Application of composites in a bikecarrier.

Bachelor assignment by
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at
University of Twente, Cato Composite Innovations and Indes

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Preface

Before you lays my bachelor thesis. This thesis marks the end of the bachelor programme Industrial Design Engineering. The result of three years of training are put in this design project.
This assignment showed how it is to work with several companies on one project. It also let me see how design problems are dealt with in practice. Overall it was a great learning experience and not just a test of skill.
The project and this report is finished with the occasional helping hand. Therefore I would like to thank all people involved, at the UT, at Indes and at Cato their time and guidance.

Stef van den Bedem

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References

Samenvatting

Dit is de bachelor eindopdracht van Stef van den Bedem. Binnen een samenwerking tussen Universiteit Twente, Indes en Cato Composite Innovations is er gekeken of composiet toegepast kan worden in een fietsendrager.
Het doel is om een fietsendrager te ontwerpen die door gebruik van composiet tot de lichtere op de markt hoort. Als uitgangspunt dient een bestaand model fietsendrager die eerder is ontwikkelt door Indes: de MovaNext M3. De dragende delen worden herontworpen. Alle componenten die hiermee verbonden zijn worden herzien tot het niveau dat blijkt dat de onderdelen werken met de composieten dragende constructie.
De nadruk ligt op stijfheid en sterkte van de dragende delen, productie en assemblage waarbij verbindingen tussen verschillende materialen ook een rol spelen. Daarnaast komen gebruik en vormgeving ook aan bod. Verbeteringen om eenvoudiger zware (elektrische) fietsen te kunnen plaatsen op de fietsendrager worden toegepast. De vormgeving is er op gericht om het lichte gewicht te communiceren en om het product te laten opvallen binnen de markt.

Het uiteindelijke ontwerp uit glasvezel versterkte nylon is sterk en stijf genoeg om fietsen op te vervoeren. De materiaal diktes die nodig zijn om dit te bereiken zorgen voor een gewichts besparing ten opzichte van het bestaande ontwerp maar deze besparing blijft achter bij de verwachtingen.
De verbindingen en assemblage veroorzaken geen problemen. Sommige onderdelen worden nu verlijmt wat enige aanpassingen aan het assemblage process vereist. Ook is het aantal onderdelen toegenomen doordat de vormgeving lossing soms onmogelijk maakt zodat een component in tweeën gedeeld moest worden.
Het gebruiksgemak is licht toegenomen. Hier en daar zijn kleine aanpassingen gedaan om dit mogelijk te maken. Doordat het bevestigings mechanisme tussen de drager en de trekhaak behouden moest blijven zijn radicale veranderingen niet mogelijk.
Het feit dat de drager uit platen composiet wordt opgebouwd zorgt ervoor dat de fietsendrager altijd massief blijft. Dit geeft echter wel ruimte om veel storende details weg te werken. Uiteindelijk is er een zakelijk, rustige en strakke vormgeving tot stand gekomen.

Het nieuwe ontwerp is een verbetering ten opzichte van het bestaande ontwerp maar doordat het gewichts criterium niet is gehaald is het onzeker of dit het beste is opvolger is voor de MovaNext M3.

Abstract

This is the bachelor final assignment of Stef van den Bedem. In co-operation between the University of Twente, Indes and Cato Composite Innovations, there is explored wheter or not composites can be succesfully used in a bikecarrier.
The goal is to design a bike carrier that stands out from the market due to its low weight. The existing MovaNext M3 bike carrier that was develloped by Indes is used as the base. The load bearing components will be redesigned in composite. Other components are revised up to the level that it can be assumed that they will work properly with the load bearing structure.
The emphasis is on the stiffness and strength of the composite parts, production and assembly including joints between different materials. Usability and appearance will also be adressed. Ease of use must be improved by making isteasier to place heavy (electric) bikes. The aim for the new appearance are communicating the light weight of the product and letting the product stand out in the market.

The final design has sufficient strength and stiffness to carry bikes. However material thicknesses needed to achieve this restrict the weight loss. The new design is lighter than its predecessor but not as light as it should be.
Assembly does not create any problems. Although the assembly process must be adapted to glueing some products instead of using fasteners. The number of parts is increased because some components had to be split to avoid draft issues.
Usability is improved slightly. Some enhancements are made but revolutionary chances could not be made because the locking mechanism between the carrier and the towbar needed to be preserved.
The sheets of composite close the shape of the carrier completely. Although this does not improve its apperant weight, it makes it possible to hide disruptive details. A calm, sleek and efficient look is achieved.

The new design is an improvement over its predecessor. However, the limited weight loss make it uncertain if this is the best successor of the MovaNext M3

Prephase

Prephase set up

The first phase of this design project focuses on analyzing the problem and getting an impression of what things influence the project. This is done by looking at the current market, the consumer, the current design, production technologies and materials. This results in design requirements.

Startup

The MovaNext M3 is the basis for this Bachelor Assignment. The goal is to reduce the weight and improve the appearance of this bike carrier. The first can be achieved by applying composite materials. Composite materials can have several forms but will most likely be fibre reinforced plastics in this project. Industrial product development agency Indes is also working on a two MovaNext successors and Cato Composite Innovations advices on the use and production processes of any composite parts. Both companies w

The emphasis of the evaluation of all components will be on weight saving although small changes to enhance the use can be made.

The clamping mechanism that is used to mount the bike carrier on the tow bar is patented and one of the unique selling points of the MovaNext carriers. Therefore this clamping mechanism will not be altered.

The larger components that remain are the light units, the pillar and the wings that actually carry the bicycles. Indes is working on new light units, which leaves the wings and pillar to achieve the weight loss. This project will be focused on the wings of the bike carrier and integrating components in the wings if possible. The integration should lead to weight reduction and also help reducing visual noise. The appearance of the new MovaNext should communicate lightness. By reducing the number of small visible components and using the right shapes a clean, sleek look should be created.

Figure 1 Clamping mechanism, pillar and wing with lightunits

Prephase

Market research

The identified competition was the same as the competition identified by Indes in appendix A. A weight at the bottom of the market should set it apart from the competition without becoming overpriced.
 tried to solve different problems showed in Figure 2. The looks of the competitors are compared in the design section.

All manufacturers deal with design problems in their own way but there are a lot of similarities, between the solutions. There are no solutions available that are significantly better than the ones used in the current product.

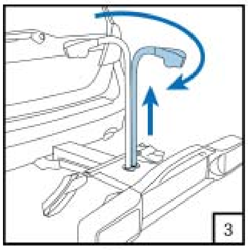
User input

Indes has tested the current model. The consumer feedback that can be useful in this project is:
- High force to unfold the wings and fixate on tow bar.
- The product does not give enough haptic feedback
- It is difficult to fold the wings neatly
- The appearance is complex
- The product is heavy

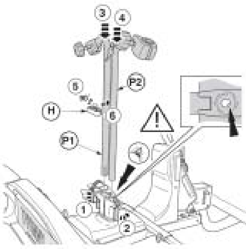
I also noticed the first three points while testing the MovaNext. Besides these points of improvement, consumers have other needs. Bike carrier should be able to carry an array of bike models. Two bikes need to be fastened rigidly. Heavy lifting should be avoided during placing of the carrier and the bikes. Ease of use with the least amount of actions.
The consumer is not the only user. Indes indicated that the MovaNext bike carriers are sold solely by bicycle dealers. The carrier is often a part of the sale of two bikes. As it is part of a sales process, it is important that a good in store demonstration can be given. Therefore the low number of handling steps, as mentioned in the consumer feedback, should be preserved.
Other users are the assembly workers and the logistics partner. At this moment subassemblies (light units, the steel frame, plastic components etc.) are assembled by hand. This should still be possible and can influence placing of screws and bolts. With regard to shipping it would be convenient that the components can be packed in boxes efficiently.

Goals for the new design set by the consumer are more

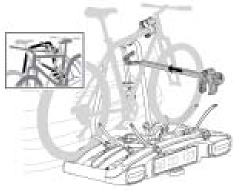
Pillar obstacle



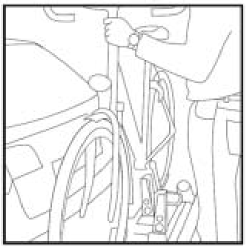
Rotating the arms out of the way



Remove the pillars

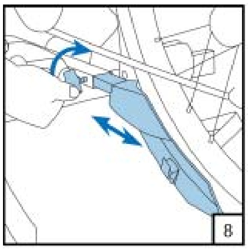


Remove the arms



Lift over lower obstacles

Fitting the wheels

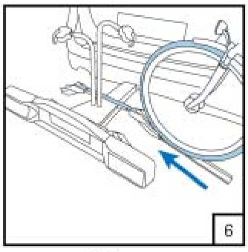


Adjusting the position of the supports

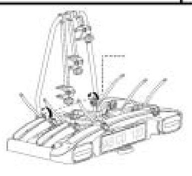
Pulling the bikes down on a round shape

Moving across the carrier

Moving the gutters together

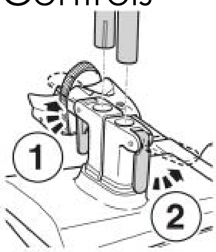


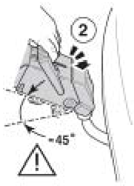
Ride across a beam between the supports



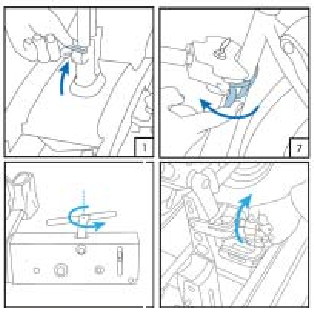
Use one large gutter per bike

Controls





Different knobs and handles



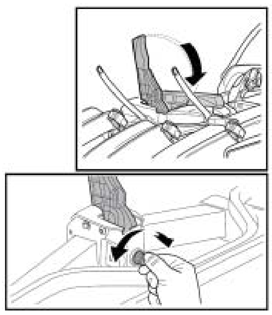


Figure 2 Solutions of other companies

feedback to the user and the number of actions to use the product should not increase. Furthermore, assembly and logistics should be taken into account where possible.

Design

The redesign of the MovaNext M3 creates the opportunity to improve its appearance. The new look should be sleeker and less complex. Indes uses the keywords: Consciousness, Efficiency, Technology, Status. Some thoughts on design examples are shown in appendix A.
Communicating the lightness of the new model is also important. The current product and the competition are compared on apparant weight and fuzziness to get a feel of what works and what does not. Figure 3 and Figure 4 show these comparisons and the area in which the new design should fit.
Figure 5 and Figure 6 give an overview of aspects that influence the apparent weight of other products. The design features in foldable bike and couch design could be translated to the design of the bike carrier. The length of the axis shows the importance of the aspect in the whole design. Reducing mass concentrations and opening products up so one can look through it are about the same and are used in different products so they have a high importance. Removing distracting components has a slightly higher importance because the complex look was mentioned as a negative by consumers. Fragility is also included and seems to contradict some of the other aspects. A light weight appearance looks less solid. The design should look as light as possible while still look strong enough to carry load. Research on colours in relation to the apparent weight of an object all indicate about the same (Wright, 1962). Black looks heaviest, then red and blue, followed by yellow and white. Less satured colours are considered heavier and dark colours are too. However in comparative tests were objects were lifted, the darker objects were evaluated as less heavy than the brighter counter part. Other research claims that hue is not as important as saturation where a low saturation, a greyish colour, appears lighter than a high saturation, a vibrant colour (Alexander & Shansky, 1976). The research results contradict eachother. Colours can probably be used best to blend smaller components in the background (the large components) or to make components that the user should interact with stand out from the rest of the product and not as a way to reduce the apparent weight.

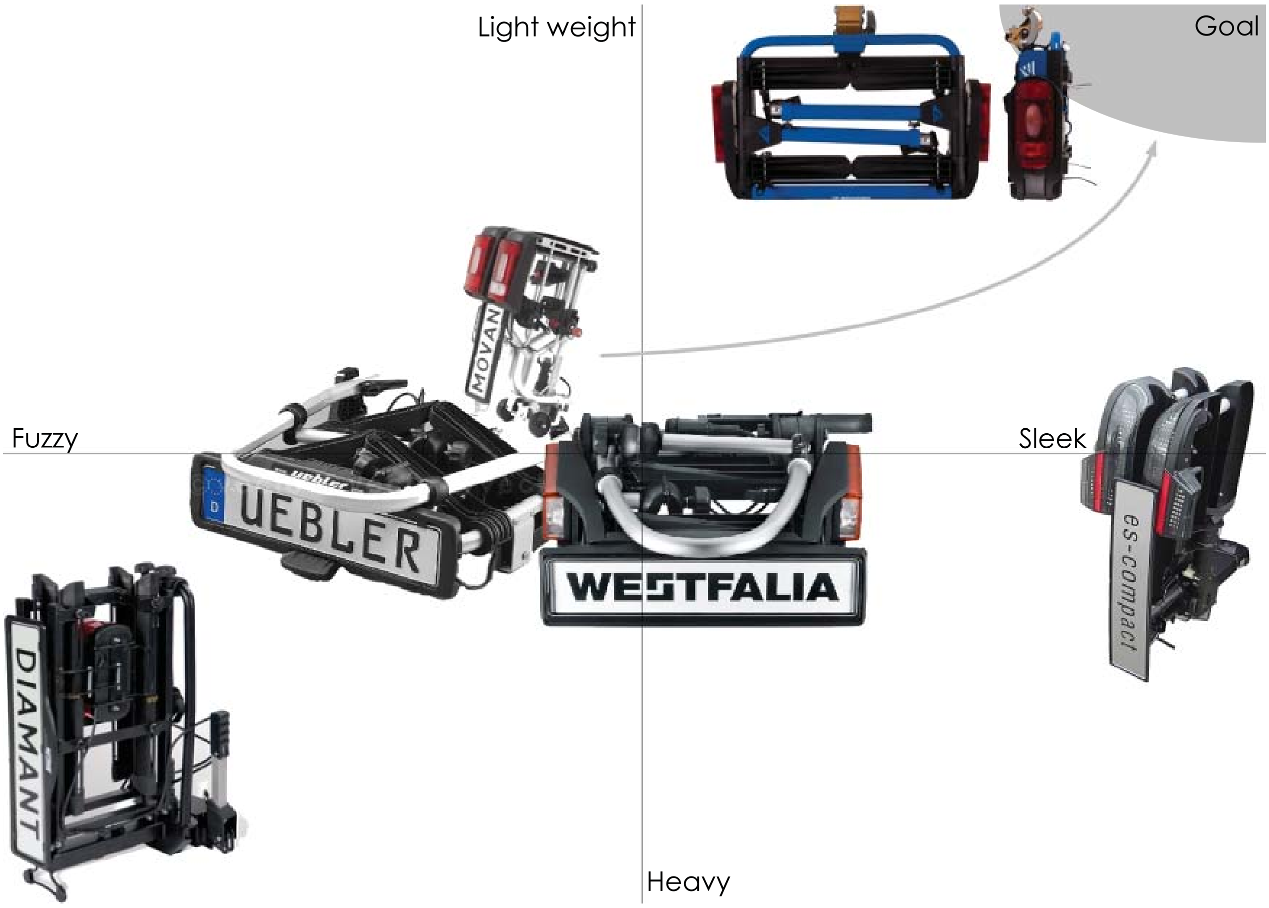


Figure 3 Design comparison between folded bikecarriers currently on the market.

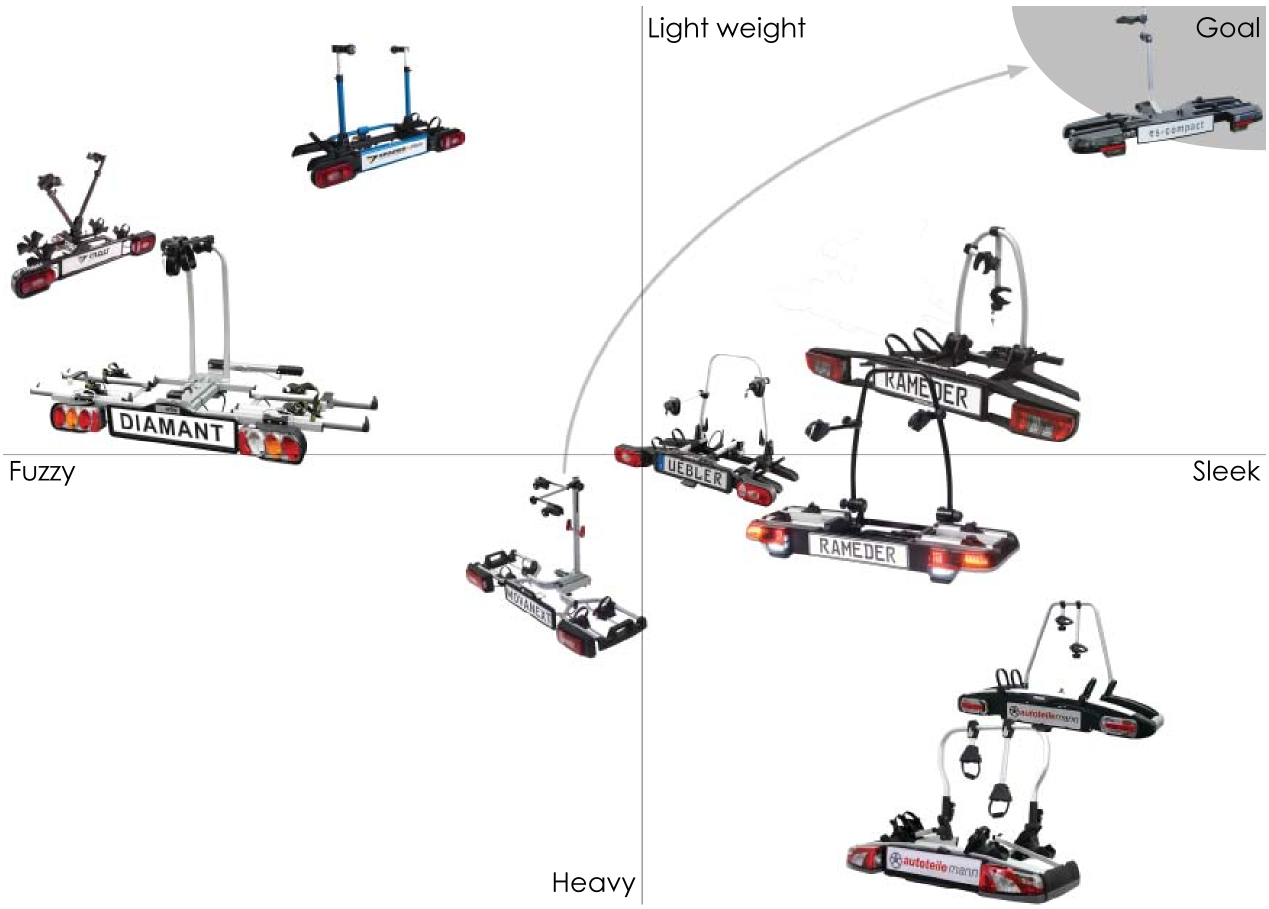


Figure 4 Design comparison between the products currently on the market.

Prephase

The direction of the new bike carrier's design is defined in keywords and the comparison of the competition. This can be achieved by following some of the design tricks found in other products. Lastly, colour can best be used to achieve sleek design and connect with the target group and not to influence the apparent weight of the product.

Figure 5 Lightweight and sleek design in foldable bicycles

Figure 6 Reducing apparent weight in couch design.

Materials

The wings are like two beams that are clamped at one end. They should be able to withstand vertical impacts as a car with a bike carrier will drive over some bumps, jolting the carrier up and down. A high yield strength is important to withstand the impacts and a high fatigue strength to withstand continious loads. To prevent elastic deformation, a high Young's modulus is necessary. Steel, as used in the current product, has those properties. When these three properties are plotted against density, which influences the weight of the product, the materials with approximately the same strength and Young's modulus with a lower density are composites, some ceramics and some metals. The results can be seen in Figure 7, Figure 8 and Figure 9. As the metals and ceramics perform poorer than composites, the focus will now be on fibre reinforced plastics. This is in line with the choices of Indes.

Weather inflences can become a problem but hard data on durability under wet circumstances and UV radiation are not available for all materials. However some classifications are available in the CES Edupackv2012 software. If the composites, in this case glass fibre with a PA6 or an epoxy matrix, are compared they show the same results. They score both excellent on resistance to fresh water which means that the materials do not

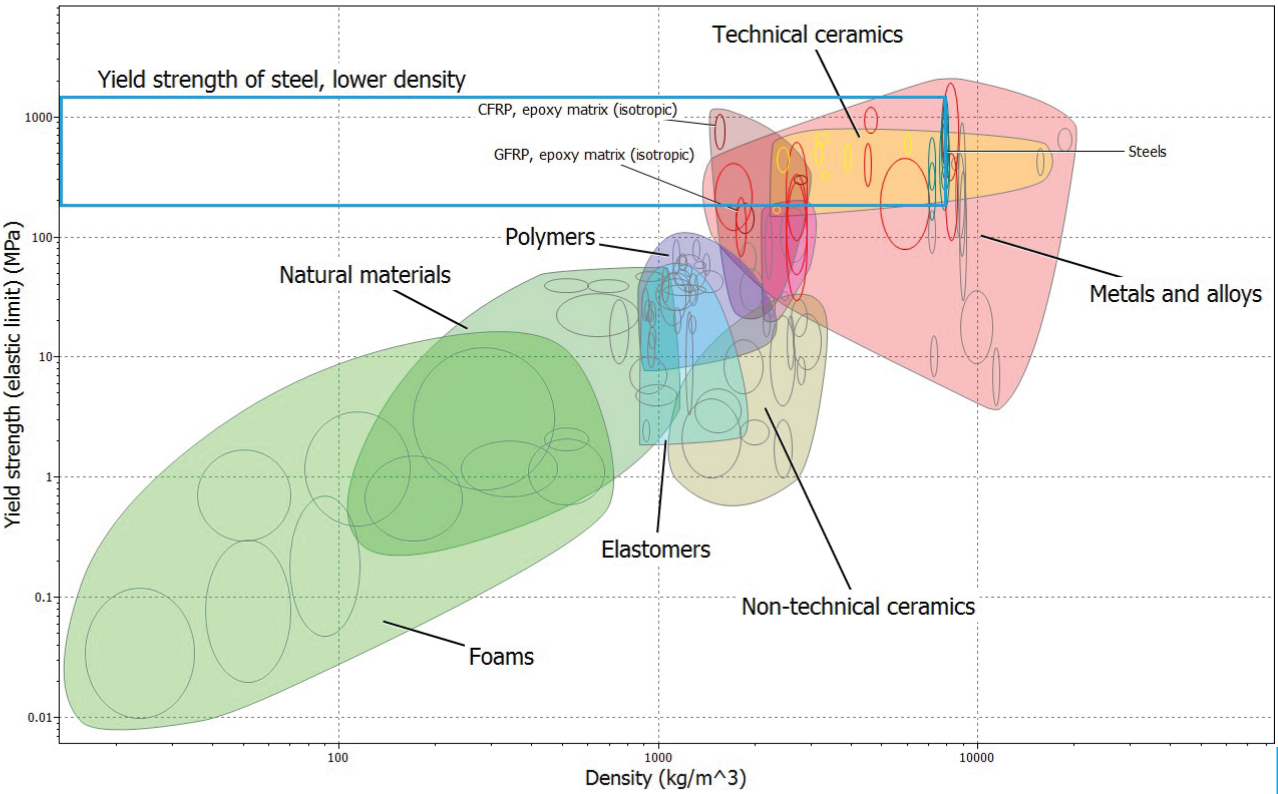


Figure 7 Density - Yield strength

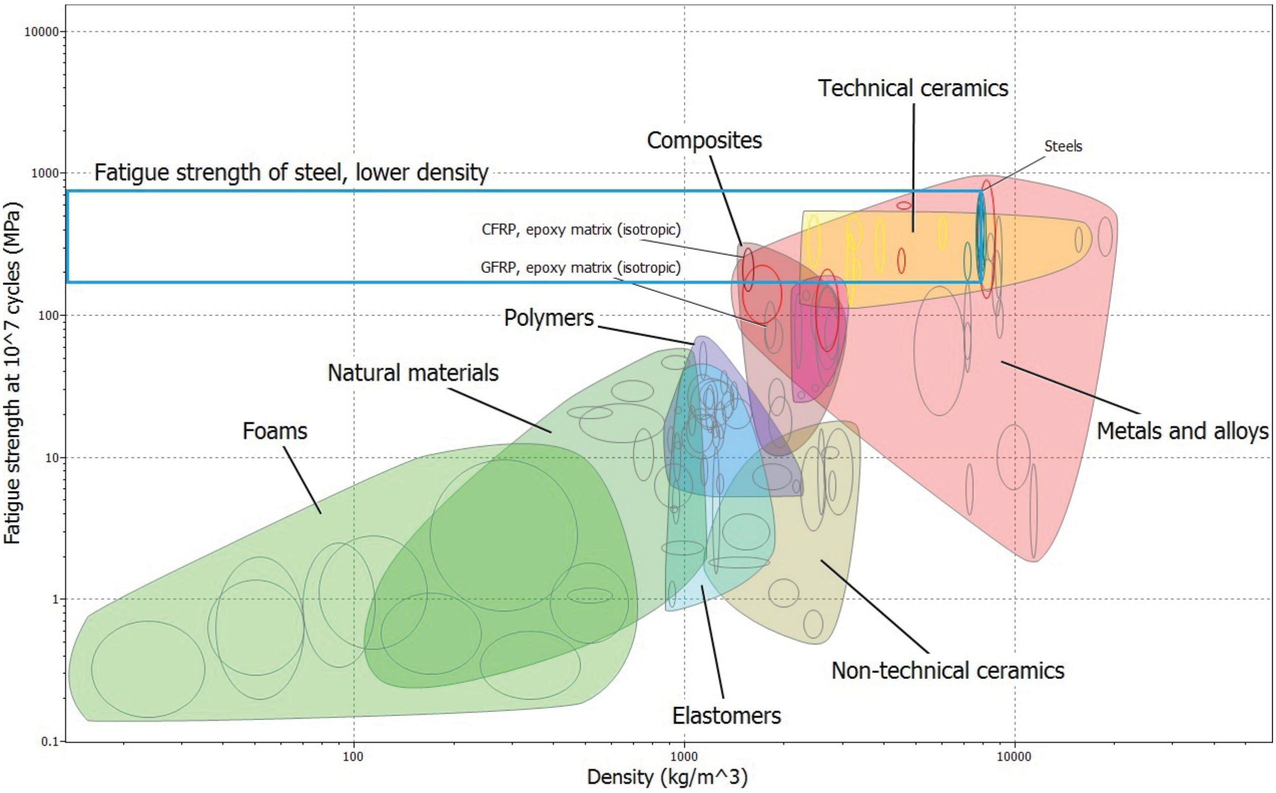


Figure 8 Density - Fatigue strength

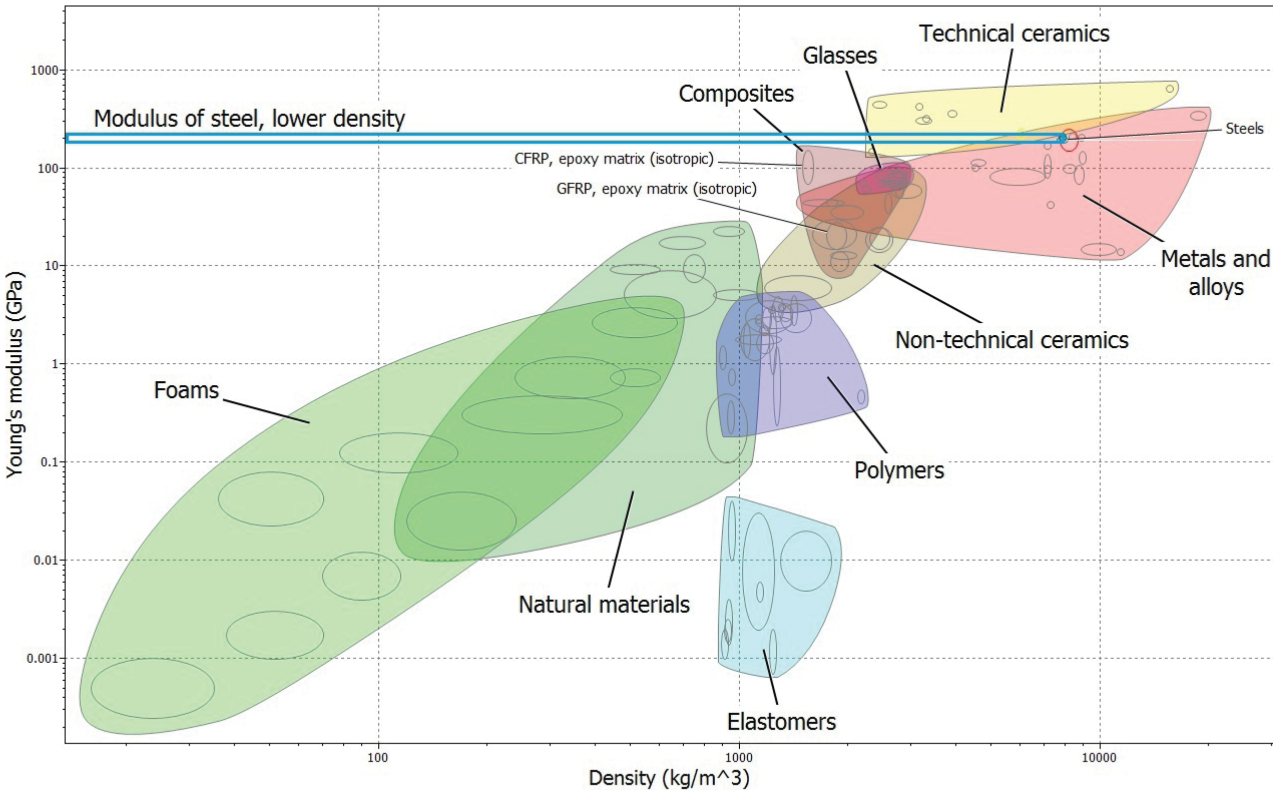


Figure 9 Density - Young's modulus

Fibre	Typical Diameter (μm)	Density ρ (kg/m^3)	Young's Modulus E_{fL}/E_{fT} (GPa)	Tensile Strength σ_{max}(GPa)	Strain to Failure ε_{max} (%)	Coeff. of Thermal Expansion α ($\times 10^{-6}$/°C)
Glass						
E-glass	10	2540	72 / 72	3.45[1]	4.8[1]	5
S-glass	10	2490	87 / 87	4.3[1]	5[1]	3
PAN Carbon						
T-300[2]	7	1760	230 / ≅20	3.53	1.5	-0.7
IM-7[3]	5	1780	300/ ??	5.31	1.31	
Pitch Carbon						
P-55[4]	10	2000	380 / ??	1.9	0.5	-1.3
P-100[4]	10	2150	690 / ??	2.4	0.32	-1.4
Aramid						
Kevlar 49[5]	12	1450	131 / ??	3.6	2.8	-2
Polyethylene						
Spectra 900	38	970	117	2.6	3.5	

Table 1 Density - Young's modulus

degrade in performance after long term exposure so rain should not be a problem. However the composites score only fair on UV. This means that degradation of the materials probably starts after months or years in direct sunlight. The results are not final as the rating is a combination of different tests with different criteria. The bikecarrier will not be stored outdoors in most cases so these results indicate that composites will survive outdoor use in rain or shine.

