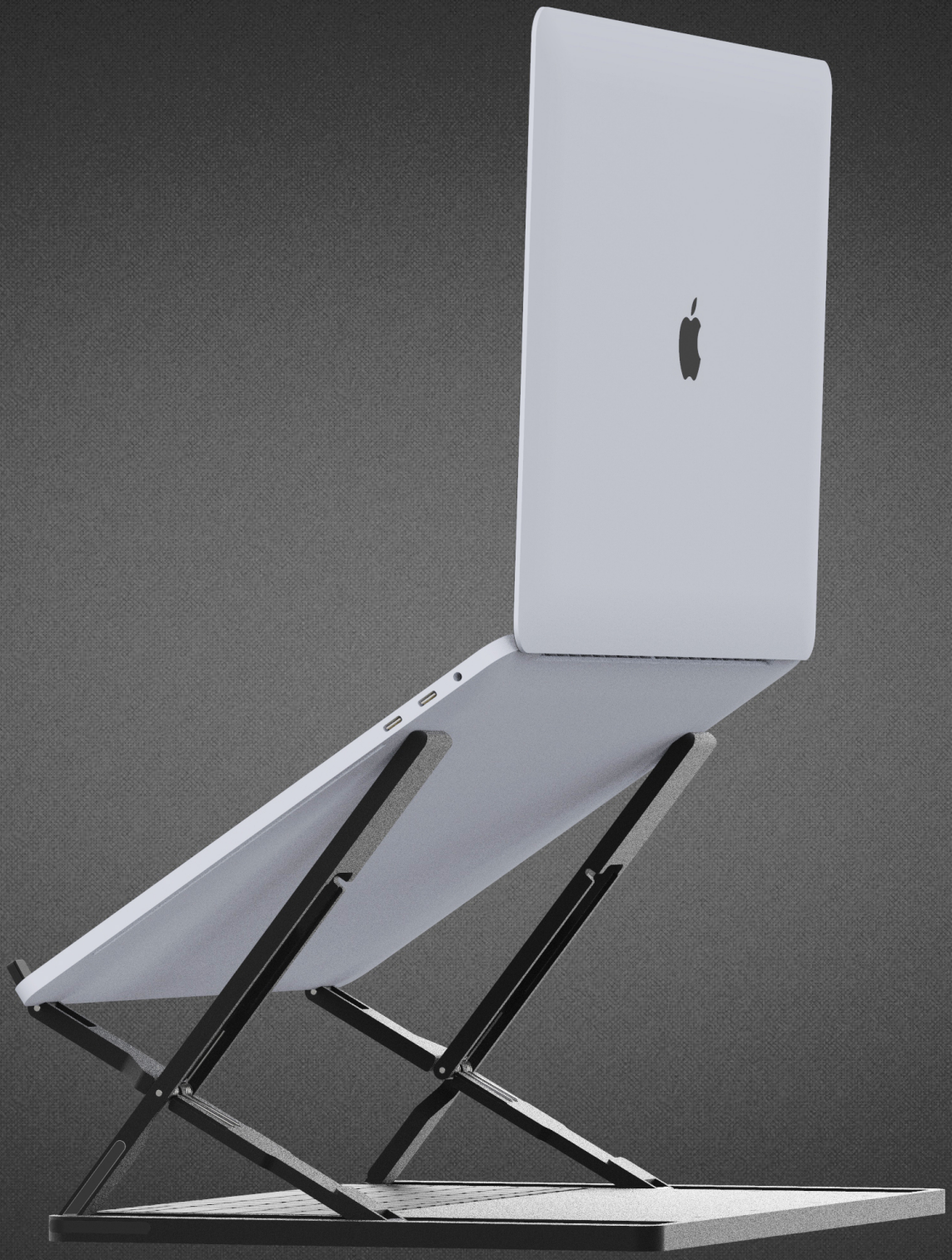

Riggid: a laptop stand that facilitates flex workers to work ergonomically

Master Thesis

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Colophon

Riggid: a laptop stand that facilitates flex workers to work ergonomically

Graduation project Thomas Zwart
February - October 2018

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Preface

Musculoskeletal disorders (MSD) has been an increasingly persistent matter ever since personal computers were introduced to the large public. A particular interesting case is the 1991 Siemens lawsuit where 43% of all 250 employees sued the company, because they were experiencing physical discomfort in shoulders, back, elbows and fingers during computer related work (Osha, 2002).

Siemens acted quickly and significantly improved the workplaces of their employees by providing ergonomic chairs and evaluating every workplace. In addition, back cushions, lumbar supports, keyboard/ mouse rests and document holders were provided along with encouragements of short breaks and exercising. In the following two years, the company had almost completely resolved the issue and saved up to an expected 20,000 hours per year of work which would have previously been lost to work related illness. Siemens concluded their actions by calling ergonomics proven science; when changes are made, the effects are predictable.

Where Siemens enabled employees who had their own workplace to work ergonomically, this report revolves around the development of a product that aids people who work in different places on a laptop. This addresses an increasingly pressing issue among flex workers.

Executive summary

This graduation project is about the development of a laptop stand that aims to allow flex workers to work ergonomically without losing the flexibility of their laptop. The graduation project is started with an entrepreneurial focus. The intention is therefore to to bring the product to the market.

Currently, 11% of all work related illness in the Netherlands is expected to be caused by MSD (musculoskeletal disorders). As flex working is showing a rapid growth over the past ten years, the increase of laptop use for work is expected to increase as well. Since it is difficult to work ergonomically correct on a laptop (i.e. the screen and keyboard are attached to each other, forcing the user in a unnatural position while working), MSD complaints among workers are expected to further increase.

Based on a literature study and online research a set of guidelines is determined for an ergonomic posture and workplace. These guidelines largely defined requirements for the laptop stand.

A survey among 225 students is conducted to determine the magnitude of the problem and why current solutions are insufficient in preventing or curing MSD (musculoskeletal disorders). Four qualitative interviews gave additional insight in the underlying problem. These studies showed that over 60% of participants at least sometimes experience physical discomfort during laptop use. Yet, only a small number of people actually use ergonomic tools like laptop stands. The main reason mentioned by respondents is that it takes too much effort and time to transport and setup an ergonomic workplace. Existing laptop stands do not tackle this problem as they seem to be designed with only the product in mind rather than the complete user journey. Therefore, the goal was to design a laptop stand that makes it easy for users to work ergonomically, without losing the flexibility and appearance of a laptop.

As the design of a laptop stand that focuses on solving the issues found was already started during Build Your Startup, the product development during this project mainly focuses on the detailing and optimization of the product's USPs: integration between laptop stand, keyboard and cover in combination with an automatic lifting system that allows users to work ergonomically within 20 seconds.

For each component of the laptop stand iterations and design decisions are discussed. One of the key features is the integration of a spring-damper system that smoothly brings up the laptop stand to the required height. Secondly, a front grip keeps the laptop in place and gradually adjusts to the position of the laptop when changing the height. Thirdly, a simple slide mechanism allows users to lock and unlock the laptop stand so it can be safely transported. The final design can be seen in figure 1.

A functional prototype is built to validate the assumptions during the design phases. Based on the prototype, the design is evaluated on the requirements as determined by the research studies.

Due to the entrepreneurial basis of this project, there was an opportunity to join the course BPC (ID4315-16) which resulted in valuable feedback with regards to branding and positioning. Based on these results, a proposal is written for the brand DNA of Riggid; the company as started during BYS (ID5659) by Thomas Zwart and Igo Boerrigter. Based on the brand DNA, important aesthetic qualities are determined and tested in a survey. The laptop stand should look reliable, professional, premium and stylish. The survey showed promising results and valuable suggestions regarding customisation of colour and materials and small adjustments regarding the geometry of the product.

Overall, the laptop stand is not yet ready for production as some requirements have not yet been met. The most critical steps forward will be the fine-tuning of the spring-damper system, doing ergonomic and usability tests with users and additional development towards the cover and aesthetic aspect of the design. However, during the project it was managed to fit all required components and functionalities within only a 10 mm aluminium casing, delivering full proof of concept and providing a clear way forward.

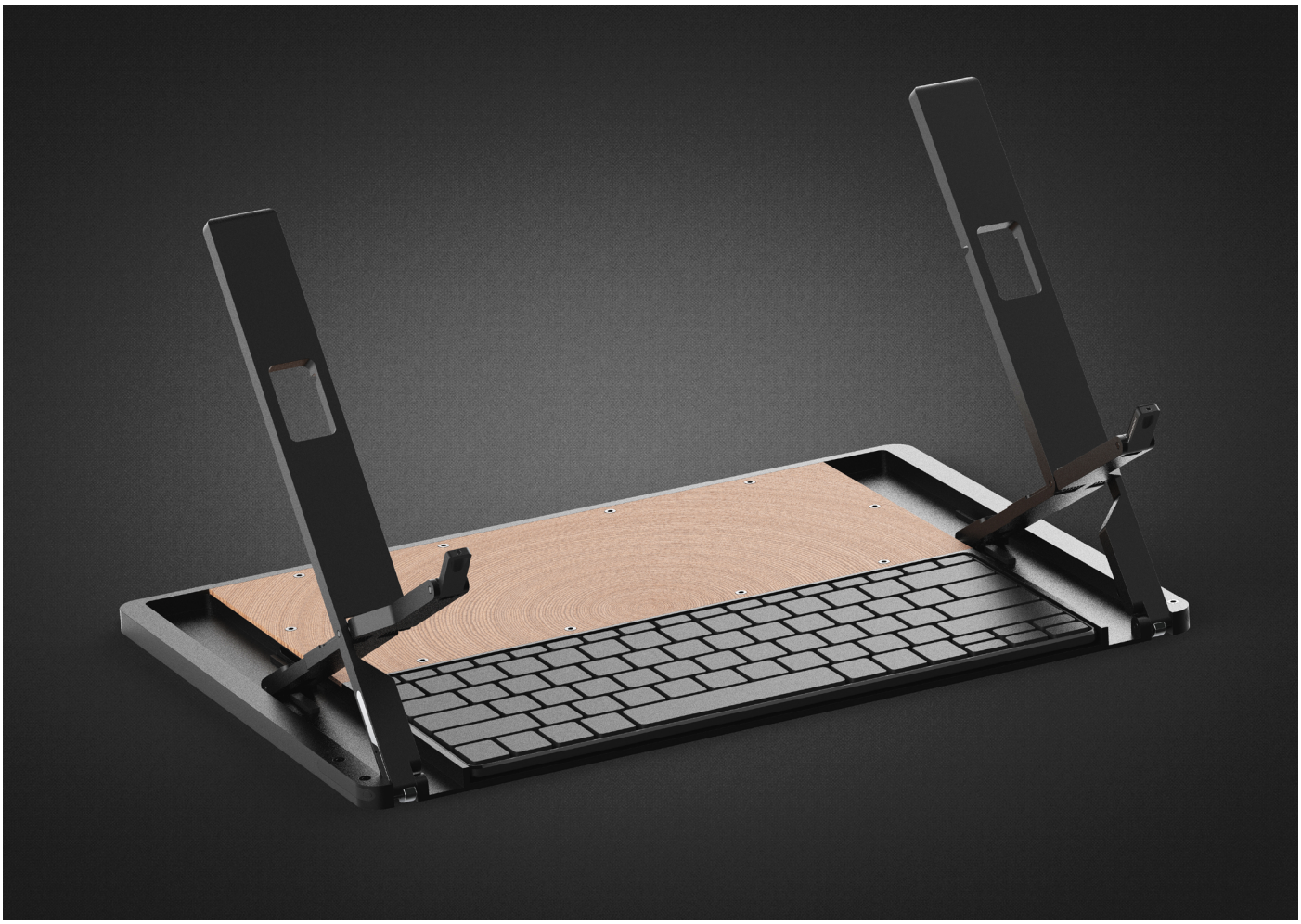


Figure 1: Final design Riggid

Content

Figure 2: An example of TU Delft students working non-ergonomically.

Introduction

As the use of personal computers has been growing ever since its introduction in 1978 (Byte publications, 1978), we are currently in an era where it is nearly unthinkable not to have access to a computing device. Because these devices are most of the time not optimized for ergonomics, extensive usage of personal computers results in musculoskeletal disorders during use (Cagnie et al, 1997). With the introduction and large adaptation of laptops, this issue is only further increased.

To date an expected 3.2 million Dutch working people have experienced work related upper limb disorders (rsi-vereniging, 2018), often referred to as RSI (repetitive strain injury), CANS (Complaints Arms, Neck and shoulder) or musculoskeletal disorders (MSD). In this report MSD will be used exclusively.

On a yearly basis, 11% of all work related illness is expected to be from MSD and concerns almost 184.000 absence instances in offices (Arbobalans, 2014) in the Netherlands alone. In 2005, the expected cost due to MSD for the Dutch market was estimated at 2.1 billion Euro (TNO, 2006). Numbers that have been unchanged to at least 2013 (TNO, 2015). These numbers are based on people working in offices where an external monitor is provided along with a keyboard and computer mouse. This is a relatively good working environment compared to working on a laptop, which is an increasing trend along with flex working (WorldAtWork, 2015, PGi Global Telework Survey, 2015). This new trend is likely to increase the physical discomfort people experience during work even further.

Even though products aimed at preventing or curing MSD are readily available on the market, the majority of laptop users does not use these or only once they experience very serious MSD. This happens for multiple reasons which are investigated through a survey among 225 students and qualitative interviews.

The purpose of this project is to design a product that tackles current issues with ergonomic tools for people who like to or have to work in different places on a laptop. For example, students working at the faculty of Industrial Design Engineering at the TU of Delft (figure 2).

This report is divided in four chapters. The first chapter discusses musculoskeletal disorders as a result of computer work, research activities and competing products. These result in the problem definition, which is translated into a list of requirements. The second chapter introduces the product, explaining different mechanical solutions, material choice and production method per part. The chapter is concluded with the prototype and discusses what was learned from both building and testing it.

The third chapter discusses the marketing and business aspect of the product. Based on input from the course Branding and Product Commercialisation (ID4315-16), the brand DNA is composed. The fourth and last chapter finishes the project with recommendations, a conclusion and discussion and personal reflection.

Chapter 1.

Research and problem definition

1.1 Musculoskeletal disorders

A literature study is done to determine important design variables for avoiding or curing musculoskeletal disorders (MSD) for flex workers.

Causes of musculoskeletal disorders

It is no secret that laptop use correlates significantly with musculoskeletal disorders (Cagnie et al., 2007). Whether the laptop is used on a desk, on your lap or with lap support, it will cause wrist extension, wrist deviation and neck flexion (Asundi et al., 2010), often resulting in musculoskeletal disorders.

A cross-study (Cagnie et al., 2007) about work related risk factors for office workers concludes that musculoskeletal disorders is positively correlating with sitting for a prolonged amount of time and often making the same movement per minute.

Another study shows a correlation between MSD and both 'chairs that only support the lumbar area' and 'a large distance between mouse and keyboard' (Celik et al., 2018).

Lastly, a study from Ariens et al. (2001) about the influence of neck flexion in relation to neck pain indicates that working for 70% of the time with the head inclined at least 10% results in twice as much neck pain compared to working without head inclination.

In general, these studies also indicate that along with above mentioned physical variables, psychosocial (i.e. stress, work pressure) and individual variables (i.e. age, gender, lifestyle) are associated with the frequency of musculoskeletal disorders. For example, Cagnie et al., (2007) shows that woman have twice as much chance to experience neck pain as man and people over 30 years old are 2.6 times more likely to experience neck pain compared to younger individuals. Also, mental tiredness at the end of the day correlates with physical discomfort. Additionally, stress and work pressure are known variables to increase MSD.

As this project has a heavy focus on the development and detailing of a laptop stand, it does not aim to improve psychosocial and individual variables such as work related pressure or lifestyle habits. However, by improving the working posture through physical adjustments, the benefits might also affect psychosocial complaints. For example, a more effective work day due to less MSD could reduce stress and work pressure.

Guidelines

In addition to the scientific research in the field of MSD, the Internet is filled with guidelines and tips on how to improve your posture and workplace. It is unclear which of these guidelines is 'the most' reliable, but in general there are some often reoccurring rules. These will be discussed in the following paragraph.

Even though not all of these guidelines have direct scientific backup, they seem logical as they revolve around the reduction of muscle strain and the increase

of blood flow. The importance of this is further supported by Kumar (2001), who says: “awkward, constrained, asymmetric, repeated, and prolonged postures can overload tissues and exceed their thresholds of tolerable stress, causing injury due to overexertion or imbalance”. Overall, the following guidelines are likely to provide a decent starting point for a design project but should not be taken as the absolute truth. Where possible, scientific backing has been provided. See figure 3.

1. Shoulders
The shoulders should be relaxed and tilted slightly backwards. According to research by Goossens et al. (2003), the optimal way of reducing back muscle activity is allowing at least 6 cm of free shoulder space.

2. Back
The back should be inclined slightly backwards at an angle between 100 and 110 degrees from the trunk. This is supported by Villanueva et al. (1997) who shows that a backward leaning trunk decreases trapezius muscle activity in some subjects.

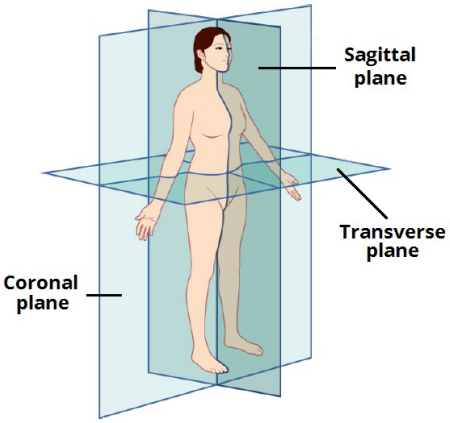


Figure 4: Anatomical planes

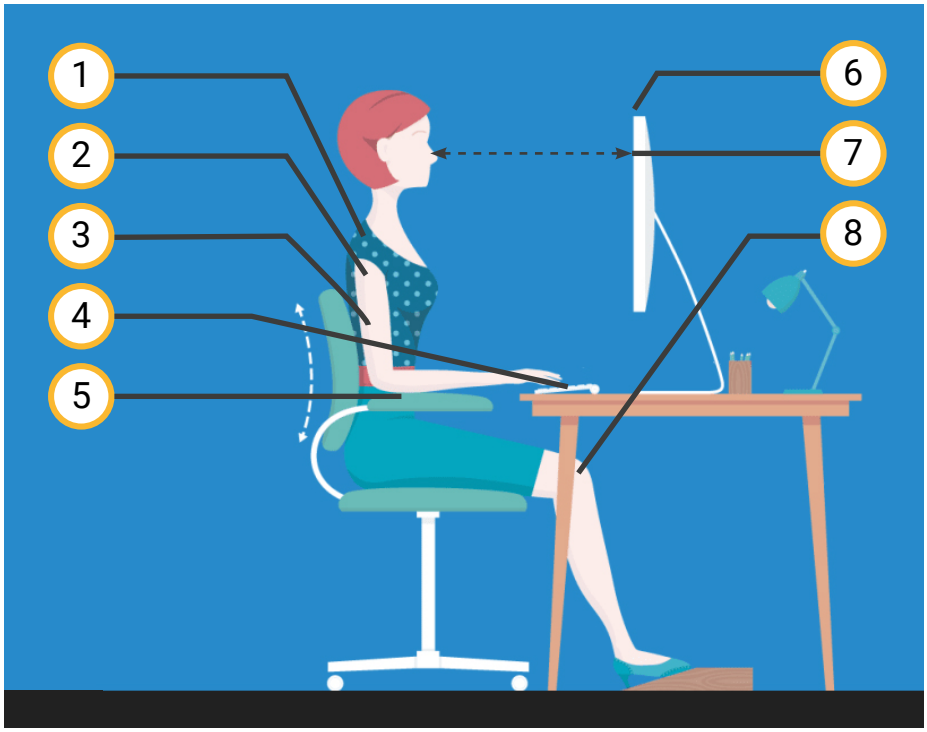


Figure 3: Ergonomic posture

3. Arms
The arms should be in a 90 degree angle in the sagittal plane, and between a 10 and 20 degree angle in the transverse plane (see figure 4). This brings the hands together at the keyboard while maintaining a relaxed body posture.

4. Wrist
A low keyboard allows the wrist to be in line with the lower arm, allowing optimal blood flow and minimizing muscle strain. In fact, Rempel at al. (1997) and Weiss et al. (1995) show that carpal tunnel pressure decreases as the wrist moves towards a more neutral posture in the flexion/extension plane.

5. Arm support
The lower arm should be supported by an arm support that should be the same height as the table or slightly higher.

6. Neck flexion
The top of the screen should be around eye-height. Even though these numbers do not seem to appear in directly scientific research, it is proven that lesser flexion of the neck results in less MSD, as it reduces neck extensor muscle activity (Villanueva et al., 1996), (Villanueva et al., 1997). In an article about laptop posture guidelines by Suebsak et al., (2015), it is claimed neck flexion should not exceed 10 degrees.

7. Eye to screen distance
In case of screens with a diagonal size of 14” or larger, the screen should be at arms length distance when leaning back in your chair. If the screen surpasses 17.3”, a typical rule of thumb is a viewing

distance of 1.5 times the screen size. These guidelines seem to match up with existing research; according to Suebsak et al. (2015) the ideal viewing distance for laptop use should be 38-62 cm. These numbers are based on research for desktop users by Saito et al. (1997), whose findings were later confirmed and translated to laptop use by Moffet et al. (2002).

8. Legs and postural adjustments
The knees should make a 90-100 degree angle in the sagittal plane and the chair should not touch the inside of the knee cap. Your feet should be flat on the floor. It is, however, beneficial to make slight postural adjustments over the day. As described by Davis et al. (2014), postural variability significantly reduces short term musculoskeletal discomfort.

Despite some of the mentioned literature being up to 20 year old, the likelihood of the results being still applicable seems reasonable because MSD complaints remain the same. Moreover, there have not been any significant changes in the embodiment of computer devices from an ergonomic point of view since the introduction of the personal computer. The laptop could be considered the largest change but does not improve on ergonomics in any meaningful way.

To further verify the findings from the literature study, the guidelines have also been discussed with cesar therapist at the TU Delft, who confirmed the expected benefits of working according to these guidelines. He also mentioned that continuous adjustments over the day, regular breaks and a healthy lifestyle are very important in preventing musculoskeletal disorders.

Additionally, he noticed that in practise many of his patients would lean towards their screen because a keyboard in front of a laptop screen often puts the laptop quite far away from your eyes. A laptop stand that would allow the laptop to be closer rather than further away from the user, according to guideline 7, would be beneficial. This will be further confirmed and elaborated on later in this report.

The continuing existance of MSD

Despite the widely available knowledge, equipment, guidelines, therapists and information, MSD is still a pressing issue for computer workers. In chapter 1.2 and 1.3 potential reasons are investigated and discussed.

To date an expected 3.2 million Dutch working people have experienced work related upper limb disorders (rsi-vereniging.nl, 2018). On a yearly basis, this means that 11% of all work related illness is expected to be from MSD. This concerns almost 184.000 absence instances in offices (Arbobalans, 2014).

In comparison with desktop use, it is even harder to work ergonomically on a laptop, because the keyboard and screen are attached to each other, which forces the user to bend their neck or strain their elbows and wrists. Therefore it is expected that the abovementioned numbers are even worse for laptop users.

Flex workers
Typically 'laptop users' concerns flex workers in the knowledge economy such as attorneys, consultants, marketeers and designers. Apart from the working force, students are also an exemplary target group when it comes to prolonged laptop use. According to research of Marijke Dekker, ergonomic expert at the TU Delft, on average 60% of students experience physical discomfort during laptop use and that number has not changed over the past 10 years.

In general the target user has been defined as a flex worker who spends more than two hours per day on their laptop in different places or on-the-go. In appendix 4 the target group has been further defined.

Figure 5: Results from survey

1.2 Contextual research

In addition to the literature study, which mainly focused on desktop ergonomics, additional insights are gathered among laptop users through a survey. The setup and main insights are explained here.

Goal

The goal of this study was to discover the extent of the issue among flex workers, what measures are currently taken to prevent and/or cure MSD and why they retain from using ergonomic equipment. This helped to discover the underlying problem and define laptop specific requirements.

Method

An online survey is created using Google Forms. The survey was distributed among and filled in by 227 TU Delft students who are considered to be flex workers, as they do not have a fixed workplace and work on a laptop. Of all respondents 51% was male and 49% female.

For this survey the respondents are divided into three different groups, to be able to determine differences in the way MSD is experienced and acted upon once complaints increase. These groups are also referred to in table 2.

- Group 1: People who never experience MSD
- Group 2: People who sometimes experience MSD
- Group 3: People who always experience MSD

Results and discussion

Working ergonomically

On average, students spend around 5 hours per day on their laptop (figure 7). Table 1 indicates that about half of the students work on a standard fixed chair and table. This varies a little per individual and per day as students have to move around the faculty and not every workplace has the same office equipment. Also, about 50% of the respondents uses an external mouse when working with a laptop, but only 5% brings an external keyboard and/or laptop stand.

What study year are you in?

227 responses

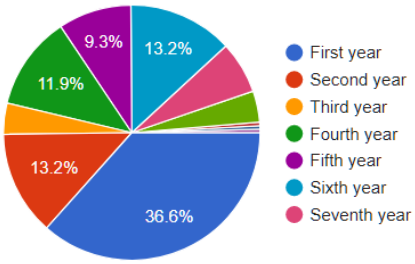


Figure 6: study year

How many hours do you spend behind your laptop at the university on average per day?

227 responses

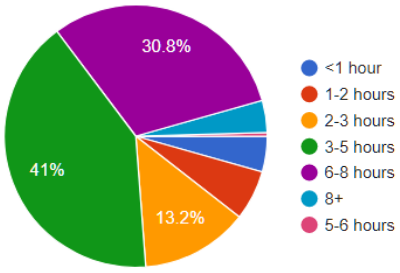


Figure 7: hours on laptop per day at the faculty

Students indicate that they value working ergonomically highly, but at the same time do not think they do enough about it themselves (figure 8).

Experience musculoskeletal discomfort

After the first section about general information, the survey splits the respondents in 3 categories; those who never experience musculoskeletal discomfort (24.6%), those who sometimes experience MSD (60.0%) and those who always experience MSD (14.4%) when working on a laptop. In total 75% of respondents seem to experience MSD at least occasionally. This is in line with a Finnish study among 6961 adolescents that report very similar numbers (Hakala et al,. 2010).

Important to note is that 36% of all respondents are first year students (figure 6). They are least likely to experience MSD, since they are expected to only use their laptop extensively on a regular basis for less than a year. Therefore, the number of people experiencing MSD may be higher in reality.

The neck and shoulders are indicated to be the most common areas to experience MSD (69.4% and 57.5% respectively for group 2 and 86.4% and 80.0% for group 3). According to the literature study, this is most likely due to neck flexion proceeding 10% resulting in increased tension in the neck extensor muscle activity.

During laptop use, which facilities do you use	
Standard fixed chair (no adjustability)	50.5%
Standard table (no adjustability)	61.1%
Office chair (adjustable height and arm rests)	58.8%
Office table (adjustable height)	35.4%
Laptop stand	4.0%
Separate keyboard	5.8%
External standard mouse	38.9%
External ergonomic mouse	12.4%

Table 1: What facilities do you use during laptop work at the TU Delft

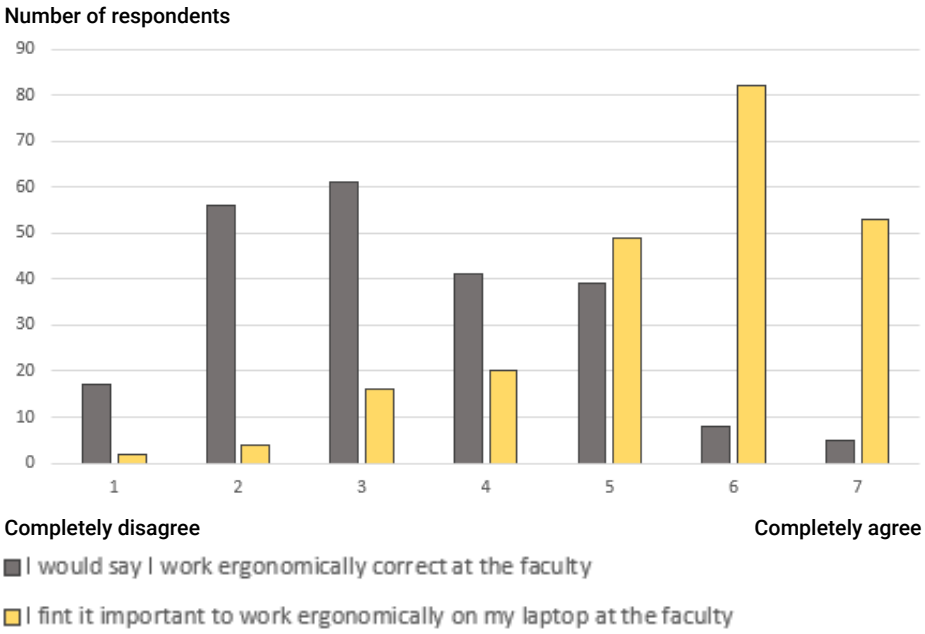


Figure 8: Working ergonomically; thinking vs. doing

Respondents that experience MSD more regularly are increasingly afraid of developing serious physical injuries.

When looking at the bottom of table 2, it is remarkable how quickly people start to care about ergonomics once the first signs of MSD occur. In the first group 34.5% indicate they simply do not care enough to use an ergonomic setup to act on their problem, in the second group this number is brought back to 10% and in the last group nobody claims they do not care enough.

Measures

When asked what measures people use to try to prevent MSD, regular breaks are the most common measurement among all groups, most likely because these breaks would be there regardless of MSD. Therefore, the number of people who are actively trying to reduce MSD complaints is expected to be lower than the survey indicates. As the

complaints increase, students pay more attention to their posture, they switch workplaces more often and make use of ergonomic tools such as drawing tablets, ergonomic mouses and laptop stands (table 2). This also goes for activities outside the university such as visits to a therapist and physical exercise.

When asked which aspects are holding respondents back from using an ergonomic setup, the amount of effort required (i.e. buying all tools, but especially transporting and setting up the workplace), is the most influential factor. As can be seen in the last section of table 2, people have increasingly more complaints about the effort required to work ergonomically when their MSD increases. This could be explained by the fact the first group may never have tried ergonomic products at all, making it difficult to determine the amount of effort that is required.

All results of the survey can be found on https://tinyurl.com/ergotudelft.

Actions to cure or prevent MSD	Group 1	Group 2	Group 3
Not trying to cure or prevent	34.5%	23.4%	9.4%
Regular breaks	44.8%	62.0%	65.5%
Physical exercise	17.2%	32.8%	62.5%
Paying specific attention to posture	17.0%	27.0%	40.6%
Switching workplaces regularly	8.6%	10.9%	18.8%
Usage of ergonomic tools			
Ergonomic mouse	6.9%	10.9%	18.8%
Drawing tablet	0.0%	13.9%	25.0%
Laptop stand	0.0%	1.5%	21.9%
MSD related software	1.7%	5.1%	9.4%
Reasons not to use an ergonomic setup			
Too much effort to set everything up	41.4%	60.6%	61.3%
Too much effort to transport everything	36.2%	59.1%	61.3%
Too much effort to buy everything I need	31.0%	30.7%	22.6%
It's too expensive	13.8%	37.2%	51.6%
I feel uncomfortable with a laptop stand	10.3%	15.3%	12.9%
I simply forget about it	41.4%	40.9%	22.6%
I don't really care	34.5%	10.2%	0.0%

Table 2: What facilities do you use during laptop work at the TU Delft

Group 1: People who never experience MSD
Group 2: People who sometimes experience MSD
Group 3: People who always experience MSD

Conclusion

To summarize, a significant part of flex workers experience MSD, but only start to care and take action when their complaints are becoming more serious. Even though they are aware they should do more, still a small number of people actually use ergonomic tools. An important cause is that it takes too much effort to transport and setup everything. Overcoming this issue will be a key aspect of this project.

1.3 **Qualitative research**

To get deeper insight in the context of using ergonomic products and the situation of people with MSD complaints, qualitative interviews are conducted with laptop stand users. This provided input for the user journey of a flex worker using a laptop stand.

Goal

Four interviews are conducted with TU Delft students suffering from MSD complaints. This gave insight in different situations of people coping with MSD, their attitude and behaviour towards the issue and how they experience using ergonomic tools.

Interview insights

As was also discussed in the results from the literature study on page 11-13, MSD complaints of participants vary in nature due to unique individual situations, which result in different MSD complaints. One general insight is that during periods of hard work, when stress plays an important role (i.e. for students towards the end of the study quarter with many deadlines), complaints get worse. This supports earliermentioned findings from literature studies.

In line with findings from the survey, people only tend to do something about their problems once their complaints get serious. Two participants had experienced MSD complaints for years and only acted upon it recently, e.g. by visiting a therapist or buying a laptop stand. For every participant, MSD complaints come and go in waves, but come back more frequently over time. Remarkable was the finding that people tend to behave more nonchalant towards their issue and stop working ergonomically once their complaints decrease (as a result of measures taken). Obviously, complaints come back again over time, resulting in a negative spiral.

Accordingly, participants indicate that they find it very difficult to keep working ergonomically, since it requires a lot of energy to use ergonomic tools, remind themselves to take regular breaks and have a good posture. One participant mentioned feeling demoralized when thinking about having to keep up with doing exercises for curing/preventing her MSD for the rest of her life.

“The complaints come back every time, especially during stressful periods like deadline weeks it gets bad.”

Although software (e.g. WorkRave or CtrlWorks) is often experienced as annoying, interviewees mentioned it did help them to take regular breaks and pay more attention to their posture. However, it also became clear that without an ergonomic setup the benefits of the software are not used to their full potential, as users quickly fall back into a non-ergonomic posture. An ergonomic setup is required to have and maintain an ergonomic posture.

Yet, current laptop stands fail to support users sufficiently. For example, one participant mentioned she unconsciously bends over to see what is on her screen when she is using her drawing tablet, since it forces the laptop to be placed too far away. Even when they do support in having a good posture, still the interactions with the laptop stand in different use stages (e.g. transporting and setting up the stand) result in a negative experience, making people reluctant to use them at all.

A process vs. a product

A customer journey (visualized on p. 20-21) illustrates these experiences and shows what it is currently like to use a laptop stand among other necessary accessories. Note that the mentioned complaints may not be experienced by every user. Rather, the journey gives an overview of the issues a user might experience, based on insights from the interviews.

First the user has to put everything required to work ergonomically in a bag; a laptop, a laptop charger, a laptop stand, an external keyboard and an external mouse. Often, the user uses protection sleeves as well for their laptop, the laptop stand and keyboard, bringing the total of required “products” to eight. Users find it a hassle to pack and fit everything in the bag. Also, some laptop stands are too big or heavy to transport.

When the user arrives at his destination he has to set up his workplace. In the most optimal current situation, the user will take the following steps:

1. Take the laptop stand out of the bag, remove the sleeve and deploy the stand
2. Take the keyboard and mouse out of the bag, position wires (if there are any) to be connected to the laptop
3. Take the laptop out of the bag, remove the protection sleeve and place it on the laptop stand
4. If possible, set the laptop stand to the required height
5. Get the charger out of the bag
6. Plug the charger, keyboard and mouse in the laptop
7. Collect the sleeves and put them back in the bag

It also became clear that while working users do not feel comfortable using the laptop stand because they do not identify themselves with the appearance of the laptop stand. The aesthetics are an important aspect when acquiring a laptop stand.

When he wants to leave, the entire setup process is repeated in reversed order.

All in all it is very understandable that users describe working ergonomically on a laptop is impractical and a hassle. This user journey clearly shows that it is not just about the laptop stand, but about the process of working ergonomically and everything that is involved in doing so.

Conclusion

Important takeaways from this research is that the product should be easier to transport in a bag (decrease weight and size) and minimize the required effort for (un)packing and setup by limiting the number of separate accessories and required user actions. Furthermore, the product should be aesthetically pleasing for the target group.

Current scenario having a laptop stand

Packing bag → **On the go**

Actions

Either have your bag ready from the last day or pack it with at least:

- Laptop
- Laptop sleeve (opt.)
- Laptop stand (opt.)
- Laptop stand sleeve
- Keyboard
- Keyboard sleeve (opt.)
- Mouse
- Laptop charger

Complaints

The stand is inconvenient (in shape, size and/or weight) to transport together with all other accessories, resulting in a mess in the bag or the stand being left at home

"I have a laptop stand for a while now but I don't use it, only sometimes at home, but it's too big and inconvenient to take with me."

"Thin and light, those things I find important, so I can bring it in my bag."

"Since a week I have a laptop stand now at home and a separate keyboard, but I don't take it with me to the TU because it's too big and heavy and takes too much space in my bag."

It's difficult to get anything out of the bag which is not part of the ergonomic set

"My headphones always get stuck when I try to get them out of my bag, because there are too many items in my bag."

Setup

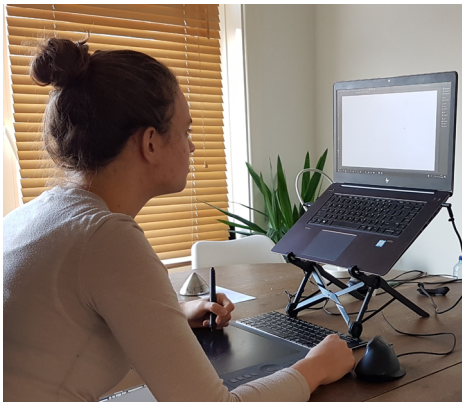
- Open bag and get everything out
- Remove sleeves from laptop, stand and keyboard
- Deploy the laptop stand and set to required height
- Place the laptop on the laptop stand
- Connect keyboard, mouse and charger
- Put sleeves back in the bag

It takes much time to set everything up due to the number of necessary products and the working mechanism of the stands

“It feels a bit silly when you are getting all these things out of your bag, just to work for a little while.”

Working

- Pay attention to posture
- Take regular breaks



Users do not feel comfortable using a laptop stand (bad aesthetics) and the stands do not support them enough in having an ergonomic posture

“It looks ridiculous.. Then I feel like a loser. If the laptop stand would be more aesthetically beautiful that would be better.”

“I can’t see what’s on my screen because I have my tablet, and then my keyboard and then the laptop stand, so it’s too far away. Then I’m automatically bending over, which is not good of course..”

Leaving

- Get the sleeves out of your bag
- Remove laptop from stand and put in it’s sleeve
- Put the laptop in your bag to create some space
- Put the laptop stand and keyboard in their sleeves
- Put laptop stand, keyboard and charger in your bag

Again, the stand is inconvenient to transport, which is especially annoying when you are in a hurry

“It’s a hassle to set everything up, then pack it all in my bag, set it up somewhere else and pack it in again during the day.”

"I often end up pushing everything in my bag because it doesn’t really fit and I’m in a hurry."

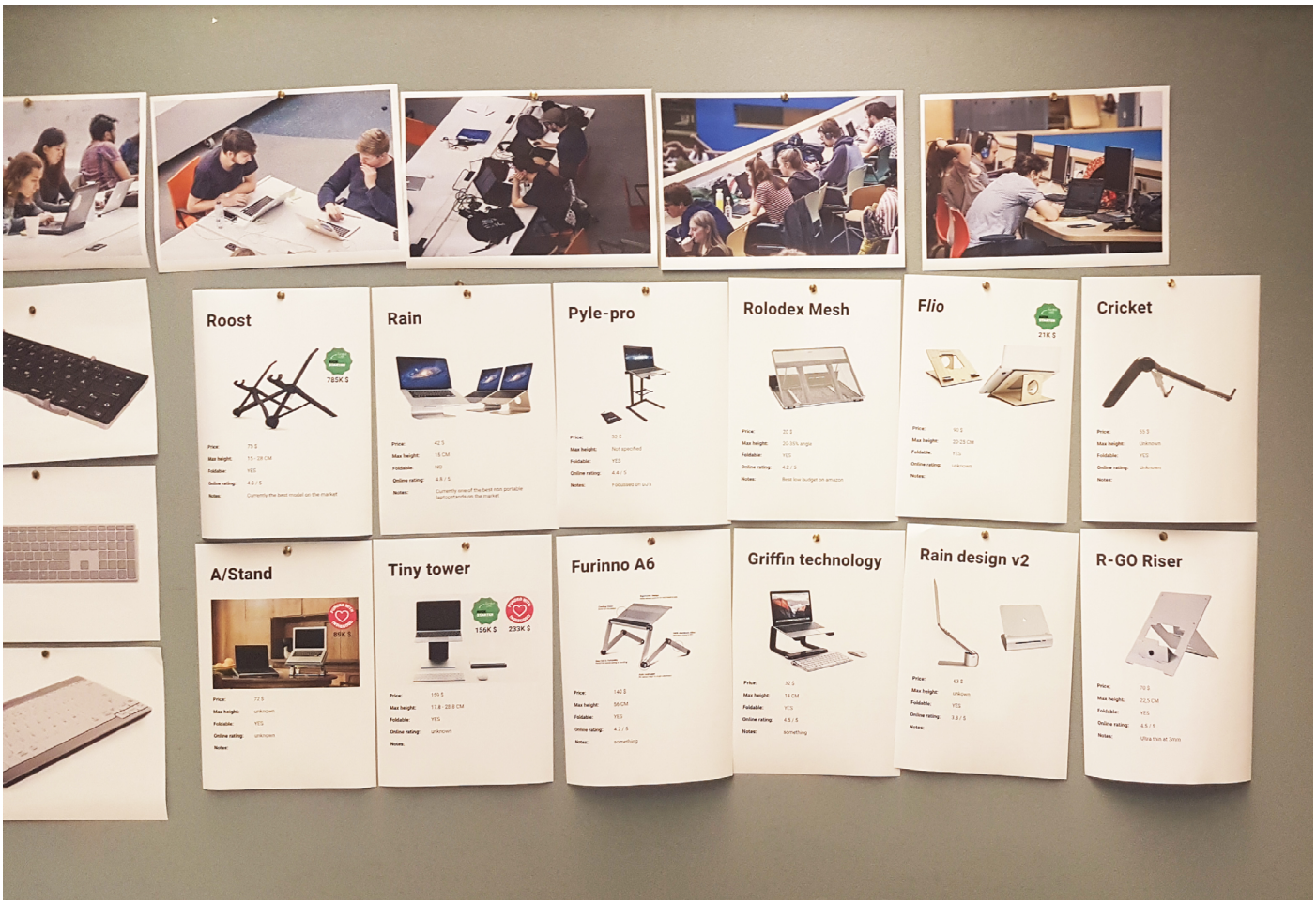


Figure 8: Overview of competitive products

1.4 Market analysis

As this project has an entrepreneurial basis, it is important not only to find out the needs of users, but also how competitive products are positioned and how a new product can be distinctive with unique selling points.

Competitors

Since the magnitude of the MSD problem is extensive, plenty of companies are providing ergonomic solutions. As the focus of this project is on laptop ergonomics, the main competing products are laptop stands. In the future this may no longer be the case if different devices or technology make laptops redundant. However, this is not expected to happen in the next 5 years, which is enough time to launch and sell the product.

The top 9 most competing products are displayed (figure 9-17). Based on an analysis of online descriptions and customer reviews on Amazon, Bol.com, Kickstarter.com, Indiegogo.com and Ergowerken.nl, they have been graded on four categories; price, aesthetics, ease of use and quality.

Cricket
The cricket is a compact and robust looking laptop stand that comes quite cheap at around €30,00. Due to its low price-point it is quite a popular choice for students. The largest drawback is the lifting height; at a maximum of 15 cm it is not really an ergonomic solution. Additionally, users are easily tempted to type on the, now tilted, keyboard, which only worsens the situation.

Figure 9: Cricket

Rolodex Mesh
This product is one of the cheapest on the market at €20,00. Due to its mesh it makes sure the laptop still cools properly and it folds in nicely and flat. The aesthetics and build quality are the biggest reasons for users not to buy this product.

Figure 10: Rolodex mesh

Roost
The roost laptop stand is arguably the best laptop stand available for digital nomads (see glossary, page 108). Coming in at €80,00 it is quite expensive for its plastic construction, but it is fantastic at what it's build for, a truly ergonomic laptop stand that is light weight,

Figure 11: Roost

reliable and quite small when folded. The biggest drawbacks are potentially the price and for some the aesthetics. According to someone it looks like ‘dental braces for a laptop’.

Figure 12: Rain v1

Rain v1 & v2

The rain product stands are very popular among apple users. They go for a respectable, and understandable price of around €65,00 Euro. They are good at what they do, easy on the eyes and go nicely together with Macbooks. Biggest problem with this product is its rigid shape, which is basically impossible to bring along (every day).

Figure 13: Rain v2

Tiny Tower

The Tiny tower is from a new start up company that has just finished their kickstart campaign. They are asking quite a bit more than the rain laptop stand, €100.00 - € 150.00, but definitely add something to the table, a combination of the aesthetics of the rain laptop stand with the functionality and transportability of the Roost. The product hasn’t been shipped yet, but it is definitely looking promising.

Figure 14: Tiny tower

F/io

F/io is also a recent kickstart project using wood laser-cutting as their main production method. This causes a natural and beautiful look. However, setting up the product is rather complex compared to the alternatives. Besides, it is quite expensive for what it offers at €90,00.

Figure 15: F/io

Furinno A6

The Furinno is quite different from its competitors, mainly due to its size. However, with an acceptable price of just under €50,00 it holds a nice niche spot. The width of the stand is almost 50cm and it can go up to 60cm as well, allowing the user to switch between sitting and standing. The biggest drawbacks are it's size and weight of 2kg.

Figure 16: Furinno A6

A/Stand

The A/stand is also new in the market and focusses heavily on multitasking. Introducing different working heights, cup holders and an iPad case all in one, it seems to offer a lot. The functionality comes at a price though, its design is quite messy with the use of many different and incoherent shapes and colours. It is also quite a thick package at just over 2 cm.

Figure 17: A/stand

Conclusion

Looking at these competing products, the market for laptop stands seems fairly satisfied, especially when considering that this is just a selection of successful products in the market. It is interesting to notice that most of these products have found their own niche, for example focussed on apple users at home, students with little funds, techy life-style, actually being ergonomically correct etc.

However, none of the competitors seem to focus on providing the complete package of working ergonomically, but rather just a laptop stand. By only focusing on making their laptop stands better, smaller and lighter, they are overlooking how the product affects interactions with the user during other use stages, as was discussed before.

Besides, some laptop stands do not even reach the required height for having an ergonomic posture (e.g. by only lifting the back of the laptop). Also, they are not suitable and specifically made for combining it with other accessories (i.e. not allowing the right eye-screen distance when keyboard/tablet is placed in front of the stand).

Figure 18: An example of TU Delft students working non-ergonomically.

1.5 **Problem definition**

A laptop allows people to be very flexible in where and how to do their digital work. However, due to the way a laptop is build, it is not a good product from an ergonomic point of view as it forces users to look downwards while working. This often causes muscoskeletal disorders as concluded by (Cagnie et al., 2007).

Due to the magnitude of the problem, there are multiple accessories like laptop stands on the market that should support the user in working ergonomically. However, in practise these products are often not used (figure 18).

According to a survey among 225 students and 4 qualitative interviews, this is mainly due to the fact that laptop stands are a hassle to use. Laptop stands seem to be designed with only the product in mind rather than the complete journey around it. First of all, they are inconvenient to transport due to the size and weight in combination with other accessories. Secondly, setting up a workplace takes too much effort and time because of the number of accessories (i.e. laptop, keyboard, stand, mouse etc.) and required actions to deploy the laptop stand.

Besides, in most cases the laptop stands do not even allow the user to have an ergonomic posture, since having a keyboard and/or drawing tablet in front of them puts the laptop (stand) too far away from their eyes, causing users to lean towards their screen.

Lastly, users find existing laptop stands not aesthetically pleasing, making them feel uncomfortable or awkward while working.

This problem definition leads to the design goal of this project:

"The goal is to design a laptop stand that makes it easy for users to work ergonomically, without losing the flexibility and appearance of a laptop."

Minimizing the amount of effort and time required to work ergonomically is a key aspect for this project.

Figure 19: List of requirements (van Boeijen et al, 2014)

1.6 **Requirements**

The final product should meet certain standards and goals, which are based on research insights of this project. These have informed design decisions during development.

A process tree has been created in order to ensure a complete list of requirements (van Boeijen et al, 2014; Roozenburg & Eekels, 1998). The process tree can be found in appendix 2. The four most important requirements that define the key aspects of the product will be discussed here. The remaining requirements can be found in the list of requirements in appendix 3.

Key requirements

The laptop stand can be setup starting in a bag in less than 15 seconds (R1.8).

This is by far the most leading requirement of this design project. During research everything pointed towards “it’s too much of a hassle” or “it takes too much time” to work ergonomically with a laptop. By taking this pain point away the laptop stand secures a very strong position in the current market.

The laptop stand allows the P90 of users to work on a 15” laptop without exceeding 10° neck flexion (R1.1).

The laptop stand should allow as many people as possible with varying length to work ergonomically, which means that the screen needs to be at or slightly below eye height. So although this requirement may seem generic, it is quite an important one. The laptop stand will specifically be designed for a 15" Macbook Pro 2017, but could be used for other 15"+ laptops as well.

The laptop stand allows the P90 of users to have a distance between their eyes and the screen between 380 and 620 mm (R1.3).

Research showed that people often have other stuff in front of their laptop (e.g. a drawing tablet) next to a keyboard. This causes the laptop to be placed too far away, resulting in users bending over to see everything on their screen, effectively ruining their ergonomic posture.

80% of people rates the aesthetics of the product at least an 8 out of 10 (R4.3).

The aesthetics of a laptop stand was found to be an important aspect when acquiring one. Existing laptop stand often lack this, making users resistant to buy one or feel insecure when working with them. By designing an aesthetically appealing product this could be solved.

When discussing the design process, there will be referred to the relevant requirements by R##.

Important to note is that in this project, decisions are based on a first production batch of 100 models to test and validate the product in the market. If product numbers significantly influenced the design, production or material, alternatives are mentioned.

“The goal is to design a laptop stand that makes it easy for users to work ergonomically, without losing the flexibility and appearance of a laptop.”

Chapter 2.

Design and validation

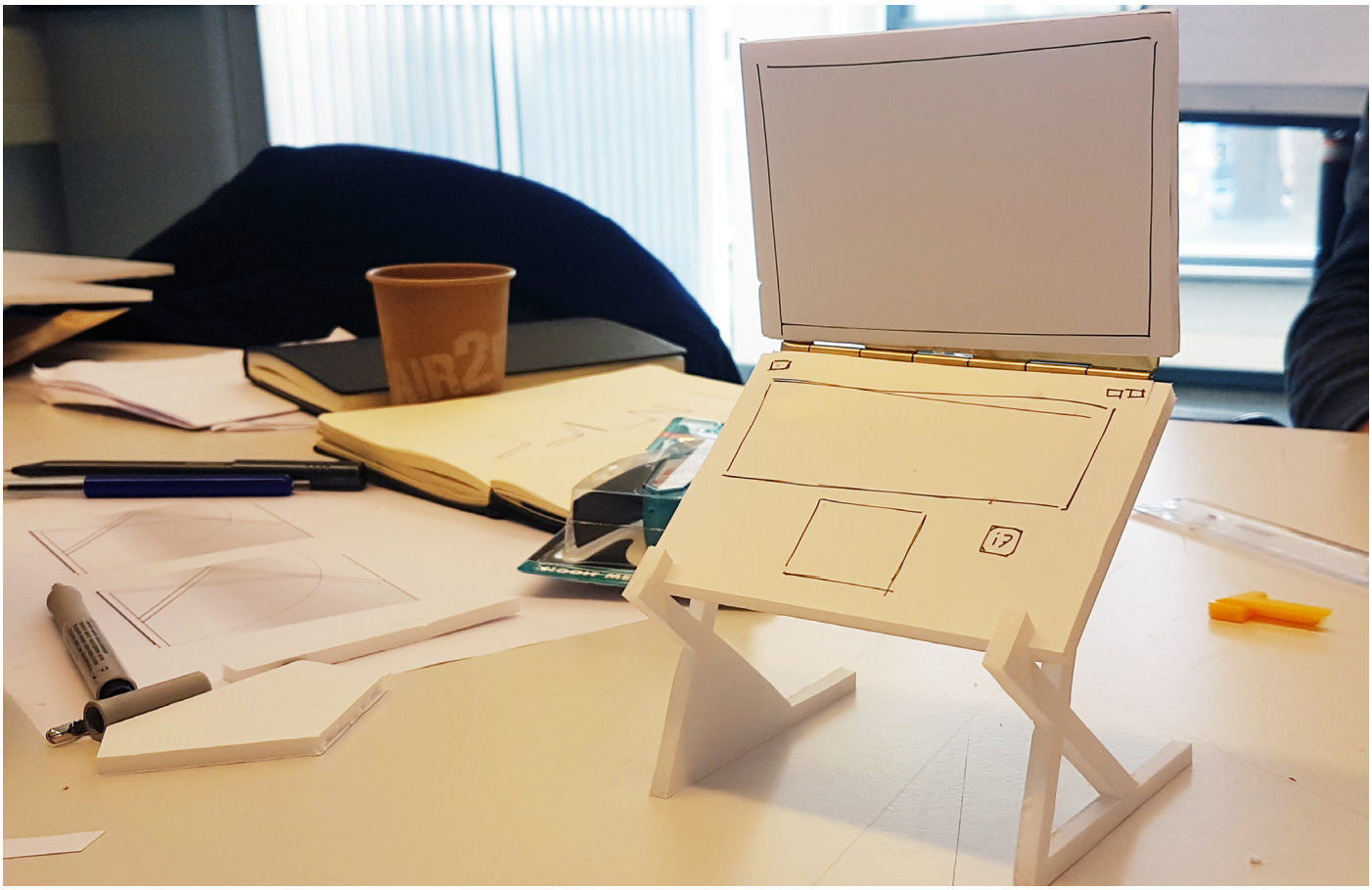


Figure 20: Paper protype

2.1 Concept introduction

The goal of this project is to design a laptop stand that allows flex workers to easily work ergonomically, without losing the flexibility of their laptop. The laptop stand should make sure the user can work ergonomically in different places, whilst allowing the user to setup and leave their workplace in seconds. Additionally, the product should be aesthetically appealing in order to make the user feel confident (rather than insecure) in using the laptop stand.

Ideation

The initial idea for the laptop stand stems from before this graduation project and emerged during the course Build Your Startup, that was done together with Igo Boerrigter. During ideation brainstorms, we realized that most of the products that are required to work ergonomically are or could be flat: the laptop, an external keyboard, the covers and the laptop stand itself.

Consequently, by combining these products, it should be possible to create one complete package that makes working ergonomically easier for each use stage: from purchasing an ergonomic set (all at once), to transport (less space required and an organized bag), setup/pack up (quick and effortless) and working (ergonomically correct). Hereby the user would skip multiple steps that are required with current solutions.

This meant, however, that the product had to offer multiple functions; the stand had to reach ergonomic standards in height, could serve as a laptop cover and provided an external keyboard. Based on this idea, possible constructions were drawn. Figure 21 shows the first result: a laptop case that provides the ergonomic tools required to work ergonomically in one flat package that fits underneath the laptop.

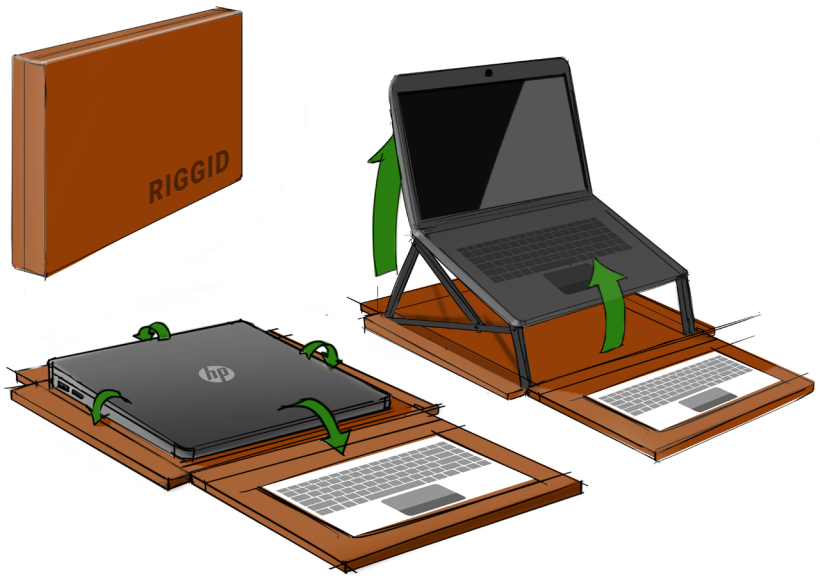


Figure 21: First idea

Simultaneously, opportunities towards furniture integration were explored, as it could be an ideal solution for universities. Due to a market that is difficult to enter and a bureaucratic sales channel this direction was discarded, because it did not fit the scope and purpose of the project.

Continuing on the laptop stand, the initial sketch was shared and discussed with a few potential users to make sure the idea was going in the right direction. During these short and informal conversations it turned out that the thickness of the package could be a potential issue, as people would no longer be able to store their laptop in the laptop specific section of their bag. However, the overall concept was perceived as very promising, both by users and tutors.

In a follow-up brainstorm, the keyboard was moved beneath the laptop to save almost an additional 10 mm in thickness in the design (figure 22, early concept sketch). Instead of a hard case, as seen in figure 21, the top of the laptop would be protected by a leather or textile cover during transport.

Conceptualisation

In the first steps towards a concrete concept, the technical feasibility was tested against the most important ergonomic requirements for a laptop stand with a short feasibility study based on literature and online research.

