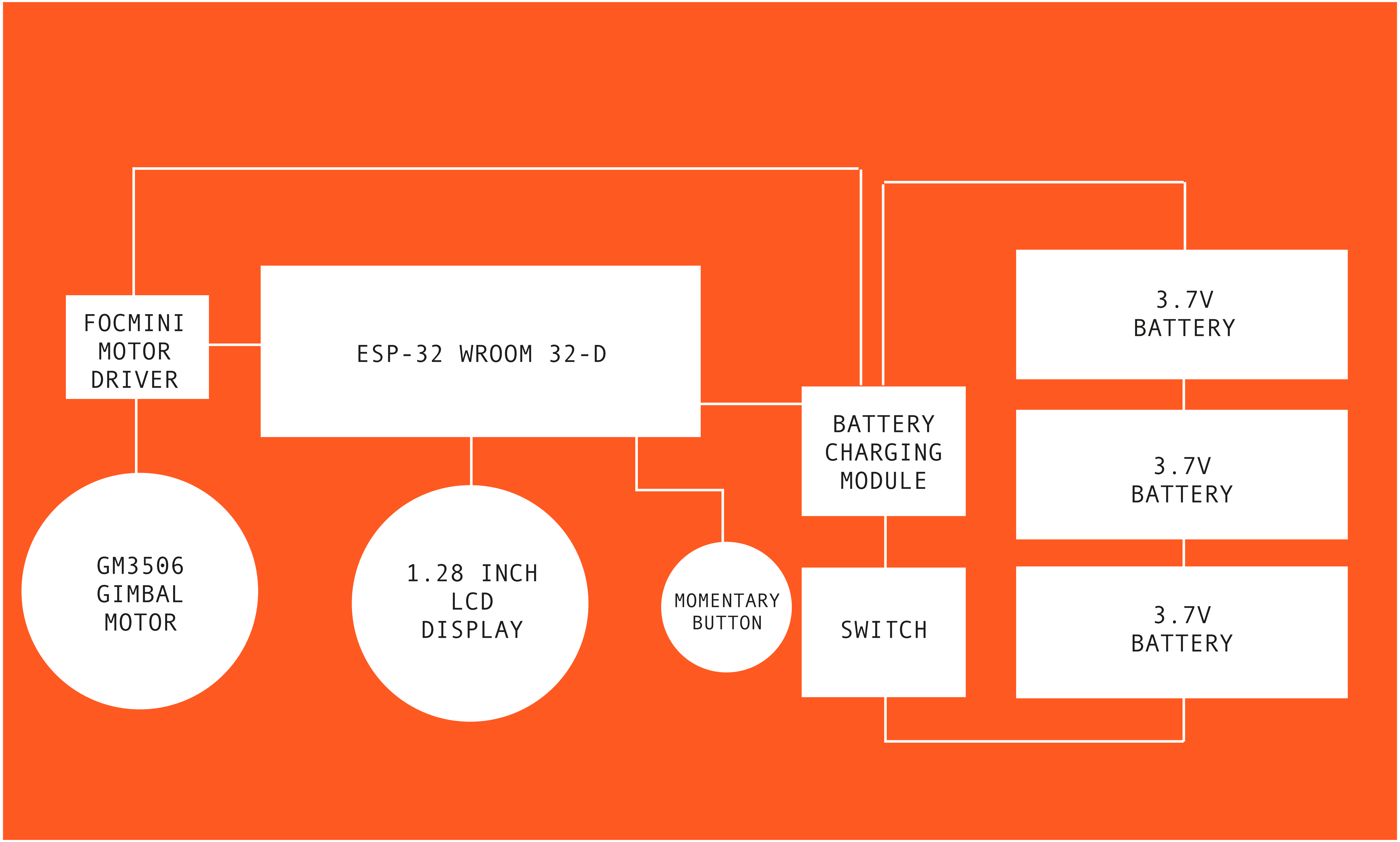
Hardware

Several iterations of electronics hardware was tested before a final functioning prototype was achieved. The primary difficulty in creating a functional device was selecting an appropriate microcontroller. A Pi Pico, Arduino Nano, & Arduino Uno were all tested before finally deciding on a ESP-32 WROOM-32D with Bluetooth.

Software

Much of the difficulty faced in this project occurred due to issues with the code. The gimbal motor we used used the FOC library, a specific library for our motor driver which has limited documentation rendering programming very difficult. Furthermore, the existing examples offered had issues and lacked reasoning - but we were able to eventually get the code to run after posting multiple questions in the forum.

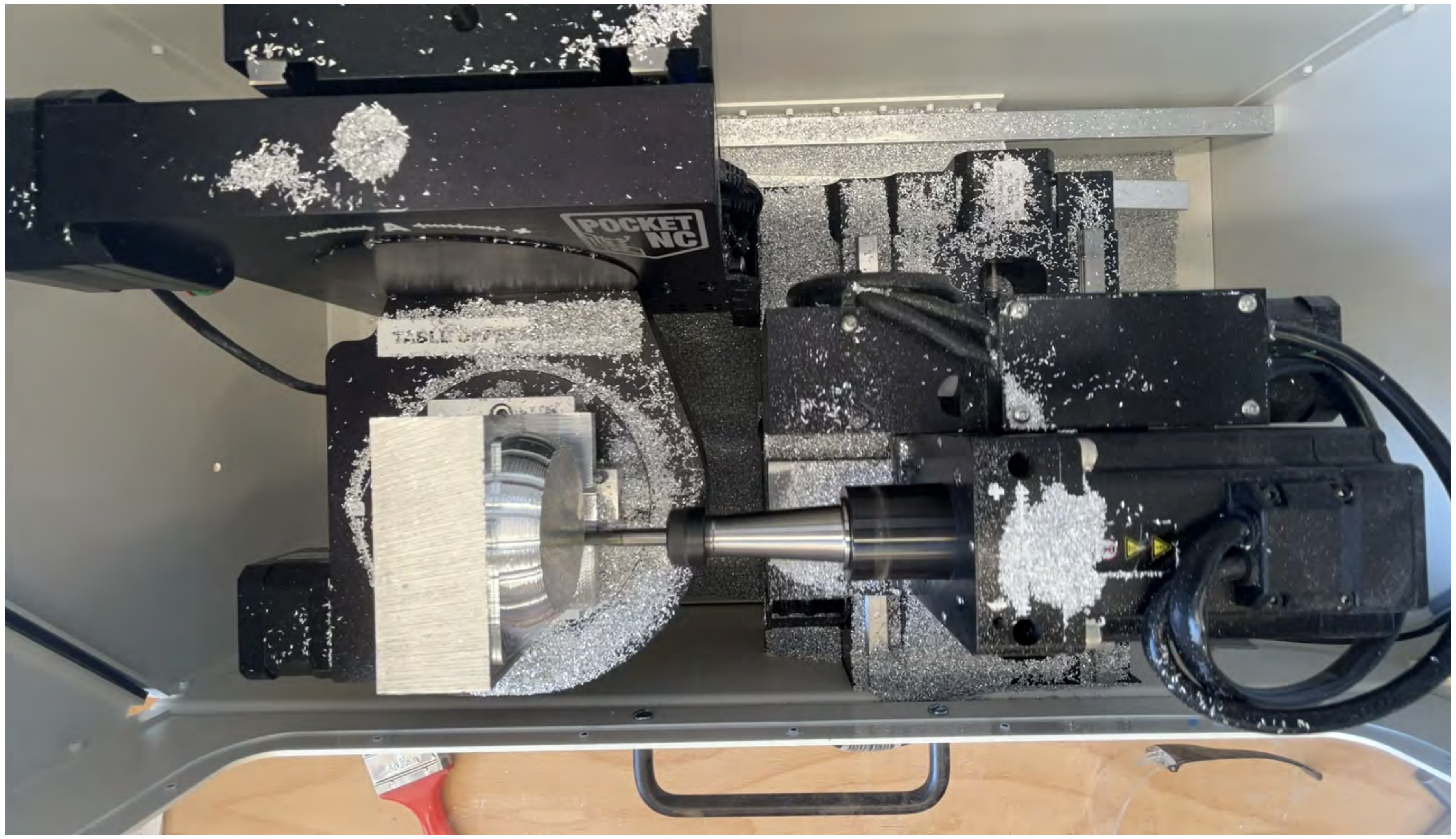
Simple Circuit Diagram



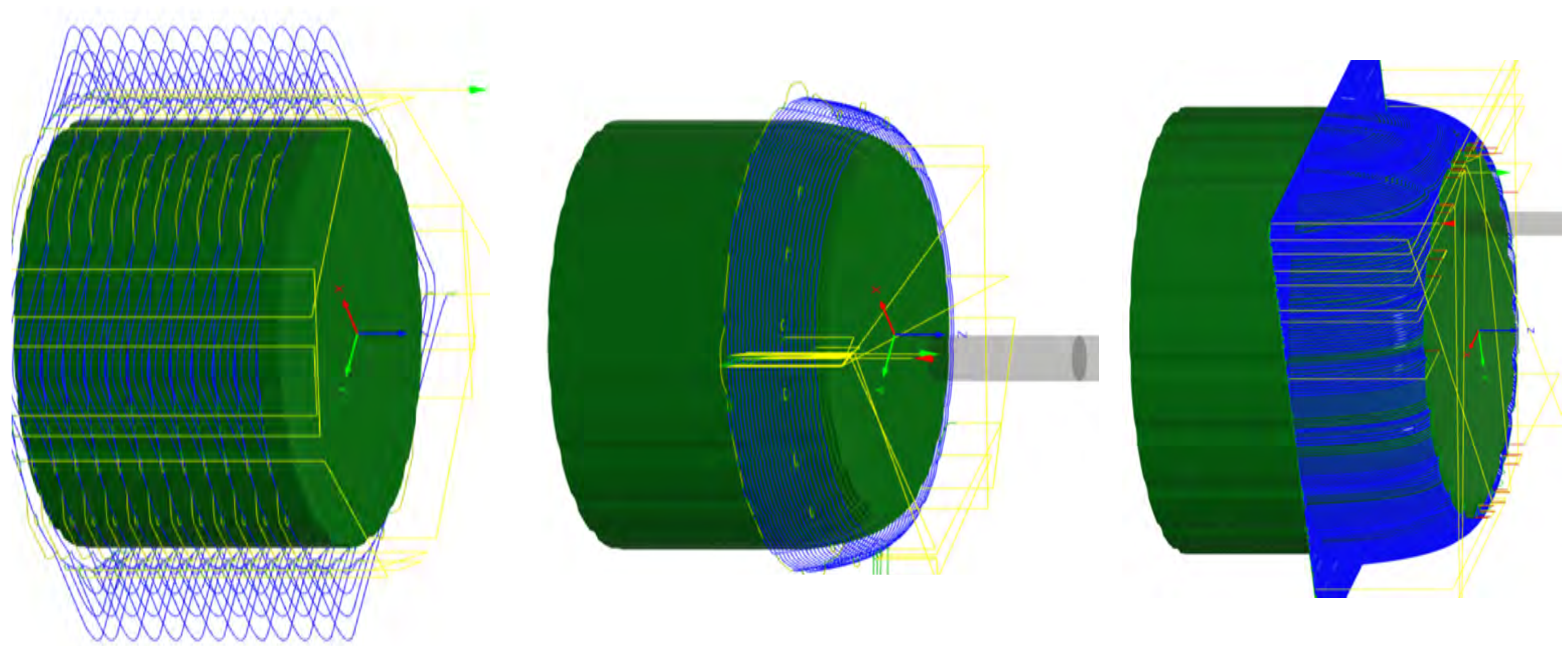
Design for Manufacturing and Assembly

Physical Machining

Using the Pocket NC V2-10 5 Axis CNC mill to machine out the dial. Came in from both sides as the 6mm flat end milling bit was not long enough to do it in 1 pass. Small issues with the machining due to the lack of probing function which meant that we had to manually line it up in the vice which led it to be off center.

