Appendices of: Application of composites in a bikecarrier.

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Bachelor Industrial Design Engineering

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Appendix A Competition and design direction

The following sheets come from a presentation of Indes. They give an overview of th current competitors. An overview of data like consumer prices and weights is given on page 8. An inspiration sheet for the design direction can also be found there.

Competitors: Pro User Diamant

- 18 kg
- 399 euro (329)
- Up to 60 kg
- Tilting mechanism
- Slightly more compact (70x50x22)
- Best buy consumentenbond

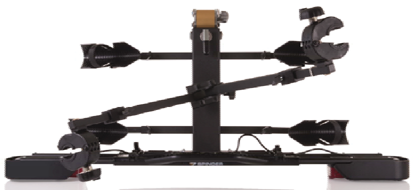
Competitors: Spinder Tour / Cross

- 11,9 (alu) / 13 kg (steel)
- 349 / 289 euro
- Up to 50 kg
- No tilting mechanism
- Not foldable 96x50x32 cm
- Might be too short

3D aanzicht - 3D view

Bovenzijde - Topside

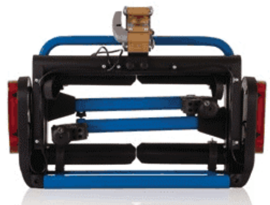
3D aanzicht - 3D view



Bovenzijde - Topside

Competitors: Spinder Urban

- 12,4 kg
- 459,- euro (459)
- Up to 50kg
- Tilting mechanism
- Compact
  75x51x17 cm



Competitors: Westfalia Portilo

- 17.5 kg
- 425 (385) euro
- Up to 60kg
- Tilting mechanism
- 69x58x22,5 cm

Competitors: Uebler X21 Nano

- 12,3 kg
- 499 (471) euro
- Up to 60kg
- Tilting mechanism
- 65x58x30 cm

Competitors: MFT ES Compact

- 13 kg / 399 euro
- Up to 60kg
- Tilting mechanism
- 66x61x26
- LED light
- Tow hook fixation like MN!

Competitors: MFT ES Compact

Competitors: Non Foldable

- MFT EuroSelect XT
  16kg, 450 euro
  up to 82,5kg
  SMD-LED

- Thule
  20 kg, 559 euro
  up to 60 kg
  LED

- Atera Strada Evo2
  16.3 kg, 459 euro
  up to 60 kg,
  No LED

Competitor overview

	M3 Verto	ProUser Diamant	Spinder Tour	Spinder Cross	Spinder Urban	Westf. Portilo	Uebler X21	MFT ES
Weight (kg)	**16**	**18**	**13**	**11.6**	**12.4**	**17.5**	**12,3**	**13**
List price (€)	**379,-**	**399,-**	**349,-**	**289,-**	**459,-**	**429,-**	**499,-**	**429,-**
Web price (€)	**359,-**	**329,-**	**329,-**	**269,-**	**459,-**	**389,-**	**471,-**	**399,-**
Up to (kg)	**80**	**60**	**50**	**50**	**50**	**60**	**60**	**60**
Tilting	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Compact (cm) (liter)	**76x53 x22** (88,6)	**70x50 x22** (77,0)	**Non folding**	**Non folding**	**75x51 x17 (65,0)**	**67x60 x27** (108,5)	**65x58 x30 (113.1)**	**66x61 x26** (104.6)

Style guide

Appendix B
Material properties

Indes and Cato have selected a nylon glassfibre composite for the bike carrier. The following datasheets were provided. The mechanical properties on page 10 and 11 are used. Some properties are missing, these properties like the density are then taken from page 12. This is the same material but does not have the right weave. Therefore the strength cannot be used but the weights and density can.

TEPEX® dynalite Glas/PA-RG600(x)/47%:

Symbol	Einheit	Bezeichnung	Wert	Prüfnorm
E_1	[GPa]	E-Modul in Kettrichtung	23,65	DIN EN ISO 527-4
E_2	[GPa]	E-Modul in Schussrichtung	23,43	DIN EN ISO 527-4
E_3	[GPa]	E-Modul in Dickenrichtung	5,4[a]	-
G_{12}	[GPa]	Schubmodul k/s	3,1	DIN EN ISO 14129
G_{13}	[GPa]	Schubmodul k/z	2,1[b]	-
G_{23}	[GPa]	Schubmodul s/z	2,1[c]	-
ν_{12}	[-]	Querkontraktionszahl k/s	0,16	DIN EN ISO 527-4
ν_{13}	[-]	Querkontraktionszahl k/z	**	-
ν_{23}	[-]	Querkontraktionszahl s/z	**	-
R^z_1	[MPa]	Zugfestigkeit in Kettrichtung	472	DIN EN ISO 527-4
R^d_1	[MPa]	Druckfestigkeit in Kettrichtung	250***	DIN 65380
R^z_2	[MPa]	Zugfestigkeit in Schussrichtung	425	DIN EN ISO 527-4
R^d_2	[MPa]	Druckfestigkeit in Schussrichtung	280***	DIN 65380
R^z_3	[MPa]	Zugfestigkeit in Dickenrichtung	63[d]	-
R^d_3	[MPa]	Druckfestigkeit in Dickenrichtung	63[e]	-
R_{12}	[MPa]	Scherfestigkeit k/s	91	DIN EN ISO 14129
R_{13}	[MPa]	Scherfestigkeit k/z	47[f]	-
R_{23}	[MPa]	Scherfestigkeit s/z	47[g]	-

1 = Kettrichtung (k); 2 = Schussrichtung (s); 3 = Dickenrichtung (z)

*** = Diese Werte sind extrem schwer experimentell zu ermitteln, da Knickgefahr während der Versuche. Reale Werte müssen deutlich höher sein.

---

[a] berechnet mit: $$E_3 = E^*_m \cdot \frac{(1+0{,}85\cdot\varphi^2)}{\left[(1-\varphi)^{1{,}25} + \varphi\cdot\frac{E^*_m}{E_f}\right]} \qquad E^*_m = \frac{E_m}{(1-\nu^2_m)}$$

[b] berechnet mit: $$G_{13} = G_m \cdot \frac{1+0{,}6\cdot\sqrt{\varphi}}{\left[(1-\varphi)^{1{,}25} + \varphi\cdot\frac{G_m}{G_f}\right]}$$

[c] berechnet mit: $$G_{23} = G_m \cdot \frac{1+0{,}6\cdot\sqrt{\varphi}}{\left[(1-\varphi)^{1{,}25} + \varphi\cdot\frac{G_m}{G_f}\right]}$$

[d] berechnet mit: $$R^z_3 = R^z_m \cdot \left[1+\left(\varphi-\sqrt{\varphi}\right)\cdot\left(1-\frac{E_m}{E_{f,quer}}\right)\right]$$

[e] berechnet mit: $$R^d_3 = R^d_m \cdot \left[1+\left(\varphi-\sqrt{\varphi}\right)\cdot\left(1-\frac{E_m}{E_{f,quer}}\right)\right]$$

[f] berechnet mit: $$R_{13} = R^s_m \cdot \left[1+\left(\varphi-\sqrt{\varphi}\right)\cdot\left(1-\frac{G_m}{G_f}\right)\right]$$

[g] berechnet mit: $$R_{23} = R^s_m \cdot \left[1+\left(\varphi-\sqrt{\varphi}\right)\cdot\left(1-\frac{G_m}{G_f}\right)\right]$$

** ergibt sich aus Schubmodul und E-Modul

Materials designed to improve

	Glass	PA
E_1 E-Modul in Hauptrichtung [N/mm²]	*73.000 (nicht erforderlich)*	*3000 (nicht erforderlich)*
E_2 E-Modul quer zur Hauptrichtung [N/mm²]	*73.000*	*3000*
G Schubmodul [N/mm²]	*30.000*	*735 (μ=0,36)*
μ_{12} Querkontraktion [-]	*0,22*	*0,36*
R_3^z Zugfestigkeit in Dickenrichtung [N/mm²]		*80*
R_3^d Druckfestigkeit in Dickenrichtung [N/mm²]		*80*
R^s Scherfestigkeit		*60*

Die obigen Angaben gelten für einen Faservolumenanteil von 47%. Für andere Glasgehalte schlagen wir ein Hoch- bzw. Runterrechnen mit folgenden Gleichungen vor:

Module:

$$E,G = x \cdot \varphi_{Glas} \cdot E,G_{Faser} + (1-\varphi_{Glas}) \cdot E,G_{Matrix}$$

Festigkeiten:

$$R = x \cdot \varphi_{Glas} \cdot R_{Faser}$$

Material Data Sheet

TEPEX® *dynalite* 102-RGUD600(x)/47%
Roving Glass – PA 6 Consolidated Composite Laminate

	Property		*Method ISO*	*Units*	*Longitudinal*	*Transverse*
Material	Reinforcement		Fibres Fabric Area weight Yarn Weight rate	 g/m^2 tex %	roving glass twill 600 1200 80	 1200 20
	Polymer		Polymer		PA 6	
	Laminate		Density Fibre content Thickness per layer	g/cm^3 % vol. mm	1,8 47 0,5	
Mechanical	Tensile	Modulus Strength Elongation Poisson's ratio	527-4/5 527-4/5 527-4/5 527-4/5	GPa MPa %	30,1 605 2,1 -	12,0 125 1,5 -
	Flexural	Modulus Ultimate stress*	178 178	GPa MPa	26,5 840	11,0 175
	Charpy impact strength unnotched	23°C -30°C	179/1eU	kJ/m^2 kJ/m^2	- -	- -
Thermal	Melting Temperature Glass transition temperature Heat deflection temperature Coefficient of thermal expansion Relative temperature index	per DSC per DSC 1,80 MPa -30°C to 23°C 23°C to 80°C 20.000 h	3146 3146 75-1/2 ASTM E831 IEC 216/1	°C °C °C E-6 1/K °C	220 60 215 - - 120	 - -

** 3-Point loading, span-to-depth ratio 16 to 1*

These values are for this specific composition only, the characteristics of composites depend on the reinforcement level and the fibre orientation. Non-standard thickness may also alter some or all of these properties. The data listed here fall within the normal range of product properties, but they should not be used to establish specification limits nor used alone as basis of design.

Version: 07-01-2009

Processing guidelines for TEPEX® Roving Glass – Polyamide 6

1. Storage/handling

Storage time: unlimited

Moisture content needs to be limited to prevent delamination due to vaporisation during heating. The material is provided in sealed packages. In order to prevent moisture condensation on the cold sheet surface the sealed packages should be stored in the working area until a temperature equilibrium is reached. The material should be processed within 1 hour after opening of the sealing or the material should be dried prior to processing (overnight, 80°C). The use of dust masks and ventilation whilst cutting, milling, drilling etc. is advised.

2. Heating

Forming temperature: between 240°C and 260°C

Forming temperature depends on the polymer to be used. In general the TEPEX® sheet should be heated ca. 20°C - 40°C above the melting temperature of the polymer. Heating cycles should be short to avoid polymer oxidation (surface colour browning). The preferred heating method is middle wavelength IR-heating. Best results are obtained when heating power is controlled as a function of the sheet temperature. Two sided heating should be applied starting from a material thickness of 1,0 mm. Contact heating is feasible but a release film should be applied. This release film will have to be moulded with the material to prevent distortion of the fabric during peeling of the release film in molten laminate status. Heating in a convection oven leads to excessive oxidation of the surface due to the length of the heat cycle and is therefore not recommended.

3. Sheet transfer

Sheet transportation: max. 2-3 sec.

The sheet should be transferred within seconds.
Circulation of cool air in the processing environment reduces the sheet temperature considerably and will lead to a reduction of fabric formability and wrinkles. Manual transfer is not recommended as it causes fabric distortion and polymer distribution caused by the sticky resin to gloves. For obtaining maximum processing stability an automatic transport of the sheet is recommended.

4. Press forming

Press speed: > 50 mm/s (1st step)
Closing speed: 5 mm/s (2nd step)

The recommended closing speed of the press is at least 50 mm/s and should be reduced to approx. 5 mm/s during the last part (10 mm) of the forming. Local clamping forces should be applied to prevent fabric wrinkling during moulding. The clamping forces and arrangements depend on the fabric type, the material thickness and the complexity of the part.

5. Cooling

Consolidation pressure: 5 bar - 100 bar
Extraction temperature: ≤ 110°C

The consolidation pressure varies over the surface of a formed part, depending on part geometry and tool material. The tool temperature should both guarantee good formability/flow and stable product extraction. Aluminium and steel can be used from 90°C up to 110°C; product extraction is then possible without any additional cooling cycle. The consolidation time depends on the material thickness, the tool temperature and the tool materials. Recommended for a laminate thickness of 2,0 mm and the aforementioned conditions is a cooling time of about 30 seconds.

When and where to apply TEPEX® Roving Glass – Polyamide 6

1. General description

Within the TEPEX® composite laminate, Polyamide 6 is a resin which can be used at temperatures from -30°C up to 120°C constantly. PA 6 is known for its toughness, stiffness, abrasion resistance, heat and chemical resistances. Roving E-Glass fibres have an excellent impact performance. This makes the composite material tough and fatigue resistant while offering excellent mechanical properties.

2. Application Areas

Typical application environments are within automotive applications, large structural parts, bumper systems, structural sporting goods applications, helmet shells.

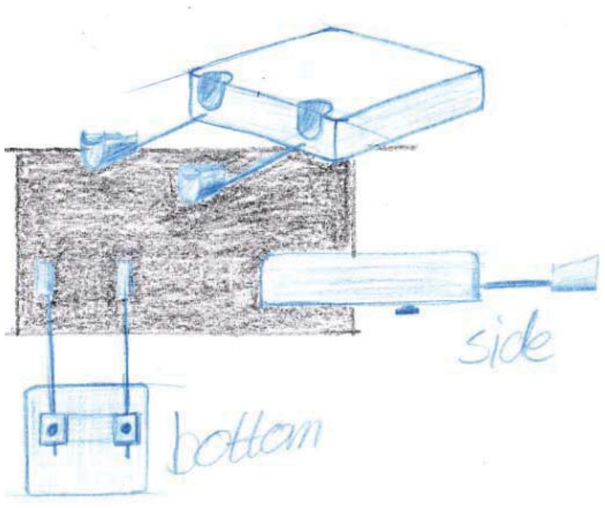


Figure 1 Original idea of a compact carrier

Appendix C
Compact carrier

The compact carrier (Figure 1) has short wings that carry the bike and an extendable piece to keep the front wheels from moving side to side. The extendable pieces require hinges or support for rods. These are hard to difficult to create without a supportive metal frame. This option should probably be made out of (lightweight) metal.
Because of the different tyre thickness it is not so simple to wedge all wheels in place without a vertical load one the extendable part. A solution may be found keeping the extending difficulties in mind, I think this is not a concept to explore further in this project.

