Good job, good organisation and project management, good communication with stakeholders. Nice result. Congratulation.

Technical Aid for Cycling

-

Implement L4

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SUMMARY

Introduction

As part of the product development project module we are working on the design of a prosthesis that helps a young child, Noé, ride his bike. He doesn't have a fully functioning hand, which makes this a difficult task for him to perform. Our team needs to design a functional final prototype to help Noé do this, which includes testing and prototyping in real conditions to ensure the safety and reliability of the final product.

Our team is tasked with developing this system for Noé because he does not have any fingers on his right hand, which makes him unable to ride a bike accordingly due to his inability to grip the handlebar. The project took place over the course of one academic year and we are currently at the final phase, which is the validation and verification of the final prototype. The group has been working with APF France handicap, an association dedicated to helping handicapped people and children like Noé, who also work in collaboration with Gre-nable, a local company that specializes in creating functional prosthetics. The group has also been working in collaboration with GI's teachers Mr MARIN and Ms PERENON.

For this project we have been using the agile project management method. We often need to be in touch with Noé's family and his therapists to make sure that the system will fit him properly, which has been a challenge for achieving our project goals at times, but in the end we have received enough feedback to create two versions of the proposed system. Initial testing showed some flaws in the first design that were fixed in the next version, which resulted in a fully functional final product that Noé is able to use to freely ride his bike at this time.

In this report we are going to detail and explain the final needs asked by our customer, describe our final product, and explain how we reached these demands throughout the course of the year in order to build a successful project. Our progress up to this point has been continually updated, tracked, and documented in order to maintain a successful timeline, which includes the associated risks, costs, and planning.

1. Final Needs Expressed by the Client

After submission of the L1 report we defined Noé's needs, the L2 further defined the requirements (*Annexe 1*) of the system, and the L3 brought everything together where we designed and proposed a first prototype with a complete architecture for the second meeting with the client. As we neared the final steps of the project we have continuously kept our gantt chart, risk analysis and cost analysis up to date, while simultaneously improving and adapting the first prototype for Noé considering feedback from the second meeting. The occupational therapist discussed the efficacy of the design, and then we were able to make improvements for the final product. We have seen Noé one last time to receive his feedback before validating it.

Part of the reason for using the AGILE management method was because our client is a child, which means needs can change quickly. For example, we asked multiple times about different colors he liked, as well as the feel of certain materials due to his sensitivity. Small requests such as this can quickly change the direction of a project, so it is important to pay close attention to any last minute changes or feedback. We have not faced any major changes to our needs and specifications except for the use of gloves: with our system Noé can ride in winter conditions with his personal gloves, so we feel it's not essential to add this to the system at this time. Requests for mobility, functionality, adequate sizing, and safety were the main concerns of the client, which we detail in the next section.

2. Specifications and Functional Analysis

To better understand our system, we redefined our functional analysis with the housing system, the guides, and the springs, which are essential pieces to Noé's comfort. Springs can affect the strength or force that Noé is able to apply to the bike, and the system housing permits him to rest his stump on somewhat of a representation of the handlebar, which are functions we discovered when we saw Noé ride his bike for the first time.

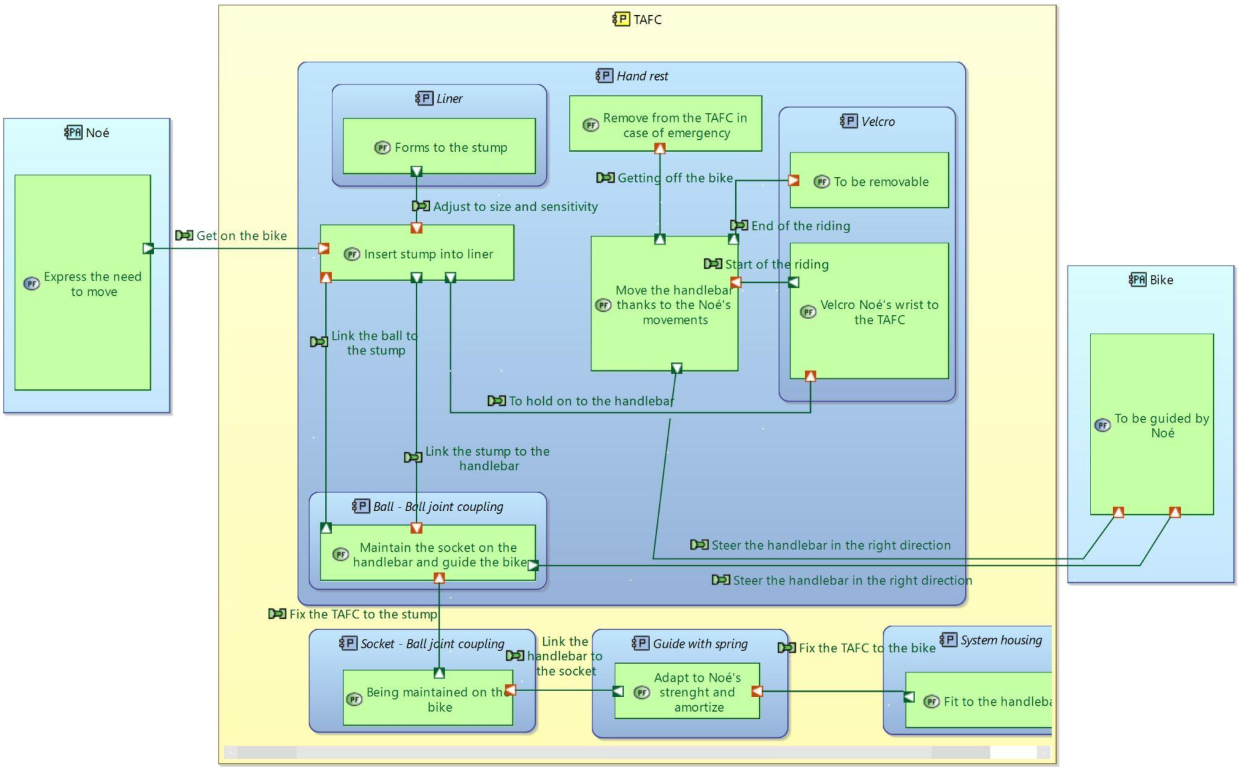

Figure 1. Up-to-Date Functional Analysis (Annexe 2)

The final specifications table has been made thanks to the second meeting with Noé and these updates to the functional analysis. From our requirements we kept functions and criteria, and we then defined the technical and logical components (solutions) that could be used to correspond to what we want or need to do. We also defined level and numeric values more precisely to respect the requirements.