There are numerous varieties of composites. Material properties differ per fibre and matrix combination but also between manufacturers, this is important to keep in mind. Table 1 illustrates that properties vary widely between composite materials. The properties can also vary within a composite, the difference in Young's modulus in longitudinal and transverse direction of PAN carbon T-300 e.g.. The weave and orientation of the fibres should be taken into account when working with composites, making calculations on mechanical properties are different from isotropic materials are used. Composite products also react different to damaging than metal or plastic products.There are several modes of failure of composite materials: transverse cracking, delaminating and fibre related failure. The last one can compromise the load carrying capacity significantly. A transverse crack between strands of fibres is in itself not a problem as the load carrying fibres are unaffected. It can however cause delamination, separating layers of fibres. This can cause high stresses in certain fibres which may snap and reduce the load carrying capacity. Therefore the possibility of any cracks should be avoided in the design process. Drilling holes for mechanical fasteners can cause delaminating of the material. However this can be prevented by using proper backing and support. Another issue is the hole itself, to create it fibres have to be cut which weakens the component. Which means that composites can be machined but must be left intact when possible.

There is no standard fibre reinforced plastics. Different mechanical properties in different directions imply that standard calculations should be extended. A rule of thumb is that the fibre should be left intact as much as possible, avoiding holes etc.

Production

The available production processes at Cato are: thermoforming of fibre reinforced plastic sheets and insert moulding where composite parts are used in combination with injection moulding. The limitations of thermoforming considering shape should be kept in mind during the design process: The starting material is a sheet and sharp, double curved edges can cause pleating of the sheet which weakens the product.
In order to get more form freedom, the fibres should be applied by hand. Double curved areas can be covered with several pieces of fibres, avoiding pleats. The direction of the fibres can also be controlled more, improving mechanical properties of the product. A matrix can be added by using vaccuum injection moulding or adding it by hand. Problem with both is that both methods are rather labour intensive. These processes are therefore slower and more expensive in larger production series. Production costs consist of fixed costs like moulds and special tooling and variable costs like labour costs. Moulds are one of the biggest investments. Keeping the number and the size of moulds as low as possible is important to keep the costs down. An important aspect of working with composites is joining two pieces of composite. The fibres cannot be joined so the processes are aimed at joining the matrix materials. Thermoplastics can be joined with friction welding. Compared to another option, glueing, this process is a lot quicker. Mechanical fasteners like bolts should be avoided as they can be tightened too much, crushing the material. Plastic components are joined with composites in the same way as composite with composite. However plastic components can also be moulded directly onto the composite piece with insert moulding.

The production cost should be kept as low as possible. In this case, the series are large enough for thermoforming but too small to invest in several dies. The design should therfore be symmetrical if possible and sharp double curved surfaces should be avoided. Joining composites and plastics is possible in various ways, mechanical fasteners can compromise the strength of the product and should be avoided in most cases.

Requirements

In the sections above is explained what aspects play a role in redesigning the MovaNext bike carrier. A few things should remain unchanged: the clamping mechanism and the double fixation of the wheels. The shape, integration of components and the working of the wing are free to alter. The requirements are listed more detailed below.

Consumer

The consumer requires:
- All operations should not require great force.
- The carrier should give more feedback with each operation.
- The number of operations should not increase.
- The bikes need to be fastened rigidly. (Two points per wheel and on the frame.)
- Less complex appearance.

And wishes:
- Bikes can be moved across the bike carrier without lifting them.

Manufacturer

Indes requires:
- Composites should be used.
- The weight of the wings should be reduced to 3,5kg a piece. (Including light units and other components.)
- The new design should have a more modern look. (As described in the Design section.)

Technical

Technical requirements
- The maximum bending under load of 20kg located 620mm from the fixed point is 14mm .
- The maximum bending under torsion cause by a load of 20kg located 160mm from the centre of the wing is 2 mm in 360mm.
- The carrier should be able to withstand a vertical acceleration of 1,5G to simulate movement when in use.
- The carrier should be able to withstand a static load of 80kg. (Two bikes with a weight distribution of 15kg on the front wheel and 25kg on the back wheel, the bikes will face opposite directions.)
- The light units and number plate should be positioned according to the German 'Strassenverkehrs-Zulassungs-

Ordnung' and the Dutch 'Regeling Voertuigen'. (Light units: less than 400mm from the side of the vehicle. The maximum vehicle width is chosen as 2000mm. There fore the criteria are: from edge to edge of the two light units is at least 1200mm and lights and license plate should not be more than 900mm above the road when mounted on the towbar.)

- The edges of all component accessible with a 165mm sphere should have a radius of at least 2,5mm
- The carrier should be compatible with bicycles with 24 to 28 inch wheels and a distance between the wheels axis of 1050 to 1200mm.

Wing design

Design

The starting point of the design phase is the wing. This is the load carrying structure and frame on which all other components are mounted. Different design directions are explored, resulting in a shape for the composite wing.

Idea genaration

The first step is to find a way to replace the currently used steel frame with a composite wing. A wide selection of rough shapes is sketched to get an overview of the possibilities. The results are shown in Figure 10 and Figure 11. The main directions are a flat sheet, a box section, a gutter and the bottom three in Figure 11, a wedge between the wheels.
Small sections with extendable arms could result in a very compact and maybe light weight product. However composites appear to be unsuitable for this direction as explained in Appendix C. Which leaves the concepts “Flat”, “Box” and “Gutter”.
“Flat” is the direction in which the wheels will be placed on a sheet or plate of composite. The appeal of this direction are looks and low material use. “Box” aims at creating one or more beams to which the

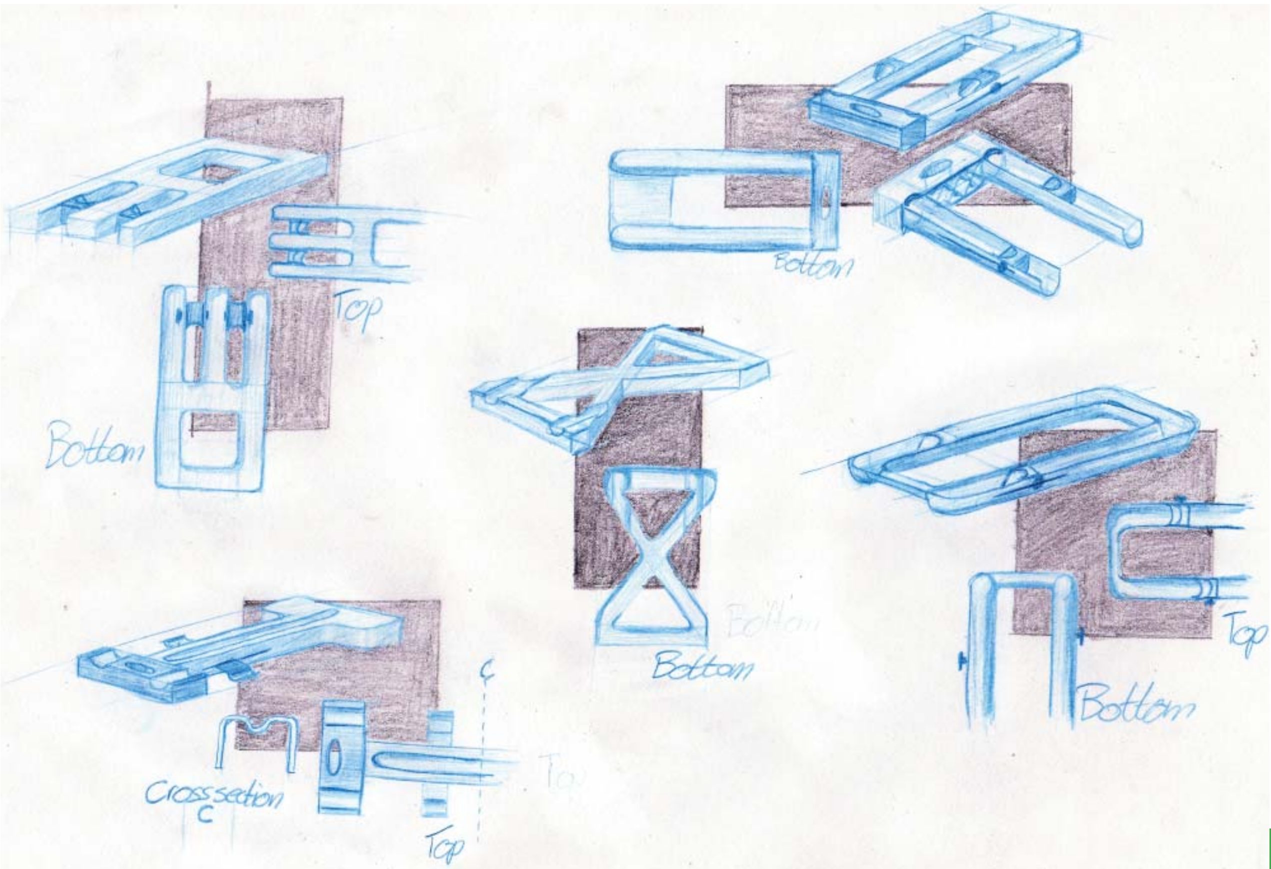


Figure 10 Ideas for shapes of the wing.

Wing design

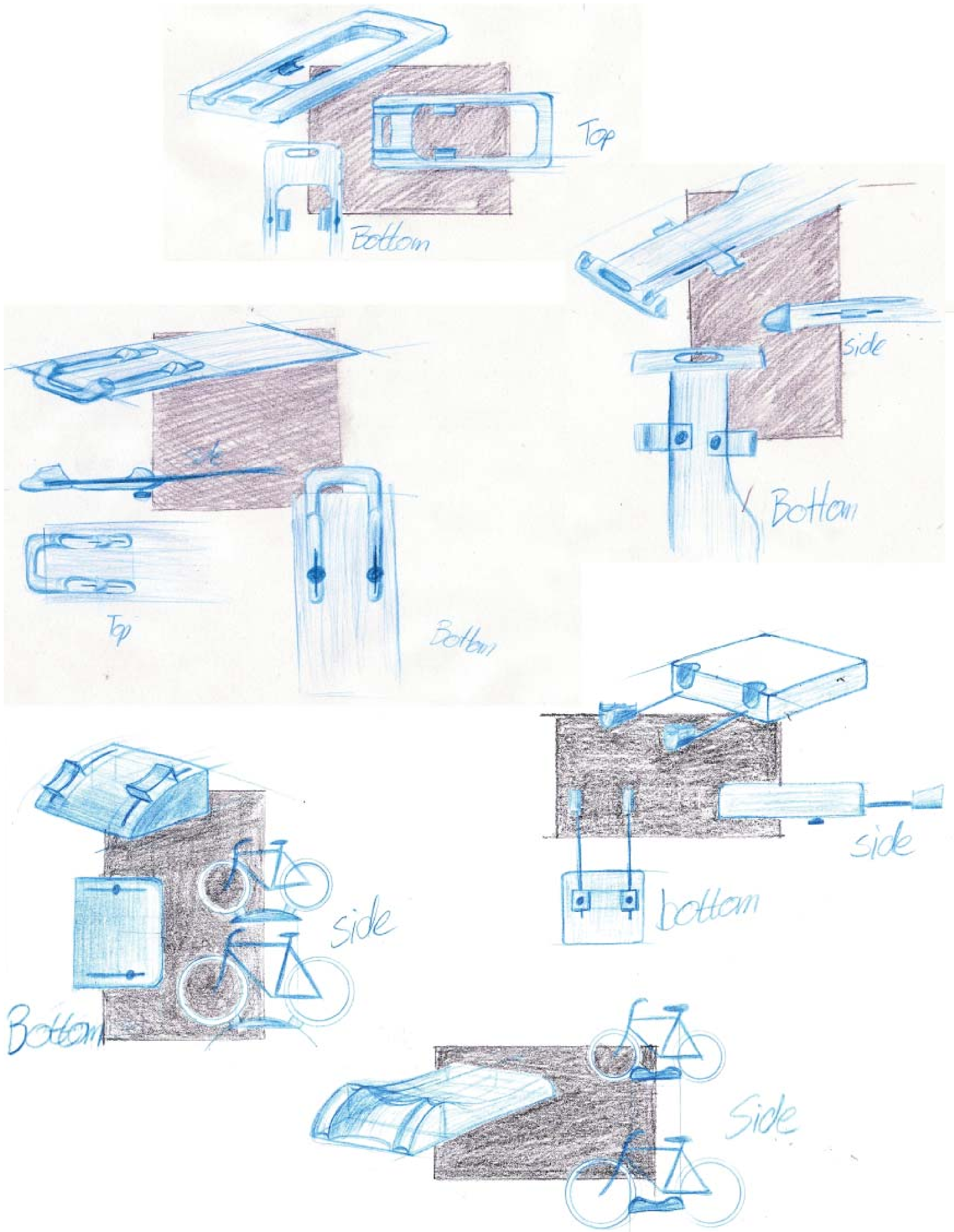


Figure 11 Ideas for shapes of the wing.

wheels of the bike can be attached. This shape can be very stiff if the section is tall by giving it a high moment of inertia. The torsion stiffness can be increased by closing the box completely and avoid U profiles. One of the challenges of this direction is the lightweight appearance as the structural beams cannot be opened up.
“Gutter” are two gutters to carry the bike, joined to facilitate the handle and connection to the hinge. The main advantages of this direction are stifness through a tall cross section and its appearance. All material is concentrated within the footprint of the bikes.

The Flat, Box and Gutter concepts are three interesting directions. Flat looks simple and clean while Gutter pursues a lightweight appaerance with a minimal footprint. The Box an Gutter variations promise high stiffness with a tall cross section.

Design direction

To choose one of the design directions a rough

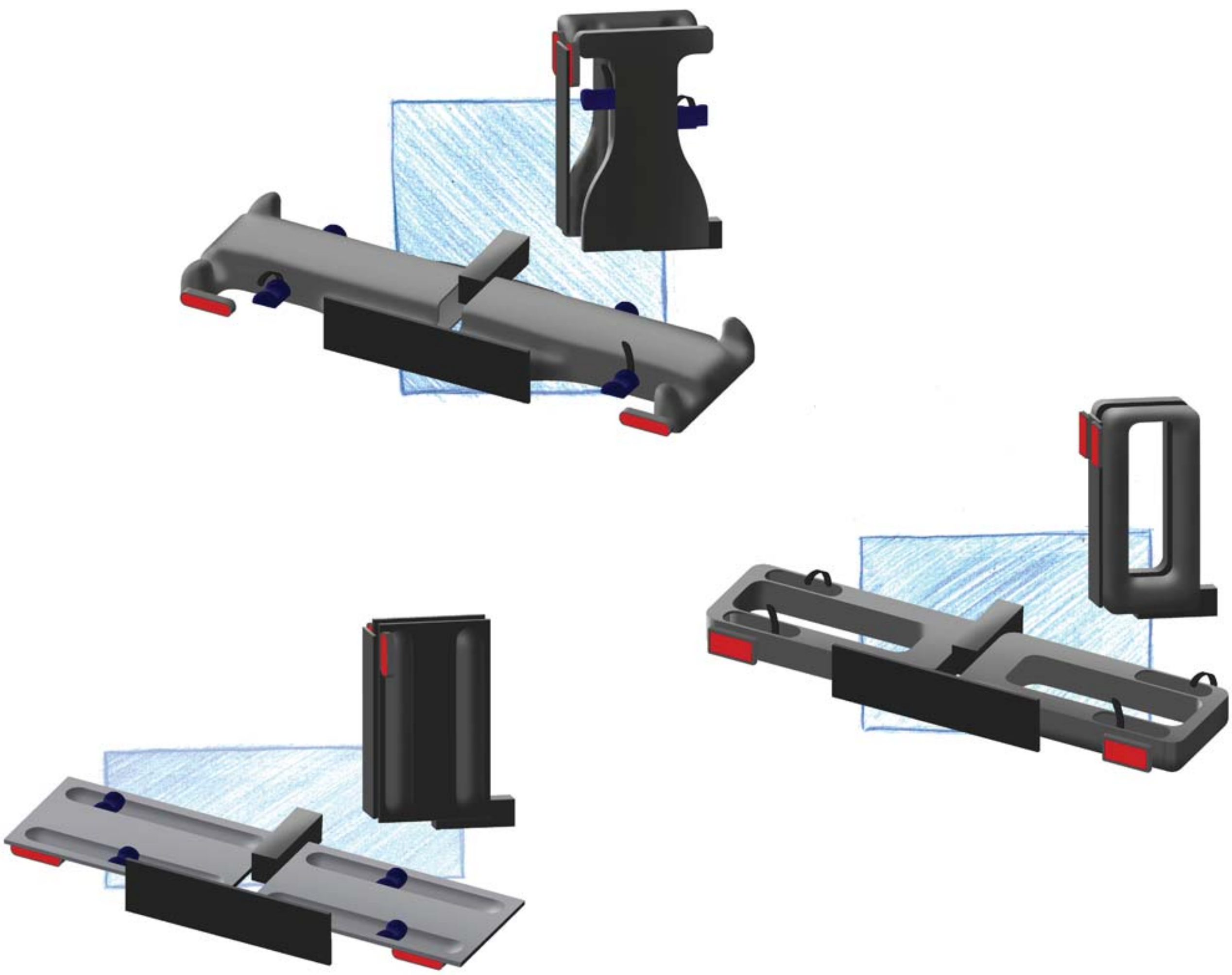


Figure 12 Visual impression of the Gutter, Box and Flat concept (from top to bottom)

	Gutter	Box	Flat
Thickness	1-1.5mm	1.5-2mm	10mm
Displacement	8.6mm	7.9mm	9.0mm
Weight	867g	1867g	5303g

Table 2 Indication of performance potential

comparison has been made on looks and mechanical properties. Digital drawings quickly give an idea of how the final product might look. A rough CAD model can give an indication of the mechanical properies of each shape. The appearances are compared in Figure 12, the stiffness and weight of the Box, Gutter and Flat directions are compared in Figure 13 and Table 2.

The hole in the gutter concept avoids the visual mass concentration like in the other two. The flat concept has no hollow compartments that can be used to hide components or wiring. The gutter concept is therefore most promising when is comes to the looks. However the designs should be refined if chosen. An example of issues that should be adressed are the sharp edges at the top of the gutters.

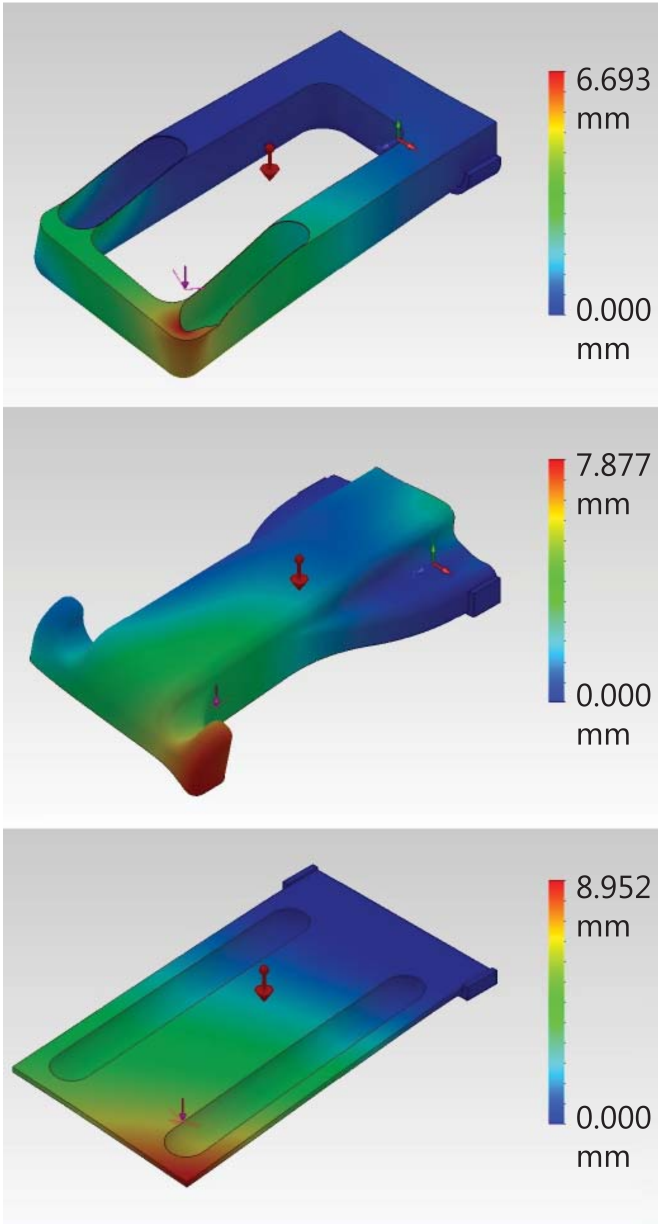


Figure 13 Displacement of the different concepts under load

In order to compare the mechanical properties and weight, three CAD models are made and analyzed. The material is considered isotropic in the analysis. The material properties used in the simulation are the properties in the fibre direction of the composite. All properties of the used composite can be found in Appendix B. Which means that the results only give an indication of the possibilities as the difference in properties in the different directions of the material and the stiffness of joints are not taken into account.

The models were adapted to the point that the displacement met the requirements and was roughly the same for all concepts because all

Gutter	--	-	+	++
Sleek look				
Lightweight look				
Stifness				
Weight				

Box	--	-	+	++
Sleek look				
Lightweight look				
Stifness				
Weight				

Flat	--	-	+	++
Sleek look				
Lightweight look				
Stifness				
Weight				

Table 3 Comparison of the three concepts

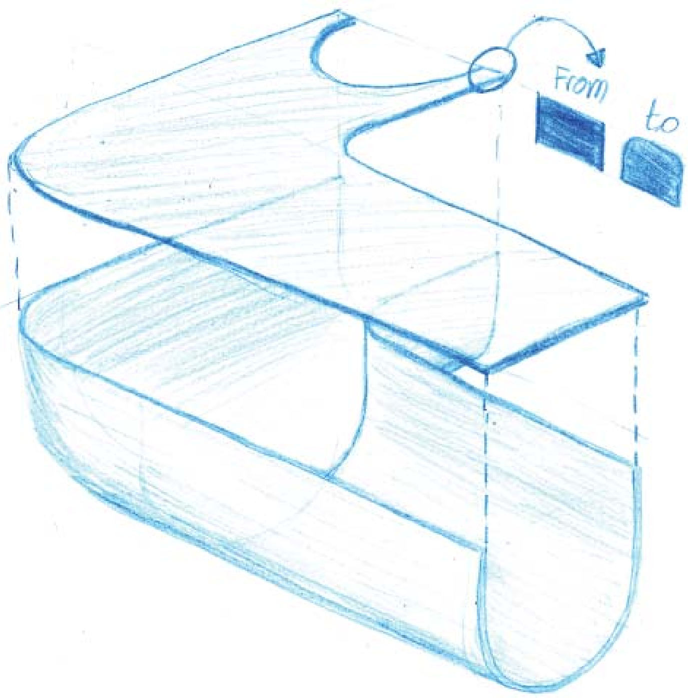


Figure 14 Gutters structure and problem

three directions follow the same specifications. The wall thickness of the models was reduced with 0.5mm at a time until the displacement was 8 to 9mm. (These increments are used to mimic layers of fibres.) With the dimsensions set, the weight could be determined. These are just for the comparison and only give an order of magnitude.

The other imput for the simulation are the load and the fixture. The load is as described in the requirements as dynamic use. The fixture chosen here is a rigid joint surface with a clamp underneath the far end. This was done because it is likely that the wing will be glued to the hinge which would also lead to a large joint area. Looking at the shape of the wings, a joint in the horizontal plane or at the sides will be most likely. A combination of both has been used with this clamp.

The two comparisons are combined in Table 3. The Gutter concept is most promising with the Box direction in second place. The Flat concept falls behind on weight and the hiding from view of other components.

However the Gutter has one problem that must be solved before it can be detailled: sharp edges at the top of the wing. If these get at least a 2,5mm radius, the Gutter concept will be chosen, otherwise the Box.

Gutter concept

Due to regulations, a 2,5mm radius should be applied to all edges which can be touched with a 165mm hemisphere. The edges where the topplate and the rest of the wing join need to be smoothed to a

Wing design

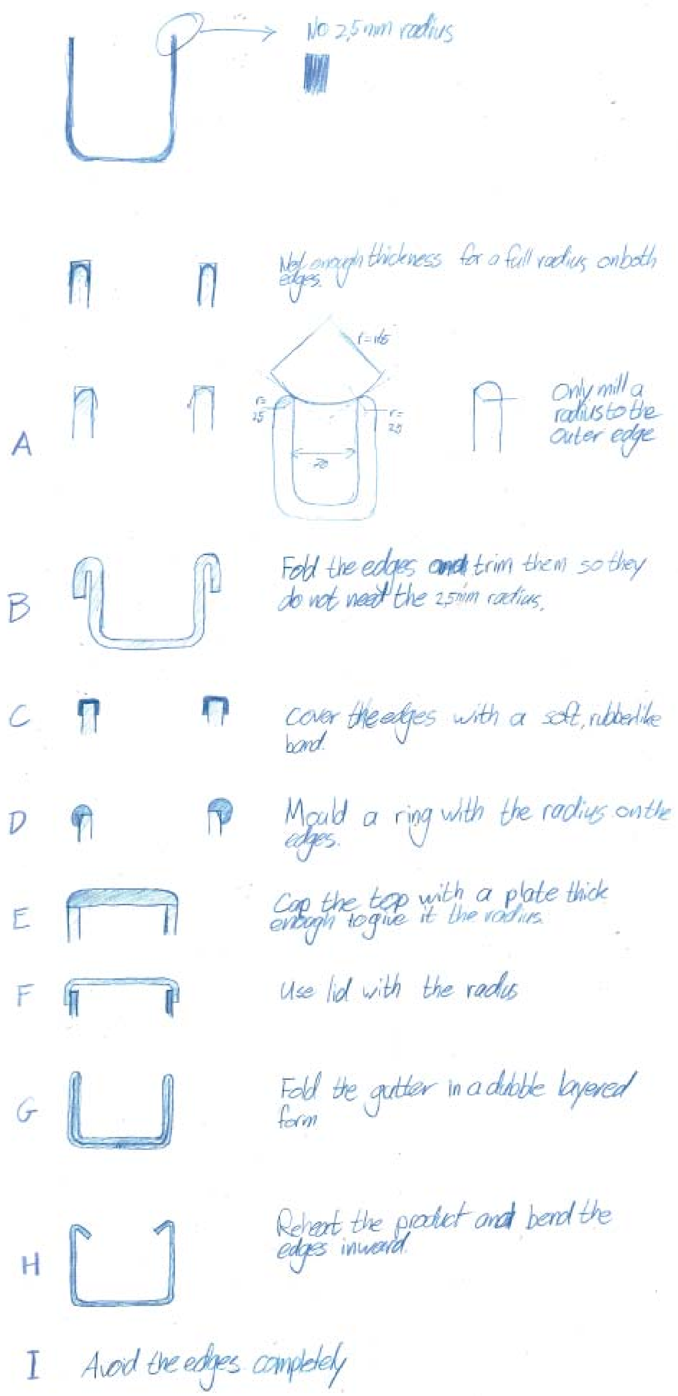


Figure 15 Several solutions to get a radius on sharp edges.

2,5mm radius, illustrated in Figure 14. Some solutions for this problem are presented in Figure 15. Option A is not really possible due to the thin walls and top plate. While options B, G and H are difficult or impossible to mould, although B can be done with a slightly larger radius. Options C, D, E and F are all realistic options that might require additional moulds or work but can be executed. Option I is very hard to use in this concept.