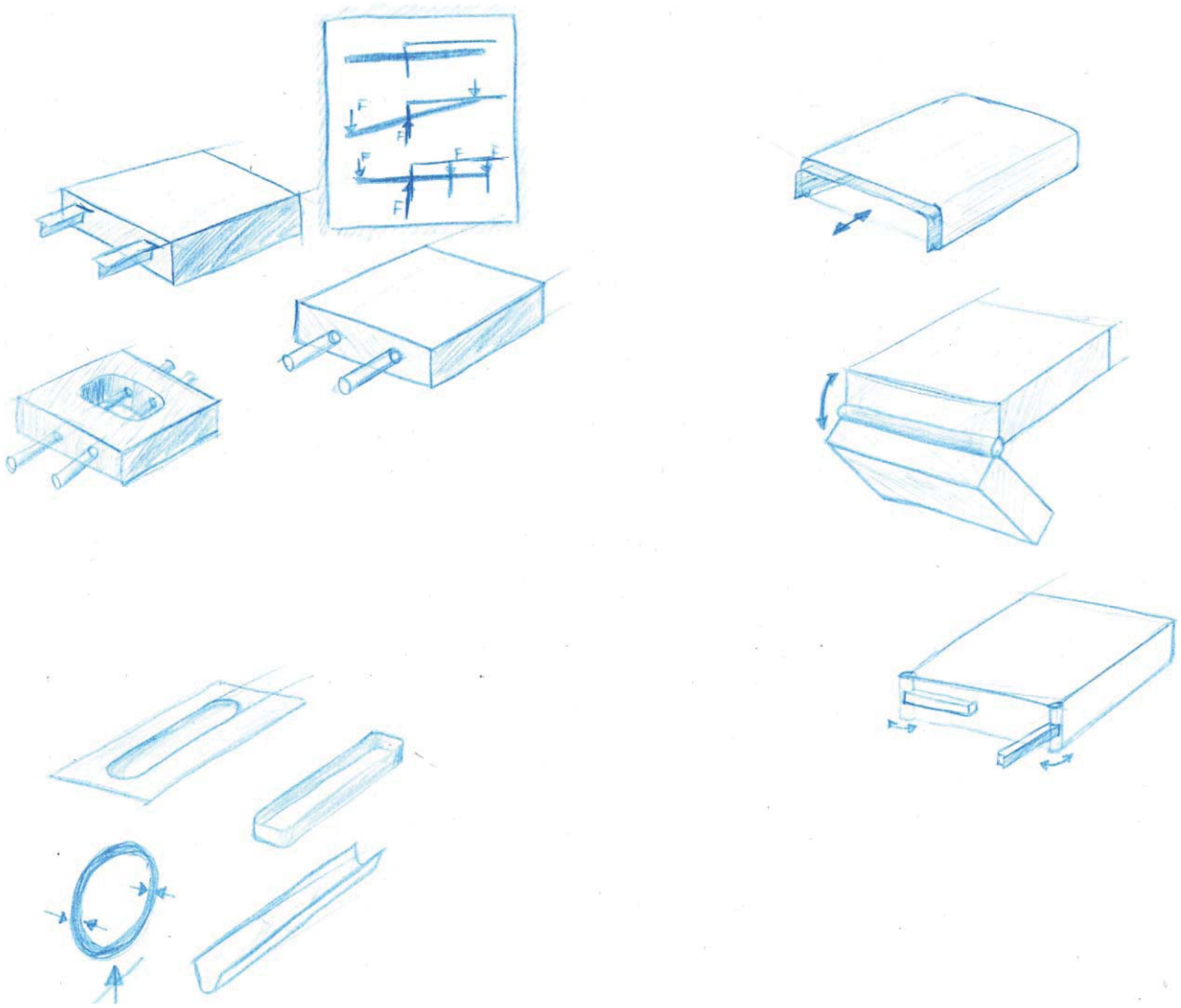
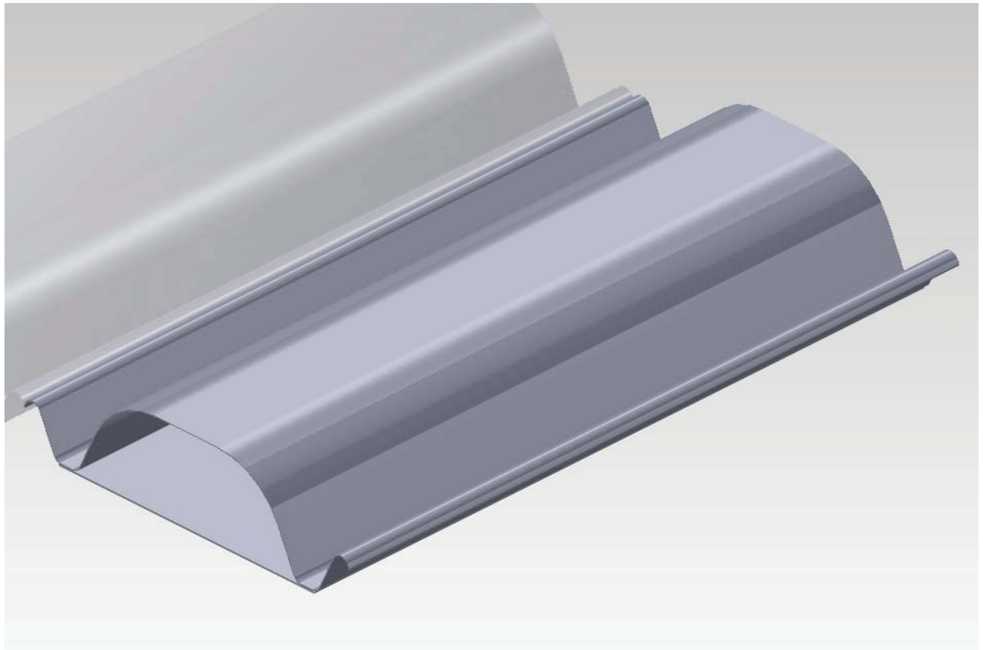


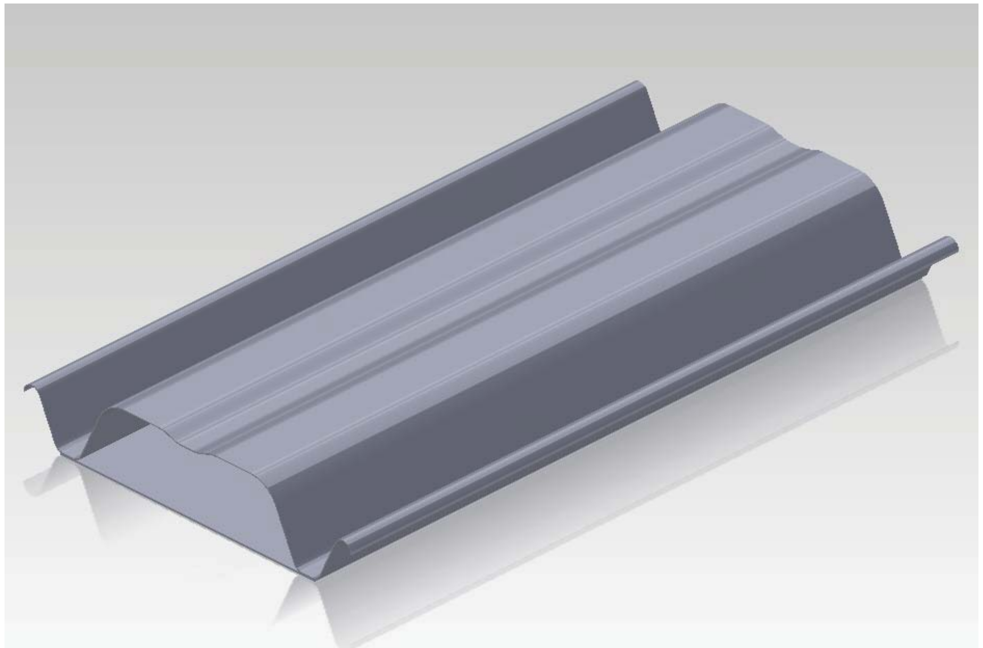
Figure 2 Possibilities for an extendable wing.

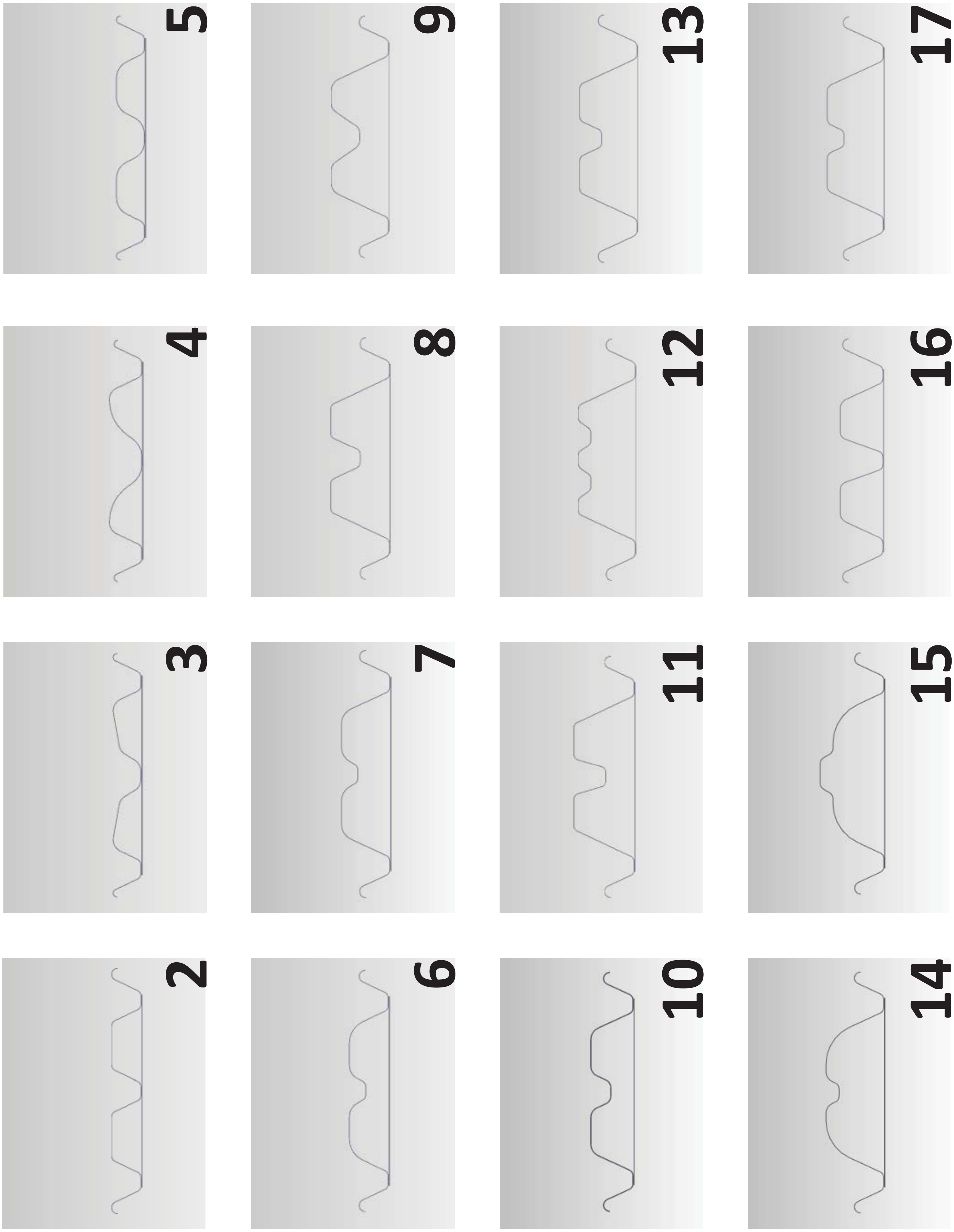
Appendix D Cross sections

The search for the ideal cross section of the wing is illustrated below. Wing 1 has been used as a starting point. This wing is designed by Indes and the dimensions are chosen in such a way that the mechanical properties are within the specifications.
As the width of the wing is determined by the spacing between the gutters, the bottom plate and with of the wing is kept constant. This width is kept the same as in the MovaNext 3 bike carrier. The moment of inertia is primarely varied changing the height of the wing.
The moment of inertia is not the only thing considered. There are also some experiments with the look of the wing as the serie of section 2 to 5 shows. The goal is to find a section that has better looks, weights less and has the same mechanical properties as wing 1.

This appendix contains an overview of different designs and their mechanical properties followed by larger pictures and their dimensions. At the back the final design is compared to the requirements with an FEA by a TPRC employee.