For FC1.2 and FC1.8, we talked with the occupational therapist and concluded that the system has to be more adjustable in height when Noé will be riding his bike, rather than being adjustable in distance he is with the handlebars. Moreover, the thing that is going to change most with his age is his strength, and maybe not so much his wrist length. This is why we decided to change these two criteria. We also saw that if we changed the depth of the socket the required strength to remove the wrist will change, and this is why the level criteria is in millimeters. For FC1.8, the level of the criteria is the length of our spring before we calculate the maximum course (seen in figure 2 below).

SPECIFICATIONS							
ID	Requirements	Solutions	Criteria	Level of the criteria	Flexibility of the criteria	Flexibility for Customer	Team Priorities (0 à 5)
OBJECTIVE	Develop a system to allow Noé, a 10 y.o boy with a right hand agenesia, to HELP TO ride a bike						
FP1	To allow Noé to install on the bike						
FC1.1	Must be installed without help	Sliding/rotating connection between system housing and handlebar, and screwed to fix to the handlebars	The system takes 3 steps to be installed on the bike.	3 steps	.+/- 1 step	Could-have	3
		Form of the Technical aid for cycling	Allowing Noé to grip the handlebars.	Fit naturally with the shape of the handlebar	/	Must-have	5
		Velcro	Less than a 5 min installation for daily usage	< 5 min	.+/-1 min	Must-have	5
FC1.2	Must be adapted ergonomically to Noé's stump	Surface of the hand rest and materials (in contact with skin)	Noé must use materials in contact with his skin that he's not sensitive to (or with gloves)	Foam padding and velcro	/	Could-have	
		Adjustment of the socket	The system must be adjustable in strenght (for Noé's growth)	2,4 mm to 3,5 mm ABS	.+/- 10 mm		
		Length and width of the socket and the hand rest	The support of the system must be same size as the stump	60 x 45 mm	L = .+/- 50 mm W= .+/- 10 mm		3
FC1.8	Can be adapted	Sliding connection with springs between system housing and socket	Height between hand and handlebar can be adjustable	20 mm	0 to 20 mm	Could-have	2

Figure 2. Parts of the Specifications Table (Annexe 3)

3. Presentation of D.U.C.K (Device for Upper-limb Cycling Kit)

3.1. General Overview

For the final prototype we managed to produce a system that was consistent with the form and function of the original design. Our system's shape ended up resembling the shape of a duck, which is where inspiration for the name came from. Prior to the second meeting with the client, the occupational therapist told us that the main problem with the previous system's function was Noé's position and posture while on his bike. His elbow was too high compared to the other arm, creating an imbalance and bad posture resulting in poor alignment of his back. Since the system awkwardly positioned his arm, it was not serving him properly and didn't have much utility as a consequence. On the aesthetic side, it was also necessary to reduce the size of the system, principally the hand rest or plank, and the system housing as they were visually bulky and not very discreet for Noé's preferences. In the end, though, we were able to correct the size and form of the final system to achieve a much better, working prototype.

An overview of the new system should be briefly introduced prior to talking about the new functions and features. As we can see in figure 3 below, the system has been modeled showing the new system in blue, mounted to a rough estimation of Noé's handlebar. For reference a grip has been added to the left hand side to better visualize how the system would look in the real world. As mentioned, the new version is simply slid over the right handlebar and tightened using two screws to prevent it from slipping off or rotating.