However, during the meeting with Cato another major issue arose. The high walls of the gutters cause problems during the thermoforming process. In essence, a piece of cloth is draped over a mould. This leads to pleating in the outer corners and a shortage of materials in the inner corners as shown in Figure 7. The cloth in the actual product is a combination of woven fibres and a plastic matrix. Unlike the matrix, the fibres can hardly be stretched. Therefore, the inner corner cannot be realized without splitting the material. Although it is not the issue originally feared, the Gutter has a major flaw and will not be continued. The Box direction will be develloped further.

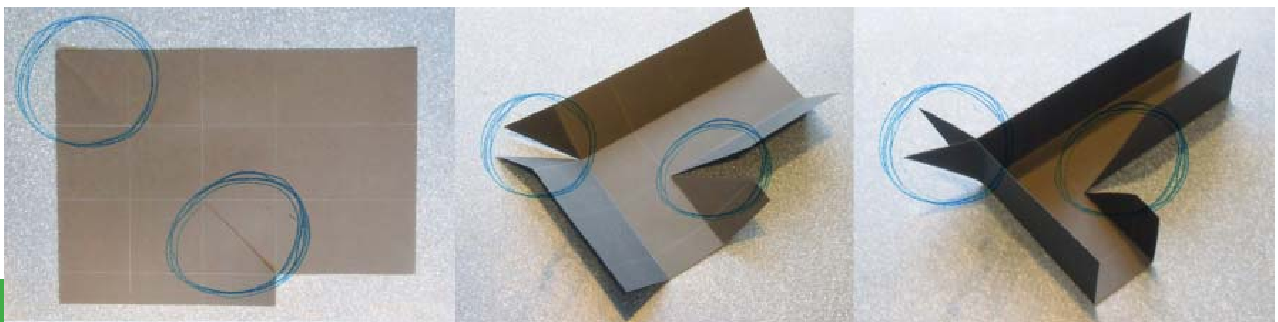


Figure 16 Material excess and lack

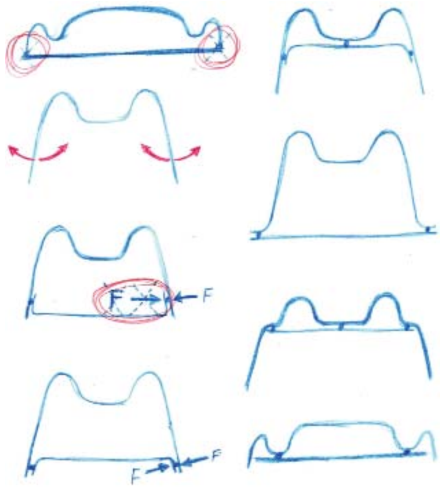


Figure 17 Joint between th bottom plate and the top.

Box concept

The initial idea was creating a boxsection with pegs integrated at the end to support the wheels and a wide base at the other to attach the wing to the center section. A bottom plate was supposed to be joined to the edge of the top part to withstand torsion.

This idea had to be adjusted because the joint between the two parts should have a larger surface area for welding, glueing or clamping. The pictures at the left in Figure 17 show the needed transition. From top to bottom: the surface area of the joint is too small, but losing the bottom weakens the structure too much, however a neat, inward folded bottom plate cannot be used as pressure cannot be applied from inside and finally a possible solution. Pressure can be applied on an accessible joint, creating a good weld or glued joint. The pictures at the right show several other possible configurations. From a costing point of view, the right bottom three are best because they have flat bottom plates. The flat plates only need to be cut to the right size and do not have to be moulded which saves a lot on tooling.

Indes has made a start with the new box concept, a model of their solution is shown in Figure 18. This shape is easier to form than the hammer like shape shown earlier (Figure

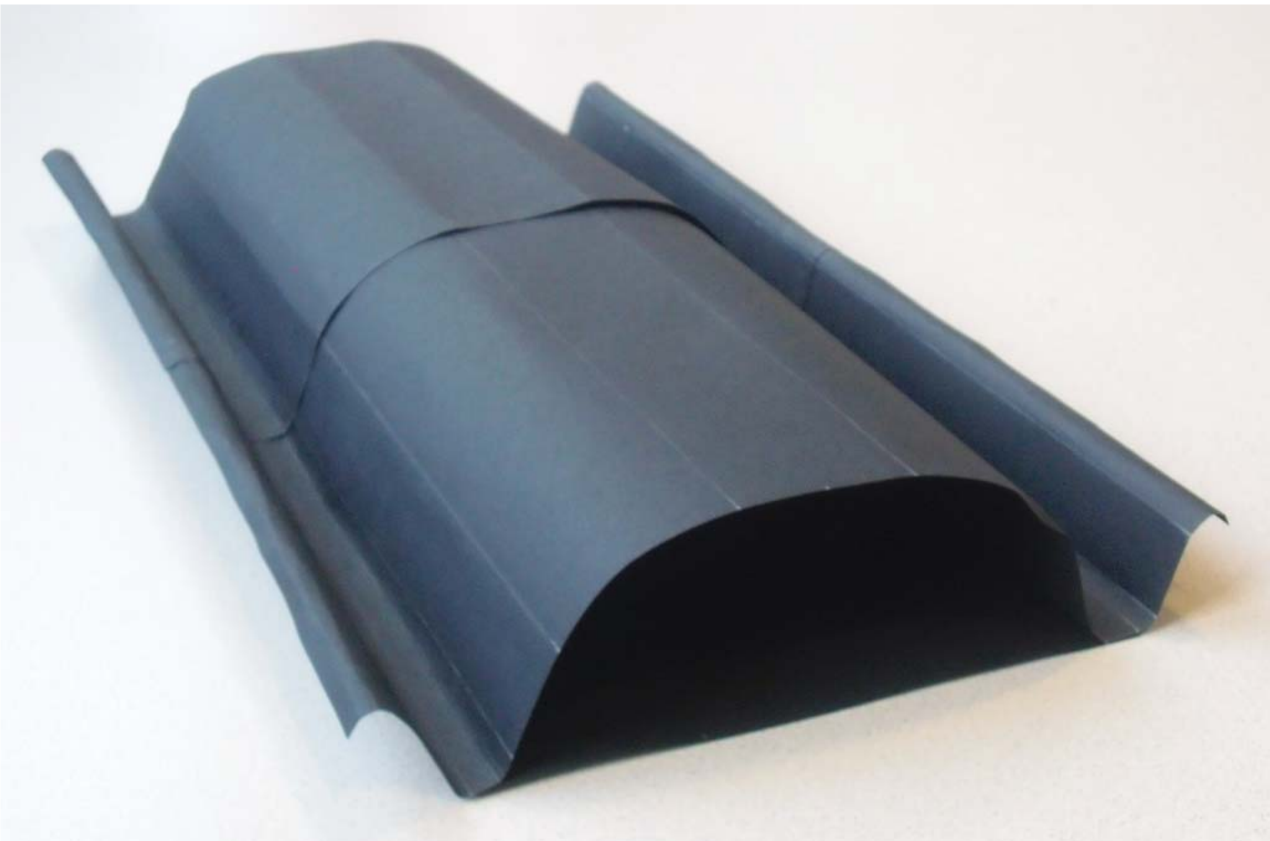


Figure 18 Fullsize model of Indes's design proposal.

12) as the sharp double curved areas at the outer end are avoided. The gutters that come with this new shape also communicates that a bike can be moved instead of lifted into place. There is however one major drawback which the model in Figure 18 shows in real life: the wing looks massive.
The paper scale models in Figure 19 illustrate the search of a shape that looks more subtle, more light weight. The use of models instead of drawings gives a feel of the limits of sheet materials. The models also give a better understanding of the proportions. The first comparison in Table 4 is about opening up the wing. This had to be done by cutting away material as it is

Open up	--	-	+	++		Avoid mass	--	-	+	++
A		■				A		■		
B		■				B			■	
C		■				C			■	
D		■				D				■
E		■				E				■
F			■			F	■			
G			■			G		■		
H				■		H		■		
I		■				I		■		

Table 4 Comparison of the models on “Avoiding mass conentrations” and Opening up the product”

not possible to make the composite transparent. The cut outs stand out most when they are in contrast with the surrounding area. The larger cutout in F and G do not work that good, it looks more like a broadening shape than that the wing becomes narrower at the other end. The second comparison focuses on avoiding a large concentration of mass. Model D and E perform exceptionally well on this design solution. The large beam that is literally broken down into two smaller ones. B and C also perform well because the sharp lines break the large surface of the original beam (A). However the dent in C does not have a real dramatic impact on the apparent weight of the wing. The option that has a big impact on the apparent weight is F. The idea was that the whole product would look more light weight by making it leaner toward the end. This was also structurally

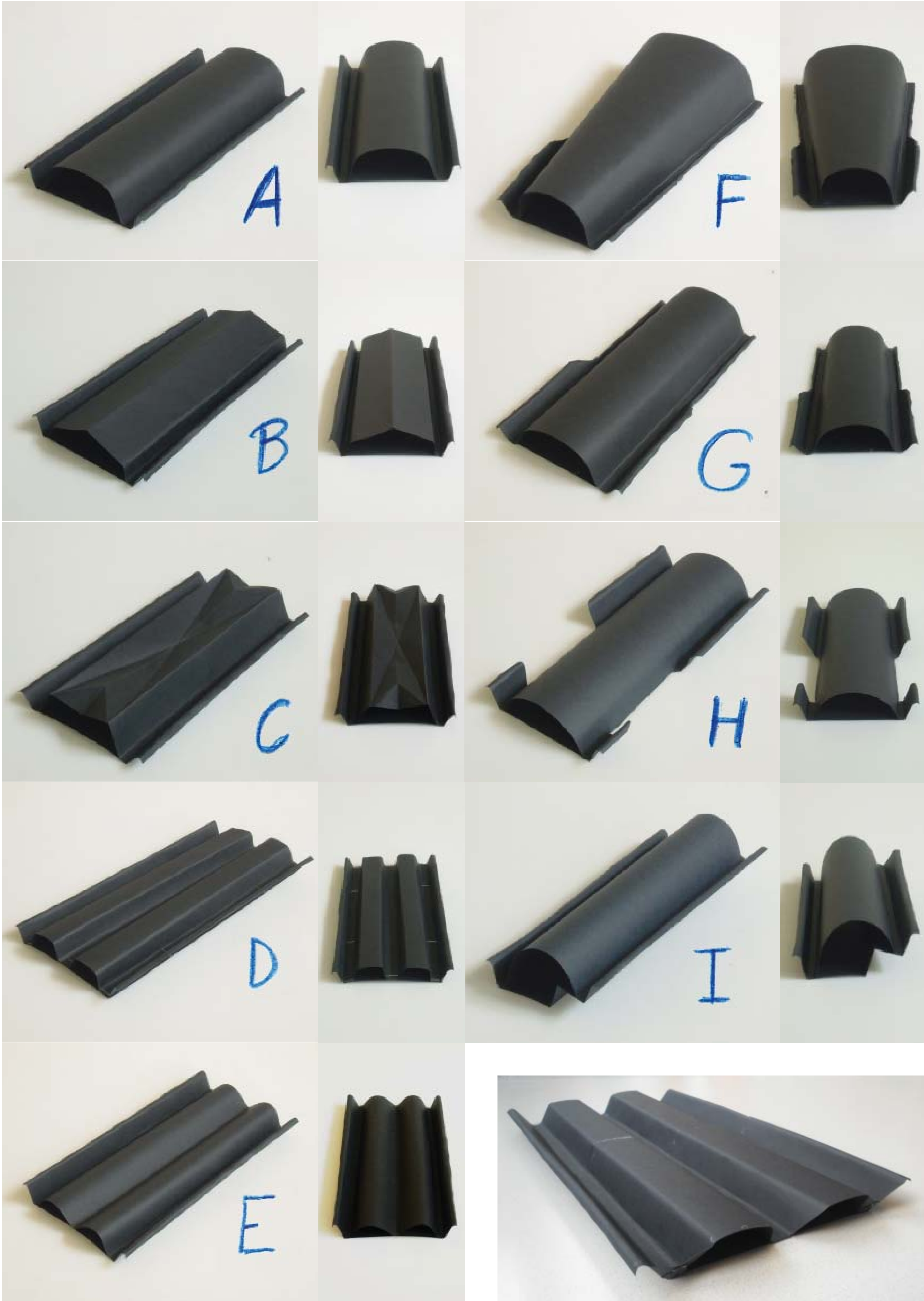


Figure 19 Possibilities to improve the apparent weight in 1:2 scale models.

possible because the moment is the largest at the hinge. This might work on longer shapes that taper in towards the end, but in this case it will result in a really large visiual concentration of mass in the middle. The leaner ends compared to the original do not compensate that concentration.
The last option is I where the width of the beam is reduced. By placing one wheel slightly higher than the other, the bikes are placed closer together. This might work but the width of the wing should become less than its height. The different frame sizes and handlebars make this impossible.

The appearance of the box section with gutters can be improved by replacing the large arch in the middle by two smaller ones. Cut outs do not have a very large impact but they might be applied in a later stadium. As the mass and mechanical properties of the original option A and option D are nearly the same, option D is the best shape to choose.

Wing refinement

In order to find the best shape of the wing, a large number of variations has been made and compared. The cross section is various and the moment of inertia, the polar moment of inertia and the area of the varieing sections are determined by the CAD program used to make the models. The deformation due to bending and torsion can be found with these. Stiffness is used as the main variable and not strength. Calculations done prior to this assignment indicate that the strength is sufficient if the stiffness requirements are met.
A finite element analysis of wing A from Figure 19 has been made previously. Therefore the values of this

Cross section

If the cross section is constant throughout the whole wing, the area determines the volume and therefore the weight of the wing. This an important parameter to compare.
The others are the Moment of Inertia and the Polar Moment of Inertia. The constant section make these good quick indications of bending and torsion stiffness. The equations below show the relation between the moment of inertia and the deflection and the polar moment of inertia and the angle of twist.

$$\delta = \frac{-PL^3}{3EI} \qquad \phi = \frac{TL}{JG}$$

δ deflection
P force applied
L length of the wing
E modulus of elasticity
I moment of inertia

ϕ angle of twist
T torque applied
L length of the wing
J polar moment of inertia
G shear modulus of elasticity

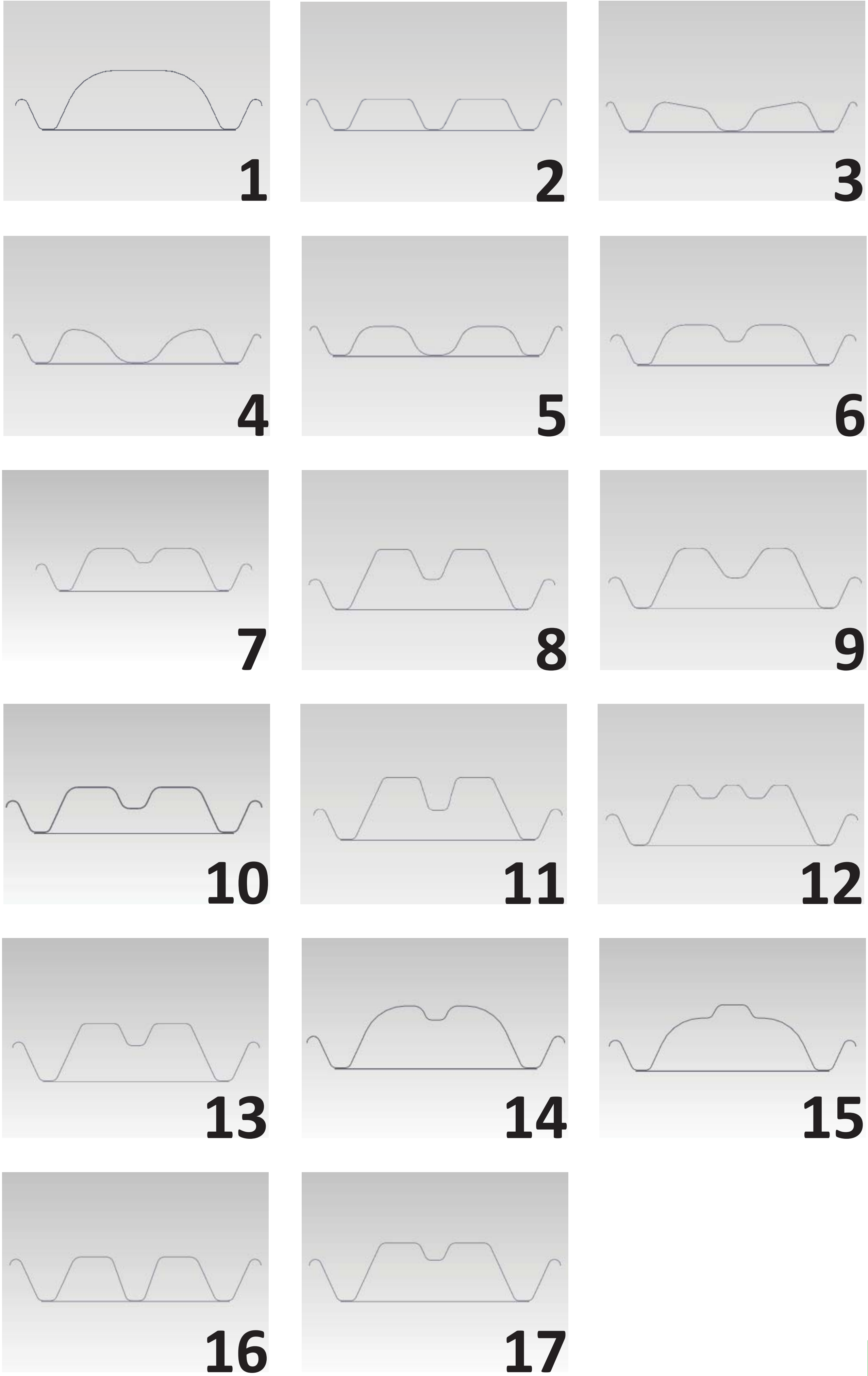


Figure 20 Search for the ideal cross section.

Wing design

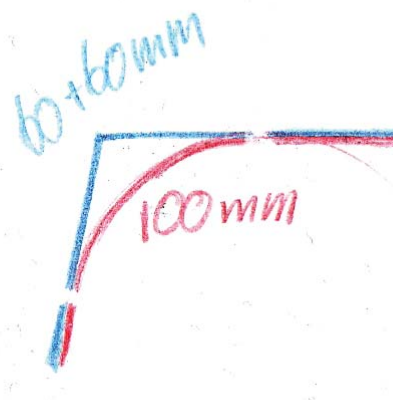


Figure 21 Advantage of a larger radius

wing serve as benchmarks. The different cross sections are shown in Figure 20, their properties can be found in Appendix D. All percentages in the appendix indicate the increase or decrease compared to that benchmark.
Each section is an evolution of the wings before or the exploration of a new direction. By comparing the properties of the different designs, the intuitive next step was found.
Section 2 in Figure 20 was a representation of the physical model shown earlier which was based on an improved appearance. The following designs up to 6 were attempts to lower the weight of the wing and increase the bending stiffness. This was done by concentrating the material closer to the perimeter of the global shape and increasing the height of the global shape. A way to achieve this without adding material was applied from cross section 8 onward, reducing the thickness of the bottom sheet. Design 14 and 15 use a large radius on the formed part to gain height without using as much material in a design with a sharp corner, as illustrated in Figure 21.
Eventually section 17 emerged which has a lower weight, the same bending stiffness and a higher torsion stiffness. This was achieved by increasing the height of the sides, using sharp corners to add material to perimeter and compensate the added weight by reducing the thickness of the bottom plate.

When the appearance is evaluated, the large bulky volume is broken down by splitting the upper surface with a gutter down the middle and more subtle, using two smaller surfaces instead of a larger curved surface. However there are two flaws. When the wing design is looked at as a volume, the height influences the apparent weight more than the gutter down the middle. The second, more problematic, flaw is that the middle gutter can be mistaken for a slot for an additional bicycle. These problems are solved in the final wing design.

Final wing design

Indes came up with a design which performed better than required. The focus had been on improving the appearance and reducing weight while keeping the high stiffness unchanged. It turned out that the original design was overdimensioned significantly. So the final design should be lower, have a shallower or wider gutter and does not have to be as stiff as the original.

The relation between the moment of inertia and the deformation is inversely proportional for both torsion and bending as shown on pagina 32. Table 6 shows how the new required moment and polar moment of inertia is determined on the basis of earlier FEA calculations.

	Bending	Torsion	Total deformation
MovaNext 3 (Steel)	14 mm	2 mm	16 mm
Original	7 mm	5,5 mm	12,5 mm
Aim	16 - 5,5 = 10,5 mm	5,5 mm	16 mm
	67%	100%	

Table 6 Indication of performance potential

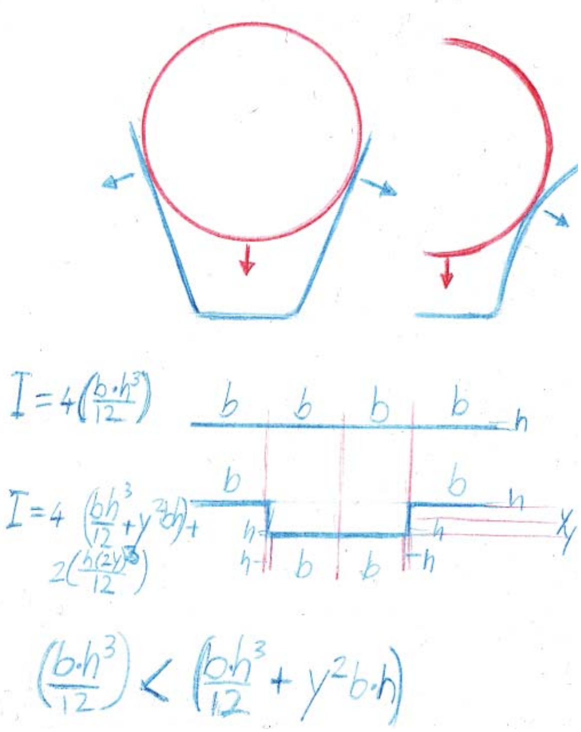


Figure 22 Stiffening the sides

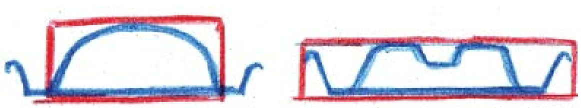


Figure 23 Drawing the sides in to the main shape

The polar moment of inertia is a sum of the area multiplied by the distance from the centroid where as the moment of inertia is multiplied by the vertical distance. This means that the width influences the torsion stiffness most and the height of the wing influences the bending stiffness as the wing is much wider than it width. Therefore the polar moment of inertia was kept the same while the moment of inertia is reduced. This resulted in a shape that dropped in height from 73,5mm to 58mm with a 5mm dent in the top.
The sides were raised slightly to reduce the diffence in height between the sides and middle in order to create a lower, wider rectangle compared to a rectangle with a smaller surface in front of it. Figure 23 clarifies this principle.
One last addition was made to the sides to stiffen them as the engineer of Indes thought the sides would bend outward when loaded. Creating small steps in the side will increase its moment of inertia as shown in Figure 22 and can double the stiffness as illustrated in Figure 24. The inner dimensions are fixed so the step will be made outward, rising the top of the wing slightly.
After all these alterations a FEM analysis

Wing design

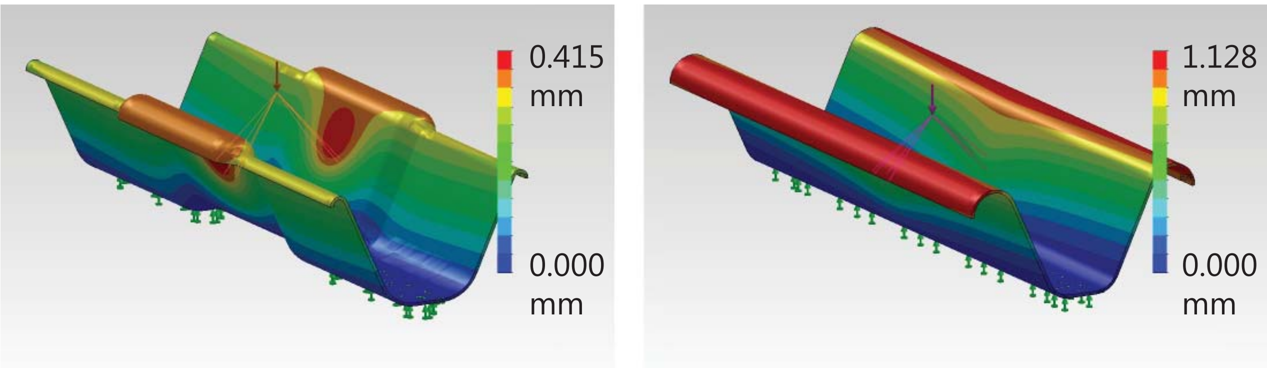


Figure 24 Increased stiffness of a stepped side

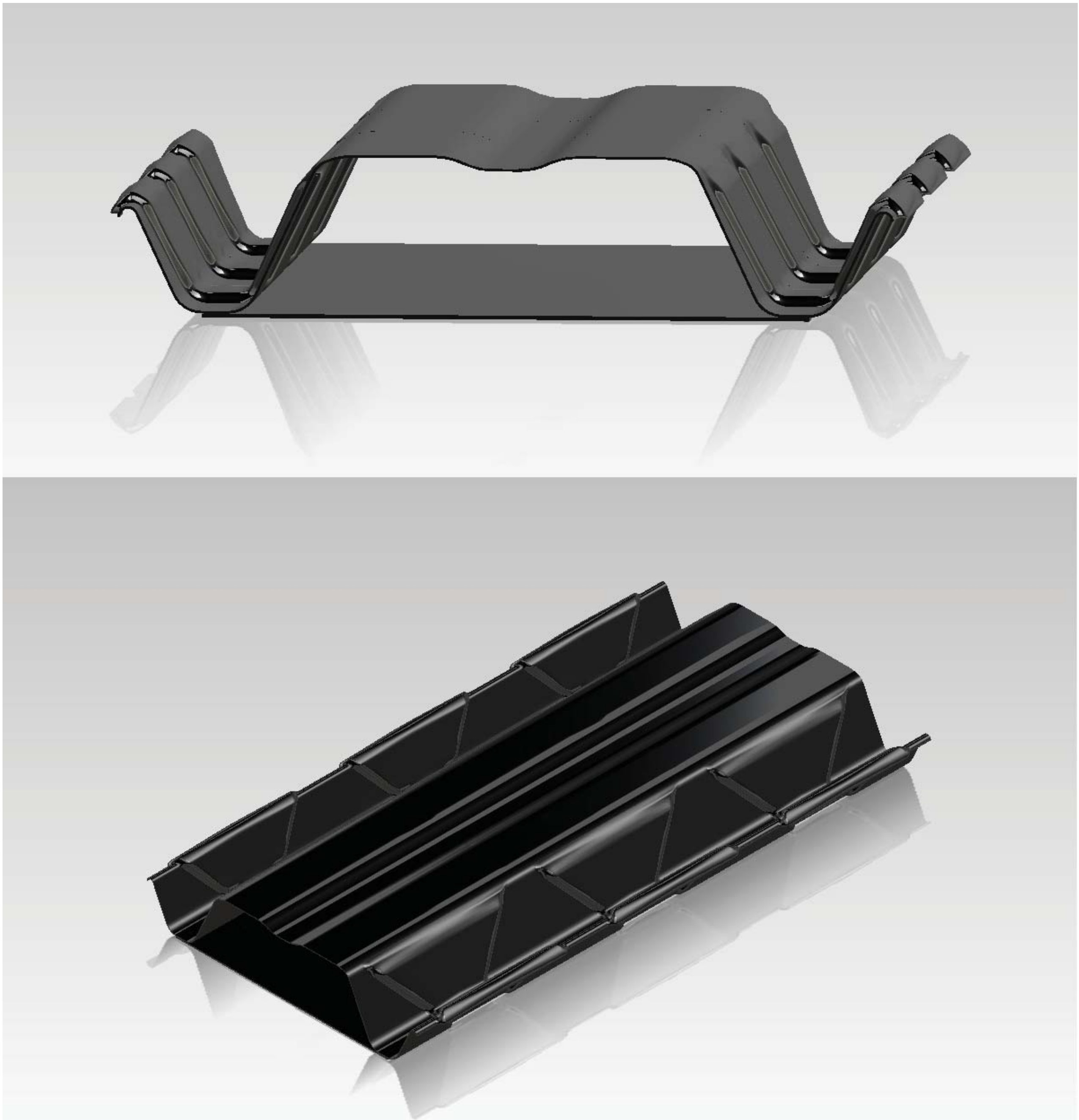


Figure 25 Final wing design

was made. The stiffness did not cause any trouble but the strength around the mounting points was unsufficient. Therefore an extra layer of glassfibre will be added to the top of the wing. This final, strengthened design bends around 2,1mm under the specified 20kg load and 4,9 mm under torsion. The full results can be found in Appendix D.

To improve the looks, the wing was lowered. The loss of stiffness did not cause any trouble but strength became a problem. An extra layer of glassfibre in the composite solves this. Figure 25 and Appendix D show the final wing design.

Additional components

With the shape of the wing determined, other components can be added. A handle, lights and a licenseplate have to be mounted. The components and assembly will be discussed. Furthermore, the joint between the two wings is briefly adressed. The design proposals for the different components and assembly will prove that a functioning complete bike carrier is feasible.