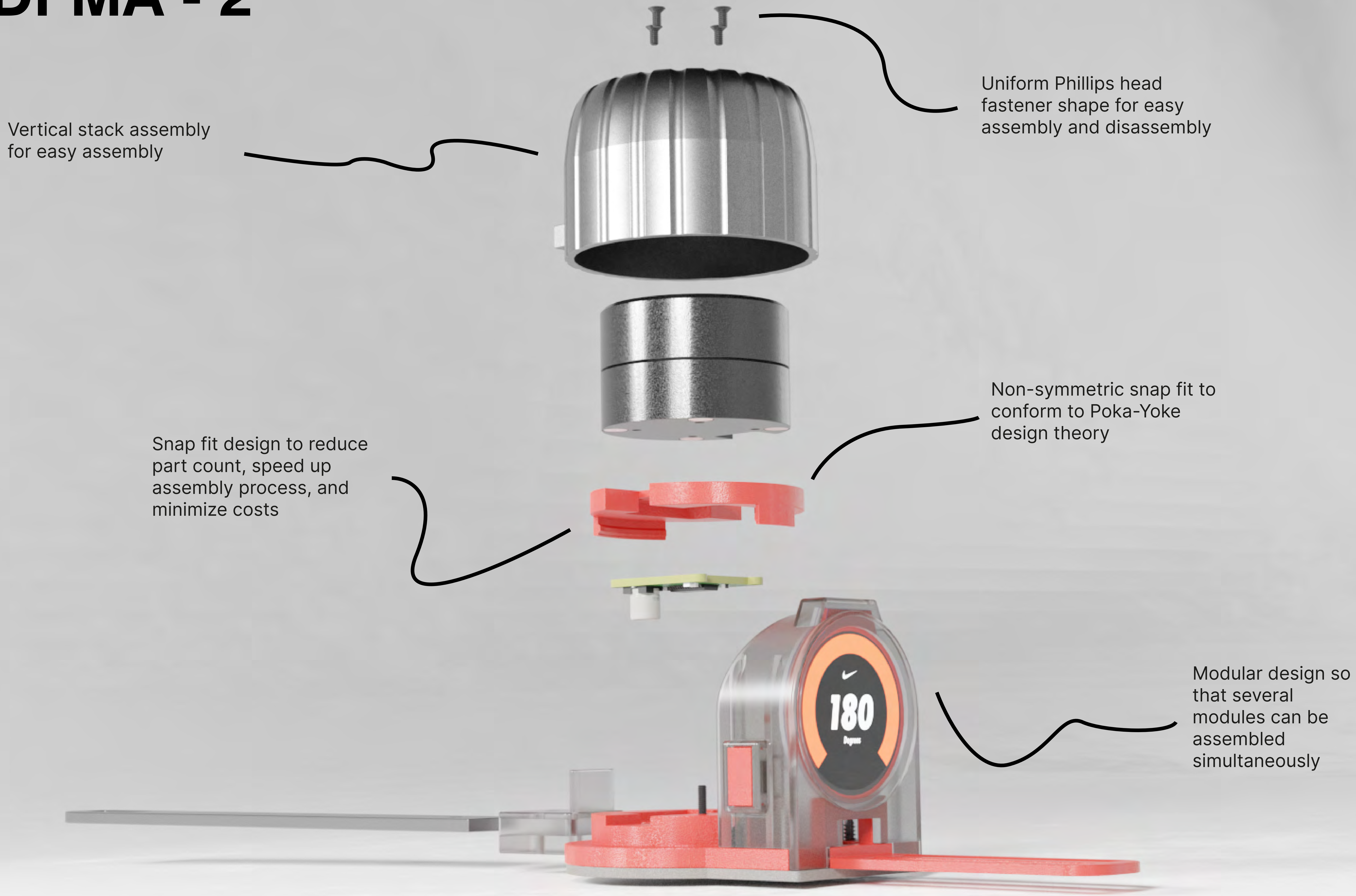


CAM Machining



To machine the dial machine paths were created inside Fusion 360 Manufacturing. A total of 8 different pathings were created to achieve the final shape. The machine pathing also required 1 tool bit change to get the smaller holes. As we need the vice to hold it all the way through, we needed to cut it off its base at the end to get the dial.

DFMA - 2


Uniform Phillips head fastener shape for easy assembly and disassembly
Vertical stack assembly for easy assembly
Non-symmetric snap fit to conform to Poka-Yoke design theory
Snap fit design to reduce part count, speed up assembly process, and minimize costs
180
Modular design so that several modules can be assembled simultaneously

Branding

Collaborations
Michael Jordan (Air Jordan), Serena Williams, Virgil Abloh (Off-White), and Travis Scott.

Vision
To remain the leading global sports brand, inspiring and serving athletes of all levels.

Positioning Strategy
Combines sports, fashion, and culture to create a lifestyle brand beyond just athletic gear.

Purpose
Empowering athletes and individuals to achieve their full potential.

JUST
DO
IT

Slogan
Reflects Nike's brand essence of determination, inspiration, and achievement.

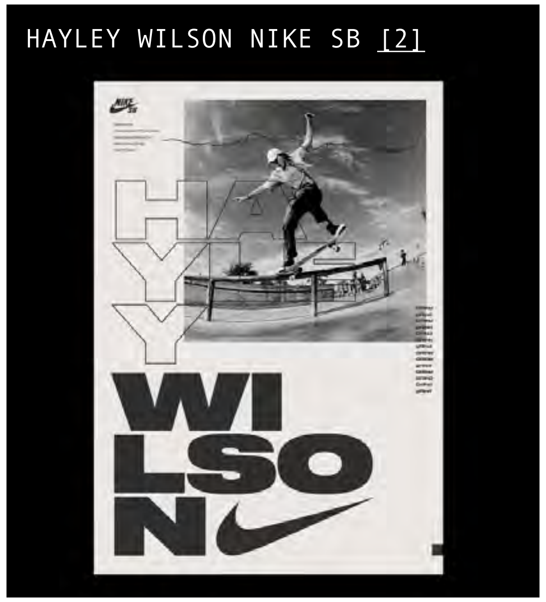
Core Competencies
Product innovation and technological advancements in sportswear and athletic equipment.

Logo
Emphasizes athleticism, innovation, and motivation.

Visual Identity
Recognisable worldwide brand known for its iconic "swoosh" logo.

Branding - 2

YANKO DESIGN APPLE WATCH X NIKE CONCEPT [1]



HAYLEY WILSON NIKE SB [2]


SUPREME X NIKE DUNK LOW [3]

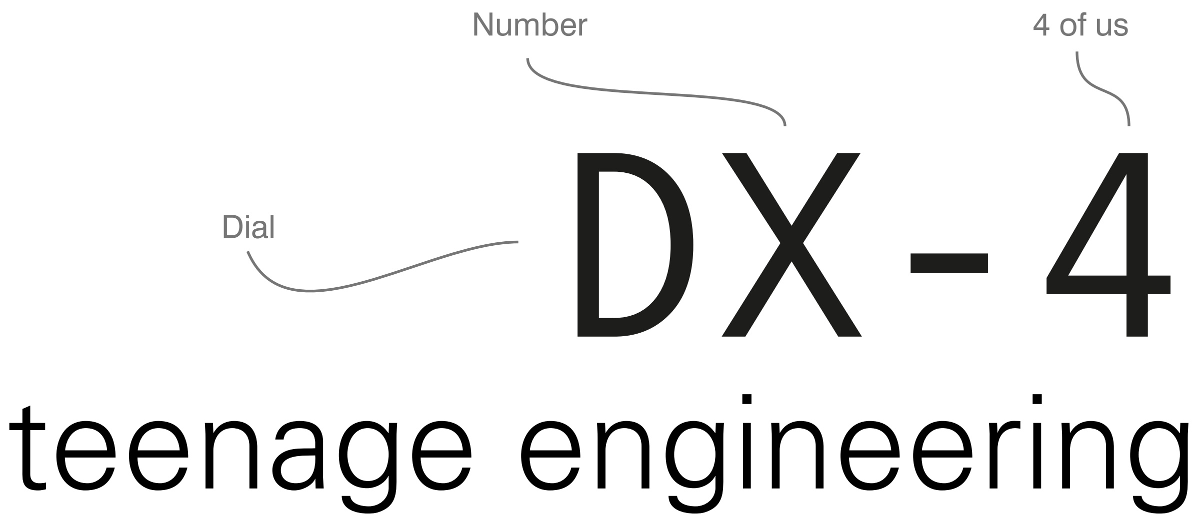
HRVOJE GRUBISIC, NIKE AIR MAX 97 – SATELLITE CULTURE [4]

Product Design Language

← These are Nike collaborations, athletes or concept designs. The case design we used as inspiration for our packaging design, with bold Nike colours used in their apple watch designs. The rest of the branding (portfolio, back of packaging and renders) is inspired by previous posters and skate fashion.

Product Design Language

↓ These are Teenage Engineering products with their unique product naming system: OP-1, TP-7 and TX-6. Our product name takes inspiration from this naming system and their design language: DX-4.



Dyson School of Design Engineering

/ Projects / Nike /23

Nike

Recover Stronger, Perform Better

How might we engagingly track progress in range of motion post ACL surgery?

/ Project: IDE / Team: 15 / Design Engineering

Product Assembly Process System Diagram

15 seconds | 15 seconds | 15 seconds | 15 seconds | 15 seconds

Dial Module

Fasten the top motor driver casing to the motor and then fasten the machined dial onto the motor
- **Time per Task:** 30 seconds
- **# of People Required:** 2
- **Required Tools & Extras:** Electric Screwdriver, M2 x5mm bolt

Solder the 10 wire terminals on the motor driver board to the necessary wires
- **Time per Task:** 60 seconds
- **# of People Required:** 4
- **Required Tools & Extras:** Soldering Iron, Solder, Flux

Add FOCMini into the casing, pass wires through casing and fasten the bottom casing into place
- **Time per Task:** 30 seconds
- **# of People Required:** 2
- **Required Tools & Extras:** None

Assemble screen assembly to bottom casing by screwing it in and ensuring cables are passed through the slots
- **Time per Task:** 60 seconds
- **# of People Required:** 4
- **Required Tools & Extras:** Electric Screwdriver, 2.2 x 12 mm screw

Solder the 20 wires coming out of screen housing to the 20 pin female IDC connector
- **Time per Task:** 120 seconds
- **# of People Required:** 8
- **Required Tools & Extras:** Soldering Iron, Solder, Flux

Stick the foam base pad onto the bottom of the motor driver casing
- **Time per Task:** 15 seconds
- **# of People Required:** 1
- **Required Tools & Extras:** None

Finished Dial Module

26 people @ $7/hr @ 75 seconds = $3.79 per product

Screen Module

Glue the round glass watch face to the screen housing
- **Time per Task:** 15 seconds
- **# of People Required:** 1
- **Required Tools & Extras:** Glue

Solder and heat shrink 2 wires to the button
- **Time per Task:** 30 seconds
- **# of People Required:** 2
- **Required Tools & Extras:** Soldering Iron, Solder, Flux, Heatshrink

Assemble the screen module by putting the screen and the button in the casing and pass the wires through the slots
- **Time per Task:** 60 seconds
- **# of People Required:** 4
- **Required Tools & Extras:** None

Shin Extension Module

Sew the thin velcro strip to the shin extension
- **Time per Task:** 15 seconds
- **# of People Required:** 1
- **Required Tools & Extras:** Sewing Maching

Screw the thumb screw into the shin extension connector and shin extension to fix it in place
- **Time per Task:** 15 seconds
- **# of People Required:** 1
- **Required Tools & Extras:** None

Finished Shin Extension Module

2 people @ $7/hr @ 30 seconds = $0.12 per product

Battery Module

Glue the male IDC 20 Pin connector into the battery case
- **Time per Task:** 15 seconds
- **# of People Required:** 1
- **Required Tools & Extras:** Glue

Install the battery, BMS, and Switch module into the battery case
- **Time per Task:** 30 seconds
- **# of People Required:** 2
- **Required Tools & Extras:** None

Solder the male 20 IDC pin connectors to the ESP-32 and the battery ports
- **Time per Task:** 120 seconds
- **# of People Required:** 8
- **Required Tools & Extras:** Soldering Iron, Solder, Flux

Fasten the top battery casing down into the bottom battery casing
- **Time per Task:** 30 seconds
- **# of People Required:** 2
- **Required Tools & Extras:** Electric Screw Driver, 2.2 mm self Tapping Screws

Finished Battery Module

13 people @ $7/hr @ 60 seconds = $1.52 per product

Product Compliance

We put the relevant product regulations and standards for the UK and EU on the label of the packaging. The packaging itself is made of polycarbonate and paperboard which are both fully recyclable after use, rendering the packaging fully sustainable and compliant with regulations.