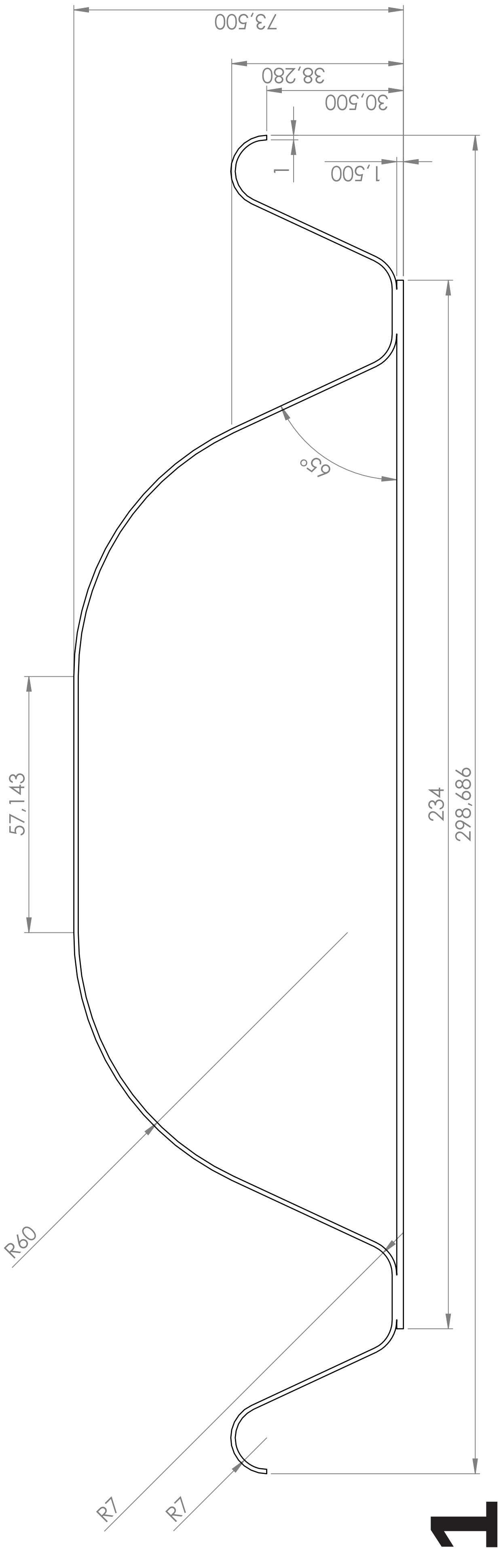


5
9
13
17
4
8
12
16
3
7
11
15
2
6
10
14

	1	2	3	4	5	6	7	8	9	
Height (mm)	**73,50**	38,50	35,50	41,27	35,50	50,50	60,50	75,00	73,00	Height (mm)
Centroid Y (mm)	**22,27**	13,31	10,79	11,42	10,92	17,16	19,95	27,65	26,12	Centroid Y (mm)
Section Area	**770,39**	782,28	740,91	751,34	743,60	767,67	782,08	714,17	699,74	Section Area
(mm^2)	**100,0%**	101,5%	96,2%	97,5%	96,5%	99,6%	101,5%	92,7%	90,8%	(mm^2)
Material length	**419,39**	431,28	389,91	400,34	392,6	416,67	431,08	480,17	465,74	Material length
(mm)	**100,0%**	102,8%	93,0%	95,5%	93,6%	99,4%	102,8%	114,5%	111,1%	(mm)
Polar moment of inertia of the area, at the centroid										
J (mm^4)	**5.756.768,68**	5.220.314,07	4.712.239,73	4.809.543,61	4.697.588,34	5.373.204,87	5.587.554,70	5.304.187,38	5.258.336,39	J (mm^4)
(Torsion)	**100,0%**	90,7%	81,9%	83,5%	81,6%	93,3%	97,1%	92,1%	91,3%	(Torsion)
Principal moments of inertia of the area, at the centroid										
Ix (mm^4)	**567.016,80**	180.398,51	122.084,11	149.052,94	130.714,06	284.100,21	405.058,67	540.490,72	478.583,31	Ix
(Bending)	**100,0%**	31,8%	21,5%	26,3%	23,1%	50,1%	71,4%	95,3%	84,4%	(Bending)
Iy (mm^4)	**5.189.751,88**	5.039.915,55	4.590.155,62	4.660.490,67	4.566.874,29	5.089.104,66	5.182.496,02	4.799.696,66	4.779.753,08	Iy
(Side to side)	**100,0%**	97,1%	88,4%	89,8%	88,0%	98,1%	99,9%	92,5%	92,1%	(Side to side)

	10	11	12	13	14	15	16	17	Final	
Height (mm)	55,00	77,00	73,00	73,00	73,50	81,00	56,00	73,50	58,00	Height (mm)
Centroid Y (mm)	24,09	28,62	27,47	28,45	22,79	22,34	21,51	28,98	23,01	Centroid Y (mm)
Section Area	887,89	727,44	696,73	725,41	778,99	768,33	747,79	723,95	979,72	Section Area
(mm^2)	115,3%	94,4%	90,4%	94,2%	101,1%	99,7%	97,1%	94,0%	127,2%	(mm^2)
Material length	435,93	493,44	462,73	491,41	427,99	417,33	396,79	489,95	419,15	Material length
(mm)	128,0%	117,7%	110,3%	117,2%	102,1%	99,5%	94,6%	116,8%	99,9%	(mm)
Polar moment of inertia of the area, at the centroid										
J (mm^4)	6.856.924,72	5.393.189,08	5.328.585,94	5.870.145,04	5.782.333,81	5.718.423,57	5.714.014,84	6.036.484,57	7.717.283,30	J (mm^4)
(Torsion)	119,1%	93,7%	92,6%	102,0%	100,4%	99,3%	99,3%	104,9%	134,1%	(Torsion)
Principal moments of inertia of the area, at the centroid										
Ix (mm^4)	624.701,02	581.963,70	527.138,22	545.821,21	568.545,24	567.379,37	340.646,71	567.098,34	511.293,86	Ix
(Bending)	110,2%	102,6%	93,0%	96,3%	100,3%	100,1%	60,1%	100,0%	90,2%	(Bending)
Iy (mm^4)	6.476.376,80	4.811.225,38	4.801.447,72	5.324.323,82	5.213.788,57	5.151.044,20	5.373.368,14	5.469.386,23	7.205.989,45	Iy
(Side to side)	124,8%	92,7%	92,5%	102,6%	100,5%	99,3%	103,5%	105,4%	138,9%	(Side to side)

Table 1 Dimensions and values of each cross section.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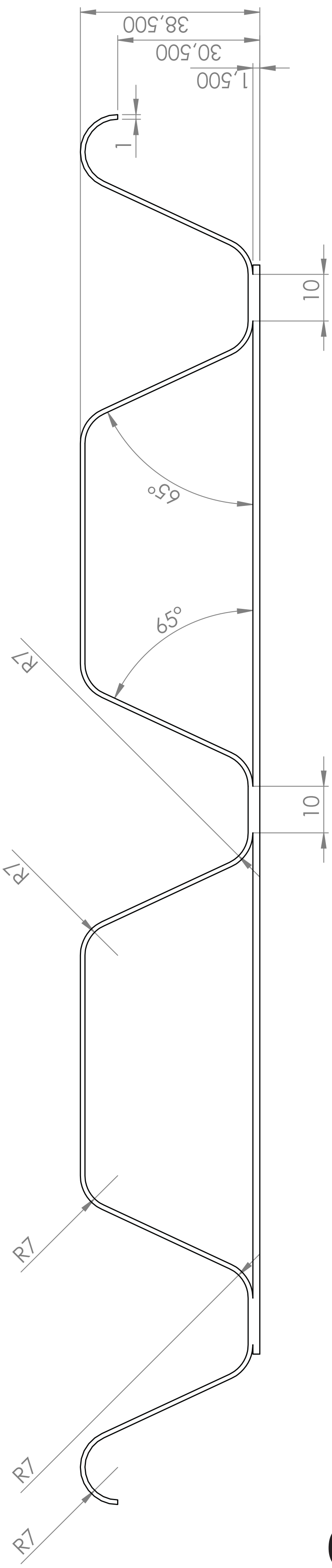
30,500
1,500
1
65°
57,143
234
298,686
R60
R7
R7
1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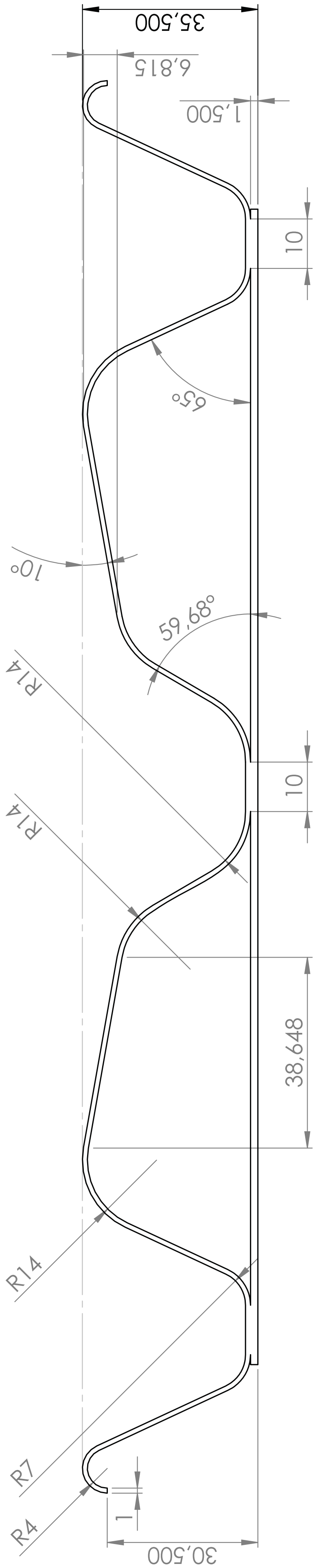
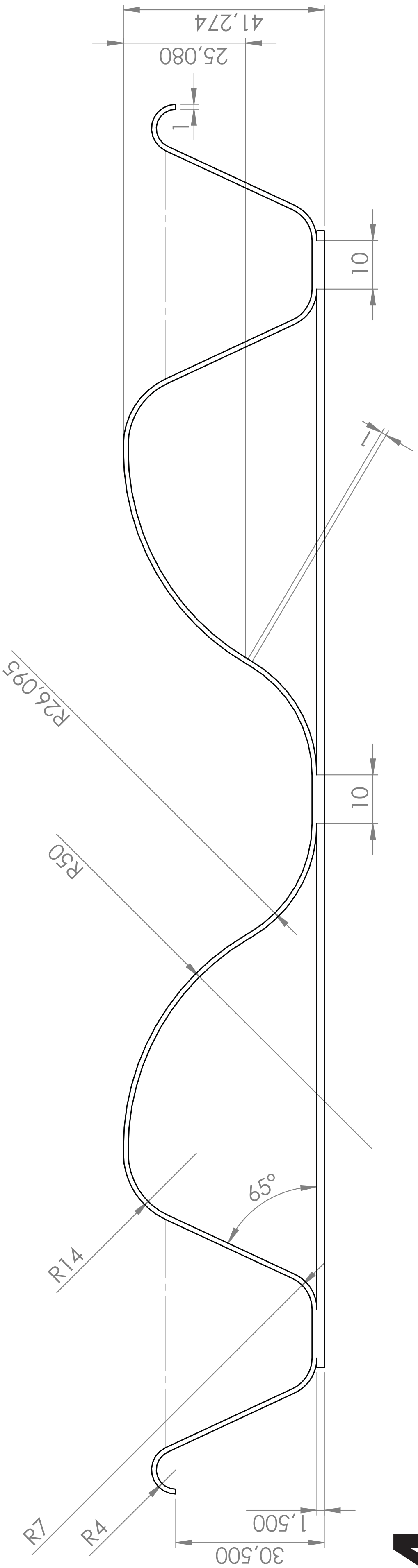
30,500
1,500
1
10
65°
65°
R7
10
R7
R7
R7
R7