Figure 22: Early concept sketch

1. Lifting the laptop screen to the required eye-height

According to Suebsak et al. (2015), neck flexion that exceeds 10 degrees correlates with increased MSD and according to Villanueva et al. (1996), lesser neck flexion is beneficial in general. Therefore it is decided that the minimum height of the laptop stand is build to reduce neck flexion to a minimum for as many people as possible, while never exceeding the 10 degree neck flexion for the P1-P99. Based on Dined (m&f, age 20-60, eye-heigh while sitting) the following numbers are found (figure 23-26):

P1: 693 mm
P5: 725 mm
P95: 879 mm
P99: 911mm

In figure 27, the different variables are visualized in a simplified overview of a human working on a laptop. In the figure you can derive the minimum required height (raise) of a laptop to be 280 mm, considering a 15” laptop and the P99 eye-height while

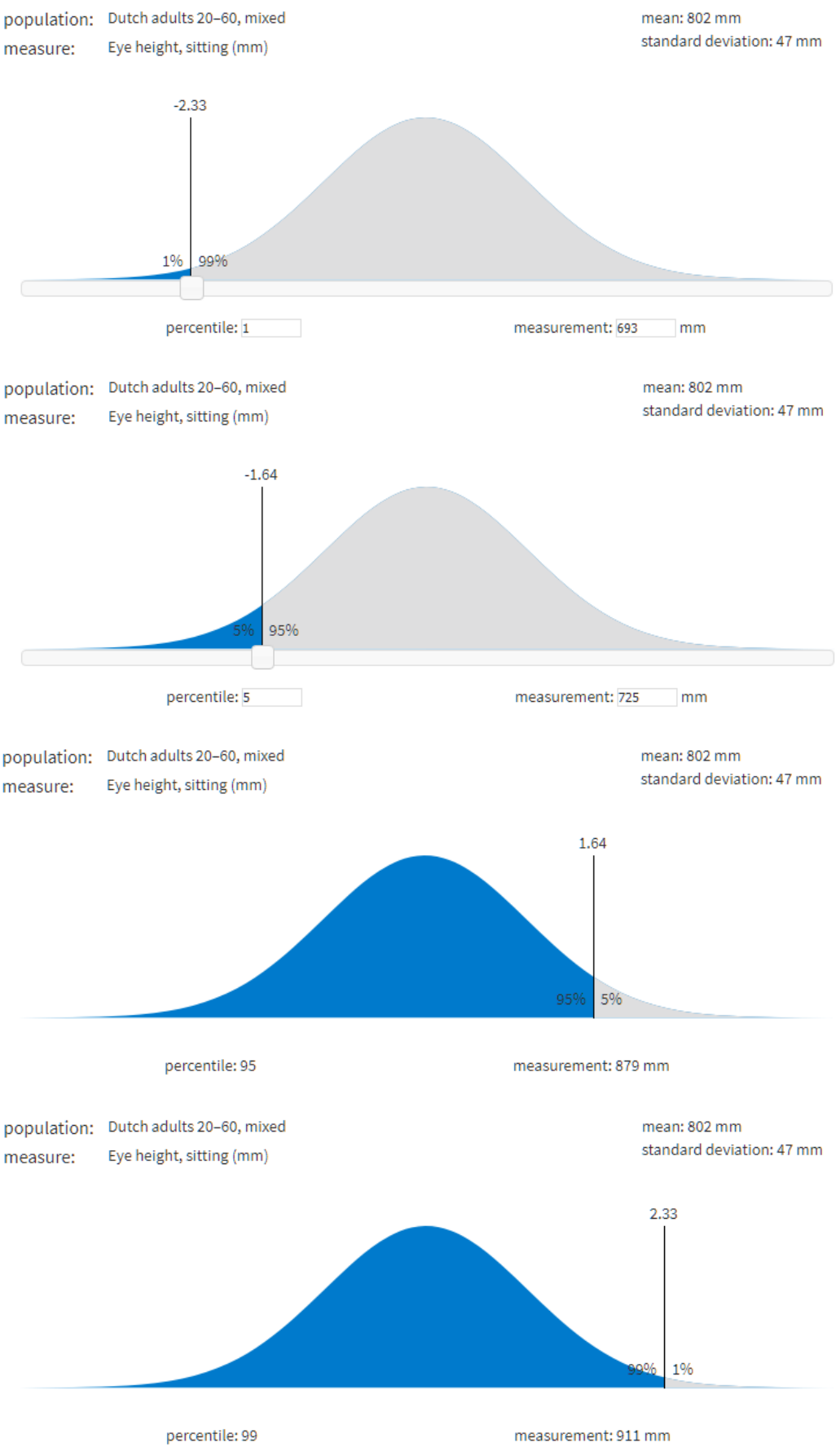


Figure 23 - 26: Percentiles 1, 5, 95 and 99 for eye-height while sitting (dined, m/f 2004, age 20-60)

sitting. This means the bottom of the laptop screen needed to be lifted at least 280 mm from the ground. This forces the front of the laptop to be lifted as well. The overview assumes that users do not lower their eyes but actually bend their neck. It is difficult to determine whether this is actually the case, but by assuming so, the real life situation could only be better than the theoretic one.

2. Allowing for optimal eye-screen distance

As indicated earlier, the optimal screen distance varies per person and situation, lying between 380 and 630 mm (Saito et al. 1997) (figure 27; minimum required screen raise). For some situations, the user needs to be able to place the laptop closeby (380), for example during graphic design work where they have to see details, and for other situations the laptop can be comfortably placed further away, for example for computer work such as word, excel or mailing. The effects of these viewing differences are visualized in figure 27 and are taken into account when determining the minimal screen lift.

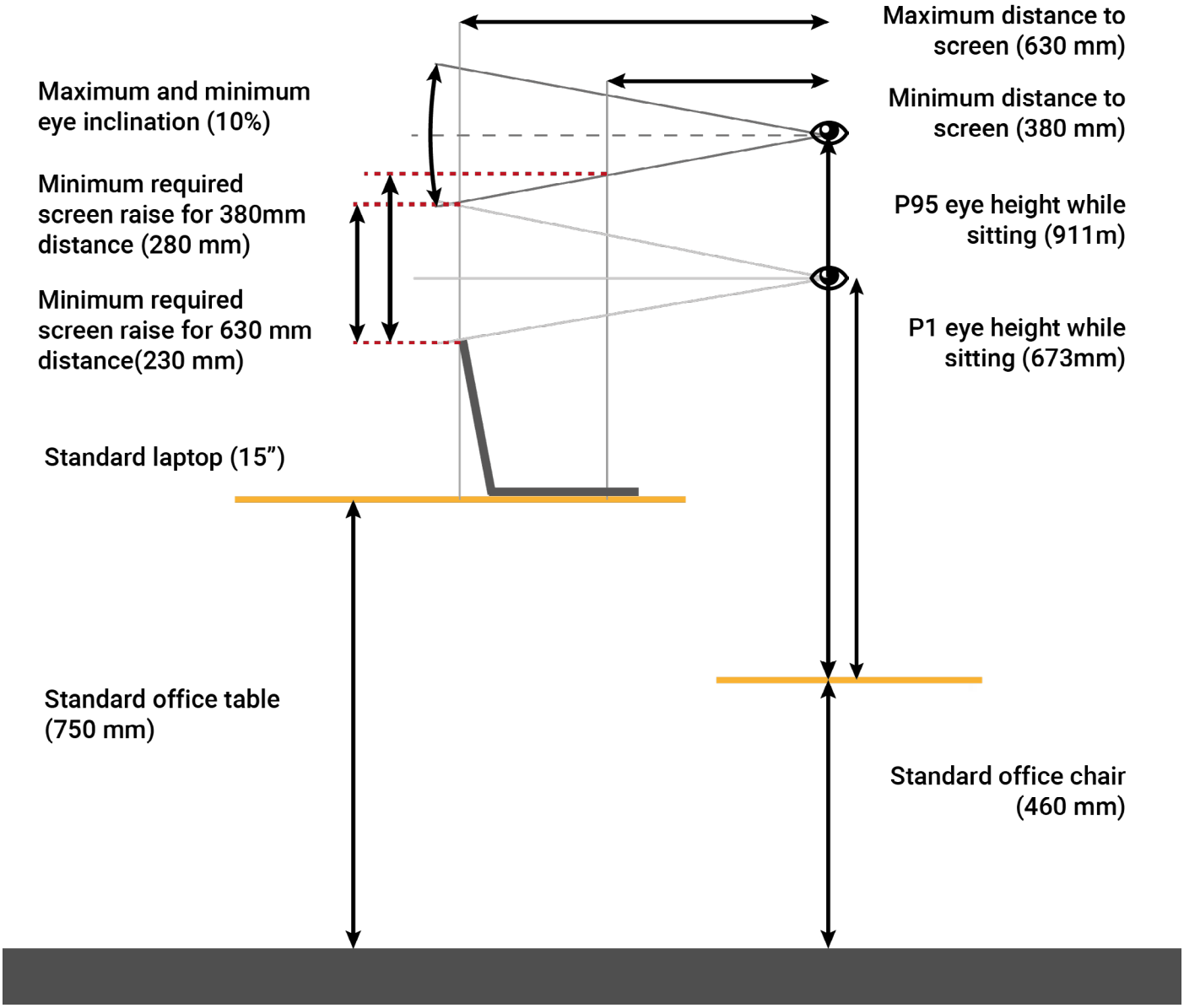


Figure 27: Minimum required screen raise

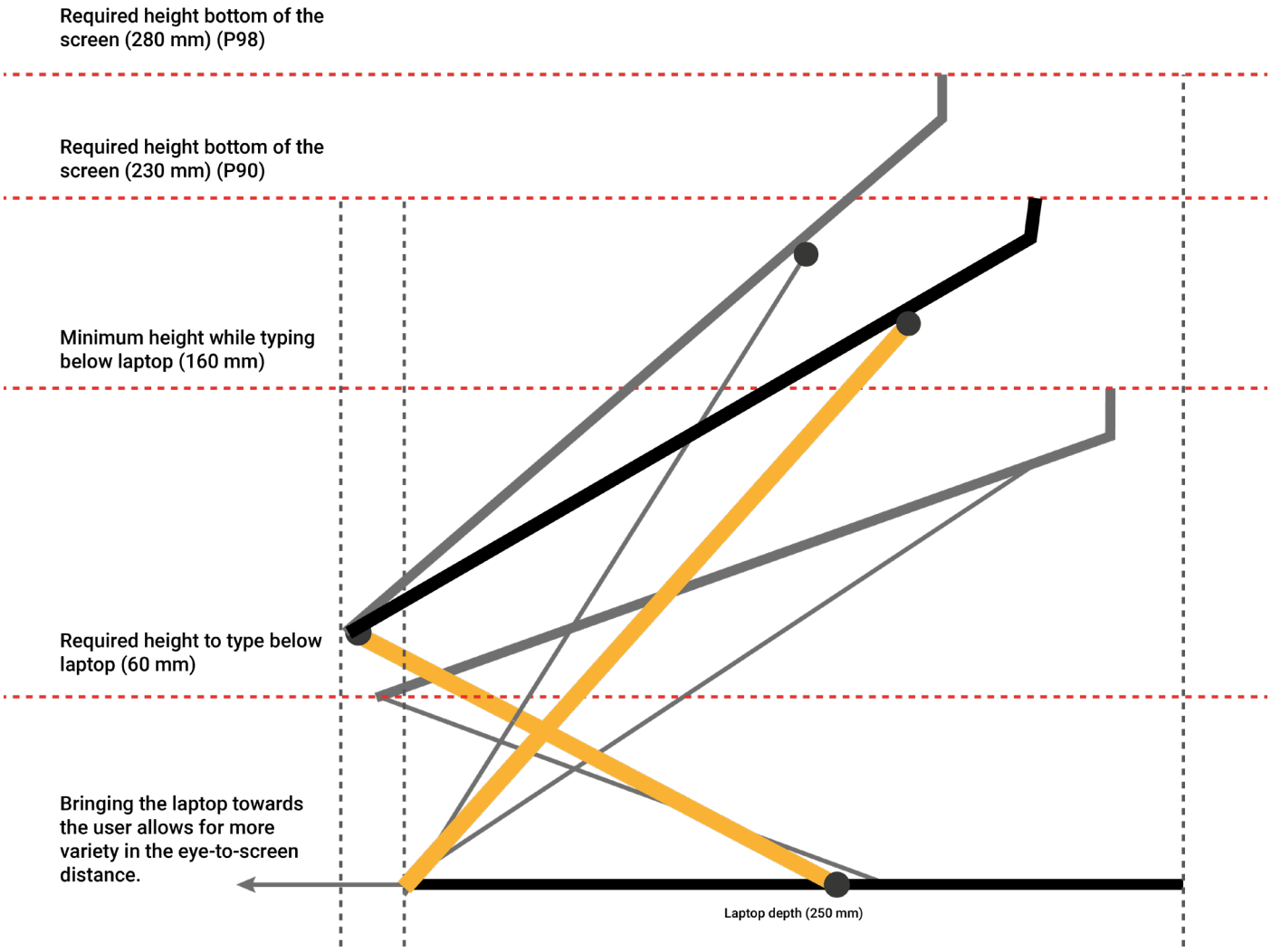


Figure 28: Billboard construction try-outs

3. Allowing different height settings

Technically speaking there is no direct need to have adjustable height settings. As can be seen in figure 27, if the laptop is raised 230 mm it allows almost all users to work according to ergonomic standards between 380 and 630 mm distance to the screen. However, due to preferences of users, an adjustable height option would increase the use and benefits of the product. It would allow to decrease neck flexion to significant less than 10° for almost all users and it would completely remove the need for some users to look upward to their screen, something that feels very unnatural in a standard work setup. Moreover, it allows users to adapt their workplace in case desk heights differ in different places, which happens regularly.

Exploration

To explore different possibilities within the design parameters, a notice board is used along with cord and thumb tacks to quickly make multiple iterations on possible structures. In figure 28 a graphic representation of this notice board is shown, which includes the final design; a simple two slider mechanism that brings the laptop closer to the user, reaches the required height for P98 of users and allows the user to type underneath the laptop stand (saving space) as long as the laptop is lifted to a minimum of 60 mm.

Continuing on the theoretic construction, multiple prototypes where made to test for reliability and some hands on experience of the structure (figure 29). During these tests it was also decided to bring the maximum height of 280 mm back to 230 mm, at least for prototyping, because the stability of the construction quickly falls off when pushing the laptop stand above 230 mm. The additional 50 mm in height does not offer enough benefits for prototyping and testing purposes to increase the risk of mechanical and or material failures.

During Build Your Startup the concept phase was finished with a prototype from wood and aluminium that was capable of holding a laptop raised to 230 mm (figure 29, prototype in the back; figure 30). At this point, the product could only be set in a certain position and was not yet easy to use, nor did it incorporate a laptop cover.

In the following parts of this report, the further development, detailing and optimisation of this product is explained in detail.

Figure 29: Early construction prototypes

Figure 30: Build Your Startup final prototype

Figure 31: Isometric view of laptop stand in folded position

2.2 The laptop stand

Over the course of this project many iterations were done on the previously discussed concept to achieve the desired design. Since the basis of the construction was already determined during Build Your Startup, the focus of this project is mostly in optimizing the product in detail.

Breakdown

For clarity of the report and to be able to explain design decisions and details for each part, the laptop stand is broken down into eight sub-assemblies. These sub-assemblies, however, are not necessarily designed in the presented order in this report. Besides, some features and solutions are dependent on other parts or components which influences the design in a specific way. When relevant, this is indicated. The different sub-assemblies and their function(s) are:

1. Base plate
The base plate is the main component of the product and the framework in which the different mechanisms are built. It is also the main form factor of the product and therefore for a large part responsible for the look and feel.

2. Sliders
The sliders form the main construction together with the base plate. They allow the laptop to be elevated.

3. Lifting mechanism
The lifting mechanism makes sure the laptop can be lifted upwards comfortably. As indicated in the requirements, the aim is to be able to lift the laptop without significant physical force and within a few seconds.

4. Front grip
Due to construction of the laptop stand, there needs to be a way of keeping the laptop in place. This part is referred to as the front grip.

5. Locking mechanism
The locking mechanism ensures the laptop stays in the desired position when folded.

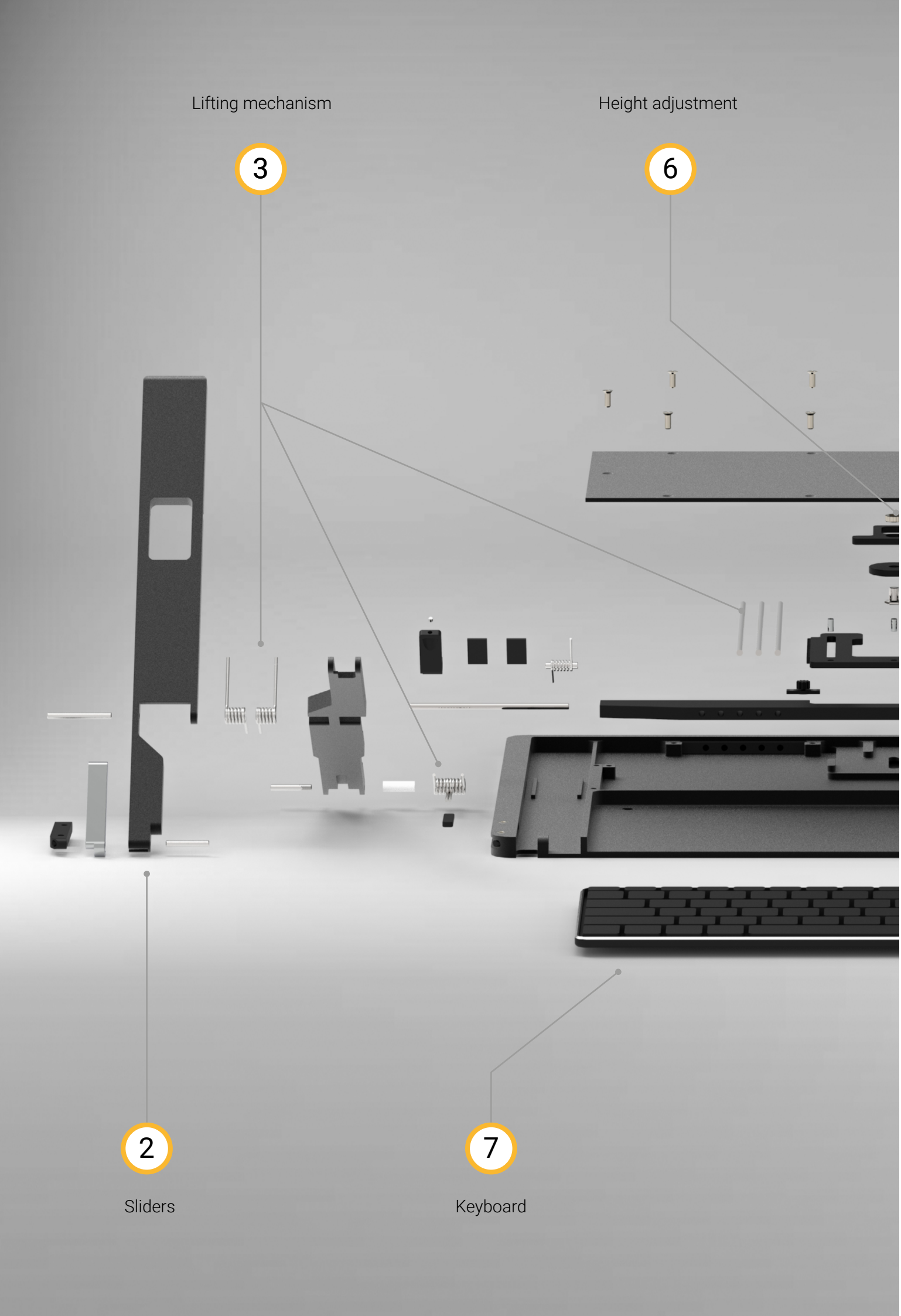
6. Height adjustment
The height adjustment feature allows the laptop stand to be used in different height settings.

7. Keyboard
The integrated keyboard allows for typing with the right eye to screen distance. Additional parts make sure the keyboard is locked in place during transport.

8. Cover
The cover included in the product allows for quick setup and protects the product and the laptop during transport.

In the following chapters these sub-assemblies will be discussed in detail, highlighting design criteria, solutions, decisions and validation. Technical details can be found in the appendices.

On the next two pages an exploded view of the final product is shown.


Lifting mechanism
3
Height adjustment
6
2
Sliders
7
Keyboard


Front grip
4
1
Base plate
5
Locking mechanism

Figure 32: Final design base plate

Considerations

+ Integrating different features in the plate increases assembly speed and reduces part count
+ Aluminium makes sure the base plate is relatively light, strong and aesthetically pleasing

- Expensive production due to the amount of milling required

2.3 Base plate

The base plate of the laptop stand is the housing for all other components. It provides strength throughout the product and ensures a stable basis for the sliders.

Design criteria

While designing the base plate, special attention has been paid to the following design criteria:

Ease of assembly (R3.2)
Because the base plate connects to many different components, the ease of assembly is important for determining the best solution.

Production (R3.1.1)
Since production methods determine the freedom in design, the producibility has been considered consistently during the design process. The production method also influences the initial cost vs the price per part significantly which is considered in decision-making.

Part count (W3.4)
Because the base plate is inherent complex, adding additional complexity was considered favorable over adding more parts as it would not significantly influence production cost.

Design process

Throughout the entire project the base plate has been adjusted the most of all parts, due to its connection with (and therefore dependence of) almost every other component of the laptop stand. Whenever a new iteration of another component was made, the base plate had to be adjusted as well. The principle 'form follows function' was continuously applied to determine the final design.

Because the different changes are largely based on adjustments from other sub-assemblies, details will be described in corresponding chapters. Up to the final version, three large iterations are made which can be seen in figure 34-36.

Iteration 1
The first iteration of the base plate (figure 33-34) is based on the idea of a lightweight and stiff product basis. By using ribs the stiffness is ensured while keeping weight to a minimum (R2.6; R2.5). However, it soon became clear that this lay-out made it nearly impossible to place other components due to a lack of space. Additionally, dimensions of the keyboard changed and the sliders had to be connected to each other (discussed in chapter 2.4).

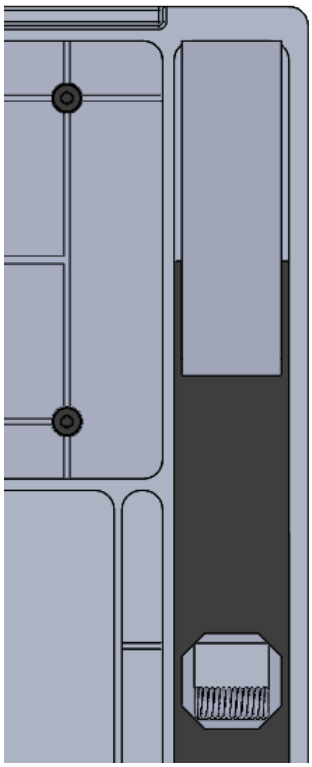


Figure 33: Components in iteration 1

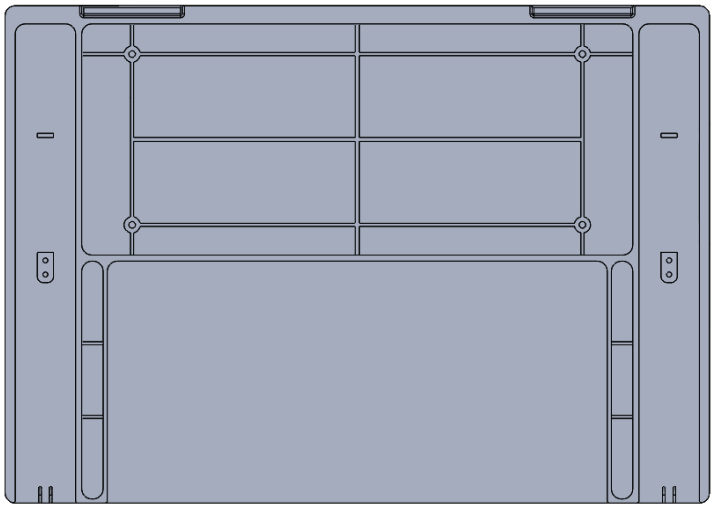


Figure 34: Base plate iteration 1

Figure 35: Base plate iteration 2

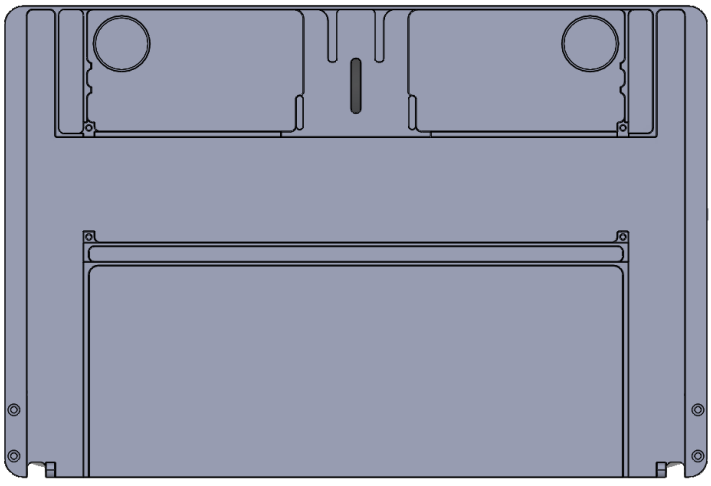


Figure 36: Base plate iteration 3

Iteration 2
By changing the position of the sliders, the keyboard and the ribs, space opened up for adding other components. For example, at the outer sides of the base plate two cavities became available and the middle section was cleared to connect the left and right slider combination (R2.3).

Compared to the first iteration only two aluminium strips are connecting the left and right side, making it very fragile for buckling. Therefore, the design had a very low overall stiffness, making it difficult to meet R2.6. Additionally, the design deemed insufficient because the lack of linear spring support (see chapter lifting) and complex tiny mechanisms (figure 37) which did not show much promise on paper (see chapter 2.7).

Iteration 3
After the second iteration the aim was to further increase stiffness and improve on the placement of the connecting components.

Partly due to a large change in the lifting mechanism (i.e. large flat torsion spring in the middle back of the product), the design of the baseplate evolved along. The sides of the product are kept solid for rigidity and a few ribs are added to make up for the loss of stiffness from the second iteration. Additionally, a supportive system (stability slider) is added in the middle which allows the sliders to be connected to each other and remain at the same height (R2.3).

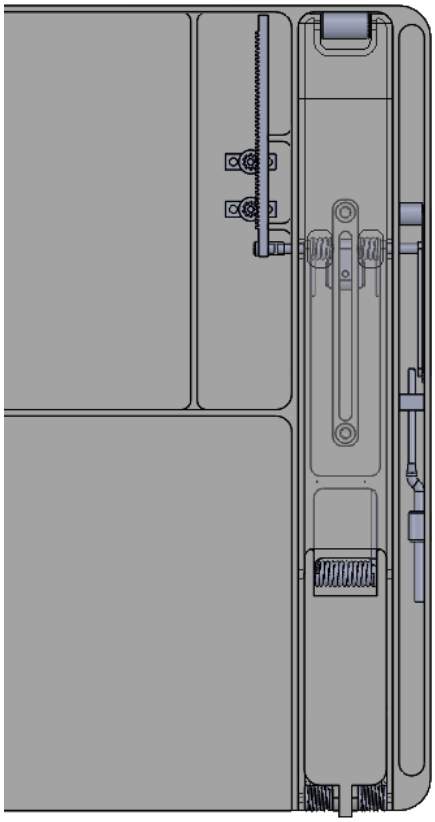


Figure 37: Components in iteration 2

Despite meeting the individual requirements for the base plate (R2.1-2.10), due to insufficient spring force from the large torsion springs (R2.11) a last iteration was made which resulted in the final design.

Final design

The final design supports both torsions springs and linear springs (see chapter lifting). It is optimized for easy assembly by embedding screw holes for the top plate [1], component placeholders for keeping the spring axles in place that connect through their form (no further assembly required) [2,3] and one-way part placement (components can only be placed in one way, which avoids wrong placement during assembly) [4,5], meeting R3.2.1 and W3.2.2.
An overview of all features of the base plate can be found in appendix 5.

Because the first model will mainly be used for testing purposes, the final design is only partially optimized for weight. Especially, in the sides and base thickness the weight can be further reduced.

A top plate (figure 39) covers the internal components (middle slider mechanism, linear springs, height adjustment) and offers a personalized surface (e.g. for branding) (R1.10, R4.6). Moreover, the top plate functions as a way to keep components in a horizontal plane, which specifically applies to point [2,3,4 and 5] in figure 38.

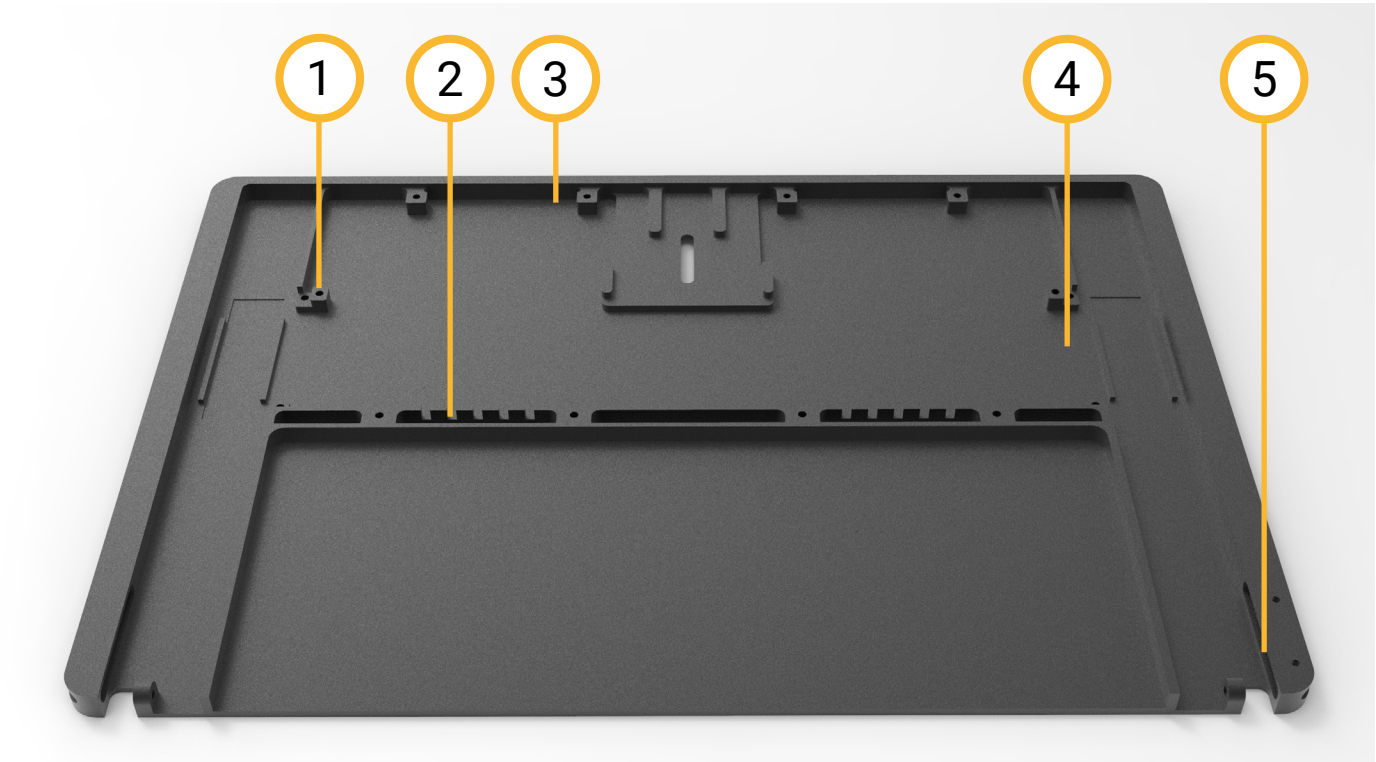


Figure 38: Final design base plate

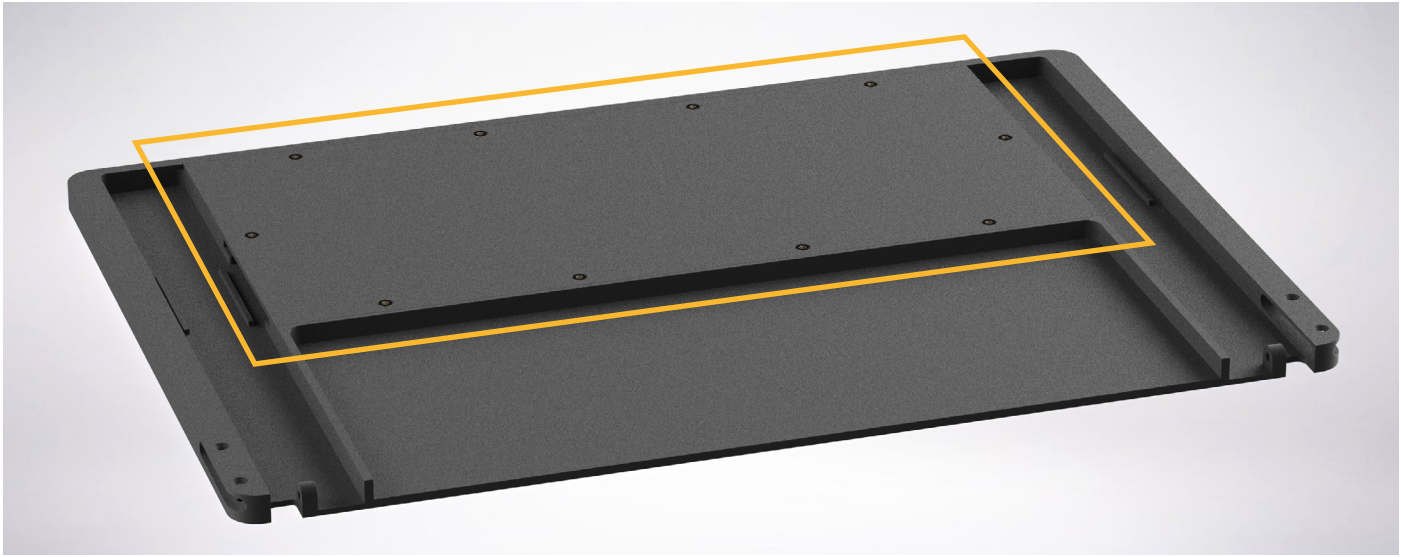


Figure 39: Top plate

Production & material

For choosing the best manufacturing method, the following requirements are taken into account:

- R3.1: Price
- R3.1.1: Tooling cost
- W4.7: Material finish

Due to the geometry and requirements of the base plate, 3D metal printing, CNC machining, die casting or injection molding are available manufacturing methods that are capable of producing the base plate. CNC machining was chosen to be the best manufacturing method because it was the cheapest option for smaller production batches. However, if the part is produced in large numbers either die casting or injection molding can be significantly cheaper. Because CNC machining is chosen, the features of this part are all optimized to be made with a minimal number of different routing bits. In this case a 12 mm routing bit is used for the main features, while all details can be done with a 3 mm routing bit. This reduces manufacturing time and lowers employee cost.

When choosing the right material for the base plate the following requirements are taken into account:

- R2.5: Weight
- R2.8: Strength
- R2.6: Stiffness
- R3.1: Price
- W4.7: Material finish
- W3.1.2: Machinability

From these requirements stiffness is the most critical one because the base plate has large thin areas that are likely to deflect. As the aim is to reduce weight as much as possible, the specific stiffness (Young's modulus / weight) is used as a main parameter for selecting materials. When plotting specific stiffness against price in CES (Cambridge Engineering Selector 2018) (figure 40), the materials in table 3 are selected based on excellent specific stiffness and a relatively low price.

	Cast iron EN GJN HV350	Alu 518, F	Alu 6082-T6	TRIP Steel, YS450	PA66 (40% long carbon fiber)
Specific stiffness (MN.m/kg)	24-28	27.6 - 28.8	25.0 - 27.5	24.3 - 29.4	22.0 - 29.0
Price (euro.e^3/m^3)	1.93 - 1.98	2.67 - 2.73	2.67 - 2.73	7.85 - 8.36	13.9 - 16.7
Tensile strength (MPa)	230-460	295 - 344	295 - 344	780 -900	297 - 320
Machining speed (mm/m)	14	104	101	20.7	unknown

Table 3: Material comparison on requirements based on CES

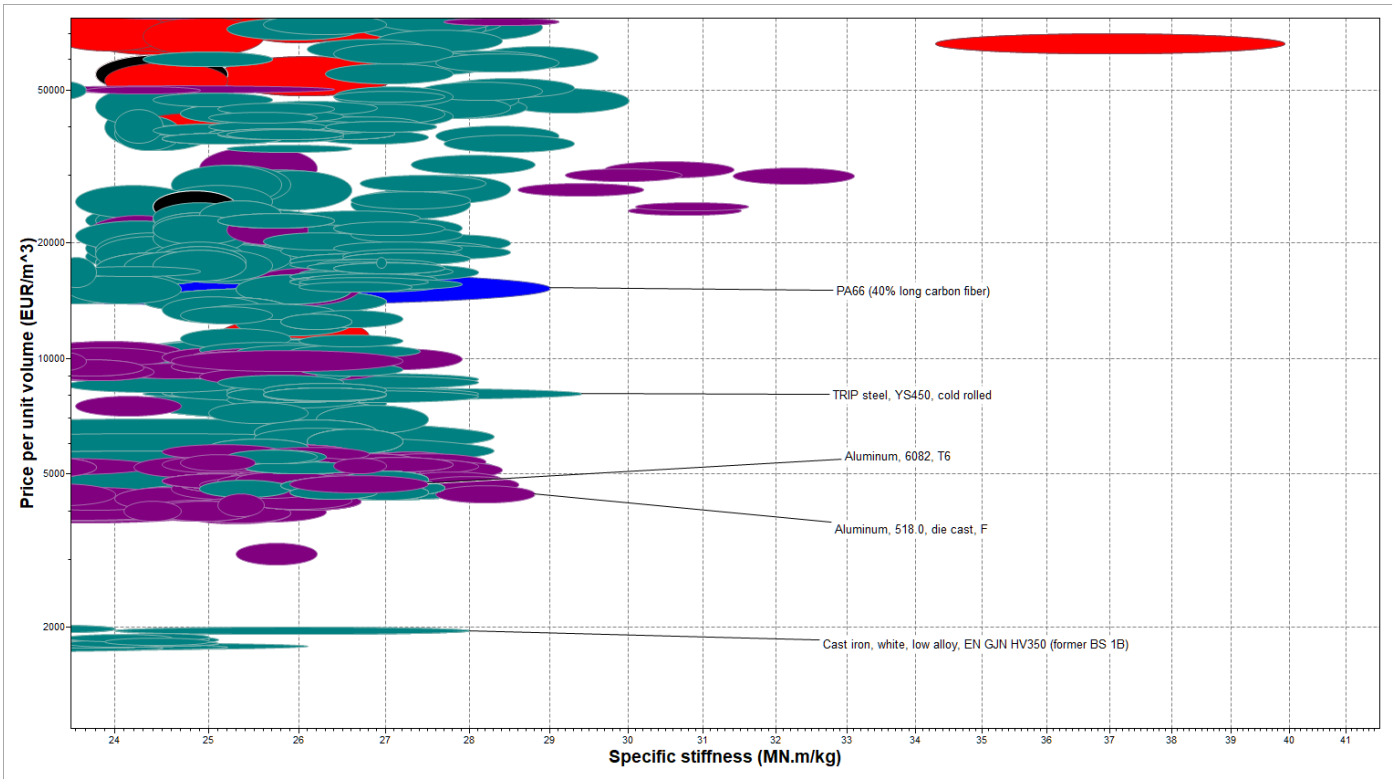


Figure 40: CES material selection; specific stiffness vs. price per m³

These materials are compared against the other requirements in table 3.

Despite Cast Iron EN GJN HV350 and TRIP Steel YS450 having their own advantages (respectively the cheapest and strongest option), they are disregarded because they take 5 - 7 times longer to produce (very low machining speed capabilities). PA66 reinforced with 40% long carbon fiber is also disregarded as the price is almost five times higher than aluminium, while there are no direct advantages.

From the two aluminium alloys the 518 F appears to be the best solution, but is only used for die casting. As a result the aluminium 6082-T6 alloy was chosen. This material is readily available, easy to manufacture and typically used for similar products (strong lightweight constructions).

If production numbers increases the aluminium 518 is an ideal alternative to aluminium 6082-T6 and due to very similar mechanical properties the design can remain identical despite a change in production method.

Validation

To be sure the base plate would not break or buckle during use, some SolidWorks simulations were run using aluminium 6082-T6. The two features that would most likely cause failures were tested:

1. Front connector
2. Deflection of entire baseplate

The simulations can be found in appendix 6 and show no further implications.

A discussion of the tolerances can be found in appendix 7.

Figure 41: Final base plate with slider system design

Considerations

+ Using a cross construction allows the back of the laptop to be lifted higher than the stand.
+ Mixing sideways and crossing sliders allows for optimal component support
+ By adding part complexity, assembly speed is improved and part count reduced

- The sliders require a lot of machining which pushes the cost price of the product

2.4 **Sliders**

The sliders are the main components that allow the laptop to be lifted upwards.

Design criteria

Along with the other requirements as described in the list of requirements (appendix 3), special attention has been paid to the same criteria as mentioned at the base plate: R3.2, R3.1.1, R3.4.

Design process

Because the available design space was limited by the outer dimensions of the laptop stand (R2.1) and the width of the keyboard (R2.4.1), the outer dimensions of the sliders were fixed and did not change during the design phase. However, the interaction between the two sliders, the lifting mechanism and the connection to other components where thoroughly explored. Along with many small adjustments, three pivotal iterations are made.

Iteration 1
The first slider design (figure 42) uses two sliders that perfectly fold into each other, opening up space for multiple torsion springs (see chapter 2.5: lifting mechanism) while maintaining a reliable appearance (R4.5.3). On the other hand, the design was limiting in the placement of other components and at places only a little material held the slider together.

The wall thickness, specifically at the point where an axle crosses ([1] figure 42), appeared to be one of the more pressing issues with this design. Therefore, a SolidWorks simulation was run to check the viability of the concept from a stiffness and strength perspective (appendix 8). This study showed the design would only meet the requirements (R2.7, R2.8) with a more expensive metal alloy such as aluminium 7075-T6. This would significantly increase the overall cost of the part (R3.1) and was considered unfavorable.

The viability of this concept was further reduced when the calculations of just the torsion springs proved insufficient (see lifting mechanism).

Thus, even though the slider system folds nicely in each other, the design was not good enough to meet all requirements.

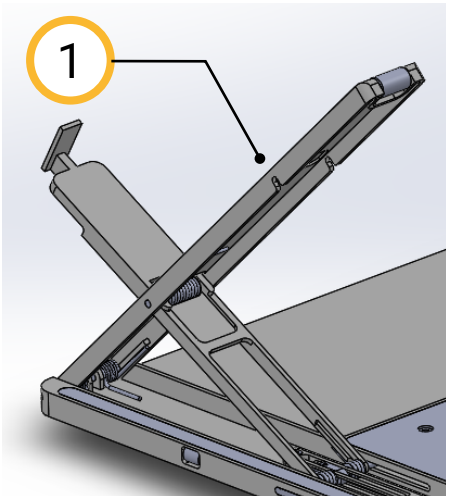


Figure 42: First iteration slider system

Iteration 2

In the second design iteration the sliders are simplified, resulting in two aluminium bars sliding next to each other instead of through each other (figure 43-44). This inherently reduces production time (R3.1, W3.1.3) and material cost (less material and therefore also less machining needed) (R3.1, W3.1.4, W3.1.2).

At the same time it also allowed for different design opportunities regarding the other sub-assemblies (e.g. locking mechanism and front grip), which will be explained in the corresponding chapters.

The main downside of this concept is the lack of space for enough torsion springs to lift, or "start" the initial elevation of the laptop (R2.11)(see chapter 2.5 lifting mechanism). The sliders would therefore not meet all requirements and a new iteration was made.

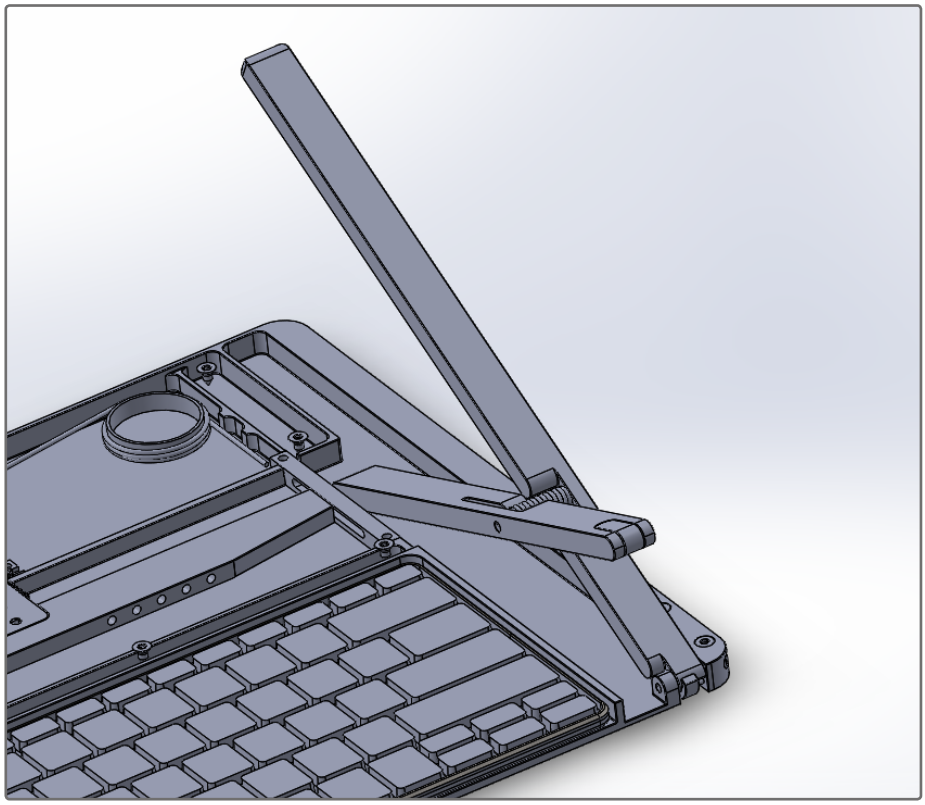


Figure 43: Second iteration of the slider system

Iteration 3

The third iteration (figure 45) is a combination of the “best” aspects of the previous two designs. The sliders will pass each other sideways partially but still fold into each other, allowing for enough torsion springs to start the initial laptop elevation (R2.11) and for enough space to properly integrate a front grip and a locking mechanism (R1.7, R1.6.1).

Additionally, the slider system became more stable (R2.13), because at the middle torsion spring the long slider encapsulates the torsion spring

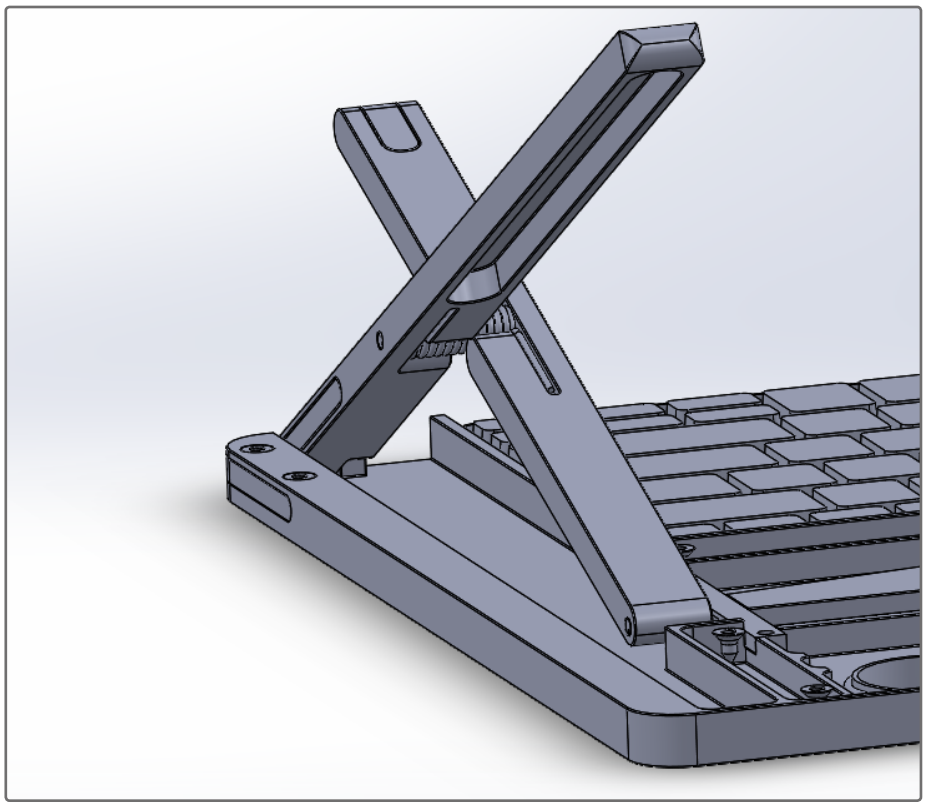


Figure 44: Second iteration of the slider system

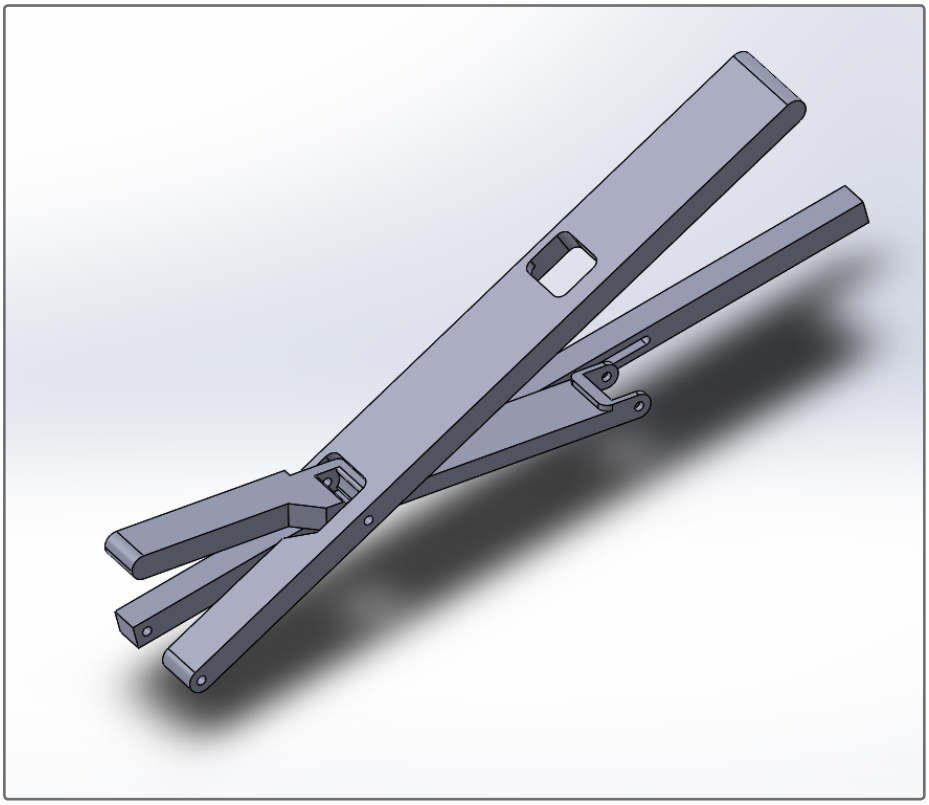


Figure 45: Third iteration of the slider system

Figure 46: Final design of the slider system

instead of supporting it on only one side.

A downside of this concept is the increased material and machining cost compared to the second iteration (R3.1.3, R3.1.4). However, this is considered a worthwile trade-off for the added benefits. This design was further detailed into the final design.

Final design

The final design offers good placement opportunities for both the front grip [1] (figure 46) and the locking mechanism [2]. Additionally, it can support up to four torsion springs, two at points [3] and [4] respectively. According to the calculations in chapter 2.5, this should be sufficient for the springs to start lifting the laptop stand from a flat position. Lastly, the system is supported by a stability slider which has been designed based on required attributes from the sliders, the lifting mechanism and the locking mechanism.

An overview of all features of the sliders can be found in appendix 9.

Stability slider

The main purpose of the stability slider is to maintain a balanced and equal position between the left and right short slider (R2.3). Additionally, it allows for the support of a scalable number of linear sliders and rotary dampers and it offers a centralized point for height adjustment (R1.1.1).

The slider design has been created along with the last iteration of the slider system, damping system and linear spring support. As a result this part nicely ties together the different components. The stability slider consists of two parts [1] and [2] (figure 47) that are connected to each other with clamping pins.

The geometry of the stability is derived from its main function; the avoidance of tilting. Based on material stiffness, friction coefficient on aluminium and availability of material, POM was chosen as material. In appendix 13 a SolidWorks simulation is run to see how the part is expected to behave. In appendix 12 the design justification is described more in-depth.

Production & material

For the same reasons as for the base plate, CNC machining will be used for the first batch of the product. This is further elaborated in appendix 10. The material of the sliders is also identical to the base plate as the same requirements are applicable.

A discussion of the tolerances and assembly can be found in appendix 11.

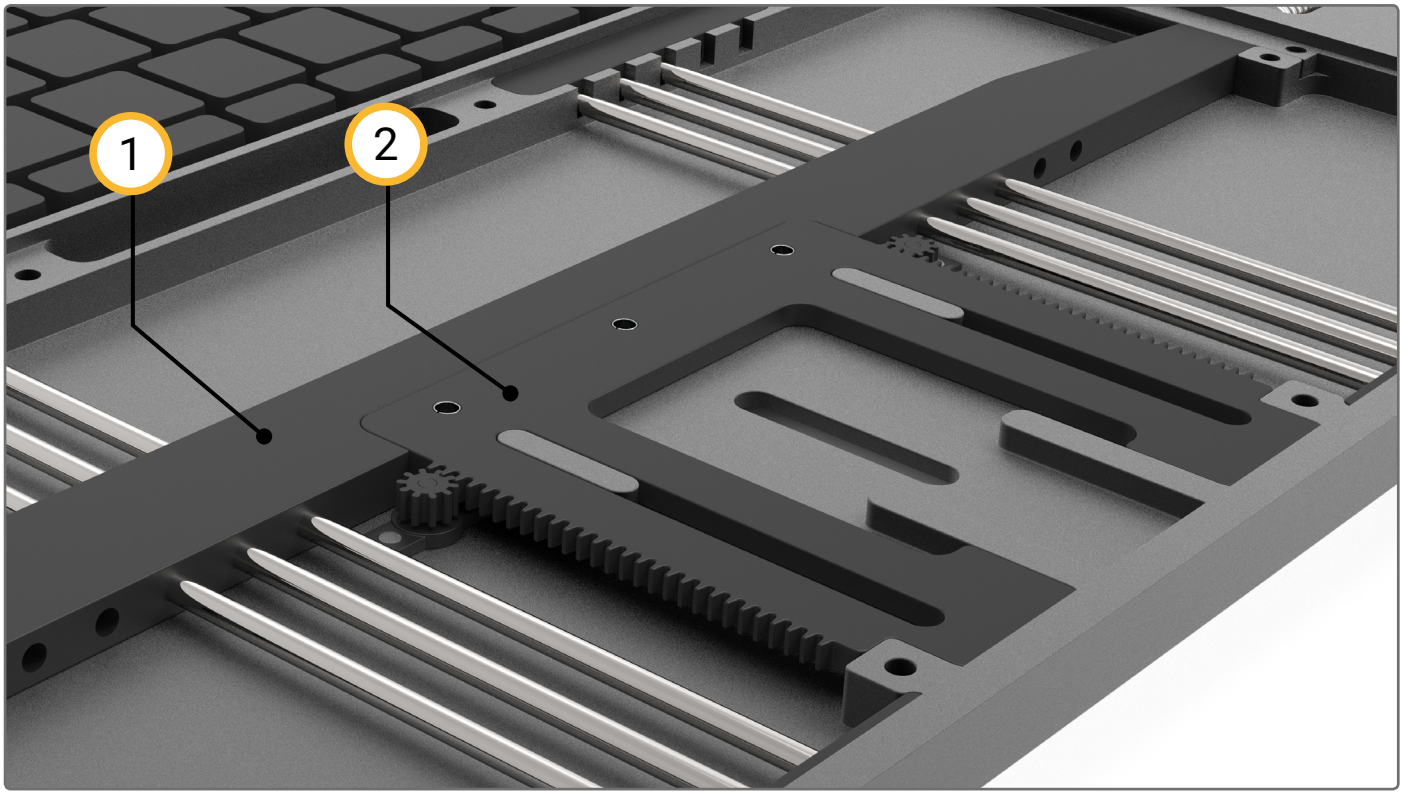


Figure 47: Close up of stability slider

Figure 48: Overview of the base plate and sliders

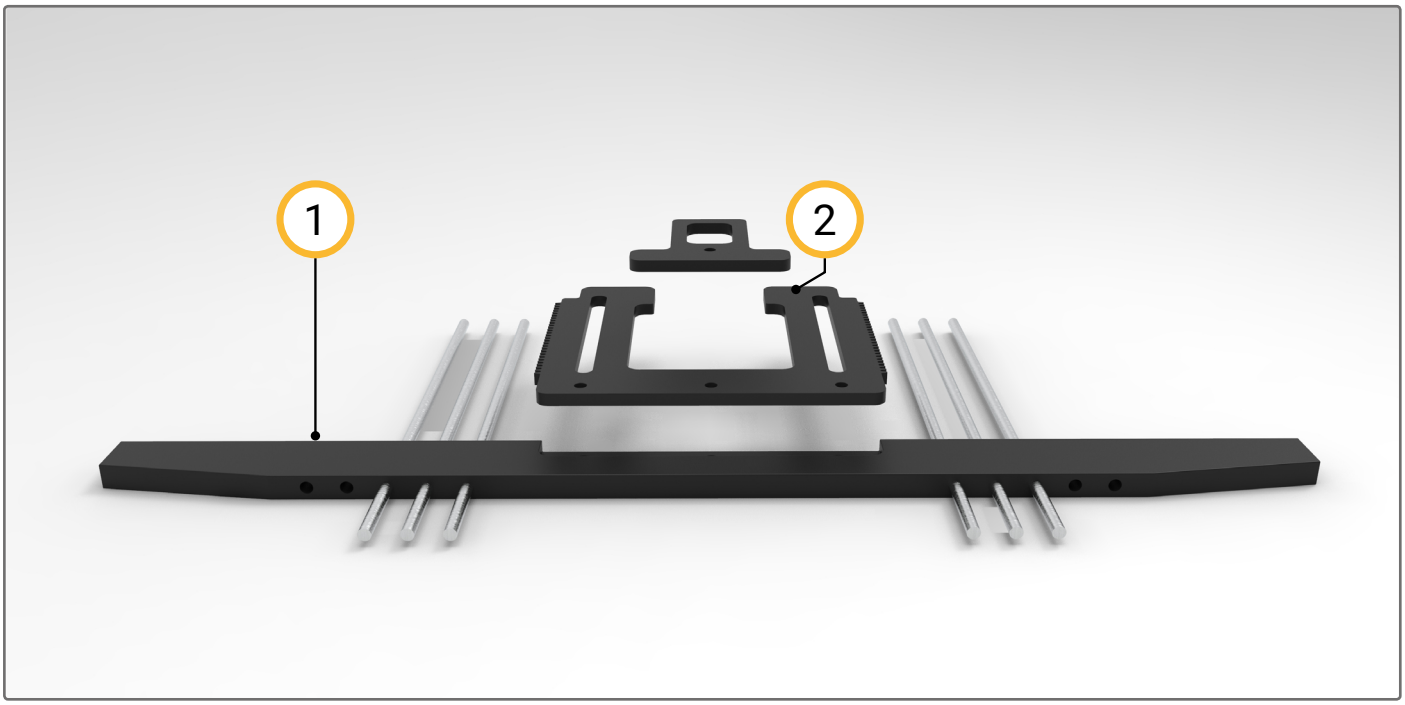


Figure 49: Semi-exploded view of stability slider

Figure 50: Laptop stand with lifting mechanism

Considerations

+ With a spring-damper system, the laptop smoothly moves up towards the user
+ By combining linear and torsion spring a gradual force distribution is reached along the laptop elevation
- The increase in usability comes at a high price in terms of design freedom and costs.