Handle

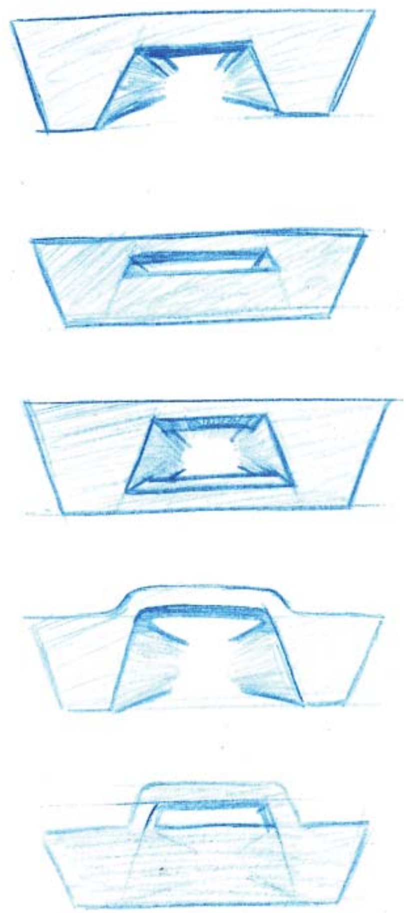


Figure 26 Grip shape

The handle has several functions: creating a void between the wings when folded, preventing the bikes from rolling out of the gutters, tieing the end of the wing together visually and of course creating a grip to carry the carrier. Only the basic shapes and ideas are sketched because the overall shape of this component becomes rather complicated. Dimensions and porportions are tested in a CAD model. The final design solution is presented with some other options and choices along the way.

The shape of the handle influences the overall look of the product significantly, this is therefore the starting point of the handle design.

Figure 26 shows some rough grip layouts. The grip is the bridge between the two gutters, a connection between them should be made. To create an open and light shape, the gutters can be extended with a grip at the top and a connection rod at the bottom to tie the two gutter stogether. The top two options lack the connection and the lightness respectively. The bottom two options with a raised grip cope better with the high middle section of the wing. However, a resemblance of a serving tray should be avoided. In order to achieve this, the bottom of the grip should be below the top of the wing.

The end piece can make the bike carrier hover on the towbar. To create this effect, the ends should rise slightly compared to the rest of the bottom. Figure 27 illustrates, that a shallow angle followed by a 45 to 60 degree angle gives the best result: B, E and G in the picture. Starting of with a 60 to 90 degree angle, like A or D creates a blunt end. The continious curves of C and F seem to obscure the rising and thinning shape. The difference can be seen in E and F. Option E is one of the lighter shapes while F is almost the same but looks more mediocre.

Figure 28 shows how the rolled edge of the wing can be formed into the front of the handle. The end of the edge has to be covered because of the safety requirements.

Component design

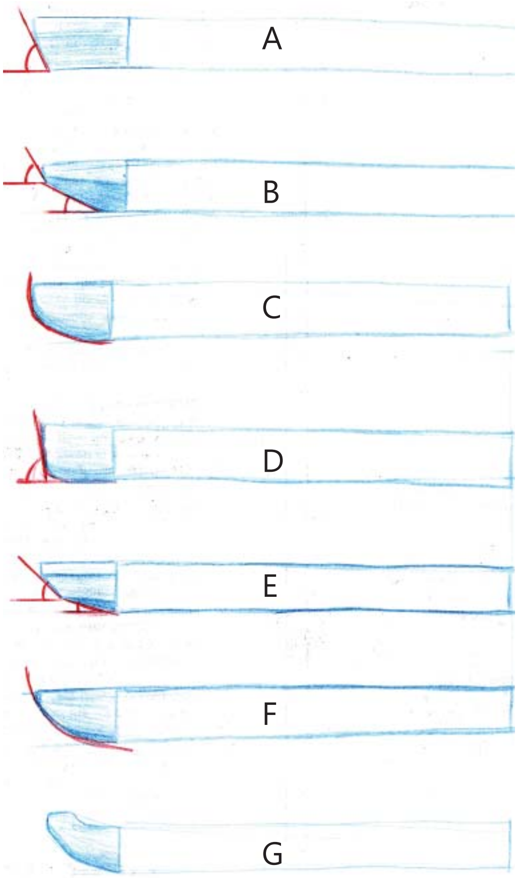


Figure 27 Effect of a end piece to the front view

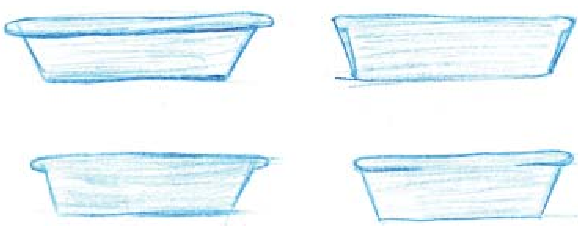


Figure 28 Integration of the rolled edge into the front of the handle

This pipe can be wrapped around the whole piece, covered roughly around the edge, fade into the front or be wrapped tightly at the sides and blend into the sides, never reaching the front. To get a clean look, it is best to blend the pipe into the sides. Whether this is done thightly or not does not really matter as the lights will cover the joint from the outside, blocking a view in the gap if a rough wrap is used.

Things to remember for the front view of the handle are: connect the bottoms of the gutters to tie them together, do not raise the grip too much and blend the cover over the rolled edges of the wing into the sides so they are not clearly visible from the front. The bottom is the most important part of the side view, a 10 degree incline followed by 50 degrees is a good choice as it visually bends upward without breaking up in a bottom and a side.

Handle versus pillar

Whether or not the handle must be raised depends on the space needed for the pillar. Removing or swivelling the pillar like the competition (Figure 2) requires extra handling steps. This is why the pillar of the MovaNext 3, shown in Figure 30, will also be used in the new design. The wings should therefore have a gap between them to hold the arm of the pillar while the carrier is

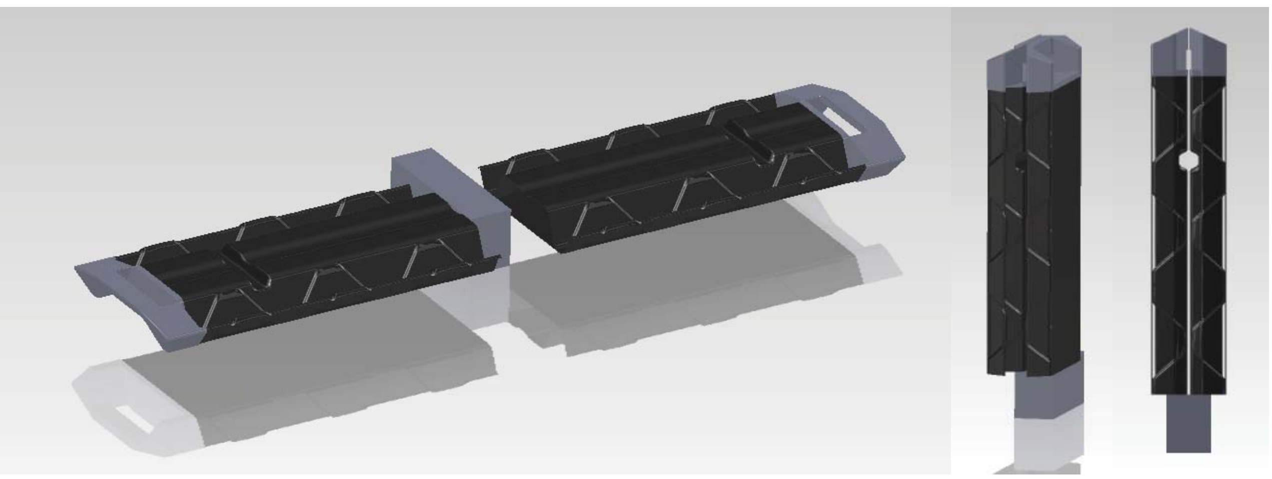


Figure 29 Narrow dent to accommodate the pillar arm.

Figure 30 Pillar with horizontal arm

folded.
This can be a narrow dent as shown in Figure 29, a larger dent or a raised grip on the handle illustrated below (Figure 31 and Figure 32). The dents are an extra feature on the wing which creates fuzzy look combined with the steps in the side. A narrow dent is less disruptive than the larger one but the height of the arm has to be adjusted to the right height before the carrier can be folded.

The extra operation of positioning the arm to fold the carrier and the disruption of the top surfaces leave the raised grip as the best option. The top of the grip should be raised 10mm above the top of the wing to make room foor the 20mm diameter of the arm of the pillar.

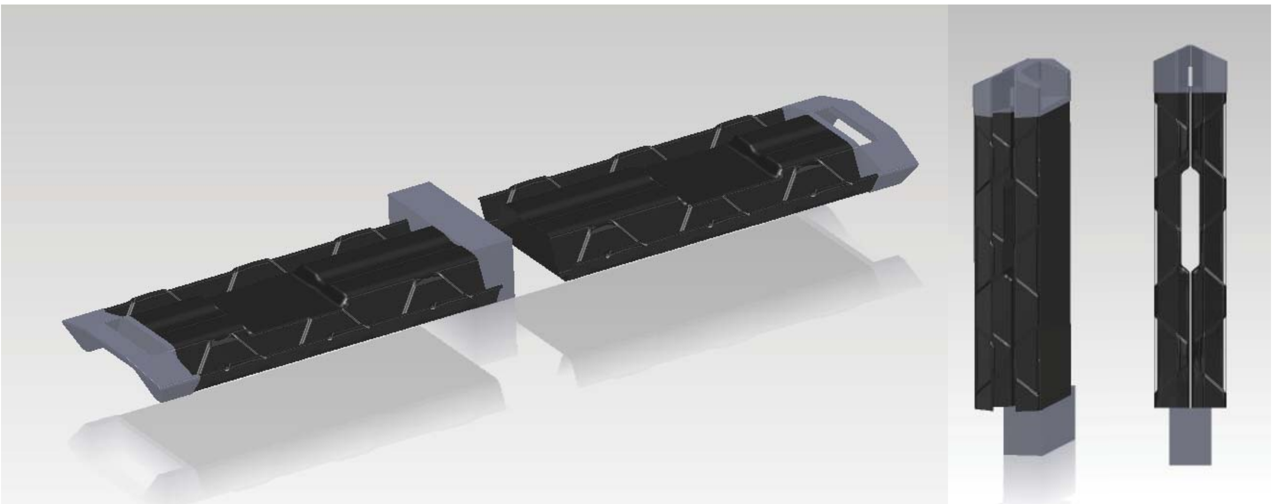


Figure 31 Broad dent to accommodate the pillar arm.

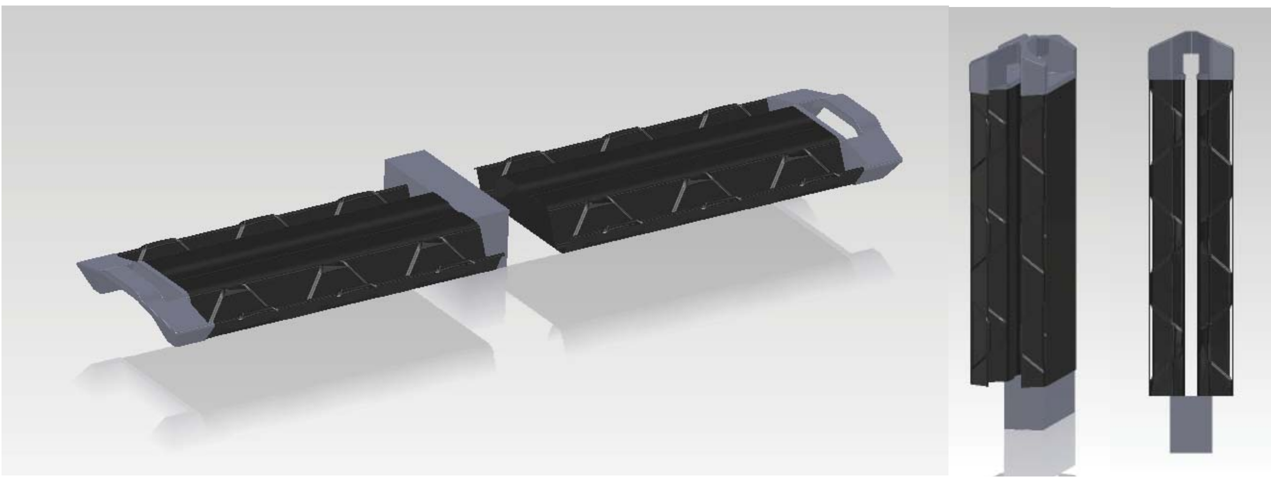


Figure 32 Gap to accommodate the arm without moving it.

Component design

Final handle

The grip is the most important part of the handle. The dimensions in Figure 33 are copied from the MovaNext 3 and checked with an anthropometric table of the Dutch population. These dimensions are used, some other dimension are dictated by the shape of the wing. The rest is chosen on looks. Strength and weight are not considered yet as the handle has to be revised by a specialist before production.

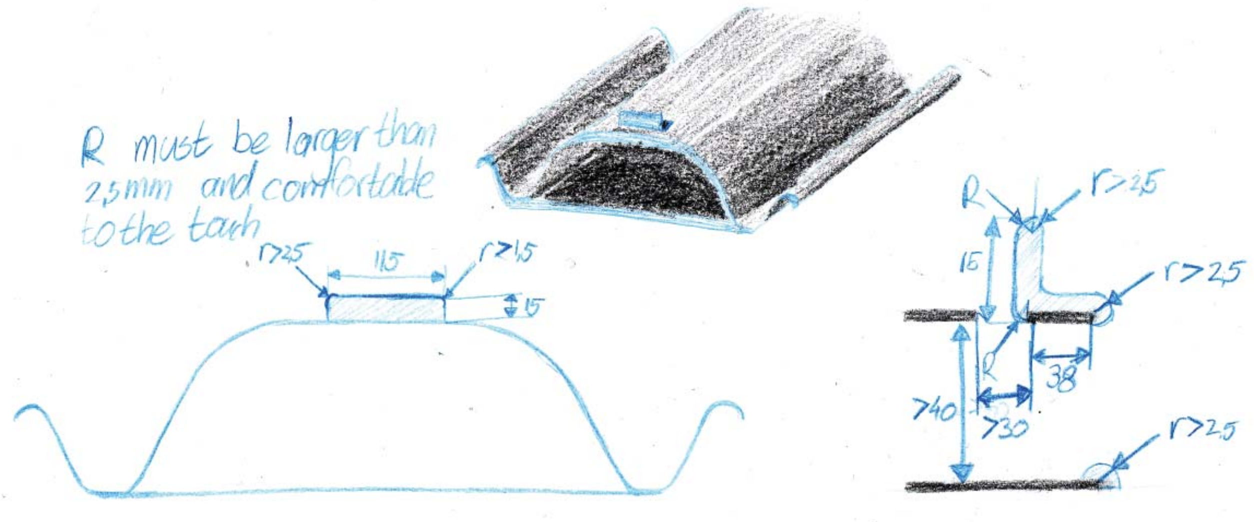


Figure 33 Ideas for shapes of the wing.

The final wing design will be explained in the following pages on the basis of images. There was also one detail that did not make the final design which is explained below.

One of the requirements was creating more feedback mechanisms. The protrusion and indentation in Figure 34 can create a click so one can feel that the wings are closed correctly. As the wings are folded one at the time, feedback for which only one wing (and the hinge) is needed is preferred. The protrusion an indentation are not used therefore.

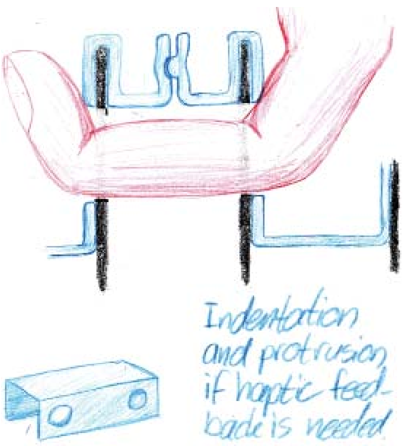


Figure 34 Feedback of the handle during closing.

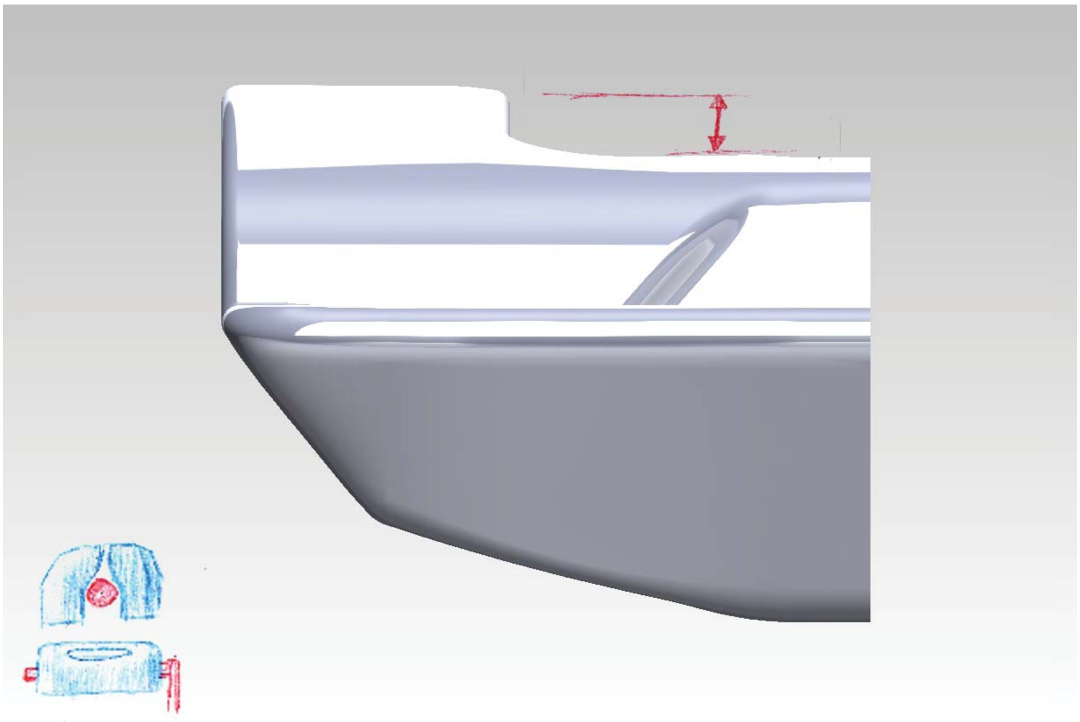


Figure 35 The grip is raised to space the wings

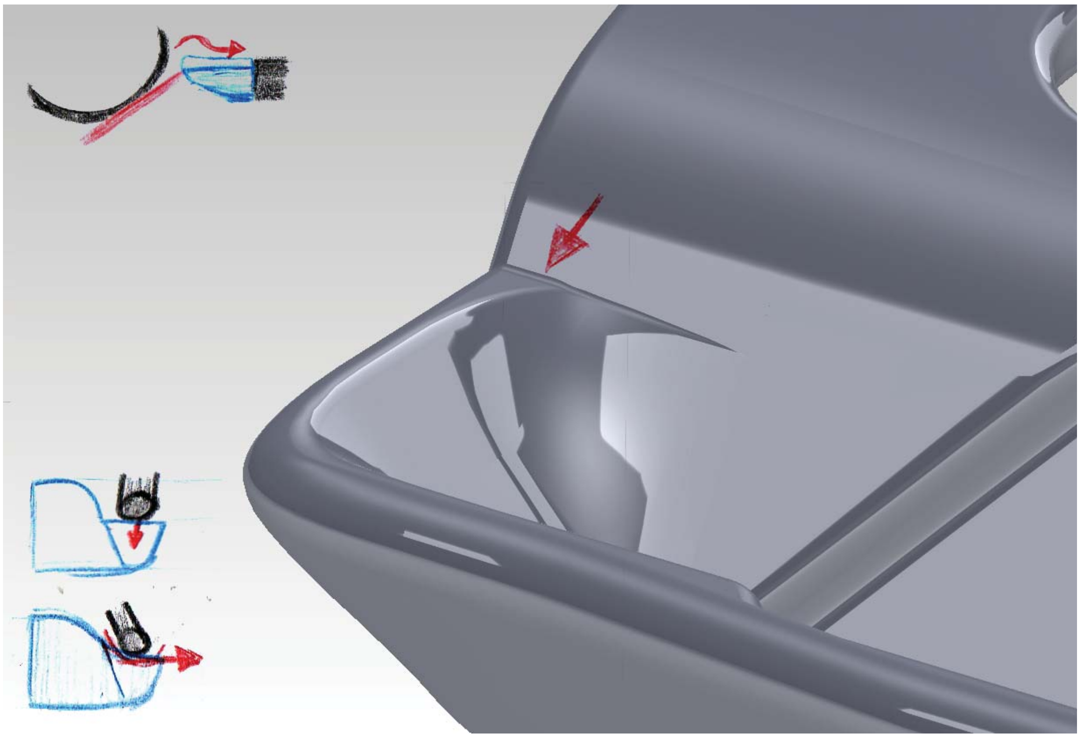


Figure 36 The gutter end is kept leveled to avoid a bike slipping from the carrier. This could occur when a ramp is used to load the bicycles on the carrier. Ease of use is more important than such a small part of the overall look.

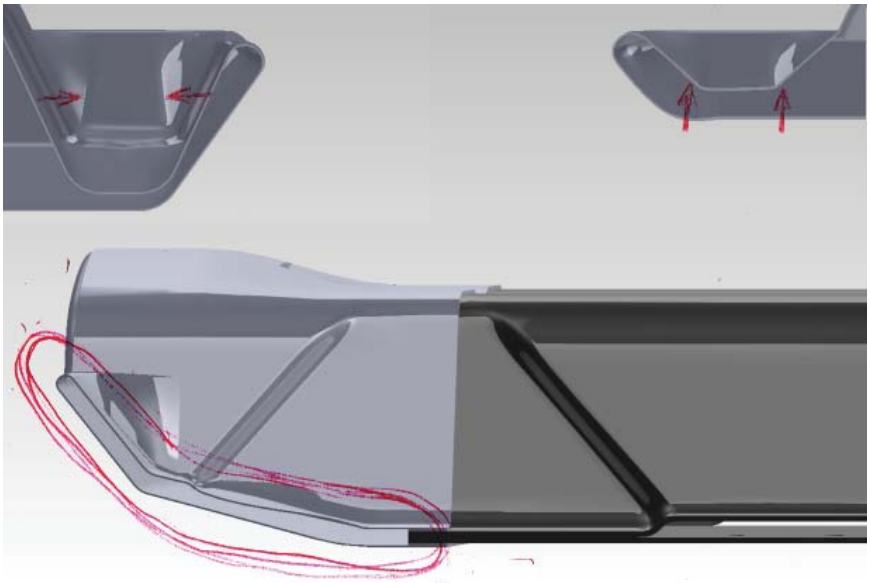


Figure 37 The gutter is narrowed and sloping upward to towards the end in order to avoid bikes rolling out of the gutter.

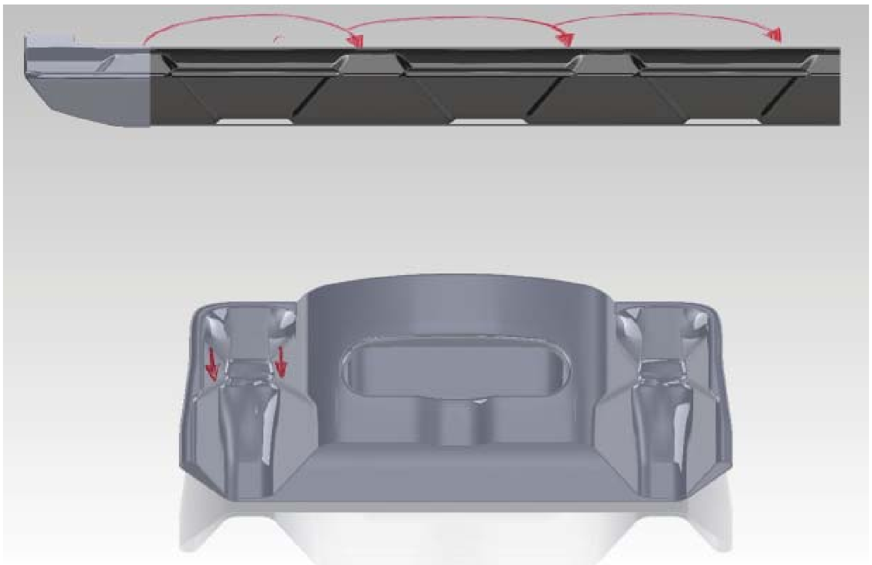


Figure 38 The step in the wings is also used in the handle. One reason is to clamp the wheels in place as the wing ends in the wide part of the step. The other is to tie the handle visually to the wing, including it in the stepped pattern. The outside is kept smooth to create a more clean, calm end of the gutter.

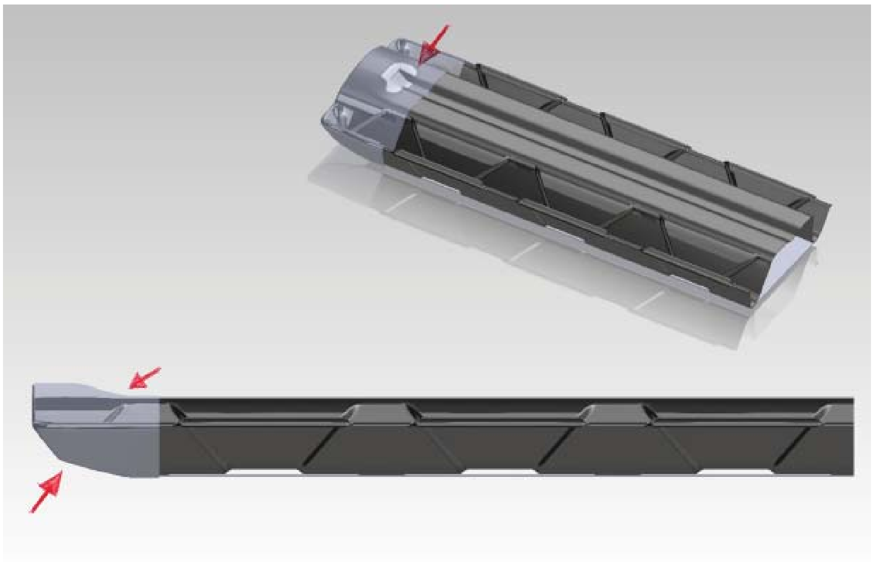


*Figure 39	The top and bottom are curved to blend different parts. The dent in the wing with the straight end of the grip and the bottom of the wing with the side of the handle.*

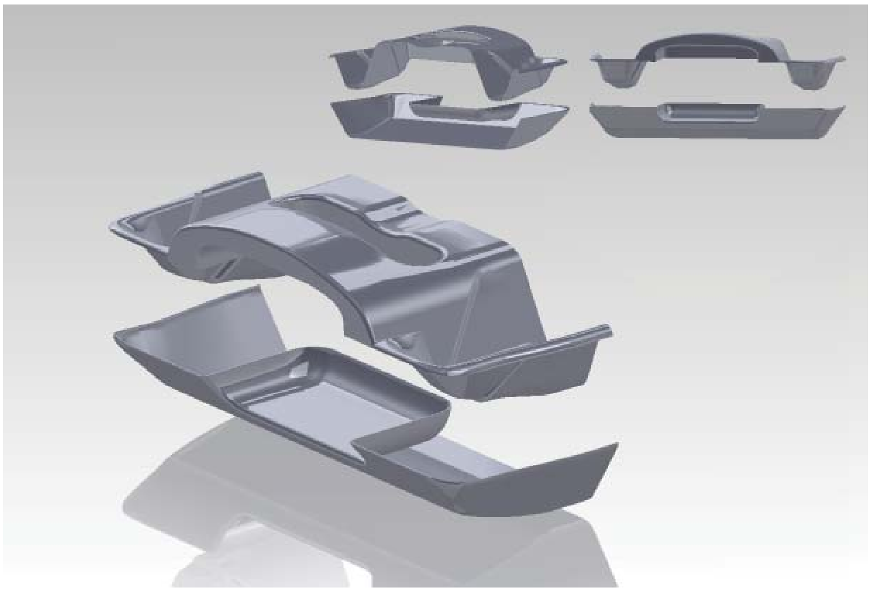


*Figure 40	The handle is split in two parts. This is done for production purposes. The other advantage is a double layered gutter wall. Ribs to strengthen and stiffen these walls can now be added between the layers if needed.*

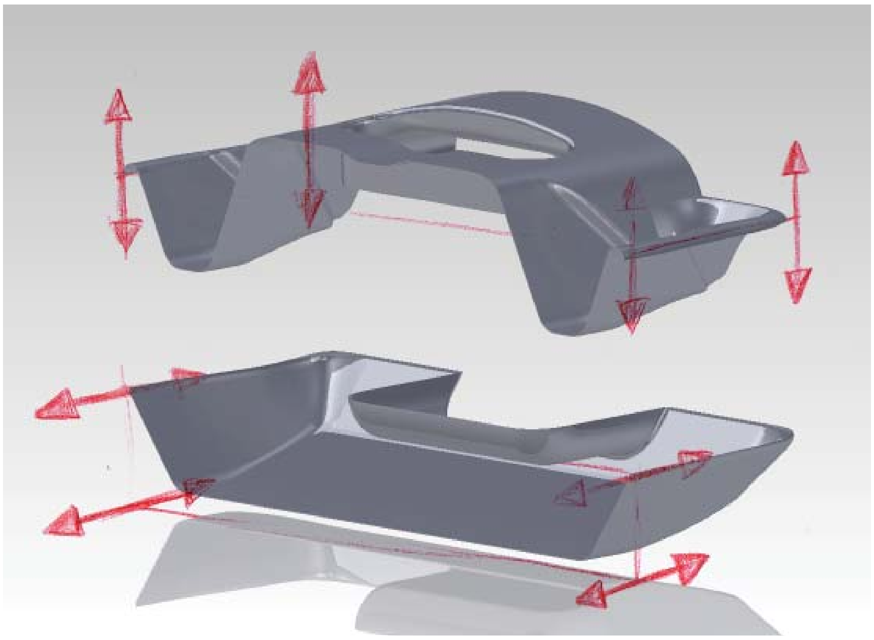


Figure 41 The complex shape is an important reason to split the handle. The step and the cavity under the grip create draft difficulties. Two draft directions can be used in a two part design and solve that propblem. It is also the easiest manner to get a comfortable radius on the edges of the grip section.