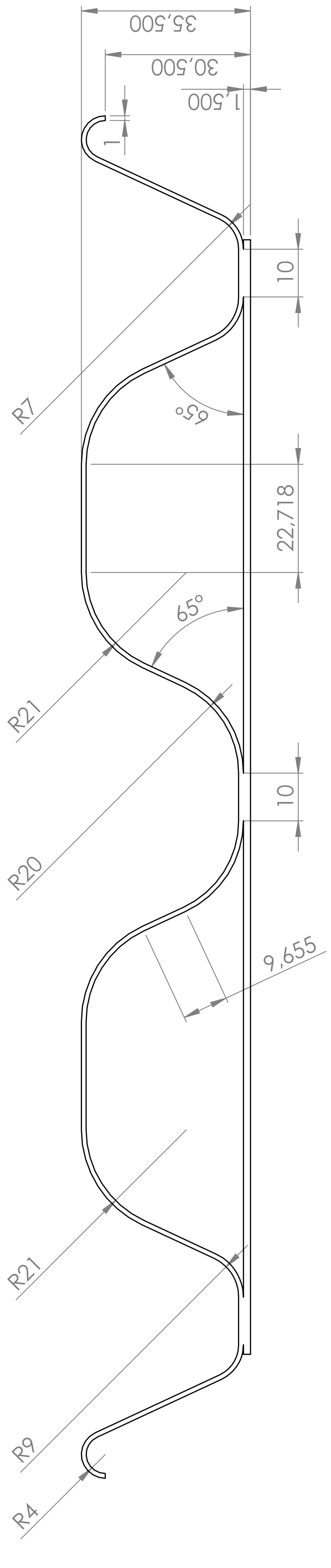
2


35,500
6,815
1,500
10
65°
10°
59,68°
R14
10
R14
38,648
R14
R7
R4
1
30,500

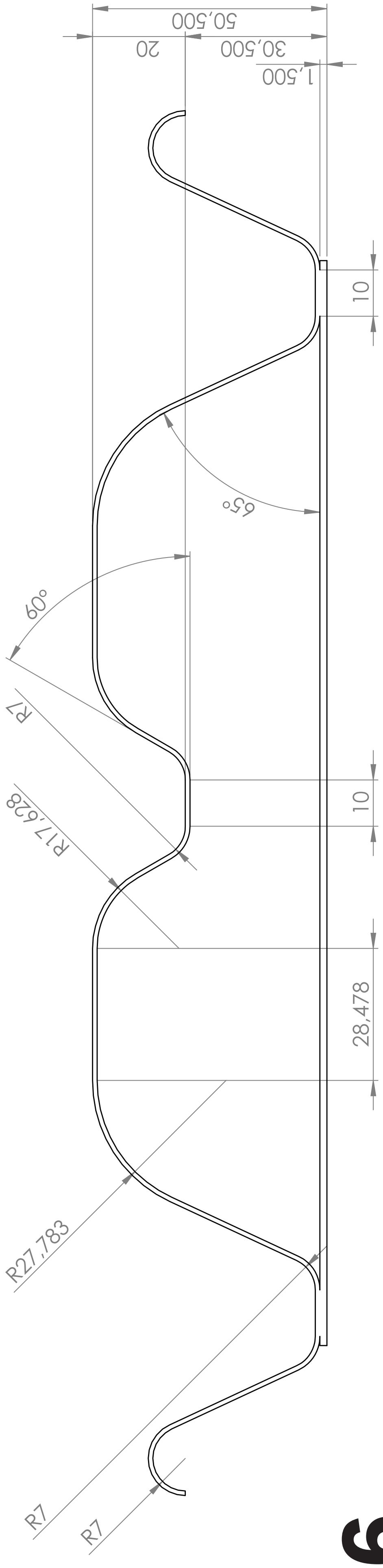
3


41,274
25,080
1
10
1
R26,095
10
R50
65°
R14
R7
R4
1,500
30,500

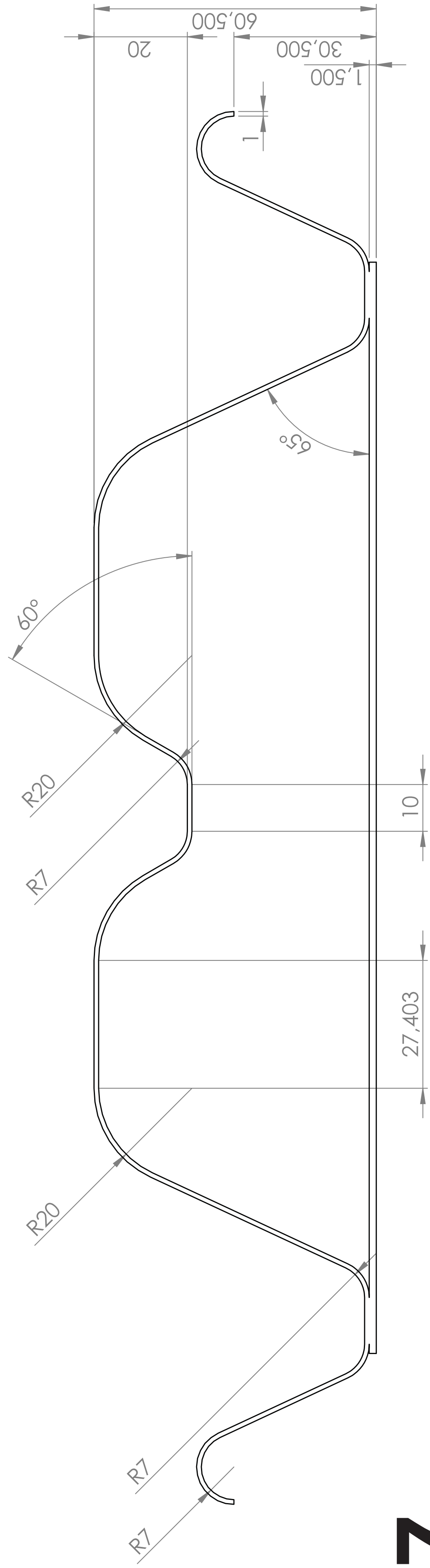
4


35,500
30,500
1,500
1
10
R7
65°
22,718
65°
R21
10
R20
9,655
R21
R9
R4

5


50,500
20
30,500
1,500
10
65°
60°
R7
R17,628
10
28,478
R27,783
R7
R7

6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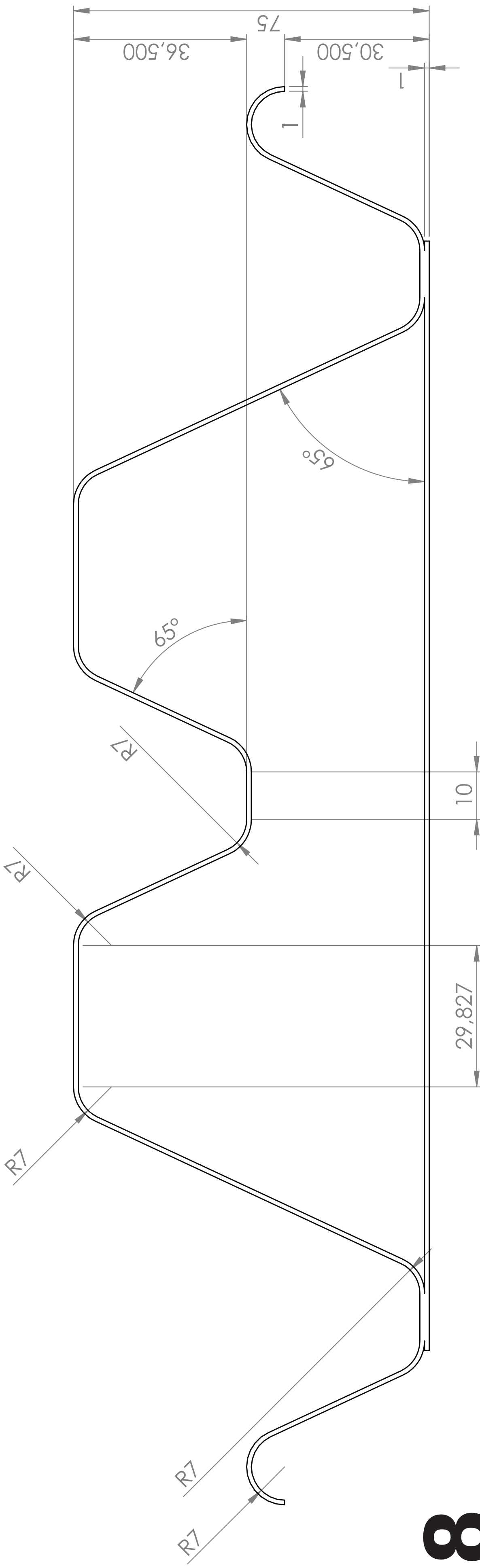
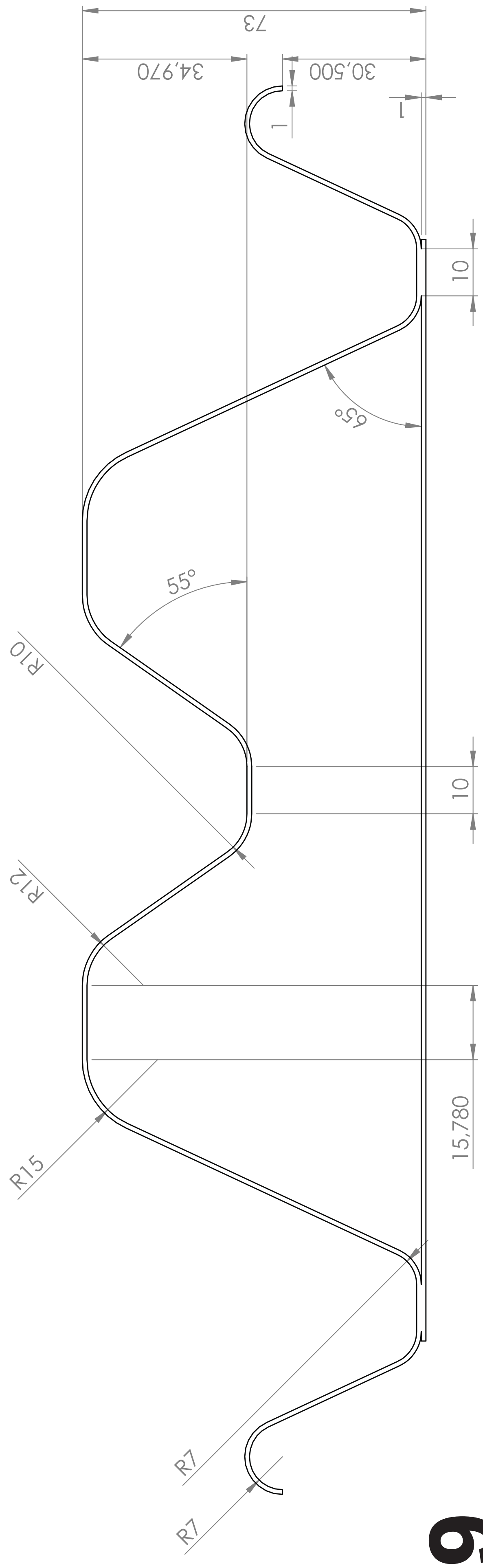
60°
R20
R7
10
27,403
R20
R7
R7

7



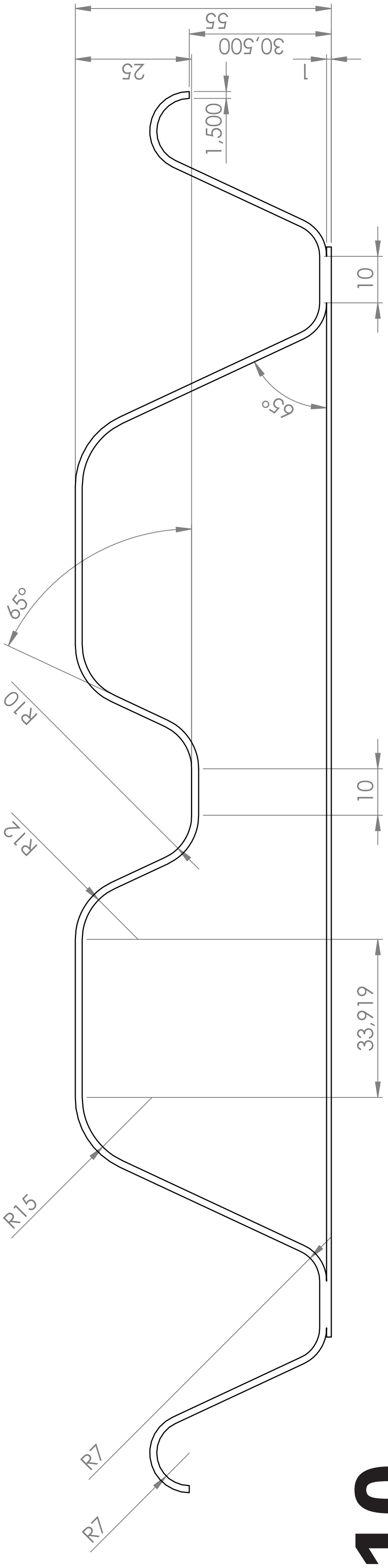
75
36,500
30,500
1
1
65°
65°
R7
10
R7
29,827
R7
R7
R7