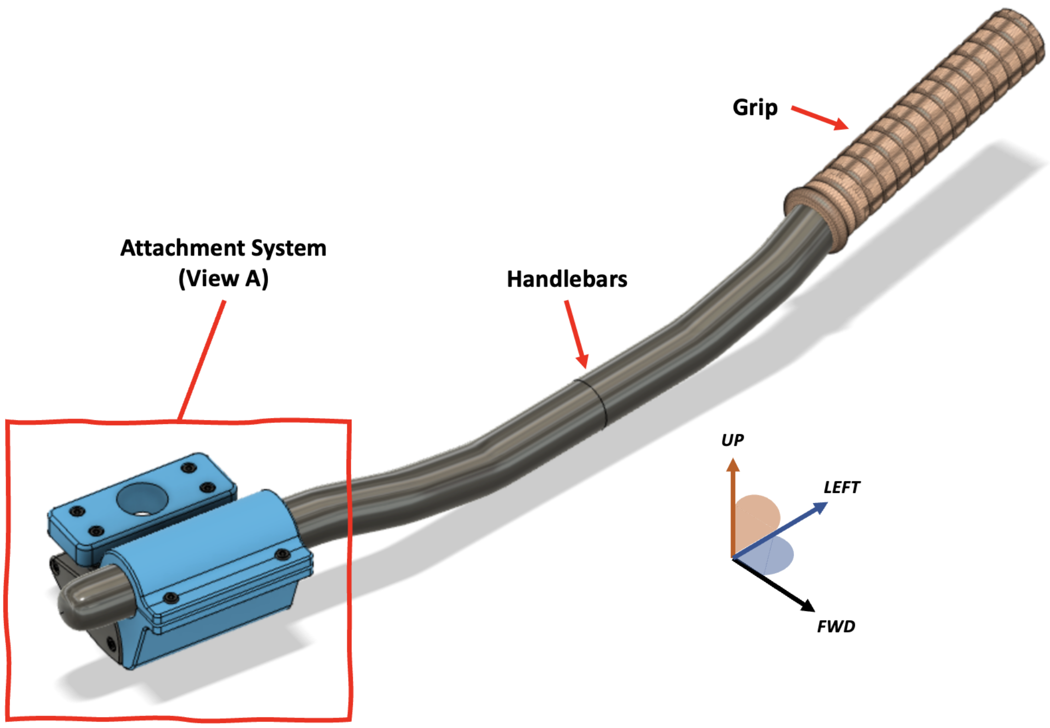

Figure 3. 3D Model of the Final Design

For a closer look at each component we can reference figure 4 in the image below. The system features the same basic components that have been redesigned in a way to make the overall footprint smaller, while maintaining the same mounting and motion principles. We still have the plank with a ball in the middle, where Noé attaches his wrist when that part of the system is configured to his arm. This piece is able to move up and down via two guide arms (or rails) that slide within the larger housing component attached directly to the handlebars. The first prototype featured a stopper in the form of a pin that was installed through the bottom of the rails to prevent the rails and the plank from sliding up and out of the housing once installed, but new components were added to accomplish this in a more discrete way. Instead, internal stoppers were added along the tracks in the housing (shown in orange below). The L-shape of these stoppers catches on the new C-shape of the guides so that when the plank and guides are at their maximum height, they are not able to slide out of the housing. Not only did this save material, but it also removed some unnecessary clunkiness and potentially sharp or pointy aspects from the design that could have posed a safety issue. The shape of both components were also strategically designed to hold springs on both sides at the same interface in this region, stacked on top of each other, where the design was then able to be more easily reduced in size. The interaction of these components can be more clearly seen in figure 5, where it will be discussed in detail.

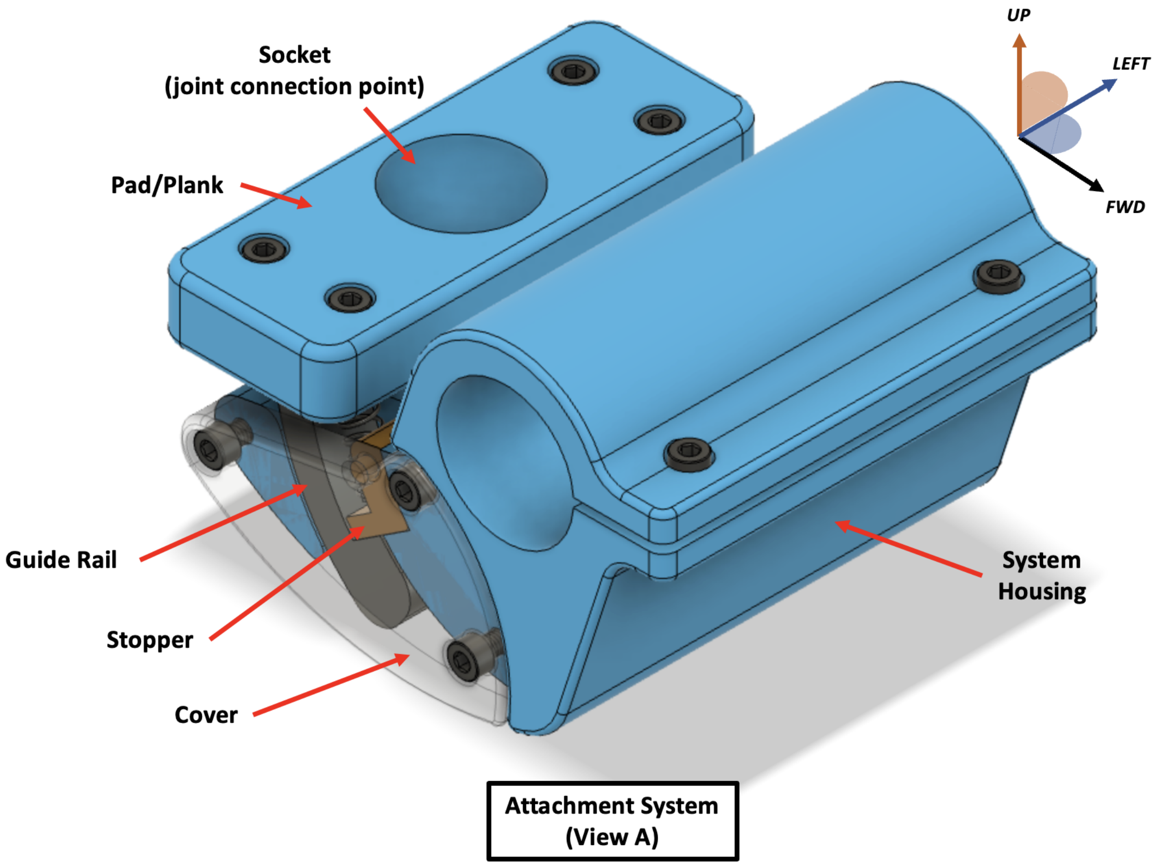

Figure 4. View A of DUCK's Primary Handlebar Components

Another set of new components includes covers on the sides of the housing, which is shown as transparent in both figures 4 and 5 to more clearly see how the system has been redesigned. One purpose of the covers on both the left and right sides is to contain the guides, stoppers, and springs from moving during operation. Another aspect of designing these covers came out of necessity, since inserting the guides and stoppers would make it very difficult to install the springs in any other way. If one imagines installing the guides attached to the plank and then the stoppers, it would be challenging to compress the springs enough to install them from the top of the housing.

The covers allow the user to first install each component from the sides of the system, where they can then all be nicely encased in a way that they will not escape during operation. At the same time, the springs have a much harder time accidentally coming out or becoming dislodged while riding. Figure 5 provides a side view of the system that makes it easier to visualize this concept (and it should be noted that the handlebar in both images 4 and 5 is not shown to make the images less crowded). This image of DUCK also highlights how the movement of the rails work in this version. Once everything is in place, the covers retain the components in conjunction with the stoppers, where the L and C-shaped features of the stoppers and guides create a retention point at the location in the dashed yellow box. Again, this is how the plank and guides are free to move up and down with help from the spring, but do not become dislodged during use. To better imagine the movement, which is the same as the first version, a black double-sided arrow is shown at the bottom of the guide rail. This is how the new design was able to reduce its size and become more sleek, which we will discuss in the next section.