2.5 Lifting mechanism

One of the key unique selling points of this product is the automatic lifting of the laptop. With a single slide movement at the front of the laptop, the user can bring their laptop to the desired working height.

Design criteria

For designing the lifting mechanism, special attention has been paid to the following design criteria:

1. Ease of setup (R1.8)
Since the product also serves as a cover, in a standard use scenario the laptop will already be on top of the laptop stand before unfolding. For minimizing the amound of effort required to setup a workplace, the stand itself should be able to provide an upward force, either to 'decrease' the weight of the laptop (allowing the user to raise the laptop with minimal force) or to lift the laptop entirely by itself. The less effort the user has to put in, the better the design solution.

2. Safety (R2.12)
Slightly depending on the design, the product will most likely be under continuous pressure. A mechanical failure could have drastic consequences for the user, so keeping safety in mind is important.

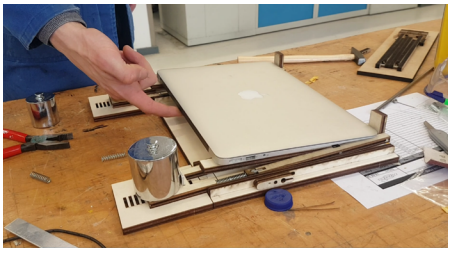
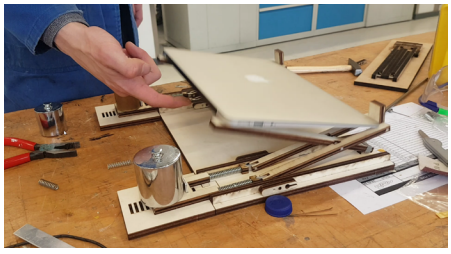
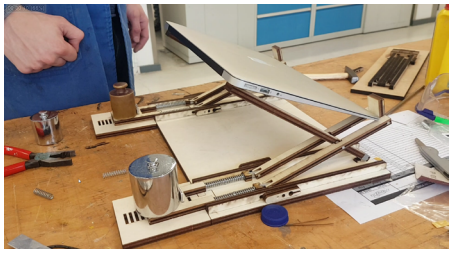
Mechanical lifting solutions

To determine the best method of lifting a product, online research was conducted to find viable solutions. Three possibilities were found: spring(damper) systems, rubber or elastic materials and electronics. The spring damper system was chosen as the best option, because it provides better possibilities than rubbers (only tension based force) while being significantly cheaper (R3.1) and lighter (R2.5) than electronic solutions. Additionally, electronic solutions would decrease ease of use (R5.6), since the laptop stand itself would have to be charged or batteries have to be replaced once every while.

Spring research

To make sure it was possible to lift a laptop with springs within a product that is less than 10 mm thick, a few simple prototypes are built to provide proof of concept and to learn how to work with springs. In appendix 14 (validation of models), this study is explained in detail.

The study clearly showed that a spring system is a viable

Figures 51-53: Spring test; lift laptop with minimal effort

solution. In fact, with a random set of springs and completely wooden structure it was already managed to lift the laptop and adjust height with minimal effort (touch of a finger, see figures 51-53). Furthermore, because the structure of the prototype was very similar to the final model, the findings of the study can be used as a baseline for further calculations to the springs system. Important to note is that the study measures the change in upwards force of the springs based on the position of the axle in the slot at the middle ([3] in figure 54, more in appendix 14).

Spring factory visit

Once it was decided to continue working with springs, spring factory Roveron was visited to learn about important design requirements regarding springs and to learn their limits. The main take-aways of this visit are described in appendix 15 and referred to here when applicable.

Design process

For the laptop stand three different spring(damper) lay-outs are explored and explained here.

Iteration 1

Of the three types of available springs (compression, extension and torsion), torsion springs was decided to be the most logical option as their force (torque) is directly applied in the lifting direction. This is in contrast to linear springs (either compression or extension) whose force has to be translated to a vertical motion first, increasing part count and complexity.

The first iteration of the lifting mechanism optimizes the available space in the slider system to place a total of five springs at each slider.

When designing the optimal springs for this concept there were two dimensions limiting their design: the outer diameter of the springs (within the thickness of the slider) and the total width of the springs (needs to fit in the slider). Additionally, the springs were required to apply pressure over the entire elevation of the laptop and then continue to apply pressure when the laptop was fully lifted to keep it in place. This means the upward spring force required in an unfolded position had to be at least equal to the gravitational force of the laptop.

Because the viability of this concept is directly dependent on the amount of torque the torsion springs can deliver, the highest possible torque was determined for fitting torsion springs. These springs are shown in table 4 and the design process is explained in appendix 14.

Note that the freedom of rotation for each of these springs is 40% more (balance between freedom of rotation and maximum torque) than they actually require to make sure they still apply pressure once the laptop stand is completely unfolded.

When plotting the expected upwards lifting force of these springs, it became clear that just torsion springs were not going to be enough to lift and keep the laptop lifted. In figure 55 the expected upwards force is plotted in Newton against the displacement of the main slider in the slot in mm. As the weight of an average modern 15” laptop is 2 kg, the upwards force needs to be at least 20N across the entire curve. This force is not met for each slot position, which marks this concept as non-viable.

The calculations on which figure 55 is based can also be found in appendix 14.

Spring design	Abbreviations	Torsion spring (1) (TS1)	Torsion spring 2 (2) (TS2)	Torsion spring (3) (TS3)
Outer diameter (mm)	OD	8.0	7.0	7.0
Wire thickness (mm)	WT	1.5	1.3	1.3
Active coils	AC	12.0	6.0	4.0
Resulting in				
Spring constant (Nmm/deg)	C	3.4	3.2	5.4
Freedom Of Rotation (degrees)	FOR	125	81	45

Table 4: Spring design properties iteration 1

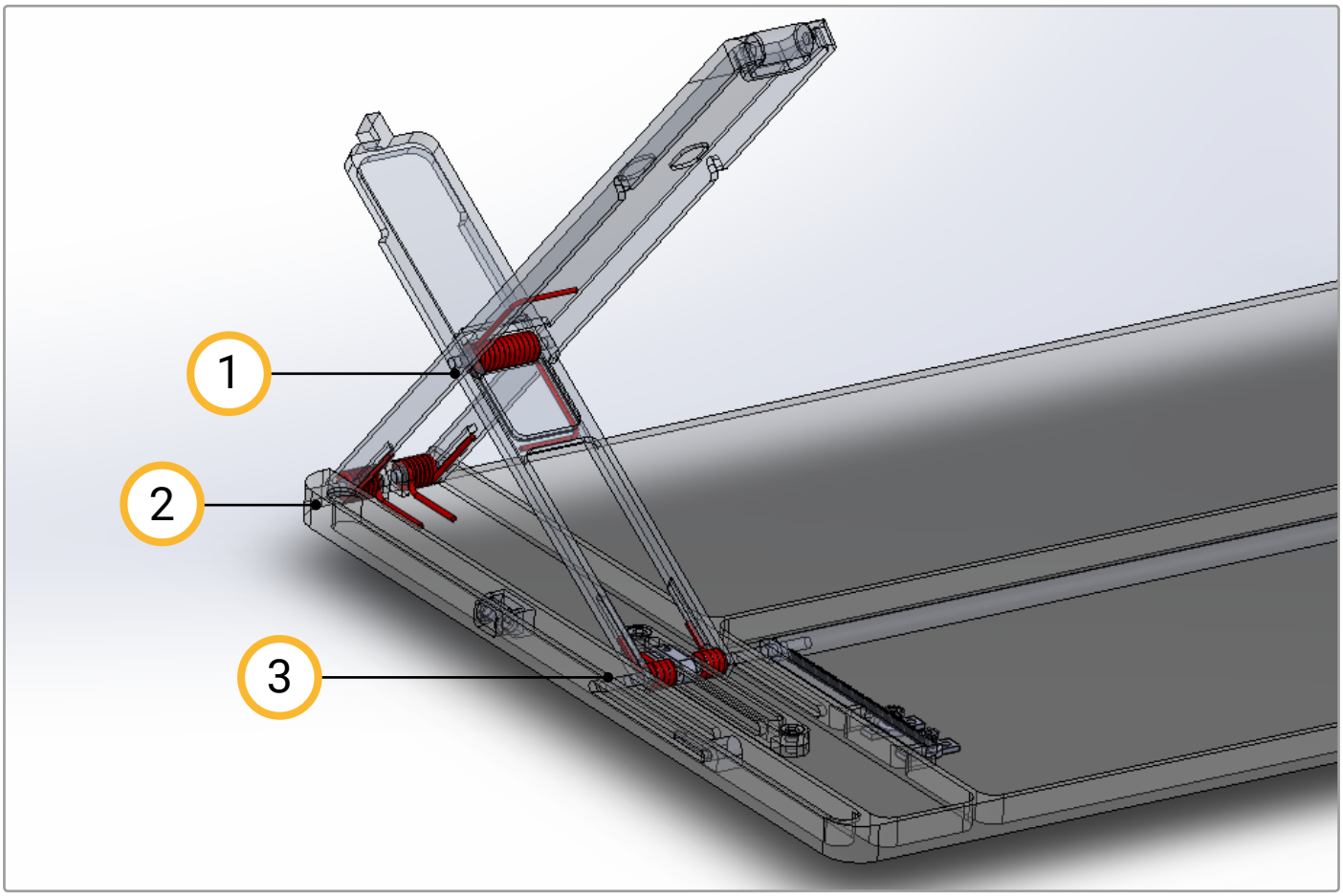


Figure 54: Spring placement Iteration 1

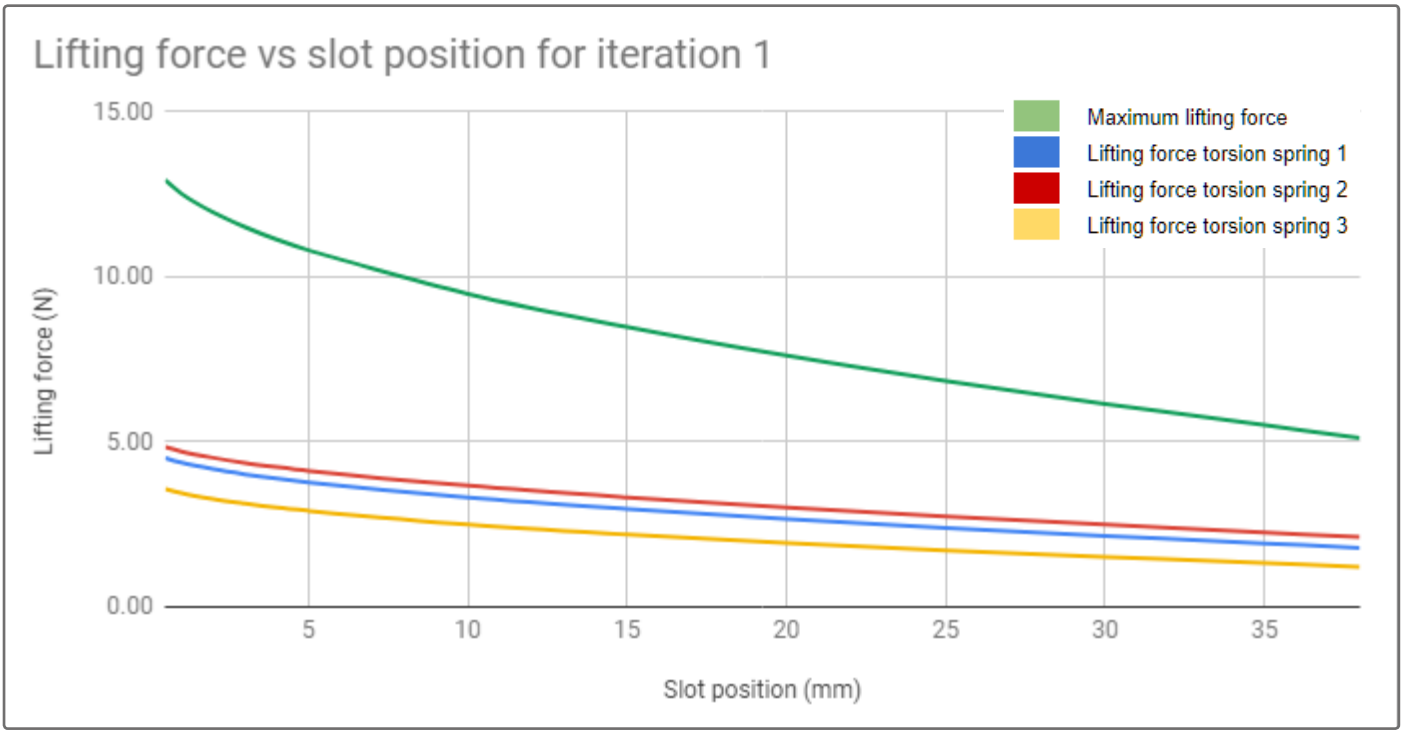


Figure 55: Lifting force vs slot position iteration 1

Iteration 2

During the second iteration the aim was to flatten out the force distribution over the elevation of the laptop which would result in a smooth upwards motion of the laptop. Also, the lowest lifting force had to be brought up to at least 20N to allow the laptop to be lifted without human, or with minimal human interference.

In this iteration there are two smaller springs placed in the middle of the sliders, similar to those in the first iteration ([1] at figure 54). Additionally, two large torsion springs are added in the empty space behind the keyboard [1] (figure 57). In this concept the springs are again optimized to their maximum performance based on the available spacing according to the earlier explanation in appendix 14.

The large torsion springs will provide the main upwards force once the laptop stand is lifted up to five degrees (appendix 14).

The expected results from this spring combination are plotted in figure 58. The resulting forces turned out to be insufficient but much better distributed compared to the first iteration.

Note that the decisions of this iteration may appear unlogical. This is because a miss calculation was made for the first iteration, which resulted in a wrong assumption about the potential force of torsion springs.

This specifically applies to the lifting force in a completely folded position which, in retrospect, could never reach the required values to start with. Despite this, the second iteration has still provided meaningful insights for further iteration.

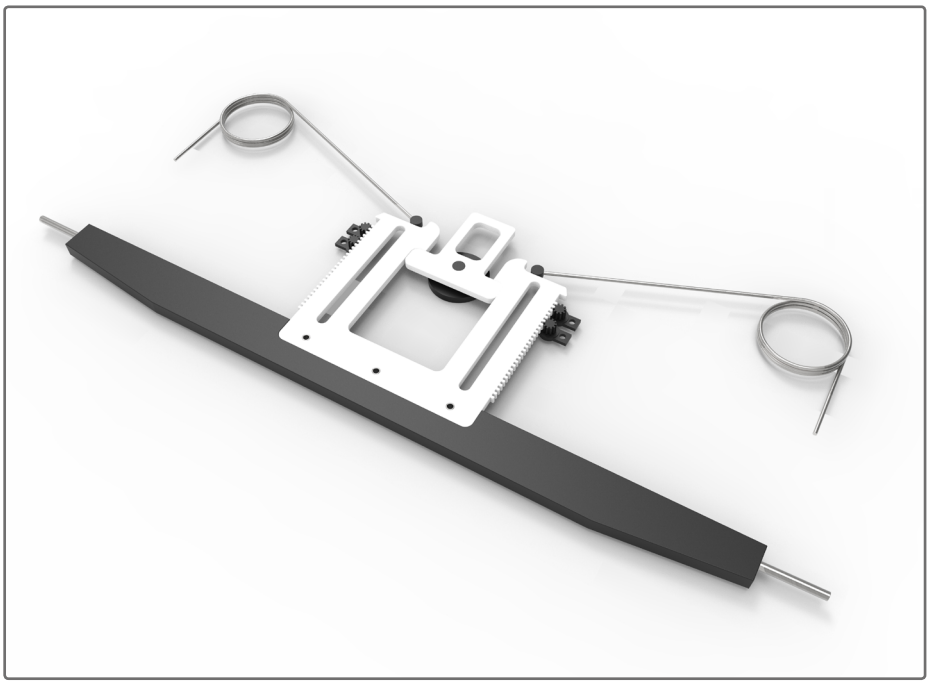


Figure 56: Isolation of large torsion spring system

Spring design	Refference	Torsion spring (1) (TS1)	Torsion spring (2) (TS2)
Outer diameter (mm)	OD	8.0	35.0
Wire thickness (mm)	WT	1.5	2.5
Active coils	AC	12.0	2.4
Resulting in			
Spring constant (Nmm/deg)	C	3.4	42
Freedom of rotation (degrees)	FOR	125	40

Table 5: Spring design properties iteration 2

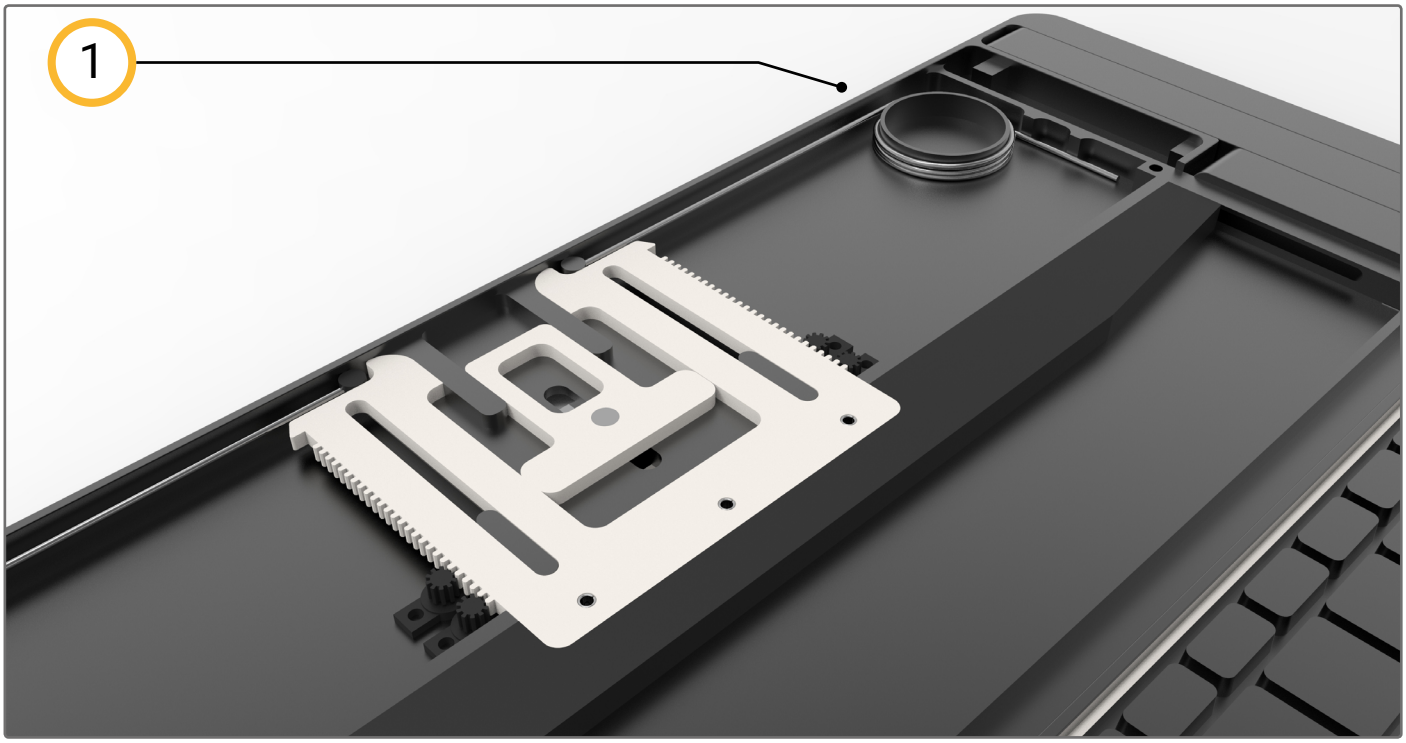


Figure 57: Integration of middle spring

Figure 58: Lifting force vs slot position iteration 2

Iteration 3

Based on the first two iterations the following was learned:

- Torsion springs in the sliders alone cannot provide enough torque to realistically lift and keep a laptop lifted.
- A large torsion spring does not provide enough upwards force to lift, or keep the laptop lifted.

It was therefore decided to add multiple linear springs which could change the requirements for the torsions springs. One of the limiting factors of the torsion spring was the required freedom of rotation. This forced the springs to have many active coils, reducing their potential in relation to their size. As the linear springs fixed the issue of lifting force after the initial few degrees, the torsion springs could be optimized towards the first few degrees only. Doing so resulted in the lifting force as visualized in figure 59, using the springs from table 6. Noteworthy is that one of the torsion springs actually starts to work negatively in relation to the lifting force after slot position 15. However, as long as this force does not let the lifting force drop too low it helps to smooth out the upwards motion (effectively becoming a damper).

Even though the calculations are estimates based on the measured results from the first prototype, the potential was definitely there and it was decided to use this spring system for the functional prototype (chapter 2.11: prototyping).

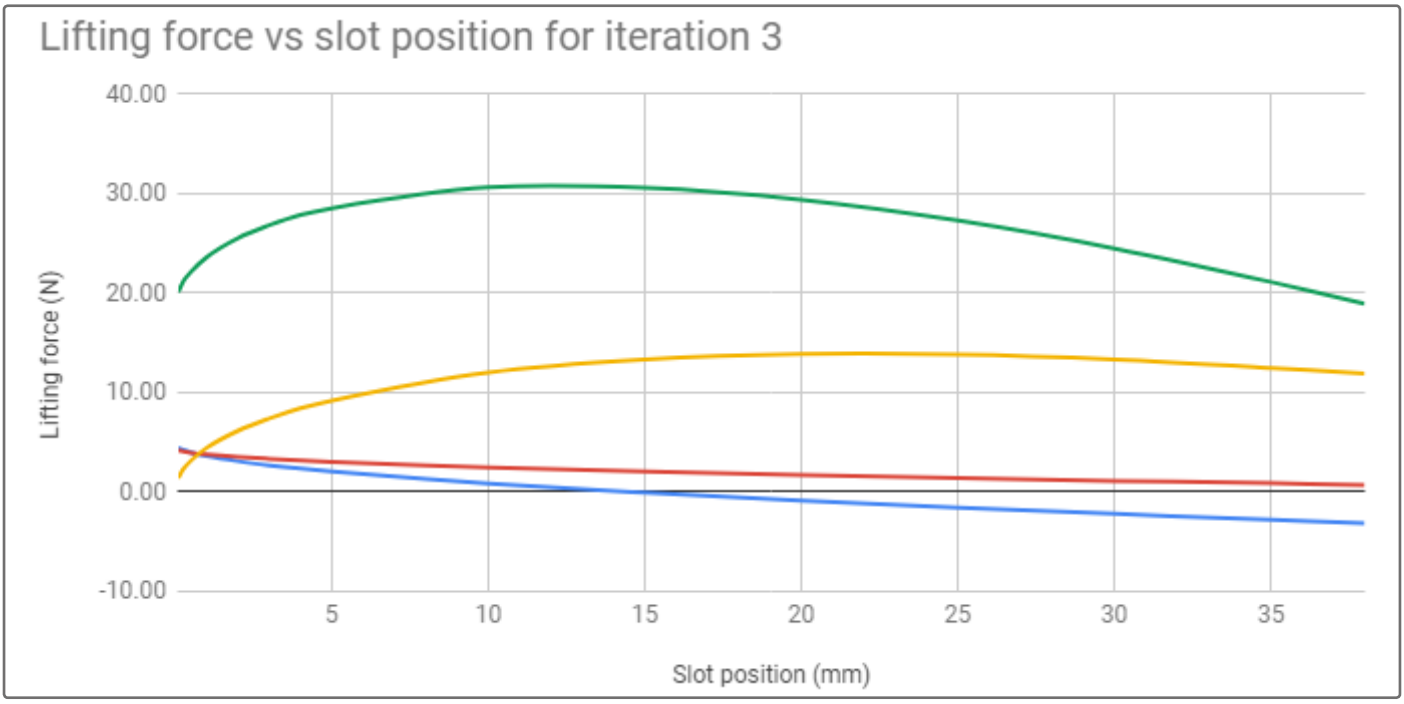


Figure 59: Lifting force vs slot position iteration 3

Spring design	Abbreviation	Torsion spring 1 (TS 1)	Torsion spring 2 (TS2)	Linear spring (LS)
Outer diameter (mm)	OD	8.0	8.0	6.0
Wire thickness (mm)	WT	1.5	1.5	0.8
Active coils	AC	5.7	3.8	135.0
Resulting in				
Spring constant (Nmm/deg)	C	8.9	11.8	
Freedom of rotation (degrees)	FOR	48	37	
Spring constant (N/mm)	C			0.481
Travel distance (mm)	FOR			70
Number of spring	NOS			1.5

Table 6: Spring design properties iteration 3

Damping system

One important aspect of springs is the way in which the force is delivered; very quickly. In case of a laptop stand this is undesirable because the laptop should be brought upwards slowly, minimizing the chance for accidents (R2.12) and adding to a luxury feeling (R4.5).

To make sure the laptop stand behaves as intended a damper system is integrated in the design. For spring damper systems two types are applicable; rotary dampers and linear dampers (either liquid or gas). Rotary dampers are chosen because they are cheaper, easier to install and fit much better within the available space.

Between the spring system and the sliders an optimal relation needs to be found which will be tested with the final prototype. To be able to do so the model is built in such a way that the multiple dampers and/or springs can be installed alongside each other.

Final design

In the final design, the spring and damper systems are both fully integrated in the 10 mm baseplate and can scale in number. This allowed for a better test setup in case some of the calculations or assumptions were wrong.

Validation

In chapter 2.11, the results with the springs as designed in the third iteration are measured and compared with the expected results.

Figure 60: Rotary damper

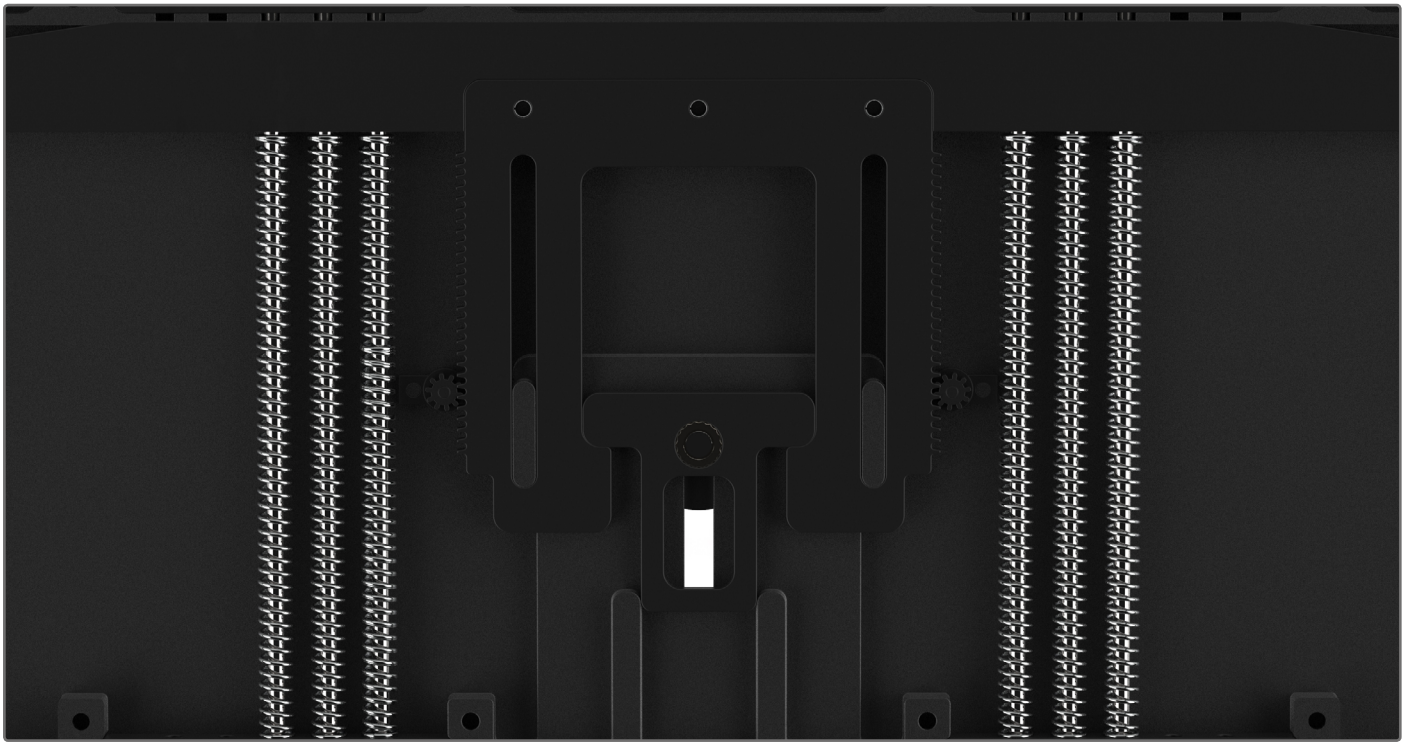


Figure 61: Topdown view of linear spring scalability

Figure 62: Front grip final design

Considerations

+ A gradually adjusting front grip ensures a smooth and seamless lifting experience
+ By integrating the front grip into the short slider the product can be folded completely flat

2.6 **Front grip**

The front grip serves a simple purpose: it makes sure the laptop will not slide down once the stand is in a lifted position.

Design criteria

For designing the lifting mechanism, special attention has been paid to the following design criteria:

1. Flexibility
As the sliders are tilted more upwards, the angle in which the laptop is positioned changes too. This means that the front grip is ideally a flexible component that can adjust in response to the changing angle of the laptop, visualized in figure 63 [3]. This would prevent the laptop from getting stuck (R1.7.1) and looking clunky (R4.5, W4.8).

2. Foldability
Furthermore, it would be better if the front grip can be folded into the base plate. This would increase the aesthetics of a folded laptop stand (R4.5) but also decrease the packaging size (R6.1, R1.5).

Design process

From the two touch points [1] and [2] (figure 63) between laptop and stand, point [1] at the front is the best place to keep the laptop from sliding down, as point [2] slides underneath the laptop when height is adjusted.

Iteration 1: Fixed
The first iteration is very simple; a upwards pinacle that prevents the laptop from sliding down (figure 64). In this design the pinacle is part of the short slider and is made during CNC milling.

Despite assembly is very easy, a downside is that shaping the required aluminium bar to this part is complex and increases material and tooling cost significantly (R3.1.1, R3.1.4). Furthermore, this solution does not allow for a completely flat package. Lastly, due to the fixed nature the front grip cannot adjust to the laptop angle as visualized in figure 63, which is expected to further decreases appearance and user expectations.

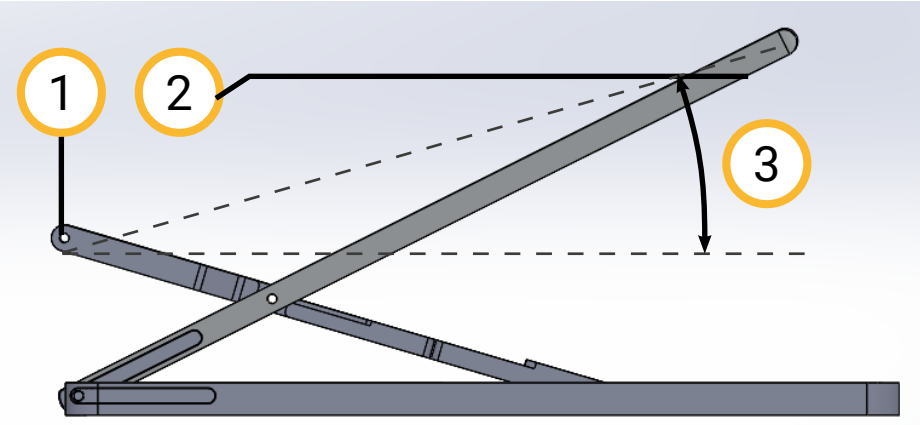


Figure 63: Changing angle of the laptop

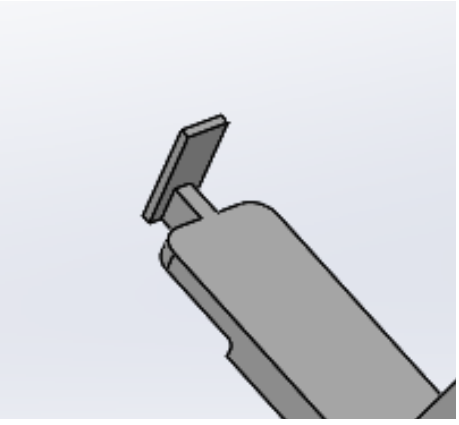


Figure 64: Iteration 1

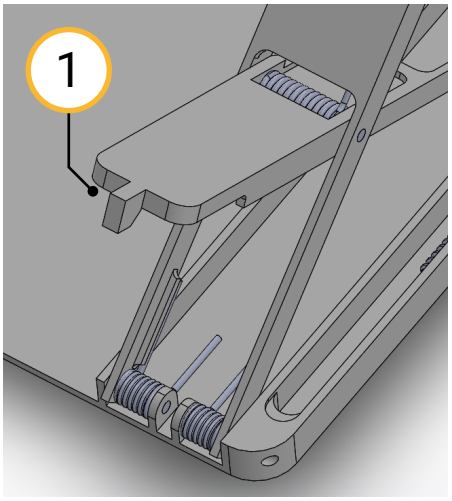


Figure 65: Iteration 2

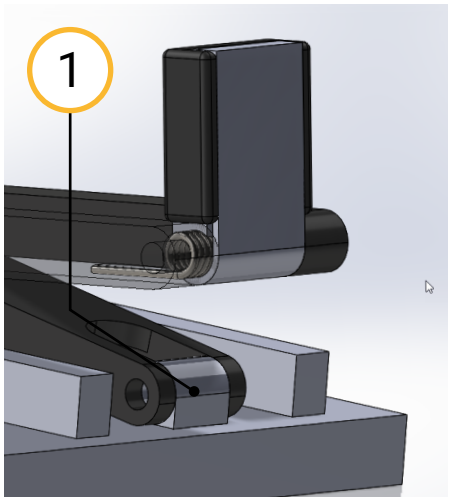


Figure 66: Iteration 3

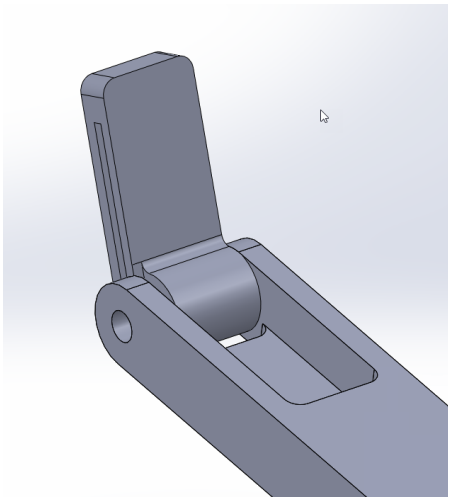


Figure 67: Iteration 4

Iteration 2: Add-on
Instead of including the front grip in the design of the short slider, another option is to attach a separate component that functions as a front grip to the front of the slider. This could be done by simply clicking, sliding or screwing a vertical component at point [1] in figure 65. This would remove the high increase in tooling and material cost from the first iteration (R3.1.1, R3.1.4). However, it still cannot be collapsed during transport nor does it adjust the angle of the front grip to be perpendicular to the laptop.

Iteration 3: SpringGrip
One of the main difficulties with the first two iterations was the available design space in which the front grip could be placed. After a new slider system was designed there were more opportunities to create something more fitting for the product as a whole. In the third iteration the middle front part is split and a front grip is placed around an axle (figure 66). By adding a small torsion spring the laptop can be kept perpendicular to the front grip. Because the long slider is connected to the base plate at position [2], the front grip cannot be collapsed. This concept also requires more expensive parts than the previous slider.

Iteration 4: Spring grip v2
Partially as a result of the impossibility of a collapsable front grip in iteration three, the sliders are rearranged. This allowed the front grip to be positioned within one slider (figure 67). This had several advantages; first of all, the design is still capable of adjusting the angle of the front grip in relation to the inclination (R1.7.1, R4.5, W4.8). Secondly, the front grip can now be collapsed to a completely flat position (R4.5, R6.1, R1.5) and lastly a more elegant design is expected to positively benefit the overall aesthetics of the product (R4.5).

Final design

For the final design the construction of iteration four is used. Because the functioning of this part heavily depends on a perfect balance between the torsion spring in the front grip and the downwards force of the laptop, the spring requirements have been calculated which is described in detail in appendix 16. Additionally, in the same appendix it is discussed how the front grip can be folded and locked with the use of small magnet. A proof of concept shows the viability of the concept and further emphasizes the importance of the correct spring design. The appendix is concluded with a short discussion about tolerances, material, production and assembly.

Figure 68 and 69 show the final design.

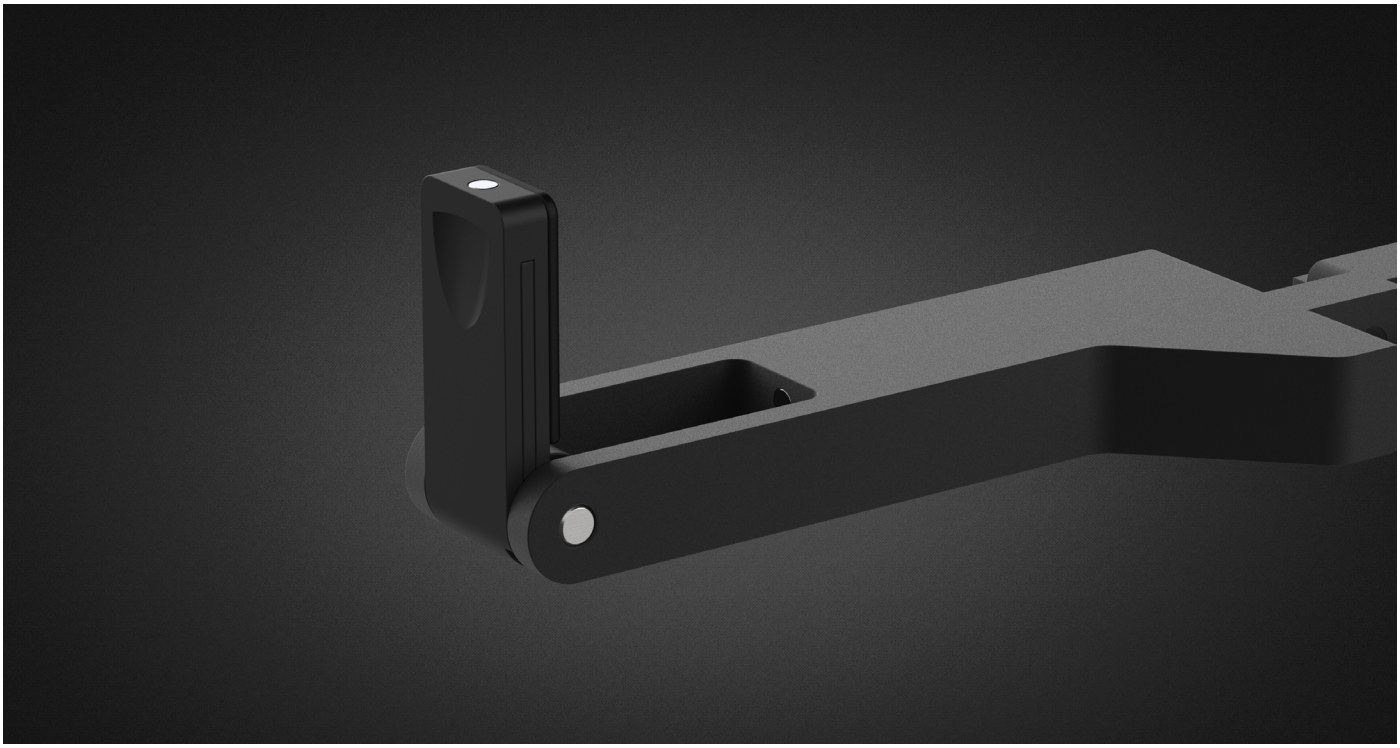


Figure 68: Final design front grip

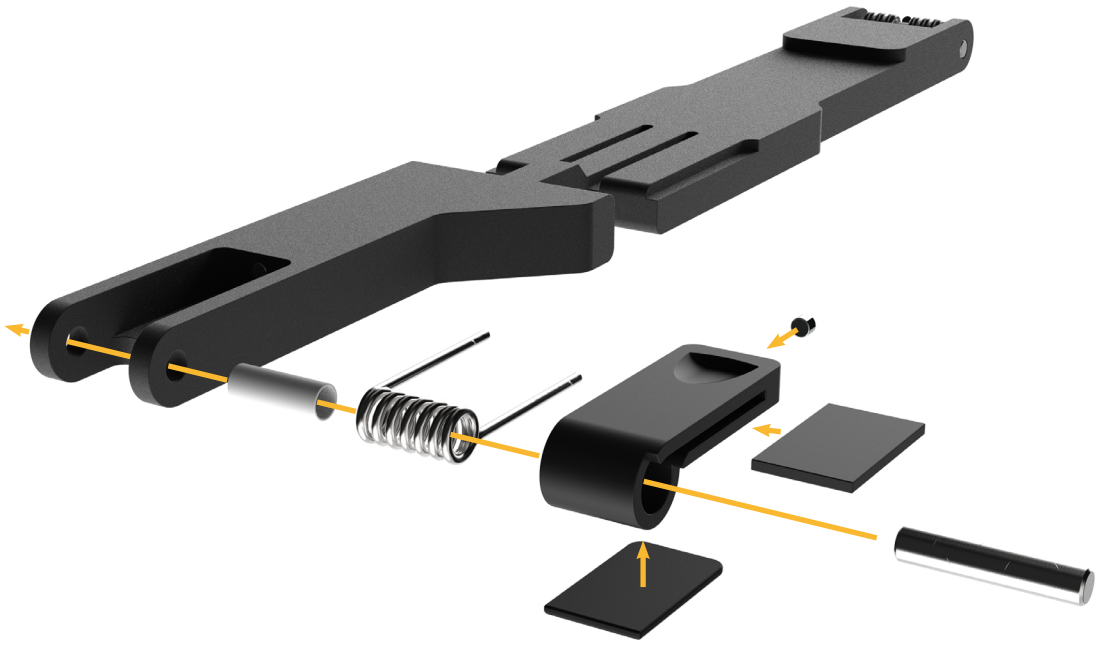


Figure 69: Exploded view front grip

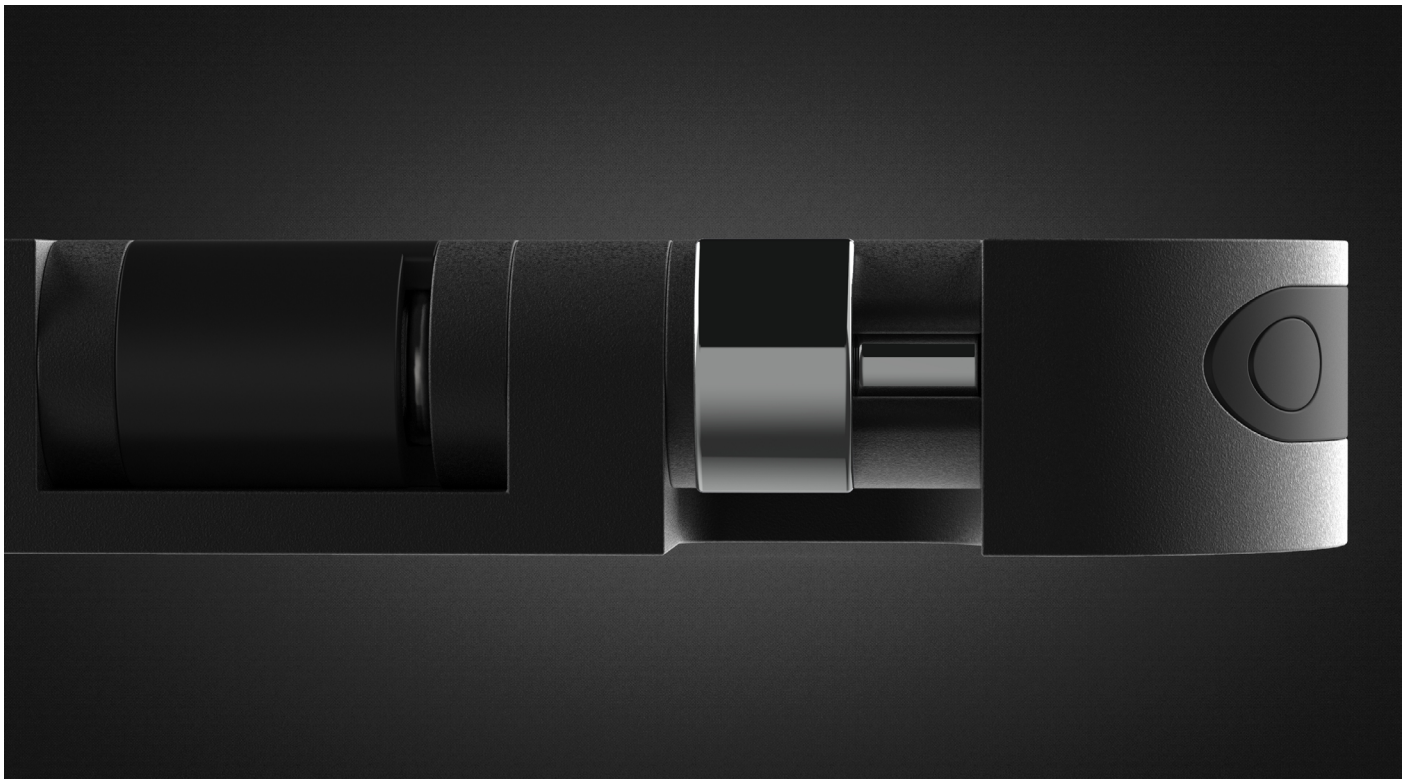


Figure 70: Locking mechanism

Considerations

+ The front locking mechanism allows the user to open and close the laptop stand easily
+ Despite using little space, the locking mechanism secures the laptop stand securely

- Production cost is relatively high due to the required tolerances

2.7 **Locking mechanism**

Due to the spring system, the product is permanently under internal pressure and should not be opened accidentally. The locking mechanism makes sure that once the laptop stand is in a folded position, it stays there until the user wants to deploy the laptop stand.

Design criteria

For designing the locking mechanism, special attention has been paid to the following design criteria:

1. Reliability (R1.6.1)
Due to the internal spring system the laptop stand is continuously under pressure. As the locking mechanism makes sure this force is securely locked away, it needs to be very reliable. For instance, a locking mechanism that can realistically unlock during transport can cause serious issues and potentially damage other properties.

2. Usability (W1.8.1)
The locking mechanism will be one of the main interaction points between the user and the laptop stand. It is therefore important that the placement of the locking mechanism can easily be accessed by the user and the interaction is simple.

Design process

For the locking mechanism five different solutions are explored. Each of them will be shortly described here, pointing out advantages and disadvantages.

Due to the double slider mechanism used in the laptop stand each of the following concepts is used twice, one on each side of the product. This is required to ensure enough stability during transport. It also significantly decreases the odds of the laptop stand being unlocked in a bag during transport, as both unlocking mechanisms need to be activated simultaneously.

Solution 1: SideClick
See figure 71. The first solution is based on a click finger mechanism. It is positioned at the sides of the product to make it easy for users to unlock the mechanism. If the laptop is pushed into a flat position, the axle connecting both sliders is locked behind the click finger. As long as there is a laptop on the stand the solution is expected to work fine, because the spring force is mostly balanced by the weight of the laptop. However, the locking mechanism also needs to keep the laptop stand in a folded position when there is nothing on top which may cause issues. Furthermore, the axle that connects both sliders through the open slot [1] (figure 72) is not an ideal locking position because a

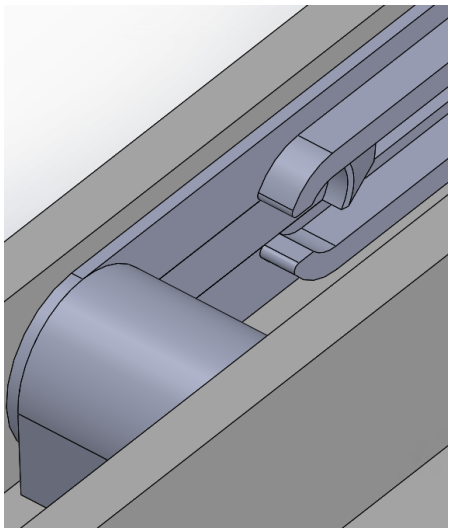


Figure 71: solution 1, SideClick

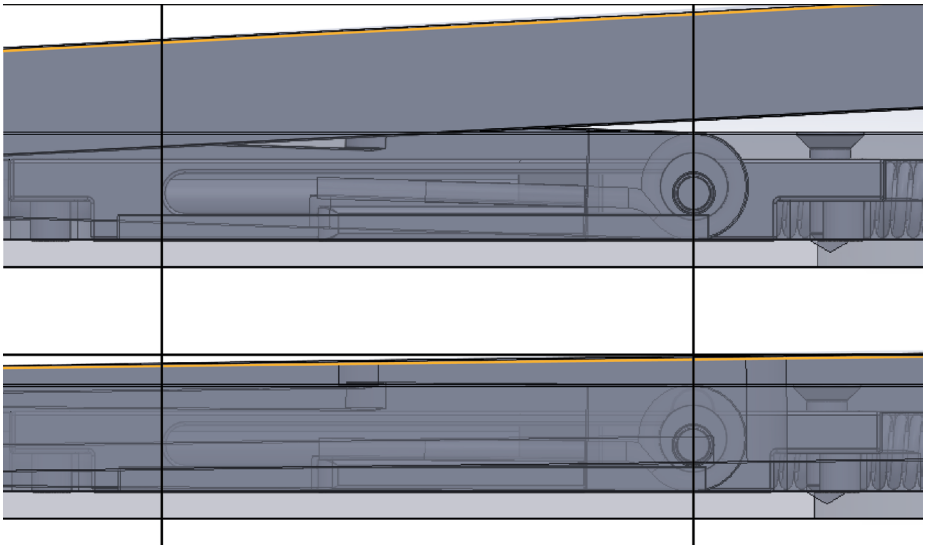


Figure 72: Solution 1

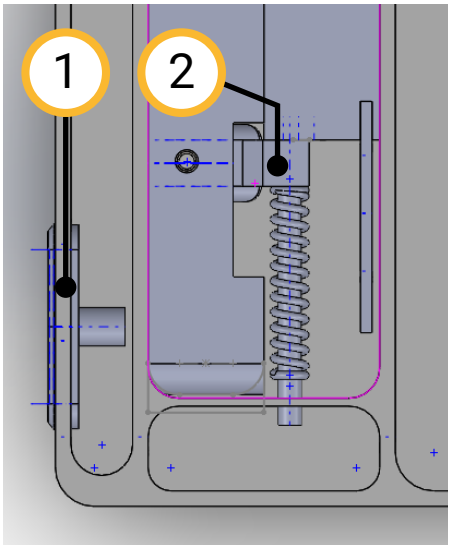


Figure 73: Solution 2, ReverseLock

tiny displacement of the axle can cause several degrees inclination of the long slider. This would make it difficult to really ensure a flat package.

Solution 2: ReverseLock
See figure 73. The ReverseLock is placed on the inner side of the long slider [2] while the unlocking button [1] is still placed on the outside for usability. This means that a larger design space can be used to securely lock the sliders in place. Therefore a more robust locking mechanism can be used compared to the first solution. However, the unlocking button needs to be transferred through, or past the slider, to create an easily accessible option for the user. This significantly increases the number of (custom) parts that are required to make this concept work in addition to a more complex assembly process.

Solution 3: SlideLock
See figure 74. The SlideLock is, just as solution one, positioned

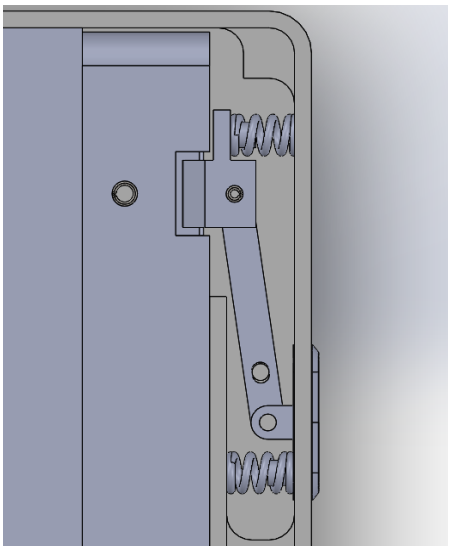


Figure 74: Solution 3, SlideLock

in the sidebar between the main sliders and the outer side of product. However, in this solution a part of the base plate is changed to provide an additional 2 mm space (25% increase). Additionally, the locking mechanism locks the long slider in place instead of the axle, which allows for a more secure lock. The amount of parts required remains high for this concept.

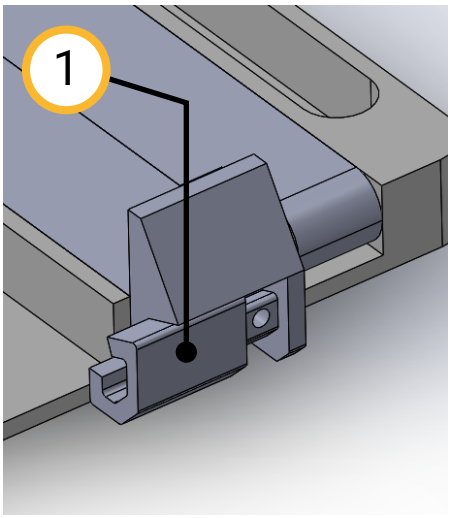


Figure 75: Solution 4, FrontLock

Solution 4: FrontLock
See figure 75. The FrontLock places the locking mechanism in a very different spot right at the front of the product. With the use of a sliding mechanism the secondary slider could be locked firmly into the base plate. The upwards force of the springs would prevent the lock slider [1] from accidentally closing and could be further secured with a little magnet. This concept

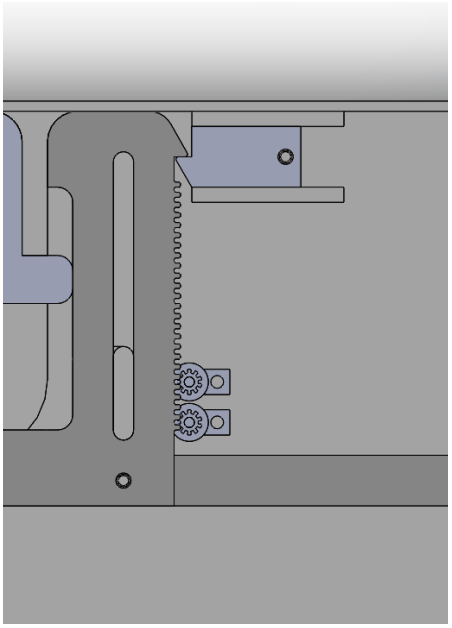


Figure 76: Solution 5, MiddleLock

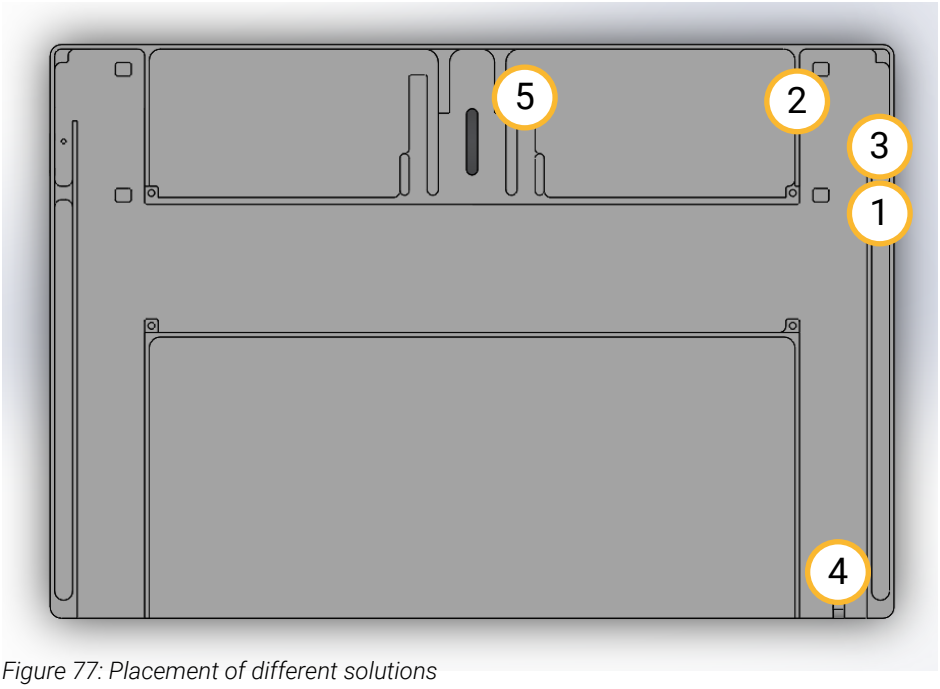


Figure 77: Placement of different solutions

complicates the aesthetic part of the design a bit and may be expensive due to the required part tolerances and milling angles. It is, however, quite a good option considering its high reliability, and easy assembly.