8

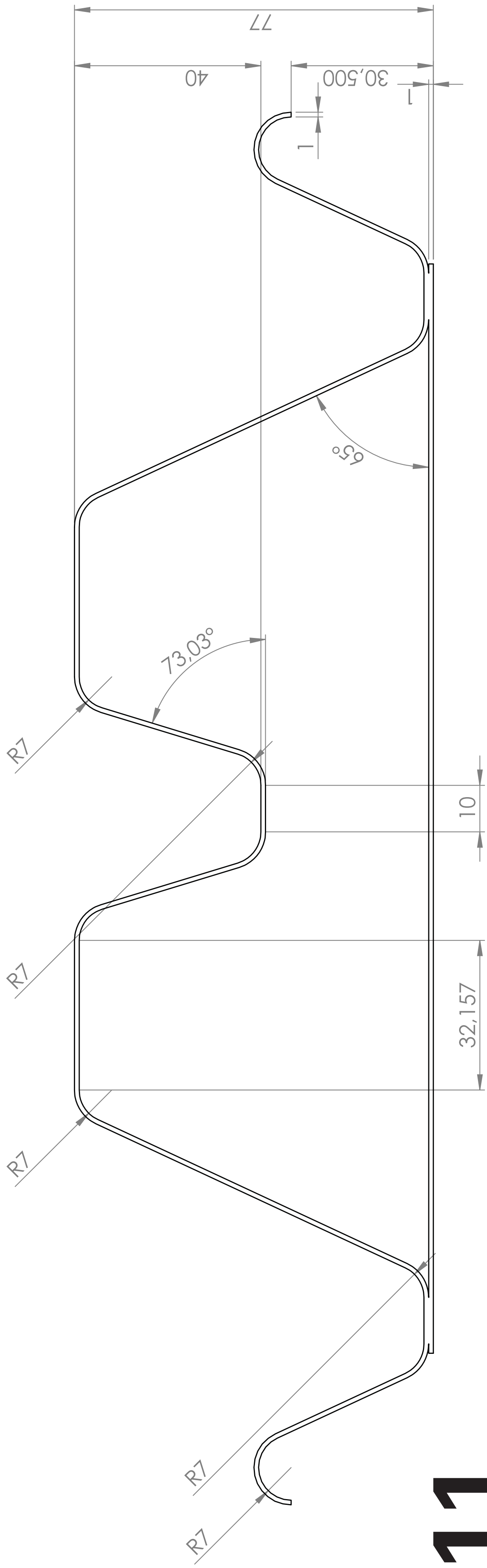


73
34,970
30,500
1
1
10
65°
55°
R10
10
R12
15,780
R15
R7
R7

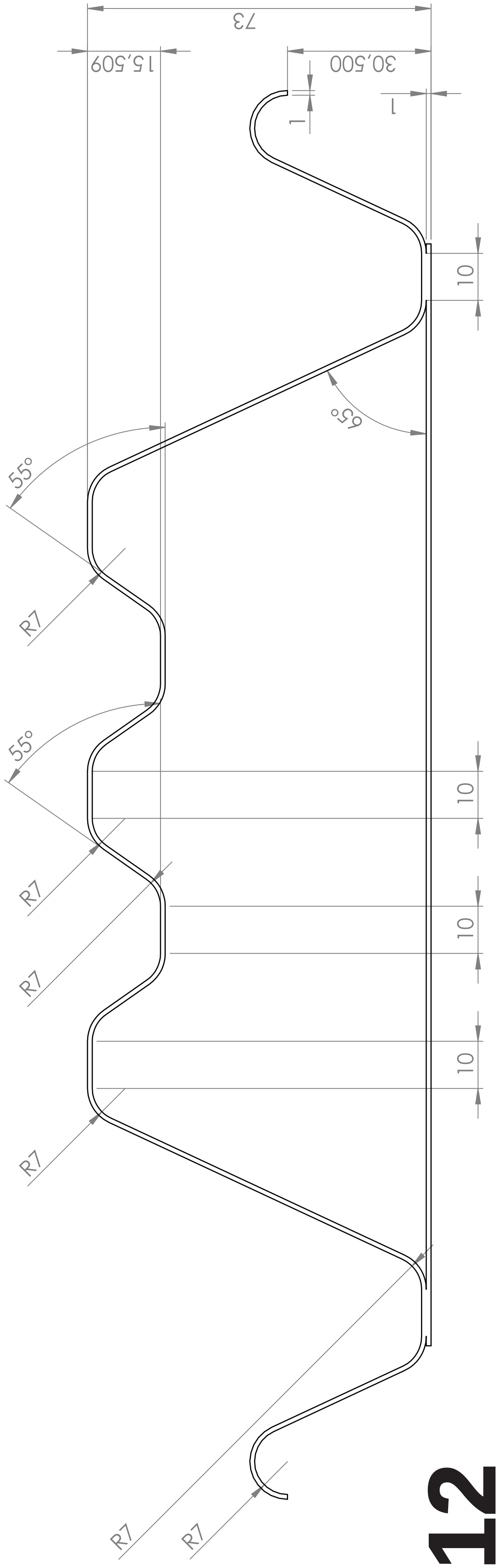
9


55
30,500
25
1
1,500
10
65°
65°
R10
10
R12
33,919
R15
R7
R7

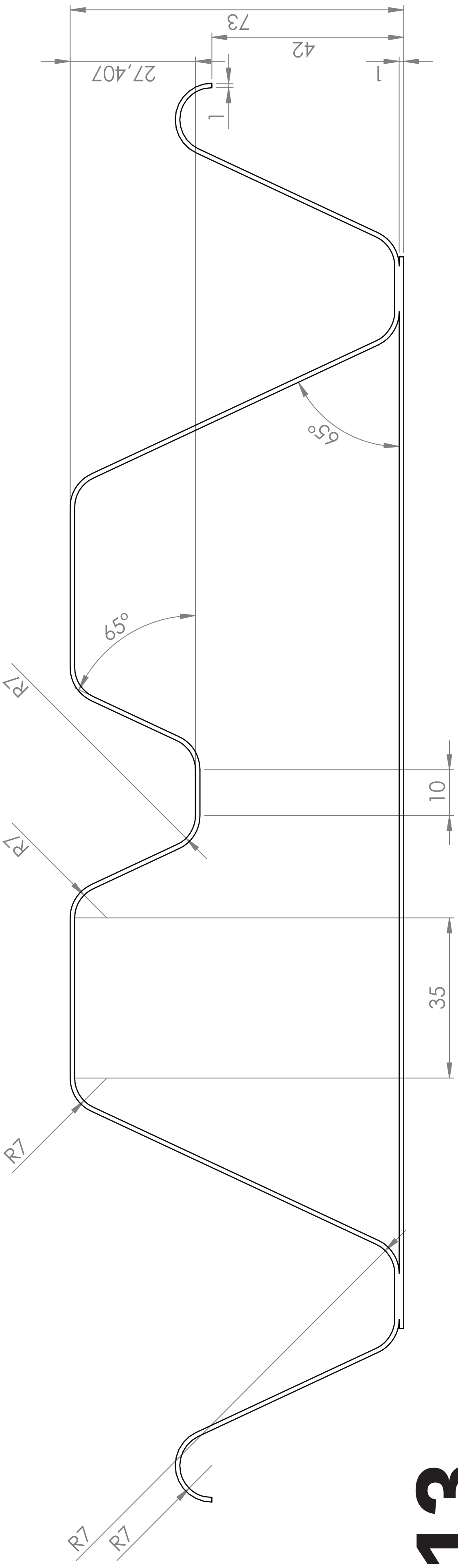
10


77
40
30,500
1
1
10
65°
73,03°
R7
10
R7
32,157
R7
R7
R7

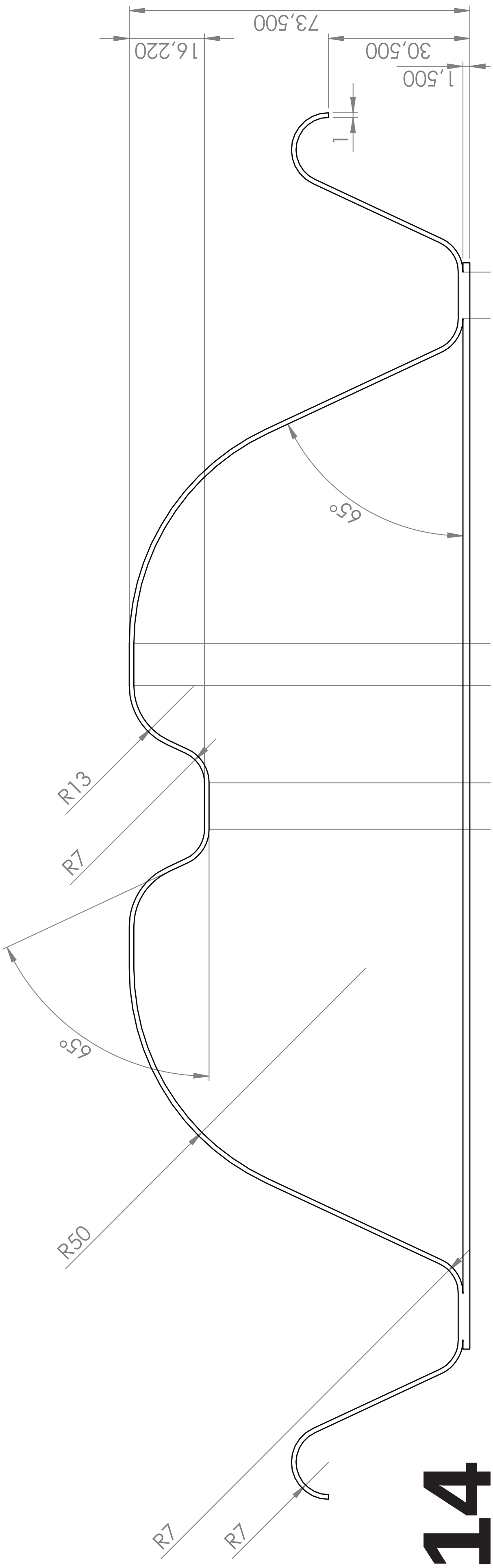
11


73
15,509
30,500
1
1
10
65°
55°
55°
R7
10
10
10
R7
R7
R7
R7
R7

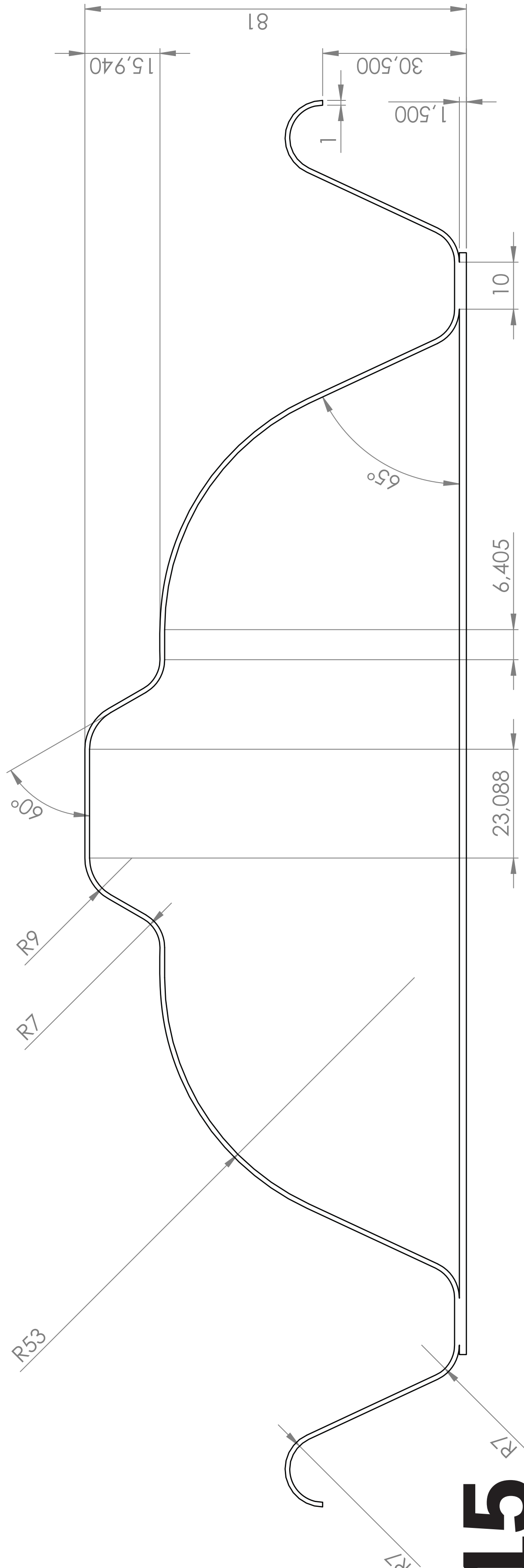
12


73
42
27,407
1
1
65°
65°
R7
R7
10
35
R7
R7
R7

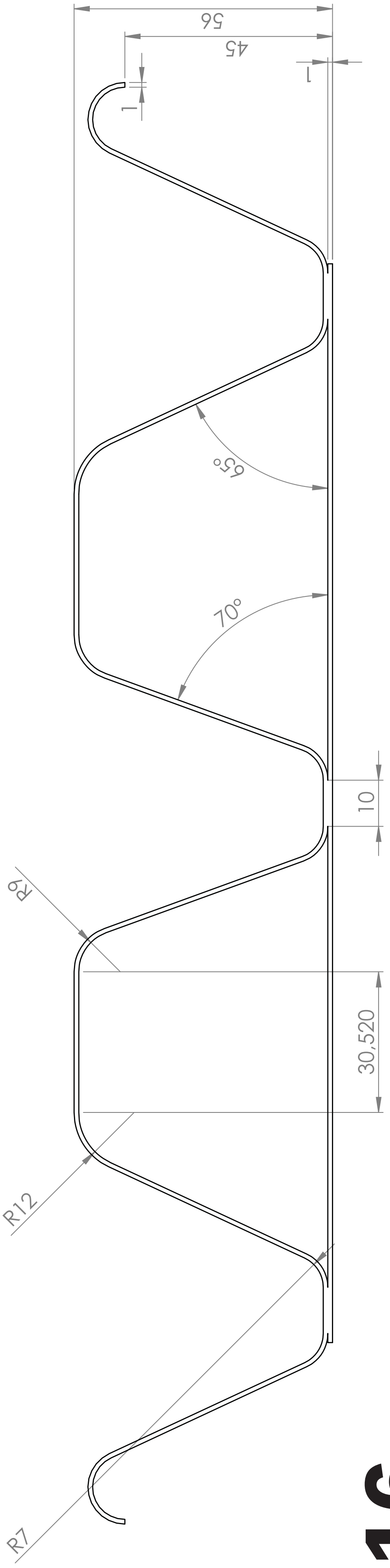
13


73,500
16,220
30,500
1,500
1
65°
65°
R13
R7
R50
R7
R7

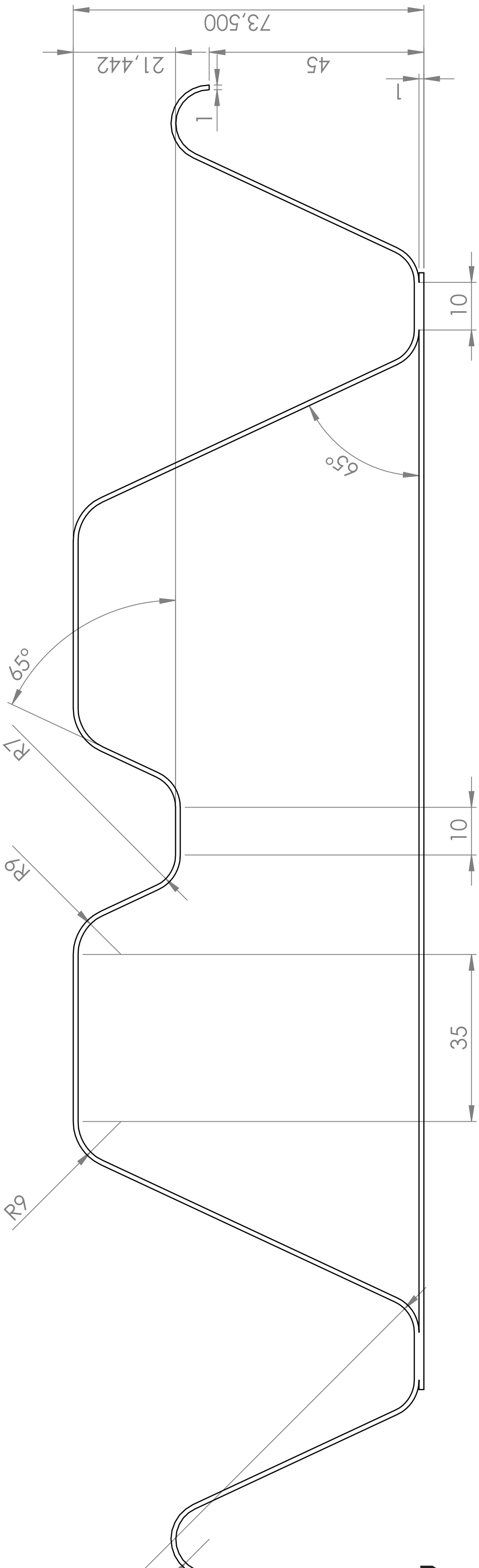
14


81
15,940
30,500
1,500
1
10
65°
6,405
23,088
60°
R9
R7
R53
R7
R7

15


56
45
1
1
65°
70°
10
R9
30,520
R12
R7

16


73,500
21,442
45
1
1
10
65°
65°
R7
10
R9
35
R9
R7
R7

17

Finite Element Analysis

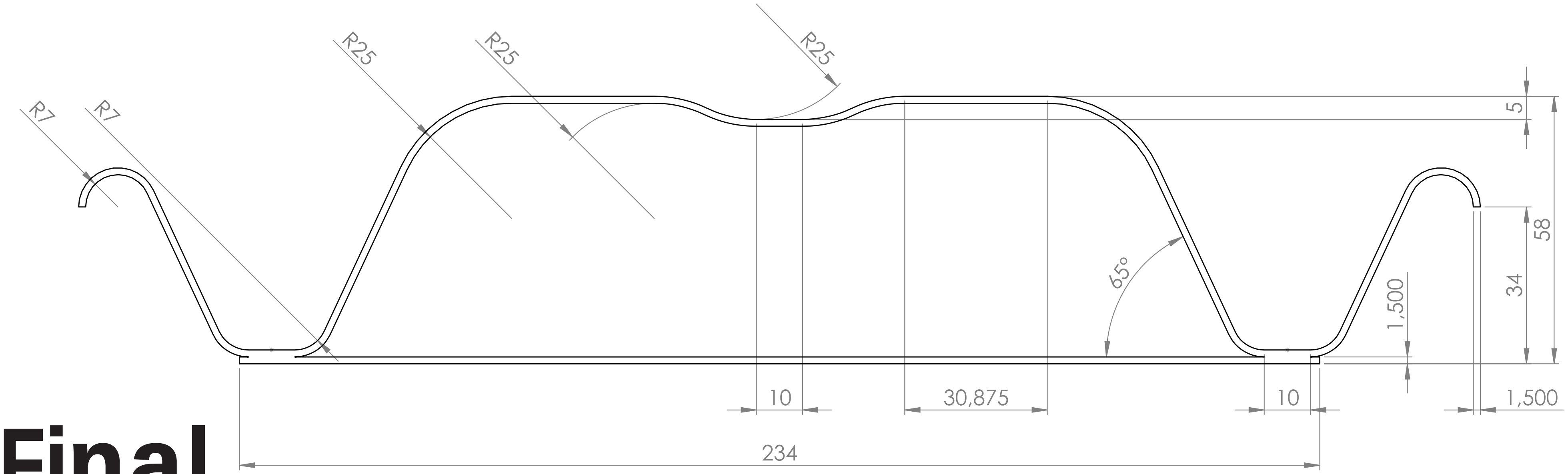
The finite element analyzes were done by a student employee of the TPRC research center. The lack of experience with calculations of anisotropic materials and the advice to outsource the analysis instead of learning how to do it within this project led to the outsourcing. All pictures on this and the following pages are made by Thijs Donderwinkel.
Table 2 is an extended table from the report. The values in the table are the deformations under a load of 20kg hanged at the end of the wing in the middle (bending) and 160mm from the middle. Only the values of the steel MovaNext 3 were measured, the others were calculated. The second row of values was provided by Indes. It contains a prediction of the metal joint to the towbar otherwise 'Original' and 'FEA Original' would be the same.
The requirements were derived from the values of the MovaNext 3. As the total deformation is eventually what is noted by the user, exceeding the requirement on torsion is acceptable as long as it is compensated by more bending stiffness than stated in the requirements.

	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
Moment of Inertia aim	67%	100%	
FEA Original	1,6mm	4,3 mm	5,9 mm
FEA Final design	2,1 mm	4,9 mm	7,0 mm

Table 2 Indication of performance potential

One could argue that the wing could be weakened further if the presumption about the joint is correct. However this joint will be one of the heavier components so reducing the amount of used material and thereby the mechanical properties could be useful. The margin that is kept intact to be able to use a lighter joint and to compensate for the difference between the presumptions and calculations on one hand and test results of a prototype on the other.
Besides the deformation in Figures 1 to 4, the stresses are shown in Figure 5. The stress is devided by the maximum allowable stress, everything above 1 is a concern. These red areas are concentrated around the edges of the fixation. To avoid these concentrations, an additional layer of fibres will be added. The addition of this extra layer was also caused by concern among the UT and Cato about denting and damaging of the wing by dropping something on it or bumbing it into something. The maximum stresses in the thickened wing can be seen in Figure 7.

Based on FEA calculations, the wing should be able to function with a thicker 1,5mm top half. The margin that still exists should be confirmed with prototype tests. If the margin is significant, the wing design could be adapted and lowered even further.



Final

Figure 1 Cross section of the final design with a three layer top part to increase its strength.

Final design (thickned)				
Deformation (torsion)	4,9 mm		Length x Width x Height	559 x 304 x 62 mm
Deformation (bending)	2,1 mm		Volume	547,7 cm^3
Total deformation	7,0 mm		Weight	985,8 g