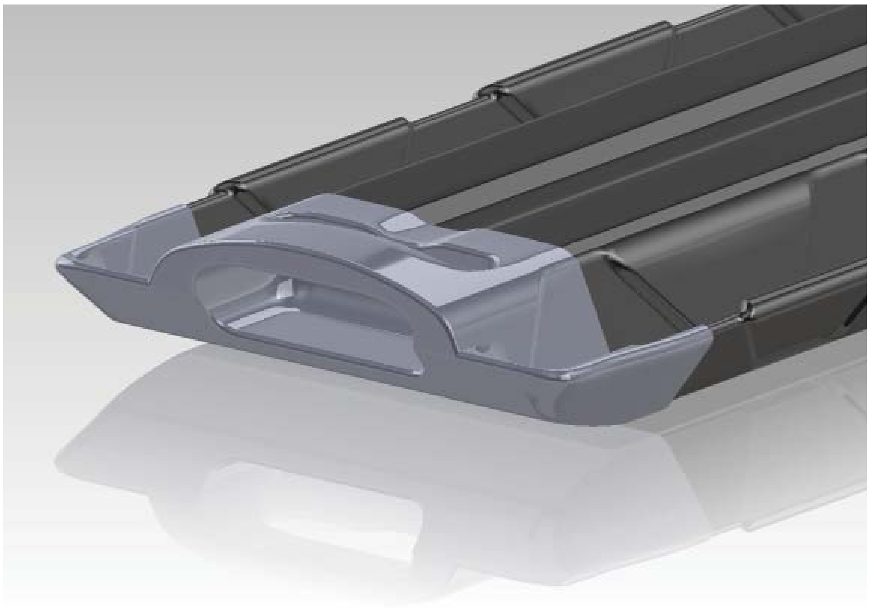


Figure 42 The final handle design mounted on the wing.

Lights and licenseplate mounting

A licenseplate and lightunits are required to use the bike carrier on public roads. They are seperate components that have to be mounted to the wing. This can be done directly or by using an additional connection part.
The function of the mount has to be established first. The lights only need to be kept in place. Therefore the mount has to be strong enough to support an estimated 500 grams. However the licenseplate needs to rotate, fold, or slide away so the bike carrier can be folded without the plate protruding. Therefore the licenseplate mount has to carry the weight of the plate and it has to enable movement. Stiffness and strength are dealt with later as they can easily be adjusted by changing dimensions and the loads are quite low.

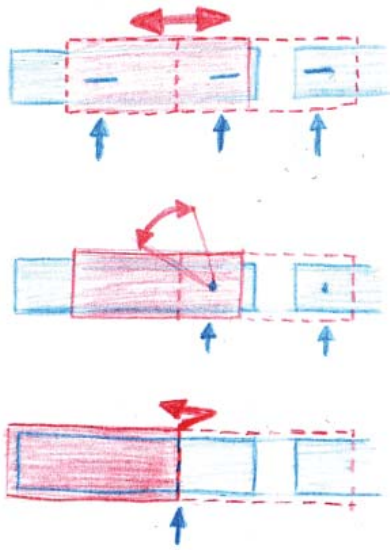


Figure 43 Moving the license plate by sliding, rotating and folding.

Moving the license plate is essential to fold the carrier after use and still position it correctly when in use. There are several ways to achieve this as illustrated in Figure 43. Sliding requires at least three places with some kind of a rail to support the plate. In the figure from left to right: support the end of the license plate when it sits in front of the wing, support a part of the plate in any position and support the end when the license plate sits infront of the gap and hangs from both wings. The pieces of rail on the left wing can be combined into on longer rail, the small piece on the other wing however cannot be combined as the wings cannot be folded together. Sliding the license plate on the second rail can cause alignment issues.
The second option of rotating the license plate is used in the MovaNext M3. A pivoting point and a support point on the other wing are needed. These are hidden from sight by the licenseplate itself when the carrier is collapsed and also when it is unfolded, removing distracting components from sight. Another advantage of rotating is that the vertical position of the license plate can be chosen freely. Where sliding and folding keep the plate at the same height in both, collapsed and unfolded, state, the rotating plate can hang lower between the gap whilst hanging higher infront of the wing. Figure 44 illustrates how moving the pivot point along the license plate and wing can have a dramatic influence on the position of the plate.

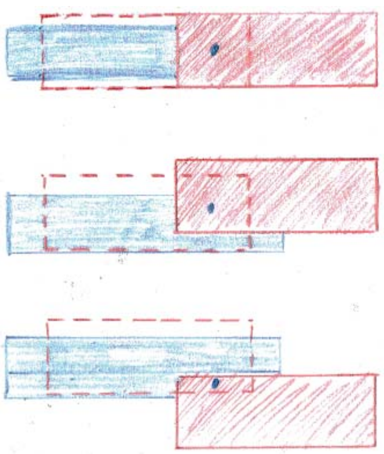


Figure 44 Variation in height by moving the pivot point.

The last option in Figure 43 is folding the license plate. A hinge at the end of the plate is needed that can carry

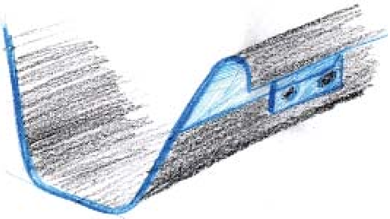


Figure 45 Integrated mounting points.

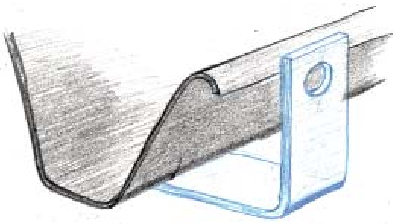


Figure 46 Mounting bracket.

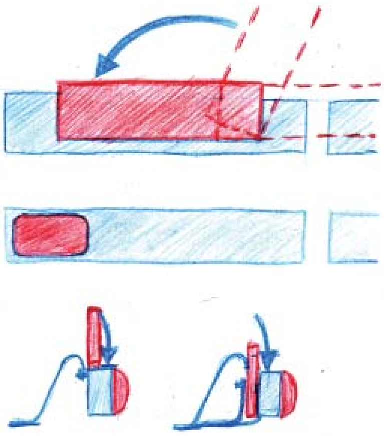


Figure 47 Potential folding difficulties.

Figure 48 Play in the pivot point.

its weight. In order to keep the plate in place, some sort of fixation should be used, like a magnet. This option is really easy to use. On the downside, the ease of folding the plate may cause doubt on whether or not it will stay in the intended position. However the most important issue is the lack of positioning freedom compared to the rotation option.
The possibility of placing the license plate in the visually best position is the big advantage of rotation. The absence of drawbacks like precise alignment makes rotating the licenseplate the best way of moving it.

Mounting the lights and license plate can be done directly or indirect as mentioned before. Figure 45 shows how the mounting points can be integrated. The lip can be an extension of the handle or integral part of the wing. If the lip is part of the wing, a lot of extra material is used which increases weight or all of the excess needs to be trimmed off. Trimming is very laborious as it can not be done with a quick and straight movement. The problem with an extended handle is that only the lights, close to the end of the wing can be mounted, whereas the license plate needs to be attached in a different way.
Another option is using four connection pieces like the bracket in Figure 46. An advantage of this option is that the depth of the lights and licenseplate can be varied. The plate can be rotated behind the lights without hitting them as shown in Figure 46. Moving the plate in front of the lightunits is also possible but this would cause the bracket to jut out a lot further. The lightunits will cover the brackets on which they are mounted. The supporting bracket for the plate however is not always covered. Eventhough it will be strong enough, a piece of sheet metal will look quite flimsy if it juts out. So the for a reassuring appearance, the plate should be mounted closest to the wing. The plate is kept in place by the light and the wing in one direction and by the brackets of both light units if the wings are folded together. The slot between the wing and the light also gives the rotation an aim, preventing the user from bending the licenseplate slightly, creating play in the pivoting point on the long term.
The last option is creating the brackets as a part of the bottom plate. This has even more serious drawbacks than the first direct mounting points. The material that needs to be trimmed of is a lot larger as the lips are really long. Waste increases the costs but the fact that the bottom plates need to be bent increases the costs even more.

Moulds of the size of the bottom plate are really costly and should be avoided.
Mounting the licenseplate and lights in such a way that they do not interfere, can be achieved with a mountingbracket. This choice is backed by the production speed and costs.

Using a rotating license plate gives a lot of positioning freedom without alignment issues. Mounting it can be done quick and cheap with mounting brackets.

Lightunit bracket design

Figure 49 illustrates the influence of the mountingbrackets, lights and licenseplate on the appearance of the bike carrier. The difference between the license plate behind or in front of the lights is very small. However, mounting the licenceplate closest to the wing, at the top in the picture,

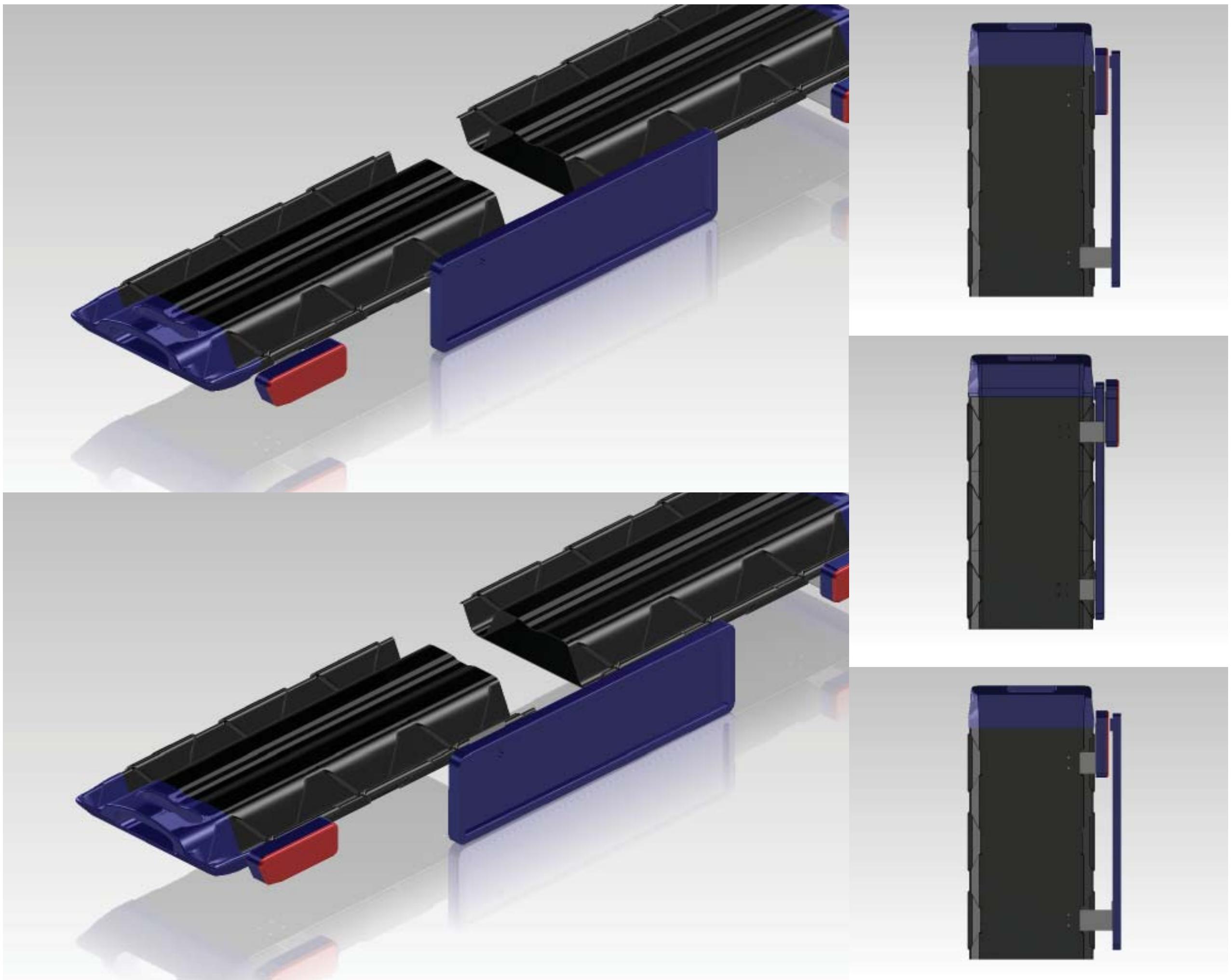


Figure 49 Visual impact of the positioning order. The license plate behind the lights results in a leaner appearance, folded and unfolded and a less fragile look folded.

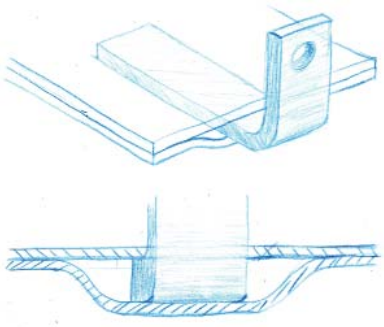


Figure 50 Blind mount for the brackets.

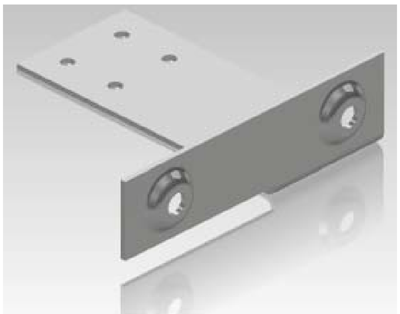


Figure 51 Mounting bracket for the light units.

gives a slightly sleeker look. This also applies to the side views. Therefore the mounting brackets of the lightunits should be longer than the other brackets.
A single bracket seems out of place where two similar brackets give a more organised look. Therefore the lights should not be integrated in the handle. The smaller the difference between these brackets is, the less attention is drawn to them. Therefore the flattest component needs to be mounted closest to the wing, one bracket juts out that thickness further than the other.
With the depth of the brackets determined, height and width are the next concerns. The mounting points are limited as the brackets will be mounted between the steps, shown in Figure 50. This should keep the bottom of the wing free of visually distracting components.
These fixed points make it impossible to mount the light units centered on the bracket, as they have to be positioned further towards the ends than the last arches of the carrier to meet regulation standards.
Another usefull design feature is to create a flat back on the light unit with its bracket so the licenceplate can slide behind it without catching on something. Protruding nuts or bolt heads can be avoided by creating a space in the bracket for them. However in order for this to work, the lightunits need this space too.
The last dimension is the height. Blending the light unit in with the wing is achieved by positioning it in front of the gutter wall. The bracket can stay as low as possible and is completely covered by the lightunit itself. Put together, these ideas result in a bracket shown in Figure 51.

The depth of the lightunit brackets must be larger than the licence plate brackets to fit the plate behind the lights. This is important for the appearance of the product. To comply with regulations, the lights cannot be mounted in the middle of the bracket. This means that the bracket will have a narrow base with a long top part to hold the light. The height can be as low as the light unit allows it to be. A helpful addition to the simple bracket are two indentations. These are useful to avoid any protruding fasteners that interfere with the licence plate.

Positioning of the licence plate with a bracket

The two brackets for the licenseplate are slightly more critical because they must position the licence plate.

Pivot point's position

The licence plate has two positions: one folded behind the light units during storage and the other hanging between the wings. Both have different requirements. The licence plate should be able to rest on the bracket of the light unit. The vertical position in the other position will be dictated by regulations or chosen on the basis of the look. To get the resting position right, the height of the pivot point in the bracket just needs to be the same as the distance from the edge of the licence plate to the pivot point. (A)

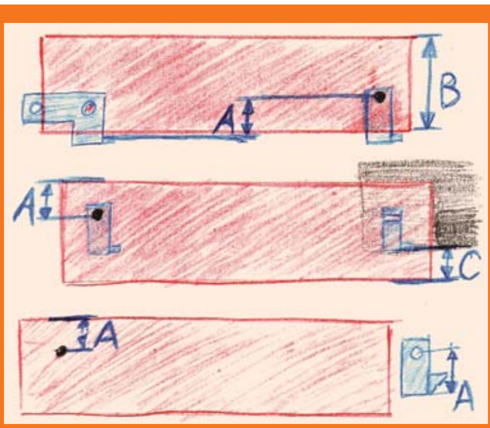


Figure 52

The height of the licence plate during use on the car is not determined yet. However the height of the plate (B) is set. When the desired position of the plate in relation to the wings is determined (C), the height of the pivot point follows:

$B=A+A+C \quad B-C=A+A$

$A=(B-C)/2$

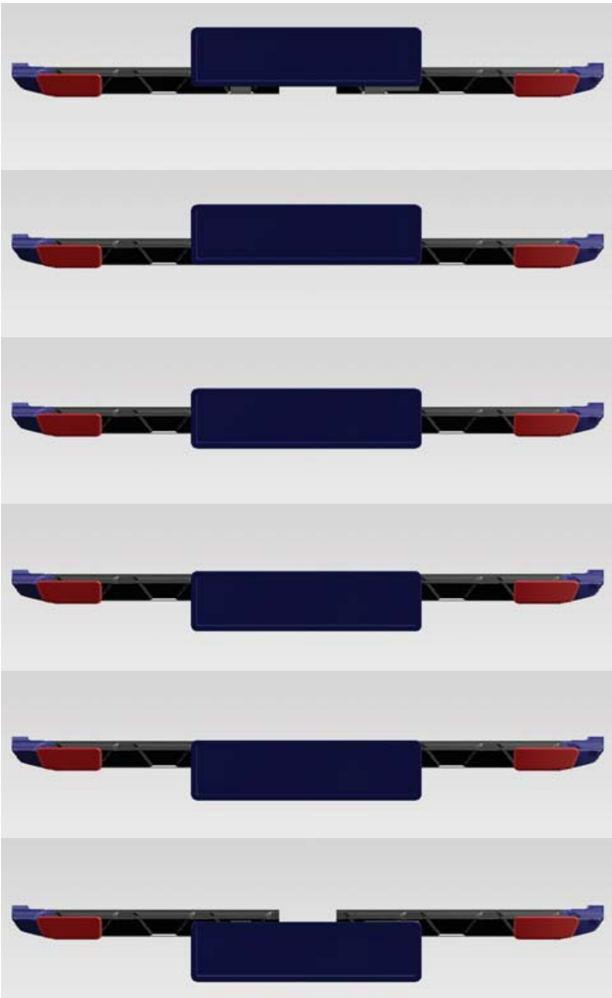


Figure 53 Visual impact of the position of the licenseplate.

By moving the hinge up and down on the bracket or the plate, the height of the licence plate can be varied. By changing both holes up or down at the same time, the plate stays at the same height. However if the plate is rotated in its storage position after the change, the height is different. The principle is explained in Figure 52.

The height of the brackets is determined in such a way that the licence plate is only just higher than the top of the wings: the fourth carrier in Figure 53. There are several reasons for this choice. The first is not really visible in the picture but the top corners of the license plate are positioned on the diagonal lines of the steps, connecting the plate and the wing visually. Secondly, the bottom of licenseplate hanging below the wing breaks the horizontal line of the bottom of the carrier. This creates a floating sensation by breaking the association with heavy structures like pyramids, parasol bases and carafes which all are widest at the bottom. The link with light things like a hot air balloon, Casper the friendly ghost and a parachute can be made instead, with the bottom tapering inward.

Component design

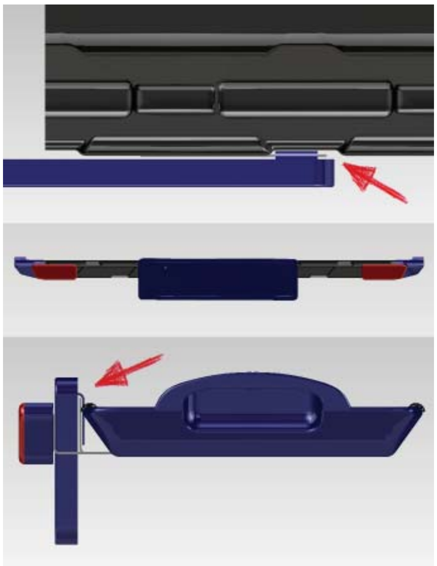


Figure 54 Clip to keep the licence plate in place. (Top, front and side view.)

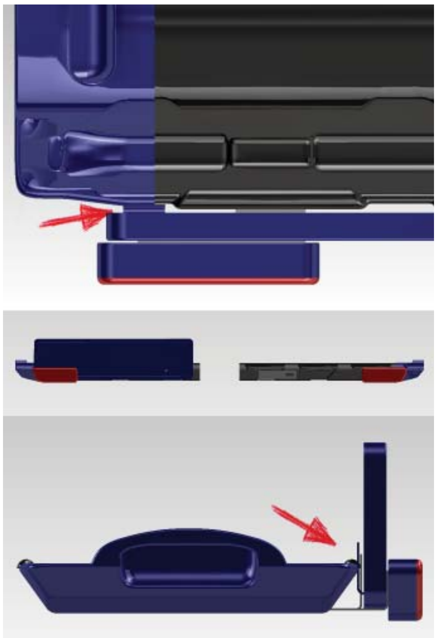


Figure 55 Avoiding contact between the clip and wing

The third reason is that the licence plate should become a part of the carrier instead of something that hangs from it. The principle to achieve this is raising the licenseplate slightly above the top of the wing.

The horizontal position of the licence plate can be adjusted in the manner explained in Figure 51. The plate should hang in the middle of the bike carrier when it is used. While it is stored, the licence plate should not jut out at the hinged side of the wing as this would be come the bottom of the product. These are fairly straight forward criteria.
The clip however prevents the licence plate from moving when carrier shakes during use. One end of the licence plate is fixed at the pivot point, the other rests with the clip on a bracket. The clip and the bracket need some extra space between the license plate and wing. A smaller product will be perceived as lighter. Therefore the design should be as compact as possible. The licence plate could be mounted a little closer to the wing if the clip is positioned in the narrow part of the step, illustrated in Figure 53. When the licence plate is rotated from use- to storage position, the clip should also be at the narrow step or after the last step in this case.
To achieve this situation, as depicted in Figure 55, the pivoting point will be shifted a little from the centre of the bracket. The rest has to cover half a period of the step.However this shape is not ideal for the strength and stiffness of the mount.
Figure 56 and Figure 57 indicate that the strength is no issue at all and that the stiffness is acceptable. The thickness is 2mm, the material steel and the load is 300N, applied 10mm from the corner of the bracket. The load of 300N is around 16kg at 2G, which simulates the bracket of one light unit taking the load of bumping the whole bike carrier (with its old weight) into something. The position of the load is chosen to take the light unit into account. The material and thickness are chosen because this material is already used in the bridge of the carrier. The brackets for the light units will work with these criteria. These brackets cover the licence plate so the licence plate brackets will take less load and can also be made from 2mm steel plate.

Figure 58 shows the bracket design for a compact and clean look and that positions the components correctly.

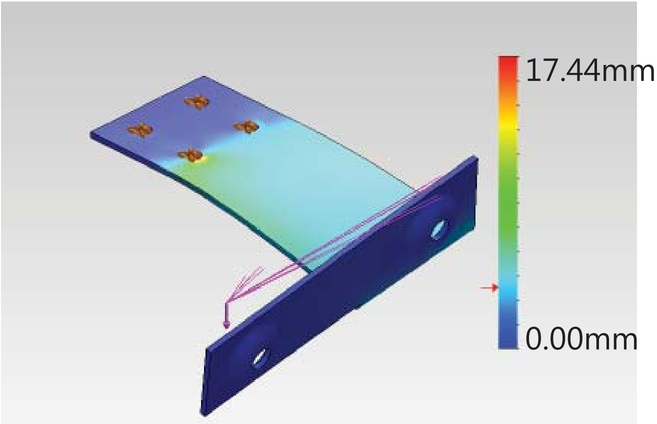


Figure 56 Bracket loaded with 16kg vertically at 2G.

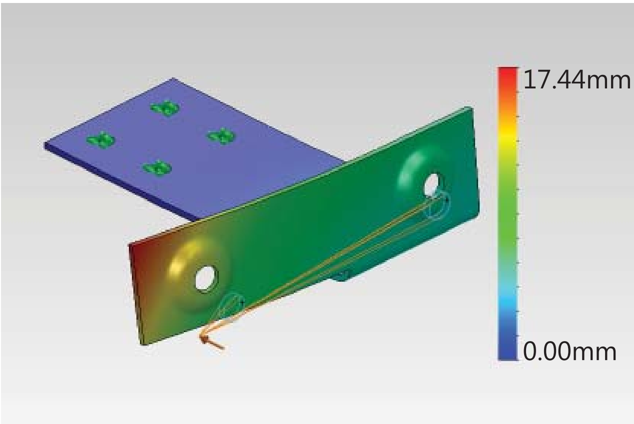


Figure 57 Bracket loaded with 16kg horizontally at 2G.

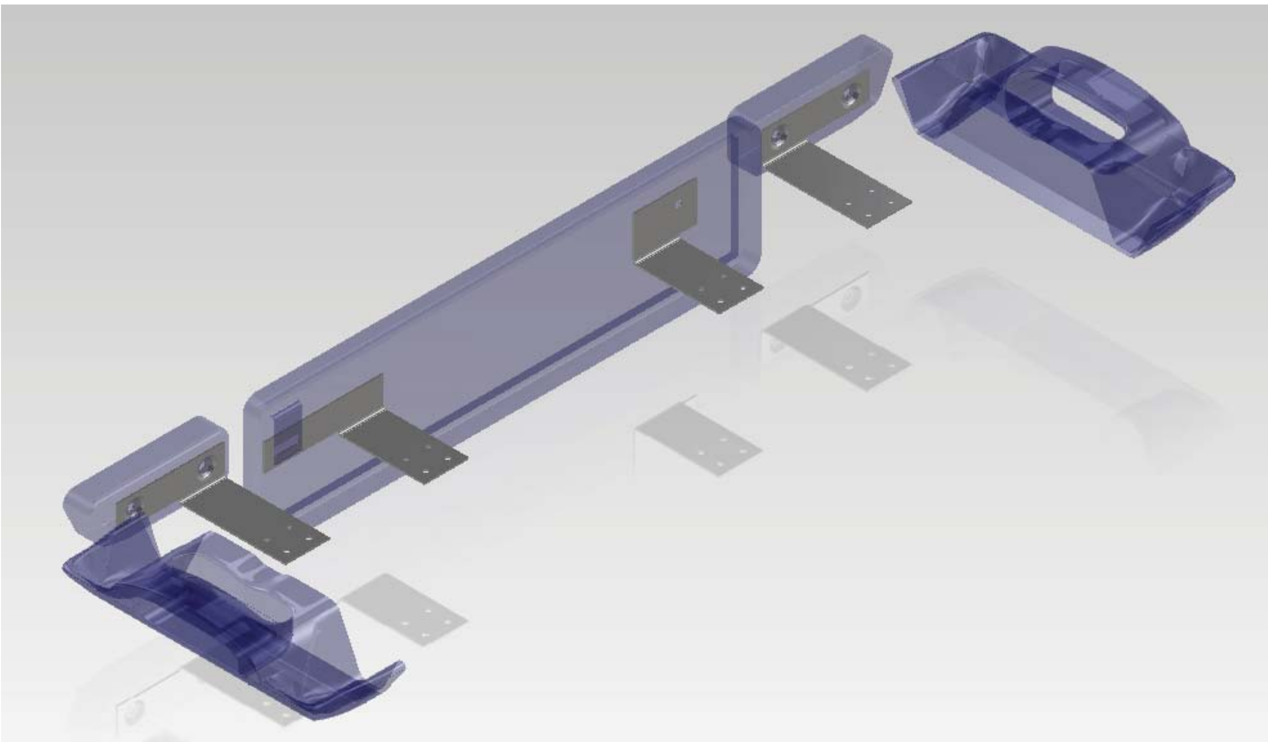


Figure 58 Global design of all mounting brackets.

Component design

Securing the wheels

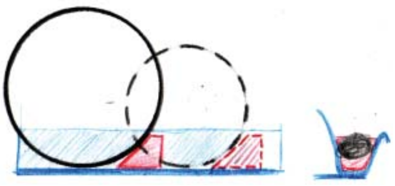


Figure 59 Purpose of the wheelpads.

The purpose of the product is carrying bicycles. In order to do so, the bikes need to be fastened to the carrier. Figure 59 illustrates what the two principles of the fastening are. Two blocks on the insides of the wheels secure the wheels in riding direction, with their shape and straps. These pads must be able to move to fit bikes of different sizes as stated in the product requirements. The other principle, on the right is the vertical support of the bicycle. This section shows that the tyre rests on the sides of the gutter, not on the bottom. Together, the pad and the gutter support the wheels on two places, keeping it in place and preventing the front wheel from swivelling from side to side.

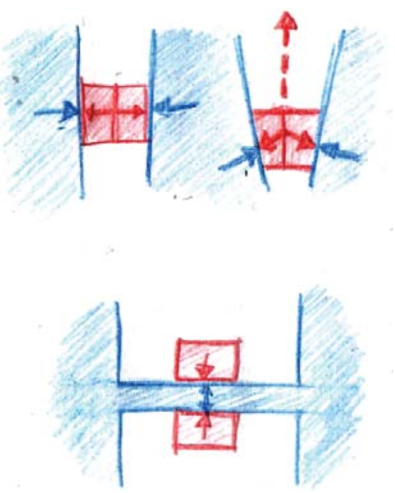


Figure 60 Wedging or clamping.