Solution 5: MiddleLock
See figure 76. The MiddleLock is placed right in the middle back of the laptop stand and uses the stability slider (figure 77) to lock onto. As the stability slider is already quite a complex part, adding two indents would not noticeably influence production cost. The locking mechanism would work with one simple spring and a retraction mechanism to unlock the system. The biggest advantage over the FrontLock is the way the mechanism is hidden inside the product.

Weighted objectives

To determine which solution is best, the Weighted Objectives method is used (Van Boeijen et al, 2014). The most important design criteria are ranked in importance and given a weight factor (with a sum of 100). See table 6. For each solution the different design criteria are rated and then multiplied by the weight factor to determine a final grade. These grades are based on the designers intuition and experience. Therefore the solution with the highest grade is not per definition the best solution. The solutions are mostly rated relative to each other as this method is used as a decision making tool. That means that scores indicate the difference between each other but also give an indication of the potential of the solution in general.

A short explanation of the chosen design criteria and their weight factor:

Reliability (R1.6.1)
The safety of the solution is what matters more than all other requirements combined because it can risk the success of the product as a whole, much more than an increase in price or worse aesthetics. This criteria was therefore given a weight factor of 55.

Usability (W1.8.1)
Because the entire idea behind the laptop stand is an effortless interaction between user and laptop stand, the usability is rated second highest at 23 points.

Production cost (R3.1) & assembly time (R3.2)
In the decision matrix these criteria are placed independent from each other at respectively

	W.F.	SideClick	ReverseLock	SlideLock	FrontLock	MiddleLock
Reliability	55	3	8	6	8,5	8
Usability	23	8	7,5	8	8	8
Aesthetics	10	8	8	8	6	8
Production cost	7	7	6	7	6	7,5
Assembly time	5	9	4	7	9	6
Total	100	**523**	**754,5**	**678**	**798,5**	**786,5**

Table 6: Weighted objectives

7 and 5 points as this makes it easier to rate the different solutions. However, they both increase price and are *combined* considered more important than aesthetics.

Aesthetics (R4.5)

It is considered important to maintain an equal level of aesthetic quality throughout the design, but it should not obstruct significantly better solutions. It was therefore decided to rate this requirement at 10 points, being the deciding factor in case other requirements are a close to a draw. Important to note is that aesthetics combined with price is weighted slightly lower than usability as in an equal outcome usability was deemed more important.

Conclusion

The FrontLock appears to be the best concept. Apart from the decision matrix this also made sense when thinking about it as it is the most reliable concept with its only real downside being production cost. Therefore, it was therefore decided to continue working on solution 4.

Final Design

Based on the FrontLock another iteration was made to improve even more on reliability of the locking mechanism. An exploded view can be seen in figure 78, exposing the different components and a view of the final design in the product in figure 79.

The locking mechanism works by sliding the restriction bar [4] between the main slider [2] and the base plate [6]. Note that only a part of the base plate is displayed in this render. The 2 small neodymium magnets [3] make sure the restriction bar [4] stays in position when the laptop stand is lifted upwards. In a folded position, when the restriction bar [4] is locked onto the base plate, the upwards force from the spring damper system will ensure that it stays in position.

A small 3D printed prototype has been made to verify this working principle and determine potential issues with the design (appendix 20).

Tolerancing of the locking mechanism is described in appendix 19 and assembly, production and material in appendix 18.

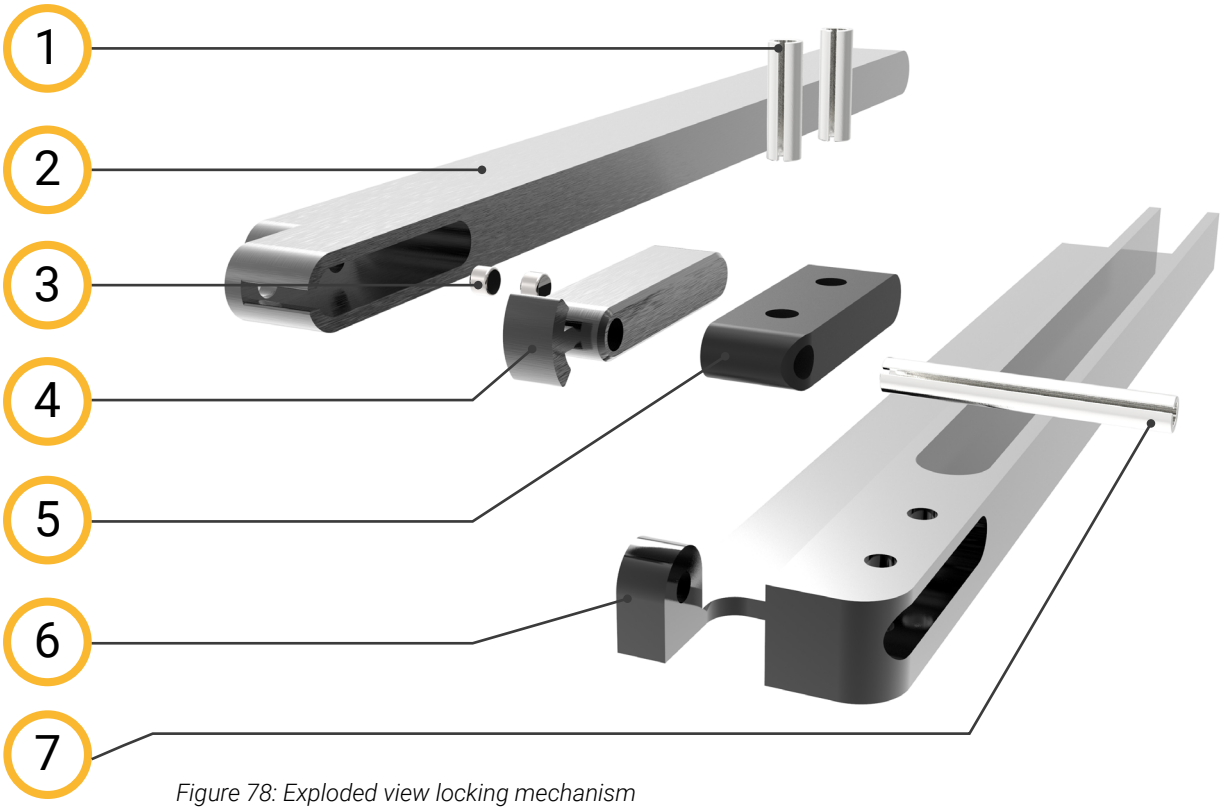


Figure 78: Exploded view locking mechanism

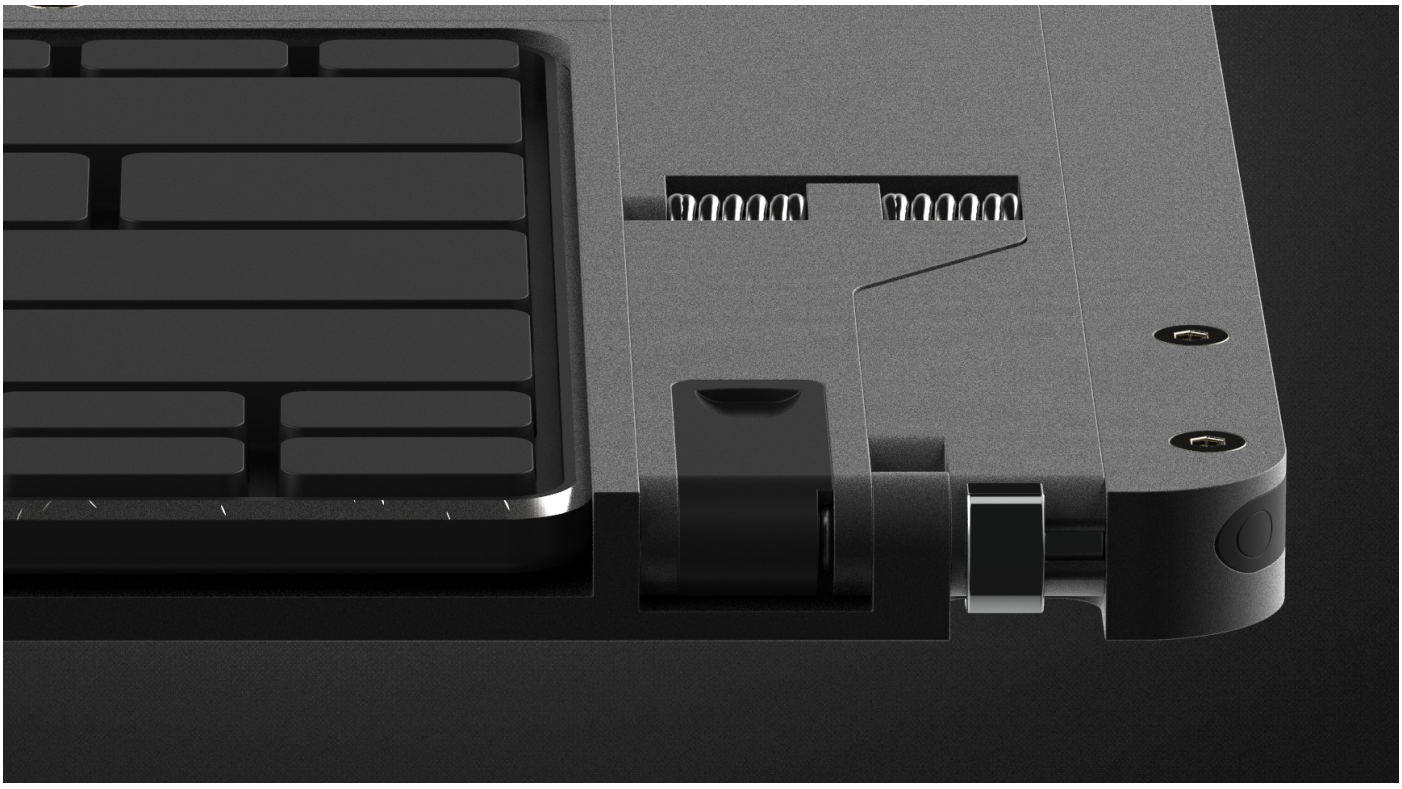


Figure 79: Locking mechanism front view

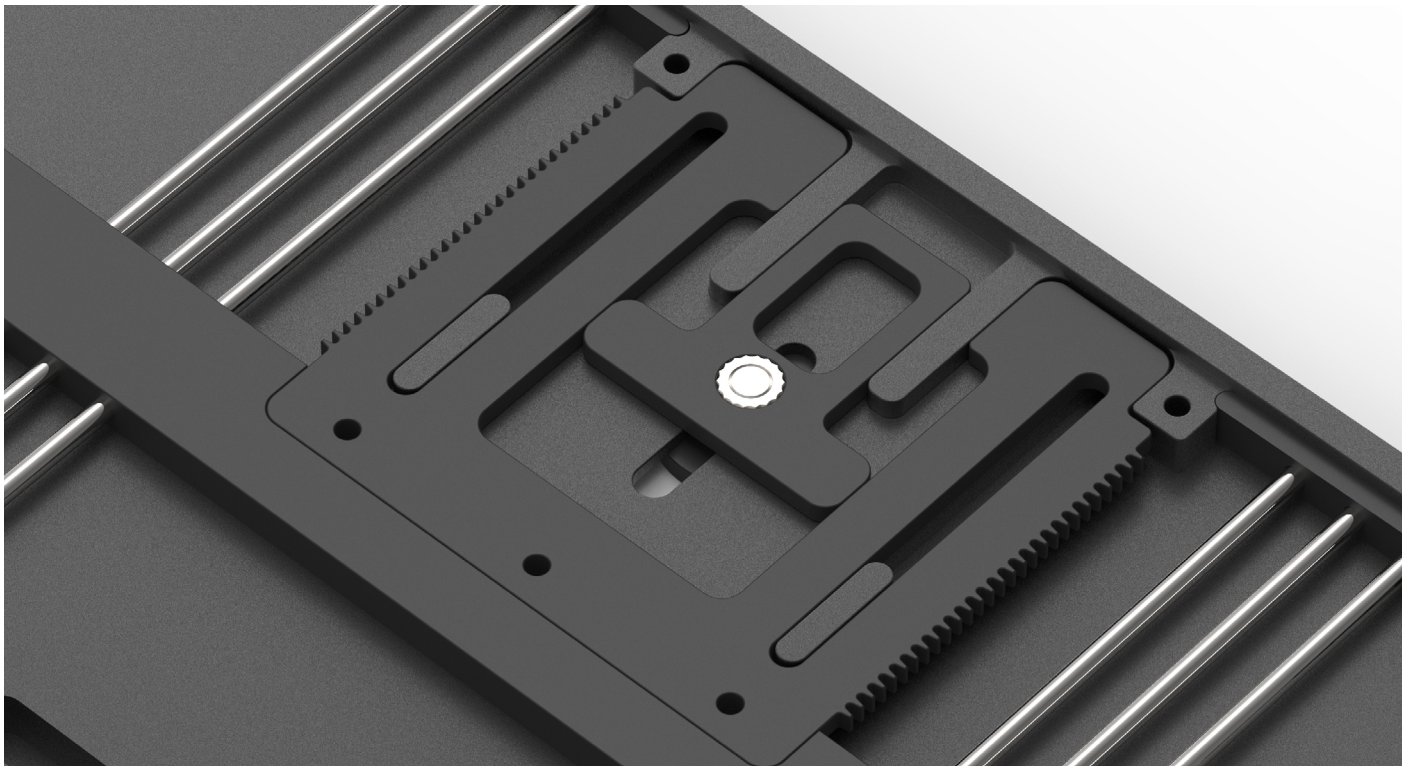


Figure 80: Height adjustment mechanism

Considerations

+ By making the height of the laptop stand adjustable between 10 and 22 cm, the user can always type beneath the laptop and set a proper ergonomic height
- Because the keyboard is placed underneath the laptop, a minimum elevation is required before the user can type comfortably

2.8 Height adjustment

Adding an adjustable height to the laptop stand allows as many people as possible to work ergonomically correct and according to their preference. Furthermore it makes it possible for users to place their laptop on a consistent height when working in multiple places with different desk heights.

Design criteria

When designing a height adjustment system, special attention has been paid to the following design criteria:

Keyboard and ergonomics (R1.3.1, R1.1)
The lowest point to which the laptop needs to be lifted equals at least 6 cm, enough to still type underneath your laptop without your hand touching the laptop stand.

Continuous height (W1.1.3)
Ideally, any height between the minimum and maximum can be achieved.

Design process

In figure 85 it is indicated that the height adjustment mechanism could be placed at both sides of the laptop stand [1] or in a central position [2].

Due to the constant upwards force of the lifting mechanism only the maximum height of the laptop stand needs to be limited. By doing so, effectively a height adjustment method is created while only having to worry about a one-way locking mechanism. This will also allow the user to always be able to push his laptop downwards into a folded position. In total, three different ideas have been designed.

1. Sidebar locking
The first solution combines a continuous height system with easy adjustability for the user at the cost of an expensive mechanism. Due to the dimensions and details of the part required (figure 81) this solution is likely to turn out very expensive, especially since the parts have to be custom made. The working principle of this idea is relatively simple. By turning the roller [2], the slot through which the short sliders move is shortened, effectively limiting the maximum height of the laptop stand. An additional difficulty with this concept is the continuous height function. In this case, the friction caused at point [2], and possibly

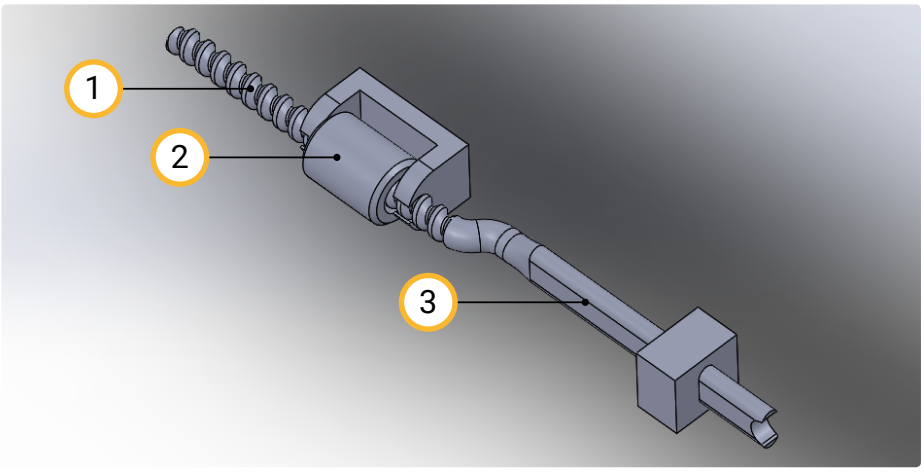


Figure 81: Sidebar locking 1

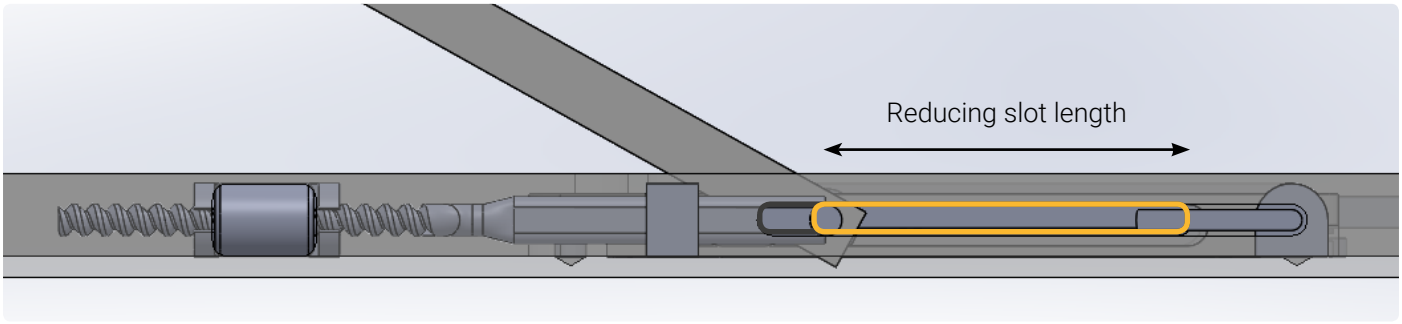


Figure 82: Solution 1 (2)

[3], has to be low enough for users to be able to comfortably twist the roller but high enough to stop the laptop from moving upwards. Additionally, a continuous height mechanism is often prone to wear, especially with extensive usage.

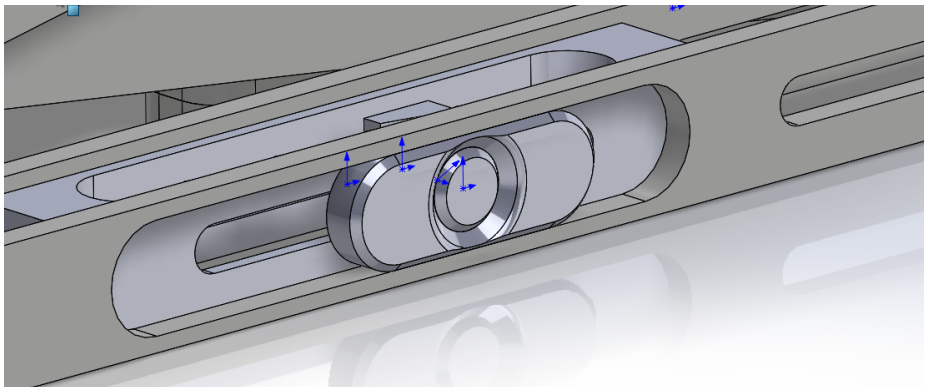


Figure 83: Solution 2

2. Sidebar lock-and-slide

In another solution, the continuous height system of solution 1 is exchanged for a step-wise locking mechanism positioned at the same place (figure 85, [2]), using a push-and-slide mechanism (figure 83-84). By pushing a small button, the slider can be moved along the outside of the base plate and by releasing it would snap into one of its height stands. This would overcome many of the difficulties of a continuous height mechanism (solution 1) at the cost of a slightly less adjustability (W1.1.3). The number of parts, difficulty of assembly and cost price are about the same.

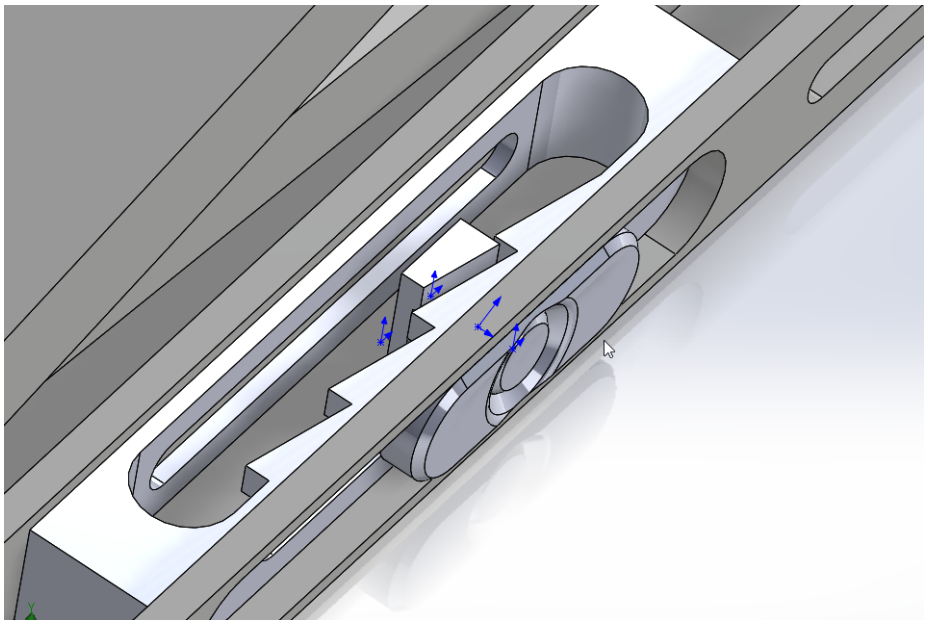


Figure 84: Solution 2 top view

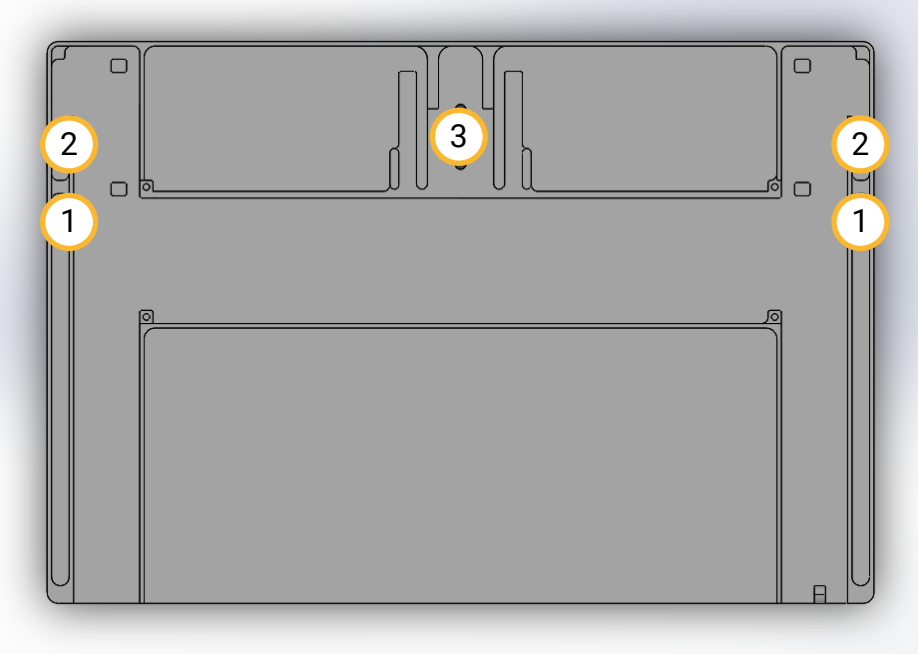


Figure 85: Placement of the three solutions

3. Middle lock

The third solution became viable after the design of the main slider mechanism was made (chapter 2.4). This allowed for another position of the locking mechanism. Since the left and right sliders are internally connected, a single locking mechanism could suffice. Additionally, in the middle of the base plate more space was available and therefore a more reliable design could be made. This concept makes use of a screwing mechanism that stops the entire main slider mechanism from moving further horizontally, effectively limiting the maximum height of the laptop stand. A downside of this concept is the usability of the feature as it can only be used before setting up the laptop stand and by turning the product upside down .

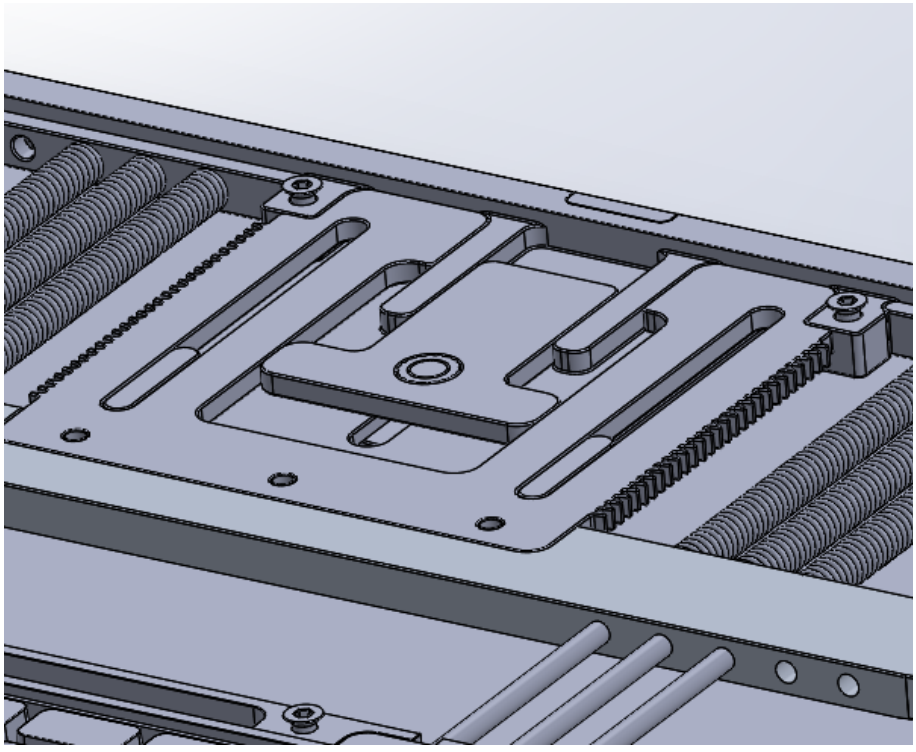


Figure 86: Solution 3

Weighted objectives

For the height adjustment the same criteria are used as for the decision of the locking mechanism due to high similarity. However, since the height adjustment is expected to be much less used than the locking/unlocking of the laptop stand, the price (assembly and production) is slightly increased and importance of usability decreased.

Based on the Weighted objectives method the Middle Lock is chosen as the best solution, even though it does not score very high in general. In retrospect this choice makes sense because it is significantly cheaper (R3.1) and more reliable (R1.7.2) than the alternative solutions and usability (R1.8) and aesthetics (R4.3, R4.5) are less important in this case.

Final design

The system works as follows: by loosening point [10] in figure 89 it becomes possible to slide plate [5] along its slot [6] (figure 88). By doing so the space between point [7] and [8] increases or decreases based on the adjustment that is being made. Since the position of plate [5] directly correlates with the maximum height of the laptop stand, it is now possible to adjust it with a simple mechanism.

When looking at the mechanism itself, a total of four parts (figure 87) are required to make this work of which two are standard parts ([1], [4]). The other two parts are relatively simple parts and both easy to manufacture. Additionally, part [9] had to be adjusted but without noticeable increase in production time.

Overall, it is a simple and effective solution at the cost of some usability.

	W.F.	Sidebar lock	Lock n slide	Middle Lock
Reliability	55	4	7	8
Usability	20	8	8	5
Aesthetics	10	8	8	5
Assembly time	8	2	4	9
Production cost	7	4	3	9
Total	**100**	**496**	**662**	**718**

Table 7: Weighted objectives height adjustment

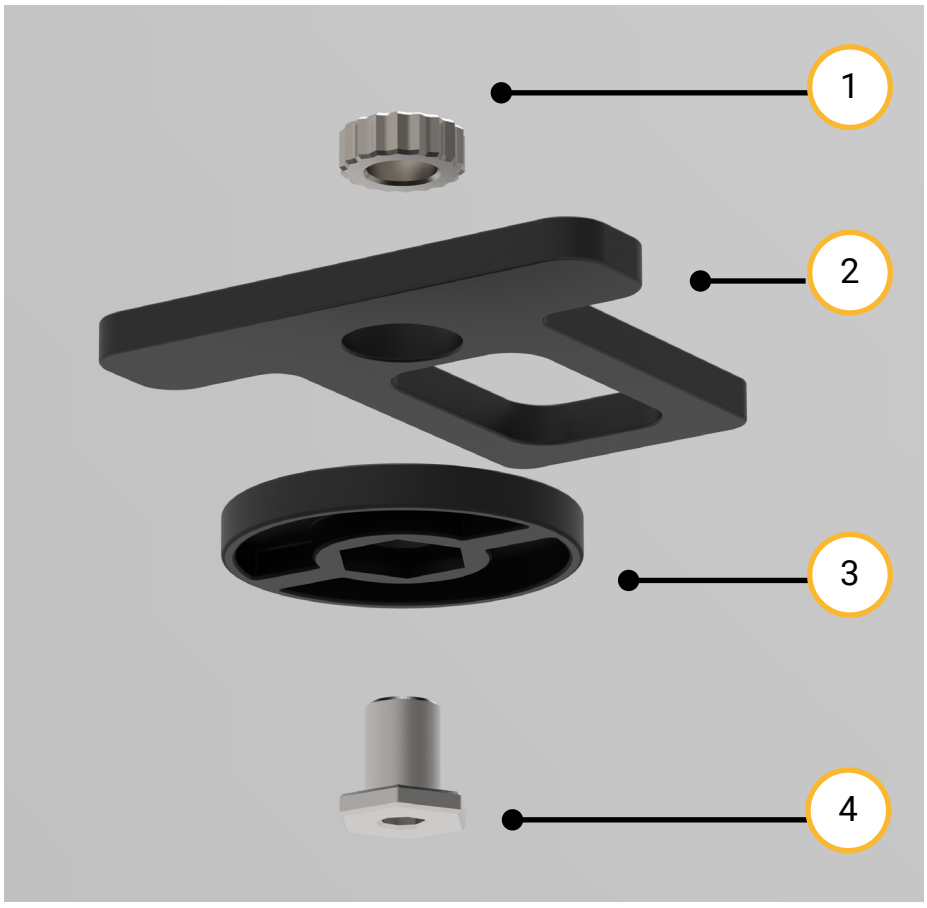


Figure 87: Exploded view of height adjustment mechanism

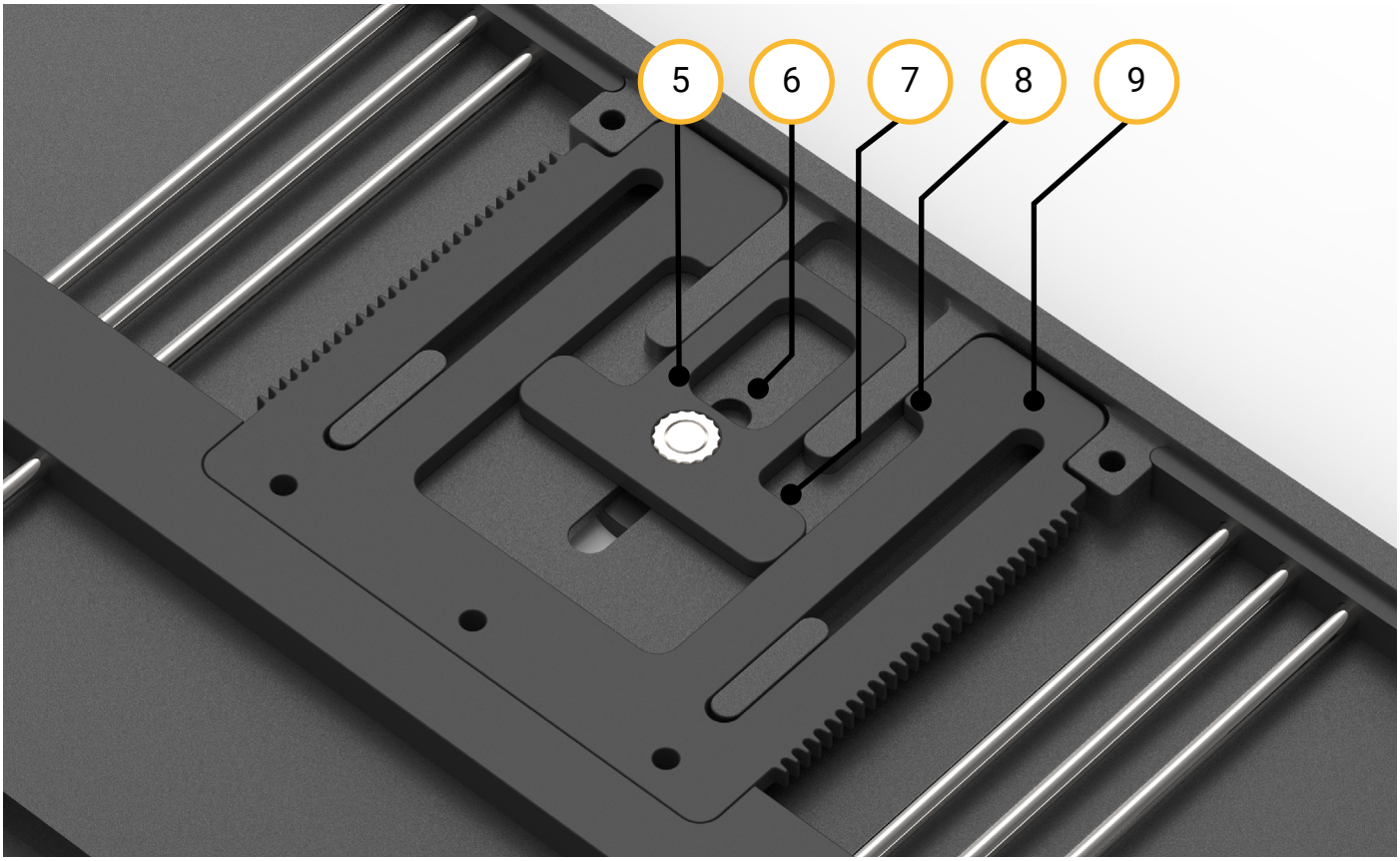


Figure 88: Final design

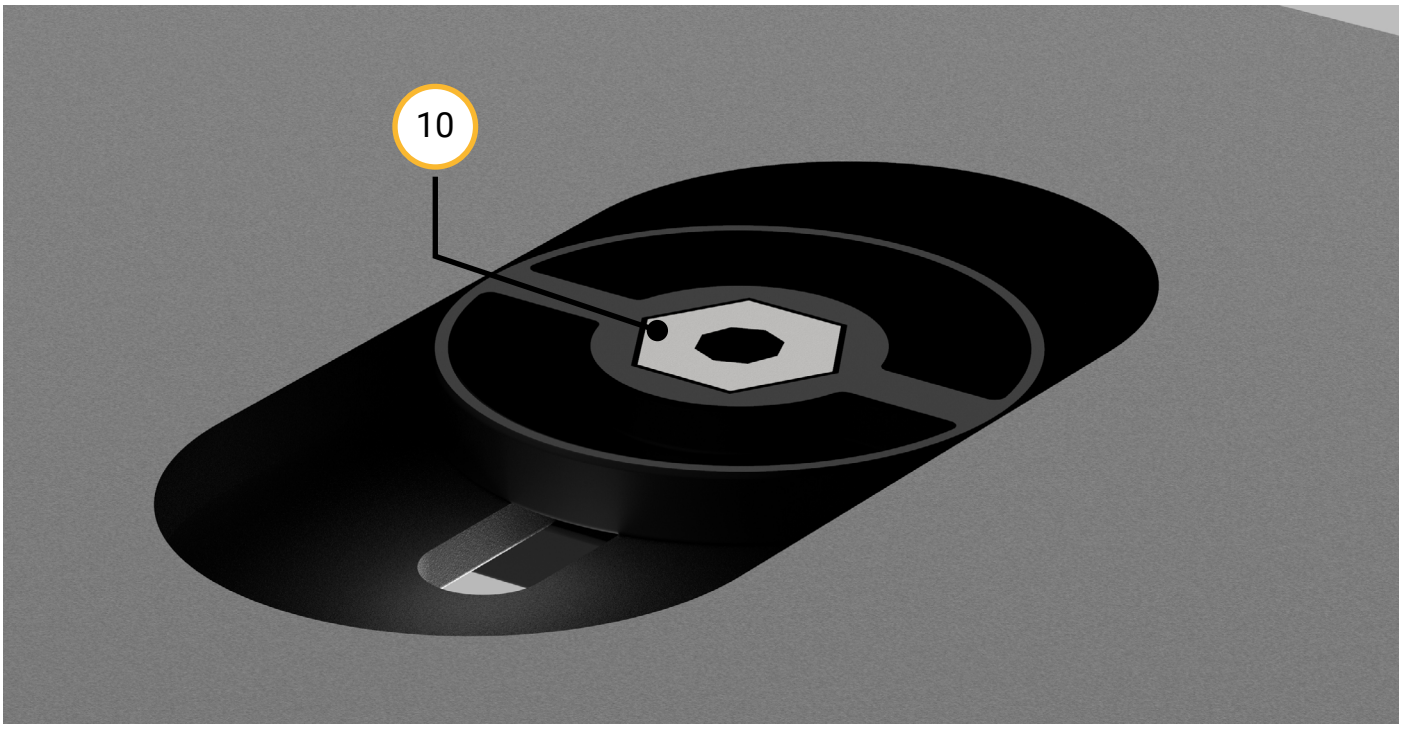


Figure 89: Close-up adjustment mechanism

Figure 90: Integrated keyboard

Considerations

+ By placing the last sliders all the way at the end an ergonomic 285mm keyboard can be used
+ Using a high end bluetooth module ensures unnoticable typing delay

- People who already own a keyboard may feel disappointed

2.9 **Keyboard**

One of the features that sets the product apart from its competitors is the integrated keyboard. Adding a keyboard within the laptop stand allows users to bring the multiple accessories required to work ergonomically in one package. As such, the keyboard will play a major role in the experience of the user as it will be inevitably the most used part of the product.

Design criteria

For a good functioning, ergonomic keyboard, the following requirements are set:

R2.4.1: They keyboard must be flat and at least 285 mm wide.

R2.4.5: Depth of the keyboard can be maximum of 120 mm.

R2.4: The keyboard is wireless.

R2.4.2: Typing delay is <40 ms.

Within these requirement a few options have been compared through testing, but only one keyboard would realistically meet all requirements (see appendix 21). This keyboard is the Stradivarius Solo X which has therefore been chosen as the keyboard for this product (figure 91).

However, even this keyboard has one issue as it is effectively 10mm too wide. This would force the base plate to be 10mm wider than the laptop and break one of the requirements (R2.1). Because none of the keyboards on the market was close enough to exactly meet the requirements, it was decided to continue with this keyboard until production number increases after which a slightly different casing may be made for a perfect fit. If a perfectly fitting keyboard is not met, the additional width of 5 mm at each side can be used for a better cover connection or to improve aesthetics through curved edges, making the laptop stand appear thinner (see chapter 3.2: aesthetics study).

For testing purposes a non functional keyboard from aliexpress is used, which did perfectly fit within the given dimensions.

A more in-depth analysis on the different keyboards and the internal layout of keyboard components can be found in appendix 21.

Figure 91: Stradivarius Solo X

Figure 92: Moodboard for cover design

2.10 **Laptop cover**

Despite technically not adding anything to the ergonomics of the laptop stand, an integrated laptop offers a few key benefits. With a laptop cover the laptop and keyboard are protected during transport and, more importantly, when setting up your laptop stand, everything is already in the right place, minimizing setup time and effort.

Design criteria

Along with the requirements as described in appendix 3, special attention was paid to the following criteria:

Protection (R1.5.1)
The main requirement of the product is to protect the laptop from scratching during transport. Increased levels of protection are inherently better. Ideally the integrated cover would protect the laptop (and keyboard) not just from scratching but also dust, water and falling damage.

Usability (R1.8, W1.8.2)
The usability aspect of the laptop cover is a two-edged sword as it both increases and decreases usability. By adding a laptop cover to the laptop stand as it is, the user requires more tasks to start working ergonomically, which is considered a bad thing. However, usually users will need a cover anyway, so in comparison it has no negative effect. Also, a laptop cover fixes the laptop in place on top of the laptop stand during transport and will therefore make it easier to get the entire package ready for set up out of your bag, with minimal user operations.

It will be a challenge to design a laptop cover that is strong enough to keep the laptop in place yet easily unlocks and is folded or stored away during laptop use.

Aesthetics (R4.5)
A laptop cover will largely determine what the user sees when not working on the laptop stand, which means the cover determines the aesthetics of the product significantly. Due to the flexibility of possible materials, color and detailing, this is beneficial in matching the aesthetics of the product with the targeted user.

Design solutions

With regards to usability, the biggest challenge was to find a solution that could keep a laptop fixed in place during transport, even when the entire package was held upside down or sideways. Additionally, the cover also had to be opened and removed during use easily.

The best fitting solution uses a folding technique and a thin solid plate to apply surface tension and keep the laptop tightly locked in place. A magnetic strip keeps the cover in this position once the laptop is clamped to the laptop stand by the tension on the textile. On the other side of the product, the back, the cover is connected in such a way that it can be sold either with (figure 93) or without (figure 94) cover depending on the users wishes. In this way, people who prefer to use their own laptop cover or case can still do so.

Due to time constraints, and the fact that the cover did not directly influence the ergonomics of the laptop stand, only this solution was explored. In figure 92 a moodboard is created to show some of the potential this part has to offer to the overall aesthetics of the product.

Due to the potential this part offers, it is important to continue doing research, designing and development on this component of the laptop stand in the future.

The "locking" can potentially become easier and more secure, the aesthetics offer a variety of possibilities as neither color nor shape matches nicely with the rest of the product yet. And, additionally, the cover only protects the laptop from scratches while there is also the potential to offer protection from dust and water.

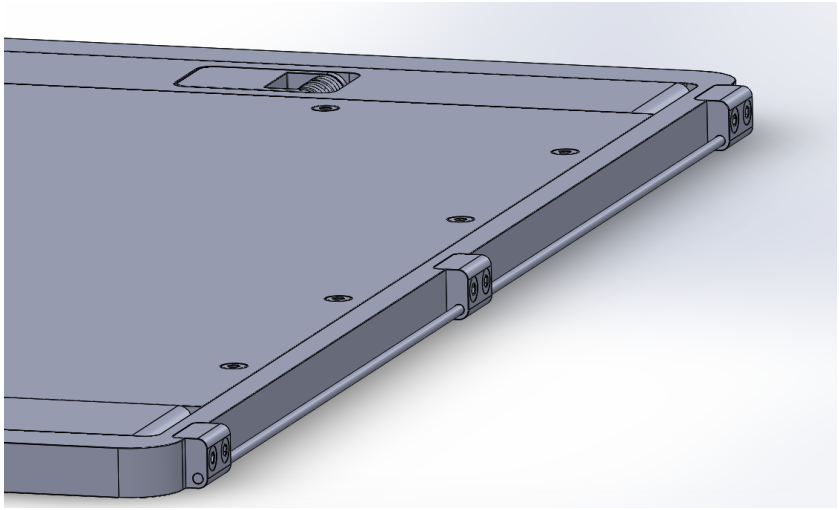


Figure 93: Situation 1, cover connection attached to the back of the base plate

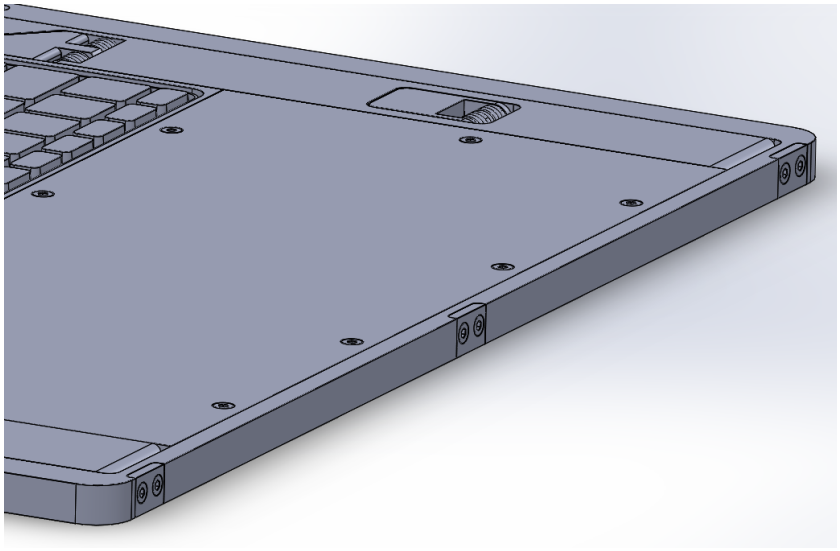


Figure 94: Situation 2, placeholders when not using the cover

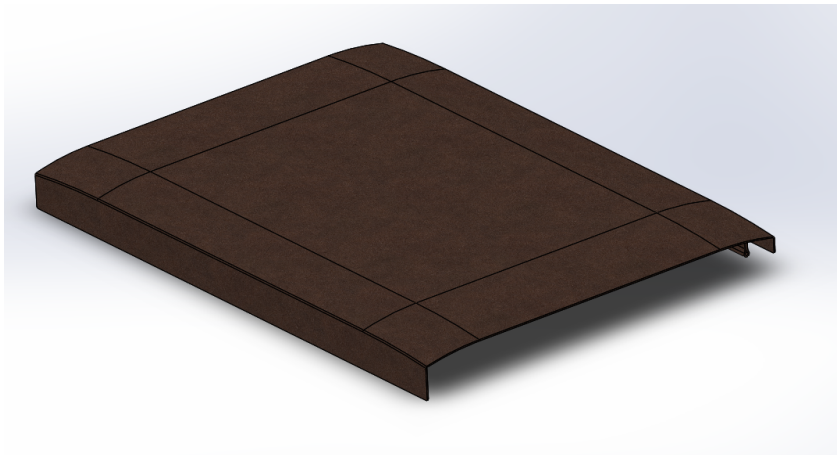


Figure 95: Initial design for leather casing

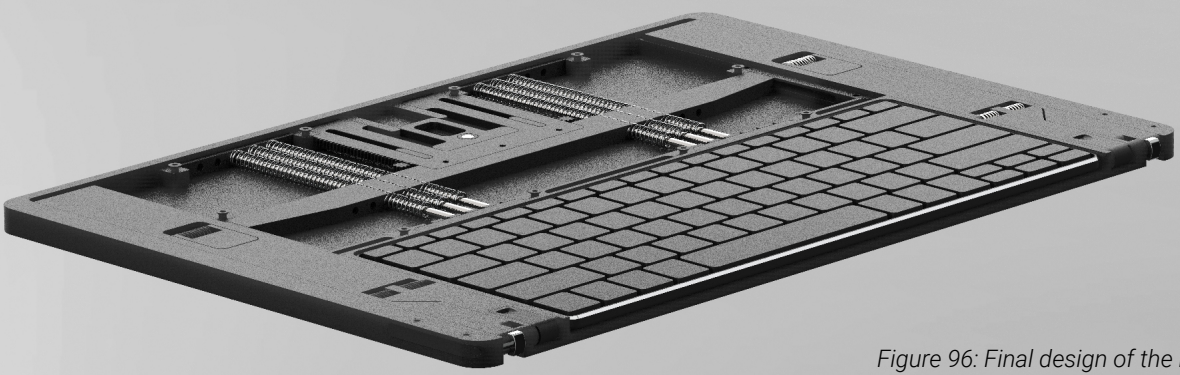


Figure 96: Final design of the laptop stand in expanded and collapsed situation

Figure 97: The start of a day prototyping

2.11 Prototyping

An important aspect of this graduation project has been the final prototype. The main steps of the production are explained here as well as learnings throughout development.

Prototype budget

Because the prototype consists of quite a few expensive parts (e.g. base plate, sliders, custom spring, damper systems) an application for the “start-up” voucher was filed and granted. This allowed the prototype to be built from aluminium and the specific spring-damper system to be integrated.

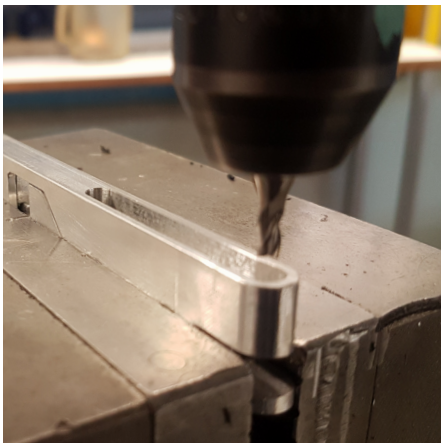


Figure 98: Milling the locking mechanism

The different components

- **Base plate, sliders and locking mechanism**
  The base plate and the sliders are all CNC machined at the IDE faculty. This significantly cut the production cost.

- **Springs**
  The spring are made at spring factory Roveron. Because a great number of custom springs this was one of the more expensive parts of the prototype at just over € 300.

- **Dampers**
  The dampers are from Acecontrols (acecontrols.com), a company that specializes in dampers. They were willing to provide a set of small rotary dampers in exchange for an opportunity to write about the use of the dampers within my product. A win-win situation.

- **Stability slider**
  The components for the stability sliders have been made from POM and are lasercut by BMTEC, a company that specializes in laser cutting high grade thermoplastics.

- **Connection parts**
  Connection parts such as axles, screws and clamping pins have all been ordered at Fabory.

- **Keyboard**
  The keyboard within the prototype is from aliexpress, the keyboard that will eventually be used is the Standivarius Solo X.

- **Other**
  Any parts not listed above is custom made by the designer.

Most components had to be machined by hand before they were ready to be assembled. For example, the base plate, sliders and stability sliders all required additional hand work after CNC machining. In appendix 22 this is described into more detail and is explained how the prototyping led to some design changes.

Testing

During testing, force is applied at positions [A] and [B]. The force is gradually increased to until the laptop stand is folded completely flat. This resulted in the conclusions discussed below.

Results

The middle slider [1] as seen in figure 99 turns out to deflect up to twice as much as the expected maximum of 1.1 mm (appendix 13). This deflection causes tilting to occur at points [E] and [F] which in turn causes the laptop stand to open and close only when very precisely adjusting both sliders in sync.

Secondly, it was noted that the slots at point [3] did not avoid tilting in a meaningful way. The tolerances and fitting of the axles in the stability sliders were not tight enough and the natural elasticity of POM all added up to this.

Thirdly, the sliders did not fold easily completely flat. It was not exactly clear what caused this as it looked like the sliders should be able to fold normally. By applying ink at the sides of the sliders it was found that at places the parts just slightly misfitted. A slight production error in one of the long sliders caused a very loose fit at point [C], which further enhanced this issue.

The top plate was initially expected to have a functional requirement to keep the components underneath the top plate in place. During the first test the product was fully functional without the use of the top plate and nothing indicated a potentially dangerous situation.

At point [4], the axle had too much freedom to move around, causing further issues with tilting.

At point [5], the shortened torsion springs had their spring legs floating in the middle [6] which looked very odd. It has already been discussed in chapter 2.5 how this can be solved and even used as damping.

At point [4] an additional two torsion springs are planned but could not yet be implemented due to an inaccurately toleranced connection between the stability slider and the short slider.

At point [D] the locking mechanism would not close nicely as a result of inaccurate production.

Adjustments

Because the stability slider was a bottleneck in testing other components and in verifying the intended upwards force, it was decided to mill a new one from aluminium [7] instead of POM to get a better understanding of the spring damper system.

Additionally, two distance rings are added at point [8] to increase the stability of the system further.

The implementation of the second torsion spring is postponed as it required relatively a time consuming and risky adjustment.

After these adjustments, pressure is applied gradually until the laptop stand is folded flat.

This time the entire product seemed to work much smoother. The pressure along the entire elevation felt nicely distributed and the laptop stand opened and closed well.

Furthermore, the expected lifting force from the springs used in the prototype is compared to the actual lifting force using a force meter. This was done by connecting points [A] and [B] with a small plate so that upwards force could be measured in the middle.

In appendix 23 the results can be found and are shortly discussed.

An indication of the cost price of the laptop stand can be found in appendix 24.

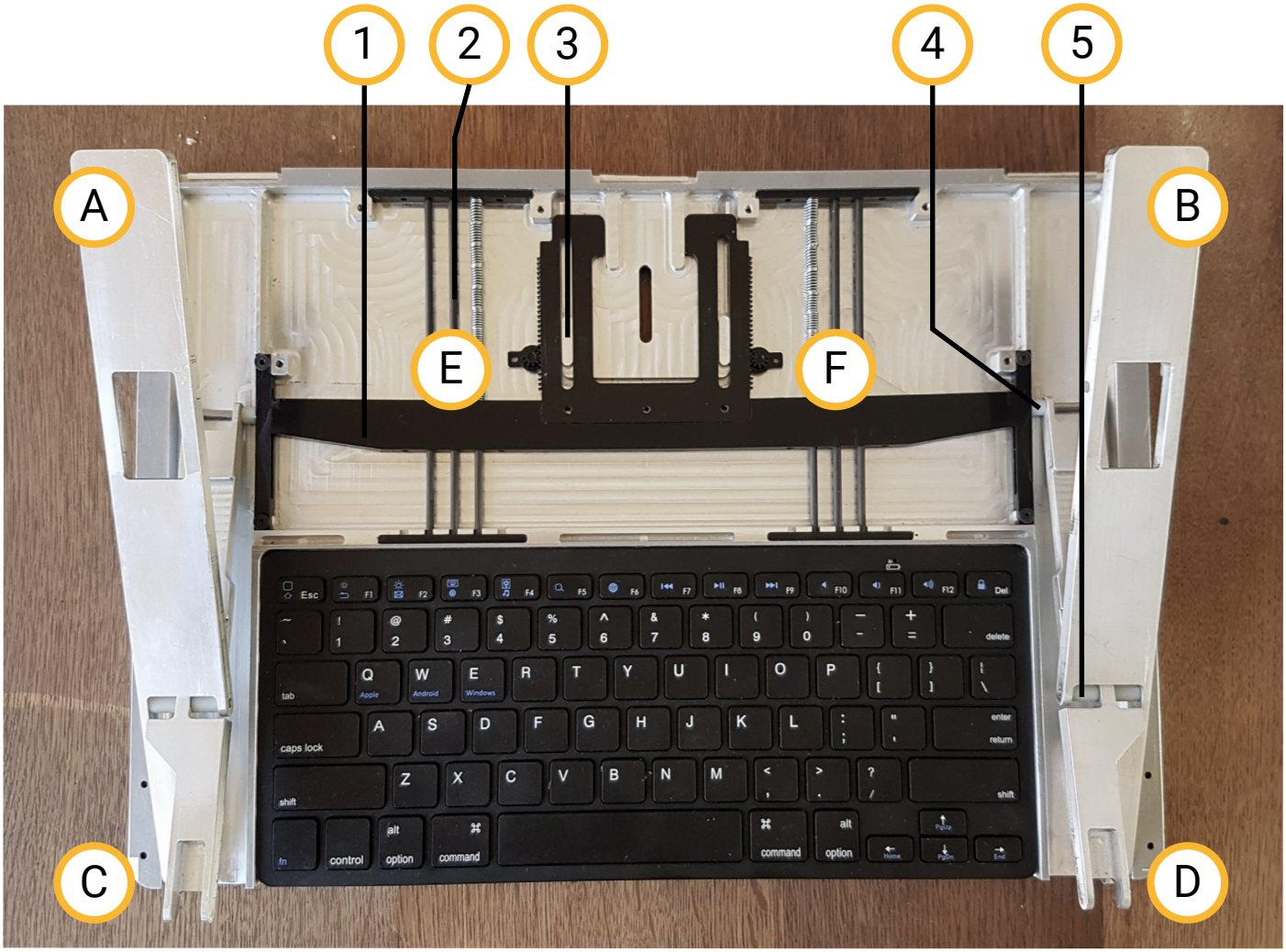


Figure 99: Functional prototype top view

Figure 100: Floating spring legs

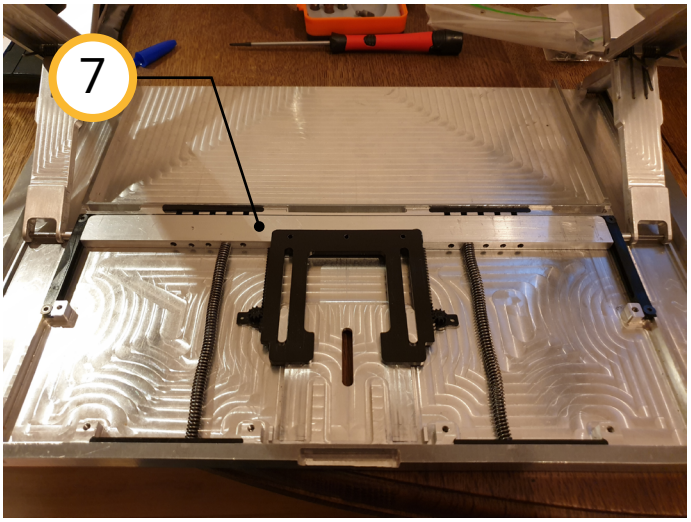


Figure 101: Adjusted stability slider

Chapter 3.