Table 3 General performance and dimensions of the final wing design

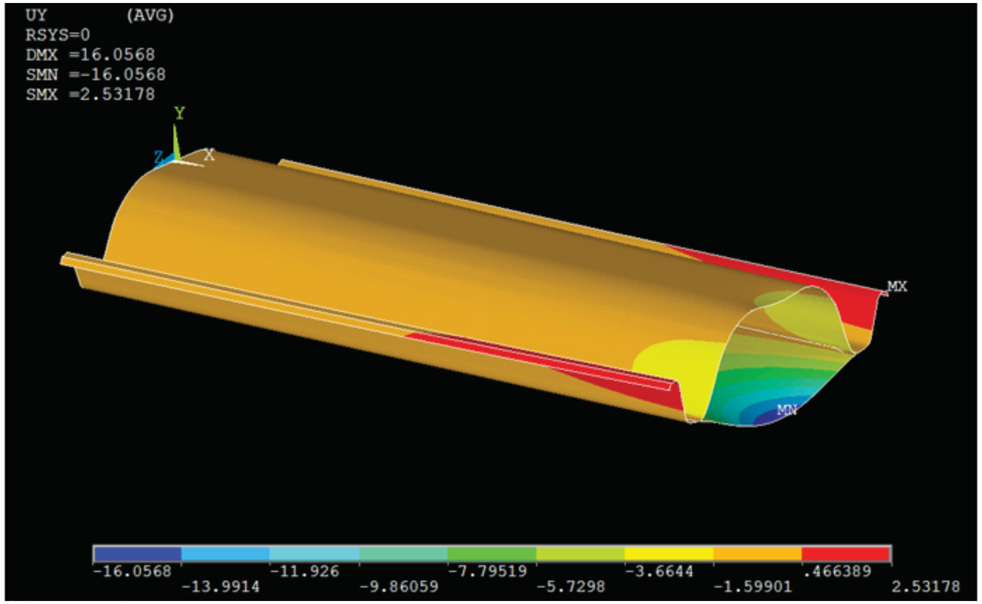


Figure 2 Bending under a 20kg load

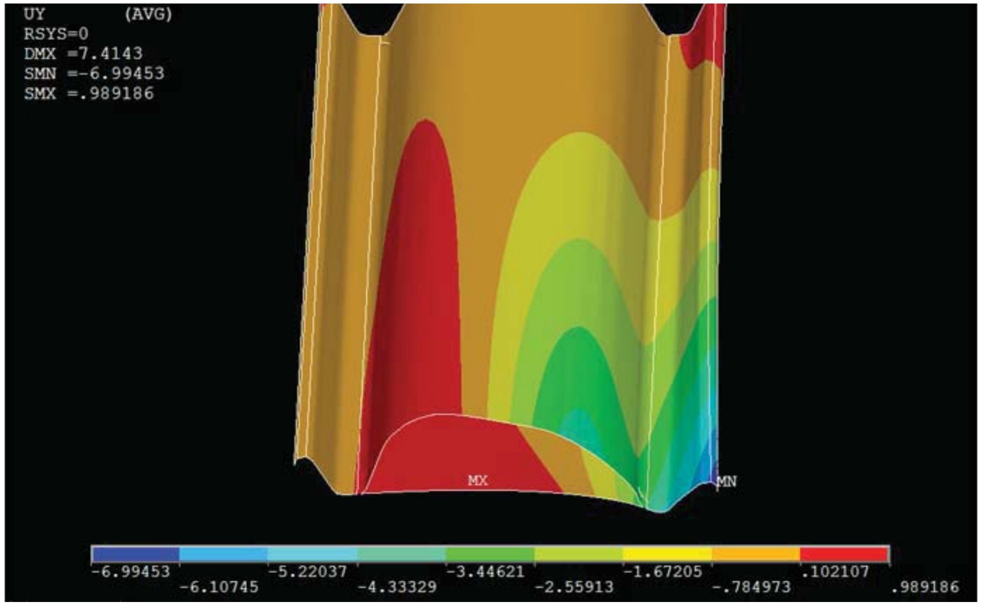


Figure 3 Torsion under a 20kg load

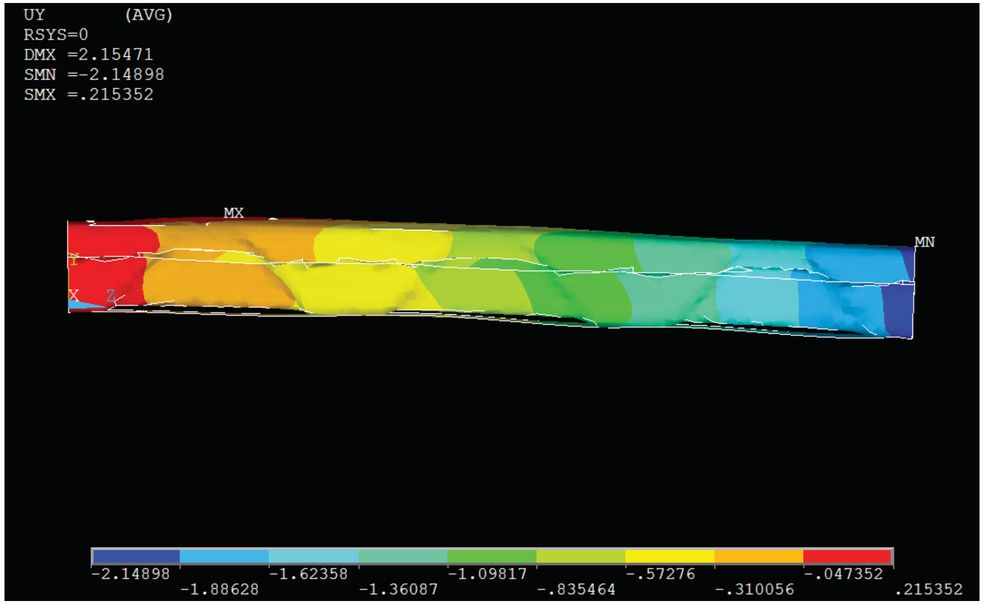


Figure 4 Bending under a 20kg load

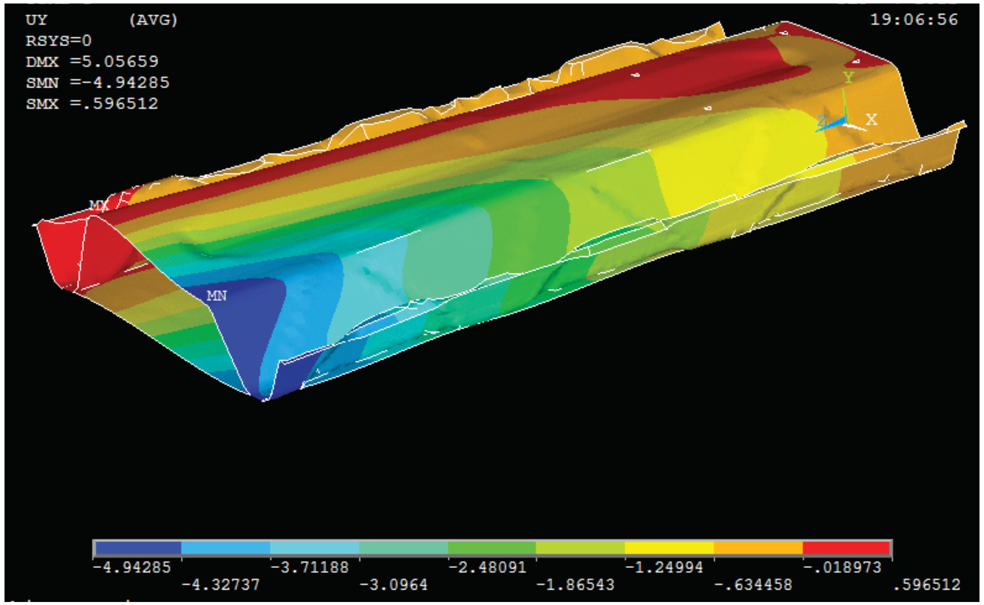


Figure 5 Torsion under a 20kg load

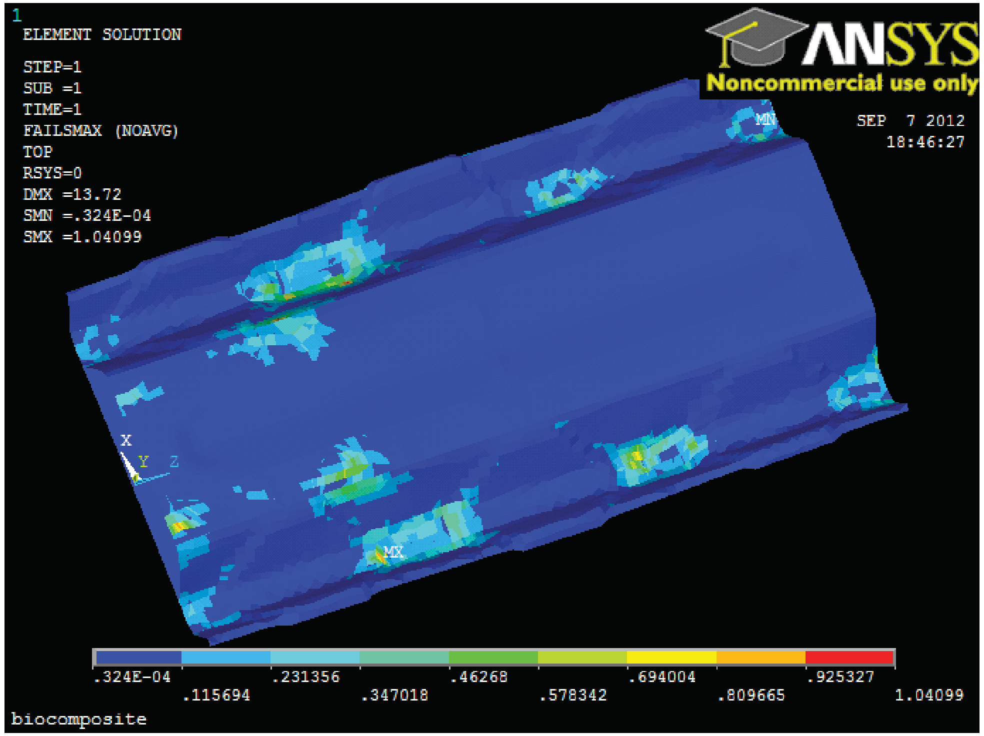


Figure 6 Percentage of the maximum allowed stresses under a 40kg load at 1,5G

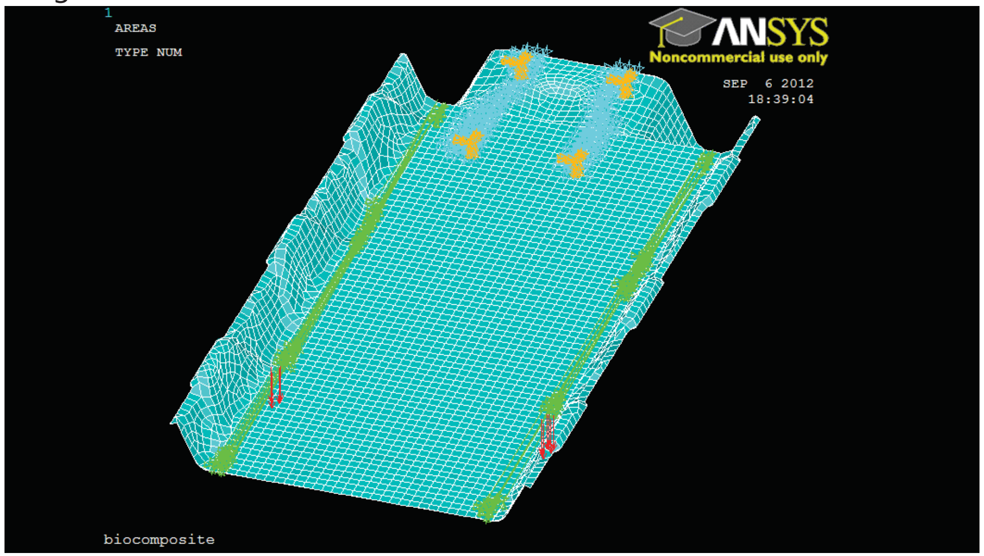


Figure 7 Fixation and loading of the tested model

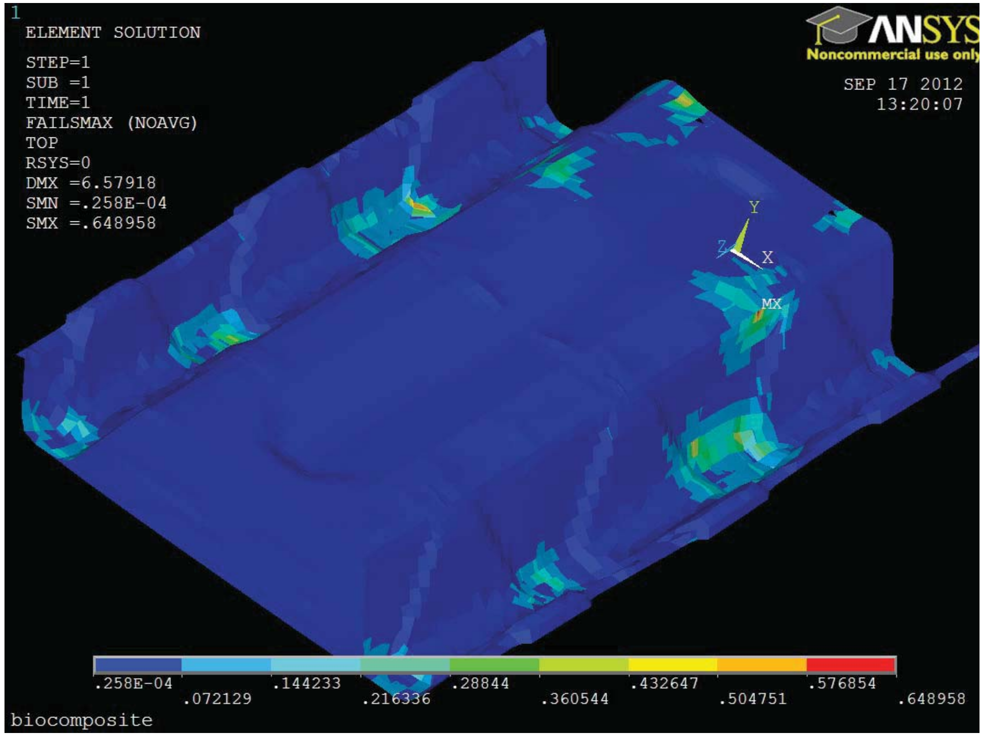


Figure 8 Percentage of the maximum allowed stresses under a 40kg load at 1,5G (Thickened 3 layer top half)

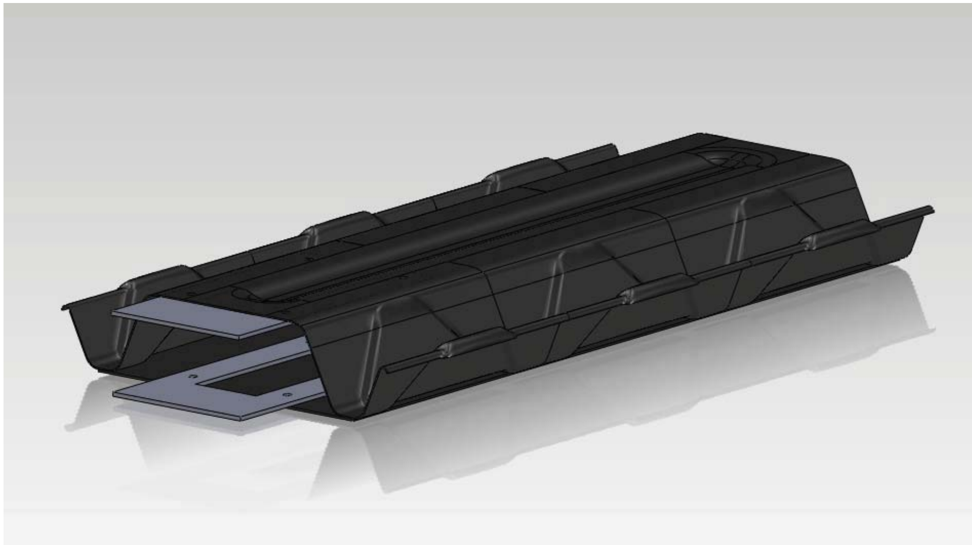


Figure 9 Fixation brackets

Appendix E Rail and wheelpad dimensions

The requirements state that the carrier should be compatible with bicycles with
24 to 28 inch wheels and a distance between the wheels axis of 1050 to 1200mm should fit. Figure 1 shows the position of the wheels in the extreme positions. The wheelpad must be able to support all these wheels.

Most dimensions on the wheelpad are set. The height is from the bottom to the top of the gutter and the top must be at least 10 to 12cm to fit the knob. The slope of the pad however was chosen. A 25 degree angle gives a contact area perpendicular to the radius of most wheels, enabling the user to strap the wheels in tight.