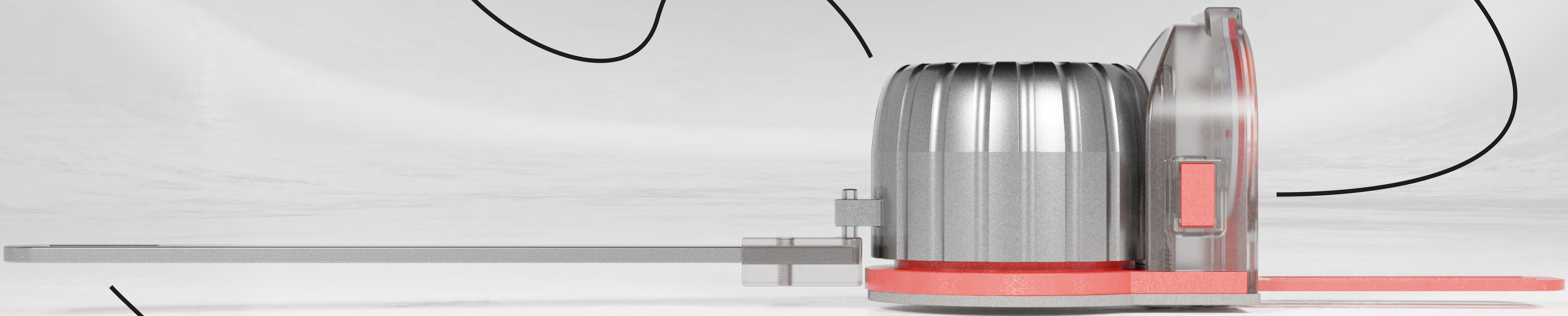
Product Labelling

Dial

→ The machined aluminium dial is the main connecting point between the motor and encoder with the rest of the device. It acts as a shield to protect the user from directly interacting with the motor and electronic components.

Button

↓ The button is used to change the resistance levels for the training program.



Lower Arm

↑ The lower arm is used to attach the dial to the calf using two velcro straps at the top of the arm (close to the dial) and at the bottom of the arm. We chose to make the lower arm out of aluminum because it is light weight, strong, flexible, and looks good.

Upper Arm

↑ The upper arm is used to attach the main device housing to the thigh with a thick cushioned velcro strap. The thicker velcro strap was chosen on thins arm due to the importance of the upper anchor point on the leg.

Product Labelling

The screen is a UI that displays the angle of the knee. The button on the side of the screen casing changes the resistance level of the device. To demonstrate the resistance change, the colour of the arc changes to green, yellow and red. In addition, the coloured arc around the perimeter of the dial moves around to visually demonstrate the achieved range of motion.

User Guide

Calibration

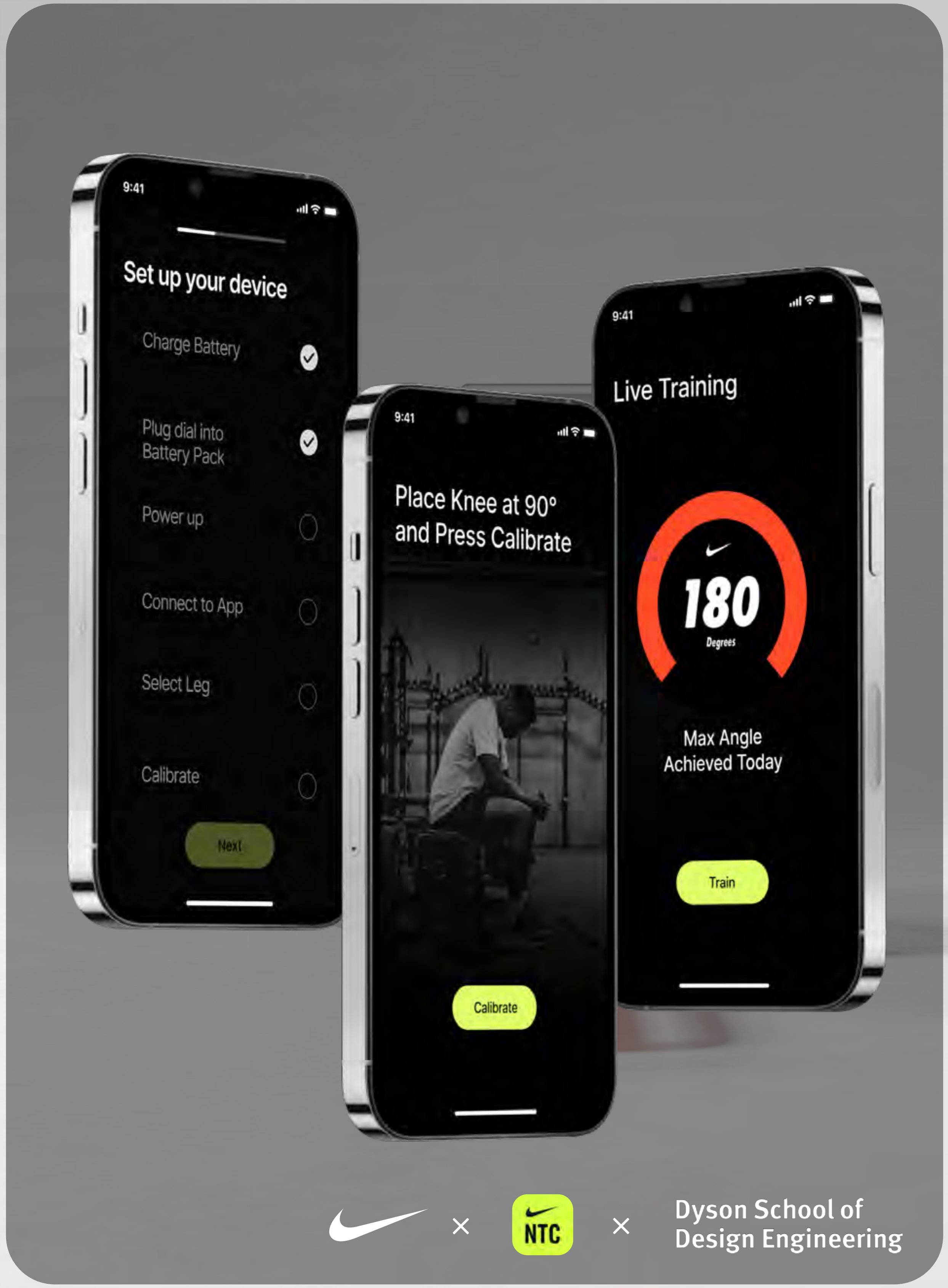
The device is designed to come calibrated straight out of the box. However, the positioning at which each user will most comfortably attach the straps may vary. As such for those users who wish to ensure maximum accuracy, they have the option to calibrate the device with the app. This involves using a known 90 degree angle and pressing calibrate on the Nike Training Club app.

Set-up

Basic set up involves charging the battery and connection to the app via the bluetooth module in the ESP 32. The User then has the ability to select which leg they will be training (left or right.) A few other basic questions are also asked such as sex, height and date of surgery.

Training

During training, the current angle achieved by the user will be displayed on the app as well as the maximum angle achieved that day for that resistance level. Once training for the day is complete, the user will be able to access graphs indication progress in range of motion



Product Packaging Design

Frosted Polycarbonate Upper Housing

↓ We opted for a polycarbonate housing design for the upper half, enabling customers to see the product inside the packaging, generating interest and curiosity. Also, it provides a sleek and modern aesthetic, enhancing the perceived value of the product whilst maintaining durable protection.

Labelling

← We placed a large logo of the product name on the back for a simple, elegant design whilst being informative with the product slogan "ACL Rehabilitation Device" for ease of understanding. Above the Nike Training Club Logo, whom we are partnering with for an app integration, is a short description for guidance - referring to the app for more information and urging safe usage.

Collaboration Logos

→ On the top of the packaging are both logos in the collaboration, above the battery due to its contrasting background.

Paperboard Lower Housing

↑ Paperboard was chosen as the material for the lower housing, with a lithographically printed wireframe below the label.