Branding and positioning

3.1 Branding and positioning

Despite branding and positioning not being the main focus of this project, it has been shortly touched upon because the design of the product is influenced by the way it is branded and positioned. Additionally, during the graduation project I had the chance to join the SPD master course Branding and Product Commercialisation (ID4315-16) as a client which resulted in a lot of inspiration for the branding and positioning of this product.

The 4C analysis has been used for defining the branding and position of the laptop stand. Thereby, the 4C analysis of team 6 has been used as a guideline as it came very close to the designer's intentions and own ideas (credits to J.T. Dai, J. Dott, P. van Esch and D. Florescu).

Competition

The Riggid laptop stand does not have any direct competition as it offers a unique combination of attributes in one package. This has been described more in-depth already at the start of the report in chapter 1.4: market analysis.

Riggid offers the most optimized laptop stand from an ease-of-use point of view while providing the tools for a fully ergonomic laptop setup in one stylish and well-designed package. However, this comes at a price point that is much higher than competitor products at an estimated €320,00. This inherently forces the laptop stand to focus on the medium-high end market and adapt a more luxurious and premium look to match the user expectactions.

Consumer

The Riggid laptop stand can be used by anyone using a 15” inch laptop but is specifically built for digital nomads who use a MacBook. More information on different potential target groups can be found appendix 4.

Context

The Riggid laptop stand will initially be offered to digital nomads who are working independently in the knowledge industry. They will be reached through a Kickstarter campaign. If the first products have been used and reviewed positively, the next step will be to target companies who rely on telecommuters. This means the focus will change from reactive (individuals usually react to their complaints) to preventing (for businesses it is beneficial to prevent MSD among workers), which increases the potential number of users significantly. An additional benefit when targeting businesses is that the price point is much less of an issue, if they can prevent employees from calling in sick due to MSD related problems. In both cases the product will be focussed on (young) working telecommuters in the knowledge industry.

The position of Riggid is further strengthened due to the fact that telecommuting work is growing rapidly since 2008 with the largest year to year growth in

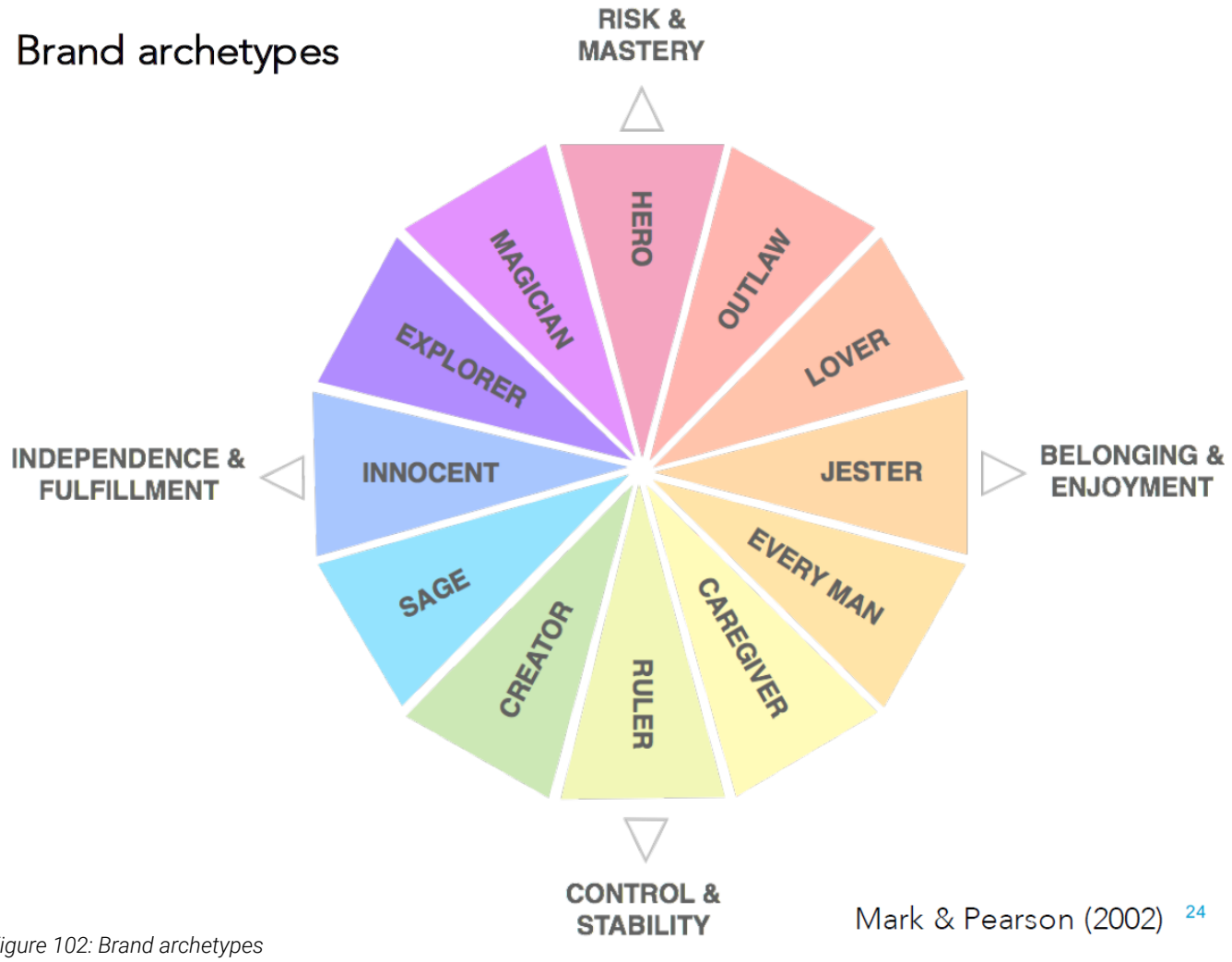


Figure 102: Brand archetypes

2016 of 11.6%. Additionally 85% of workers in the USA indicate they would like to work as telecommuter at least part time (GlobalWorkPlaceAnalytics.com, 2016).

Company

The company consists of Thomas Zwart and Igo Boerrigter, with backgrounds in Integrated Product Design (IPD and Design for Interaction (DfI) respectively. Riggid started with back problems from Igo and the lack of a user friendly solution in the market. Together they discovered that laptop ergonomics was a very common issue with no real solution and decided to join their skills and tackle this problem forever.

Brand DNA

The brand DNA is based on the 4C analysis and built up from three corner stones: purpose, personality and positioning.

Purpose (why):
People work best when their well-being is ensured.

Personality
Ruler personality (figure 102 and appendix 26)
- Ergonomic
- Stylish
- Smart
- Improve

Positioning
- Professional
- Reliable
- Stylish
- Premium

Riggid's purpose is to improve the well-being of digital nomads

by improving the way they work. By doing so two advantages can be described: the user can work more efficiently, reducing work pressure induced stress, but also improve off-work time by decreasing musculoskeletal discomfort/disorders which increases the overall happiness and results in a positive spiral as it also positively affects future work.

As a brand, Riggid identifies itself as the Ruler personality while leaning a little towards the Creator. In appendix 26 the main characteristic for these personality types are described.

The main goal of Riggid as a company is to give people the tools to improve how they work, their work-life balance and ultimately allow users to be more productive and perform better, without physical discomfort or pain. Riggid epxresses ergonomic knowledge in a smart and stylish way with of focus on personal improvement.

By building products of high quality from both a manufacturing and a design perspective they can be positioned as reliable, professional and luxurious.

Market prospects appear to be positive as well as people start to work remotely in rapidly increasing numbers (PGi Global Telework survey, 2015) and it is expected that this is one of the main reasons MSD complaints across workers keep increasing as it is relatively difficult to maintain a good posture when working outside a professional office.

How does this affect the design?

To ensure the Riggid laptop stand fits the brand personality and positioning, the product needs to convey qualities such as "reliable", "professional", "premium" and "stylish". In chapter 3.2, a survey is conducted to validate to what extent the current model achieves these qualities.

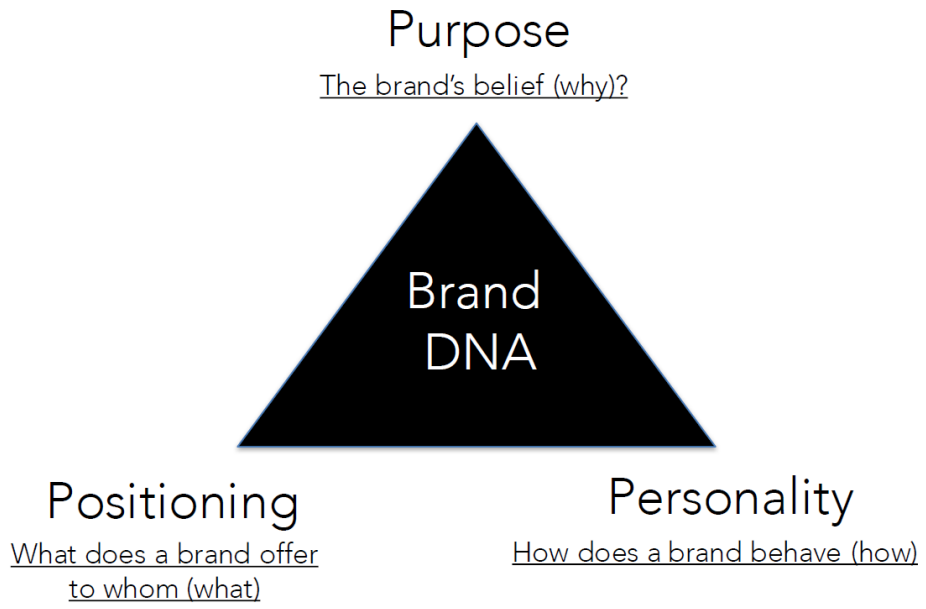


Figure 103: Brand DNA

[1]

3.2 **Aesthethics study**

In order to evaluate the aesthetics of Riggid a questionnaire was conducted among laptop users.

Goal

The goal of this study was to be able to reflect on requirements R4.1-R4.5.4, so to find out how users rate the appearance of the product in general and in relation to their laptop, whether users would mind to use the product in public and if the laptop stand is perceived as premium, professional, reliable and stylish (to fit a luxurious product line). Lastly, it would provide valuable insights in how the aesthetics could be further improved.

Method

Participants were asked to what extent they agreed with the statement "If I (would) use a laptop stand, the appearance of the laptop stand is important to me". Then, based on an image of the laptop stand (with laptop), they rated 10 word pairs on a 7-point scale. The word pairs included the intended design qualities or words related to them and general attractiveness qualities:

- Complicated - Simple
- Unreliable - Reliable
- Unprofessional - Professional
- Conservative - Innovative
- Tacky - Stylish
- Cheap - Premium
- Unpresentable - Presentable
- Ugly - Attractive
- Technical - Design
- Repelling - Appealing

Next, some additional questions were asked about overall appearance, use in public and influence on laptop appearance.

To avoid bias, participants were not told that they were about to rate the laptop stand that was designed, but that their answers would contribute to research about the appearance of laptop stands. Additionally, next to the designed laptop stand, participants were asked to rate two other laptop stands from the market analysis (Roost and Furinno; comparable on appearance and both ergonomically correct) on the same questions to have a point of reference. In this way it could be assessed how the aesthetics of the designed laptop stand are compared to the competition.

After each laptop stand was rated, in the next section the actual designed laptop stand was introduced by explaining its functionality and advantage. A video showed how it works.

Results and conclusions

The questionnaire was filled in by 26 people. In line with earlier findings from the interview, it was again verified that users find the appearance of a laptop stand quite important, with a score of 4.76/7 (totally disagree - totally agree). All word pairs scored on the positive side. Interestingly, Riggid scored highest on the four intended qualities (apart from "presentable", which also scored high: 5.5/7), with a 5.2/7 on "reliability", 5.6/7 on "professional", 5.0/7 on "stylish" and a 4.9/7 on "premium". Therefore it can be concluded that the laptop stand expresses the intended aesthetic qualities to a sufficient extent and R4.5-R4.5.4 are achieved.

In comparison with the other laptop stands, Riggid scored significantly higher on all qualities with an average of 4.9/7 compared to 3.7/7 for Roost and 3.1/7 for Furinno. The overall appearance grade given was a 7/10 compared to a 5.4/10 for Roost and 4.4/10 for Furinno. This means R4.3 was not met and shows improvements need to be made on the overall aesthetics of the laptop stand.

Participants indicated that they would not mind to use Riggid in public (with a score of 5.4/7 on the statement "I would not mind to use this product in public", 7 = totally agree), whereas they were doubtful about the Roost (4.1/7) and did rather not want to be seen with Furinno (2.9/7). Furthermore, participants generally indicated that the laptop stand does not negatively influence the appearance of their laptop (2.6/7). Thus, R4.1 and R4.4 were both achieved.

Finally, Riggid was in general given an average of 8.0/10 when participants knew its function. 73% of the participants gave an 8 or higher, which means that R4.2 was not met but is expected to be met as aesthetics are improved. Participants were very positive about how it worked, mentioning that it "looks easy to use", looks "handig" and "comfortable", providing initial proof for having achieved the design goal.

One given suggestion for the appearance was to provide multiple color or material options (e.g. lighter colour or a wooden look, see figure 104 and 105). This confirms the need for some degree of personalization (R4.6). Other suggestions were to make the sliders look cleaner or more elegant (e.g. straight lines), which would be beneficial for the luxurious look.

All in all it can be concluded that the appearance of the laptop stand is successful, especially considering the fact that it was not yet optimized during this project.

All results of the survey can be found on https://tinyurl.com/aestheticriggid.

Discussion

Although participants were specifically asked not to change their previous answers once they knew which laptop stand was designed, it cannot be guaranteed that participants rated their answers more positively to be more "friendly" towards the designer. However, some participants indicated that the aesthetics were better on the video showed afterwards than on the image, so this might mean the actual answers would have been more positive. However, all together it is expected that the ratings generally give a good image of how the appearance is actually perceived.

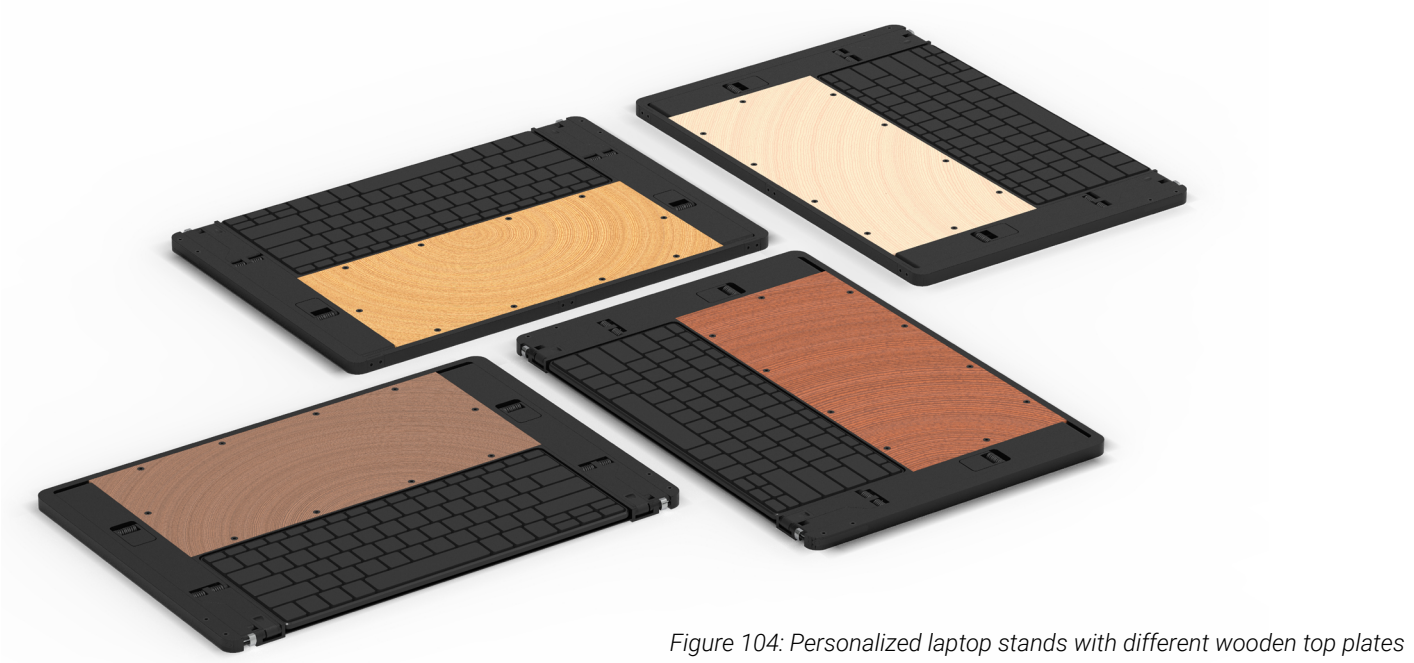


Figure 104: Personalized laptop stands with different wooden top plates

Figure 104: Transparent top plate

Chapter 4.

Conclusion and reflection

4.1 Recommendations

Based on the learnings from building and testing the prototype and aesthetics research a list of recommendations is composed for further development of the laptop stand.

Spring-damper system
The last prototype was a very clear proof of concept and the results were surprisingly close to the expectations. However, a lot of improvement can be gained from optimizing the balance between the springs and the dampers and finding the best fitting springs. This will be a longer process of trial and error but is likely to succeed based on the results thus far. Continuing research on this topic should be a main priority.

Change in axle connection
The axle through the slots (connecting the lower point of the short slider to the stability slider) is not stable enough for the spring to be implemented. For the spring damper system to work, this issue has to be solved. The most straightforward solution is to use a longer axle and connect it from the stability slider, through the short slider and secure it in the side bars of the base plate. The current prototype can be adjusted for this solution to be tested.

Spring position
In the current prototype the torsion springs within the sliders are only functional between a flat laptop stand with 25 degree elevation. After the 25 degrees they are simply hanging in the air. To solve this, the spring legs need to be connected to sliders. This has a key advantage as the torsion springs will also function as a damper to smoothen out the elevation of the laptop stand. Within the current prototype it may be possible to test this by glueing the spring legs to sliders. However, this would be a temporary solution.

Top plate
During testing the top plate did not require as many screws as was initially expected, potentially another solution can be used entirely. This could also improve the aesthetics of the laptop stand.

Cover
The cover could become a key element in the design of the laptop stand but needs further research, design and development, as only the first possibilities have been explored. Findings from the aesthetics study further emphasize that the appearance needs to be improved and a good fitting cover is expected to aid in resolving this issue.

Cost price
A key part of the success of this product is likely going to be the cost price. For a relatively small production batch of 100 units the expected cost price is somewhere around €100, which really pushes the limits for the viability of a laptop stand.

Market validation
With a now fully functional 3D CAD model, it is relatively easy to do additional user research and determine the interest in the product as it currently is. A/B testing with different value propositions on Facebook is expected to be a good first option for relatively little funds. This

could also be a pre-kickstarter campaign and confirm whether or not to continue the product as it is.

Ergonomic and usability research
It would still be very interesting to conduct the ergonomic and usability study that was initially planned for this graduation project. It is recommended to conduct this research to strengthen the benefits for potential clients, especially companies.

Front grip
The front grip has the potential to be more secure with a few adjustments. Currently, the part of the front grip that faces the laptop is completely flat. During prototyping it was realized that nothing in the design limits this front grip to have a slight edge clamping the laptop a little more secure.

4.2 Conclusion and discussion

Conclusion

The initial design goal was to "design a laptop stand that makes it easy for users to work ergonomically, without losing the flexibility and appearance of a laptop." This addresses an increasingly pressing issue among flex workers.

The designed laptop stand reaches this goal by combining the following key features:

An automatic lifting mechanism allows users to quickly set-up their ergonomic workplace. This in contrary to ordinary laptop stands that have to be deployed first after which a laptop can be placed on the laptop stand. This feature was tested with the final prototype and despite not being completely functional, the results very accurately matched the expected outcome. Therefore, it is very likely the concept as developed will be fully functional with a few adjustments to the prototype.

The integration of an ergonomic keyboard further enhances the speed in which an ergonomic setup can be realized by the user. By smartly positioning the keyboard at the front underneath the laptop stand, it also allows users to work at their preferred eye to screen distance even if they have additional accessories in front of them.

A continuous height adjustment allows the user to work exactly at their preferred height and allows the P90 of users to work according to ergonomic standards.

The integrated locking mechanism at the front and an adjustable front grip complete the required functionality of the laptop stand.

The aesthetics of the laptop stand needs to be further improvement as the requirements have not yet been met sufficiently (average of 7/10 of the required 8/10). Additionally, only 73% graded the product in general with an 8 or higher, which is lower than the required 80%. Despite not meeting the aesthetic requirements, the Riggid laptop stand scored significantly better than its competitors Roost and Furinno.

Overall, the product as it has been designed is showing promise and will be ready for first user testing after the implementation of a few adjustments.

Discussion

Usability vs price

A major consideration for the design has been the addition of a spring-damper system to make the laptop stand easier to use. The increase in required components, detailing and production cost may however be too much compared to benefits it offers. In hindsight, an argument can be made for either and due to promising interim results it seems logical that during the process the design and integration of a spring-damper system was continued.

This does bring the question whether the product is market viable. Because of the complex nature, usage of materials and safety concerns, the product is going to be expensive compared

to alternatives. It does however also bring much more to the user than alternative products, as the Riggid laptop stand is the only product on the market that optimizes the entire customer journey in the use of a laptop stand. Additionally, the price point can also be matter of perspective; for example a €2500 MacBook or a €2800 MacBook with a professional ergonomic set seem quite reasonable whereas a €300 Windows laptop suddenly cost twice as much with this laptop stand, which is not so reasonable. Adding to that, if the product is actually really easy in use it could be a very interesting product for companies as it would be much easier to convince their telecommuting employees to work ergonomically, decreasing MSD among employees and increasing work efficiency.

Aesthetics
In the aesthetics survey at the end of this project the laptop stand was graded lower than is required (7/10 instead of 8/10). This makes sense because even though the design decisions during this project have always been made with aesthetics in mind, there have not been many steps focussed on aesthetics specifically. The given advice on how to improve the aesthetics included simple factors such as color (matching with laptop, vibrant, light/dark) and material (wood, brushed aluminium) which implies that with these adjustments the aesthetics grade would also increase. As the product is designed with these possibilities in mind it can be implemented easily and is likely to reach the required aesthetic score.

Cover
The laptop cover may make or break this product from a marketing point of view. The cover will play a major part in the aesthetic experience of the product and allows for plenty of options for personalisation and branding. The focus during this assignment hasn't been too much on this cover because it did not add much from an ergonomic point of view which was considered more important. Further research and design optimization of a fitting cover are expected to pay off eventually.

Production
The high cost price is mostly determined by the tooling cost of the base plate and the sliders. Optimisation on this could really benefit the product and potentially lower production cost. There is also a lot of material "wasted" with CNC milling (it can be re-used but it is not ideal). Changes to the way the base plate is built (perhaps more than one part) could significantly lower material and production cost but increase assembly time and likelihood of product failure. Overall it could be an area well worth investing in in further development.

Combining
The laptop stand alone is unlikely to solve all MSD complaints as it remains difficult to completely adjust your posture without reminders during work. Combining the product with ergonomic software (e.g. RaveWorks or CtrlWorks) or tools such as the UprightGo is expected to provide the best results and remains important. When bringing this product on the market, additional research should be done to what extent a combination of ergonomic tools provides the best results.

4.3 **Reflection**

For me, this graduation project has been, with quite a margin, the most challenging project during my time as IDE student. This is arguably very logical because the graduation project is the most important and largest assignment, but I believe there is more to it. In the Bachelor and IPD Master study at the TU Delft there is a very strong focus on team work, something I have always appreciated and enjoyed despite the troubles team work sometimes causes. I love arguing, brainstorming, critiquing and working towards a goal togheter. I can now add to the list, based on this graduation project, that I also seem to function a lot better as an individual in a team than I do when I work alone for a prolonged amount of time.

I believe this can be reasoned back to motivation and discipline. For example, I find it very difficult to keep focusing on a task if there is nobody to discuss it with, if there are weeks without strict deadlines and if there is nobody to keep you motivated apart from yourself. As a result, the tasks I did not enjoy doing (e.g. report writing) became a tedious core and it was difficult to push through. I certainly did not make it any easier for myself by choosing a project with an entrepeneurial focus, in which I was going to do the development alone.

Additionally, life gave me two great opportunities at the wrong time; a new house and a new business. I decided to split my time between my graduation project and these opportunities to try and keep everyone around me happy. This resulted in a seven days a week / twelve hours a day work schedule with mostly work that had to be done rather than that I enjoyed doing it. Inevitably this resulted in lower levels of motivation and concentration, putting myself in a bit of a downward spiral.

Looking backwards at this graduation project, I would have done it quite differently. Starting right at the beginning I now think I gave myself somewhat of a false start and set the wrong expectations. Because I already started working on a laptop stand during Build Your Startup, I felt like I was continuing on that project more than I was doing a graduation assignment. It therefore took me a long time resetting my mindset and focus on what is expected of me as a graduation student rather than how am I going to make this laptop stand work.

Besides, keeping myself to own deadlines is not one of my strenghts as I seem to just indefinitely postpone them with a variety of creative excuses. Not something I am exactly proud of but clearly a tough skill to master for me. I certainly did improve during this project but it will be a continuous challenge in my life onwards.

Knowing myself, I should have made smaller deadline windows with verifiable deliverables. By doing so I would have had more structure, a better understanding of the bigger picture and a general idea on how the different pieces would tie together and fit within the available time. Instead, I felt like time was not a key factor at the start of my project and I planned on getting as far possible

within the available time. At the time it made sense to me, but by allowing myself this mindset, I put myself into a position without boundaries and without a specific focus.

Because I already had a clear idea about the base construction of the laptop stand before I started with the graduation assignment, the design process has been quite traditional; analysis (literature, survey, interview) > criteria (list of requirements) > synthesis (iterations) > simulations (testing) > evalution (comparing to requirements) > decision (final design). Because of internal dependencies this was a lot of back and forth designing.

At points I feel a more broad, or distanced, approach would have been better and allowed me to fixate a little less on details but focus on the bigger picture. I do however think that the time I spent on designing, building and testing is definitely justified.

NICE STEP TO GET FROM A DIGITAL MODEL TO A WORKING PROTOTYPE, PROUD OF FINAL PRODUCT

HOPE TO CONTINUE WITH IT?

The different tests and reporting on interim results could have been much better, more concise and more academical. I think that is a pity because I feel I do have the capability to do so but due to the way things worked out I seem to have completely missed that chance.

Only after reserving six weeks straight to finish my graduation, things started falling into their place again and I can now happily write I have a new home, an upcoming business and hopefully a Masters degree in Science.

4.4 **Word of thanks**

First of all I would like to thank my chair Peter Vink and mentor Henk Crone for the feedback they have provided throughout my graduation project. I must have looked like as quite a stubborn student as it took a shy five months before I really started listening to the feedback. Special thanks to Peter for always being able to give me confidence in the progress of my graduation project and a special thanks to Henk Crone to always destroy this confidence and put me right back in my place. The two of you make a great supervisory team.

I would also like to thank Igo Boerrigter for helping me with prototyping during times two hands were not enough and assistance during the occasional brainstorm.

Thirdly I would like to thank my family for always supporting me and pushing me to focus on my graduation project over other things that seemed equally important to me.

Lastly, and most importantly, I would like to thank my girlfriend Noëlle for supporting me beyond reason in the final weeks of my graduation project. Thank you for always being there when I needed you, for the countless hours of proofreading, discussing ideas and critiquing my work. But mostly thank you for assisting me through this assignment which at times was quite a struggle. I sincerely doubt I would be where I am now without you. You mean the world to me.

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Glossary

Digital nomads

Digital nomads are a type of people who use telecommunications technologies to earn a living and, more generally, conduct their life in a nomadic manner. Such workers often work remotely from foreign countries, coffee shops, public libraries, co-working spaces, or recreational vehicles.

Knowledge industry

An industry or area of economic activity that is based mainly on information and knowledge rather than on the production goods. The majority of new jobs have been in knowledge industries.

MSD

Short for musculoskeletal disorders (discomfort if specifically mentioned). Musculoskeletal Disorders or MSDs are injuries and disorders that affect the human body's movement or musculoskeletal system (i.e. muscles, tendons, ligaments, nerves, discs, blood vessels, etc.)

Telecommuting

Telecommuting (also known as working from home, or e-commuting) is a work arrangement in which the employee works outside the office, often working from home or a location close to home (including coffee shops, libraries, and various other locations).

Appendix

Appendix 1

Original project brief

In the 20 weeks prior to this graduation project, I have been working on a product together with Igo Boerrigter for the course “Build your own startup”. During this course we started the development of a laptop stand that helps flex workers (working people without a personal office or desk) to work ergonomically on their laptop wherever they are. During my graduation I would like to continue working on the development of this project as it has a good market potential. Additionally, the initial feedback was very positive and I greatly enjoyed working on the product. We finished the course with a 3D model (fig. 1) and a prototype (fig. 2) that had the right base construction, but not the user experience, dimensions and appearance we were aiming for.

The main stakeholder in this project will be people who work on a laptop on a daily basis without a fixed workplace, for example students, starting entrepreneurs and consultants.

Prior to this graduation assignment, we found In a survey with 225 students at the TU Delft we found that over 75% of all students have experienced physical discomfort when working on a laptop, of which 15% said this to be a daily issue. Additionally, students are aware that they are currently not working ergonomically and strongly agree that they would like to do so (an average score of 5.41, with 1 being “completely disagree” and 7 being “completely agree”).

Since students seem to be aware of the problem, but do not do anything about it, there must be something that is holding them back. Based on answers from the questionnaire and additional interviews it became clear that current products are too much of a hassle to work with; It’s annoying to bring multiple accessories, it’s annoying to keep setting up your workplace if you switch places regularly and it quickly becomes a mess in your bag. Additionally there are complaints about the aesthetics of available products.

Currently, working ergonomically is a very reactive process. Once significant pain is experienced by the user, they are much more likely to spent money on ergonomic products. This may be caused by the fact that current solutions are reducing the flexibility of a laptop and people are not willing to go through the hassle of working ergonomically if they may never get RSI. Since students did show a very significant interest in working ergonomically, a product that does not reduce the flexibility of a laptop is being received as very appealing.

One of the biggest opportunities is to change a market that is currently reactive to a market that is proactive. It is my goal to design a laptop stand that interacts very intuitively with the user, thereby maintaining the flexibility a laptop offers. Additionally, I believe it is very important to create a product that looks appealing to allow people to be proud of working ergonomically. As a result I hope create a product that users without RSI also love to use.

I believe the current market is limited in the way that all required accessories to work ergonomically are developed separately. Laptop stands are becoming smaller and thinner and lighter. Keyboards are becoming smaller and are better designed and there are ergonomic mouses. However, nobody brings these elements to work ergonomically together in one package. I think there is an opportunity to combine everything required to work ergonomically and make it as simple as possible for the end user.

Appendix 2

Process tree

A process tree is used to complement the completeness of the list of requirements (see next page).

It is based on the different steps the product will go through during usage, starting with production and ending with recycling or disposal.

In figure A1 the different stages are named and split into more detailed stages if possible. The different stage are then double checked to see if there were missing items in the list of requirements in appendix 3.

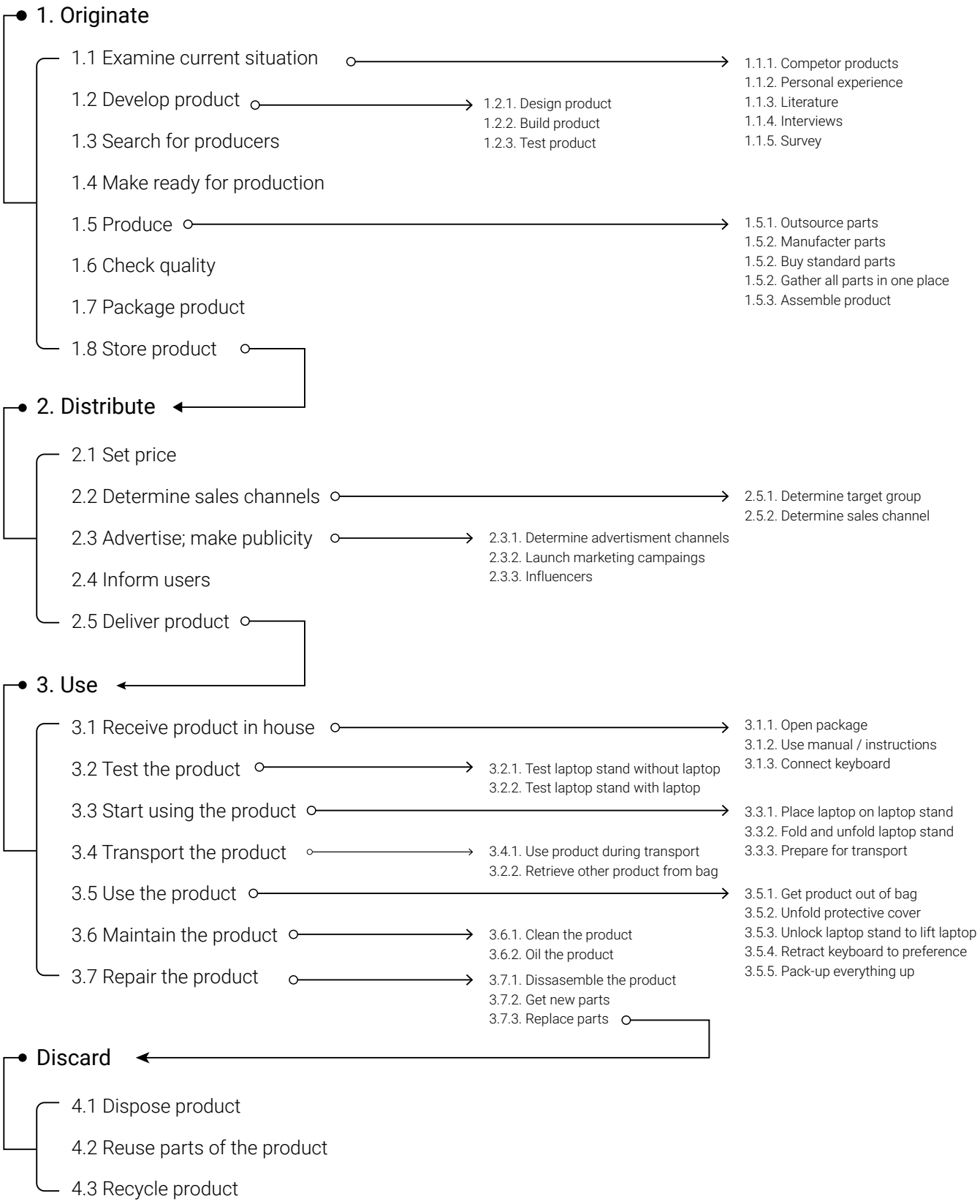


Figure A1: Process tree

Appendix 3

List of requirements

The requirements of the laptop stand are described on the next pages. To ensure the completeness of the list, a process tree and the requirement checklist from "Productontwerpen, structuur en methoden" (Roozenburg & Eekels) is used.

Since some requirements can use some extra clarification or are based on assumptions, additional research is required to make sure they are correct. Requirements affected by this are discussed below:

R1.8:
Setting up a laptop from your bag takes around 12 seconds. Since it is the aim to create a laptop stand that maintains the flexibility of a laptop it is decided that the set-up should take no longer than 50%. This scenario assumes a bag with a zipper and a laptop without protection sleeve.

R1.10:
Because some parts of the laptop stand will be under continuous pressure, the user is not supposed to be able to access those parts. This applies specifically to the linear springs under the base plate as they put out much more force than the torsion springs.

R2.4.1:
The keyboard needs to be at least 285 mm wide because if it is smaller, an ergonomic setting for the P90 of users cannot be guaranteed. This is because of the angle your wrist has to make to type comfortably as described in the literature study.

R2.4.2:
The keyboard ping is based on personal experience. It may slightly differ per individual but it should be a safe bet to stay under 40 ms. This is also in line with the fact that humans see approximately 24 frames per second, which translates to 1000/24 = 41.67 ms.

R2.5:
The maximum weight of the laptop stand is determined on 1/3rd of the weight of a laptop. This needs further testing. In general the product has always been optimized to weigh as little as possible, or decisions are made to enable weight optimization in the future.

R3.1:
The cost price of the product is determined based on the combined cost of all required accessories the laptop stand offers; a laptop stand, a keyboard and a cover. Because the laptop stand is going to be a luxurious high end product, the prices of the accessories are also based on high end products. If the accessories are bought separately, the combined cost are around €200,00 euro (Roost at €70,00, Standivarius solo X at €80,00 and a textile cover at €50,00).

Because of novelty, additional value due to being a package and use of luxurious materials a fair price point is estimated at €320,00. Because the product is going to be sold through online retailers (bol.com, amazon.com and riggid.com), the margins can be smaller than with regular products and is set at a factor of 3. Because the keyboard

needs to be bought by Riggid, the remaining €240,00 (320-80) is divided by three and equals €80,00. Important to note is that the first batch of 100 product is not expected to be profitable.

R3.2:
This requirement is added to keep the focus on easy assembly and low part count. Assuming an hourly rate of €32,00 per hour, the assembly takes up 10% of the total cost price which seems acceptable.

R4.5:
Because this requirement is difficult to validate on itself, four sub-requirements are added with word pairs associated with luxurious products.

Function

R	1.1	The laptop stand allows the P90 of users to work on a 15” laptop without exceeding 10% neck flexion.
R	1.1.1	The laptop stand can raise the back of a 15” laptop between 10 and 22 cm.
R	1.1.2	The laptop stand can lift the entire laptop, not only the back of the laptop.
W	1.1.3	The laptop stand has a continuous height adjustment system
R	1.2	The laptop stand can be lifted while the laptop is on the laptop stand.
R	1.3	The laptop stand allows the P90 of users to have a distance between their eyes and the screen between 380 and 620 mm.
R	1.3.1	The laptop stand allows the P90 of users to use accessories (e.g. drawing tablet and keyboard) while maintaining an ergonomic eye to screen distance
R	1.3.2	The laptop stand allows the P90 of users to type comfortably independant of the distance between the eyes and the laptop screen
R	1.4	At least 95% of the users is able to use the laptop stand without error after reading the manual and testing the product once.
R	1.5	The laptop and laptop stand can be transported on top of each other in a completely flat position (10mm + laptop thickness)
R	1.5.1	The laptop is protected from scratches during transport
W	1.5.2	The laptop is ideally protected from dust, water and falling damage
R	1.6	The laptop is securly fixed on top of the laptop stand during transport
R	1.6.1	The spring-damper system is locked securly locked during transport (requires at least two motions in different directions to completely unlock)
R	1.7	The laptop is securly fixed on top of the laptop stand independent from the level of elevation during use
R	1.7.1	The laptop does not get stuck while adjusting the height of the laptop stand
R	1.7.2	The height adjustment can block the spring force even if there is no laptop on top of the laptop stand
R	1.8	The laptop stand can be setup starting in a bag as fast as possible and maximum in 18 seconds
W	1.8.1	The user can access the locking mechanism easily
W	1.8.2	The user can setup the laptop stand with as little operations as possible
R	1.9	The laptop can be completely removed from the stand without additional actions, unless the laptop cover is in use
R	1.10	The user cannot acces the spring damper system directly (with an exception to the torsion spring coils)

Physical properties

R	2.1	The laptop stand fits the laptop's dimensions exactly in width and and length
R	2.2	The thickness of the laptop stand is as low as possible and maximum 10 mm
R	2.3	The left and right slider of the laptop stand are connected and cannot move independantly from each other
R	2.4	The laptop stand can store a wireless keyboard
R	2.4.1	The keyboard has at least a width of 285mm to comply with ergonomic requirements
R	2.4.2	The keyboard ping, or delay, is not noticible by 90% of the users (<40 ms)
R	2.4.3	The keyboard can be locked, or connected in place during transport
R	2.4.4	The maximum keyboard thickness is equivalent with the laptop stand thickness minus 2mm
R	2.4.5	The depth of the keyboard is maximum 120 mm
R	2.5	The weight of the laptop stand is as low as possible and is not greater than 680 grams (including keyboard)
R	2.6	The base plate does not deflect or buckle visibly during standard use (deflection <1mm)
R	2.7	The sliders do no deflect visibly during standard use (deflection <1mm)
R	2.8	The maximum stress on a component does not cause plastic deformation using a safety factor of three based on normal use (to account for abnormal use)
R	2.9	The laptop stand can be used for two years with 10 daily set-ups without reaching spring fatigue or breaking parts
R	2.10	Part tolerances are always tight enough to avoid tilting
R	2.11	The laptop stand is supported by a mechanism that enables the laptop to be lifted with minimal human force (max 1N)
R	2.12	For safety reasons, the spring-damper system is balanced in such a way that the laptop stand will never expand faster than one second
R	2.13	The maximum allowed height difference between the right and left slider is 5mm.

Price

R	3.1	The cost price of the laptop stand is as low as possible and maximum € 80,00 in a production batch of 100 units
R	3.1.1	The tooling cost is under €1000,00 for the first production batch of 100 units
W	3.1.2	Machinability of materials (mm/min) is as high as possible
W	3.1.3	Production time is as fast as possible
W	3.1.4	Material cost is as low as possible
R	3.2	The product can be assembled within 15 minutes
R	3.2.1	Product components that can potentially be placed in the wrong orientation are designed to fit in only one way
W	3.2.2	Product components are designed to be montaged with as little connections parts as possible
R	3.3	The sales price of the laptop stand including keyboard and cover is estimated at € 320,00
W	3.4	It is preferred to use fewer components if possible

Aesthetics

R	4.1	At least 95% of flex workers would not mind to use the product in public
R	4.2	80% of people rates the product in general at least an 8 out of 10
R	4.3	80% of people rates the aesthetics of the product at least an 8 out of 10
R	4.4	80% of people agrees (score of 5+ on a 7-point scale) with the fact that the product does not bring down the appearance of their laptop
R	4.5	The product (including laptop stand, cover and keyboard) fits a luxurious product line
R	4.5.1	The product's appearance is seen as 'premium' rather than 'cheap'
R	4.5.2	The product's appearance is seen as 'professional' rather than 'unprofessional'
R	4.5.3	The product's appearance is seen as 'reliable' rather than 'unreliable'
R	4.5.4	The product's appearance is seen as 'stylish' rather than 'tacky'
R	4.6	The product can be personalized according to branding wishes from companies
W	4.7	The product can be finished with a soft and precise surface and can be painted in different colors
W	4.8	The spring-damper system causes the laptop to raise smoothly to the required height.

Maintenance

R	5.1	The laptop stand can be cleaned with water and soap
R	5.2	The laptop stand can be used indoors
R	5.3	The laptop stand can be used outdoors in dry conditions
R	5.4	The laptop stand functions as intended if the temperature is between 0 and 60 degrees celcius.
R	5.5	The laptop stand can only be disassembled with specific tools and cannot be repaired by the user
R	5.6	The laptop stand does not require additional maintenance apart from cleaning

Transport

R	6.1	The laptop stand can be packaged in a flat cardboard box with a 12 mm inner dimension
R	6.2	The laptop stand can be stored for at least 2 years without spring fatigue occuring

Appendix 4

Target user

The target user can broadly be defined as a laptop user who spends more than two hours per day on their laptop in different places or on-the-go. When defining the target group a little deeper there are three major categories of users that fit the above description.

1. Students

Despite heavy discussions whether or not laptops should or should not be used in the classroom as a way to enhance education, it seems to be happening anyway. The Technical University of Delft is a good example; it is quite literally unthinkable to follow IDE without a laptop. This makes this target group very vulnerable for physical discomfort during laptop work, especially since the law does not oblige universities, in contrary to companies, to offer proper alternatives or ergonomic solutions to VDT users. Whereas laptop use in university has been the norm for the past decade(s), the trend of laptop use is also rapidly moving towards higher education (Sana, Weston & Cepeda, 2013) which will likely result in more and earlier complaints.

Even though the educational market offers a high potential, it is also very difficult to sell products to universities, since they have to make public purchases involving multiple parties. Selling the product to students on an individual level is also not ideal, as students often do not have a lot of money to spent, especially when it comes to purchases other than clothing, food and drinks.

From a business point of view, the focus would have to be mainly on individuals who care about their well being or are already experiencing physical discomfort. The survey study showed that the former rarely ever happens as users are unlikely to spent money on something that is not yet happening to them. In short, students are a large target group that would benefit from this product, but they are difficult to reach and convince to use a product as expensive as this one.

2. Digital nomads

Digital nomads is a term used to describe people working location independent, who rely on technology to perform their jobs. They are often young people working in the knowledge economy, which means that their jobs will usually be in marketing, design, IT, writing, media and consulting (investopedia, 2018).

Due to this lifestyle, which is often fast paced and stressful, a product that allows them to improve their overall well being and to be more focussed during work would be a valuable addition. This target group could very well be targeted individually and a kickstart campaign would make sense. This target group is also expected to have enough funds to buy a more advanced, and expensive, laptop stand.

3. Flex working companies

In companies, ergonomics has been an issue for many years, but with the rise of flex working the problem is both

increasing and becoming more complex to solve. Especially in companies in law, consultancy, design and marketing a new organizational structure is appearing; telecommuting employees. Instead of using a main office from which the company operates, employees are “detached” to other companies as being their client. This allows companies to work much more closely together, improving the quality of work while saving cost for the operating company in terms of office space and affiliated costs. Employees, however, will have a very diverse and ever changing work environment, which increases the need for laptops.

In this target group, the company with telecommuting employees would be an excellent sales channel, since the company cares about the prevention of MSD as it will save them money. Important to note is that individual customers will most likely react to MSD while companies have a high interest in preventing. This largely increases the potential market and is considered very beneficial.

Additionally, there is often already a budget and policy regarding ergonomic work. Which makes it easier for companies to spent money on an ergonomic set-up than it is for individuals.

Appendix 5

Base plate part description

The different features and specialties of the base plate are described here.

Final design

The final design of the base plate has many different features, as could be seen in figure A2. These will be described shortly. If at any of these points something critical is happening it is pointed out.

[1] Connection point of the long slider & locking mechanism
These features are made to enable the locking mechanism and are further explained in that chapter.

[2] Cavity for sliders
The space is required for the two sliders in a folded position.

[3] Connection point for top plate
There are 10 points across the middle-back section of the base plate that connect the top plate to the base plate. These holes can be wire-tapped during CNC milling to increase assembly speed.

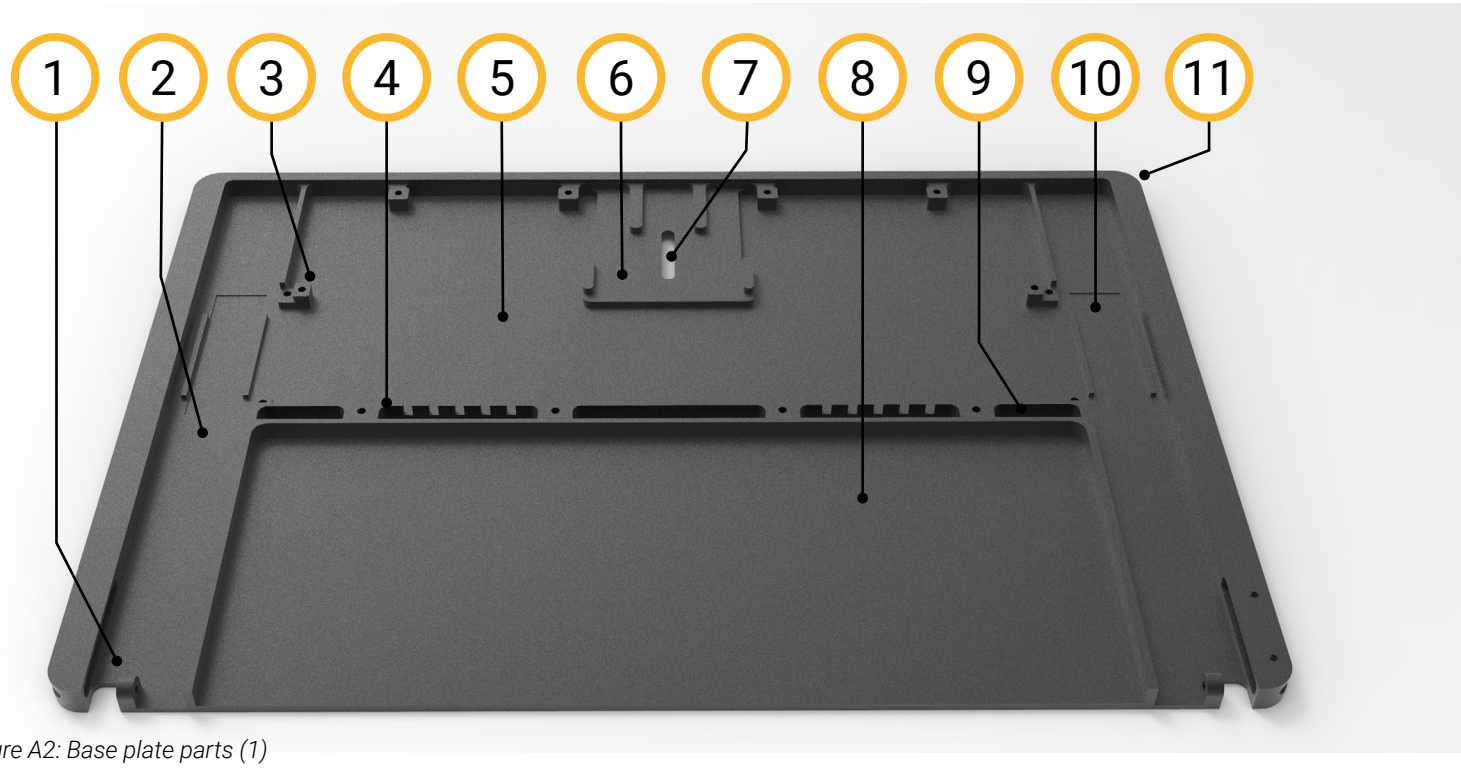


Figure A2: Base plate parts (1)

[4] Connection point for spring axis support
The main slider mechanism is kept in place, by three axles [13] (figure A3) left and right of the assembly centre. The cavity pointed out at point [4] allows for a plastic place-holder to be dropped into the cavity and be locked in place by the top plate.

[5] Cavity for main slider mechanism
In this space the main slider mechanism (chapter 2.4) connects the left and right slider with a long and stiff plate [12] and maintain an equal position between both.

[6] Support for main slider mechanism
The main slider needs to be guided to be stable as the height changes between the different parts of the main slider mechanism.

[7] Cavity for height adjustment
The maximum height of the laptop stand can be adjusted before setting it up as explained in chapter 2.8. In order to do so a cavity underneath point [7] allows part [14] to be locked in place by a screwing mechanism. This means that the production plate needs to refixed during production.

[8] Cavity for keyboard integration
This place is used to store and implement an ergonomic keyboard.

[9] Weight reduction cavities
For production a better connection (more material) along the product from left to right allows for an easier fixture and more machining at once.

[10] Cavity for low friction slider
Since at this point torsion springs will press on the base plate and have to slide forward, a very thin layer of Nylon is applied to reduce friction as much as possible.

[11] Connection point for cover
At the back of the laptop stand the cover is connected (chapter 2.10).

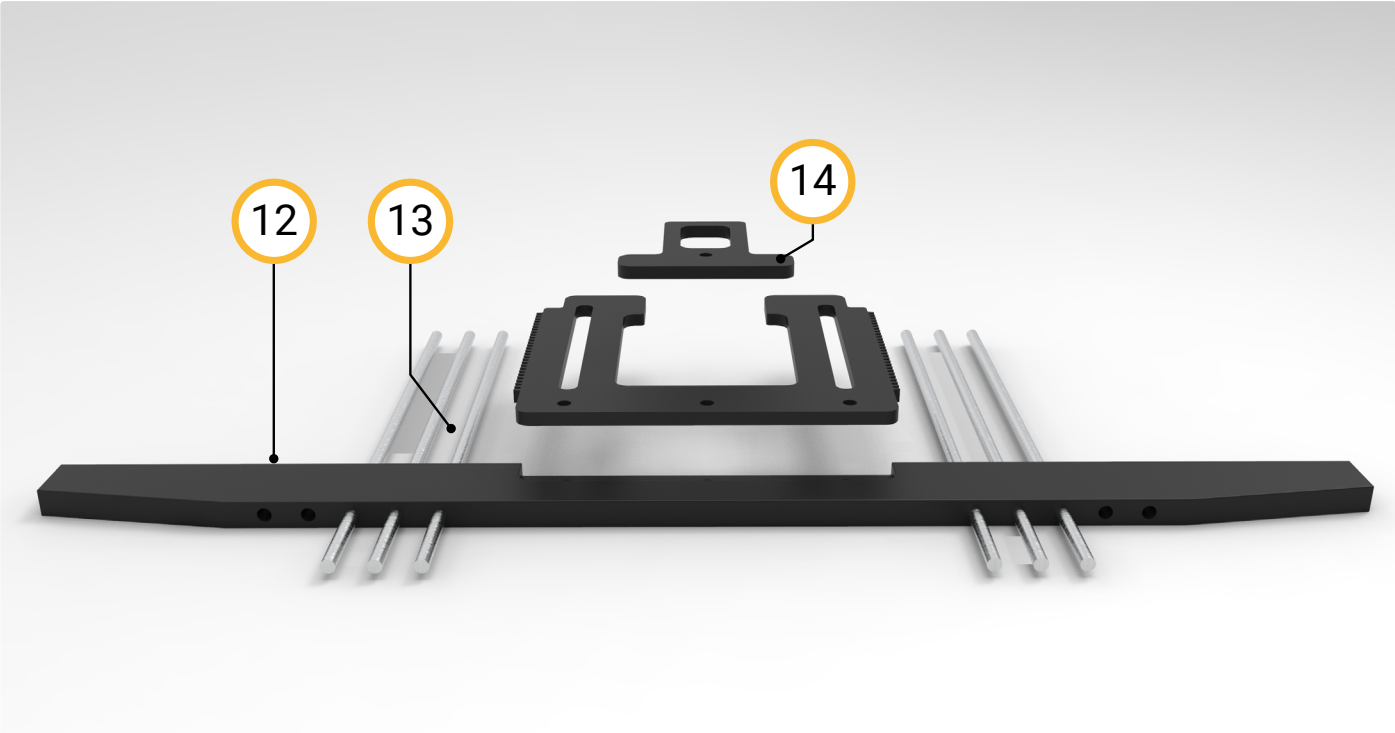


Figure A3: Base plate parts (2)

Appendix 6

SW simulations base plate

Solidworks simulations are conducted to determine if the base plate is strong enough to resist expected forces with a safety factor of 3x (R2.8).

Study 1

For the first study the stress, strain and deflection of the front connector are measured because at this point the largest force can be expected. For calculation the full weight of the laptop is used, divided by 2 (the laptop stand has two sides) and multiplied by 3 for the safety factor.

In this study aluminium 6061-T6(SS) is used instead of aluminium 6082-T6 as it was unavailable in the SW material library. The main difference between the two materials is the tensile strength which is on average 40 MPa lower for the 6061 alloy. This means that the final model will be stronger than the model on which the tests are run.

It can be concluded that the expected forces cause no issues.