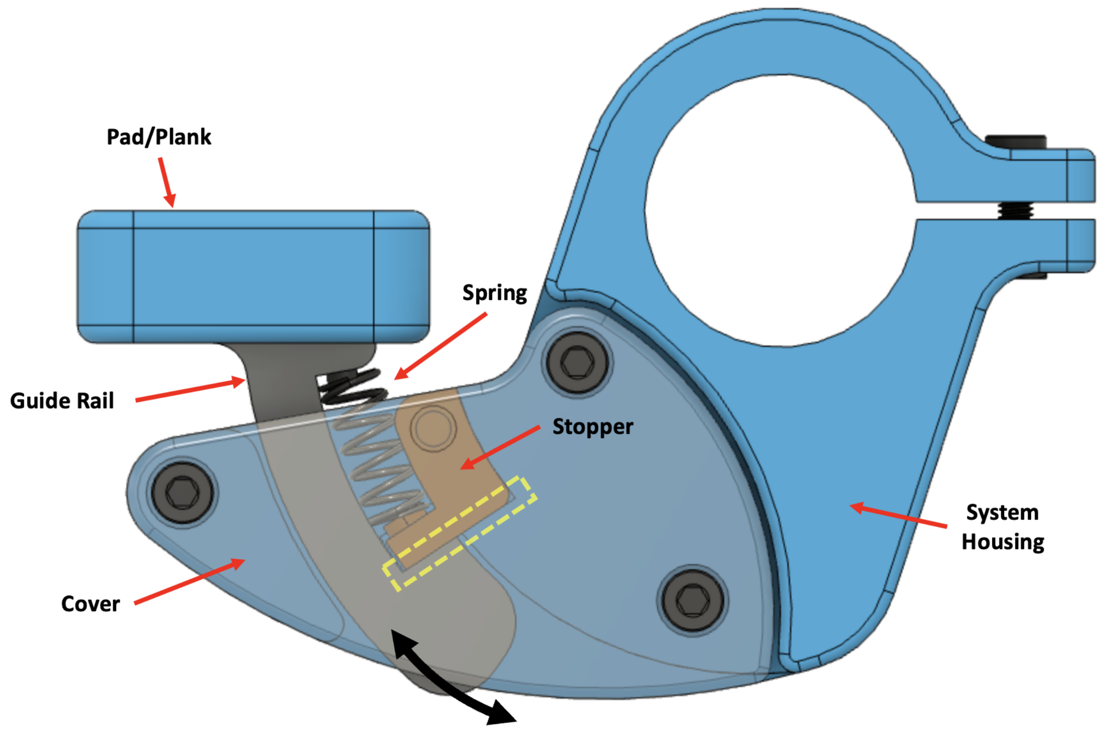

Figure 5. Side View of the System

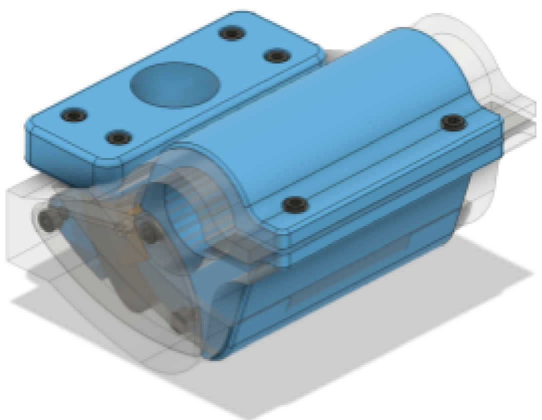

Figure 6. Size Reduction of Version 2

Figure 6 to the left is the final system overlaid with the housing used in the first version (shown as transparent). This is to visualize how much the system size was reduced, primarily in the lateral direction. Being told the first prototype was rather large inspired many aspects of the second version. Compressing more of the components in a smaller area allowed our group to reduce the width of the housing from 127mm to 100mm. And the requirement of lowering the position of the plank to get Noé's arm in a lower position forced us to lower the height at which the DUCK's "back," or face where the plank contacts the housing, was located. Overall there was approximately a 20% cut in the amount of material used for the housing components alone, which proved to be a bit of a challenge, but satisfied our client's desire to shrink the system.

As mentioned, it's noteworthy to define how the system's movement was laid out and designed. When the team initially had the idea of using a ball-joint system to connect the user to the handlebars, we knew we could achieve plenty of movement for a comfortable ride. But when thinking about other small movements that happen while riding a bike, we knew the wrist would have to be able to move up and down as well. This is detailed further in section 3.4.

3.2. Ball Joint Coupling - Tests and Experimentations

The ball joint coupling is the primary connection point between the bike and the rider. These two parts, the ball and the socket, allows the rider to easily disengage with the system in case of a fall. It is therefore very important to size it properly in order to ensure the security of Noé. To reduce the lever arm, which provides better solidity and more stability for Noé, we changed our ball joint coupling system slightly. Instead of having more mobility in the socket, the ball will be the soft piece that can deform and enable more movement. The socket can now be integrated in a bigger part, saving space and materials. The socket is now completely solid, printed in ABS and does not have any mobility (completely rigid). Due to these changes it was necessary to size the system properly for Noé, so we then developed an experiment plan.

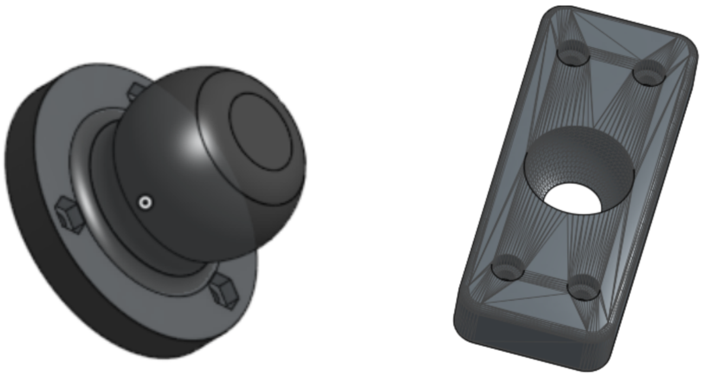

Figure 7 : CAO of the ball joint coupling's components.
Left : Soft ball Right: Solid socket

3.2.1.Experiment Plan

3.2.1.1 The Parameters

Several parameters have an influence on the force needed to separate both parts when engaged, so we will call this force the "release force". The radius of the ball and the socket were made to the same dimensions to ensure good mobility.

Socket depth : Changing the depth of the socket will make the ball harder to remove, and because the system is round, making it deeper will allow more plastic to wrap around the ball, which will need to be squeezed more to be released. We need to have at least the depth of half a sphere (14.1mm), or its radius, to have a release force (and for retention, too). For better comprehension, we will say for example that a socket offset of 3mm from the surface has a depth of 14.1 + 3 = 17.1mm. Please see figure 8 for more context as well.