Packaging Render

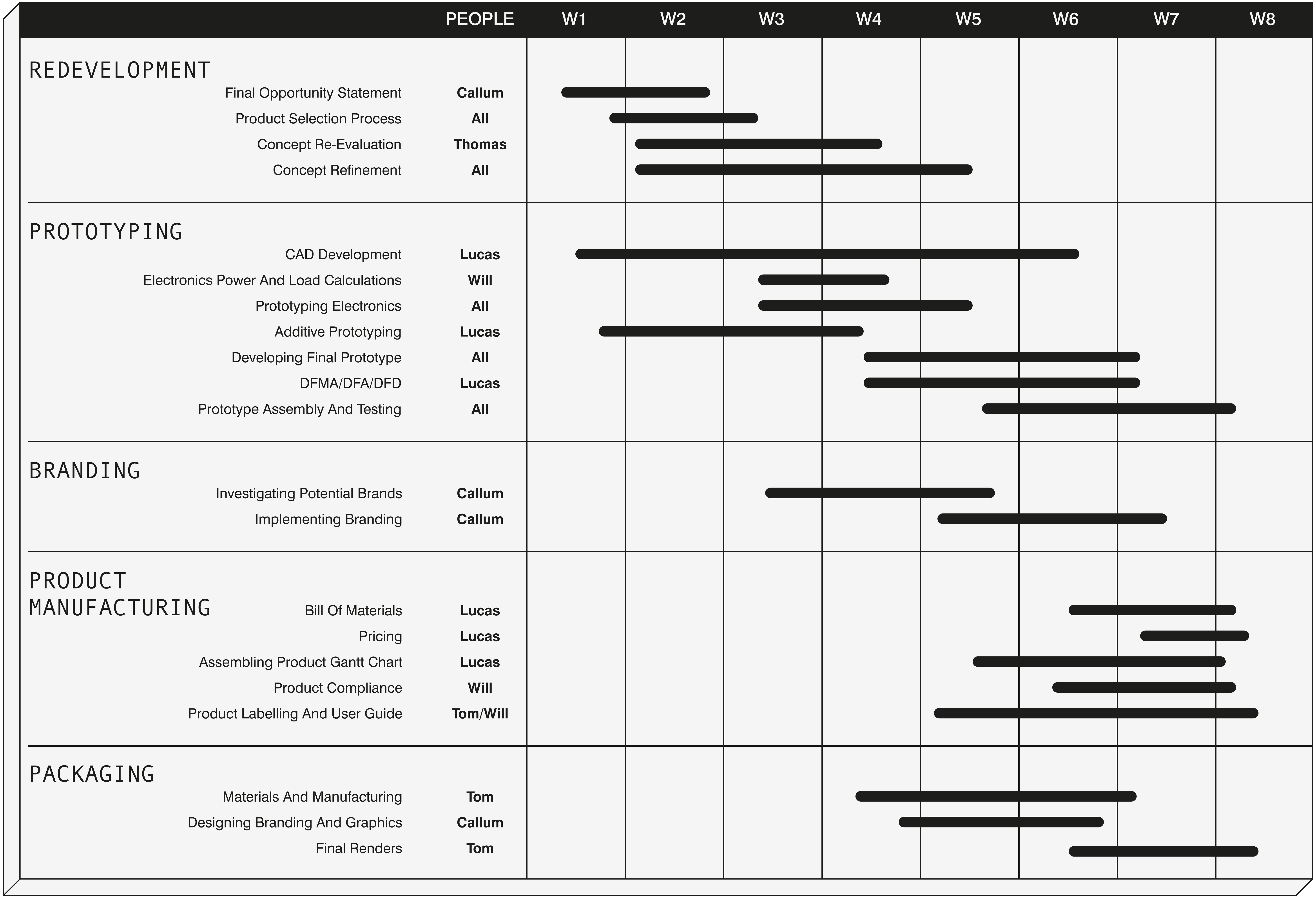
The rendered packaging with the products inside. The frosted polycarbonate creates a turntable like appearance, with the DX-4 logo on the side for an eye-level view, ideal for in-store retail. The upper casing has a snap-fit design into the lower lithographic paperboard

Final Design - Render

https://youtu.be/T4XsXyOQoug | Link to product Video

Final Design - Physical Product

Gantt Chart


PEOPLE
W1
W2
W3
W4
W5
W6
W7
W8
REDEVELOPMENT
Final Opportunity Statement
Callum
Product Selection Process
All
Concept Re-Evaluation
Thomas
Concept Refinement
All
PROTOTYPING
CAD Development
Lucas
Electronics Power And Load Calculations
Will
Prototyping Electronics
All
Additive Prototyping
Lucas
Developing Final Prototype
All
DFMA/DFA/DFD
Lucas
Prototype Assembly And Testing
All
BRANDING
Investigating Potential Brands
Callum
Implementing Branding
Callum
PRODUCT MANUFACTURING
Bill Of Materials
Lucas
Pricing
Lucas
Assembling Product Gantt Chart
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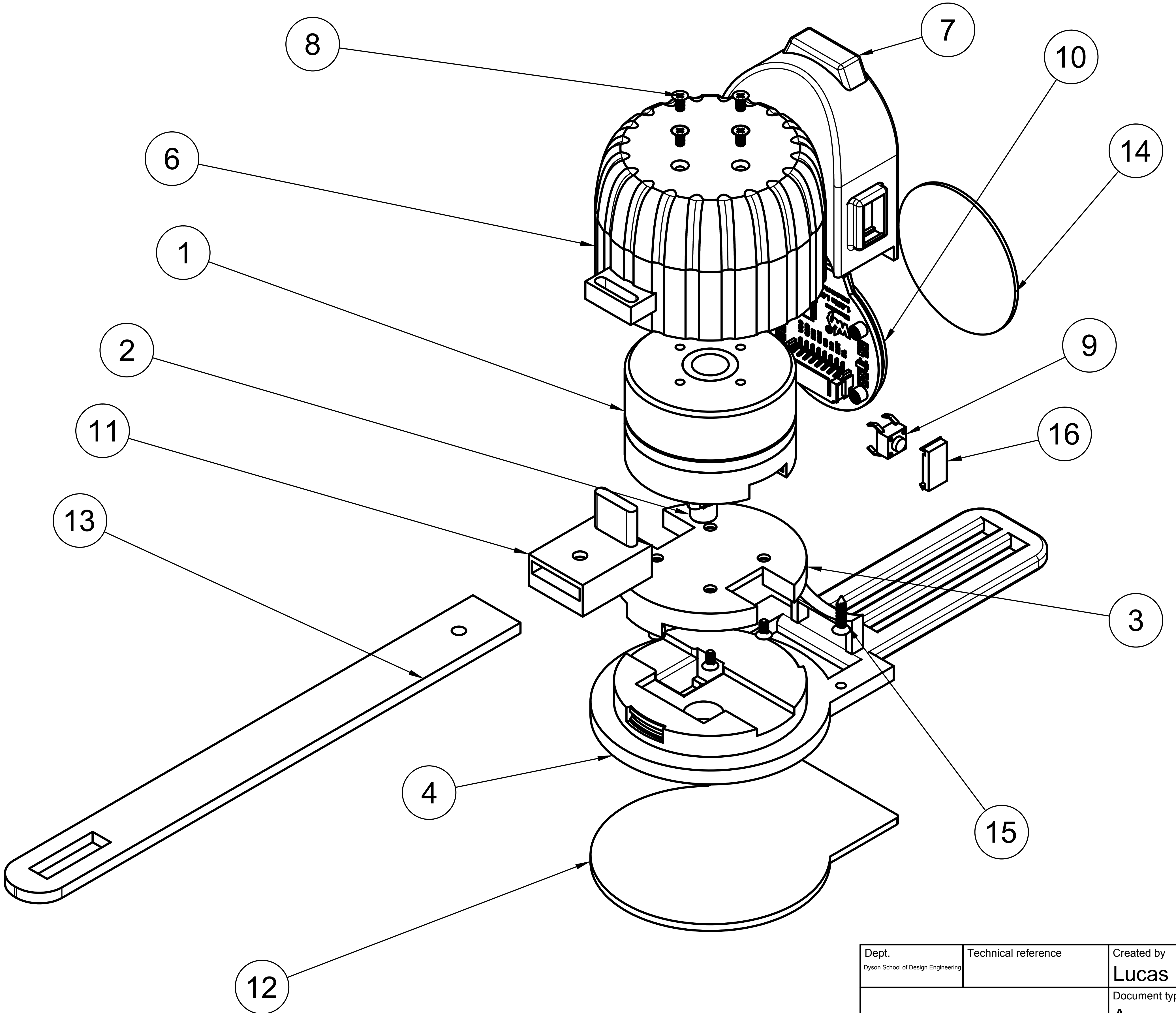
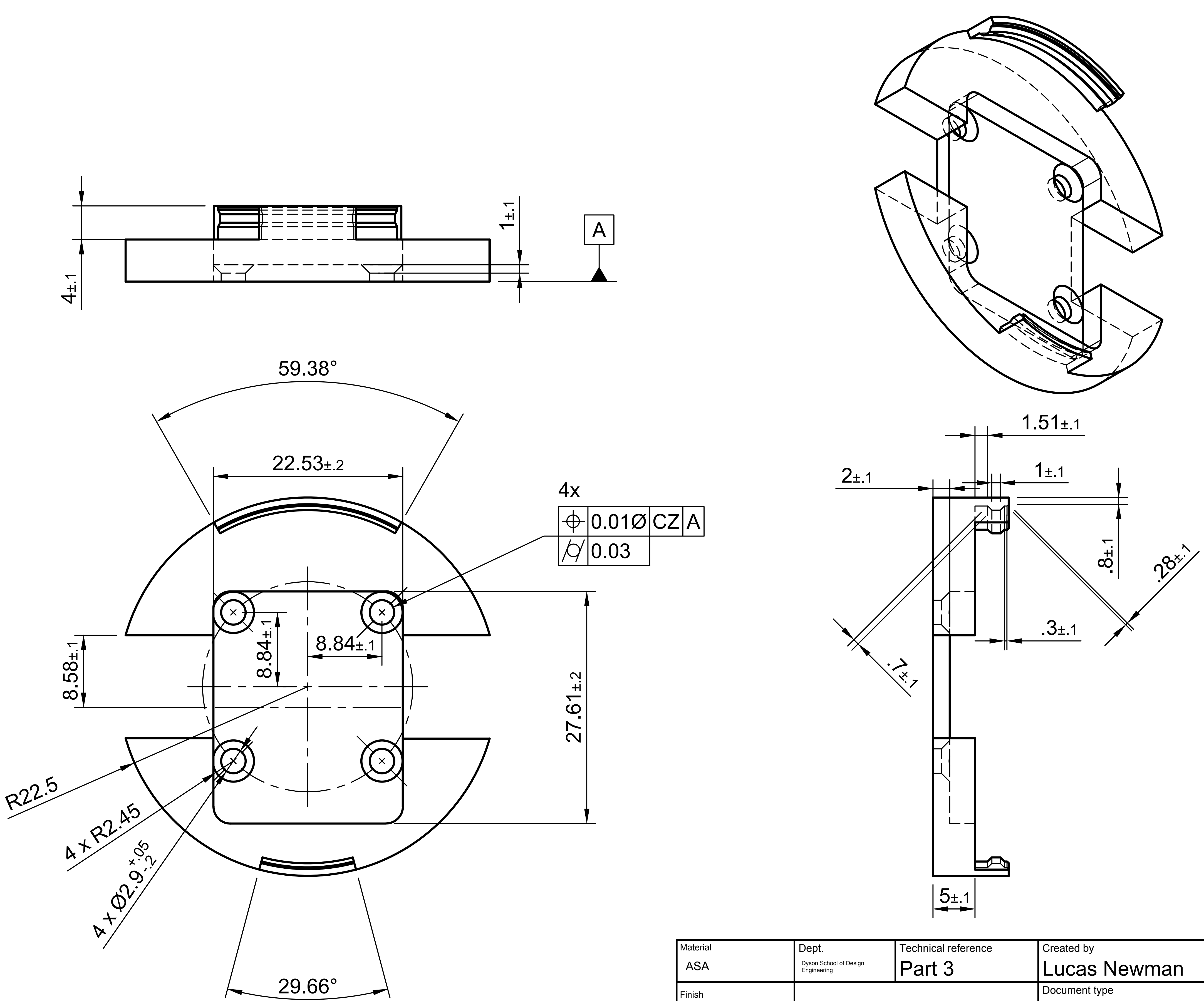
Callum
Final Renders
Tom



Parts List			
Item	Qty	Part Name	Material
1	1	GM3506 Motor with Encoder v1	
2	1	FOCmini_1 v1	Steel
3	1	Top Motor Driver Housing	ABS Plastic
4	1	Bottom Motor Driver Housing	Polyethylene, Low Density
6	1	Exterior Dial	Aluminum 6061
7	1	Screen Housing	ABS Plastic
8	1	M2 x 4mm Bolt (1)	Steel
9	1	Button v1	Steel
10	1	Waveshare 1.28in Round Display v1	Steel
11	1	Shin Extension Connector	ABS Plastic
12	1	Foam Base	Steel
13	1	Shin Extension	Aluminum 6061
14	1	Glass Watch Face	Glass
15	1	2.2 x 12mm Screw (1)	Steel
16	1	Button Cover	ABS Plastic

Dept.	Technical reference	Created by	Approved by
Dyson School of Design Engineering		Lucas Newman 6/21/23	
		Document type: Assembly	Document status: Final
		Title: Full Device Assembly	DWG No.: ASM_1
			Rev.: 04 / Scale: 1:1 / Sheet: 1/1



NOTES UNLESS OTHERWISE SPECIFIED:

1. **ALL UNITS ARE IN MM**
2. **SURFACE ROUGHNESS Ra 3.2 um OR BETTER**

Material	Dept.	Technical reference	Created by	Approved by
ASA	Dyson School of Design Engineering	Part 3	Lucas Newman 6/20/23	

Finish: As-is for all parts except specified surface finishes where polishing is applied

Drawing & Tolerence Standards

BS EN 22768-1:1993 'medium' class for all linear dimensions

BS 8888:2020 for general technical dimensioning

3rd Angle Proj.