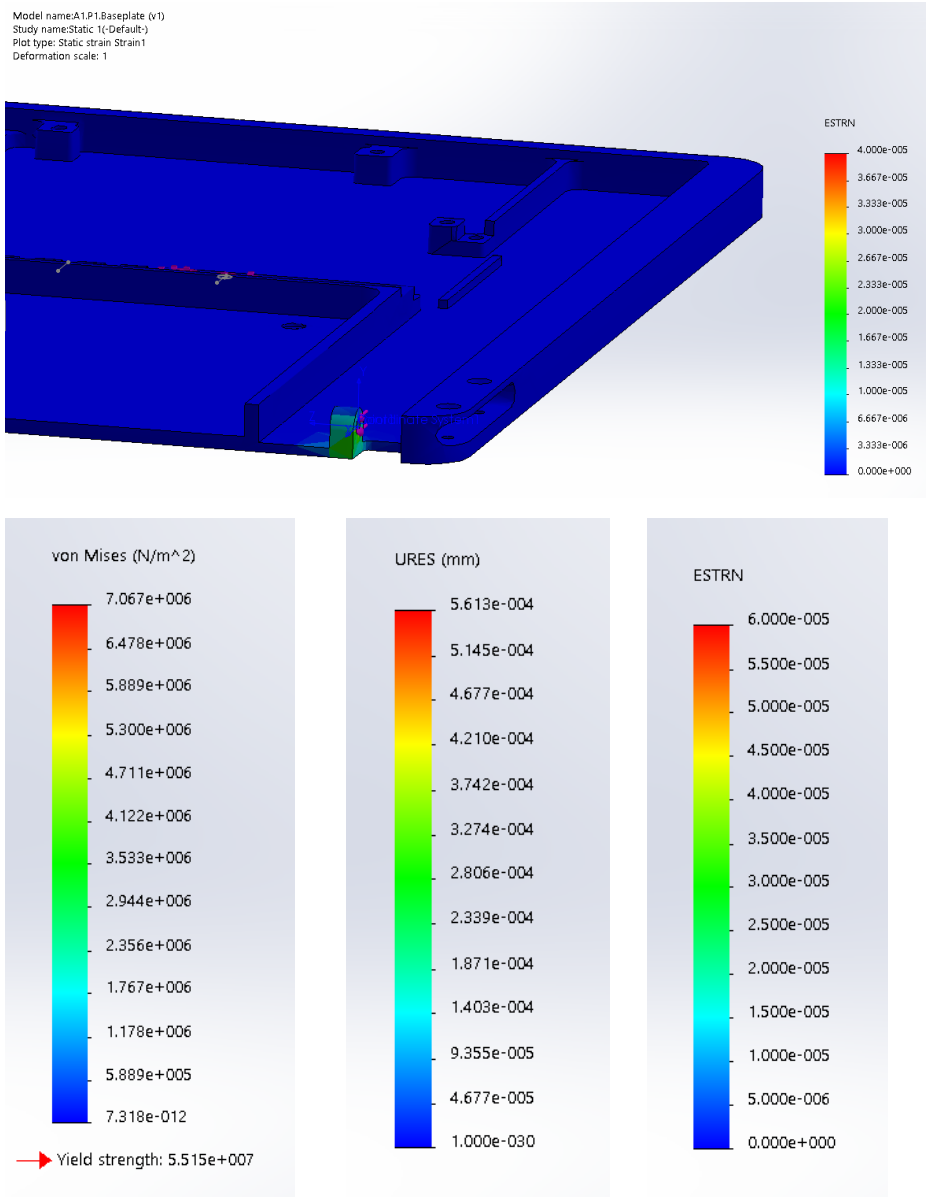


Figure A4 - A7: Stress, displacement and strain of SW study front connector

Study 2

For the second study the overall stiffness of the baseplate was measured by applying a torque around the center of the product. See figure A8.

Eventhough this is not necessarily a “normal use” scenario, odds of it happening are realistic. For example someone testing the product on first use, or someone swinging it absent-mindedly with the laptop stand in one hand.

In this study aluminum 6082-T6(SS) is used and a centrifugal acceleration of 2 rad/s is applied.

The results show no issues whatsover in either displacement, strength or strain values. This also indicates that the base plate has a lot of potentional to be optimized for further weight reduction.

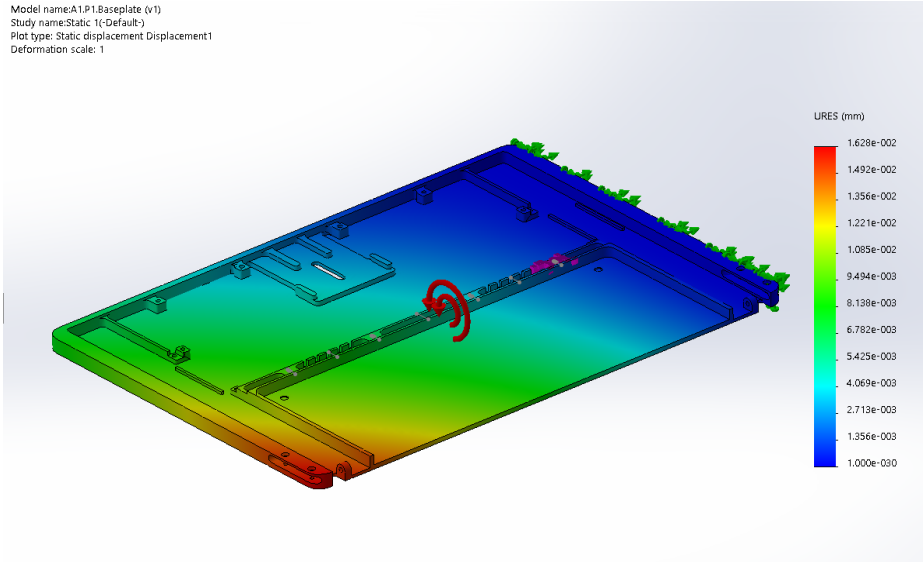


Figure A8: Deflection of base plate by applying a rotational force

Appendix 7

Base plate tolerances

The base tolerances of this part are determined by the precision of the CNC router. Typically this is between 25 and 1.6 micrometers (see tables in appendix 25), which translates to 0.025 - 0.0016 mm. Assuming the lower tolerance, the product is dimensioned such that parts who are sliding during use (e.g. the different sliders) can move freely. This means that two parts touching each other and are made with CNC milling are both dimensioned at -0.03 mm in the CAD files.

For points where axles are either using transition fittings (k6) or interference fittings (p6) the accuracy of the CNC router (drilling) needs to be at least 12 micrometer. Looking at the table in appendix 25, this falls well within typical accuracy range for drilling and should not cause issues during production.

Appendix 8

SW simulation sliders interation 1

With a SolidWorks simulation the differences in deflection are calculated for the first iteration of the long slider.

The part is fixed at both the points where an axle keeps the slider in place and a force is applied on the outer right part to imitate the weight of the laptop. A force of 37.5 Newton is applied at each slider to make sure the safety factor of three (R 2.8) is met.

The deflection for aluminium 6061-T6 is shown in figure A9 and equals 4.6 mm at most.

The deflection for aluminium 7075-T6 is shown in figure A10 and equals 1.24 mm at most.

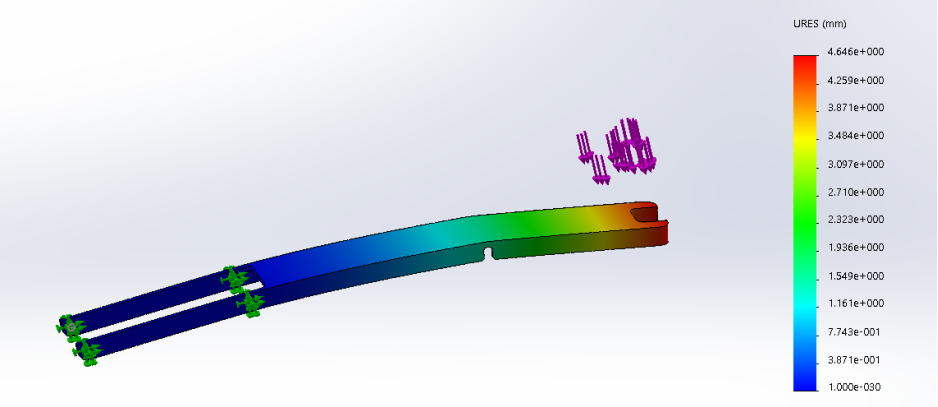


Figure A9: Deflection of long slider with aluminium 6061-T6

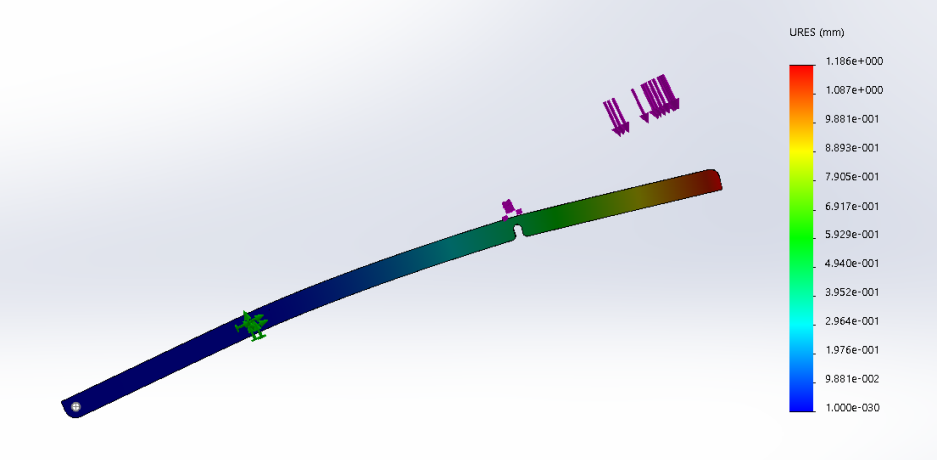


Figure A10: Deflection of long slider with aluminium 7075-T6

Appendix 9

Sliders

Long slider

Just as the base plate, the long slider is made of aluminium for very much the same reasons. However, for the sliders the mechanical properties are even more important and cannot be replaced by engineering plastics using the current design. See figure A11 and A12. The main features of this part are:

[1] Cavity for locking mechanism
The long slot shaped cavity is where the locking mechanism is connected to the base plate. At this point the long slider is also connected to the base plate itself.

[2] Connection to short slider
This point is expected to be somewhat critical in the stability of the slider due to turning.

[3] Small indent for stability
In the image of the base plate at point [2] and [10] there are two small bars at the middle of the slider cavity. The small indents [3] make sure the slider still fits within the cavity while maintaining enough wall thickness for the required stiffness.

[4] Axle clearance
This open spacing in the side of the part has an unfortunate placement as the construction loses a lot of stiffness. This alone might even force the product to be made from aluminium over plastic. However, this allows the left and right sliders to be connected to each other and for the crucial support of linear springs (chapter 2.5).

[5] Weight reduction
As the product already balances on the edge of the requirements regarding weight, being able to reduce weight only at the expensive of a slight increase in production time is a worthwhile decision.

Short slider

The short slider resembles the long slider in most ways except for its geometry. A summary of the key part features:

[6] Connection with stability slider & torsion spring support

This point multi-functions as connection point to the stability slider, but also allows for two torsion springs to be connected. In the base plate the nylon layer will reduce friction as much as possible.

[7] Double torsion spring support
In the middle, an additional two torsion springs allow for enough upwards force to start lifting a laptop. The slot-like shapes nicely keep the torsion spring legs in place.

[8] Connection to long slider
At this point the slider is connected to the long slider. The open space allows the body of the torsion springs to be placed here.

[9] Connection to front grip
To avoid the laptop from sliding from the stand it needs to be fixed in place. The front grip is placed at this point.

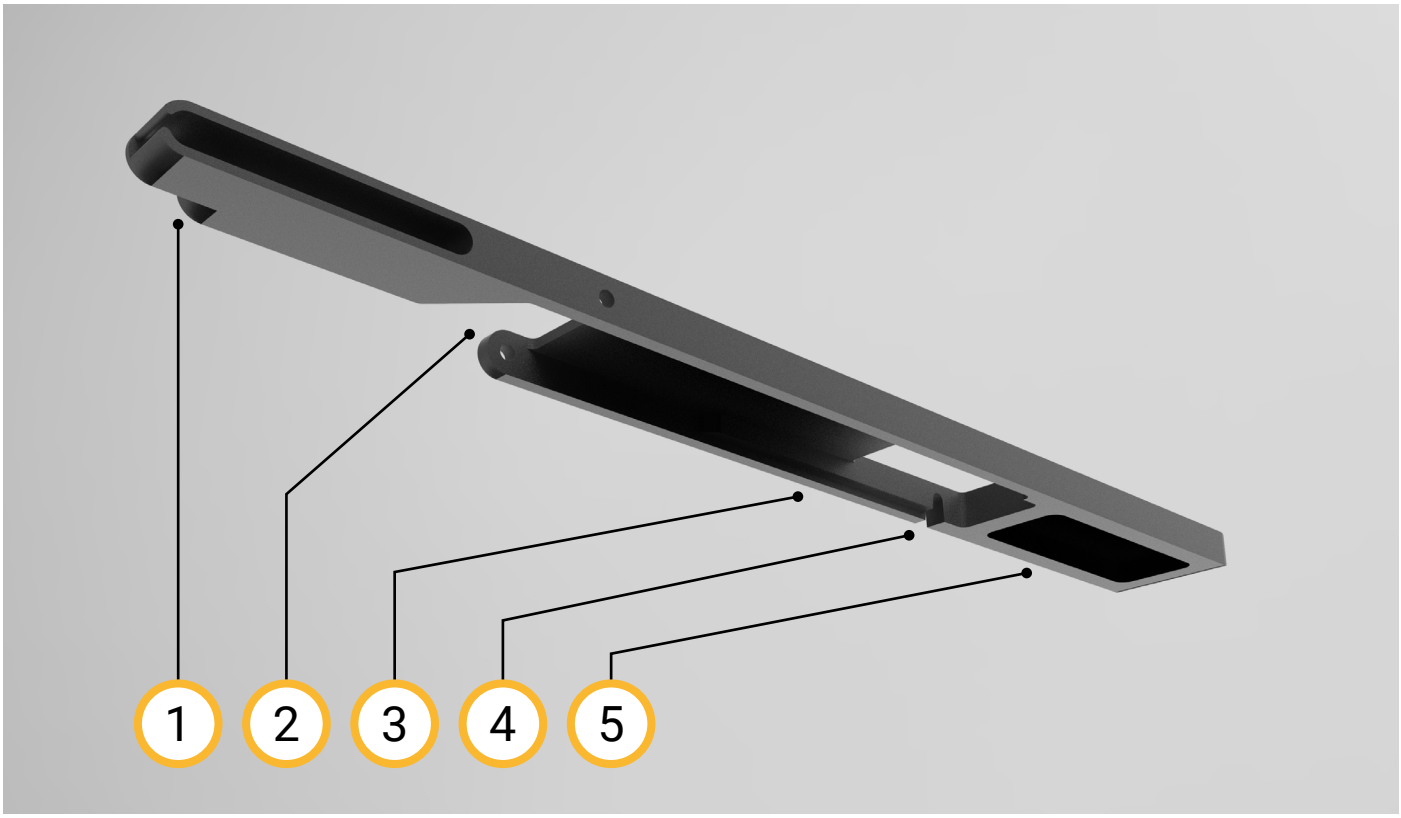


Figure A11: Long slider

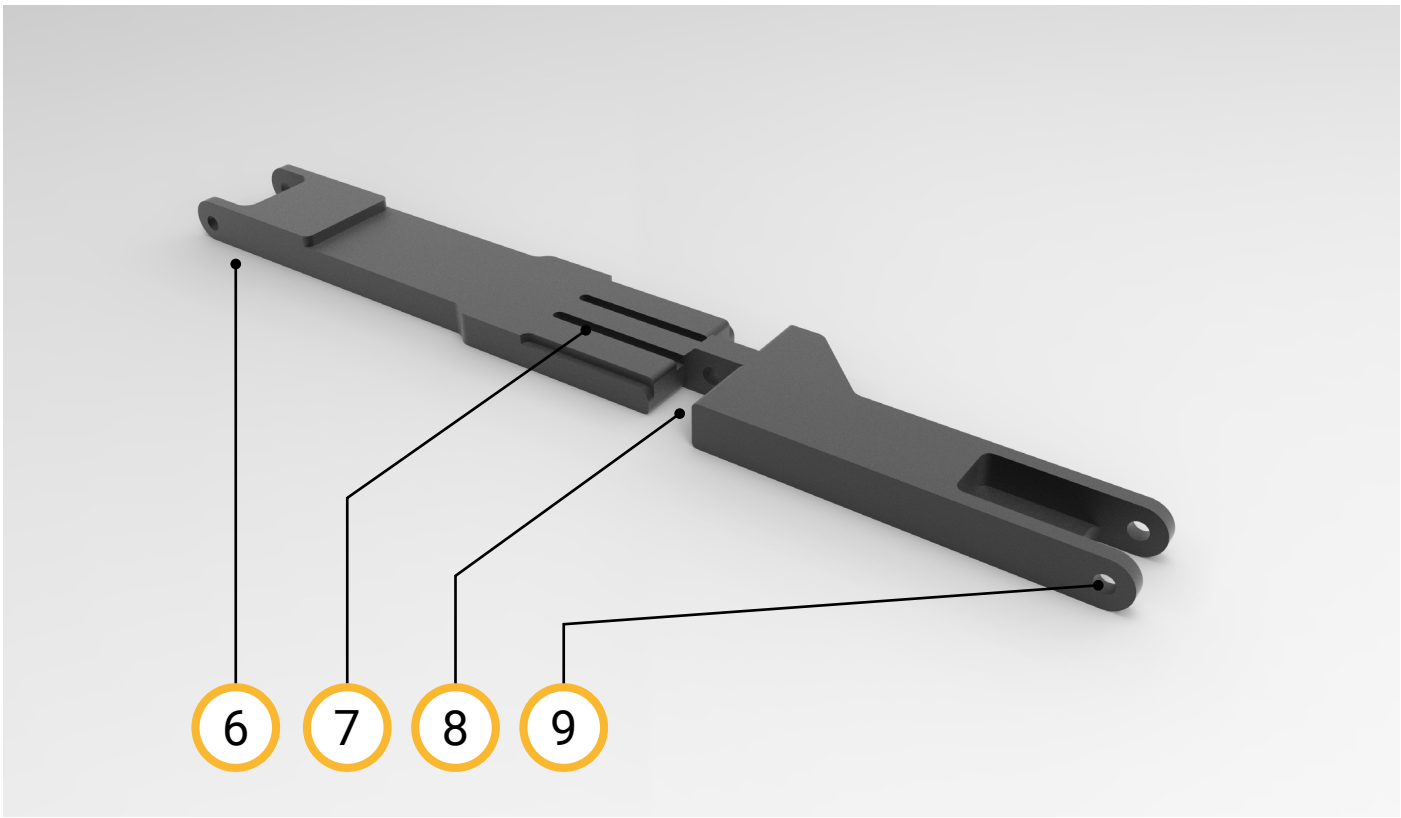


Figure A12: Short slider

Appendix 10

Slider production

Production long sliders

As this part is made from aluminium, the two contenders in production are CNC milling and aluminium die casting. In general CNC milling is the better option for smaller batch sizes as there are little to no tooling cost involved, whereas die casting is favourable in larger production sizes as it is quicker, reduces waste to a minimum and surface details can be applied directly.

In this case, CNC milling will be chosen as the production method for the prototype and for the first batch of test products. The part is therefore optimized for CNC milling and can be made with three fixtures. Fixture 1 as shown in figure A13 allows to cut the general outline of the product and some of it's main cavities. Fixture 2 allows for the remaining edges and allows to remove some of the previously made fillets, for example at [1]. The holes made in fixture 2 can be used to get the exact same position in fixture 3 where the part is essentially flipped over.

Due to the thin wall thickness and importance of tolerance in the slot at point [3] this is crucial to do.

Production short slider

For the same considerations as the long slider this part will be made with CNC machining. Due to some of the complex shapes this part requires 4 fixtures (figure A14). For each of these fixtures the CNC outlines are determined (yellow lines) to make sure each feature of the product can be produced.

The same has been done for the long slider, which is slightly easier as it only requires three fixtures.

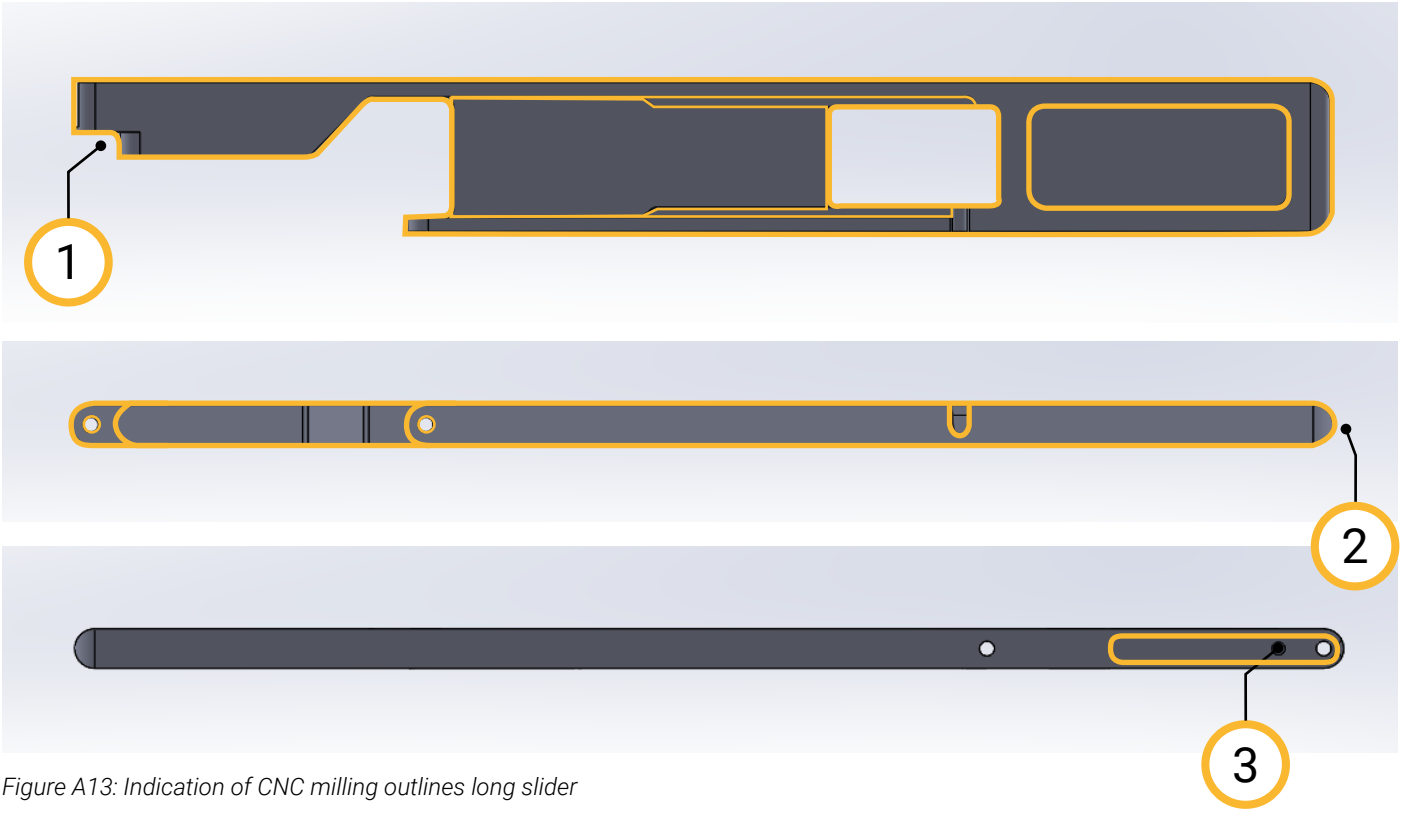


Figure A13: Indication of CNC milling outlines long slider

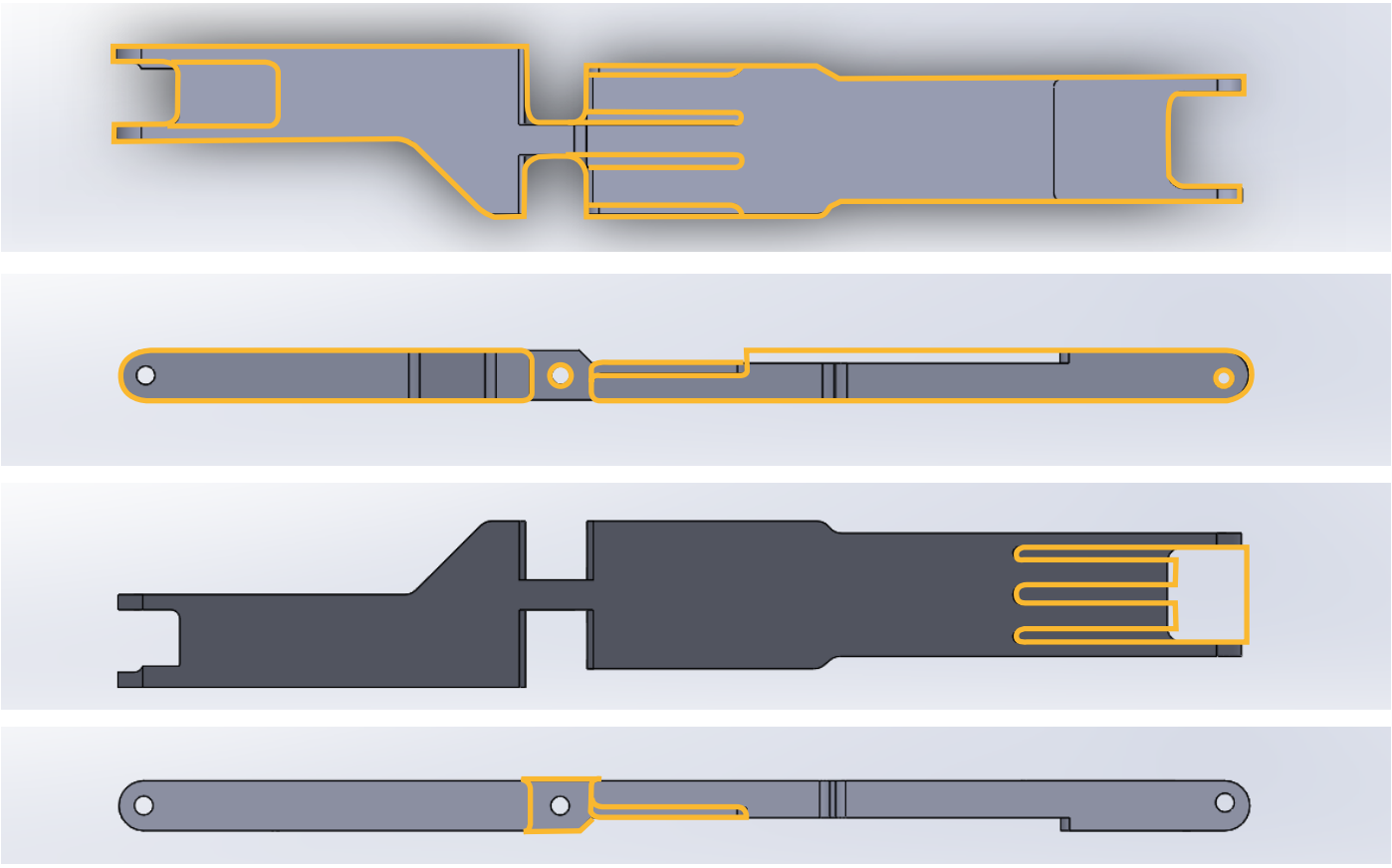


Figure A14: Indication of CNC milling outlines short slider

Appendix 11

Sliders tolerances & assembly

Tolerances

As the main construction components, the base plate and the sliders, not only connect together but also connect to many different parts, there are several critical points where tolerances have to meet certain requirements. The exact type of requirement is mostly dependent on the kind of fit that is needed between two components.

For CNC milling an average tolerance of +- 0.025 mm is used. This number is both supported online (appendix 25) and by the PMB machining employees. However the latter usually go with 0.05 mm. An overview of tolerances of different machining operations can be found in appendix 25.

Increasing the accuracy of tolerances, however, has a large impact on production cost (R3.1). By adding a decimal in tolerances prices go up two to four times very quickly, because tools are more expensive, processes are added and required inspection/ testing increases.

It is therefore beneficial to slightly decrease the part size, which allows the standard machining tolerance to be enough. For example, by making the sliders 0.1 mm smaller (at least 0.05 at both sides), a clearance fitting is made without increasing production cost.

Axles

In the middle, the two sliders are connected to each other with an axle as can be seen in figure A15. The parts involved at this point are shown in figure A16. The axle keeps the different components together and allows them to rotate along each other. Because the axle cannot exceed the width of the combined sliders, it is fixed into hole [3] in figure A16. This means we are talking about an interference fitting at this point. Typically H7 / P6 tolerances are used for these fittings. As these tolerances also fall within production capabilities of CNC machining (considering a 3mm axis and hole; H7 = 0 -12, P6 = +20 +12) this is the correct tolerance. At points [1] and [2] the sliders need to be able to rotate along each other, that means a transition fitting is the right option. In this case H7/k6 for the axis and k6 for the hole. Additionally, the two sliders need to be able to fold into each other. Allowing the sliders to be folded into each other is achieved by dimensioning the inner part at 0.1 mm smaller.

Assembly

The assembly of the sliders is partially dependent on other components which have not yet been introduced. They will be discussed in corresponding chapters.

In general the assembly of the sliders is very straightforward, the sliders can only be placed into each other in one way (meeting R3.2.1) and a clamping axle will be used to created an interference connection to fix the axle in the long slider at [3] in figure A16. This will also make it very difficult for users to play around with the spring system which is one of the requirements (R1.10) of the product.

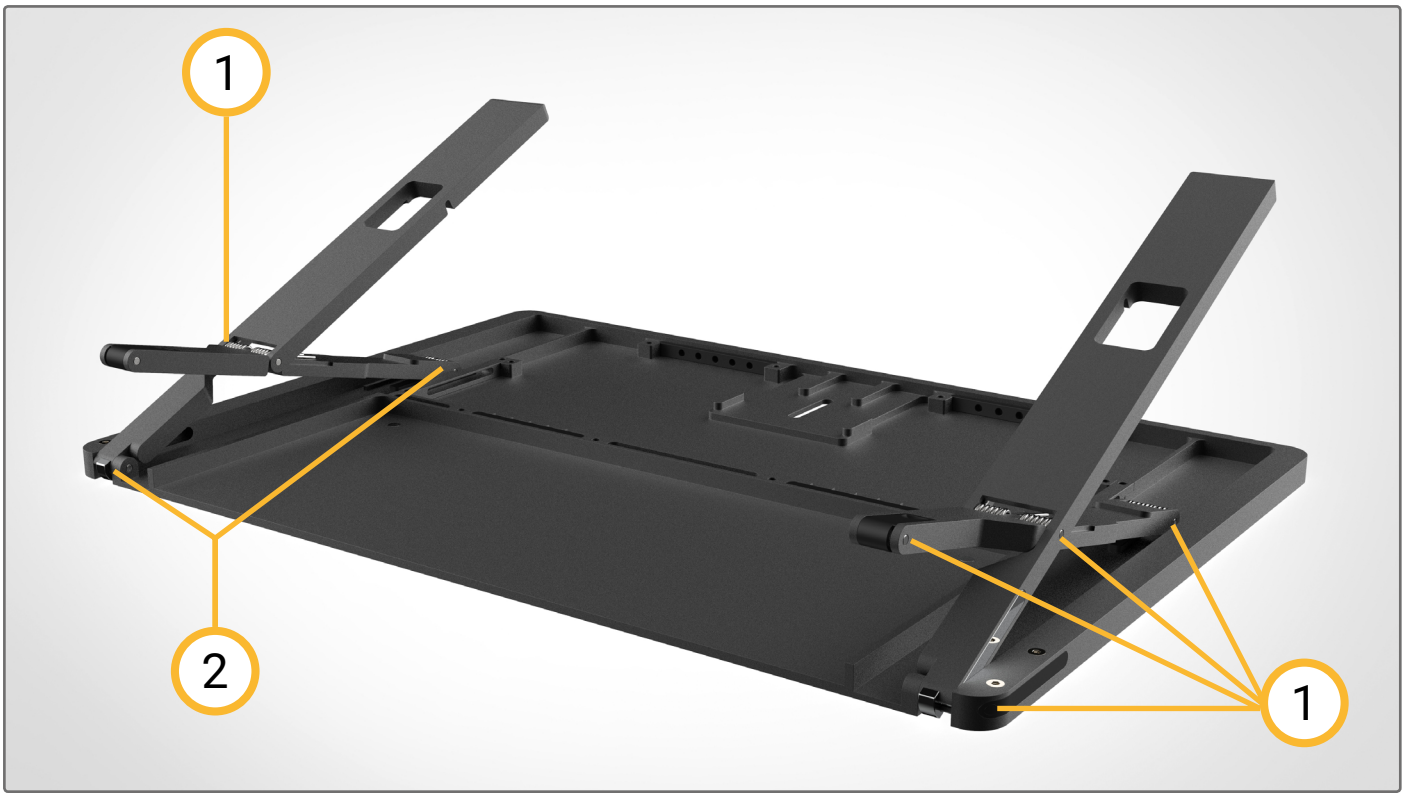


Figure A15: Indication of CNC milling cutting lines

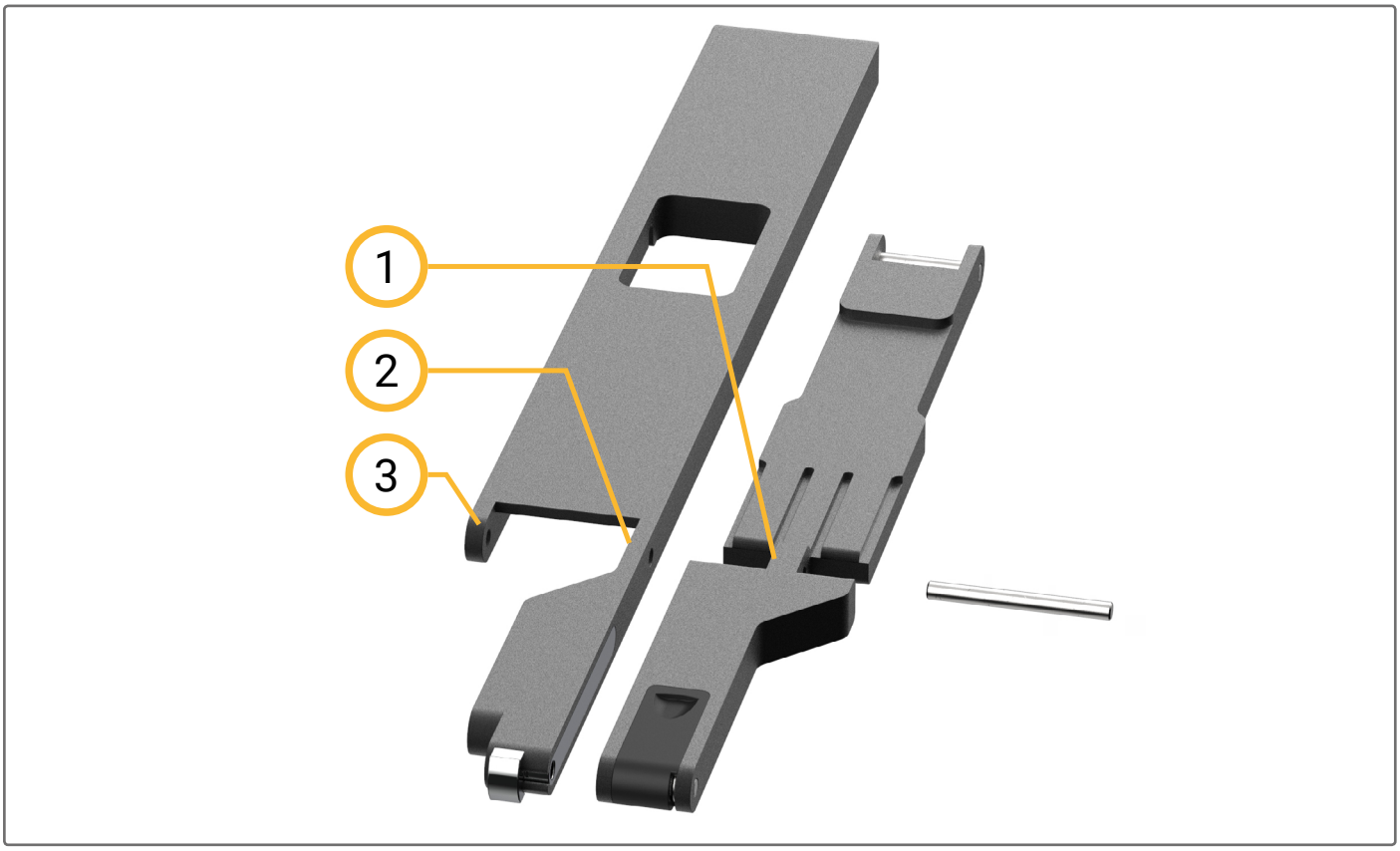


Figure A16: Indication of CNC milling cutting lines

Appendix 12

Stability slider

The design of the two main components of the stability slider were directly derived from their main functions. First of all, the stability slider should provide stability. Because tilting of the sliders is the most common reason to cause instabilities, the stiffness of this part is the most important. Furthermore, the stability slider has to move over aluminium smoothly, which means the friction coefficient was a key factor in decision making. Due to this combination it was decided to make the stability slider from POM due to relatively good mechanical properties in addition to easy manufacturing with lasercutting. To be sure the stiffness was meeting the requirements a SolidWorks simulation was run (appendix 13).

With regards to the geometry, the stability slider (figure A17) has been as wide as possible [3] to maximize the stiffness. The free left over space is required for the linear springs to compress without reaching their box length. The axles [6] in figure A19 are positioned towards the center of the product to give enough space for a strong fixture for the perpendicular placed axles that

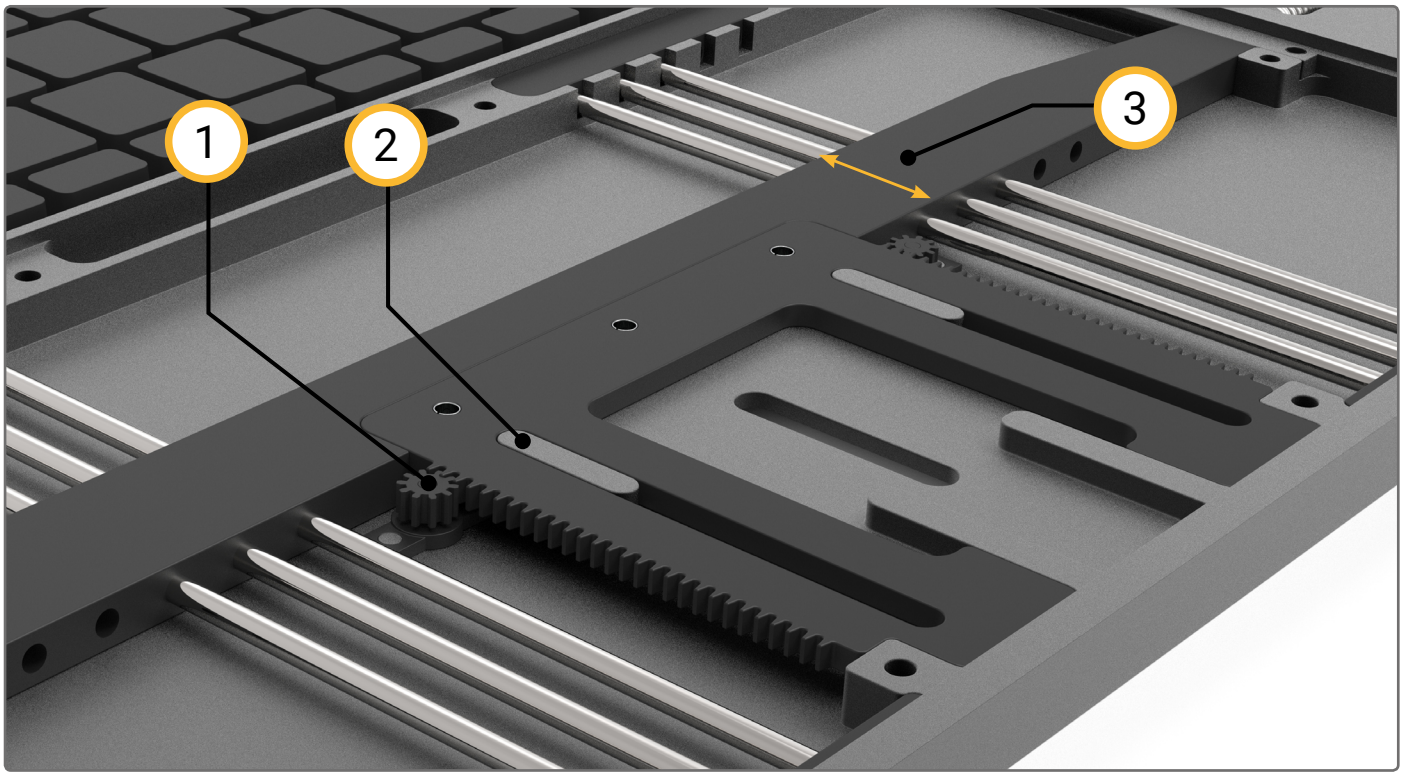


Figure A17: Stability slider

connect to the short slider [4]. In hindsight, this may have not been the best solution as it creates a greater risk for destabilisation due to a smaller pivoting point.

The second part of the stability slider [8] in figure A19 is also made from POM. This part fulfills two functions: it further prevents tilting of components by utilizing two slots [2] and secondly, it provides an integrated gear rack to allow rotary dampers [2] to damp the spring systems.
The entire stability slider is kept in place by the top plate that covers area A in figure A18.

In general, based on mechanical properties alone, PA with either glass or carbon fiber is expected to be a better alternative, but for the prototype it was not possible to obtain and manufacture the material quickly enough. Alternatively, aluminium with a thin layer of PA, kevlar or any other material with a low friction coefficient on aluminium could work as well.

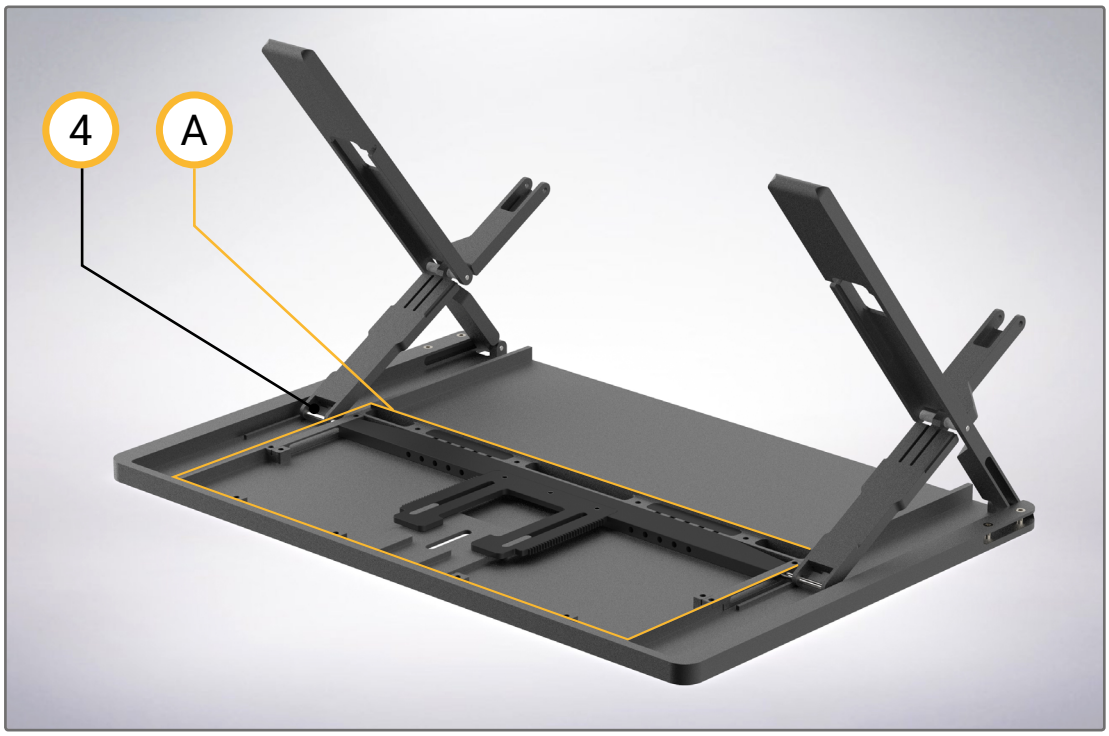


Figure A18: Semi-exploded view of main slider mechanism

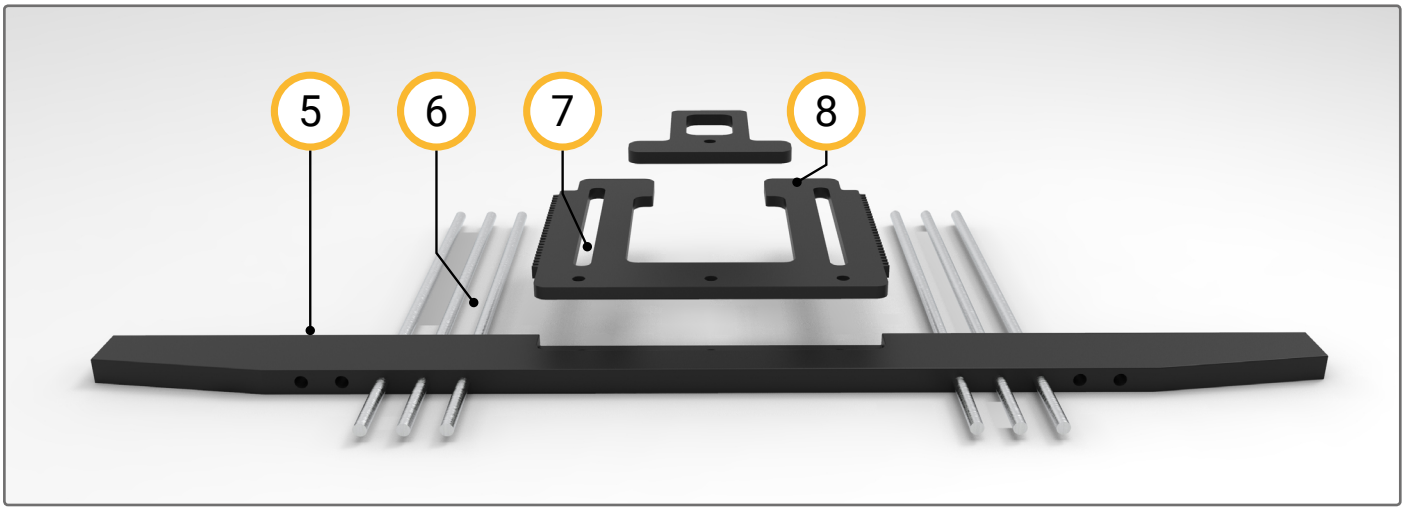


Figure A19: Semi-exploded view of main slider mechanism

Appendix 13

SW simulation stability slider

A SolidWorks simulation to test deflection of the stability slider is discussed here.

Set-up

The stability slider is fixated at the sides where it connects with the short slider. The spring force is simulated around the purple arrows and totals at 100N (maximum force at 70mm compression, 6 linear springs at 0.481N each). This results in a maximum deflection of 1.18mm.

Conclusion

The resulting deflection is at the edge of being acceptable.
It was decided to continue working with POM because it was easy to get acces to and process on the short term.

However, a new study was run with different materials (aluminium 6063 and 7075-T6) to aqcuire knowledge about the possibilities when testing the prototype. Using aluminium 7075-T6 with the same geometry would lower the deflection from 1.2 mm to 0.04mm. Which means much better results can be reached if required.

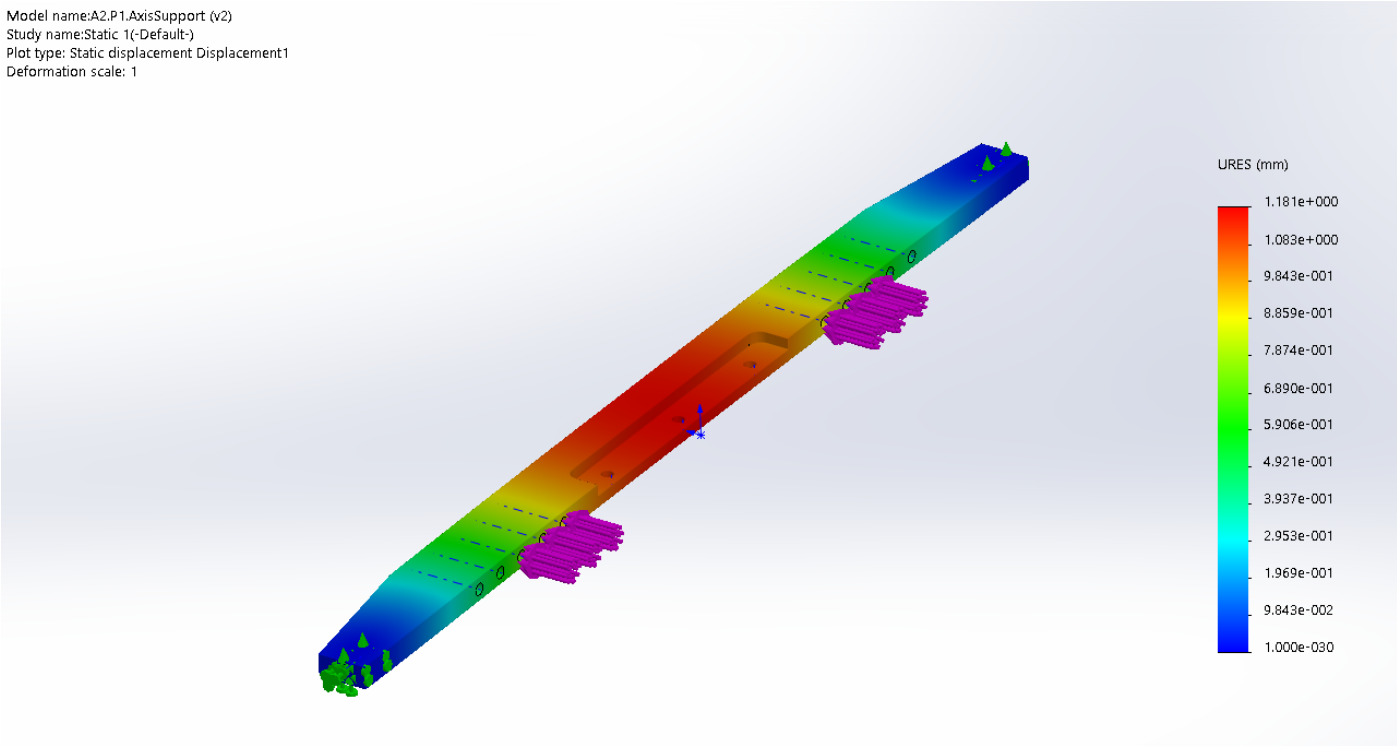


Figure A20: Deflection on stability slider with normal use

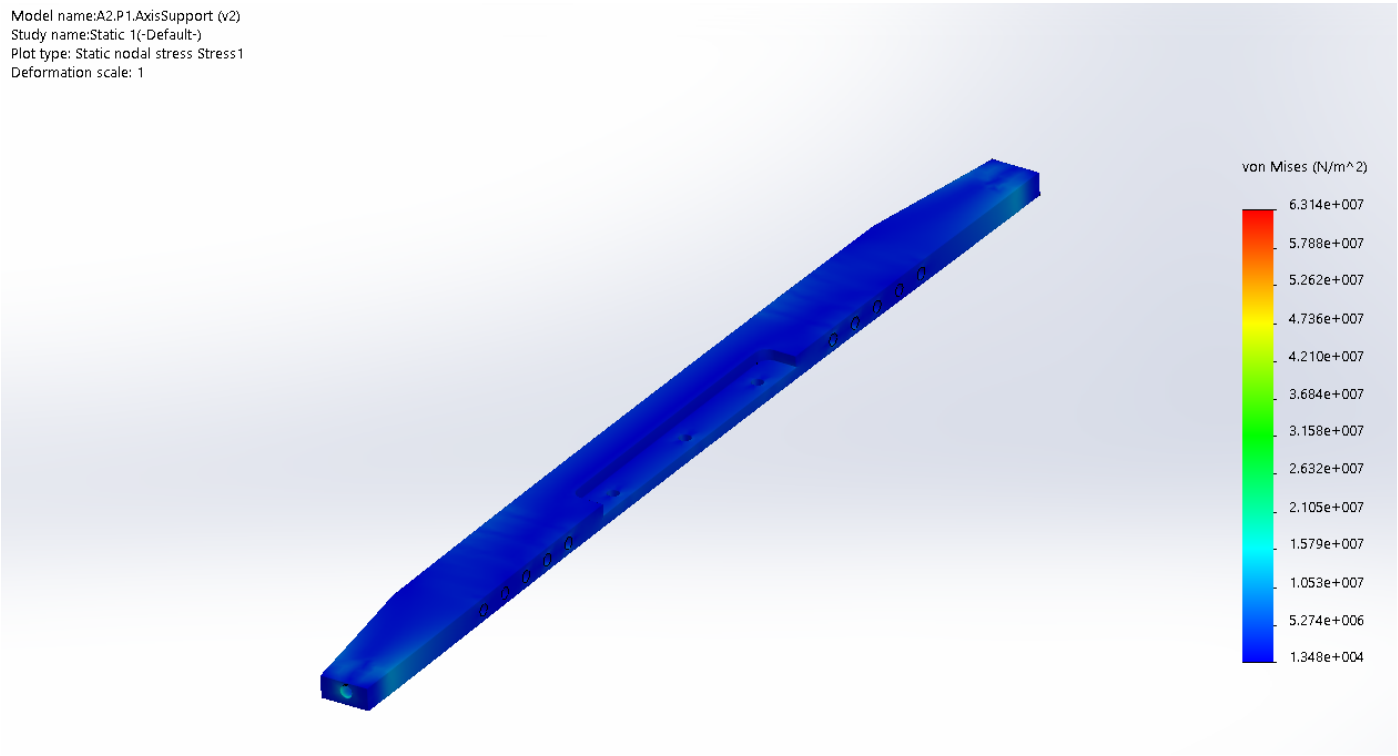


Figure A21: Stress on stability slider with normal use

Appendix 14

Spring calculations

The spring system that is placed within the laptop stand applies forces on different levels and at different points, which makes it difficult to determine the exact force that is translated into the lifting force. In Google Sheets a simplified model was made and then compared to testing with an early prototype. Based on those conclusions the models for the different spring system have been designed, which can be seen in the different tables in this chapter.

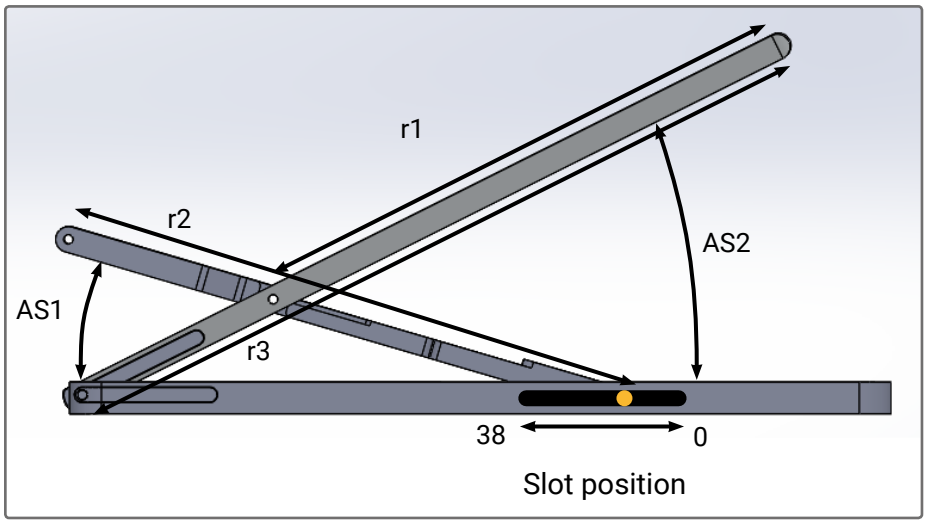


Figure A22: Angles and dimensions for calculation sheets

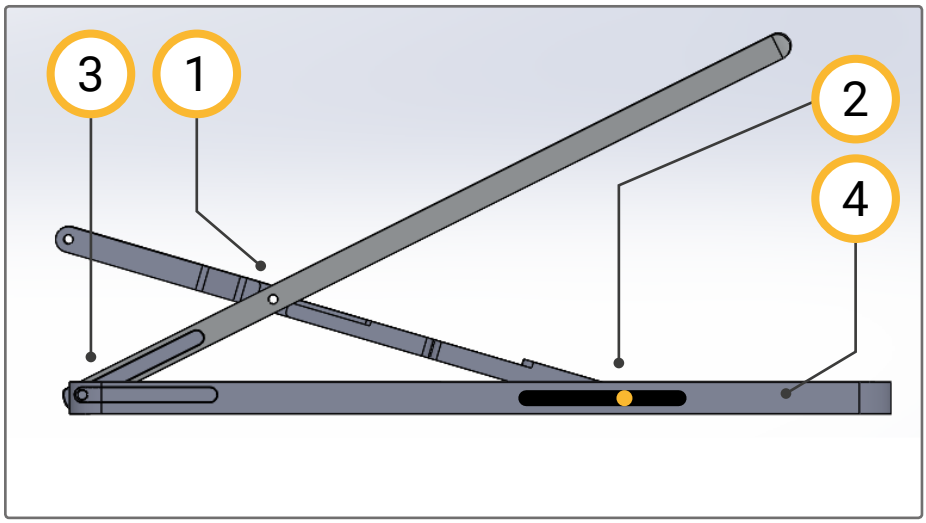


Figure A23: Placement of torsion springs

Explanation of tables

In the tables a lot of references are made to locations, lengths and abbreviations. In figure A22-A25 these are highlighted.