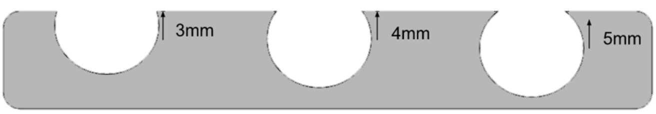

FIgure 8 : Example of Different Socket Depths

Softness of the ball : To change the softness, we changed the infill percentage when 3D printing this component. We could have changed the interior geometry of the balls but changing the infill % allows us to keep a resilient structure for the piece, and this makes it easier to classify the different balls after printing.

Materials used : Changing the materials for 3D printing will change the properties of the materials and how they influence the system. For the socket, we chose not to change it and keep it as ABS V2 because we needed a solid piece. Having this piece made of a single material makes testing simpler, too. The ball is printed in SemiFlex, and there are different types of SemiFlex usable in GI-Nova such as: Ninja Cheetah and Zortrax SemiFlex.

There are more parameters that could influence the release force, such as the friction between both parts, the form of the system (not perfectly round) etc… But we chose to do our experiment plan on those parameters because we thought they were the main ones with the largest consequences on the release force.

3.2.1.2 The Experiment

The goal of the experiment is to test different combinations of balls and sockets to be able to furnish the client with a kit that allows an optimal release force. Noé will be able to change the release force as he wants by selecting the combination he finds best suited to his capabilities.

Even if having a dynamic pull is closer to reality (a fall), it is complicated to recreate the exact same dynamic pull every time. We did not have the time to come up with every possibility and simulate the system under similar dynamic situations because of the countless possibilities, so we chose to do very slow pulls, close to static. It is not the real case of release force in all situations, but it enables us to compare properly all of the configurations so we can provide Noé with the best combination.

For the setup of the tests, the socket would be fixed on a bench vice, and with the aid of a dynamometer we will be able to observe and record the maximum force applied to release the ball from the socket, which is our release force.

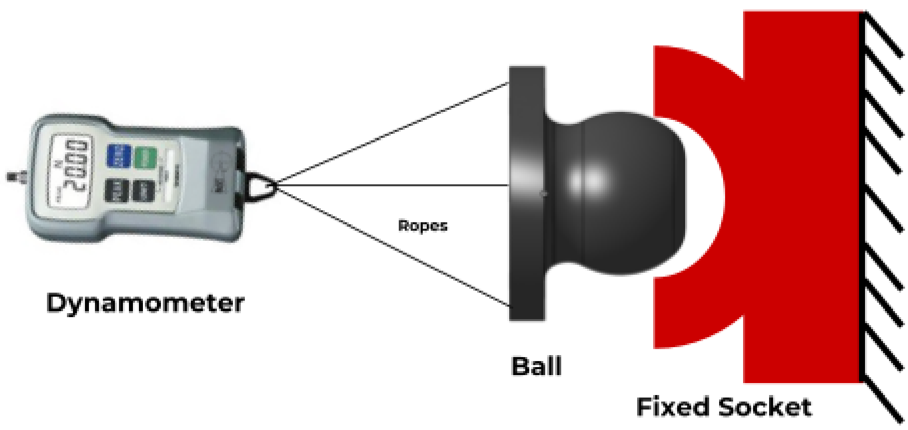

Figure 9. Diagram of the Ball and Socket Testing Setup

In order to save plastic, we did not print complete planks with sockets. Instead, we printed a piece with many different sized sockets of varying depths (see figure 10 below).

Figure 10. CAD Model of Socket Test Piece

We decided for each ball's material used, to test 4 densities (10%, 20% , 30%, 40%), and 12 socket's depths ranging from 2.4 to 3.5 mm. We originally planned to test 2 different materials, which would result in 96 different tests that we could then compare. Due to printing problems, we could not print as many balls as wanted and therefore test all of the possibilities. GI-Nova staff decided to stop allowing Zortrax SemiFlex printing to free the printers for all the ABS pieces needed for different projects amongst the many groups. The semi flex printing was done on a single printer, from Creality. Due to the novelty of the printer, we missed a few printing, and the printer was set on PLA before we could print other Ninjaflex balls. We decided to run the tests on only 3 balls and compare the results, then we could see if it was sufficient or not at the next meeting with Noé. The results of our tests can be seen in the plot below (Annexe 5) :

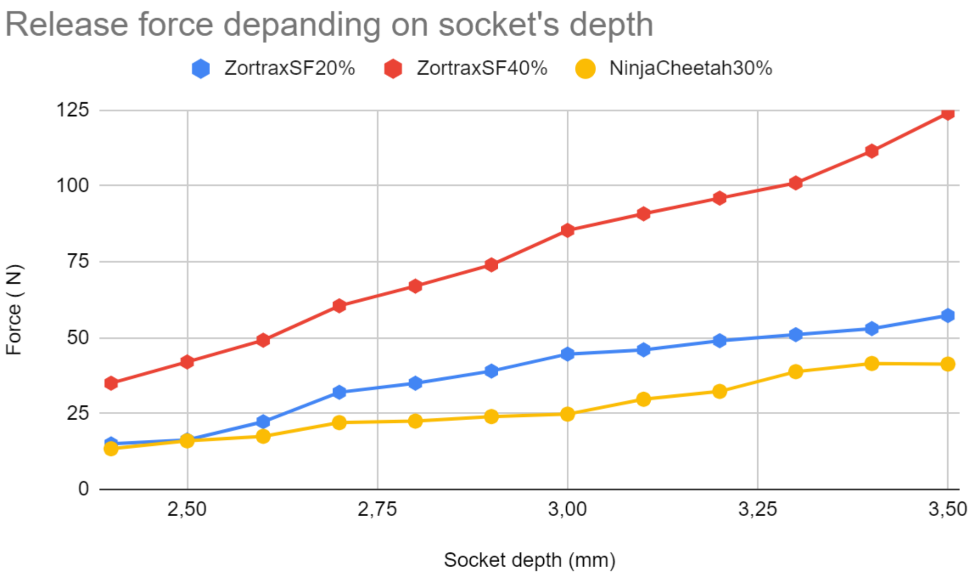

Figure 11. Plot of the Ball and Socket Test Results

Each value on the Annexe 5 is the average of 10 tries.