Finally, Figure 3 shows that the wheelpad should be able to move at least 114mm. However some play is useful during installing or removing bikes or to carry children’s bicycles. Furtermore some room infront of the rail is needed to feed the pads onto the rail during manufacturing. Therefore a rail fitting in the flat part between two steps would be too short with 119mm.

To guide the entire wheel pad from the outer position in Figure 3 to the most inward position, adding 60mm of play to the requirement, an 375mm long rail as shown below.

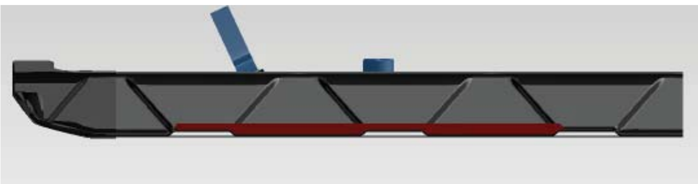


Figure 4 Section of the gutter with a red rail.

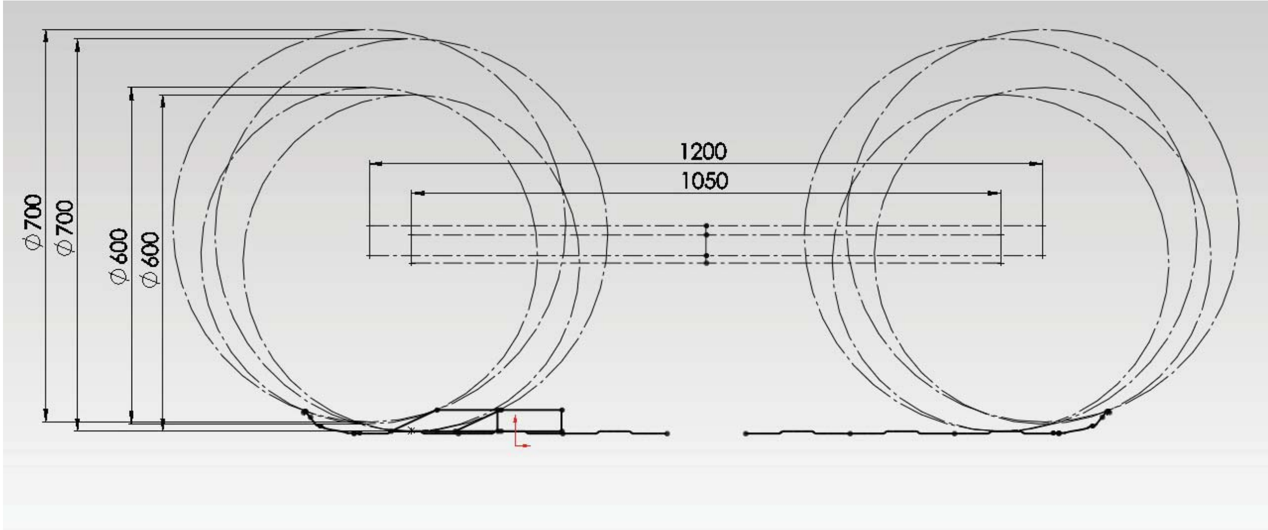


Figure 1 The extremes of the wheel size and axis distance requirements.

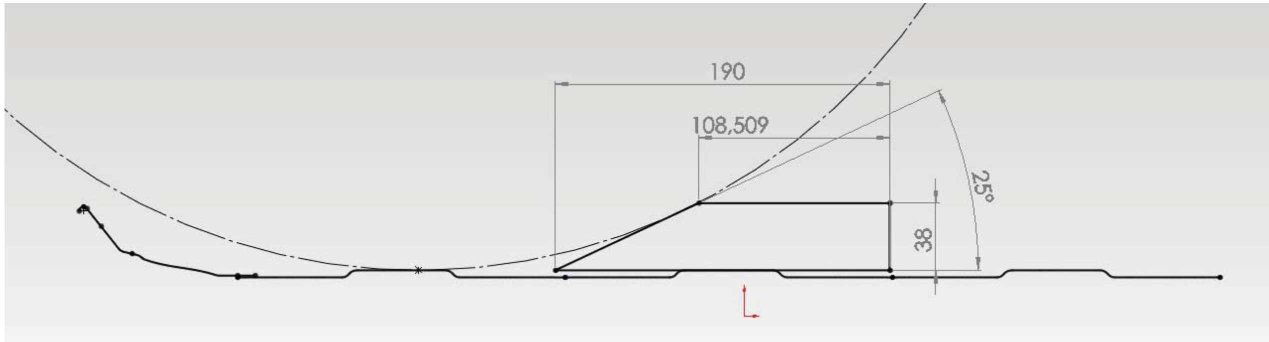


Figure 2 Dimensions of the wheel pads.

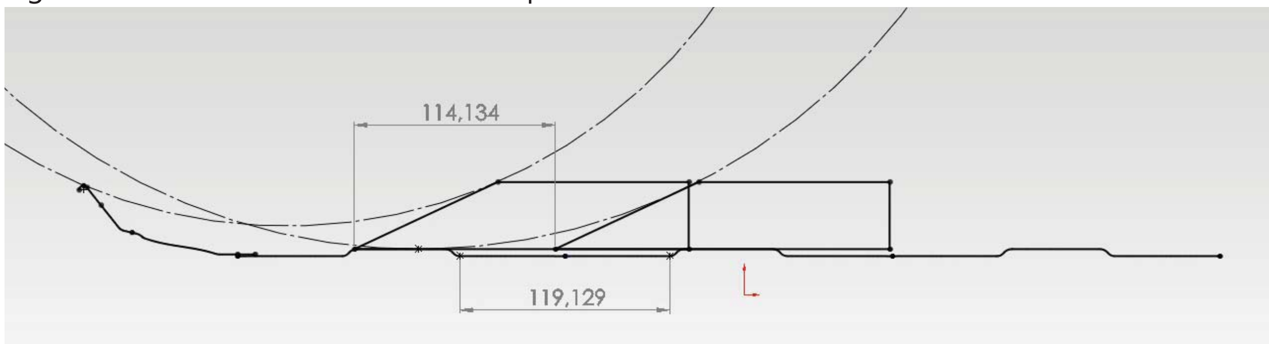


Figure 3 Minimum distance of movement and length of the horizontal part in the step.

Appendix F Rivets

Blind rivets can clamp two pieces of material together. They are not very often applied on composites. One of the concerns is that installing the rivets crushes the composite. In this appendix some calculations are done with data supplied by the rivet manufacturer to find if and which kind of blind rivets can be used.