Slot position
The "slot position" is used as key measurement and works as follows: If the laptop stand is lifted higher, the slot position moves towards the front of the laptop. The numbers at the slot position (0 and 38) refer to the

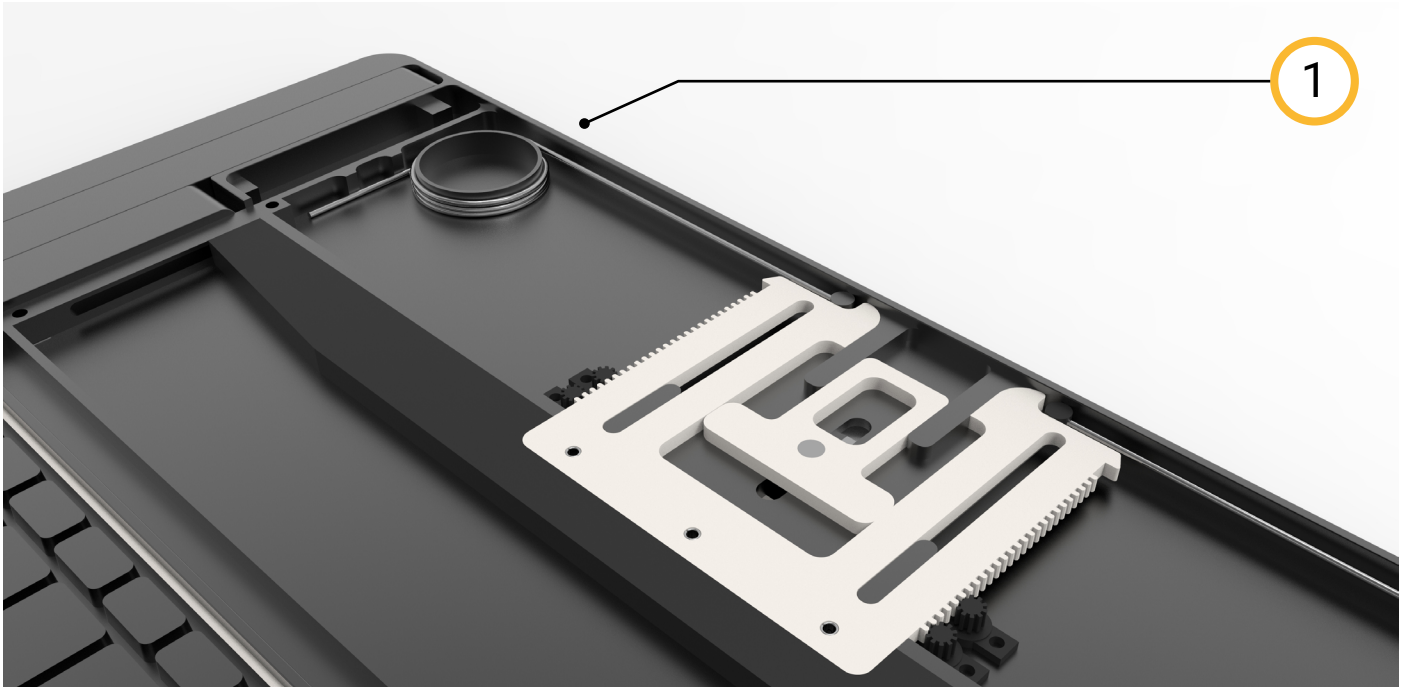


Figure A24: Placement of large torsion springs

amount of millimeters the center of the axle is at within the slot.

Because this position was easy to measure during testing, the slot position is also used as horizontal axis in the different graphs in chapter 2.5 and as main parameter in the tables on page 140-141. From this position the corresponding angles of the laptop stand can also be easily derived and are also shown in the tables.

Figure A23 shows the possible spring placements for the different spring systems. For each table the corresponding springs refer to this figure.

Additionally, table A3 uses a large torsion spring. This spring is placed at point [1] in figure A24. The angle under which this spring is calculated is angle α as seen in figure A25.

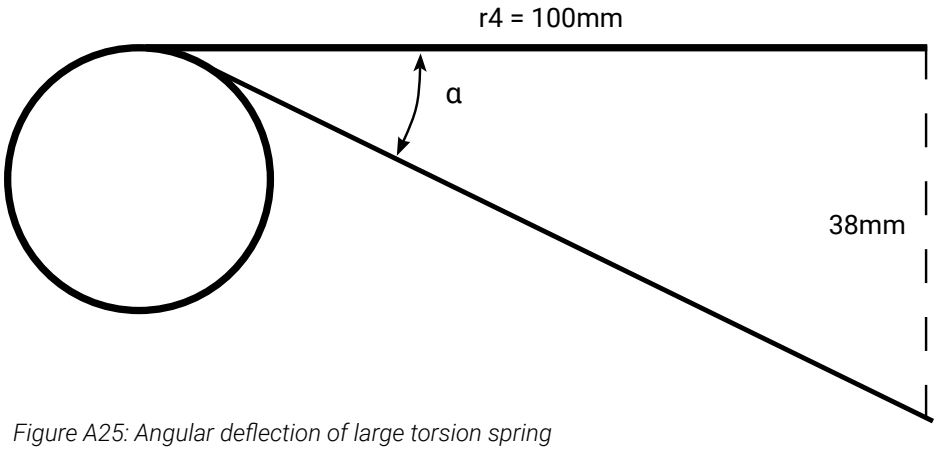


Figure A25: Angular deflection of large torsion spring

Validation of models

As it was difficult to determine the exact influence of the different springs in the laptop stand, a prototype was made to be able to verify the expected values from the mathematical model. In the prototype both linear and torsion springs have been used. In figures A27-A30 the prototype can be seen.

Figure A26 shows a graph based on the calculation in table A1. The graph shows the expected lifting force dependent on the slot position for the springs as used in the prototype.

As a 15" laptop weighs around 2 kg, it can be derived from the graph that between slot position 5 and 25 the laptop is expected to either be lifted or remain in position (depending on static or

dynamic friction coefficient). During testing two different laptops (HP Zbook and MacBook air) are placed on top of the laptop stand to see between which slot positions the lifting force of the mechanism was high enough to lift the laptop.

Results

The test results turned out to be quite similar to the theorized results. Between slot position 5 and 25 the MacBook (1.35 kg) could easily be balanced without human interference and, with a little nod to start the motion, it would also lift the laptop itself all the way up to slot position 27.

The heavier HP laptop (2.09 kg) would not lift completely by itself, but a tiny bit of upwards force was enough to effortless maneuver the laptop between slot position 5 and 25.

During these tests the friction of the material clearly played a quite important role, because the laptop would stay in any position it was left it in between slot position 5 and 25. When building future prototypes it is assumed the friction coefficient will be much lower than the expected friction coefficient of 0.6 (aluminium on lasercut (rough) wood).

In short, the test roughly validated the theoretical model and clearly showed the potential of the system in general. It was decided to use similar formulas as used for the prototype (table A1) to determine the spring force for other spring systems (table A2-A4).

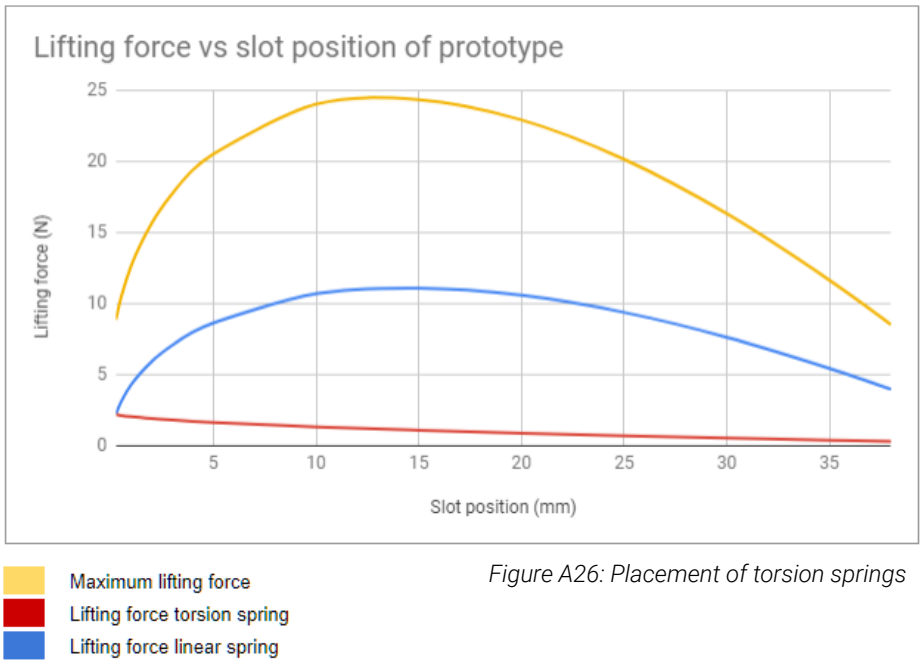


Figure A26: Placement of torsion springs

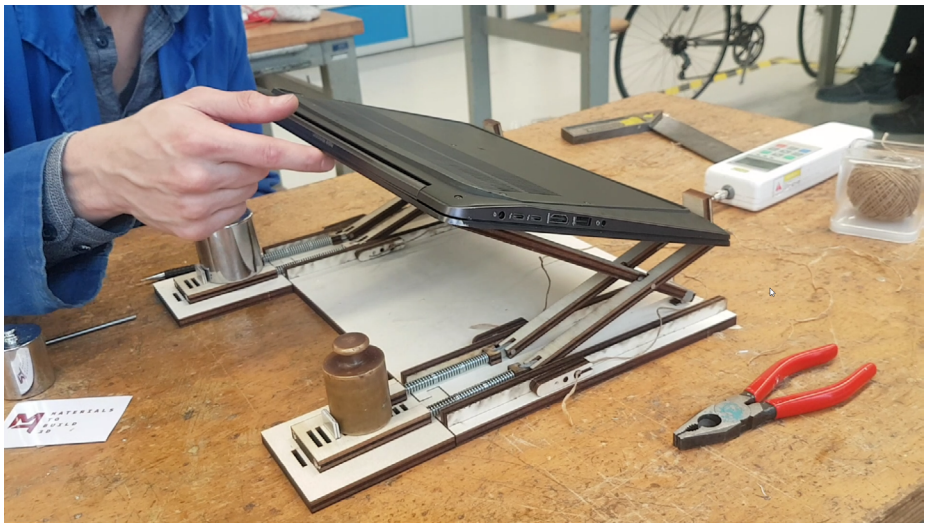


Figure A27: Testing with HP Zbook

Also, it was a pleasant surprise to notice how well this system already worked while nothing about it was really optimzed in any way.

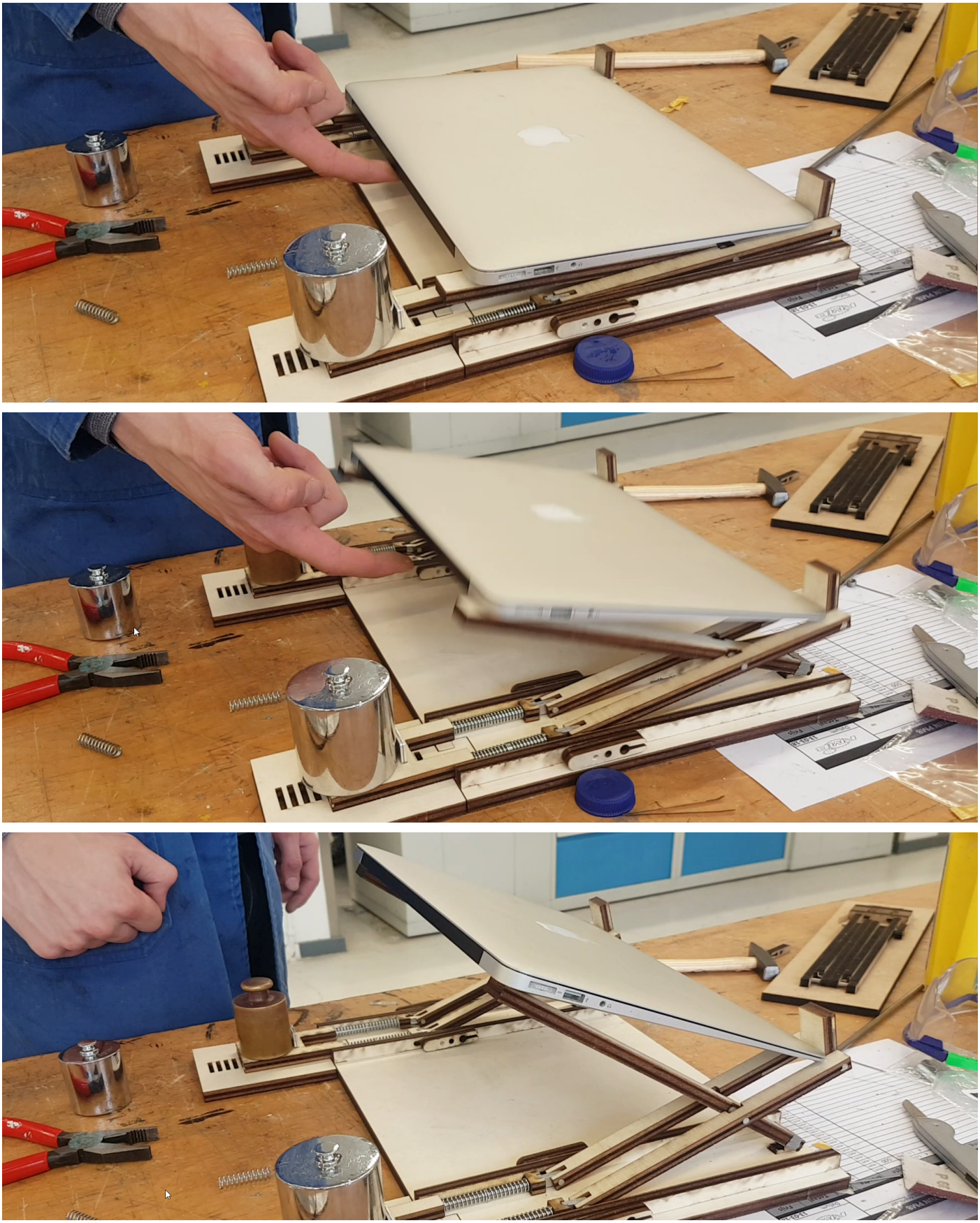


Figure A28-A30 Testing with Macbook

Prototype (linear springs in combination with torsion springs)							
Calculating expected spring force							
Slot position (SP)	**Angle slider 1 (AS1)**	**Angle slider 2 (AS2)**	**Linear spring force (LSF)**	**Torsion spring torque (TST)**	**Expected lifting force linear spring (LFLS)**	**Expected lifting force torsion spring (LFTS)**	**Expected total lifting force for two sliders**
mm	degrees	degrees	Newton (N)	Torque (Nmm)	Newton (N)	Newton (N)	Newton (N)
As indicated in figure $$			C1 * (TD - SP)	C2 * (FOR - (AS1 + AS2))	LSF * SIN(SP1)	TST/r1	2* (LFLS + LFTS)
0	0	0	49.5	0.41	0.0	2.37	4.73
0.1	1.6	2.4	49.4	0.40	1.4	2.26	7.28
0.25	2.6	3.7	49.2	0.39	2.2	2.20	8.87
0.5	3.6	5.3	49.0	0.37	3.1	2.13	10.41
1	5.1	7.4	48.4	0.36	4.3	2.04	12.68
2	7.2	10.4	47.3	0.33	5.9	1.90	15.66
3	8.8	12.8	46.2	0.31	7.1	1.80	17.73
4	10.2	14.8	45.1	0.30	8.0	1.71	19.39
5	11.3	16.6	44.0	0.29	8.6	1.63	20.51
10	16.1	23.6	38.5	0.23	10.7	1.32	24.00
15	19.6	29.1	33.0	0.19	11.1	1.09	24.31
20	22.6	33.9	27.5	0.15	10.6	0.88	22.90
25	25.2	38.2	22.0	0.12	9.4	0.70	20.13
30	27.5	42.1	16.5	0.09	7.6	0.54	16.31
35	29.6	45.8	11.0	0.07	5.4	0.38	11.63
38	31	47.9	7.7	0.05	4.0	0.29	8.52

Spring Design	Abbreviation	Linear spring (4) (LS)	Torsion spring (1) (TS)
Outer diameter (mm)	OD	8.0	8.0
Wire thickness (mm)	WT	1.5	1.5
Active coils	AC	40.0	8.8
Resulting in			
Spring constant (Nmm/deg)	C		4.6
Freedom of rotation (degrees)	FOR		90
Force (N/mm)	C	1.1	
Travel distance (mm)	TD	45	

arm length	length (mm)
r1	0.175

Table A1: Prototype

Iteration 1: just torsion springs							
Calculating expected upwards spring force							
Slot position (SP)	**Angle slider 1 (AS1)**	**Angle slider 2 (AS2)**	**Torsion spring 1 lifting force (TS1LF)**	**Torsion spring 2 lifting force (TS2LF)**	**Torsion spring 3 lifting force (T32LF)**	**Expected maximum lifting force for two sliders (N)**	
mm	degrees	degrees	Newton x meter (Nm)	Newton x meter (Nm)	Newton x meter (Nm)	Newton (N)	Newton (N)
As indicated in figure $$			2* (C1*(FOR1 - (AS1 + AS2))/r1)	2*2*(C2 * (FOR2 - AS2))/r2	2*2* (C3 * (FOR3 - AS1))/r3	(TS1LF+TS2LF+TS3LF)	
0	0	0	4.86	5.18	3.89	13.93	
0.1	1.6	2.4	4.70	5.03	3.75	13.48	
0.25	2.6	3.7	4.61	4.95	3.66	13.22	
0.5	3.6	5.3	4.51	4.84	3.58	12.93	
1	5.1	7.4	4.37	4.71	3.45	12.53	
2	7.2	10.4	4.17	4.52	3.27	11.96	
3	8.8	12.8	4.02	4.36	3.13	11.51	
4	10.2	14.8	3.89	4.24	3.01	11.13	
5	11.3	16.6	3.77	4.12	2.91	10.81	
10	16.1	23.6	3.31	3.67	2.50	9.49	
15	19.6	29.1	2.96	3.32	2.19	8.48	
20	22.6	33.9	2.66	3.01	1.94	7.61	
25	25.2	38.2	2.39	2.74	1.71	6.84	
30	27.5	42.1	2.15	2.49	1.51	6.15	
35	29.6	45.8	1.93	2.25	1.33	5.51	
38	31	47.9	1.79	2.12	1.21	5.12	

Spring design	Abbreviations	Torsion spring (1) (TS1)	Torsion spring 2 (2) (TS2)	Torsion spring (3) (TS3)
Outer diameter (mm)	OD	8.0	7.0	7.0
Wire thickness (mm)	WT	1.5	1.3	1.3
Active coils	AC	12.0	6.0	4.0
Resulting in				
Spring constant (Nmm/deg)	C	3.4	3.2	5.4
Freedom Of Rotation (degrees)	FOR	125	81	45

	length (mm)
arm length 1	0.175
arm length 2	0.200
arm length 3	0.250

Table A2: Iteration 1

Iteration 2: small torsion springs and large torsion springs							
Calculating expected upwards spring force							
Slot position (SP)	**Angle slider 1 (AS1)**	**Angle slider 2 (AS2)**	**Angle torsion spring 2 (ATS2)**	**Torsion spring 1 lifting force (TS1LF)**	**Torsion spring 4 force (TS4F)**	**Torsion spring 2 lifting force (TS2LF)**	**Expected maximum lifting force for two sliders (N)**
mm	degrees	degrees	degrees	Newton (N)	Newton (N)	Newton (N)	Newton (N)
As indicated in figure $$			Arctan((SP/1000) /r2)	(C1 * (FOR1 - (AS1 + AS2) / r1))	(C2 * (FOR2 - ALTS)) /1000	(TS2F / r2) * sin(AS1)	TS1LF + TS2LF
0	0	0	0.00	4.25	1.68	0.00	4.25
0.1	1.6	2.4	0.06	4.11	1.68	0.94	5.05
0.25	2.6	3.7	0.14	4.04	1.67	1.52	5.55
0.5	3.6	5.3	0.29	3.95	1.67	2.09	6.04
1	5.1	7.4	0.57	3.83	1.66	2.94	6.77
2	7.2	10.4	1.15	3.65	1.63	4.09	7.74
3	8.8	12.8	1.72	3.52	1.61	4.92	8.44
4	10.2	14.8	2.29	3.40	1.58	5.61	9.01
5	11.3	16.6	2.86	3.30	1.56	6.11	9.41
10	16.1	23.6	5.71	2.90	1.44	7.99	10.89
15	19.6	29.1	8.53	2.59	1.32	8.87	11.46
20	22.6	33.9	11.31	2.33	1.20	9.26	11.59
25	25.2	38.2	14.04	2.09	1.09	9.29	11.38
30	27.5	42.1	16.70	1.88	0.98	9.04	10.92
35	29.6	45.8	19.29	1.69	0.87	8.59	10.28
38	31	47.9	20.81	1.57	0.81	8.30	9.87

Spring design	Refference	Torsion spring (1) (TS1)	Torsion spring (4) (TS2)
Outer diameter (mm)	OD	8.0	35.0
Wire thickness (mm)	WT	1.5	2.5
Active coils	AC	12.0	2.4
Resulting in			
Spring constant (Nmm/deg)	C	3.4	42
Freedom of rotation (degrees)	FOR	125	40

Arm length	length (m)
r1	0.175
r4	0.100

Table A3: Iteration 2

Iteration 3: small torsion springs and linear springs						
Calculating expected upwards spring force						
Slot position	**Angle slider 1 (AS1)** (degrees)	**Angle slider 2 (AS2)** (degrees)	**Torsion spring 1 - Lifting force (N)**	**Torsion spring 2 - Lifting force (N)**	**Linear spring 4 - Lifting force (N)**	**Expected maximum lifting force for two sliders (N)**
As indicated in figure $$			2* (C1 * (FOR1 - AS1)) / r1	2* (C2 * (FOR2 - AS2)) / r2	NOS*((C3*(TD-SP))*sin(SA1))	2 * (TS1 + TS 2 + LS)
0	0	0	4.88	4.37	0.00	18.50
0.1	1.6	2.4	4.48	4.18	1.41	20.12
0.25	2.6	3.7	4.24	4.06	2.28	21.17
0.5	3.6	5.3	3.98	3.94	3.15	22.13
1	5.1	7.4	3.61	3.76	4.43	23.60
2	7.2	10.4	3.09	3.52	6.15	25.52
3	8.8	12.8	2.69	3.33	7.40	26.82
4	10.2	14.8	2.34	3.16	8.43	27.87
5	11.3	16.6	2.04	3.03	9.19	28.53
10	16.1	23.6	0.84	2.47	12.00	30.63
15	19.6	29.1	-0.07	2.05	13.31	30.59
20	22.6	33.9	-0.86	1.70	13.86	29.40
25	25.2	38.2	-1.57	1.39	13.82	27.30
30	27.5	42.1	-2.20	1.12	13.33	24.50
35	29.6	45.8	-2.79	0.87	12.47	21.12
38	31	47.9	-3.14	0.71	11.89	18.91

Spring design	Abbreviation	Torsion spring 1 (TS1)	Torsion spring 2 (TS2)	Linear spring (4) (LS)
Outer diameter (mm)	OD	8.0	8.0	6.0
Wire thickness (mm)	WT	1.5	1.5	0.8
Active coils	AC	5.7	3.8	135.0
Resulting in				
Spring constant (Nmm/deg)	C	8.9	11.8	
Freedom of rotation (degrees)	FOR	48	37	
Spring constant (N/mm)	C			0.481
Travel distance (mm)	FOR			70
Number of spring	NOS			1.5

Arm length	length (mm)
r1	0.175
r2	0.200

Table A4: Iteration 3

Appendix 15

Spring factory visit

A visit to a spring factory, Roveron, provided a lot of insights in how to design with springs and what was important to keep in mind when doing so. A couple of key takeaways are:

For the strength of either linear or torsion springs, the wire diameter is by far the most influential factor. It is however not possible to just keep increasing the wire diameter of springs as they also have a so called spring index.

The spring index is calculated by dividing the mean diameter with the wire diameter. Ideally this number varies between 6 and 12. If the spring index becomes lower, the price in production goes up. A spring index below 4 is practically impossible to manufacture. If the spring index goes up, the difficulty in production also increases and tolerances may vary a lot.

In the case of this design project, where there is a need for springs with a large wire diameter (high strength) and a small outer diameter (flat design), it is important to make sure the spring index does not break the 4.0 index value.

For torsion springs, increasing the amount of windings also increases the freedom of rotation, but it does not affect the maximum possible torque. This allows for very accurate fine tuning of force distribution as long as the width of the spring can be increased.

Figure A31: Factory Roveron

Appendix 16

Front grip

Detailing

When looking more in-depth what the front grip exactly needs to be able to do, three different functions can be determined. Each of these subfunctions is discussed and integrated into the the final design.

1. Flexibility: the front grip has to gradually adjust to the angle between the laptop and the slider as the elevation increases.

To allow for a gradual inclination of the front grip, the pulling force of the torsion spring needs to be equal or slightly higher than the gravitational force of the downwards sliding laptop. This will cause the front grip to be either perpendicular to the laptop or a few degrees inclined towards the laptop. The correct spring force can be estimated with some calculations.

In figure A32 a Free Body Diagram is shown of a slightly simplified situation of the laptop on the laptop stand. In this figure we assume a friction coefficient between the laptop and sliders of 0.1 (static friction coefficient between aluminium on nylon, Material Contact Properties Table, 2008). Additionally, we assume the working arm of the torsion spring to be 10 mm, which is roughly the thickness of the laptop.

$\Sigma F=0$

$F_{downwards} = Fx - Fr$

$Fx = Fz * \sin(\alpha)$

$Fr = Fn * C_{friction}$

$Fn = Fz * \cos(\alpha)$

$F_{downwards} = Fz * \sin(\alpha) - Fz * \cos(\alpha) * C_{friction}$

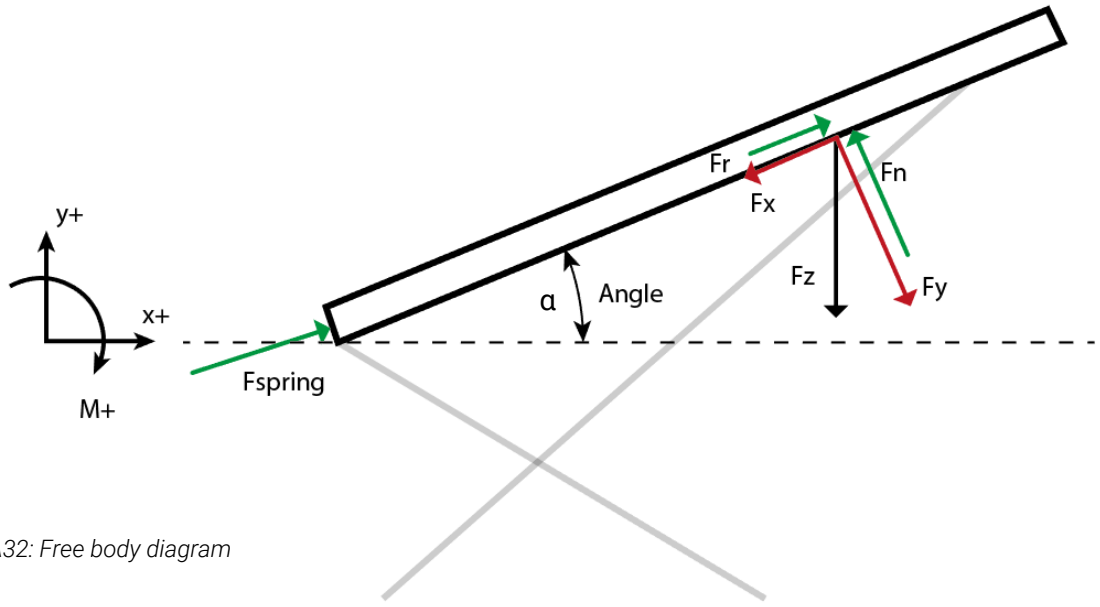


Figure A32: Free body diagram

The resulting force ($F_{downwards}$) is plotted in Maple over a changing angle from 0 to 30 degrees. The result can be seen in figure A33. The maple file used can be found in appendix 17. This means that the spring should neutralize this force to maintain a perpendicular position between laptop and front grip. Thus, ideally:

$F_{spring} = F_{downwards}$
so:
$(C_{spring} * \beta)/Springleg = Fz * \sin(\alpha) - Fz * \cos(\alpha) * C_{friction}$

For the above equation to be solvable, β had to be expressed in α. β is the angle between the front grip and the short slider. As this was not achieved by geometry calculations, the relation between the two was derived from measurements in the SolidWorks model. At intervals of 5 degrees increase in α, β was measured. α and β were then divided by each other and plotted in a graph (figure A35). This graph was slightly simplified (dotted line) and translated into a formula. It could therefore be said that:

$\beta = -0.006*\alpha + 2.164$

Because the spring force is dependent on the starting position of the front grip and the spring constant, there were too many variables to solve the equation mathematically. However, it is possible to closely approach the desired balanced state. By playing around with the starting angular deflection of the front grip and the spring constant, the results in figure A34 are achieved. In the figure the

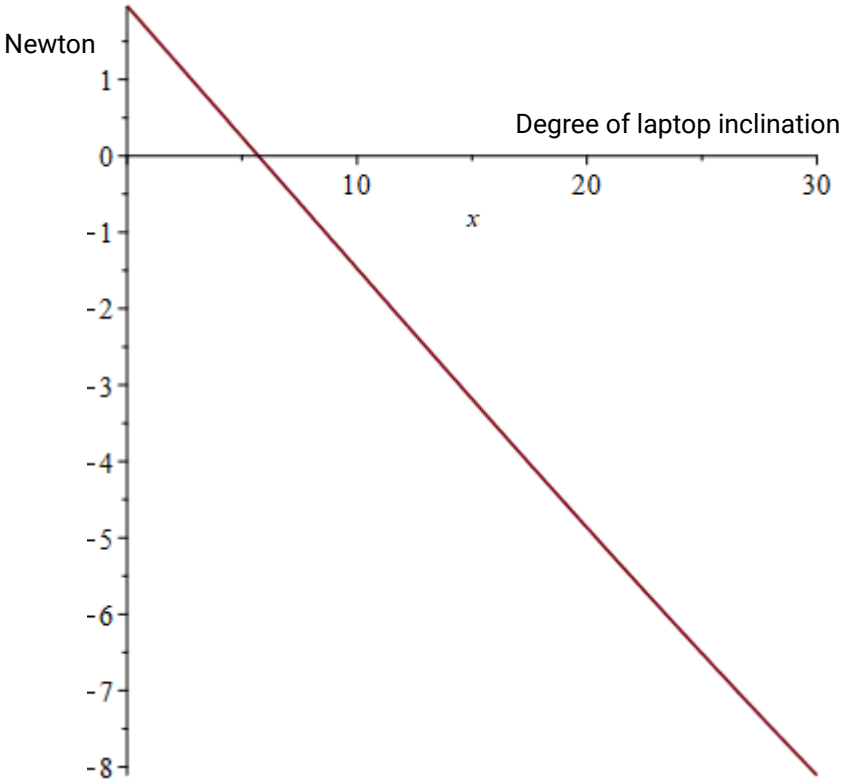


Figure A33: Maple plot: $F_{downwards}$ from 0 to 30 degrees

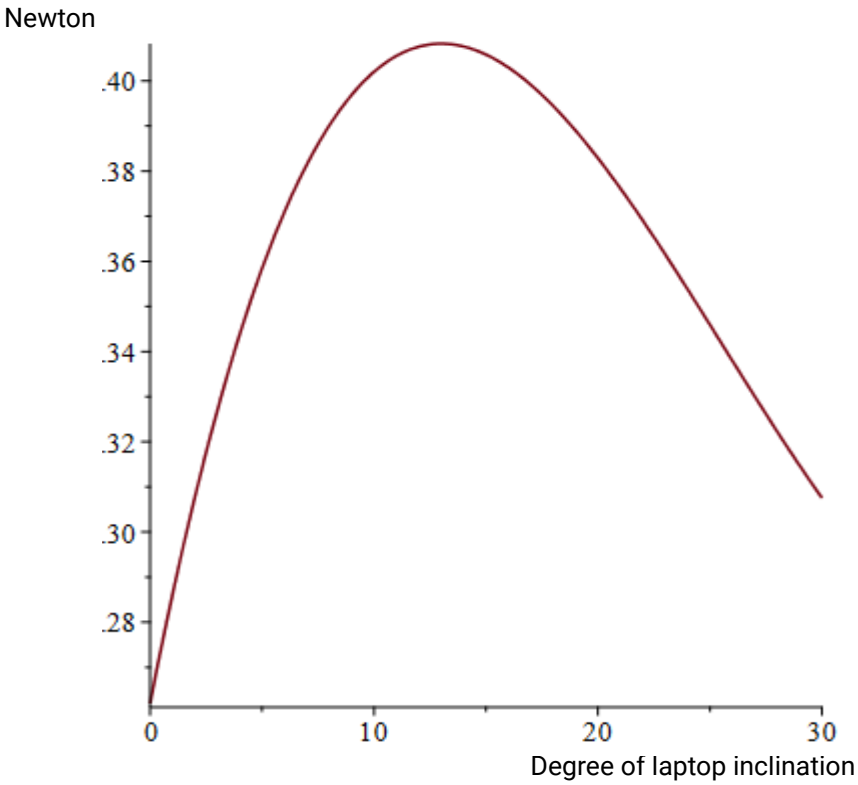


Figure A34: Maple plot: F_{total} from 0 to 30 degrees

resulting force (F_{total} = - $F_{downwards}$ + F_{spring}) is plotted for x between 0 and 30 degrees. The fact that the force is always positive and between 0.2 and 0.4 Newton means that in reality the front grip will incline slightly (maximum of 3 degrees) towards the laptop before reaching a static balance. This is perfectly fine as it clamps the laptop in position while the user will hardly notice the front grip is not perfectly perpendicular.

Based on the following required spring properties, the spring as seen in figure A36 is designed.

- Torque of 1.7 N/mm
- Freedom of rotation 80 deg.
- Outer diameter max 5.6 mm
- Inner diameter max 1.4 mm

Because the mathematical approach was based on a slightly simplified situation, it is important to note that there is enough flexibility within the spring design to compensate if in reality the product behaves differently.

2. Foldability: the user must be able to flatten and 'pop-up' the front grip.

For the previous concept to work, the neutral position of the spring is at a 80 degree angle between the laptop stand and the front grip in a folded position. This means the front grip will always have the urge to move upwards from the flattened position (figure A38).

The force of this upwards pull (F_{pull}) = C_{spring} * 80 / 20mm. Using the spring from figure A36 this

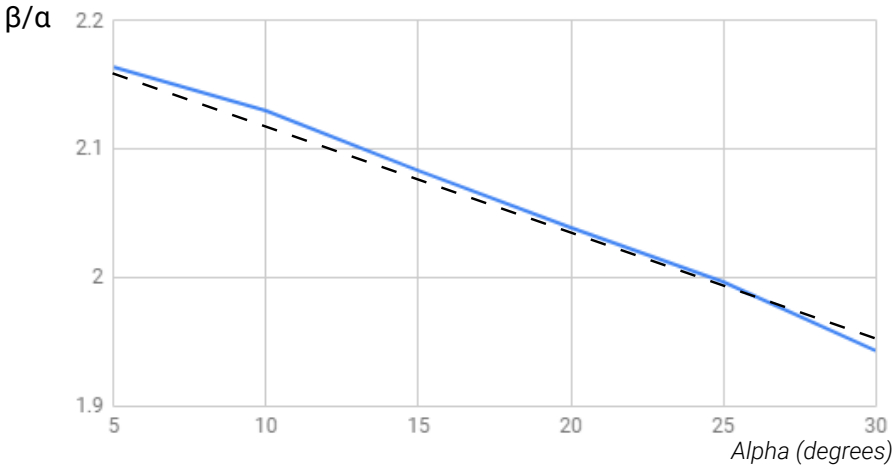


Figure A35: beta / alpha

Rates & Torques	
Rate per degree :	1.696 N-mm/Degree
Spring Rate (or Spring constant) per 360 degrees, $k_{360\ degrees}$:	610.616 N-mm/360 Degrees
Maximum torque possible, $Torque_{max}$:	160.695 N-mm

Safe Travel	
Maximum safe travel, $Travel_{max}$:	94.7407 Degrees

Physical Dimensions	
Diameter of spring wire, d:	1.060 mm
Outer diameter of spring, D_{outer} :	5.600 mm
Inner diameter of spring, D_{inner} :	3.100 mm
Mean diameter of spring, D_{mean} :	4.540 mm
Number of active coils, n_a :	8.722
Body length, L_{body} :	10.305 mm
Length of leg 1:	10.000 mm
Length of leg 2:	10.000 mm
Total leg length:	20.000 mm
Direction of wind :	Left hand
Spring index, C :	4.283

Material type	
Material type:	Music Wire ASTM A228

Figure A36: Spring design front grip

means F_{pull} is roughly 6.8N. By adding two tiny neodymium magnets (figure A39) that are slightly stronger than F_{pull} of the torsion spring (8.4N pull force), the front grip will stay nicely in a flattened position. However, with just a little nudge from the user they will pop-up after which the laptop stand can be used. This solution also avoids the need for additional components typically seen in click and lock mechanism such as pens and trashbin caps (figure A40).

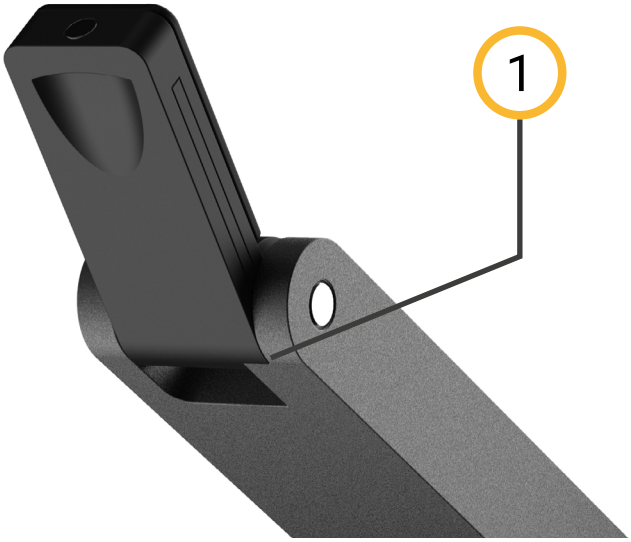


Figure A37: front grip below

3. Locking: when the laptop is fully lifted there needs to be a full stop, meaning the laptop can never really slide away.

To ensure the laptop never actually falls of the laptop stand, a “hard stop” is integrated in the short slider and front grip ([1], figure A37). This point [1] is set at an angle of 150 degrees between the front grip and the short slider. This means the torsion spring in the front grip needs an angular deflection of 70 degrees in an opened position and 80 degrees to be closed completely. Therefore the freedom of rotation of 80 degrees does not have to be changed.

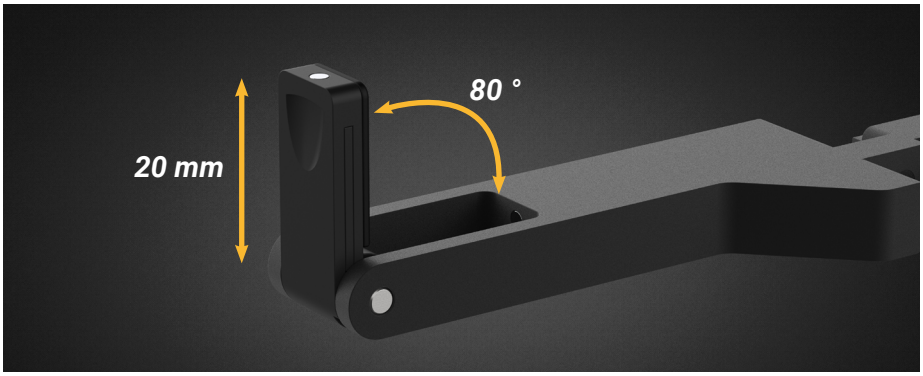


Figure A38: Neutral spring position of front grip

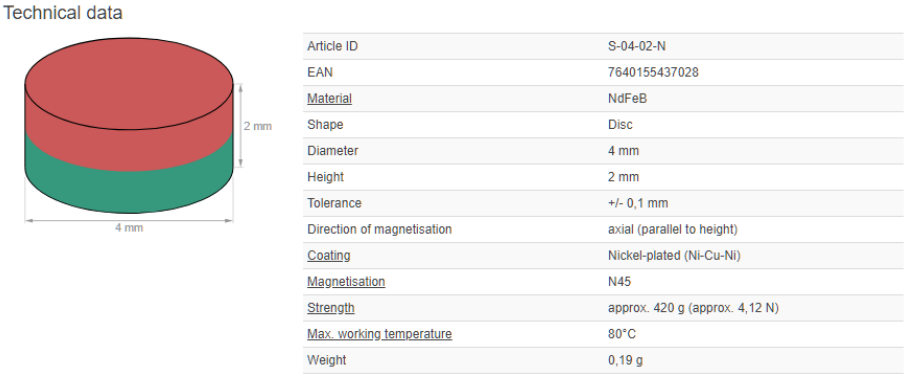


Figure A39: Neodymium magnet

Validation

In addition to the theoretic working principle of the the front grip, a proof of concept prototype was made with one of the earlier wooden prototypes. In figure A41-A43 the prototype is shown. The front grip [1] is supported by two sliders [3,4] and placed in a neutral position of 90 degrees by

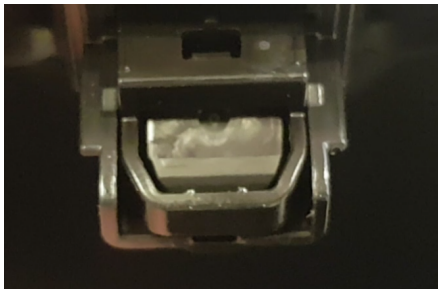


Figure A40: Click and lock of a trashbin

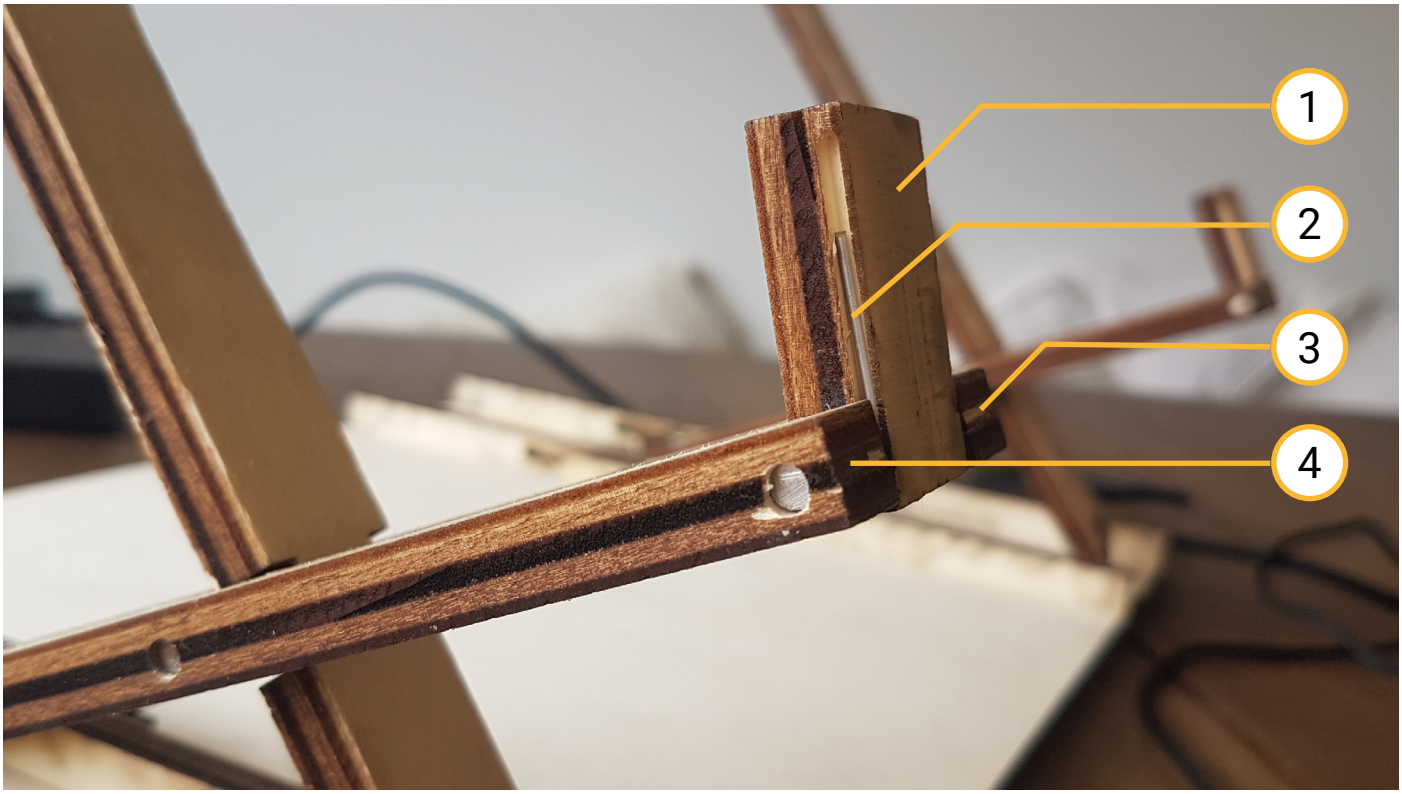


Figure A41: Prototype front grip

two torsion springs, one at each side of the front grip. In figure A41 the spring leg of one of the torsion sliders is visable at point [3].

The prototype is capable of folding completely flat [5] and adjust to the required angle [6]. The springs used in this prototype had the following properties:

- Wire thickness: 1mm
- Active coils: 3,75
- Outer diameter: 7mm

This means that each spring had a spring force of 2.36 Nmm/deg. As there are two springs working in parallel, this number could be doubled to 4.72 Nmm/deg per slider. The maximum safe travel distance of these springs is just under 60 degrees. Therefore the springs were not exactly the best option, but they were cheap and directly available for use.

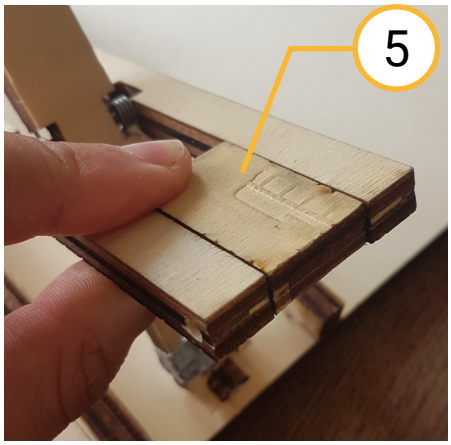


Figure A42: Prototype front grip - flat

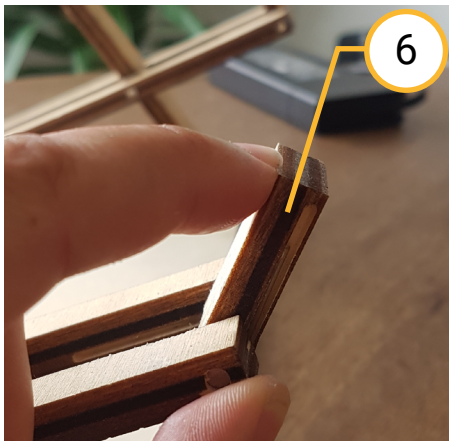


Figure A43: Prototype front grip - open

Using a wooden plate of around 1.25 kg the weight of laptop was recreated on one of the two sliders.

During testing the strength of the spring (2.36 Nmm/deg) proved to be the around the correct strength. However, once the spring was slightly too strong or weak, depending on the position the laptop had the urge to start sliding up and down. In the final design it would be much better to prevent this at all and make a little dent in the rubber grip as an additional safety measure.

Tolerances

As can be seen in figure A44 the front grip mechanism is centred around an axle. This axle will have one transition fitting and one interference fitting which will lock the axle in its place. The axle, which can be bought directly at Fabory, has a tolerance of H7. This means the first hole needs to be toleranced at p6 and the second one at k6 to provide the proper fittings. It is important that part [4] has a clearance fitting in the slider, but this can be solved by slightly adjusting the dimensions and simply use the standard CNC tolerance of 0.025 mm. Part [6], a simple plastic card is pressed within part [4] using an interference fitting (IT12) (EngineersEdge).

Production & material

The front grip only has a few parts that need to be custom made. Parts [2], [3], [5] and [7] can be ordered directly at a retailer. Parts [6] and [7] can be ordered as plate material and only require minor tooling. Part [4], the core of the front grip, is the only component that needs to be manufactured specifically. Initially it was decided to make this part from POM because it could be laser cut along with stability slider. In hindsight, the material decision is fine but the production needs to be changed to CNC machining or injection molding to meet the required tolerances and surface finish (R2.10, W4.7). For the first 100 models CNC machining is chosen.

Assembly

The front grip can be assembled relatively easily. It is important that the entire mechanism (part [2], [3], [4], [5], [6] and [8]) are assembled first. Of these, parts [2] and [3] are kept in place after pressing part [6] into the front grip case [4]. The rubber grip [8] needs to be glued to the aluminium or plastic casing, as does the neodymium magnet [5]. Both of these can be glued to either aluminium or plastics (Masterbond, Adhesives for Plastic Substrates).

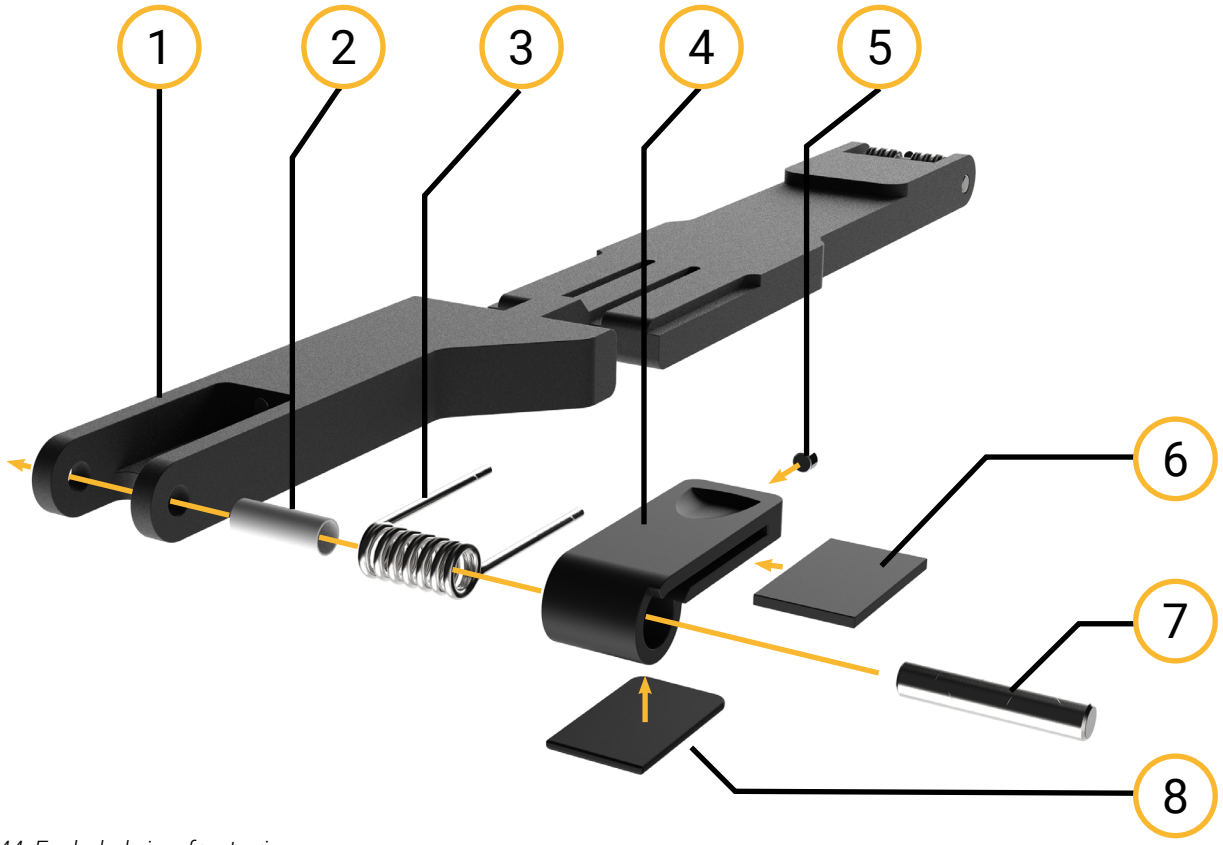


Figure A44: Exploded view front grip

Appendix 17

Front grip Maple sheet

```
> restart;
> Ftotal := Fspring + Fr - Fx;
```

$$Ftotal := Fspring + Fr - Fx \quad (1)$$

Sliding force

```
> Fx := LaptopWeight·Gravity·(evalf(sin(AngleAlpha·Pi/180)));
```

$$Fx := LaptopWeight\ Gravity \sin(0.01745329252\ AngleAlpha) \quad (1.1)$$

```
> Gravity := 9.81;
```

$$Gravity := 9.81 \quad (1.2)$$

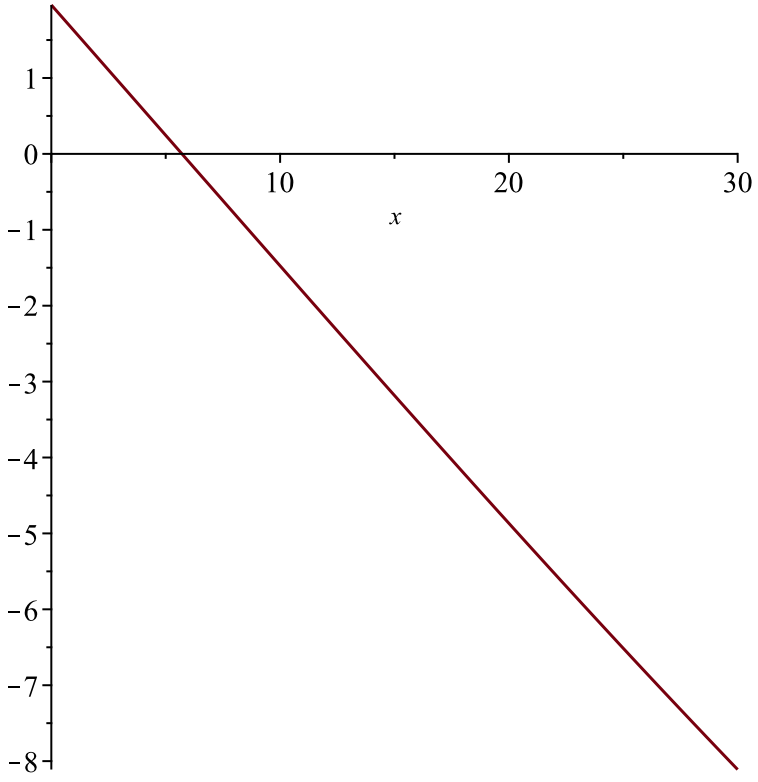
```
> LaptopWeight := 2 ;
```

$$LaptopWeight := 2 \quad (1.3)$$

```
> AngleAlpha := x;
```

$$AngleAlpha := x \quad (1.4)$$

```
> Fdownwards;
> plot(Fdownwards, x = 0..30);
```



Friction force

> $Fr := Fn \cdot FrictionCoefficient;$

$$Fr := Fn\ FrictionCoefficient \tag{2.1}$$

> $Fn := LaptopWeight \cdot Gravity \cdot \left(evalf\left(\cos\left(\frac{AngleAlpha \cdot \mathrm{Pi}}{180} \right) \right) \right);$

$$Fn := 19.62 \cos(0.01745329252\ x) \tag{2.2}$$

> $FrictionCoefficient := 0.1;$

$$FrictionCoefficient := 0.1 \tag{2.3}$$

> $Fr;$

$$1.962 \cos(0.01745329252\ x) \tag{2.4}$$

> $Fdownwards := Fr - Fx$

Spring force

> $Fspring := \frac{(Cspring \cdot AngleBeta)}{SpringLeg};$

$$Fspring := \frac{Cspring\ AngleBeta}{SpringLeg} \tag{3.1}$$

> $Cspring := 1.7;$

$$Cspring := 1.7 \tag{3.2}$$

> $AngleBeta := (AngleAlpha \cdot ((-0.006 \cdot AngleAlpha) + 2.164)) - 10;$

$$AngleBeta := x\ (-0.006\ x + 2.164) - 10 \tag{3.3}$$

> $SpringLeg := 10;$

$$SpringLeg := 10 \tag{3.4}$$

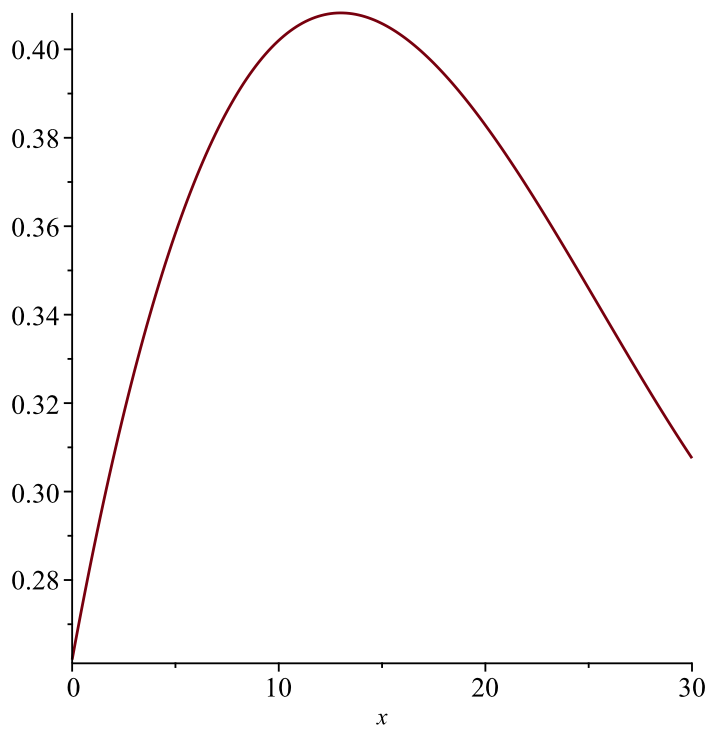
> $Fspring;$

Resulting force = Fspring + Ffriction -Fdownwards

> $Ftotal;$

$$0.1700000000\ x\ (-0.006\ x + 2.164) - 1.700000000 + 1.962 \cos(0.01745329252\ x) - 19.62 \sin(0.01745329252\ x) \tag{4.1}$$

> $plot(Ftotal, x = 0..30);$



>

Appendix 18

Locking mechanism material, assembly and production

Material and production

The locking mechanism only has a few parts that need to be custom made. Part [1], the core of the locking mechanism is made from aluminium because the mechanical properties are more than sufficient and an aluminium CNC set-up is already required for other components. Changing material and machine type does not have any noticable advantages but is expected to increase initial cost and human labor cost.