Even if this experiment is not quite enough to write a definitive conclusion about a realistic or “perfect” kit showing a large range of release force possibilities, we see that a big range of release forces are still accessible (from 14 N to 125 N). It is necessary to keep in mind that these forces are static forces, and with a dynamic movement the release force can be much smaller but not measurable with our measuring tools.

3.2.1.3 Limits of the Experiment

As explained previously, we had several printing problems while making the balls. On the original test socket plank, there was a big issue due to its large size. The bottom of the plank bent due to poor adherence to the printing bed, and half of the sockets were unusable for our experiment. We decided to reprint half of it (the problematic part) with the same printer using the exact same material and printing parameters. Even if theoretically the sockets are supposed to be similar, having two different parts not printed together could induce errors or change the results in some way. Nevertheless, we did not observe significant errors in the results that could be explained by this limit.

3.2.1.2 Tests with Noé

When we met Noé for the last time, we decided to make him try all of the ball/socket configurations that we had to see what would suit him better, supervised by Anne Marie.
Thanks to his feedback, where he provided on a scale of 1 to 10 how hard it was to disengage with each of the sockets and different balls, we could see that his sensations were close to our results. Noe and Anne Marie tested the different combinations and they were really satisfied with the 20% NinjaFlex Cheetah with the 3mm deep socket.

3.3. Hand Rest System

After the latest meeting with Noé, we saw that modifications were necessary to improve the hand rest’s comfort. First, the piece squeezed his arm when he was wearing a coat. So we increased its length to 160 mm and decided to propose two versions of the hand rest for Noé : one for the summer and another larger one for when it is cold outside to make his hand’s insertion easier. Thanks to that, he could have a hand rest more appropriate according to his arm, clothes, or conditions.

Next, the precedent prototype had two holes for velcro to connect his arm and the piece. However, we saw that Noé hardly inserted his hand and had attached the two velcro pieces around his arm, which complicated the system. So in the end we chose to only use one large 50 mm velcro strip. Moreover, we decided to shorten the hand rest to give Noé a bit more mobility. At the meeting we discovered that the hand rest was too long and he was limited with some movements. So, we reduced the larger to 60 mm, a little bit longer than the diameter of the support for the ball.

To hopefully increase the lifespan and resistance of this system, we increased the thickness of the piece from 3 mm to 5 mm. Also, to make sure that Noé adopts the system we decided to make this piece in blue, just like he wanted. We also applied fileted edges everywhere to ensure Noé’s security and fight against the possibility of him getting hurt.

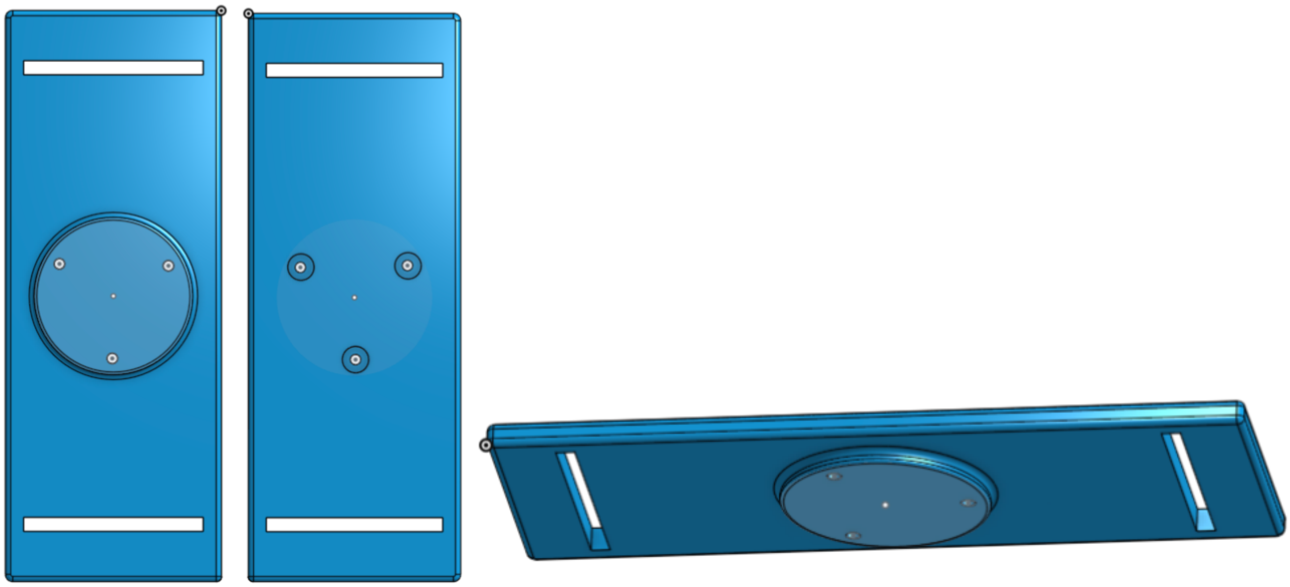

Figure 12 : CAO of the Final Hand Rest

Finally, when we met Noé, we asked him to touch different materials since he is sensitive to certain kinds. The one he prefers will be in the inside of the hand rest to bring comfort. He chose the black one (figure 13). This material is very convenient for us because the side in touch with the hand rest could be fixed with velcro. Noé could take it off to wash it as well.