The current product uses a sliding pad, clamped to a tubular frame. An advantage of sliding is the ease of use: the pad slides along a guided path until it touches the tyre, no precise positioning is required. The sliding motion will therefore be preserved.
Keeping the pad in position can be done by either wedging it between two faces or clamping it, which is illustrated in Figure 60. Simply wedging the pad in the gutter is impossible as it will be driven upward if the to surfaces are not parallel. The difficulty of clamping the pad is that two parts on either side of the component it is clamped on have to be connected. Therefore both options need an additional rail or other component which is fastened to the wing or a slot should be milled in the wing so the two clamping parts can be connected.

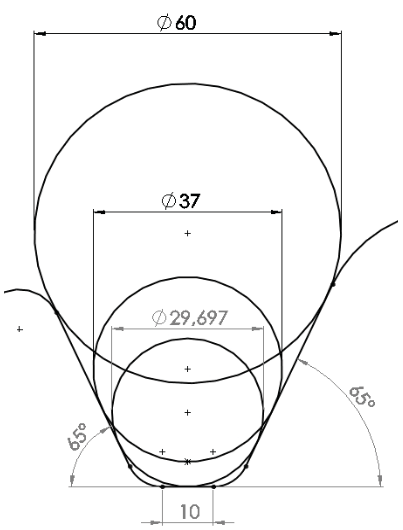


Figure 61 Contact points of various tyres

Milling a slot in the wing has two downsides, the slot weakens the wing and the machining causes damage to the laminate increasing the risk of delamination and failure of the wing.
Another problem of mounting the pads directly on the wing is the stepped gutter wall. In order to accommodate the bikes with wheels between 24 and 28 inches and 1050 and 1200mm between the axis, the pad has to be able to move further than the longest flat surface between the steps. Appendix E explains the minimal length of travel. An additional component could bridge the gaps between the steps. Modifying the wing by flattening part of the step will undermine the purpose of the steps and cause difficulties with draping the material of the wing over the mould. Therefore an additional component is necessary eventhough it causes an extra assembly step and extra manufacturing costs.

This additional component should not be mounted on the inside of the gutter as the wheels make contact with the wing there. Figure 61 shows that this applies to the whole gutter. 60mm is the diameter of a mountainbike tyre, 40mm the diameter of a standard bicycle tyre and all tyres under 29mm, like racing bike tyres, stand on the bottom of the gutter. It will be frustrating for customers if only certain bikes fit on the carrier, therefore none of the common tyre sizes should be excluded. The joint between the component and the wing should not bear the load of the bikes, so the rails should not be mounted on the walls of the gutter.

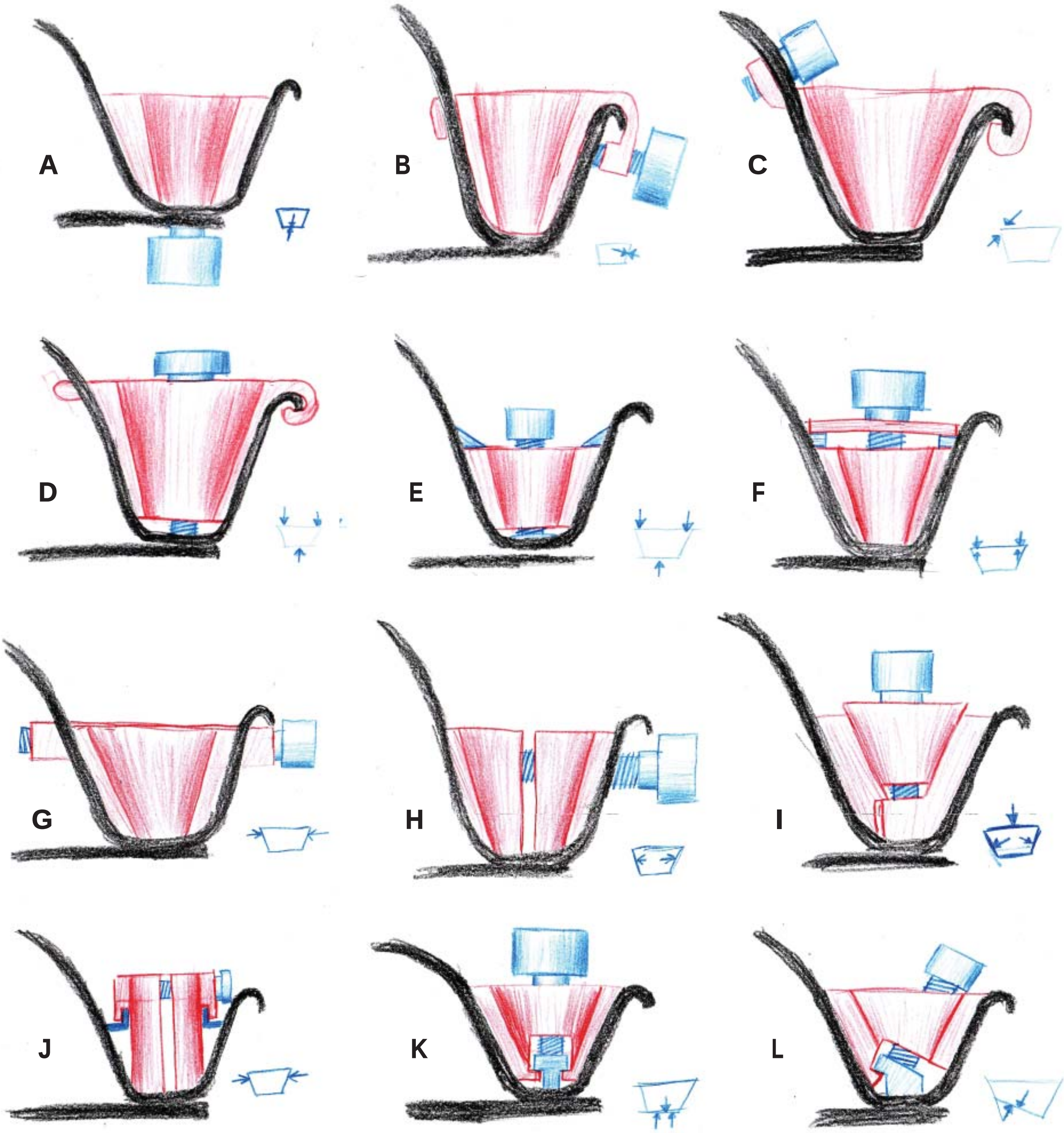


Figure 62 Sliding mechanisms for the wheel pads.

The sections in Figure 62 show all ideas on fastening the pads. Almost all options will cause problems with either machining the wing or rails on the walls of the gutter. Option K and L however use a rail on the bottom of the gutter. Where K has a vertical knob, the knob of L is tilted so it can be accessed easier without touching the tyre. These two are the most promising options.
Rail K is symmetrical and one version can be used for all four pads whereas L has a left and a right version which need two different moulds or machining operations. Then both versions have to be stocked. This increases the costs. Assembly errors are more common as the two similar rails can be mistaken for one another.
These errors and costs make option K the best to use so a rail needs to be added to the wing.

Rail

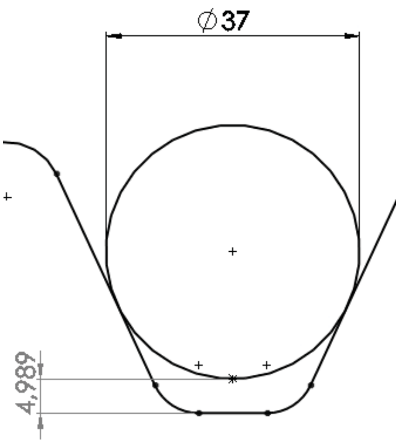


Figure 63 Space beneath a regular tyre.

The rail is quite simple in design. It is a T-shape as shown in Figure 61. The bottom half following the wing and the top stays level only dropping towards one end. This is done to keep the wheelpad from slipping off the rail. If the pad is loosened and slid carelessly out of the way to make room for the wheel, it will be slid backward, towards the centre of the carrier. If the pad is not clamped and the wings are being folded, the pad will slide towards the hinge. Therefore the inside end of the rail is dropped. The other end is kept straight so the pad can be slid on the rail or replaced after the rail is mounted to the wing.
Figure 63 shows the space beneath a tyre with the most common width on touring and city bikes. In the ideal situation, the rail fits underneath the tyre without touching it as this would let the tyre wedge in the gutter. The front wheel will swivel less if it is wedged in place. To achieve this, the T has to be lower than 4,9mm. About 2mm for the material thicknesses A and B in Figure 64 leaves some play to move the pads and tolerances.

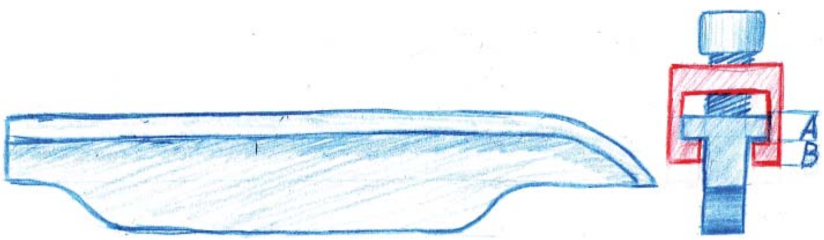


Figure 64 Side view and front view of the rail

Wheelpads

Figure 65 Wheel above the tightening knob.

The component that supports the wheel on the inside has three features: providing support, secure the wheel to the support and hold the supported wheel in place.
This pad will be the body of the component with the other features being added to it. To ensure that they function with the other parts, some size restrictions will apply: The wheel pad must fit in the gutter and on the rail. Secondly, the top of the complete wheelpad should stay lower than the top of the wing so the user does not have to move the pads to be able to fold the wings together. The other dimensions are not dictated but might be influenced by the wheel and the licence plate.

Holding the wheel in place is the main function of the wheelpad. In order to do so, the pad will be clamped on the rail with a threaded rod as illustrated in Figure 64, option K. A injection moulded knob with a bolt as an insert is used by the user to fasten the wheel pad. The solid gutter prevents positioning the knob in the side or at the bottom of the pad, which is done in the open frame of the current product.
A wheel will eventually rest on the wheelpad thereby limiting access to the knob. To which extent was tested with a cardboard model of the gutter and pad. Users cannot use certain grips on the knob in a situation as depicted in Figure 65. A few grips are shown in Figure 65, from top to bottom: Using only the fingers to turn the knob, grapping the knob from above and turn from the wrist/underarm and using the wrist but with the knob at an angle. The hand of the user can be aligned with the knob without immediately hitting the wheel if the knob is mounted at an

Figure 66 Different grips on the tightening knob

Figure 67 Wheel above the tightening knob.

angle like in Figure 67. The vertically orientated knob can also be moved back, where there is more space between the tyre and the wing. The difference in access between vertically place knobs can be seen in Figure 67.

Figure 68 Available space above the knob can be increased by moving the knob back.

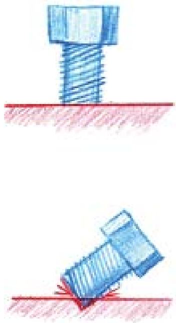


Figure 69 Cutting of the edge of a bolt in plastic.

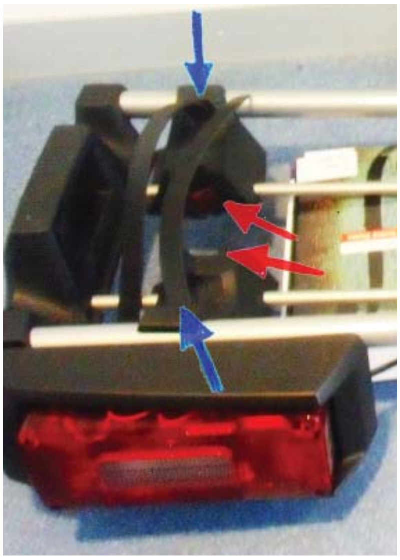


Figure 70 Fixed points of the straps in blue and adjusting points in red.

The user clamps the wheelpad in place which, in turn, will secure the bicycles. Besides actually doing so, the wheelpad must also convince the user the that it will do so. Therefore, the user must be able to apply force on the knob, screwing the rod tightly to the rail. This cannot be done just with the fingers. Mounting a vertical knob close to the wheel is therefore a bad choice.

The tilted knob has a different drawback: it will probably damage the rail. Figure 68 shows how a flat end on the rod or bolt can cut into the rail. The vertical bolt at the top makes contact with the whole end while the diagonal bolt at the bottom makes contact with an edge. The increased pressure, caused by the small contact area might deform the plastic rail. Leaving a vertically orientated knob as the best option.

The now supported wheels will be kept in place with a strap. Alternatives for the strap are hard to find because of the different sizes of wheels that have to be fastened. Which leave some necessary chances. The straps are fixed at the outside (marked blue in Figure 70) are adjusted on the inside (indicated in red) and jut through the frame of the wing. Because of the solid wing, the ends of the strap must stand up in the air or hang over the side of the gutter.

The strap is passed through a slot to keep the strap clamped in place. Users pull the end of the strap to tighten the loop. This is much easier if the strap is not bend sharply around the slot and if users can grap the

end of the strap after they fed it through the slot.
Figure 71 illustrates several possible layouts for the strap, its fixed end (indicated with a blue arrow) and the slot to adjust the strip (indicated with a red arrow). The license plate limits access on the outer side of the gutter, ruling out the top option. The sharp bending rules out the second, third and fifth option. With the additional problem of the wheel for option three and five. Leaving the fourth option. This option needs a more complicated wheel pad as the strap needs to loop through it but the accessibility and the ease of use compensate for that drawback.

The pad has to be fabricated eventually. One of the biggest differences between the new and the old wheelpad is the draft. The new pad drafts inward from to bottom, due to the shape of the gutter while the old pad drafted outward. Each of the pad has a top surface that is clearly visible and a ribbed inside for strength and guiding the pad along the wing. In order to finish the pad with smooth surfaces on all visible sides, a two part design as in Figure 71 should be used.

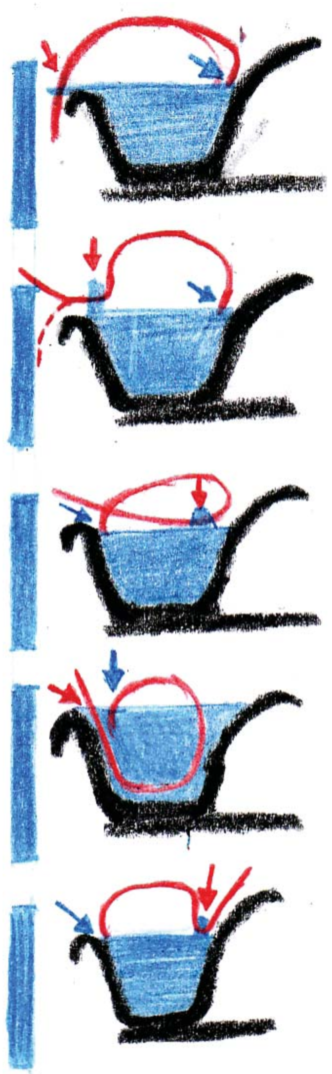


Figure 71 Strap layouts Fixed end indicated blue

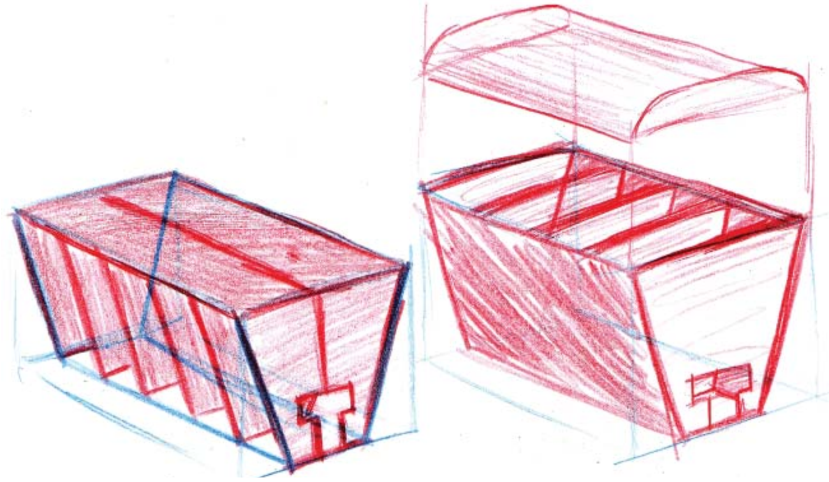


Figure 72 Surfaces on a single and a two piece design.

However, the main reason of the division of the wheel pad in two parts are the cavities and inserts. The nut insert for the clamping bolt, the mounting of the strap, the tunnel for the strap and the guide rail all have different draft directions. By using two pieces with the draft directions indicated in the bottom part of Figure 73, only the guide rail will be at an angle with the draft direction of the part. The cavities for the strap are created with ribs, between the two parts as shown in Figure 73.

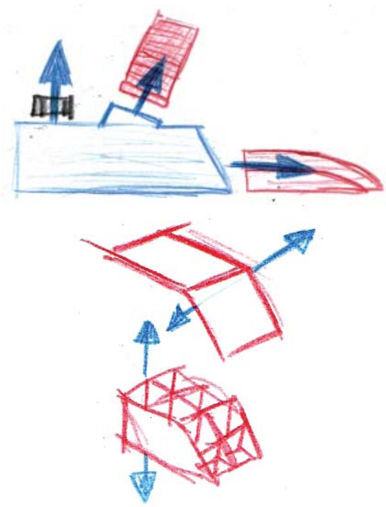


Figure 73 Draft directions for cavities and inserts

Figure 75 and Figure 76 show the merger of the sections above. A two part wheelpad, fastened to the guide rail with a bolt and a strap looped through the wheelpad to ensure access for the user.

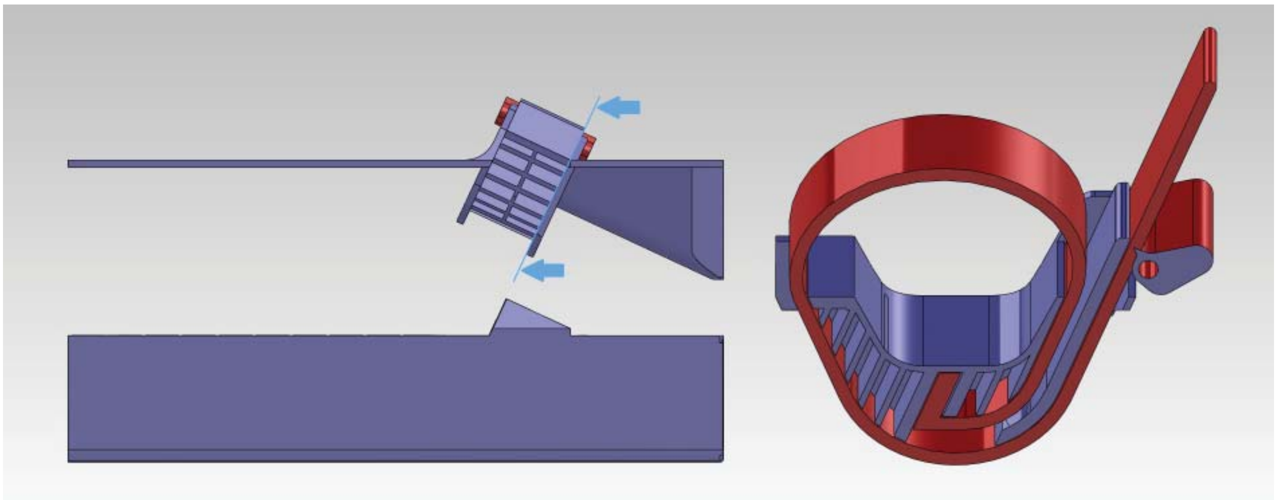


Figure 74 Section with the fastening of the strap

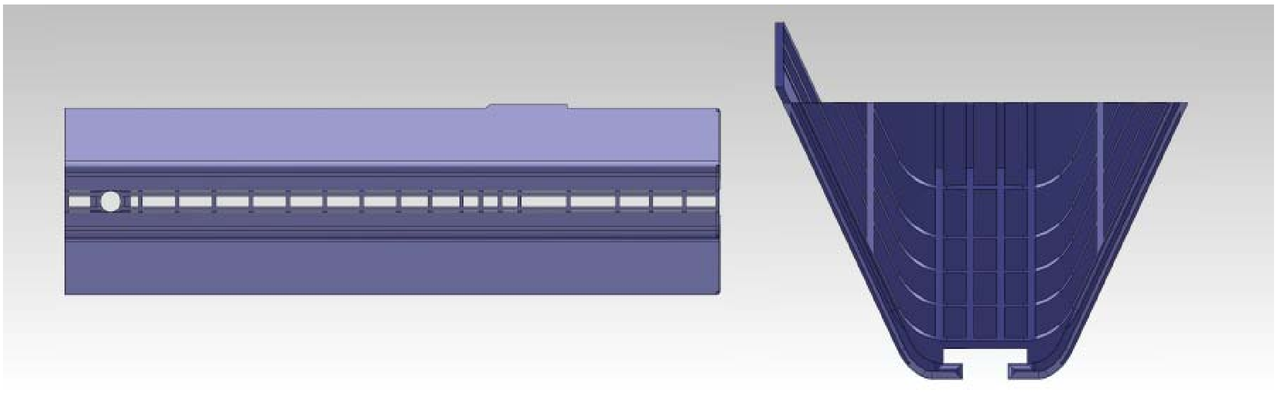


Figure 75 Guide slot: solid at the bottom and resting on the rail with ribs.

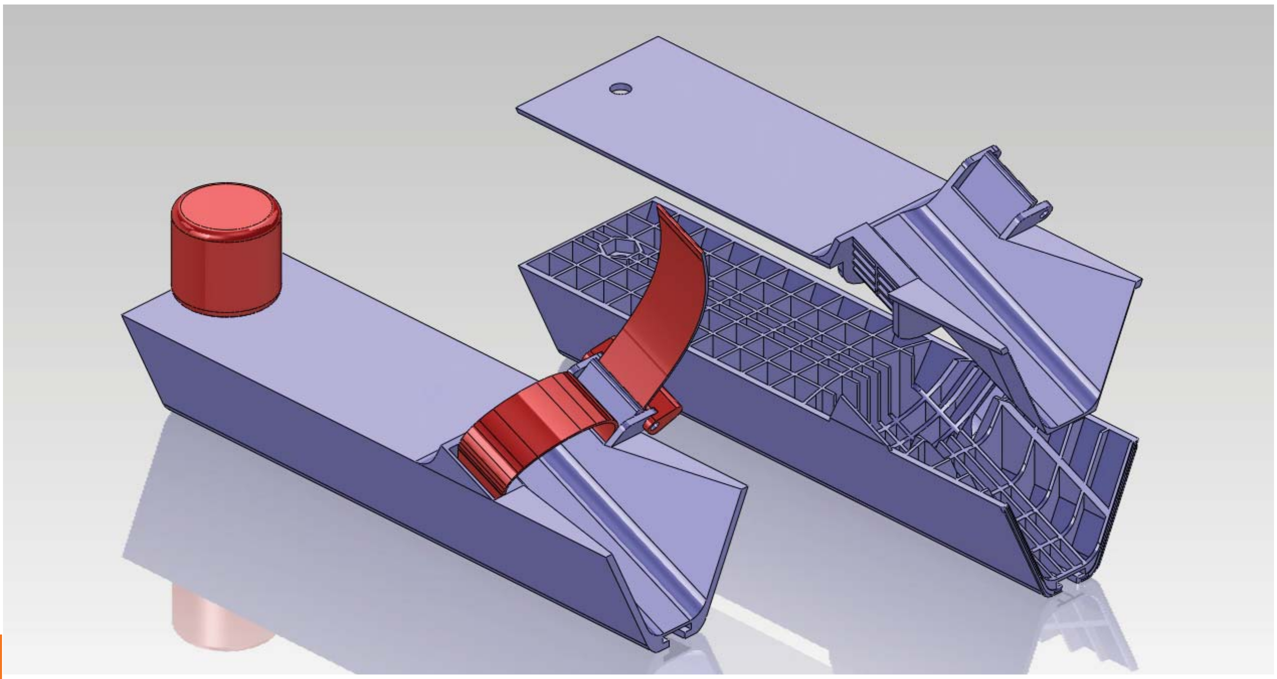


Figure 76 Overview of the two-part wheelpad.

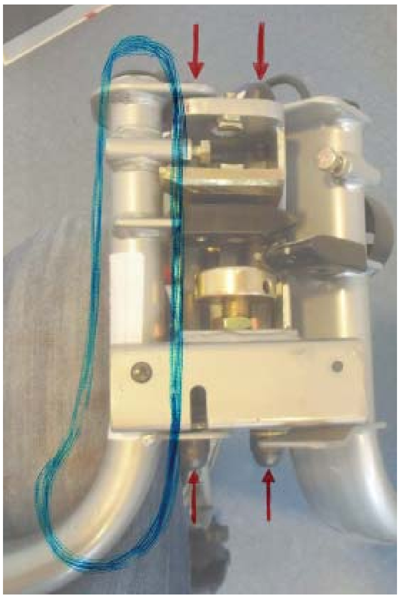


Figure 77 The section that needs to be replaced and the pivot points.

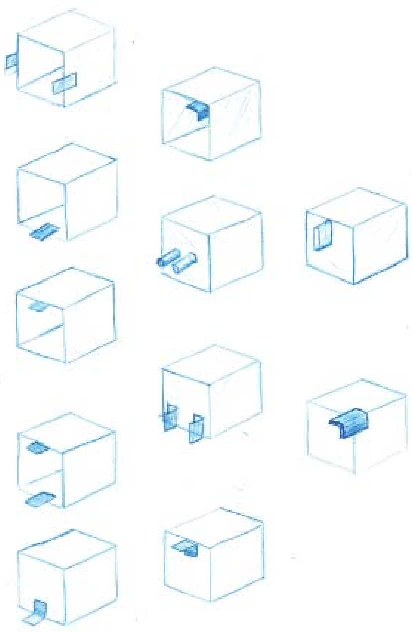


Figure 78 Schematic wings with possible mounts

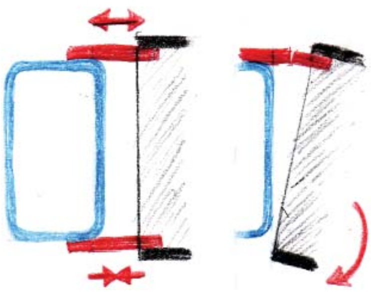


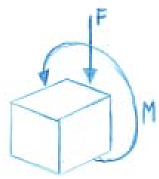
Figure 79 Necessity of a second point of support.

The design of the wheel pad is quite long to create space between the knob and the wheel. Using a shorter wheel pad with a tilted knob is not acceptable as this could damage the guide rail. Splitting the part in two pieces and looping the strap through the component is also necessary to provide access to the end of the strap and the release tumbler.

Connection to the bridge

Patents on the clamping mechanism are a reason to avoid the bridge section in this design process, but a new connection piece between the wing and the bridge section is needed. The section that must be replaced is circled in Figure 76.

The current design is a steel tube with several metal plates and smaller tubes attached. Most of these attachments are part of the clamping mechanism. To maintain their mechanical properties, a steel tube or beam will be the main part of the connection with the bridge. The wings have to be mounted directly on this beam or additional plates or tubes must be added.



Mounting the wing to the beam to carry the bend and torsion load can be done in lots of ways as shown in Figure 78. Welding plates to the beam is easiest with a lap joint on top or underneath or a vertical T-joint. Production speed and cost are ideal if the pieces only need to be cut in the right shape and do not have to be formed in any other way. There are no vertical walls on the wing, leaving a horizontal plate.

Horizontal plates can be mounted inside the hollow wing, hiding most of them. One thin steel plate however cannot carry the same load as the wing. By adding a second plate, the cross section enormously increases avoiding a failure as pictured in Figure 79.

To combine the two plates with the wing, the top plate has to be split into two tongues to make room for the dent in the top of the wing. These tongues are unlikely to be strong enough. A vertical reinforcement like in an I beam is a possible solution. This would result in a connection piece as shown in Figure 80.