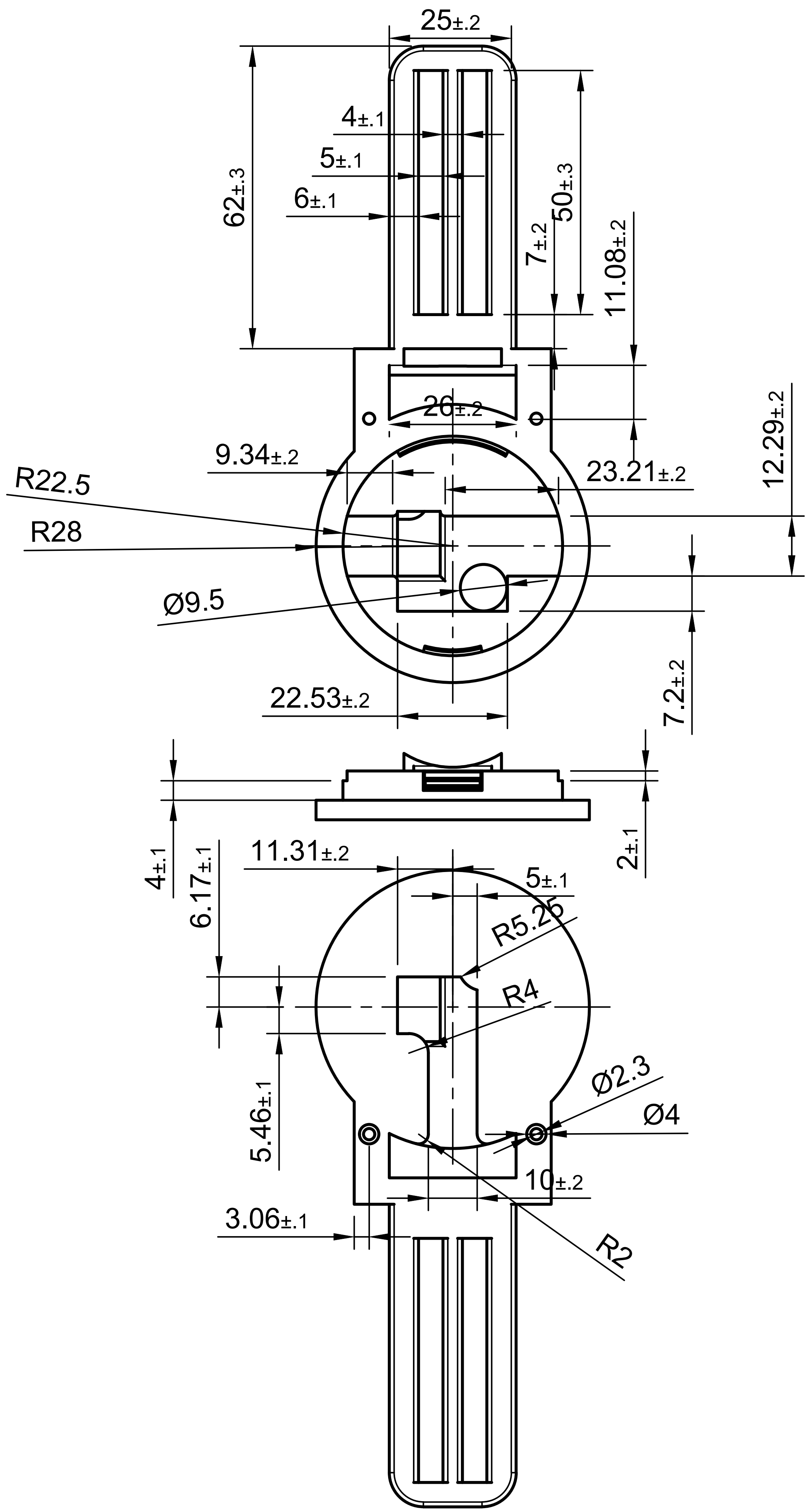
Document type: Drawing

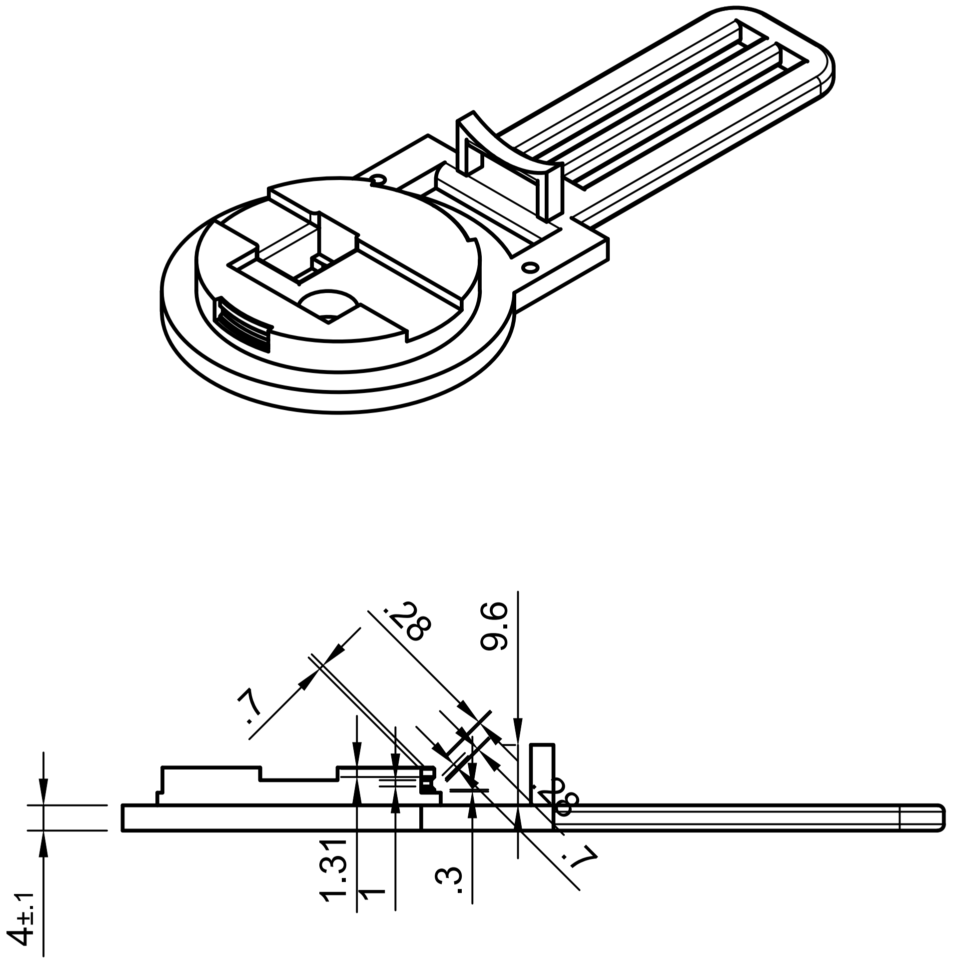
Document status: Final

Title: Top Motor Driver Housing

DWG No.: DWG_01

Rev.	Scale	Sheet
01	2:1	1/1

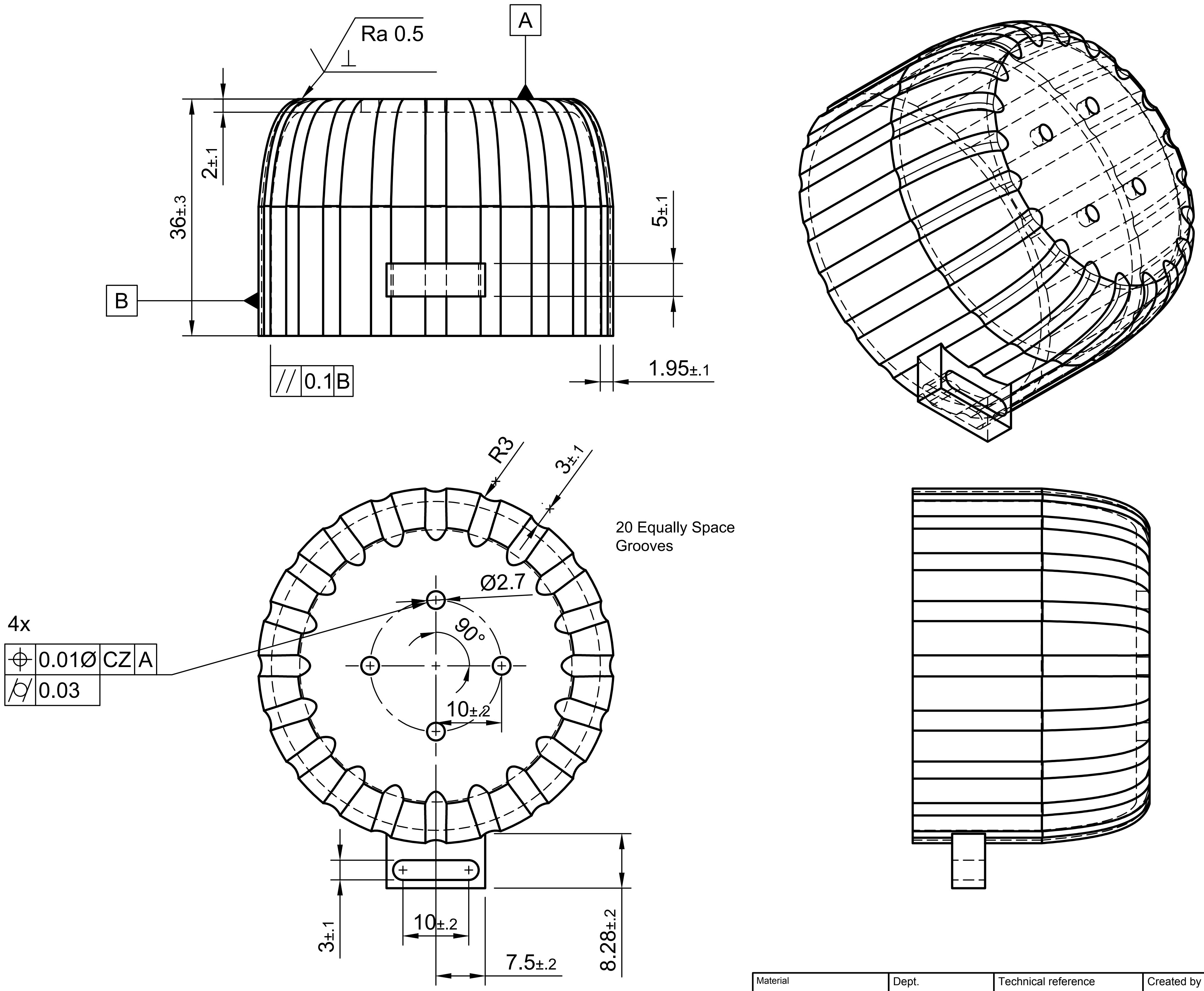




NOTES UNLESS OTHERWISE SPECIFIED:

1. **ALL UNITS ARE IN MM**
2. **SURFACE ROUGHNESS Ra 3.2 um OR BETTER**
3. **ALL FILLETS ARE 2 MM**

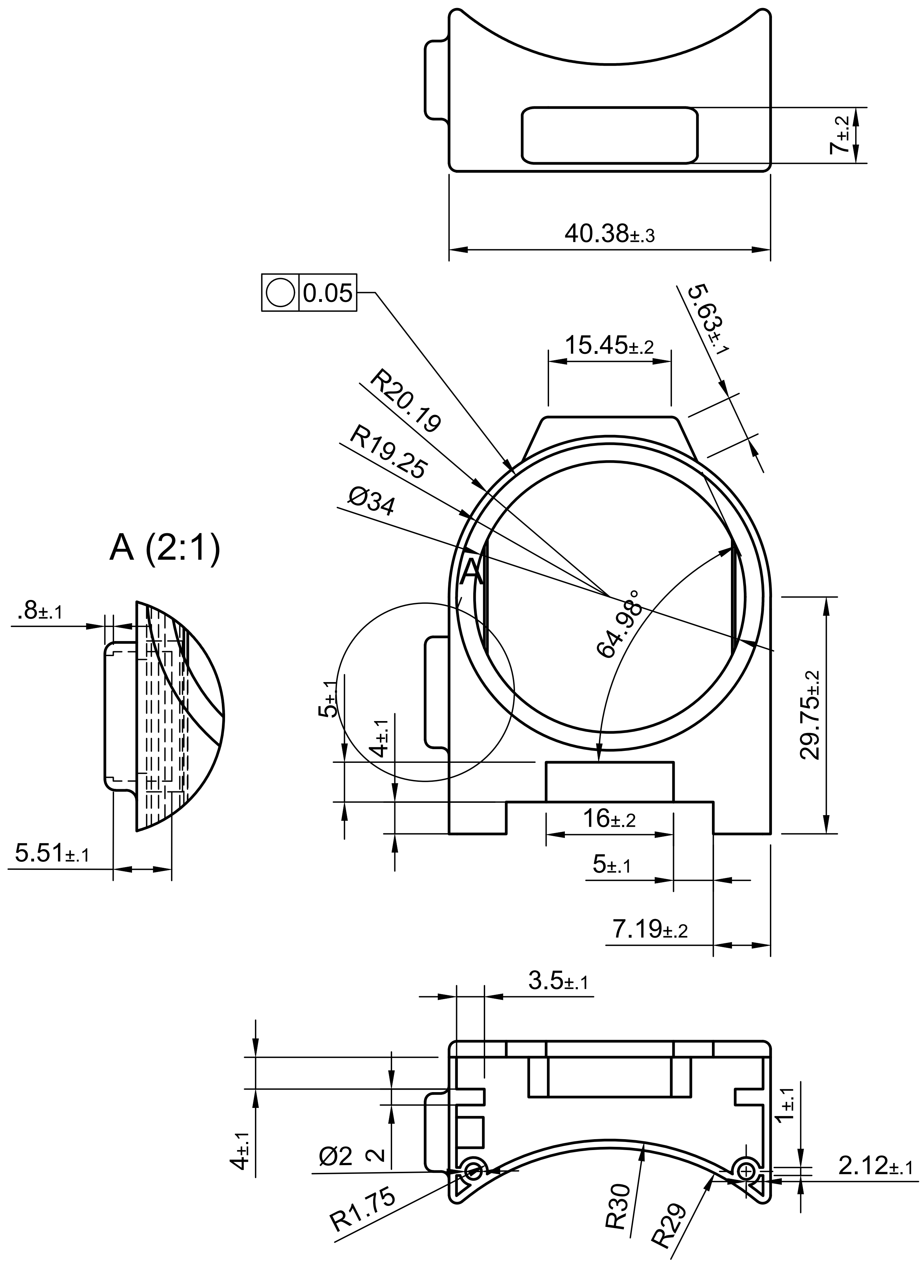
Material ASA	Dept. Dyson School of Design Engineering	Technical reference Part 4	Created by Lucas Newman 6/19/23	Approved by
As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type Drawing	Document status Final
Drawing & Tolerence Standards BS EN 22768-1:1993 'medium' class for all linear dimensions BS 8888:2020 for general technical dimensioning			Title Botom Motor Driver	DWG No. DWG_02
				Rev. 02 | Scale 1:1 | Sheet 1/1

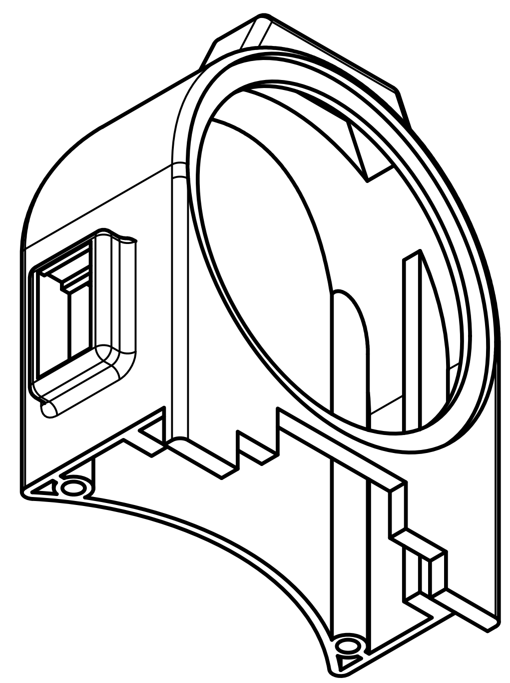


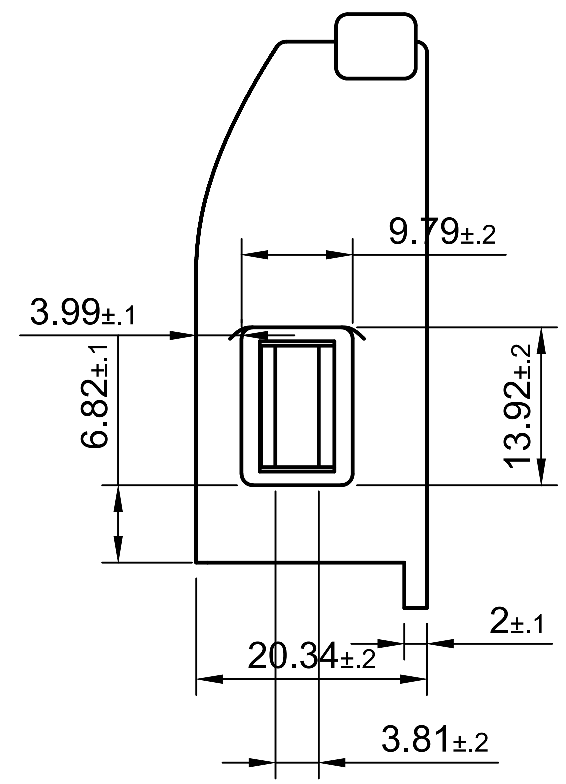
NOTES UNLESS OTHERWISE SPECIFIED:

1. **ALL UNITS ARE IN MM**
2. **SURFACE ROUGHNESS Ra 3.2 um OR BETTER**
3.

Material	Dept.	Technical reference	Created by	Approved by
Aluminum 6061	Dyson School of Design Engineering	Part. 6	Lucas Newman 6/19/23	
Finish: As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type: Drawing	Document status: Final
Drawing & Tolerence Standards: BS EN 22768-1:1993 'medium' class for all linear dimensions; BS 8888:2020 for general technical dimensioning			Title: Exterior Dal	DWG No.: DWG_3
				Rev.: 08 · Scale: 1.5:1 · Sheet: 1/1



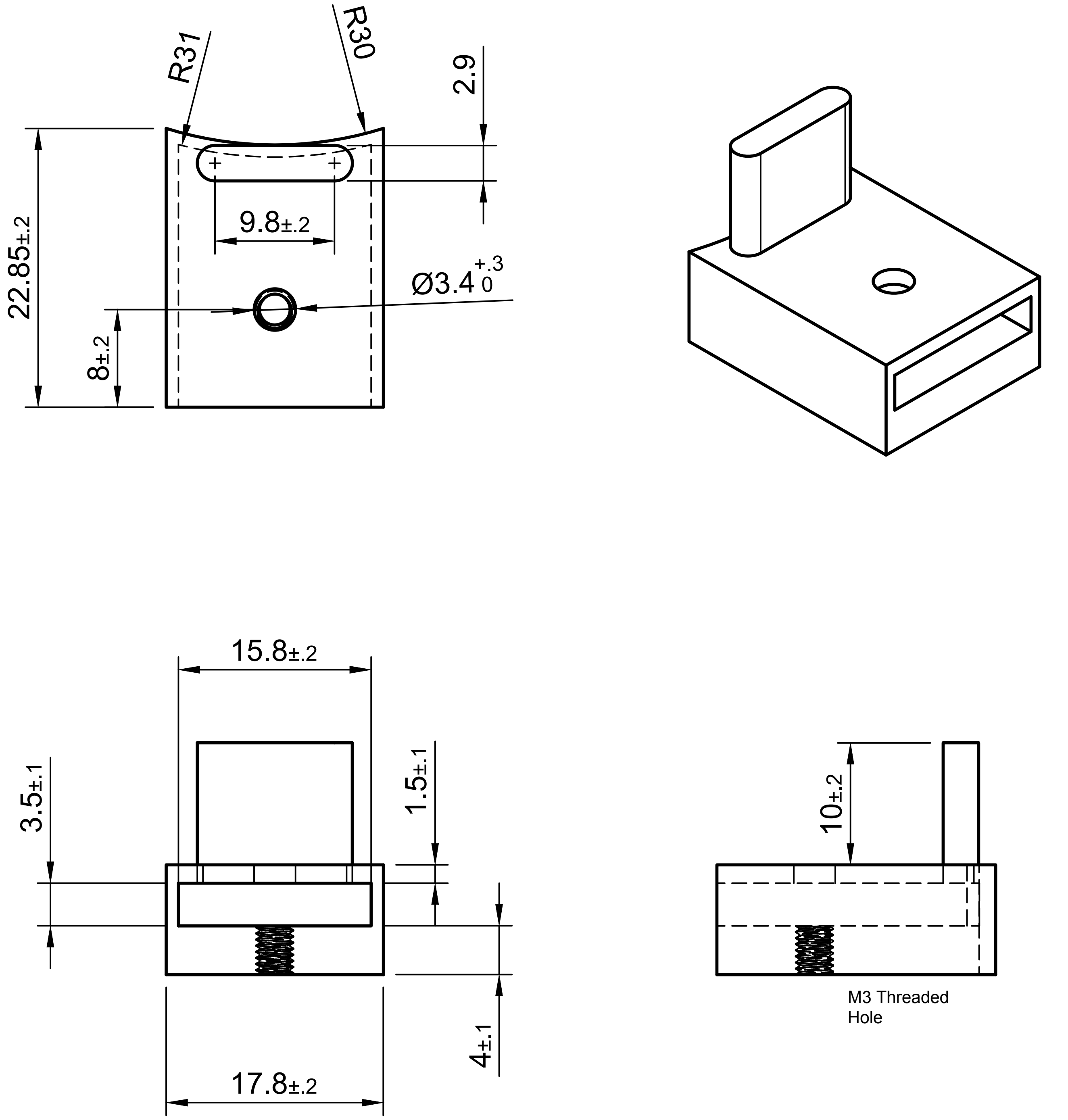




NOTES UNLESS OTHERWISE SPECIFIED:

1. **ALL UNITS ARE IN MM**
2. **SURFACE ROUGHNESS Ra 3.2 um OR BETTER**
3. **ALL UNLABELED FILLETS ARE 1 MM**

Material: ASA	Dept.: Dyson School of Design Engineering	Technical reference: Part 7	Created by: Lucas Newman 6/19/23	Approved by:
Finish: As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type: Drawing	Document status: Final
Drawing & Tolerence Standards: BS EN 22768-1:1993 'medium' class for all linear dimensions; BS 8888:2020 for general technical dimensioning			Title: Screen Housing	DWG No.: DWG_4
				Rev.: 07 / Scale: 1:1 / Sheet: 1/1



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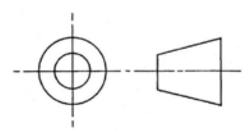
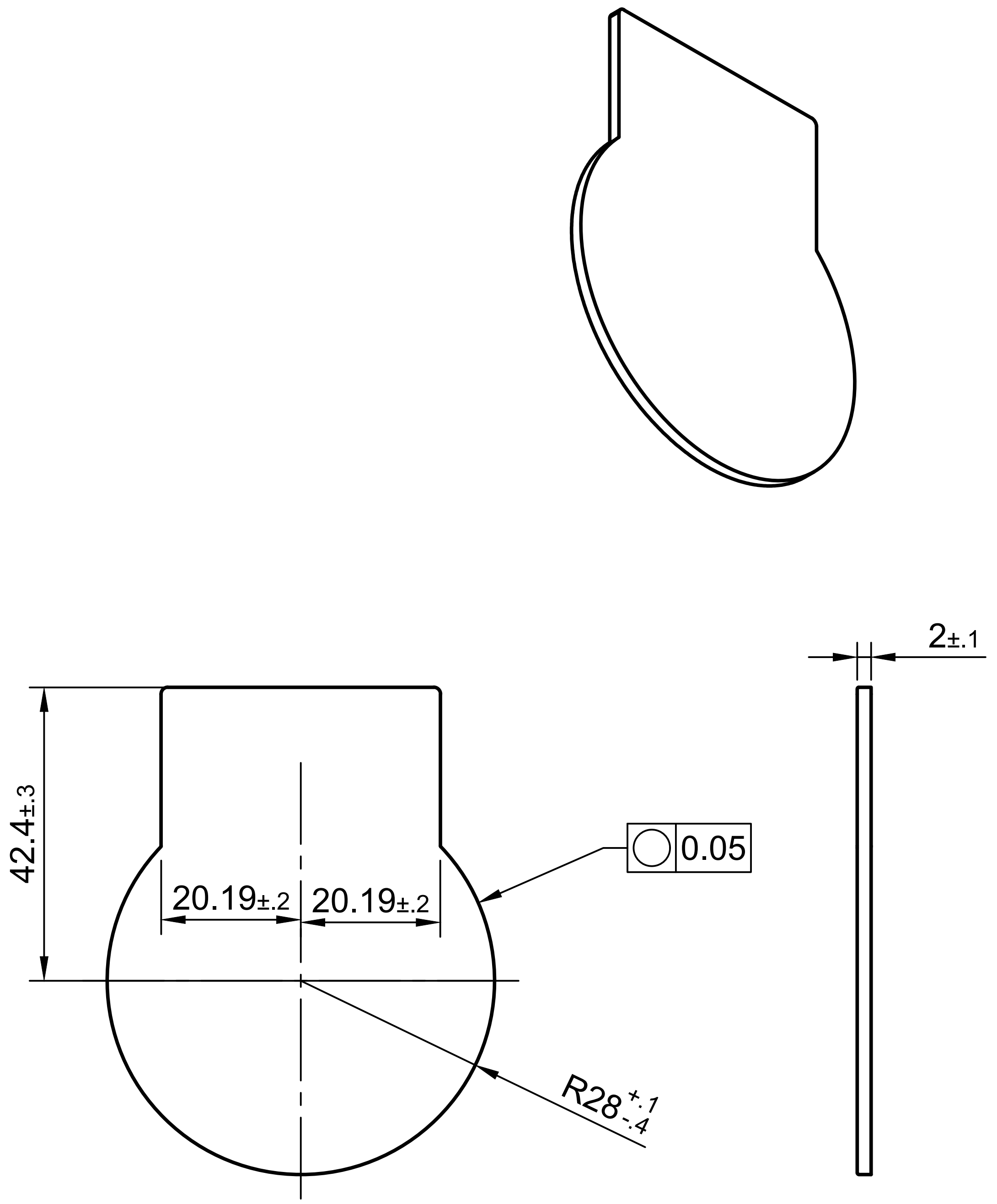
Material ASA	Dept. Dyson School of Design Engineering	Technical reference Part 11	Created by Lucas Newman 06/19/23	Approved by
Finish As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type Drawing	Document status Final
Drawing & Tolerence Standards BS EN 22768-1:1993 'medium' class for all linear dimensions BS 8888:2020 for general technical dimensioning			Title Shin Extension Connector	DWG No. DWG_05
				Rev. 01 · Scale 2:1 · Sheet 1/1





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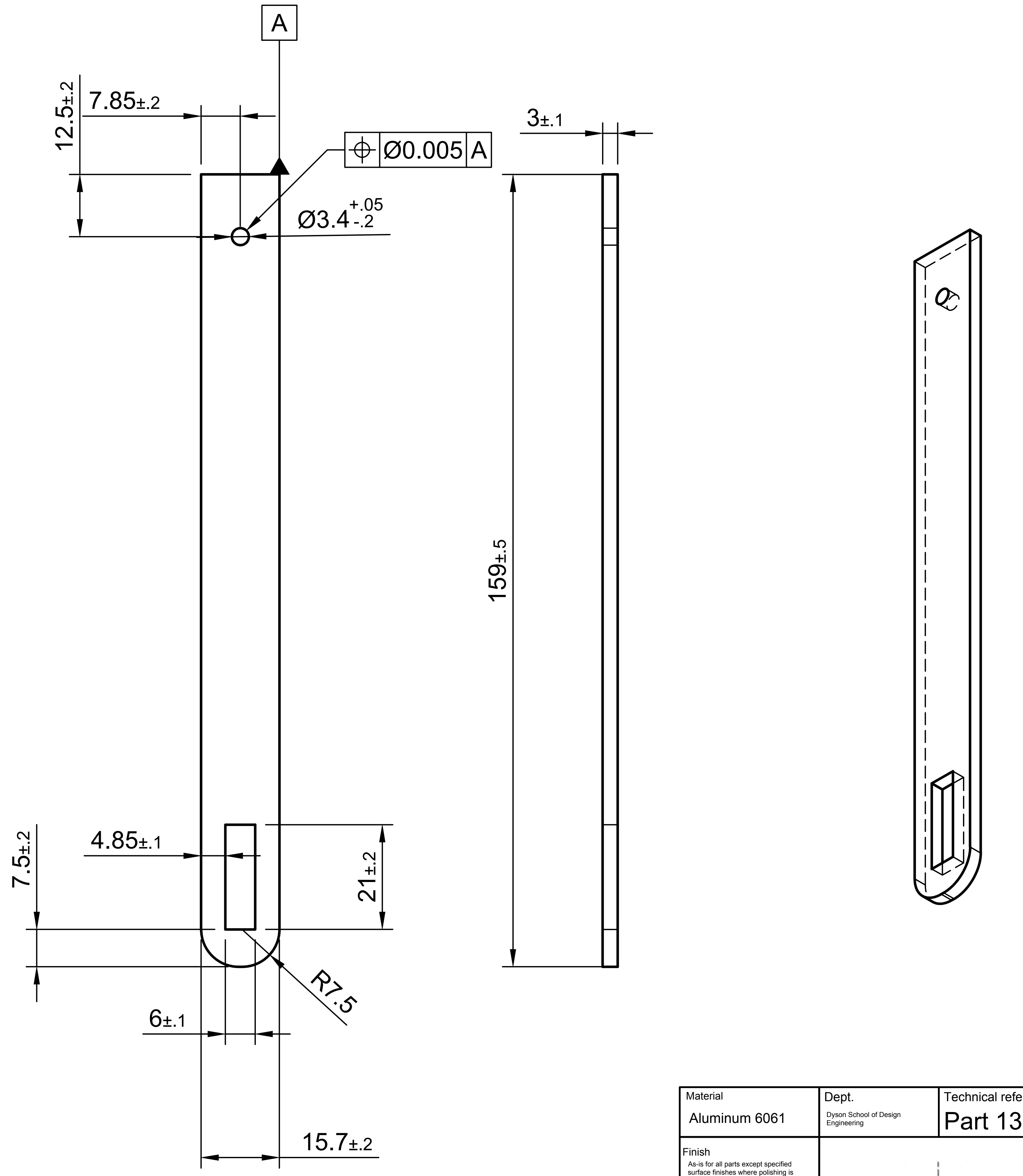
Material	Dept.	Technical reference	Created by	Approved by
Low Desnisty Polyurethane	Dyson School of Design Engineering	Part 12	Lucas Newman 6/18/23	
Finish: As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type: Drawing	Document status: Final
Drawing & Tolerence Standards: BS EN 22768-1:1993 'medium' class for all linear dimensions; BS 8888:2020 for general technical dimensioning			Title: Foam Base	DWG No.: DWG_06
				Rev.: 01 · Scale: 1:1 · Sheet: 1/1