Figure 13 : Material chosen for Noé's comfort (top of the material : in touch with Noé's skin, bottom of the material : attach with velcro to the system)

3.4. Attachment System - Designing the Right Length (AGILE Method)

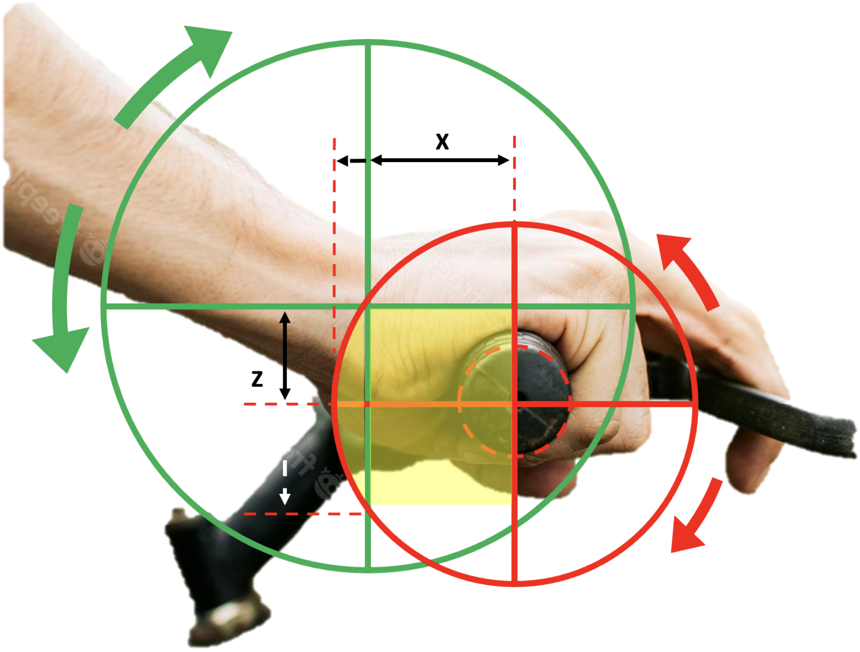

Figure 14. Rotation Principles Used to Design D.U.C.K.

The shape of the first and second prototypes was not an accident, or done purposely to look like a duck. Figure 14 above shows the two primary points of rotation when a hand grips onto a bike's handlebars. The hand and fingers will naturally rotate slightly around the center of the handlebar, which is shown by the red circle and arrows. Second we have the joint at the wrist where the hand and the arm rotate, shown by the green circle and arrows. DUCK's shape and function was created when thinking about the movements at these two locations. If the hand rotates, it will follow a path somewhere along the red circle. But if the wrist were to also dip down, for example, a stationary system with only a ball joint allowing motion along a plane projected into this image (or, orthogonal to the page) would not comfortably accommodate the rider's motion, which is where the plank and guide system was conceived. Next, we had to think about where to position the center point of the rotational movement of the guides so it felt natural. Initial thoughts told us to center everything around the handlebars, but looking at this diagram shows that it may not be the best position. Any position where the center point of the green circle fell while being rotated around the red circle showed us a window of where the best locations could be. Based on the natural position of one's hand, a location somewhere in the shaded yellow area above would likely be an ergonomically friendly area to position the center point of the guide's rotation, which is what our team did. Dimensions X and Z can be used to help describe the important dimensions used during the design. The first prototype allowed us to make a guess at the position based on Noé's hand size, as well as his position on the bike. After testing, we were able to find a more comfortable position slightly lower within the yellow area for the second prototype.

Figure 15 : Prototype of the system

3.5. Spring Analysis

To select the right spring for our system, we have made some hypotheses about different variables. First the length was supposed by the previous system and the tests with Noé. On the previous system we took a spring 26,9 mm in length, so we supposed that 20 mm would be sufficient and able to be fitted to the new system. Also, with the new system design, we wanted to reduce as much as possible the space taken by the spring. So we wanted to have a diameter below 8 mm, less than the previous spring.

A characteristic we wanted was the strength exerted by Noé on the system. Thanks to three different springs that we had on-hand, we could experiment with which resistance of the spring we wanted for our approach. We wanted springs near 7,25 N (third one on the Figure 15), quite similar to the strength necessary to remove the stump from the bike.

	String's diameter (mm)	Interior diameter (mm)	External diameter (mm)	Number of spirals	Length (mm)	Minimal length (mm)	Course (mm)	G (N/mm2)	Rigidity (N/mm)	Strength (N)
1	0,8	7	8,6	9	30	8	22	81000	2,59	56,98
2	1	9,2	11,2	8	26,9	9	17,9	81000	1,53	25,66
3	0,5	3	4	18	19,2	6	13,2	81000	0,55	7,25
4	0,5	5,8	6,8	/	20	15,32	4,68	81000	0,46	7,093
5	0,5	5,8	6,8	/	20	15,32	4,68	81000	0,98	6,092
6	0,5	5,8	6,8	/	20	6	14	81000	0,40	5,47

Figure 16 : Table of the parameters of the springs chosen (Annexe 4)

So, due to the hypotheses we made, we found three springs that could fit with our expectations with (lines colored in green on figure 16) 5.47N, 6.092N and 7.093N. Those ones were found on the Ferroflex, Mc master and Sodemann websites [1][2][3].

We have done the different calculations with the formula : $f = \frac{8*F*n*D^{3}}{G*d^{4}}$

4. Verification of Requirements

To verify that we met the requirements of the client, we used a code with “Y” which means that the requirement was verified and “N” if it was not. The goal is to verify all the requirements, or as many as possible. To do so, we based our verifications mostly on the “Level of the criteria” and “Flexibility of the criteria,” and then we tested it with the “Measure of the criteria.” These columns have numbers and measurements that should be verified and highlight the way we should do it. So, by experimentation, we could verify the requirements or not based on this. If the requirement was not verified we gave a justification and explained why there is an error. The verification table according to the requirements are found in the following link :
G5 - Technical aid for cycling - Requirement & verifications - 01

We can see that two requirements have not been verified. The FC1.4 which satisfies Noé’s aesthetic requirements is not respected. This one was a must-have but we have some parts of the system which are in dark gray such as the solid pocket (Figure 6) whereas Noé said that he does not like gray and black, so this was not reached simply due to an aesthetic aspect that was not respected. Also, FC1.7 requires that the system must be adapted for winter, however, it was not verified. Indeed, “The system must have a removable glove for winter conditions” but we conceived a piece where Noé can use his own glove. So, with the occupational therapist we decided at the 2nd meeting that making a removable glove for winter was not necessary as long as he has one.