Calculations to dimension the component properly would be needed. Cato however said that it is possible to mould multiple pieces of composite together in one the forming process. All steel work between the beam and the wing

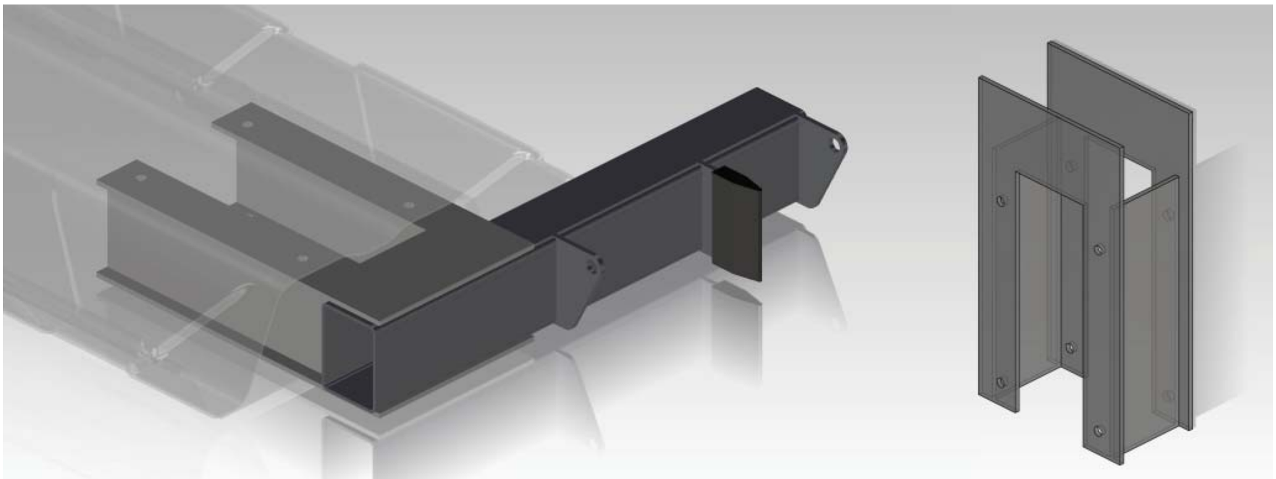


Figure 80 Steel connection piece between the wing and the bridge.

can be replaced by an extra sheet of composite moulded to the top of the wing and a longer bottom plate. An example is shown in Figure 81. Cato will work out which size and thickness are needed to meet the strength requirements. These values also depend on the behaviour of the joint and will therefore not be discussed further here.
Something that is worth mentioning is the stiffness of the hinge. Folding the wings is not that easy, so loosening the hinge increases the ease of use. More feedback is an additional benefit as the contrast between resistance of the hinge and contact between the beam and the bridge or the wing and the arm increases. It is recommended to decrease the stiffness of the bridge when the bridge is reviewed

A straight beam will be taken from the previous design to keep the working and strength of the bridge section intact. The wing will be mounted directly onto this beam as this require the least and the lightest material, saving weight. This design leaves the bridge unaltered. The stiffness of the hinge should be decreased if that section is reviewed in the future to increase the ease of use.

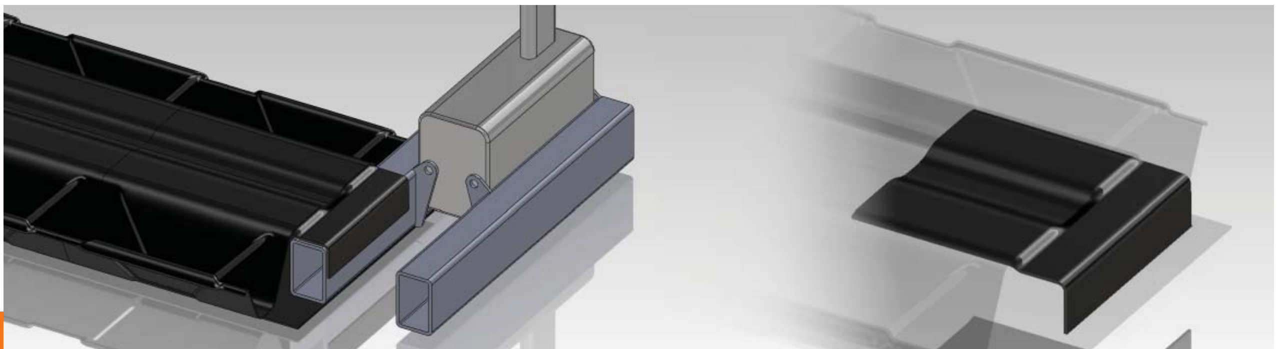


Figure 81 Composite connection piece to the bridge.

Colour and finish

The composite comes in black and other products made by Cato with the same process have a satin gloss finish. All the other components should complement the wing with their colour but also with their finish.

Key words for the design as stated in Appendix A and the Prephase are efficiency, technology and status. These associations should be strengthened with the colour scheme. Red, yellow and blue are compared in Figure 82 to Figure 84.

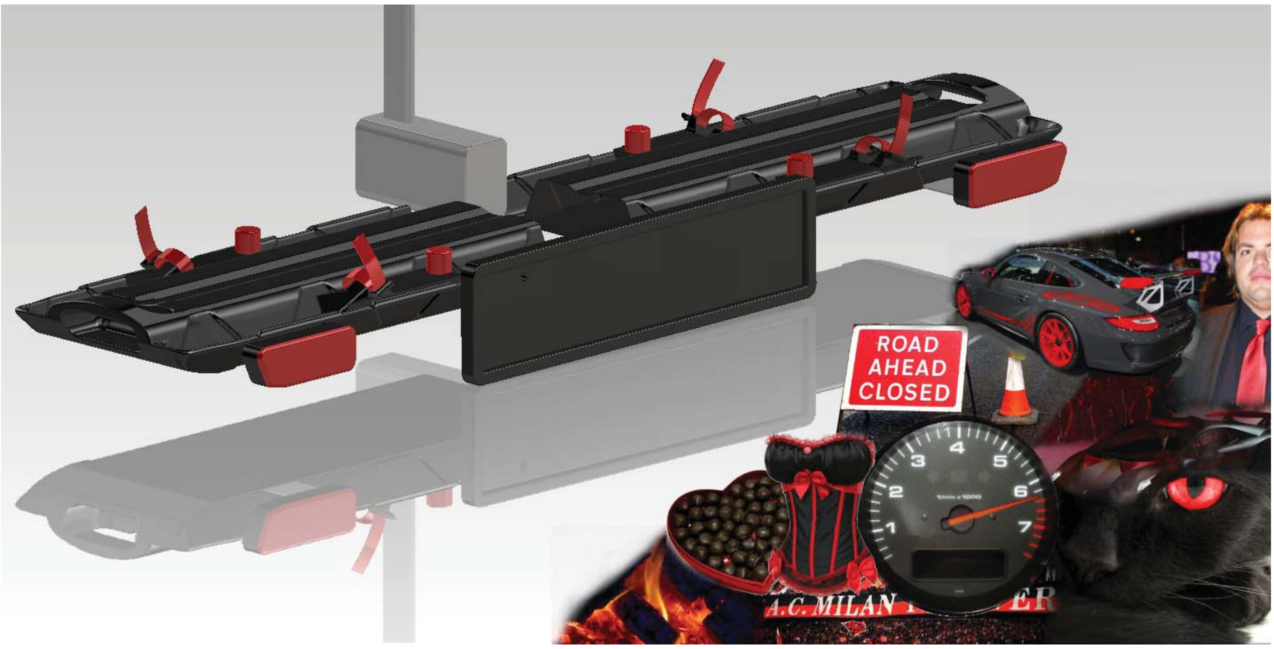


Figure 82 Black-Red: warmth, sensual, dangerous, sinister

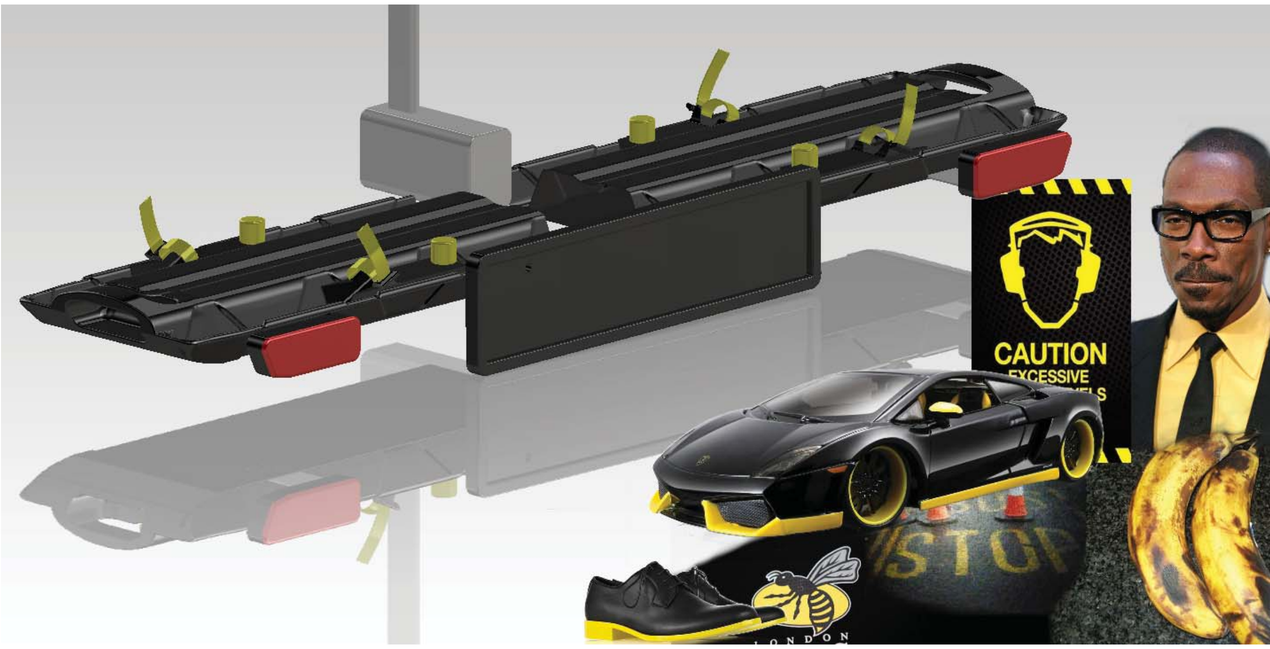


Figure 83 Black-Yellow: showy, roadmarkings, caution signs, bananas, bees and wasps

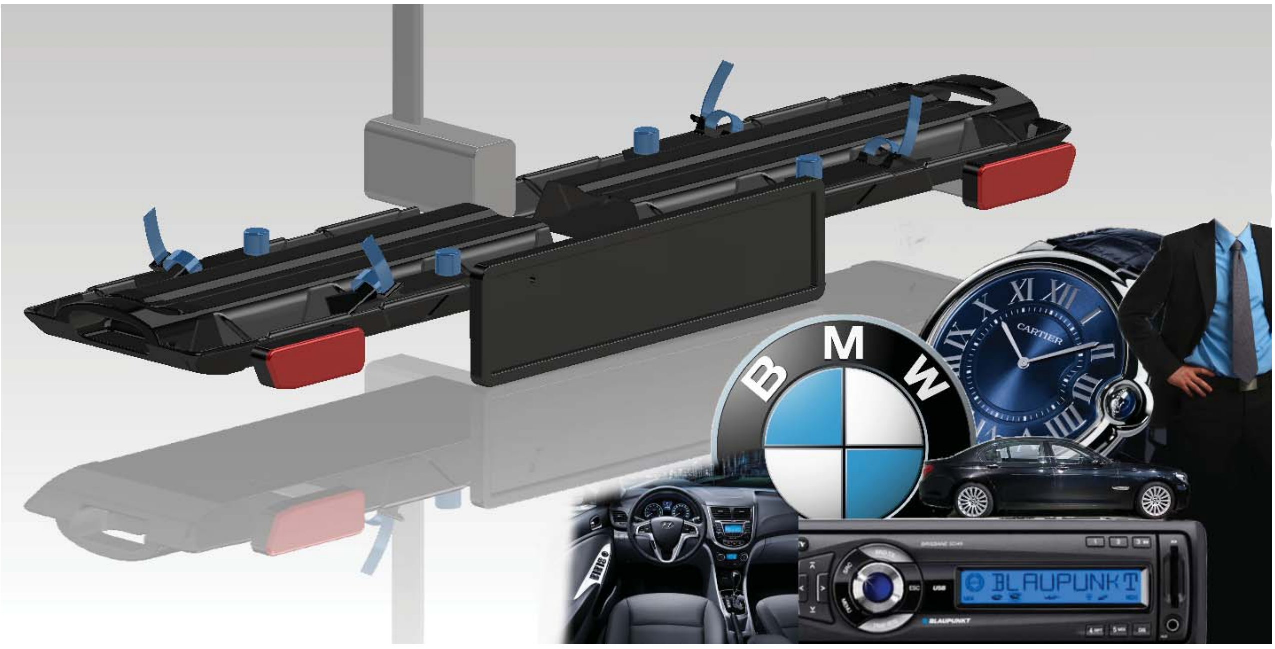


Figure 84 Black-blue: modest, business, electronics

Warm and vibrant colours create a strong contrast with the black of the wings. That contrast can be avoided with blue. Blue also does not have strong associations. Red and yellow do have stronger associations with (forbidden) passion and attracting attention respectively. Figure 85 completes the overview but non of the colours exceed blue. Pink, purple, lime and orange are a bit flashy, dark

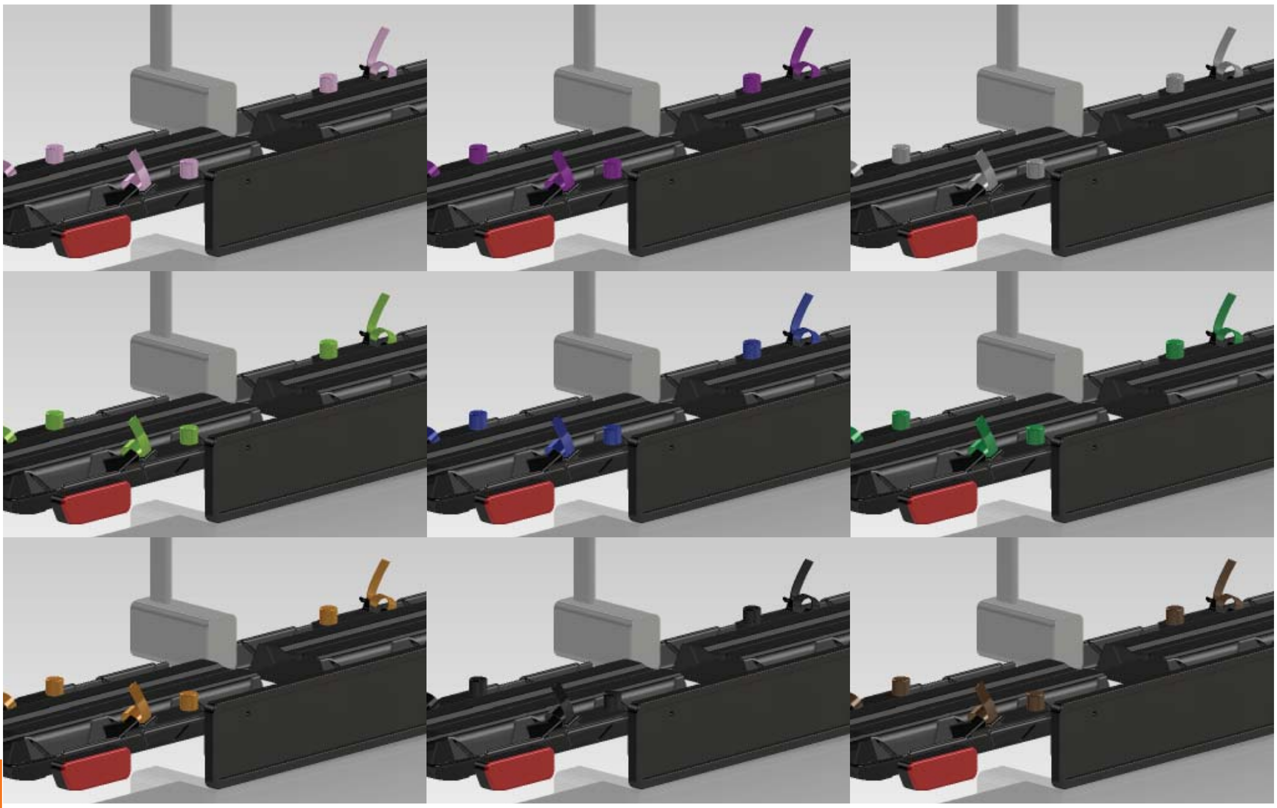


Figure 85 Pink, purple, grey, lime, dark blue, green, orange, black and brown

blue and black make the knobs and straps difficult to spot and grey, green and brown are a bit dull compared to the fresher blue.

The next step is choose the components that will be used in the support colour and which in the colour of the composite. Earlier was mentioned that colour should be used to blend components in the background and not to reduce the apparent weight of the carrier.

	A	B	C	D
Binding wings	1/4	3/4	2/4	4/4
Seperate arm	4/4	4/4	1/4	1/4
Calm look	1/4	3/4	2/4	4/4
Interaction	4/4	3/4	4/4	3/4
Total	**10**	**13**	**9**	**12**

Table 7 Comparison of colour schemes.

To create the image of a hovering board, the two wings should blend together while the vertical part stays seperated. The technological, sleek and efficient look will benefit from a calm look with small accents. Finally, the ease of use will be increased if the consumer can detect the parts to interact with from their background. Figure 87 D and Table 7 show the best colour scheme.

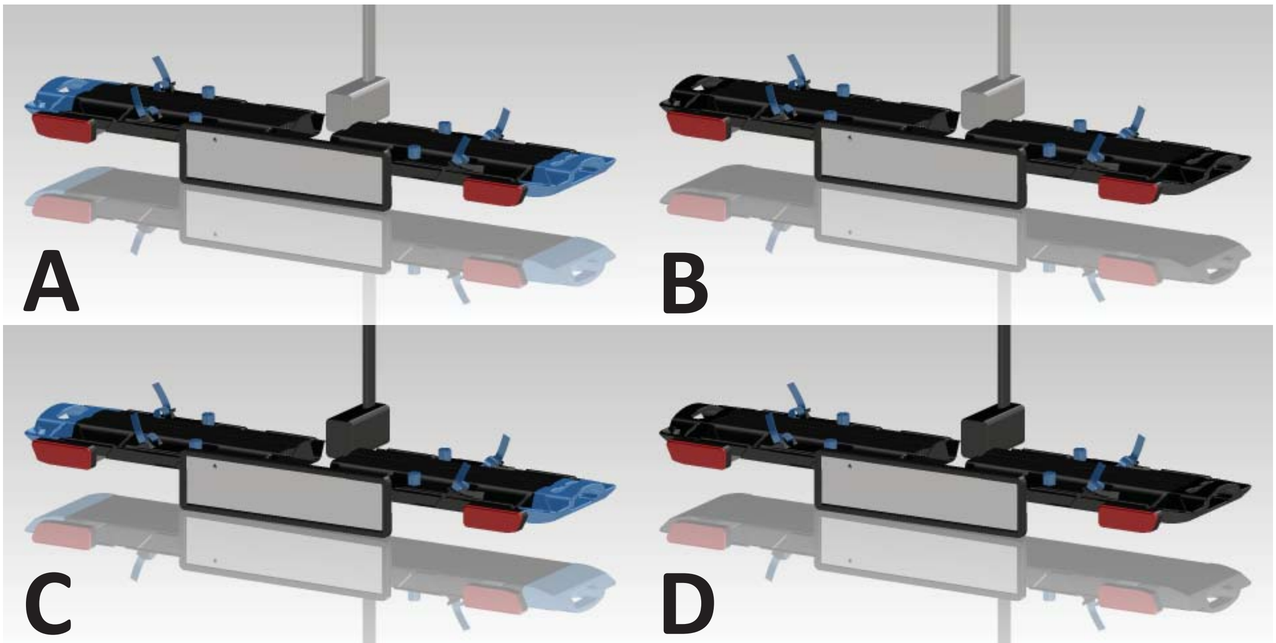


Figure 87 Overview of possible colour schemes.

Figure 86 Gloss on glass fibre reinforced PA-6

Just one addition to colour scheme B should be made and that is the finish. A strong contrast between the wing on one hand and the rails and handles on the other should be avoided. Therefore a high gloss finish on the plastic parts should be avoided.

Black satin gloss plastics should be used with blue for the knobs and straps. The metals of the bridge will be painted grey. This will result in a clean, efficient looking design that is easy to use.

Assembly

Linking all components

The large amount of parts that need to be mounted to the wing need to stay put. This chapter will adress the main assembly steps and joining processes.

Joining processes

The wheelpads will not be secured directly to the wing. The rails, brackets and handle however will be mounted straight on the wing. The strength and speed of assembly are the most important things to consider. It is not necessary to use a releasable connection as all components are unlikely to need maintenance. The connection of the light units and the licenseplate with their brackets will need to be releasable as they may be replaced during the life of the bikecarrier.

Several joining options have been explored: glueing, welding, bolting and rivetting. Cato Composites will weld the wing as this is relatively simple with the correct equipment and rather quick compared to glueing. Another advantage is that no machining is needed (drilling holes etc.) to make the joint. Wings are then shipped to the assembly location where the other components are added.
Bolting is out of the question for the handle and brackets as both sides of the joint have to be accessible. Glueing and welding take some time but so does drilling holes for the rivets. This drilling could be done during manufacturing so assembly is not slowed down by it. However not time but positioning is the main reason to use blind rivets. The holes for the rivets can be drilled automated, consistently in the right spot. When holes in the bracket and the bottom plate of the wing line up, the rivet will clamp the brackets in position.

Riveting

A rivet needs to be strong enough to keep the components in place. There are two things to consider here. The strength of the rivet and the material strength of the wing. Figure 88 illustrates how a blind rivet works. After sticking the rivet through two sheets of material, a clod is formed by pulling the mandrel through the tube. The mandrel is pulled until it snaps, leaving the rivet with a flat head on one side and a clod on the other. The force of is distributed evenly over the head on the bottom sheet whereas the bulging tube pushes against the insides of the holes and the corners indicated in the drawing.

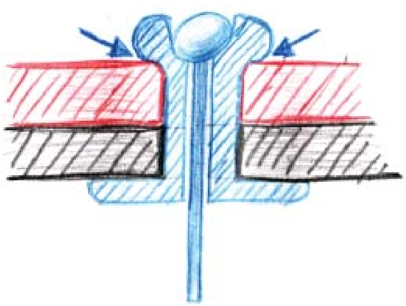


Figure 88 Section of fastening with a rivet.

Holloway (1990) states that the forming of the rivet applies a pressure which cannot be controlled on the laminate, which can cause damage. This would be the case on the places pointed out in Figure 88. However if metal brackets are used, only the black part will be made out of the glass reinforced nylon laminate. If the holes in the laminate are slightly larger than the tube of the rivet, the rivet can expand without putting lateral pressure on the composite according to Holloway (1994).
The part of the rivet in contact with the composite is the head. The force needed to let the mandrel snap will be spread over the contact area with the head. The pressure on the head of the rivet needs to stay below the compression strength in the thickness direction of the laminate to prevent the installation of rivets from damaging the wing.
After installation, the rivets will have to hold the components together. Rivets can be replaced and adjusted more easily than the wing so to be on the safe side, the rivet should fail before the material does. The material fails if the rivet is pulled through the material with als the material underneath it, illustrated in Figure 89. The strength of rivet should be higher than the shear surface multiplied by the shear strength of the composite. That surfaces is the circumference of the rivet head multiplied by the material thickness.
In Appendix F can be found that several varieties of rivets can be used without damaging the composite wing.

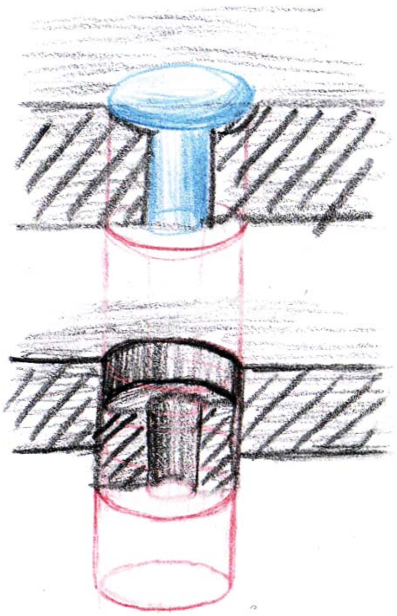


Figure 89 Material failure in a riveted joint.

Rivet holes can influence each other eventhough single rivets are able to bear the load. The close grouping needed to mount the brackets can become a problem. Gay (2003) states that the regions of the composite around a hole are weakened 40 to 60% in tension and 15% in compression. He therefore recommends a certain spacing, illustrated in Figure 90. According to these recommendations, the holes are too big (or the laminate thickness to thin) and the pitch to small. Smaller rivets were not found and the laminate thickness will not be adjusted so the use of one of the found 4,8mm thick rivets is a gamble and needs to be assessed with the prototype. The

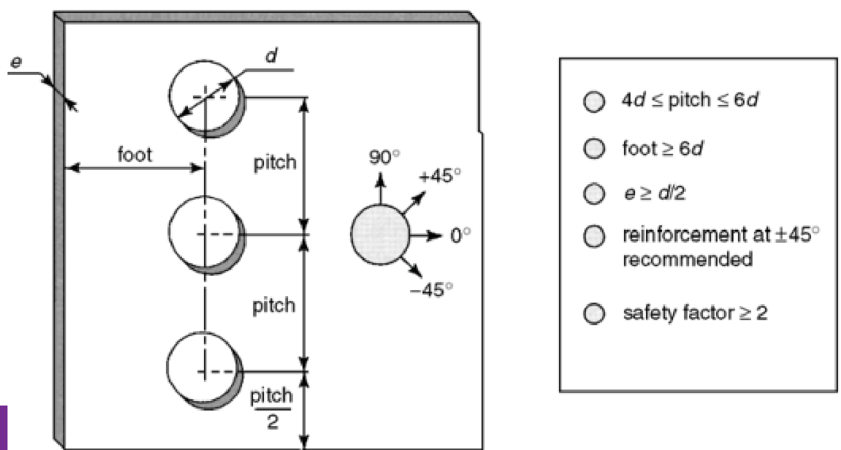


Figure 90 Recommended hole spacing

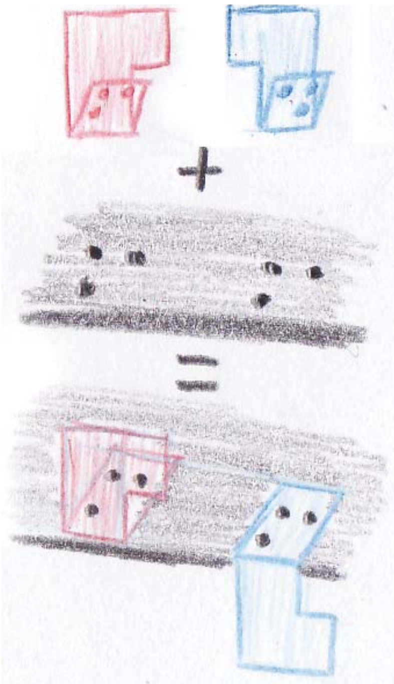


Figure 91 Asymmetric rivet pattern.

brackets however should be able to accommodate the recommended pitch. With two rivets side by side through a bracket, a pitch of 4*d is possible in a 50mm wide bracket.
Two rivets side by side are useful to cope with the torque load and to prevent wiggling of the brackets. If these two or three rivets are positioned in an asymmetric pattern, components cannot be installed on the wrong wing. The two brackets for the licence plate will not be misplaced because they would be upside down then, which is notable. The principle is illustrated in Figure 91.
To create a orderly pattern, a line of rivets is preferable. A third rivet to create the asymmetry can be added then resulting in the pattern already shown in Figure 91.

Rivets can be used but it is important to choose the right kind to avoid damage to the laminate. The lack of data on riveting composites to metal make it necessary to test the riveted joint in the prototype. If everything holds, an L shaped pattern can help preventing mistakes in assembly.

Glueing

Glueing and welding are comparable processes in the sense that they both create a non-detchable connection without extra components.
The performance of the processes differs slightly. BASF (2003) indicates that welds as strong as a nylon matrix can be achieved under optimized conditions but that most joints are 70 to 80% of the strength of the thermoplastic matrix. Cyberbond claims a strength of 4000 psi (27,6 Mpa) with the Cybercryl 800 glue, recommended for among others nylon and composites. This is around 46% of the shear strength of the matrix. A glued joint with a square centimeter surface can carry more than 2800N or 280kg. This is significantly more than a bike or the carrier (less than 16kg). Considering the size of the wing, a small overlap of 10mm would create a sufficient contact area between the wing and the handle to move the whole carrier around with one handle.
A difference between the two processes is the needed equipment. Where as the welding needs a machine to create friction between the parts, glueing only needs the glue and a clamp to apply presure. The parts that have to be glued are the two halves of each handle, the top and bottom of the wheelpad and the rails to wings. All of which will be added to the wing during assembly. The number of different glue joints per wing make it

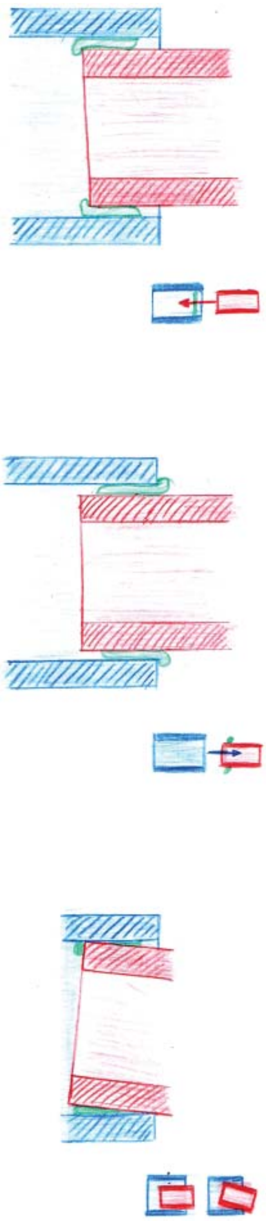


Figure 92 Behaviour of glue in a joint.