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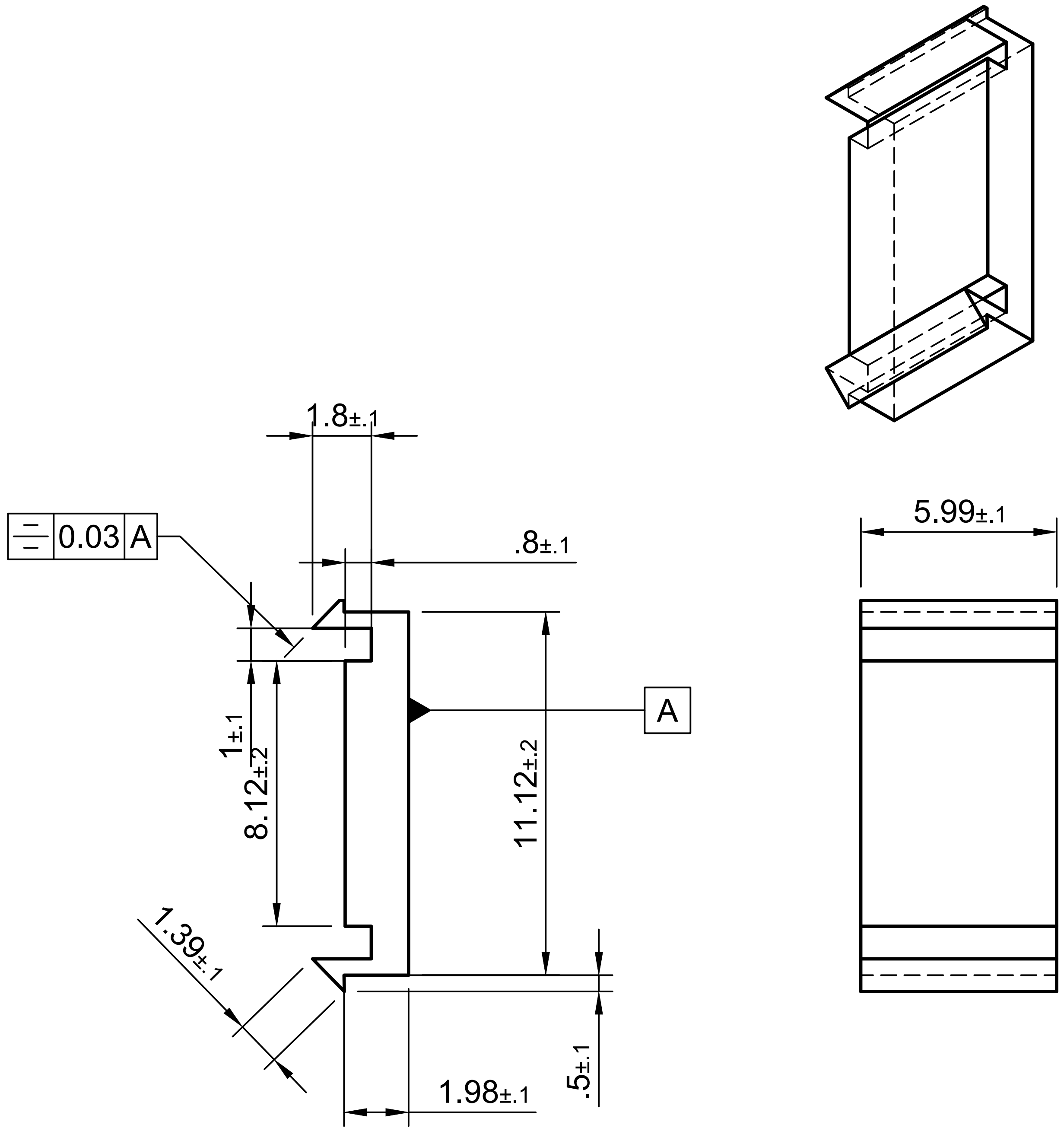
Material Aluminum 6061	Dept. Dyson School of Design Engineering	Technical reference Part 13	Created by Lucas Newman 6/19/23	Approved by
Finish As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type Drawing	Document status Final
Drawing & Tolerence Standards BS EN 22768-1:1993 'medium' class for all linear dimensions BS 8888:2020 for general technical dimensioning			Title Shin Extension	DWG No. DWG_07
				Rev. 01 / Scale 1:1 / Sheet 1/1



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2. **SURFACE ROUGHNESS Ra 3.2 um OR BETTER**

Material: ASA	Dept.: Dyson School of Design Engineering	Technical reference: Part 16	Created by: Lucas Newman 6/20/23	Approved by:
Finish: As-is for all parts except specified surface finishes where polishing is applied			Document type: Drawing	Document status: Final
Drawing & Tolerence Standards BS EN 22768-1:1993 'medium' class for all linear dimensions BS 8888:2020 for general technical dimensioning	3rd Angle Proj.		Title: Button Cover	DWG No.: DWG_08
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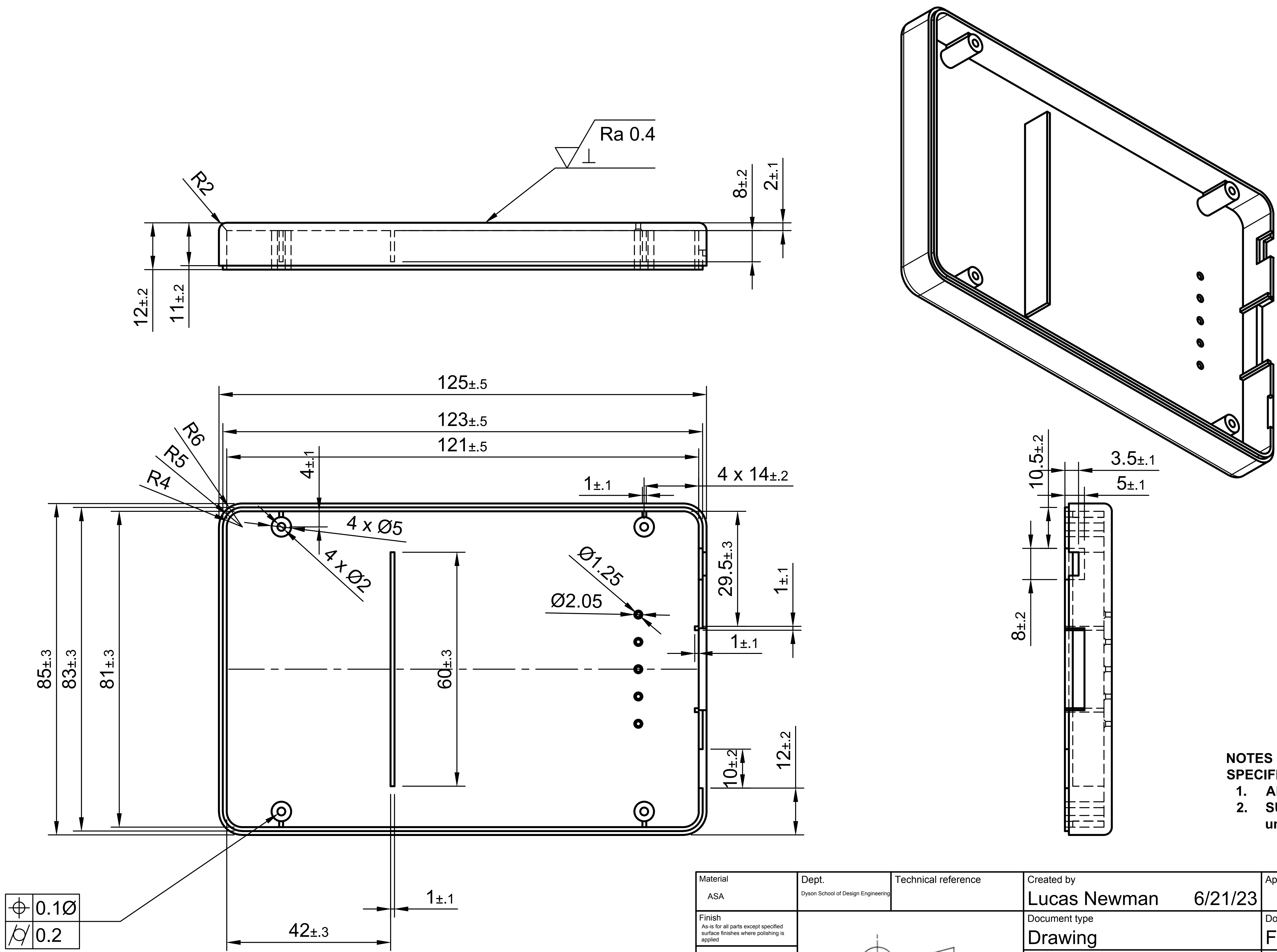

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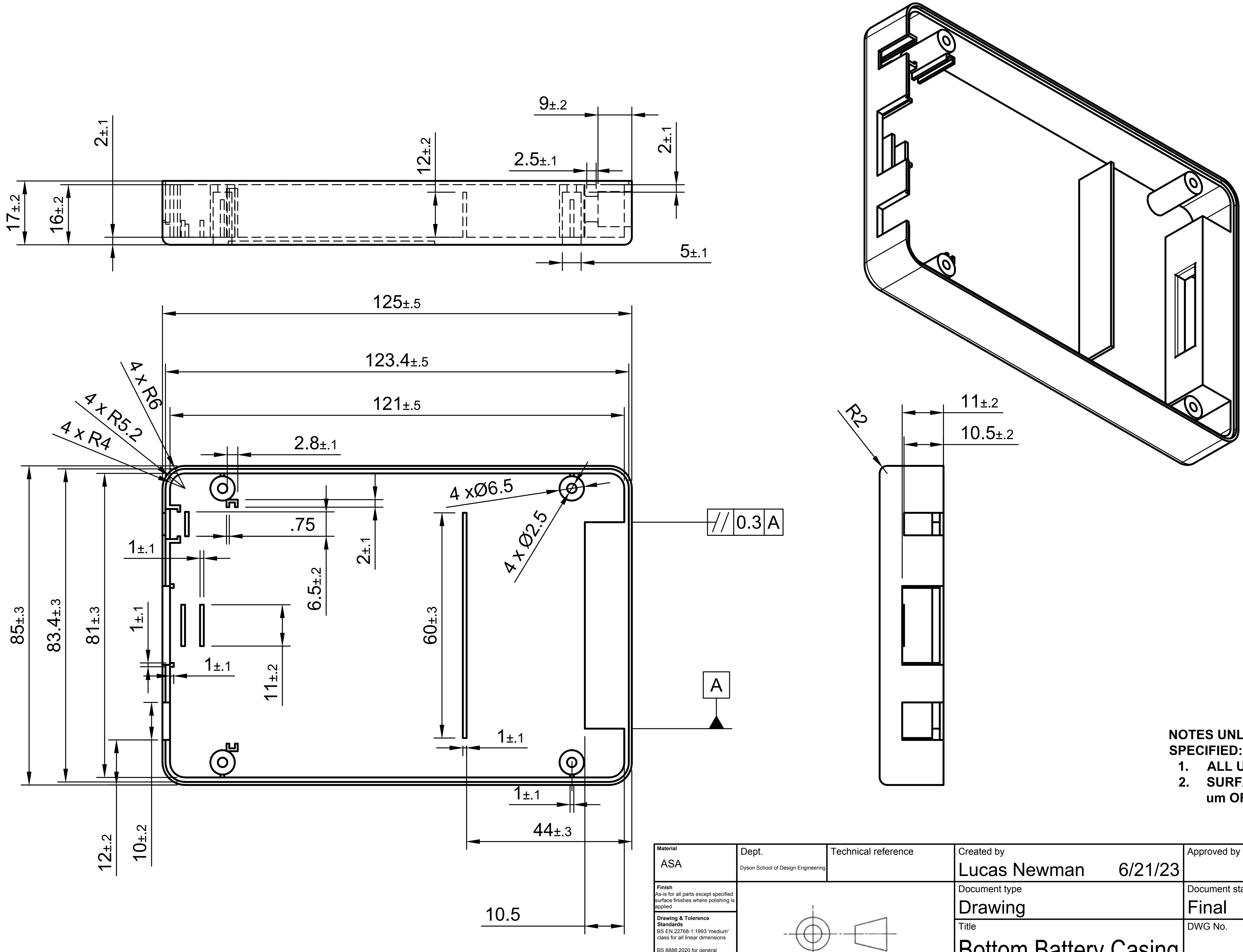
Material: ASA	Dept.: Dyson School of Design Engineering	Technical reference	Created by: Lucas Newman 6/21/23	Approved by
Finish: As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type: Drawing	Document status: Final
Drawing & Tolerence Standards: BS EN 22768-1:1993 'medium' class for all linear dimensions; BS 8888:2020 for general technical dimensioning			Title: Top Battery Casing	DWG No.: DWG_09
				Rev.: 03 · Scale: 1:1 · Sheet: 1/1



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Material	Dept.	Technical reference	Created by	Approved by
ASA	Dyson School of Design Engineering		Lucas Newman 6/21/23	
Finish As-is for all parts except specified surface finishes where polishing is applied	3rd Angle Proj.		Document type: Drawing	Document status: Final
Drawing & Tolerence Standards BS EN 22768-1:1993 'medium' class for all linear dimensions. BS 8888:2020 for general technical dimensioning			Title: Bottom Battery Casing	DWG No.: DWG_10
				Rev. 01 · Scale 1:1 · Sheet 1/1