Requirements											
ID	Requirements	Solutions	Criteria	Level of the criteria	Flexibility of the criteria	Measure Criteria	Constraint to measure	Flexibility for Customer	Team Priorities (0 à 5)	Vérification (Y = Yes, N = No)	If it is "N", give a justifaction and/or the mesure obtained
OBJECTIVE	Develop a system to allow Noé, a 10 y.o boy with a right hand agenesia, to HELP TO ride a bike										
FP1	To allow Noé to install on the bike										
FC1.1	**Must be installed without help**	Sliding/rotating connection between system housing and handlebar, and screwed to fix to the handlebars	The system takes **3 steps to be installed** on the bike.	3 steps	.+/- 1 step	Test with Noé	We can't always see Noé	Could-have	3	Y	
		Form of the Technical aid for cycling	Allowing Noé to grip the handlebars.	Fit naturally with the shape of the	/			Must-have	5	Y	
		Velcro	**Less than a 5 min installation for daily usage**	< 5 min	.+/-1 min			Must-have	5	Y	
FC1.2	**Must be adapted ergonomically to Noé's stump**	Surface of the hand rest and materials (in contact with skin)	**Noé must use materials in contact with his skin that he's not sensitive to (or with gloves)**	Foam padding and velcro	/	Test with Noé, modelling his stump.	We can't always see Noé	Could-have	3	Y	
		Adjustment of the socket	The system must be adjustable in **strenght** (for Noé's growth)	2,4 mm to 3,5 mm ABS	.+/- 10 mm	Embeding and test of strenght.				Y	
		Length and width of the socket and the hand rest	The support of the system must be same size as the stump	60 x 45 mm	L = .+/- 50 mm W= .+/- 10 mm	Test with Noé				Y	
FC1.3	**Must be attached to the handlebars and be stable.**	Fix the translation with screws and rotation with clamping force and friction	A part of the system must be **embedded to the bike**: block the 6 degrees of freedom of the system-handlebar link.	2 screws	.+/- 1 screw	Test of strenght		Must-have	5	Y	
FC1.4	**Satisfying Noé's aesthetic requirements**	Colors and materials	A system with a **minimal footprint, adapted to Noé's aesthetic** requirements	Red, purple,blue and rough material	grey and black for the little part	Test with Noé	His color's taste may change	Must-have	5	N	Some parts of the system are in dark grey.
FC1.5	**Allow for system maintenance**	Removable material on the surface of the hand rest	The fabric part **must be removable for cleaning.**	System unlock in less than 30 seconds	Could be cleaned without being removable	Test of detachment		Must-have	5	Y	
FC1.6	**Allow aeration**	Width of the Hand rest and form	The system must allow for aeration so that in warm conditions Noé's hand doesn't get too hot	Open form	width of .+/-10 mm	Temperature test		Must-have	5	Y	
FC1.7	**Must be adapted for winter**		The system must have a removable glove for winter conditions	Width of 45 mm	.+/- 10 mm	Test with a glove		Must-have	5	N	Noé can wear his own glove, so we do not need to make a removable glove for him.

Figure 17 : A part of the verification's table according to the requirements

Finally, we can see that globally we verified the requirements except two whose one (FC1.7) was discussed with the occupational therapist. Now, we have to talk with the client to see if they validate our system.

5. Validation

We have done a final meeting with Noé, his parents, the occupational therapist and the kinesitherapist to validate our product - D.U.C.K. Because we have changed the design of the system, we were not able to obtain the correct spring at this moment. However, at the 2nd meeting we tested the system with the springs and the occupational therapist found it relevant for the comfort of Noé. So, at the final meeting, we could test all other aspects of the system with Noé and see if other criteria were validated or not.

First, Noé was more satisfied by the product compared to the first version presented in the second meeting. He felt the real utility of the product and we saw it because he was able to snap and unsnapped the ball with more strength each time and turn the handlebar using the system. Moreover, we observed that he used the housing system to rest his hand on it and be more comfortable. Secondly, the occupational therapist and the kinesitherapist were satisfied to see that Noé rode the bike as before as he rode and they indicated to us that the positions of his back were perfect and corresponded to their expectations. So the team was successful in solving the problem of poor posture due to the position of his arm.

There are some points concerning those that weren't verified in the previous section, such as the components that were not made in blue, purple or red as he said he preferred. We asked him if it disturbs him or not, and he told us that it is not a big deal. The occupational therapist added that it was a small piece so it doesn't make a big difference. For the glove during the winter, the occupational therapist assured us that making a glove wasn't necessary, but making two types of hand rests, one for summer and one for winter (larger), would be more useful and appropriate for the future.

So the global system was validated by Noé and APF in the final meeting. They perceived all the advantages of the system and the D.U.C.K filled all of the major expectations of our customer. You can see the validation comparing all of the requirements through this link :
G5 - Technical aid for cycling - Customer validation - 01

6. Improvements

Although the project in the end was successful in providing a useful product for our client, there are some points that could have been improved upon. For example, the design changes in version two of the system were well executed but could have been adapted for more adjustability. More specifically, the design aspect with regard to the adjustment of the height of the wrist could have been improved slightly. In the second version, the wrist is situated at nearly the system's lowest position and is able to move up and down several millimeters. If the position of the L-shape of the stoppers was redesigned so that the point of contact between them and the guides was higher up, the height of the wrist and the amount of movement could be increased. With the covers, offering several different stoppers could make the system more adjustable since these pieces could be swapped and installed relatively easily. However, since the current stoppers worked well for Noé, it was decided to leave the design the way it was.

Considering the second design worked much better than the first and met nearly all of our client's needs, we can definitely consider the system a success despite the small design improvement opportunities. Nearly all designs and products in general could be improved in some way, even if only to a minimal degree. It is good to recognize and reflect on these improvements for future projects that require similar methodologies, too, especially as our group continues studies in engineering and eventually more professional experiences.

In the end, the team was very satisfied to have met our goals when faced with the challenges presented by this project. Our group managed our time very well, and was able to equally distribute the work throughout the year in a way that made it possible to have a successful outcome. This has proven to be a very interesting subject to work on that taught us valuable lessons and skills that can be taken away and used in our futures, too.

Figure 18. Photo of the student group (without Loan and Tristan) and Noé

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Annexe

Annexe 1 : G5 - Technical aid for cycling - Requirements - 03
Annexe 2 : G5 - Technical aid for cycling - Architecture system - 03
Annexe 3 : G5 - Technical aid for cycling - Specifications - 01
Annexe 4 : G5 - Technical aid for cycling - spring table - 01
Annexe 5 : G5 - Technical aid for cycling - Experiment plan - 01