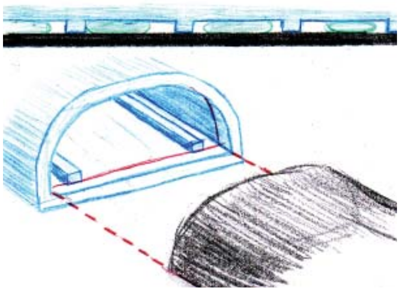


Figure 93 Ribs to set the thickness and depth of the joint.

probably quicker and easier to glue the parts and store them to cure than to feed weld all the parts, changing the settings of the machine for each component. However if a seperate welding setup for each joint is cheap enough, welding could become the better option.
A glued joint might not always meet the specifications of the supplier. Frank van den Reeken, an adhesive specialist of 2BOND B.V., said that it is rather difficult to work consistently with adhesives. There is an optimal adhesive thickness and pressure during the curing of the glue. A overdimension of the contact surfaces can compensate for fluctuating strength of the joint. Even if a design is made to create the perfect film between two parts, a slight angle like at the bottom of Figure 92 can influence the glue distribution. Another factor is the part on which the glue is applied. Sliding a component into an other with glue will push the adhesive in to the first component while sliding a component over a part with glue can push the excess out. A third factor is the fit and the pressure applied. Both can squeeze all adhesive from between two components. A large pressure will not result in a high strength joint.
Using small protrusions on one of the surfaces of the joint will keep a cavity for the adhesive of a determined thickness between the two components. The same effect can be achieved with some adhesives as they have glass beads mixed in the glue which can not be compressed unlike the glue. Costs must determine whether protrusions in the components or glass bead filled adhesive are the best way to achieve the perfect film thickness. The glue looks like a good option as all the moulds with the protrusions requires a lot more precision milling.

A proper assessment of the costs is necessary to confirm glueing to be the best joining process for the handles and rails with the wings. Good joints can definetly be achieved with adhesives. Their strength is sufficient eventhough it is dissuaded to create minimal contact surface in order to compensate for fluctuations in the glueing process. To help reduce these fluctuations, an adhesive filled with glass beads can be used .

Positioning components

The brackets and wing, the lights and brackets and license plate and bracket will be put in the right place by aligning the holes in each pair of components. The strap of the wheelpad will be locked in place when the two halves

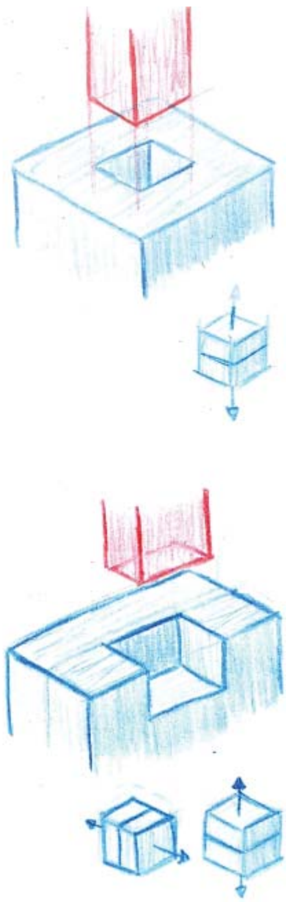


Figure 94 Draft directions of a hole.

of the wheelpad are joint and the knob bolts into place. Other components which are joint without fasteners can need additional features to align properly. Two or more peg and hole connections would prevent translation in two and rotation in three directions while the (glued) joint itself would prevent the last translation. This could cause problems between parts as the peg and hole have the same draft direction, vertical in Figure 94. However, the two handle halves have different draft directions as was shown in Figure 41. Opening the hole on one side like the bottom part of Figure 94 makes it possible to create a vertical hole with a horizontal draft direction. This leaves one degree of freedom. That last horizontal translation can be prevented by using the wing as a giant peg.

Figure 95 and Figure 96 show how ribs on the handle can be used to lock the parts of the handle into place. The ribs indicated in red on the top part of the handle will slide in between the two on the bottom, preventing translation from side to side and rotation around the vertical axis. The edge on the parts will make contact, defining the vertical position and preventing rotation around a horizontal axis. Finally the handle can slide over the end of the wing, aligning the two handle pieces along the longitudinal axis of the wing.

This principle of using ribs instead of “pegs and holes” can also be used on the two parts of the wheel pad. The bottom of the rail however follows the contour of the

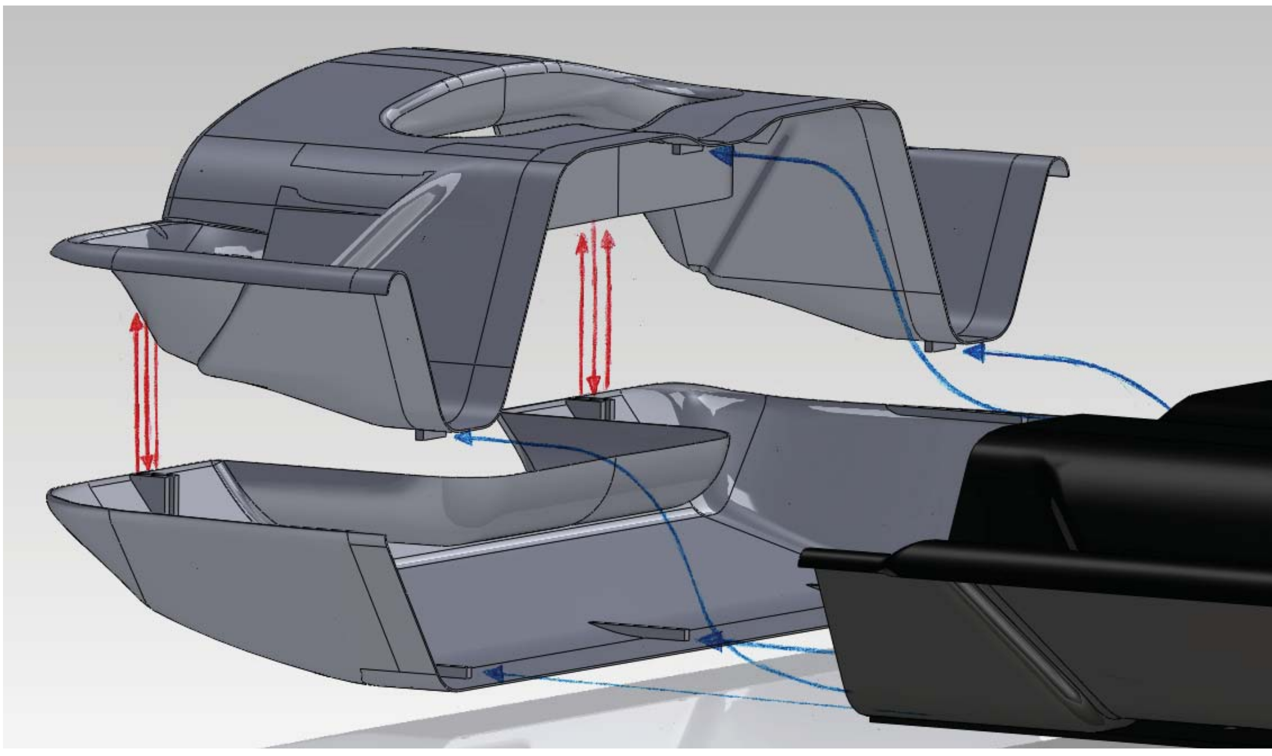


Figure 95 Contact points between the handle halves in red and with the wing in blue.

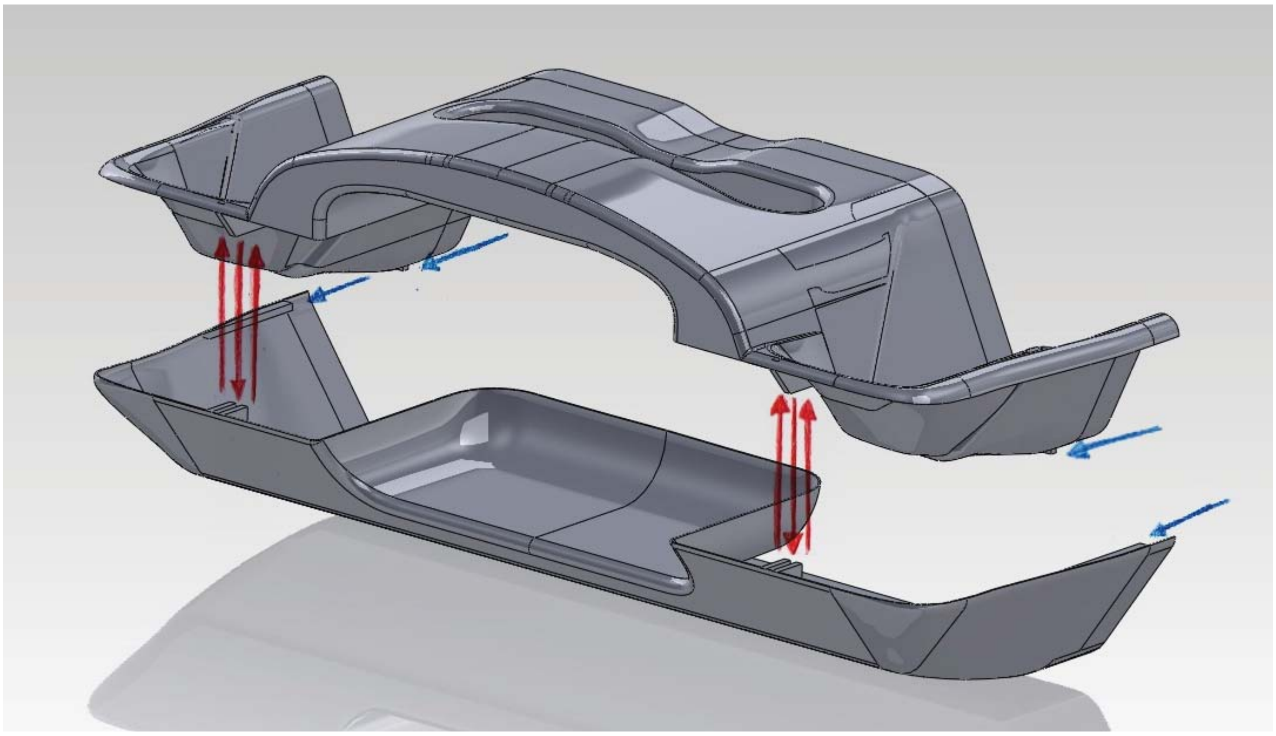


Figure 96 Contact points between the handle halves in red and with the wing in blue.

step in the gutter. Contact between the rail and the gutter will let the rail slide in the correct position as shown in Figure 97.

All components fastened with bolts or rivets will be aligned with these fasteners. Small ribs wil replace the fasteners for the components that will be glued. The rails in the gutter will follow the contour of the wing to be positioned correctly.

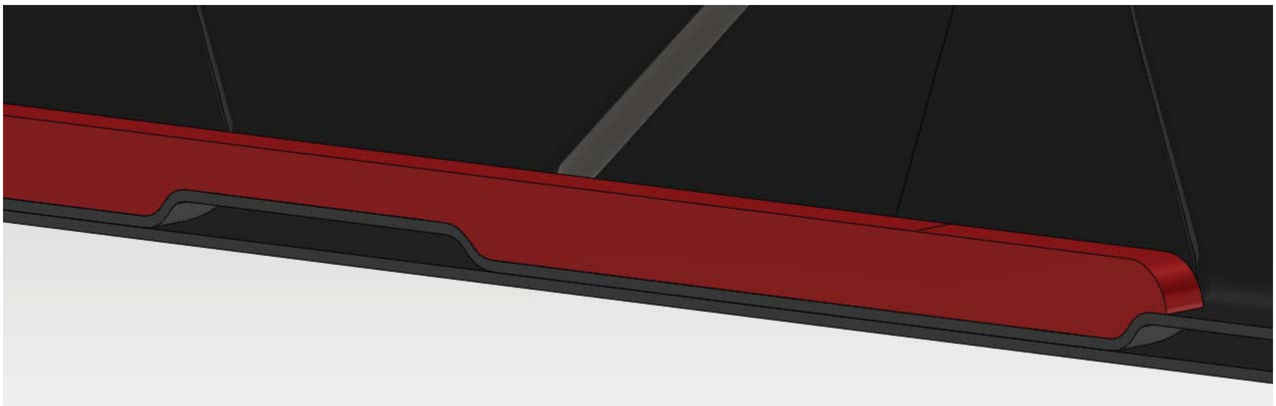


Figure 97 Section along the bottom of the gutter. The step

Conclusion

Review

All requirements set at the beginning of this design process are reviewed one by one in this section. Followed by recommendation to improve the design.

Consumer related requirements

- *All operations should not require great force.*

The hinge between the wing and bridge requires the most strength of the user. The hinge is part of the bridge so there is no design change but a recommendation to decrease the stiffness of the hinge.

Using a smaller knob to fasten the wheelpads means that some extra force is needed. The lack of space limits the size of the knob. It is not beneficial but hopefully not problematic.

- *The carrier should give more feedback with each operation.*

Contact between the top of the wing and the arm of the frame clamps creates some extra feedback that the wing is folded completely.

Making the hinge between the wing and bridge less stiff gives a bigger difference between the resistance of the hinge and the blocking of overstretching. This creates clearer feedback compared to the earlier carriers.

There are no methods of feedback lost in the new design.

- *The number of operations should not be increased.*

The user will not have to to perform any extra operations compared to the older models.

However, the frame clamps might interfere with the wheelpads when the wings are folded together. A solution besides sliding the wheelpads back before folding the wings is difficult as the height and width of the gutter are set by the tyre sizes.

- *The bikes need to be fastened rigidly. (Two points per wheel and on the frame.)*

The design lets each wheel rest on the bottom of the gutter or the handle and on the wheelpad. A bike will therefore always stand straight on the carrier and can be strapped to the wheelpads to keep them there. The additional clamp at the frame is adopted from the previous model.

- Less complex appearance.

Wiring and most fasteners have been hidden by placing out of sight or removing them. The tube frame is replaced by the solid composite wing. Visible ribbing on the bottom of most plastic parts on the MovaNext 3 has been avoided by using two part components. Using one part component would result in clearly visible ribs on the top of the components as they taper inward instead of outward like on the older components.

Color has been used to blend components together with the measures above reducing the number of distinguishable components, creating a less complex appaerance.

Room for improvement are the steps in the gutter walls. If testing shows that the handle can make the end of the gutter stiff enough, the steps could be removed, creating an even less complex look.

- Bikes can be moved across the bike carrier without lifting them.

The end of the gutter, the handle, has a horizontal end to enable bikes to ride over the edge from a ramp without slipping of. When on the carrier, the wheels can move through the gutters with only a small gap between the two wings.

There are however two obstacles in the gutters: the knob on the wheelpads and the connection to the bridge. The knob could be positioned outside the gutter without weakening the wing and the bridge section can also not be moved below the gutter without weakening the structure. Eventhough some obstacles are present, a bike can be rolled across the carrier with just lifting one of the wheels while the bike rests on its other wheel. It might not meet the wish but it is a slight improvement over the previous model.

Manufacturer's requirements

- Composites should be used.

The steel tube frame of the wing has been replaced by a hollow composite wing. Prefabricated sheets of glass filled nylon can be formed into a proper component.

- The weight of the wings should be reduced to 3,5kg a piece. (Including light units and other components.)

Table 8 shows a breakdown of the weights of all components mounted to the wing. The amount of ribbing in the larger plastic components is not optimized yet so values of the handle and wheelpad can fluctuate. A new light unit is designed so the 400g is an rough estimation. Overall the weight of one wing will probably come in between 4 and 4,5kg. Therefore, the requirement is not met.

The weight loss from switching to composites was not as dramatic as expected. A bare wing weighs 2870g where a aluminium design from Indes weighs 2,4kg. Both are an improvement but even with the unthickened wing, composite only matches the 2,4kg of aluminium.

	Material	Weight	Amount	Weight per carrier
Wing	Composite	2170g	2	4340g
Handle (top half)	Plastic	107g	2	215g
Handle (bottom half)	Plastic	94g	2	187g
Rail	Plastic	29g	4	116g
Wheelpad (top half)	Plastic	32g	4	127g
Wheel pad (bottom half)	Plastic	78g	4	313g
Knob	Plastic	25g	4	100g
Strap	Plastic	7g	4	29g
Light unit mounting bracket	Steel	149g	2	297g
Light units	Plastic	400g	2	800g
License plate mount	Steel	122g	1	122g
License plate support	Steel	132g	1	132g
License plate holder	Plastic	385g	1	385g
Connection beam	Steel	700g	2	1400g
Rivets etc	Various			100g
Total				**8862g**
Weight per wing and connection beam				2870g
Weight per wing including all components				4331g

Table 8 Indication of performance potential

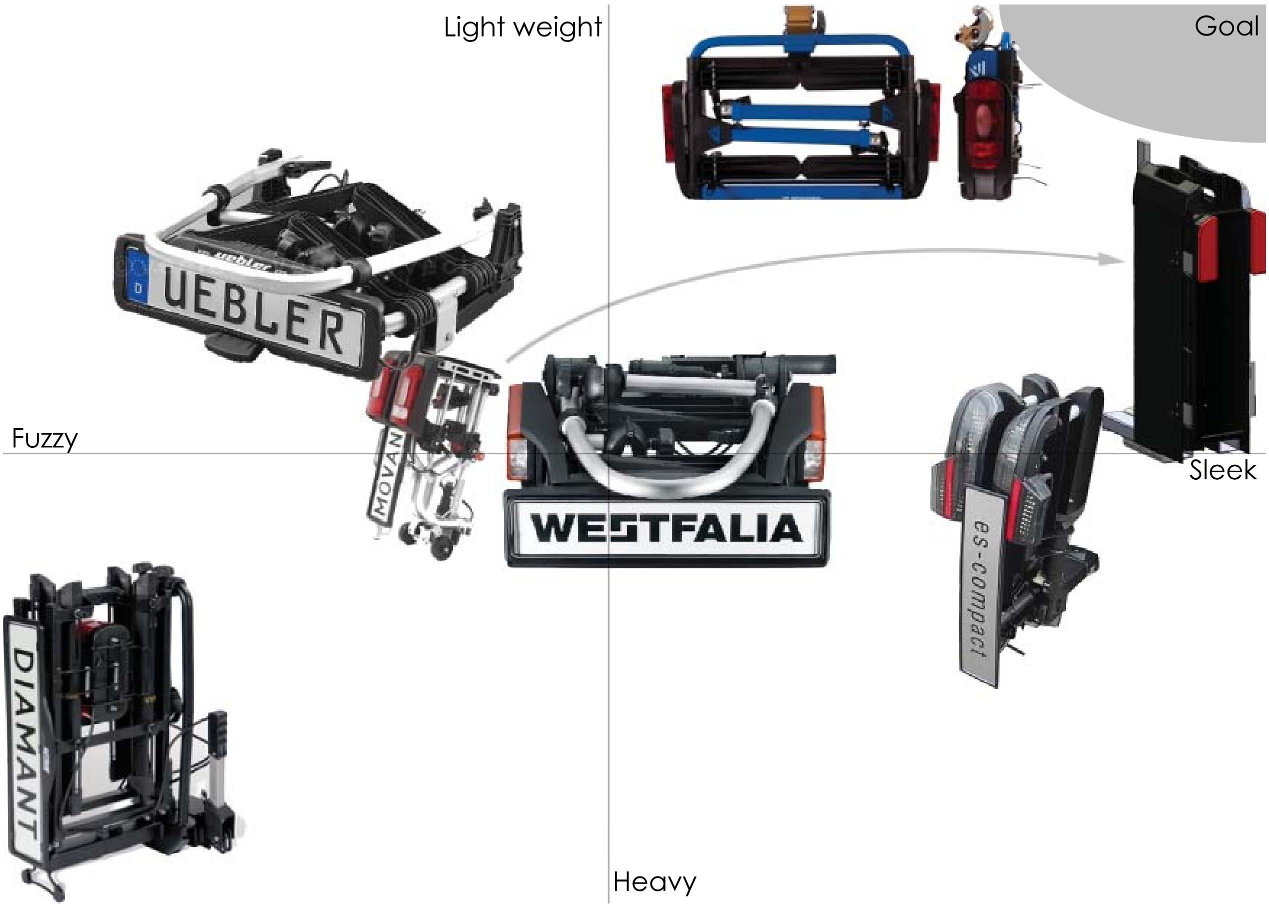


Figure 98   Comparison of the new design with the current market.

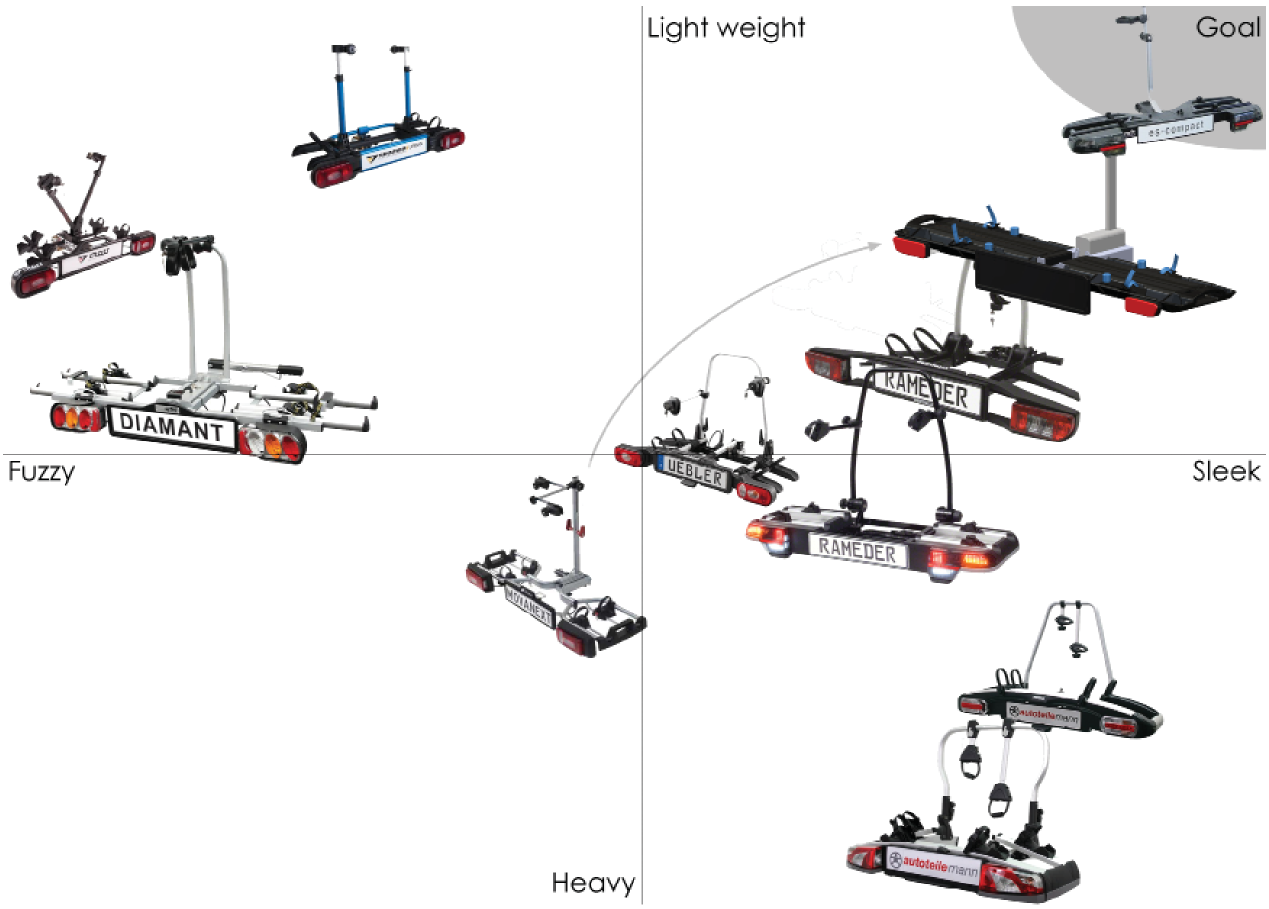


Figure 99   Comparison of the new design with the current market.

The requirement of 3,5kg is a part of the weight reduction of the whole carrier. Maybe the bridge section can be revised as this is also a heavy component of the carrier. However it must be concluded that the use of composite does not bring the expected weightloss which was one of the main reasons for this redesign.

- The new design should have a more modern look. (As described in the Design section.)

Switching from tube to sheet material creates a much denser look. However it also gives more opportunities to hide smaller components and replaces a lot of seperate tubes with one shape. This results in a bulkier but calmer and more effecient appearance. Figure 98 and Figure 99 indicate the position on looks of the new design in the current market.

The shape and dimensions of the gutter are set and the wings height driven by its stiffness. All free shapes and details of the wing and other components are aimed at communicating a low weight. This results in a modern appearance. However the plastic parts can be refined, improving the overall look.

The archetypical composite look determines the surface of the wings and therefore the majority of the carrier. A black and blue colour scheme keeps the appearnce calm and highlights the parts that are important to the user. It is also modern and business without becoming flashy.

Technical requirements

- The maximum bending under load of 20kg located 620mm from the fixed point is 14mm.

FEM analysis indicate that the wing will probably meet this requirement. Physical tests will have to be carried out to confirm that the bending will be around 2,1mm. The weld between the top and bottom of the wing and the connection with the bridge have some influence. The 2,1mm is significantly less than 14mm but trading of bending stiffness for extra weight loss can compromise the strength of the wing.

- The maximum bending under torsion cause by a load of 20kg located 160mm from the centre of the wing is 2 mm in 360mm.

Deformation under torsion is calculated at 4,9mm. This excess is compensated by the much higher bending stiffness mentioned above.

- The carrier should be able to withstand a vertical acceleration of 1,5G to simulate movement when in use.

The composite is thickened to create an acceptable strength. This was necessary around the corners of the connecting piece to the bridge. The need for the reinforcement is reduced by swapping the riveted steel connection piece with a welded flap of composite. Prototype testing can determine whether or not a two layer composite can be used instead of the three layer material used in the final design.

- The carrier should be able to withstand a static load of 80kg. (Two bikes with a weight distribution of 15kg on the front wheel and 25kg on the back wheel, the bikes will face opposite directions.)

The FEM analysis of one wing can carry a 40kg load at 1,5G so two wings will carry a static load of 80kg without problems.

- The light units and number plate should be positioned according to the German 'Strassenverkehrs-Zulassungs-Ordnung' and the Dutch 'Regeling Voertuigen'. (Light units: less than 400mm from the side of the vehicle. The maximum vehicle width is chosen as 2000mm. Therefore the criteria are: from edge to edge of the two light units is at least 1200mm and lights and license plate should not be more than 900mm above the road when mounted on the towbar.)

The light definitive design of the lights are not used yet but there are no foreseeable problem with regard to positioning and mounting. The outer edges of the light units are now positioned 1315mm apart.

- The edges of all component accessible with a 165mm sphere should have a radius of at least 2,5mm.

All outer edges on the plastic components have a radius of 2,5mm or more. The edge of the composite of the wing close to the bridge however is not due to its thickness. This should not be problematic as the bridge fills the gap, preventing the sphere from reaching the edge.

- The carrier should be compatible with bicycles with 24 to 28

inch wheels and with a distance between the wheels axis of 1050 to 1200mm should fit.

The gutter and the handles are just long enough to fit the bikes described. By applying an upward slope in the handles, bicycles will self center in the gutter instead of rolling of the end.

Conclusion and Recommendations

FEM analysis indicate that the composite wing as presented is feasible. Prototype testing by Indes should confirm this. Cato is confident that the final design can be manufactured with the current specifications.

Although some components become more difficult to manufacture because of the use of composite sheets, all components can be made. Adhesive will be needed in some cases to join these components. Slowed and complicated assembly is the price that must be paid.

The design as presented is distinctive in the market when it comes to appearance. The intended weight specification is not met and weight will not be a clear advantage over the competition.

Usability is improved slightly compared to the previous MovaNext bike carrier. Leaving the bridge section unaltered limits the possibilities of making it easier to install heavy (electric) bicycles. Maintaining compatibility with the existing ramp accessory is achieved. Furthermore, the gutters let the wings take most of the weight while bikes are moved across the carrier. Reducing the overall weight also make it easier to handle the carrier. These small improvements are combined with a redesign of the other components to work with the composite wing without compromising on their usability.

The design as presented is distinctive in the market when it comes to appearance. Its solid composite appearance stands out between the metal tube based products. The intended weight specification however is not met and weight will not be a clear advantage over the competition. This makes the new design more a novelty item than a revolutionary step forward in the bike carrying market.

Eventually, the succes of this redesign comes down to costs. The glass fibre reinforced nylon is quite expensive compared to steel and aluminium and several plastic

components require multiple moulds, increasing tooling costs. Eventhough costs are not assessed yet, it will probably turn out that the benefits of the design do not justify the increased costs.
There are however some recommendations or points of attention that can improve this design.
- The hinges between the wings and the bridge section should be made less stiff. This improves the ease of use and also creates clearer haptic feedback.
- The clamps that hold the frame of the bike need to be reduced in size. Narrowing them is necessary to fit them next to top of the wing when the carrier is folded. By also reducing the height, the clamps can fit between two wheel pads whilst folded. The advantage of the lowered design is that the carrier can be closed no matter what the position of the wheelpads is.
- If prototype testing indicates that the gutter is extremely stiff with the end kept in shape with the handle, the steps can be reduced or removed. This creates a calmer appearance.
- The extra composite piece to make the connection with the bridge does not pierce the wing as a sharp corner on the metal mounting piece. If the top part of the wing feels sturdy (not easy to dent), it can be thinned. This would save 400g per wing.

The new design is an improvement of the MovaNext 3 when it comes to appearance, usability and weight reduction. However, the weight reduction was not as revolutionary as it was hoped to be while material and tooling costs increase significantly. Costing is more important than ever to determine whether or not the bike carrier becomes a commercial success.

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