A potential problem with this decision is the high friction coefficient of aluminium on aluminium (1.05-1.35). However, because the force working on the locking mechanism is very low as long as a laptop is on top of the laptop stand, the frictional resistance is also very low (Fnormal * friction coefficient). This means the friction coefficient works as an additional safety measure because it will be very difficult to unlock the laptop stand without a laptop on top.
Part [2] (figure A45) keeps the locking mechanism [1] from sliding too far to the sides, but it is mostly designed as aesthetic finish for the side of the base plate [3]. It is decided to make this part from HDPE because of low price and easy machinibility. If more variance in color would be required an alternative option is ABS. Either of these can be used for injection molding if production is to scale up.

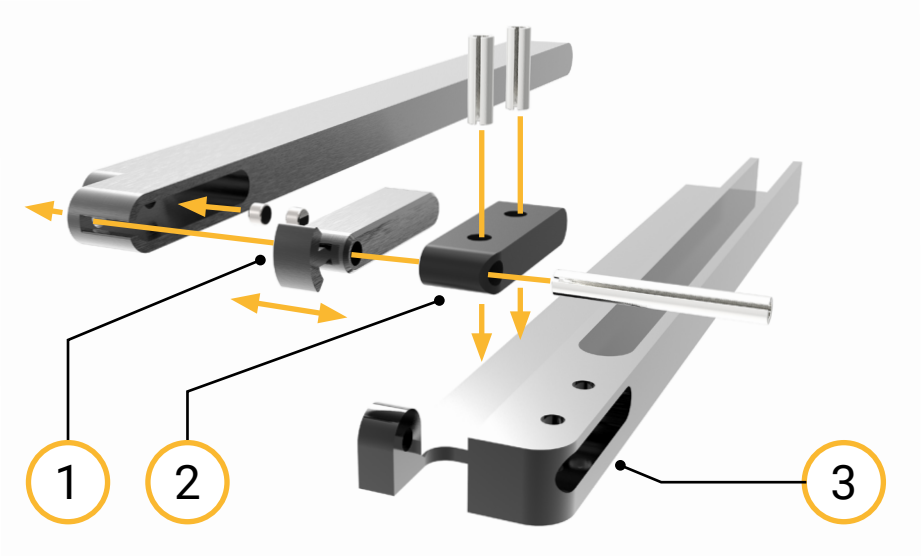


Figure A45: Assembly order

Assembly

The assembly of the locking mechanism is simple, but the order in which parts are placed does matter. First of all the magnets should be glued into position, making sure they are turned in the correct direction as they need to pull each other. Next, restriction bar can be placed within the main slider, after which they can be placed in the baseplate. The conical clamping pin can now be placed from the outside of the baseplate and pressed into the interference hole, which is also part of the baseplate. The Position chamber can now be placed in position and locked with the two clamping pins.

Appendix 19

Locking mechanism tolerances

Tolerances

The tolerances of important contact points are discussed in this section, the different fittings are explained with figure A46 and the ISO tolerance table to can be found in appendix 25.

Clamping pins

This sub assembly uses two clamping pins, of which the long one [7] is a cylindrical one.
The two short clamping pins have a diameter between 3.3 and 3.5 mm, the smallest diameter the clamping pin can reach when fully compressed is 2.7mm. The holes through which the clamping pin moves are therefore dimensioned at 3H12.

The cylindrical clamping pin moves through the position chamber [5], the restriction bar [4], the main slider [2] and eventually locks itself into place in the baseplate [6]. Through the first 3 components there needs to be a clearance fitting, as the cylindrical axis is toleranced at H8, the holes have to be toleranced at k6.
The pin is eventually clamped into the baseplate whit in interference fitting toleranced at p6.

Restriction bar

The restriction bar needs to slide freely in the main slider. It thus needs to be a clearance fitting, the parts are toleranced at H7 and g6 respectively.

Position chamber

The position chamber needs to be placed into the baseplate. This part does not have to move and is locked into place with the short clamping pins. A transition fitting makes the most sense in this scenario which results in an H7/k6 tolerance.

Magnets

The magnets [3] are placed both in the restriction bar [2] and in the main slider [4]. According to the website of magenete.com the magnets are 4 x 1.5 +- 0.1 mm. This means the holes in both the restriction bar and the main slider need to 4.1 mm. As the holes should never be smaller but the outer dimension is not very important the holes are toleranced at H12.

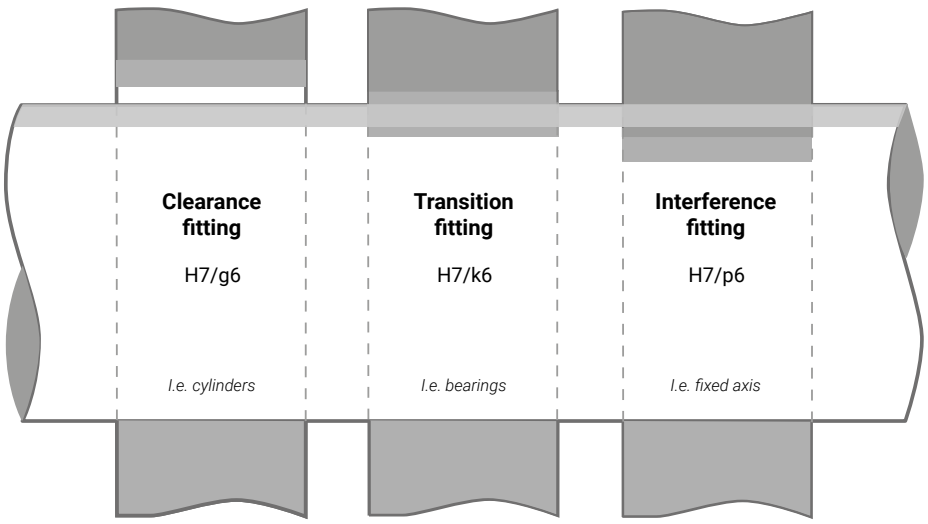


Figure A46: Tolerances explained

Appendix 20

Locking mechanism validation

To make sure the mechanism works as intended a small prototype is made using 3D printing. In figure A47 the results of the prototypes are shown. This prototype shows the concept is promising but also has some potential issues.

Test model

In general the 3D printed model worked surprisingly well. The little piece at the front was enough to move the entire restriction bar through the slot and secure the slider in place. This was despite the rather rough tolerances of 3D printer which can even be seen in the surface finish in figure A48.

Because the locking mechanism needs to be able to widthstand the entire lifting force of the laptop stand it was decided to make the final model from aluminium just as the rest of the product.

Avoidance of tilting of the restriction bar was also found to be very crucial. Only a slight tilt of the restriction bar would completely block any motion and ruin a smooth user interaction. That makes the tolerances on this part very important. Ideally these would be a transition fitting but in that case the friction coefficient of aluminium on aluminium may be too high too smoothly adjust the mechanism. Fortunately there are plenty materials (thermoplastics) with much better friction coefficients that would suffice.

Lastly, the grip [1] that the user can slide sideways is small, but doable. It would however be better if the size of the grip could be larger.

Conclusion

The idea is very promising but also emphasized the importance of tolerances and material choice.

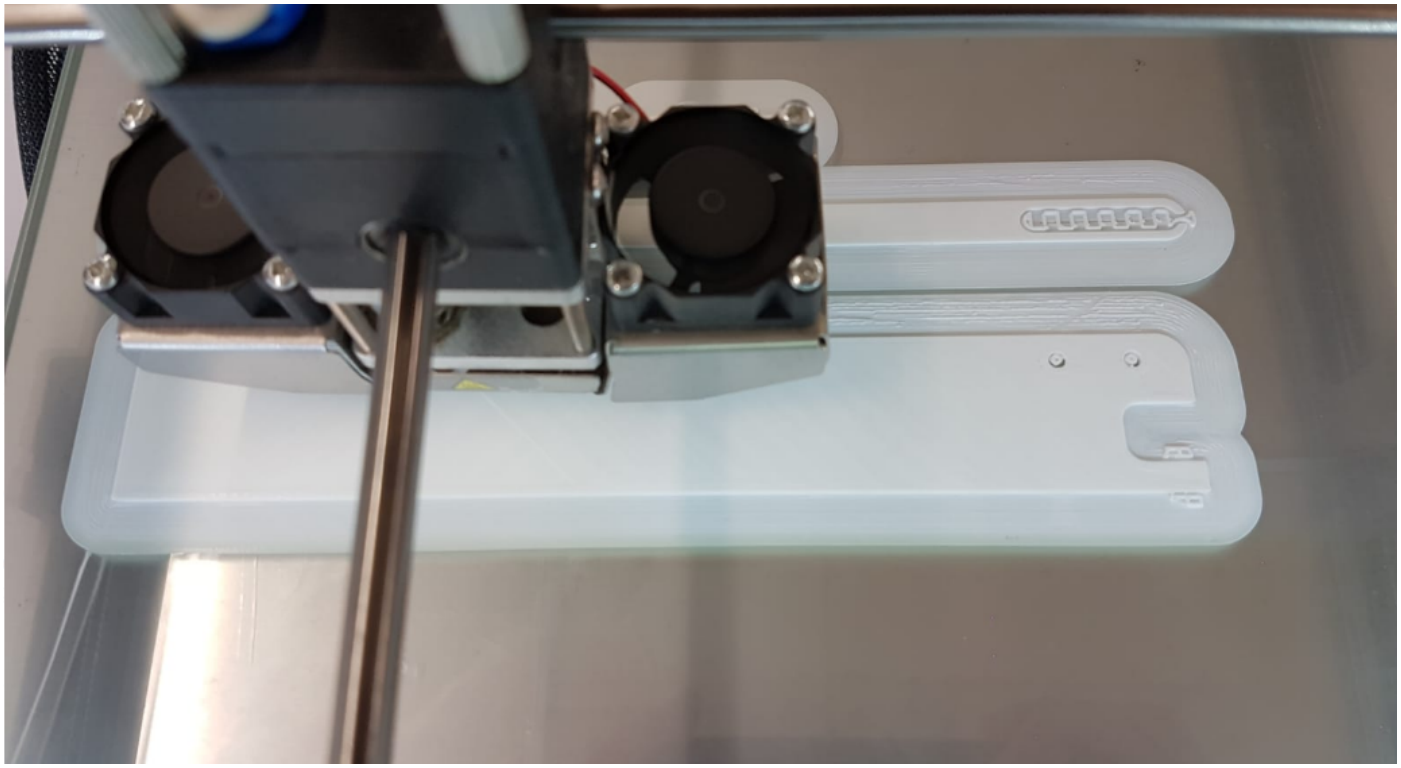


Figure A47: 3D printing locking mechanism

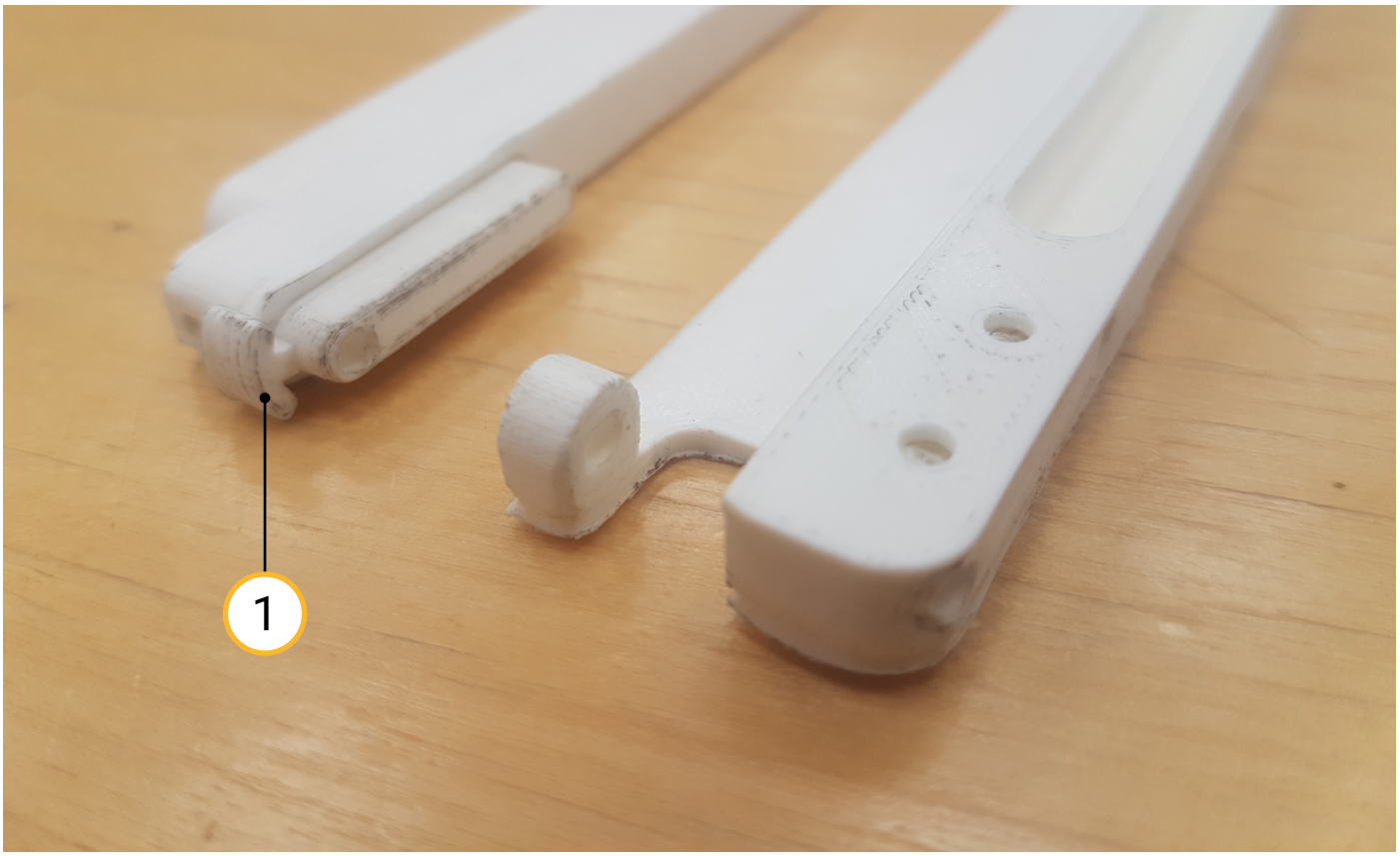


Figure A48: 3D print of locking mechanism

Appendix 21

Keyboard

Design criteria

Especially the dimensions and type comfort of the keyboard are important.

Dimensions (R2.4.4, R2.4.5)
It must fit within 8 mm available height and between the two sliders. The depth of the keyboard is the least important factor as the main sliding mechanism could be adjusted to suit the keyboard dimensions. A benefit of the maximum height of 8 mm is the fact that flat keyboards are generally considered ergonomically as they do not restrain blood flow at the wrist.

Type delay (R2.4.2)
Type delay is the next important design factor and, even though partially based on personal preferences, there a few features that the keyboard has to provide in general. First of, due to the dimensions of the product, the keyboard must be wireless. That makes that connectivity (delay) is a critical factor in determining the right keyboard.

Ergonomic standard (R2.4.1)
Secondly, the keyboard also needs to have the “standard” key layout instead of the small one (235mm versus 285mm width). This is required to meet the ergonomic standards as smaller keyboards can increase MSD due to awkward and constraint wrist

Figure A49: Standivarius Solo X (www.standivarius.com)

positioning for people with larger hands.

Transport (R2.4.3)
Lastly it is important that the keyboard stays into its position during transport and while typing. They keyboard should not be fixed in place, because it is extremely likely users will prefer to retract their keyboard a little or even entirely if they have not learned how to type blindly yet.

Solutions

Considering the required dimensions, only a few models are usable.

At first, different types of keyboards have been ordered in China to check on build quality, type quality, dimensions and required components for a keyboard. As keyboards can come as cheap as 10 dollars a piece, it was relatively simple to test a small variety of keyboards (figure A50-A52). In general all the keyboards under 20 dollar made by a Chinese manufacturer had a very low battery life (1 week at best) and mediocre connectivity. The keystroke on those keyboards was surprisingly nice and the dimensions were often promising. This proves that it was at the very least physically possible to fit a keyboard into the design space available in the laptop stand.

Next, it was decided to aim for the best keyboard available on the market given all the requirements. The best one by far turned out to be the Standivarius Solo X (figure A49) which not only has (almost) perfect dimensions but also

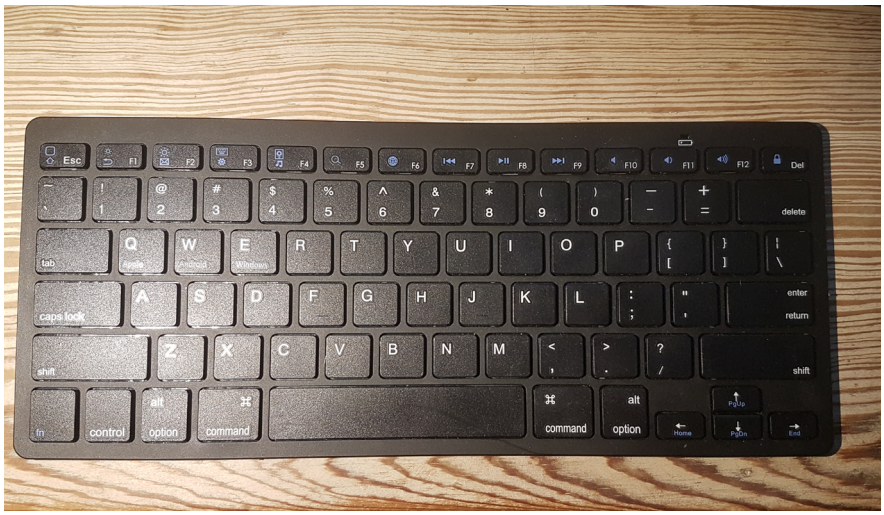


Figure A50: One of the keyboards ordered at Ali-express.com

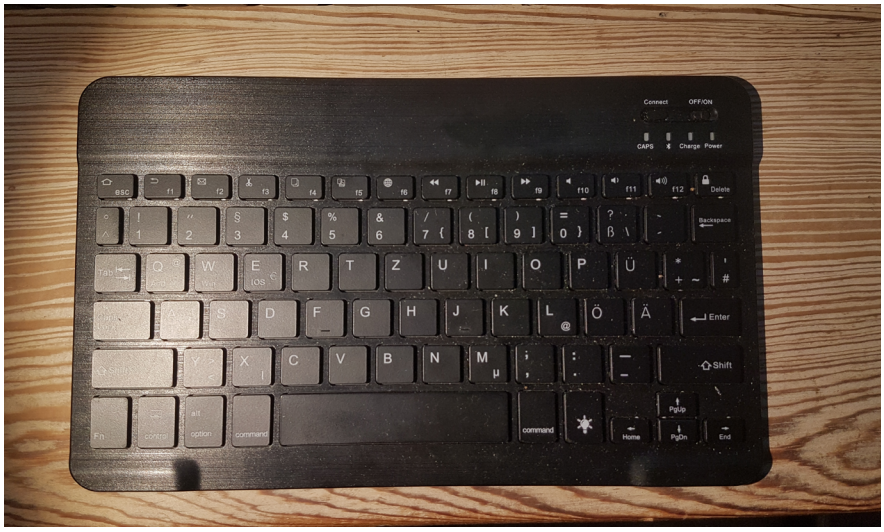


Figure A51: One of the keyboards ordered at Ali-express.com

Figure A52: One of the keyboards ordered at Ali-express.com

excellent connectivity, battery life and type comfort. This was found out by buying the product and testing it for several weeks to make sure the product did exactly what it was supposed to do. Another large benefit was the design of the keyboard that fitted very nicely into the design of the laptop stand. As nothing else in the market comes close to this keyboard in terms of dimensioning in combination with battery life and type comfort this keyboard was chosen.

Even though the keyboard was the best option, it was not entirely perfect as it is actually 10 mm too wide. Additionally it is quite an expensive keyboard at € 79,99. This means a significant increase in market price for the entire laptop stand.

In the perfect situation Standivarius is willing to make a new product in which they move the battery, charging port and blue-tooth connector to the top of their laptop instead of the side. This would completely solve any issue there currently is. This scenario however is only remotely likely if the laptop stand is selling incredibly well and we can promise to buy at least a certain number of products from them. Another solution is to simply make the laptop stand 10mm wider. This would mean it does not perfectly fit underneath the laptop but the excess width could be used for the laptop cover to attach to, providing sideways protection as well.

A third solution is to temporarily use a keyboard that is less well from a Chinese manufacturer.

Final Design

Having decided to use the Standivarius Solo X keyboard which outperforms its competition easily, the first batch of laptop stands will be made a little wider than the laptop that is placed upon it.

For prototyping purposes a Chinese keyboard that fitted perfectly will be used. The disadvantage of this keyboard, and one the reasons why it cannot be used otherwise, is a huge bulky bar at the bottom used for 2 AA batteries. For a single prototype it is possible to completely remove this bar and add some Lithium Ion batteries as shown in figure A53.

With regards to the locking, or clamping of the keyboard in its place, two tiny neodymium magnets will be used. With a light nudge it will unlock the keyboard, allowing the be placed wherever the user want. With the same ease, the keyboard will snap into its position once the magnets are aligned again.

Validation

The functioning of the keyboard itself has been tested through the use of the keyboard during the graduation project. During that time I have really come to like it and it has never failed in connectivity issues. On average the keyboard had to be recharged for about an hour every two weeks, which in my opinion is very acceptable.

Testing the magnets was done with magnets from supermagnete.com in the final prototype (figure A53). By using 4 magnets (2 on the keyboard and two in the laptop stand) of 1*1*2 mm the keyboard could lift its own weight and had a distinctive click when placed back.

It was also tested if the magnets would interfere with the bluetooth connectivity. Additionally, since Li-Ion batteries consist of Lithium, an alkali metal, it is non magnetic. The Carbon inside a Li-Ion battery is Propylene carbonate, which is an organic carbon mixture, and is classified under low grade magnetic field. This means that consumer grade magnets will not affect it.

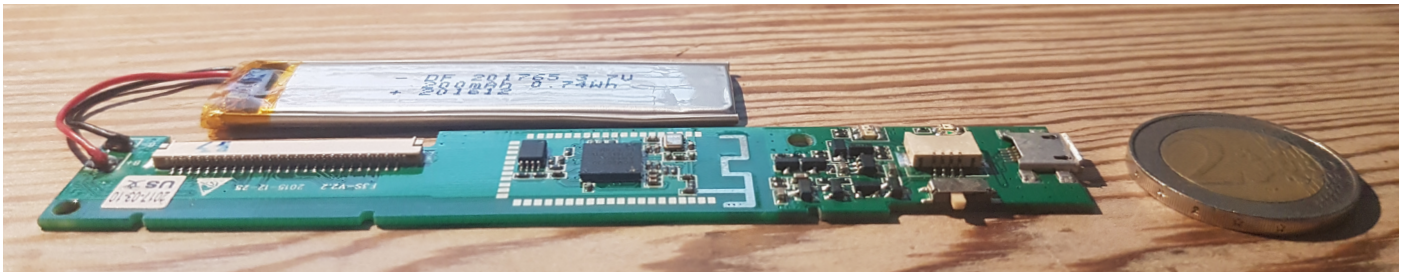


Figure A53: Electronics required for a keyboard

Appendix 22

Prototyping

Prototyping

Figure A57 shows what has been my daily workplace for quite a while. Figure A55 shows the machining of a component for the locking mechanism. This was all done by “hand”. Due to small tools and the relative hardness of metals this was a very tedious and meticulous task. Often having to go up and down the slider up to 45 times reducing the thickness by 0.3-0.5 mm each time. Even thought CNC machines can do this much quicker than I ever can it still provides a very clear understanding of how much tooling is actually required for certain parts. At this point, the construction plate also had

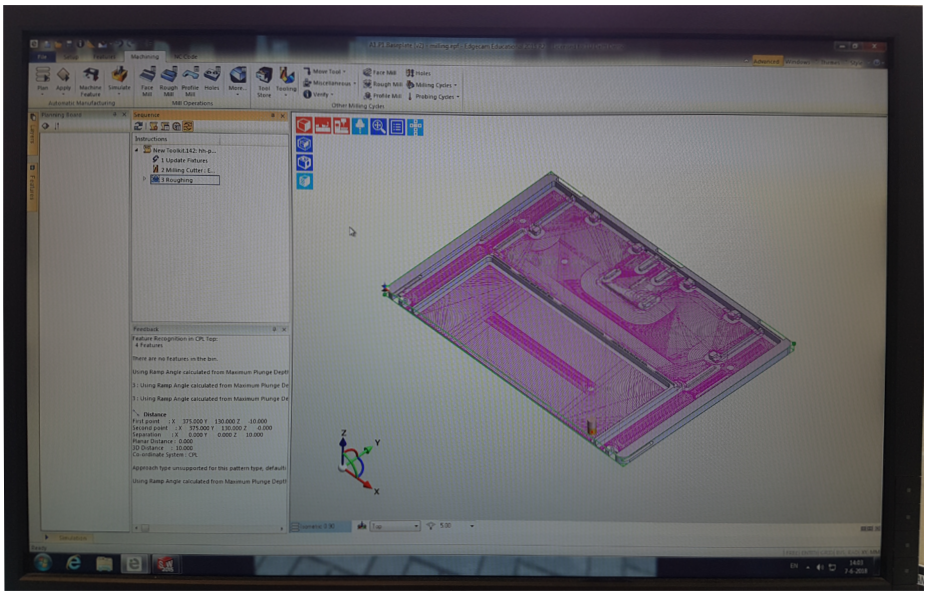


Figure A54: CNC pathing animation of base plate

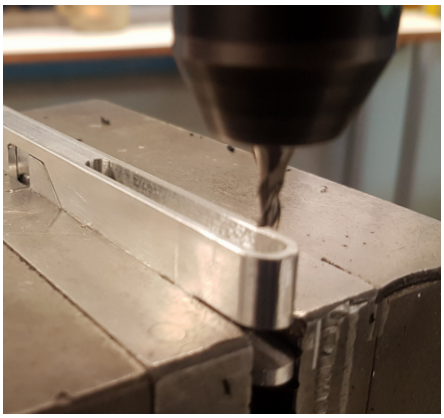


Figure A55: Milling the locking mechanism

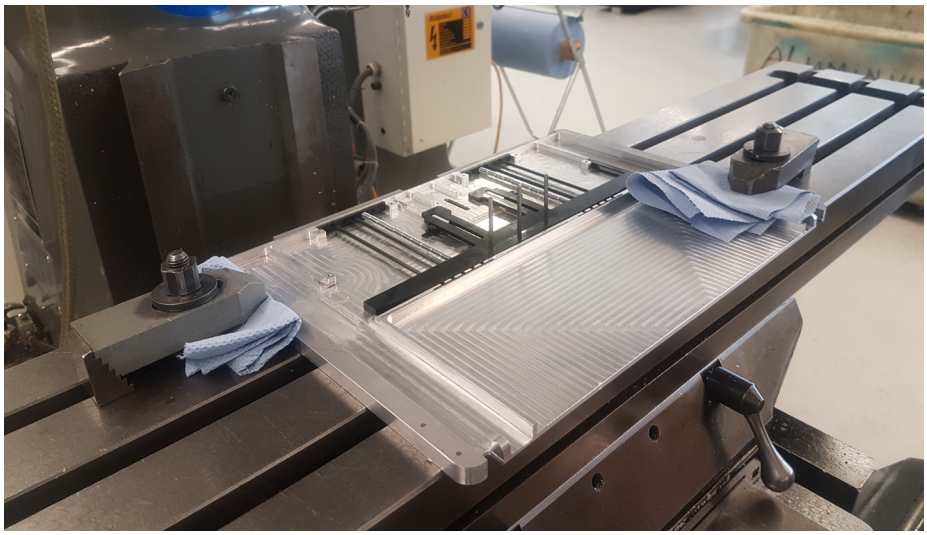


Figure A56: Base plate finetuning

Figure A57: First attempt of assembly

Figure A58: Aluminum plate in CNC machine

various radius throughout the design which caused me to switch tools regularly which is very time consuming, even more so for CNC machines that do not have an automatic tool switch. From a design perspective it was perfectly possible to change the radius to all be the same.

Figure A57 is where the assembly starts and where tolerances started to play a very important role. Intuitively you think that a 10th of a millimetre is neglectable amount of material but when working with metals it is super crucial. For example, the amount of time required to remove a tiny production error in the CC machine during the turnover of the product resulted in many hours of sanding while never reaching the right tolerances. By experiencing how important the right tolerances are, the extra effort you have to put in the correctly tolerance your computer model suddenly goes with ease.

Figure A59: Overview of workplace

Appendix 23

Comparing lifting force

A comparison between the expected upwards force of the spring damper system vs the measured results.

Set-up

The expected lifting force of the prototype has been adjusted to exactly the springs used in the prototype. These were slightly adjusted to the ones designed for the final iteration but due to some production flaws in the prototype not every spring could be properly placed.

The lifting force from the prototype has been measured with a digital force meter between the two end points of the long slider. This resulted in the measurements as shown in table A5 and graph A60.

Results

In general the graphs largely correspond with each other after slot position 5. The lifting force below that slot position was surprising large and did not add up with any calculation that were made.

By further inspecting what exactly happens during the first few mm, it is expected that the torsion springs get slightly compressed at the bending point [1] which causes unrealistic high resistance to bounce back. This is likely caused by a the rounded edge which the torsion spring is supposed to fold around [2].

At the end the force in the test model also slightly exceed the expected force but this is much easier to explain as the theoretical model assumes a negative force from the torsion spring after slot position 15, while in reality the torsion spring just hangs in the air, not applying pressure anywhere.

Overall, the force in the prototype seems to be slightly lower than in the mathematical model which can be explained by unaccounted friction and the use of the two small rotary dampers.

Figure A60: Lifting force vs slot position, theory and practice

Prototype: Expectations vs reality							
Calculating expected upwards spring force							
Slot position	**Angle slider 1 (AS1)** (degrees)	**Angle slider 2 (AS2)** (degrees)	**Torsion spring 1 - Lifting force (N)**	**n.v.t**	**Linear spring 4 - Lifting force (N)**	**Expected maximum lifting force for two sliders (N)**	**Measured results**
As indicated in figure $$			2* (C1 * (FOR1 - AS1)) / r1		NOS*((C3*(TD-SP))*sin(SA1))	2 * (TS1 + TS 2 + LS)	
0	0	0	4.88	0.00	0.00	9.76	20.00
0.1	1.6	2.4	4.48	0.00	0.94	10.83	16.04
0.25	2.6	3.7	4.24	0.00	1.52	11.53	15.56
0.5	3.6	5.3	3.98	0.00	2.10	12.15	15.00
1	5.1	7.4	3.61	0.00	2.95	13.12	14.80
2	7.2	10.4	3.09	0.00	4.10	14.38	14.60
3	8.8	12.8	2.69	0.00	4.93	15.23	14.40
4	10.2	14.8	2.34	0.00	5.62	15.92	14.21
5	11.3	16.6	2.04	0.00	6.13	16.34	14.08
10	16.1	23.6	0.84	0.00	8.00	17.70	15.40
15	19.6	29.1	-0.07	0.00	8.87	17.61	15.23
20	22.6	33.9	-0.86	0.00	9.24	16.76	15.18
25	25.2	38.2	-1.57	0.00	9.22	15.30	14.06
30	27.5	42.1	-2.20	0.00	8.88	13.37	12.82
35	29.6	45.8	-2.79	0.00	8.32	11.06	11.40
38	31	47.9	-3.14	0.00	7.93	9.57	10.42

Spring design	**Abbreviation**	**Torsion spring 1 (TS1)**	**Torsion spring 2 (TS2)**	**Linear spring (4) (LS)**
Outer diameter (mm)	OD	8.0	8.0	6.0
Wire thickness (mm)	WT	1.5	1.5	0.8
Active coils	AC	5.7	3.8	135.0
Resulting in				
Spring constant (Nmm/deg)	C	8.9	11.8	
Freedom of rotation (degrees)	FOR	48	37	
Spring constant (N/mm)	C			0.481
Travel distance (mm)	FOR			70
Number of spring	NOS			1

Arm length	**length (mm)**
r1	0.175
r2	0.200

Table A5: Final prototype and measured results

Conclusion

The theoretic model seems to give a very good indication of the actual lifting force of the laptop stand. The differences can be accounted for and solved with slight adjustment in either the design of the sliders or the springs.

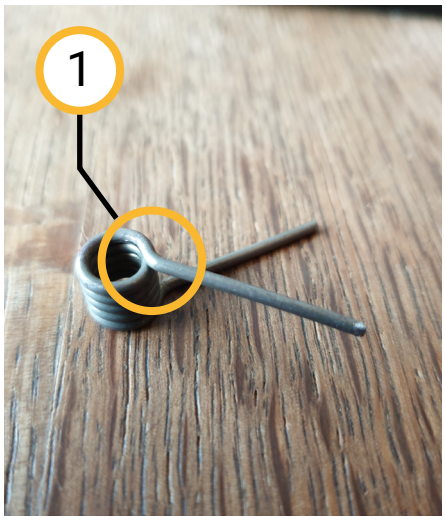


Figure A62: Milling the locking mechanism

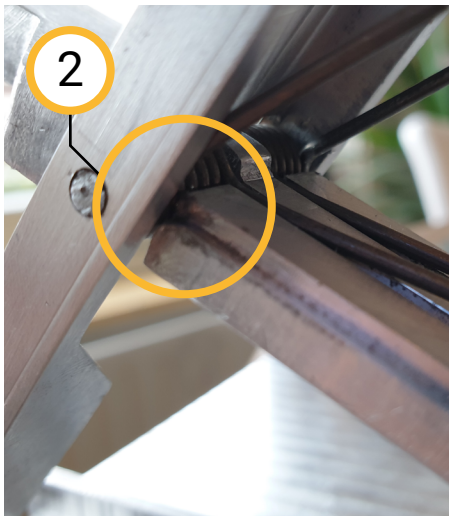


Figure A63: Milling the locking mechanism

Appendix 24

Part list and cost price

In this chapter an overview of all parts is made and an indication of cost price is composed based on the production of 100 models.

Cost price

The cost price as written in table A6 is based on the following:

- Prices of standard parts are derived from corresponding websites.
- Prices of materials are derived from CES whenever applicable.
- For CNC machinging the volume of the material is used rather than the weight to determine the price. The rest material could be recycled but is unrealistic to be profitable with a small production number.
- CNC machining and anodizing is quoted by a chinese manufacturer (Ego-mfg group). The prices are an indication by one of their engineers.
- The prices of the springs are discussed with Roveron.

Assembly time is estimated at 15 minutes per product and €32,00 per hour.

Storage, transport and overhead costs are excluded from the table as they are difficult to determine and are unlikely to make or break the cost price.

Conclusion

Based on this indication it seems to be impossible to stay under a cost price of € 80,00 considering a first production batch of 100. Especially since there is absolutely no margin for error in the current estimate and it is expected another 20% will be added to cost price.

As the cost price does not exceed the €80,00 mark by a very large margin it could be considered to take a smaller profit on the first batch of products and aim to lower production cost for larger batches. A definitive decision on this matter has not been made yet.

Cost price indication for 100 laptop stands								
	#	Material	Material cost (€ / m3)	Material cost per part	Machining cost	Part cost (standard)	Total cost	Details
Base plate								
Base plate	**1**	Aluminium 6083-T6	€4,500.00	€3.16	€30.85		€34.01	Ego Mfg Group
Top plate	1	Aluminium 6083-T6	€4,500.00	€0.63	€3.00		€3.63	Ego Mfg Group
3x6 hexagon bolts	14	Stainless steel				€0.01	€0.17	Fabory
Slider axle support	2	POM	€1,441.00	€0.01	€0.50		€1.02	
Slider system								
Short slider left	1	Aluminium 6083-T6	€4,500.00	€0.20	€4.56		€4.76	Ego Mfg Group
Short slider right	1	Aluminium 6083-T6	€4,500.00	€0.20	€4.56		€4.76	Ego Mfg Group
Long slider left	1	Aluminium 6083-T6	€4,500.00	€0.27	€6.12		€6.39	Ego Mfg Group
Long slider right	1	Aluminium 6083-T6	€4,500.00	€0.27	€6.12		€6.39	Ego Mfg Group
Torsionspring left (mid)	2	Music Wire ASTM A228				€0.35	€0.70	Roveron
Torsionspring right (mid)	2	Music Wire ASTM A228				€0.35	€0.70	Roveron
Torsion spring left (bottom)	2	Music Wire ASTM A228				€0.30	€0.60	Roveron
Torsion spring right (bottom)	2	Music Wire ASTM A228				€0.30	€0.60	Roveron
40x3 axle	2	Stainless steel				€0.17	€0.33	Fabory
24x3 axle	2	Stainless steel				€0.10	€0.19	Fabory
Linear spring	4	Music Wire ASTM A228				0.2	€0.80	Roveron
Rotary damper	2	n.v.t.				€1.00	€2.00	Acecontrols
Distance tube	4	Plastic				€0.02	€0.08	Fabory
Stability slider	1	Aluminium 6083-T6	€4,500.00	€0.27	€3.00		€3.27	CNC only
Connector linear spring	4	POM					€0.00	Lasercut
145x4 axle	4	Carbon				€0.20	€0.80	Conrad
Front grip								
Front grip casing	2	HDPE	€4,500.00	€0.01	€2.00		€4.02	Ego Mfg Group
Front grip rubber	2	Sillicone rubber		€0.05	€0.10		€0.31	Cutting
Front grip cover	2	HDPE	€1,380.00	€0.00			€0.00	Cutting
Front grip magnet	4					€0.22	€0.88	Supermagnete.com
Torsion spring left	1	Music Wire ASTM A228				€0.30	€0.30	Roveron
Torsion spring right	1	Music Wire ASTM A228				€0.30	€0.30	Roveron
12x3 axle	2	Stainless steel				€0.07	€0.13	Fabory
Distance tube	2	Plastic				€0.02	€0.04	Fabory
Locking mechanism								
Restriction bar	2	Aluminium 6083-T6	€4,500.00	€0.05	€1.00		€2.11	Ego Mfg Group
Cap	2	HDPE	€1,380.00	€0.00	€1.00		€2.00	Ego Mfg Group
24*3 axle	2	Stainless Steel				€0.10	€0.19	Fabory
Height adjustment								
Locking bar	1	HDPE / POM	€1,380.00	€0.04	€2.00		€2.04	Lasercutting
Twister	1	HDPE	€1,380.00	€0.00	€0.50		€0.50	Ego Mfg Group
5*6 hexagon bolt	1	Stainless Steel				€0.03	€0.03	Fabory
Locking nut	1	Stainless Steel				€0.25	€0.25	Fabory
Assembly							€8.00	
Total							**€92.30**	

Table A6: Cost price

Appendix 25

Tolerances table

Tables A7 and A8 show the common and possible tolerances of different machining operations.

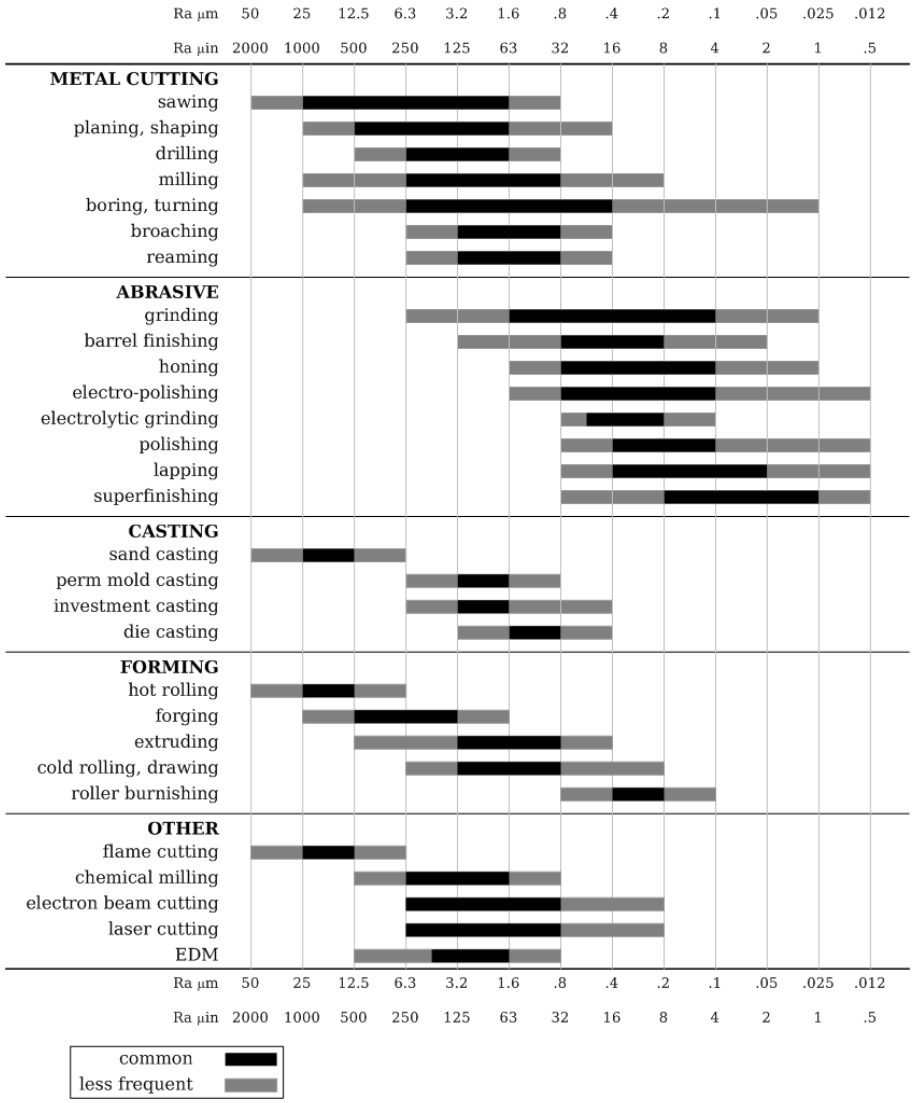


FIGURE 15.10. Surface finish produced by various processes. **(Source: Wikipedia)**

Table A7: Operation tolerances

http://www2.mae.ufl.edu/designlab/Lab%20Assignments/EML2322L-Tolerances.pdf

ISO Tolerances for Shafts (ISO 286-2)																				
Nominal Shaft Sizes (mm)																				
over	3	6	10	18	30	40	50	65	80	100	120	140	160	180	200	225	250	280	315	355
inc.	6	10	18	30	40	50	65	80	100	120	140	160	180	200	225	250	280	315	355	400
micrometres																				
a12	-270 -390	-280 -430	-290 -470	-300 -510	-310 -560	-320 -570	-340 -640	-360 -660	-380 -730	-410 -760	-460 -860	-520 -920	-580 -980	-660 -1120	-740 -1200	-820 -1280	-920 -1440	-1050 -1570	-1200 -1770	-1350 -1920
d6	-30 -38	-40 -49	-50 -61	-65 -78	-80 -96		-100 -119		-120 -142		-145 -170			-170 -199			-190 -222		-210 -246	
e6	-20 -28	-25 -34	-32 -43	-40 -53	-50 -66		-60 -79		-72 -94		-85 -110			-100 -129			-110 -142		-125 -161	
e13	-20 -200	-25 -245	-32 -302	-40 -370	-50 -440		-60 -520		-72 -612		-85 -715			-100 -820			-110 -920		-125 -1015	
f5	-10 -15	-13 -19	-16 -24	-20 -29	-25 -36		-30 -43		-36 -51		-43 -61			-50 -70			-56 -79		-62 -87	
f6	-10 -18	-13 -22	-16 -27	-20 -33	-25 -41		-30 -49		-36 -58		-43 -68			-50 -79			-56 -88		-62 -98	
f7	-10 -22	-13 -28	-16 -34	-20 -41	-25 -50		-30 -60		-36 -71		-43 -83			-50 -96			-56 -108		-62 -119	
g5	-4 -9	-5 -11	-6 -14	-7 -16	-9 -20		-10 -23		-12 -27		-14 -32			-15 -35			-17 -40		-18 -43	
g6	-4 -12	-5 -14	-6 -17	-7 -20	-9 -25		-10 -29		-12 -34		-14 -39			-15 -44			-17 -49		-18 -54	
g7	-4 -16	-5 -20	-6 -24	-7 -28	-9 -34		-10 -40		-12 -47		-14 -54			-15 -61			-17 -69		-18 -75	
h4	-0 -4	-0 -4	-0 -5	-0 -6	-0 -7		-0 -8		-0 -10		-0 -12			-0 -14			-0 -16		-0 -18	
h5	-0 -5	-0 -6	-0 -8	-0 -9	-0 -11		-0 -13		-0 -15		-0 -18			-0 -20			-0 -23		-0 -25	
h6	-0 -8	-0 -9	-0 -11	-0 -13	-0 -16		-0 -19		-0 -22		-0 -25			-0 -29			-0 -32		-0 -36	
h7	-0 -12	-0 -15	-0 -18	-0 -21	-0 -25		-0 -30		-0 -35		-0 -40			-0 -46			-0 -52		-0 -57	
h8	-0 -18	-0 -22	-0 -27	-0 -33	-0 -39		-0 -46		-0 -54		-0 -63			-0 -72			-0 -81		-0 -89	
h9	-0 -30	-0 -36	-0 -43	-0 -52	-0 -62		-0 -74		-0 -87		-0 -100			-0 -115			-0 -130		-0 -140	
h10	-0 -48	-0 -58	-0 -70	-0 -84	-0 -100		-0 -120		-0 -140		-0 -160			-0 -185			-0 -210		-0 -230	
h11	-0 -75	-0 -90	-0 -110	-0 -130	-0 -160		-0 -190		-0 -220		-0 -250			-0 -290			-0 -320		-0 -360	
h12	-0 -120	-0 -150	-0 -180	-0 -210	-0 -250		-0 -300		-0 -350		-0 -400			-0 -460			-0 -520		-0 -570	
j5	+3 -2	+4 -2	+5 -3	+5 -4	+6 -5		+6 -7		+6 -9		+7 -11			+7 -13			+7 -16		+7 -18	
j6	+6 -2	+7 -2	+8 -3	+9 -4	+11 -5		+12 -7		+13 -9		+14 -11			+16 -13			+16 -16		+18 -18	
j7	+8 -4	+10 -5	+12 -6	+13 -8	+15 -10		+18 -12		+20 -15		+22 -18			+25 -21			+26 -26		+29 -28	
js5	+2.5 -2.5	+3 -3	+4 -4	+4.5 -4.5	+5.5 -5.5		+6.5 -6.5		+7.5 -7.5		+9 -9			+10 -10			+11.5 -11.5		+12.5 -12.5	
js6	+4 -4	+4.5 -4.5	+5.5 -5.5	+6.5 -6.5	+8 -8		+9.5 -9.5		+11 -11		+12.5 -12.5			+14.5 -14.5			+16 -16		+18 -18	
js7	+6 -6	+7.5 -7.5	+9 -9	+10.5 -10.5	+12.5 -12.5		+15 -15		+17.5 -17.5		+20 -20			+23 -23			+26 -26		+28.5 -28.5	
k5	+6 +1	+7 +1	+9 +1	+11 +2	+13 +2		+15 +2		+18 +3		+21 +3			+24 +4			+27 +4		+29 +4	
k6	+9 +1	+10 +1	+12 +1	+15 +2	+18 +2		+21 +2		+25 +3		+28 +3			+33 +4			+36 +4		+40 +4	
k7	+13 +1	+16 +1	+19 +1	+23 +2	+27 +2		+32 +2		+38 +3		+43 +3			+50 +4			+56 +4		+61 +4	
m5	+9 +4	+12 +6	+15 +7	+17 +8	+20 +9		+24 +11		+28 +13		+33 +15			+37 +17			+43 +20		+46 +21	
m6	+12 +4	+15 +6	+18 +7	+21 +8	+25 +9		+30 +11		+35 +13		+40 +15			+46 +17			+52 +20		+57 +21	
m7	+16 +4	+21 +6	+25 +7	+29 +8	+34 +9		+41 +11		+48 +13		+55 +15			+63 +17			+72 +20		+78 +21	
n5	+13 +8	+16 +10	+20 +12	+24 +15	+28 +17		+33 +20		+38 +23		+45 +27			+51 +31			+57 +34		+62 +37	
n6	+16 +8	+19 +10	+23 +12	+28 +15	+33 +17		+39 +20		+45 +23		+52 +27			+60 +31			+66 +34		+73 +37	
n7	+20 +8	+25 +10	+30 +12	+36 +15	+42 +17		+50 +20		+58 +23		+67 +27			+77 +31			+86 +34		+94 +37	
p5	+17 +12	+21 +15	+26 +18	+31 +22	+37 +26		+45 +32		+52 +37		+61 +43			+70 +50			+79 +56		+87 +62	
p6	+20 +12	+24 +15	+29 +18	+35 +22	+42 +26		+51 +32		+59 +37		+68 +43			+79 +50			+88 +56		+98 +62	
r6	+23 +15	+28 +19	+34 +23	+41 +28	+50 +34		+60 +41	+62 +43	+73 +51	+76 +54	+88 +63	+90 +65	+93 +68	+106 +77	+109 +80	+113 +84	+126 +94	+130 +98	+144 +108	+150 +114

Table A7: ISO tolerances

http://www.tribology-abc.com/calculators/iso_shafts.htm

Appendix 26

Branding and positioning

The posters on the next page are the results from the students of the cours BCP.

When a Ruler personality?

- High-status product used by powerful people to enhance their power
- Product that helps people be more organized
- Product or service that can offer a lifetime guarantee
- Services that offer technical assistance or information that helps maintain or enhance power
- Organization with regulatory or protective function
- Product at the moderate to high price range
- Brand seeking to differentiate from a more populist one or that is the clear leader in the field
- Field that is relatively stable or a product that promises safety and predictability in a chaotic world

When a Creator personality?

- If your product's function encourages self-expression, provides the customer with choices, helps foster innovation
- In a creative field, like marketing, the arts, technological innovation (such as software development)
- When a do-it-yourself element saves the customer money
- If your customers have enough discretionary time for creativity to flourish
- If your organization has a Creator culture

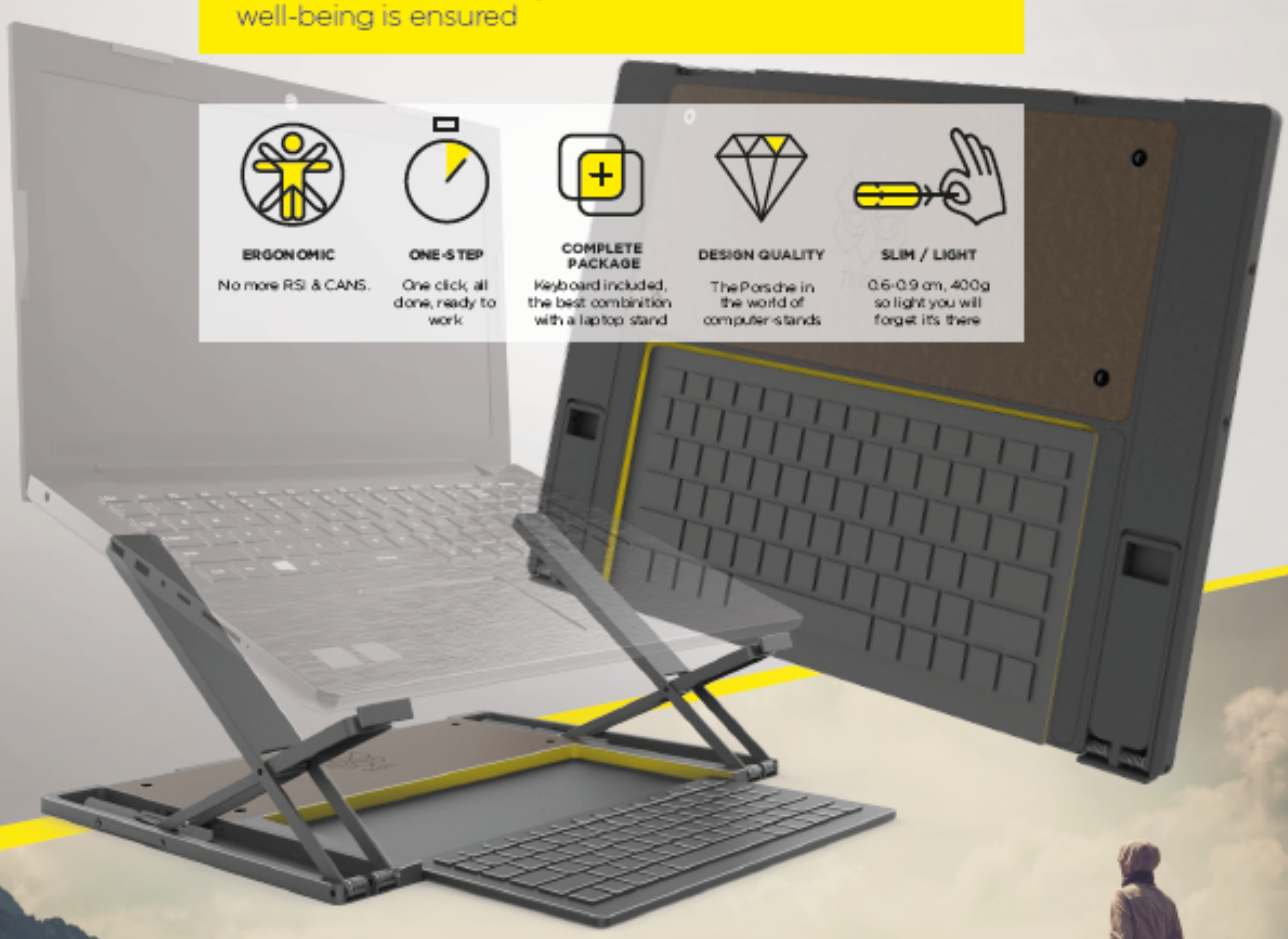
Mark & Pearson (2002)

THIGO

Work to live
Don't live to work

Be Wise, Work Smart.

We believe that employees perform the best when their well-being is ensured



ERGONOMIC
No more RSI & CANS.

ONE-STEP
One click, all done, ready to work

COMPLETE PACKAGE
Keyboard included, the best combination with a laptop stand

DESIGN QUALITY
The Porsche in the world of computer-stands

SLIM / LIGHT
0.6-0.9 cm, 400g so light you will forget it's there

Team 6 Jiun Tyng Dai - 4706498 • Jelle Dott - 437 2131 • Pip van Esch - 4397789 • Dan-Stefan Florescu - 4740653

''Unify believes that your workday should support your healthy lifestyle''

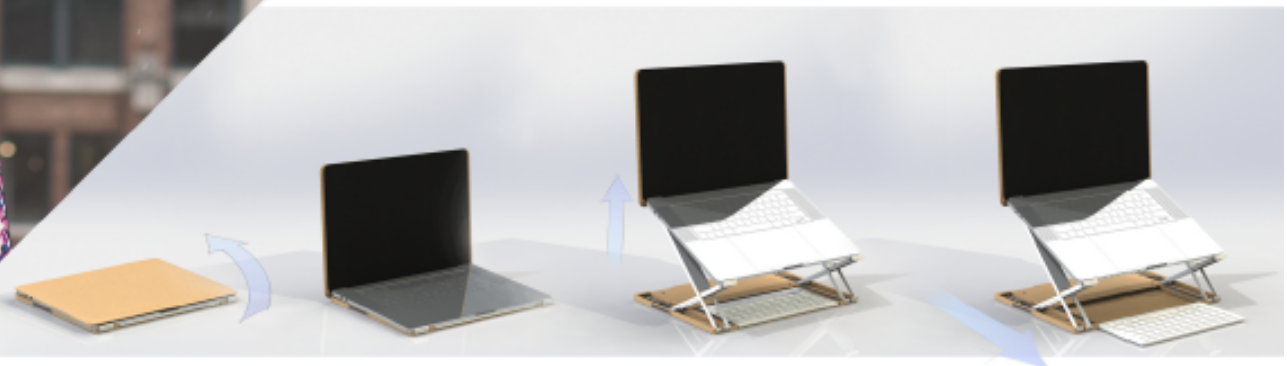
Healthy body is

Good exercise.
Good posture.

The efficient solution for being *ambitious* and *healthy* at once.

unify flex

For the ambitious healthy enthusiasts, Unify offers a sophisticated gadget that unfolds your workspace in one second, makes sure your hard work pays of by integrating your healthy lifestyle and gives people the power to become a part of the fit-spiration movement



unfolding your entire workspace in **one second**

group 29: Jens Hellewaard, Elsbeth Maas, Manon Schuurman & Puck Veelenturf

Unleash your full potential

LEGIT

Working with LEGIT's Uno, you experience the new working standard.
Uno is an all-in-one solution, so forget the hassle of carrying your own keyboard. Convert your MacBook Pro into a professional workstation. Get things done efficiently without any neck or back discomforts when using Uno, which is set with a push of a button.

Uno
WORKSTATION

WHAT'S IN THE BOX

LEGIT's Uno comes in a slick package, containing the laptop workstation and its integrated keyboard. The product fits nicely under your MacBook Pro 15" to create your flexible & mobile workstation, and is ready to use right out of the box.

PREMIUM FINISHES

You are able to personalise your LEGIT's Uno and make it more personal by choosing between oak wood or authentic leather designs. Pick the right colour that is matching your Macbook Pro and choose for your personal premium look.

HOW IT WORKS

LEGIT's Uno is comes with an efficient lockup system, that is adjustable to the correct eye level. Its special trigger makes your workstation unleash automatically.

Adjustable eye level
Select the height that fits you. Uno is freely adjustable.

Lockup system
The lock ring enables the system to rise automatically.