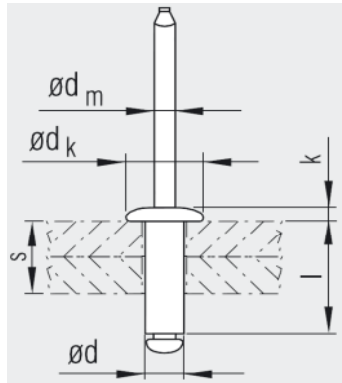
Rivet	Shear strength rivet N	Tensile strength rivet N	Mandrel material	Yield strength mandrel N/mm2	D mm	Dk mm	Dm mm	Thickness laminate mm
300 921 Soft Set	460	640	AlZnMgCu 1,5	450	4	7,7	2,4	1,5
300 871 LSR Foldingleg	2000	2500	Steel (Zinc)*	1000	4,8	9,2	2,9	1,5
300 841 LSR Foldingleg	700	900	Aluminium alloy*	500	4	7,7	2,3	1,5
300 851 LSR Foldingleg	1000	1400	Aluminium alloy*	500	4,8	9,2	2,7	1,5
423 150 TIFAS Multigrip	1500	2300	Steel (Zinc)*	1000	4,8	15,7	2,8	1,5

Rivet	Compression strength laminate N/mm2	Shear strength thickness laminate N/mm2	Area mandrel mm2	Area head mm2	F installation N	F installation/ Area head F/mm2	F max (pullthrough) N
300 921 Soft Set	63	91	4,523893421	32,71183351	2035,75204	62,23289316	3301,970959
300 871 LSR Foldingleg	63	91	6,605198554	46,84114647	6605,198554	141,0127431	3945,212054
300 841 LSR Foldingleg	63	91	4,154756284	32,71183351	2077,378142	63,50540216	3301,970959
300 851 LSR Foldingleg	63	91	5,725552611	46,84114647	2862,776306	61,1167002	3945,212054
423 150 TIFAS Multigrip	63	91	6,157521601	173,9578392	6157,521601	35,3966319	6732,590136

Background

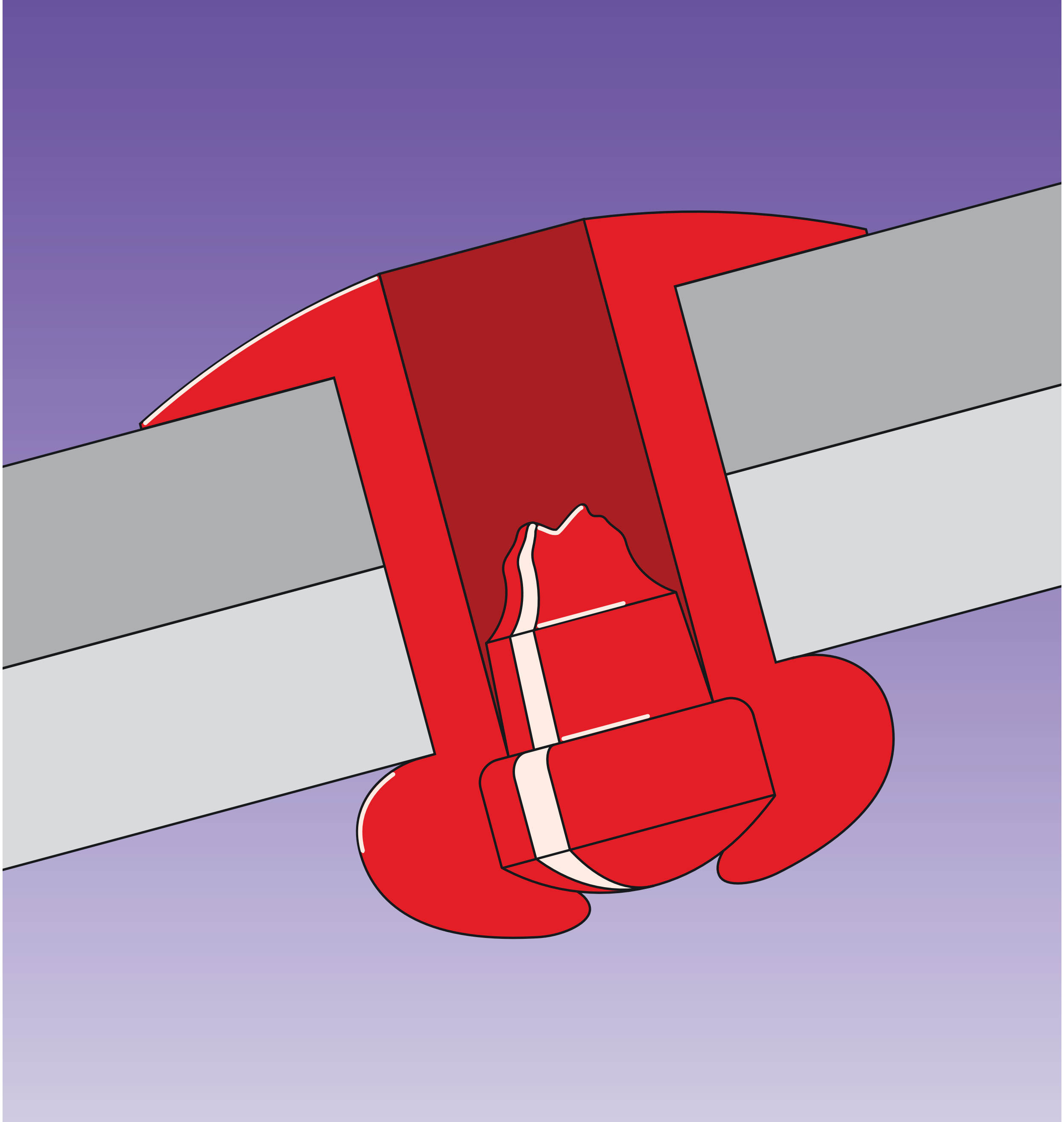
Two clomns are coloured, green indicates that the laminate will not be damaged. Red indicates material failure.
The green in the first colomn means that the pressure excerted by the contact area of the rivet head during the installation does not exceed the compression strength of the laminate.
In the second column green indicates that the tensile strength of the rivet is lower than the force needed to pull the whole rivet through the material. The maximum allowable force is calculated with the shear strength of the laminate and the shear surface. The shear surface is in this case the perimeter of the head, multiplied by the thickness of the laminate.
300 841 and 300 871 LSR Foldingleg cause damage during installation, the other rivets can be used.

D	Specified by TITGEMEYER	
Dk	Specified by TITGEMEYER	
Dm	Specified by TITGEMEYER	
Shear strength rivet	Specified by TITGEMEYER	
Tensile strength rivet	Specified by TITGEMEYER	
Mandrel material	Specified by TITGEMEYER	
Yield strength mandrel	Determined with CES Edupack 2012	
Compression strength laminate	Specified by Bond Laminates	
Shear strength thickness laminate	Specified by Bond Laminates	
Thickness laminate	Defined in the wing design	
Area mandrel	Sectional area calculated with the diameter	$(A=\pi/4*Dm^2)$
Area head	Contact area of the head	$(A=(\pi/4*Dk^2)-(\pi/4*D^2))$
F installation	Area head * Yield strength mandrel	$(F=A*p)$
F installation/Area head	Pressure on laminate during installation	$(p=F/A)$
F max (pullthrough)	Head circumference*Thickness*Shear strength	$(F=A*p)$



*The rivet manufacturer gives these generic material descriptions. The yield strength is chosen is if the strongest variety is used, the worst case scenario.

■ POP® **Soft-Set** blind rivets



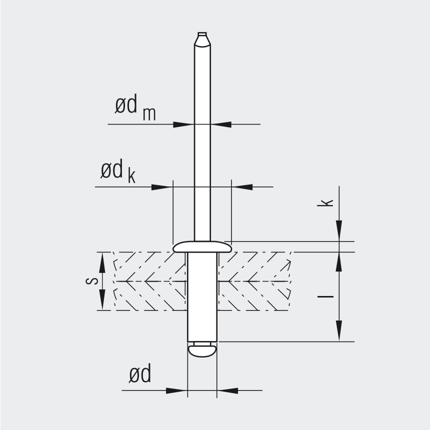
TITGEMEYER Tb1398GB(1011)1

Dome head

Material

Sleeve
Aluminium Al99
Melting point 650 – 660 °C

Mandrel
Aluminium AlZnMgCu 1.5



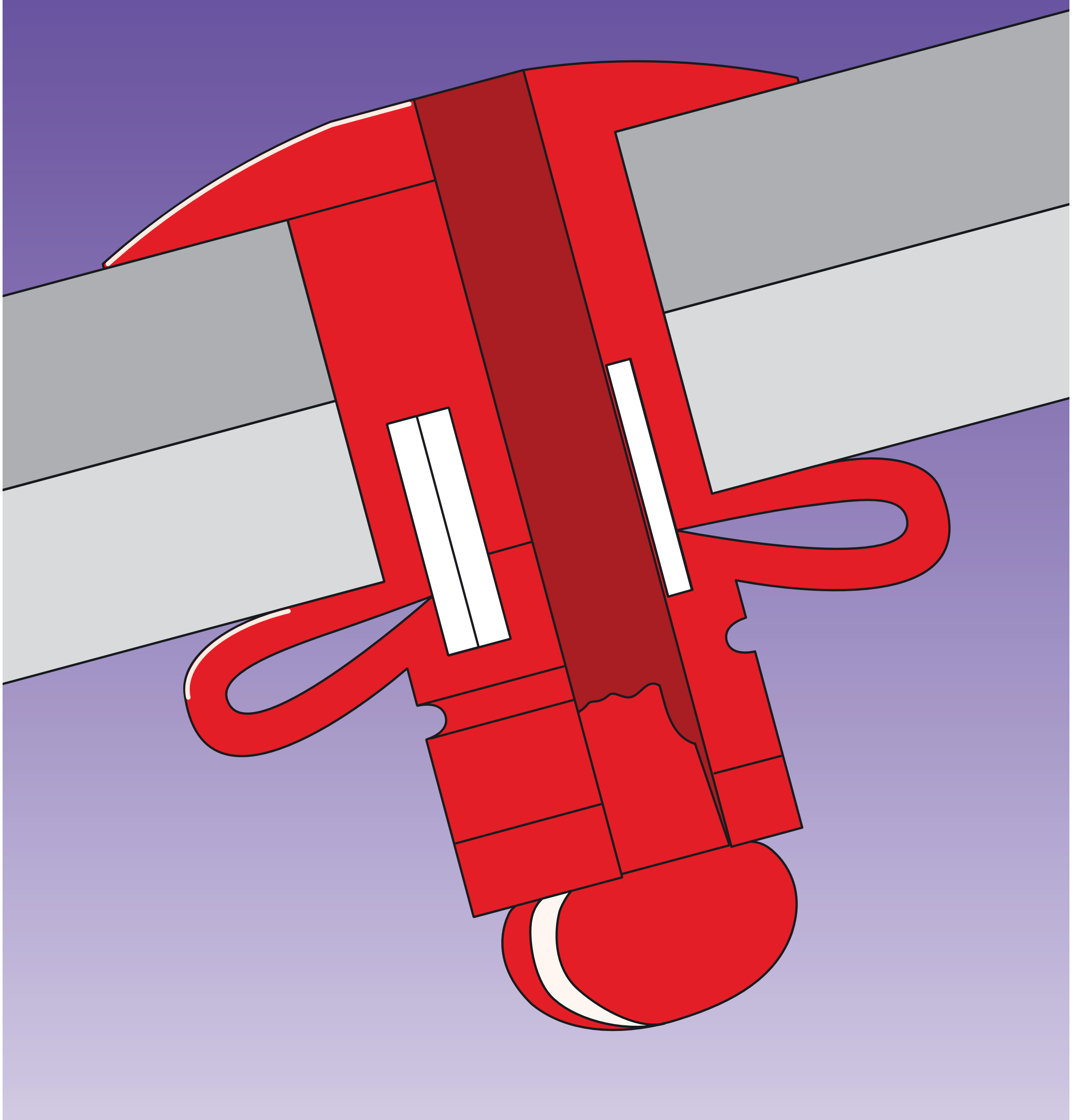
Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l +1.0 -0.2 [mm]	Head ø d_k ±0.3 [mm]	Head Height k ±0.2 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
3.2	3.3	4.8 – 6.4	9.5	6.5	1.0	1.9	280	370	**300 910**
		6.4 – 9.5	12.7	6.5	1.0	1.9	280	370	**300 911**
		9.5 – 12.7	15.9	6.5	1.0	1.9	280	370	**300 912**
4.0	4.1	3.2 – 6.4	10.2	8.0	1.2	2.4	460	640	**300 920**
		6.4 – 9.5	13.0	8.0	1.2	2.4	460	640	**300 921**
		9.5 – 12.7	16.4	8.0	1.2	2.4	460	640	**300 922**
4.8	4.9	6.4 – 9.5	14.0	9.5	1.4	2.9	650	910	**300 930**
		9.5 – 12.7	16.8	9.5	1.4	2.9	650	910	**300 931**

[1] *Minimum based on rivet failure*

We reserve the right to amend specifications at any time.

TITGEMEYER Telephone: +49 (0)5 41/58 22-0 Telefax: +49 (0)5 41/58 22-494 E-Mail: export@titgemeyer.com

■ POP® LSR folding leg blind rivets



TITGEMEYER Tb1399GB(1011)1

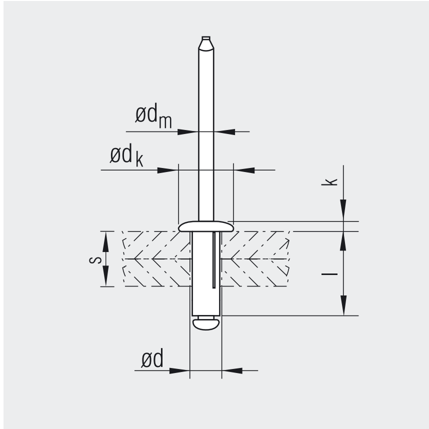
POP® LSR folding leg blind rivets

Dome head

Material

Sleeve
Steel zinc, passivate

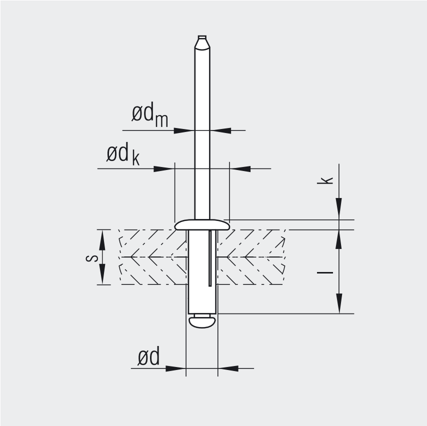
Mandrel
Steel zinc



Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l ±0.5 [mm]	Head ø d_k ±0.3 [mm]	Head Height k ±0.2 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
4.8	5.0	– 6.4	17.2	9.5	1.5	2.9	2000	2500	**300 870**
		3.0 – 8.5	19.5	9.5	1.5	2.9	2000	2500	**300 871**

[1] *Minimum based on rivet failure*

We reserve the right to amend specifications at any time.



Dome head

Material

Sleeve
Aluminium AlMg 3/3.5

Mandrel
Aluminium alloy

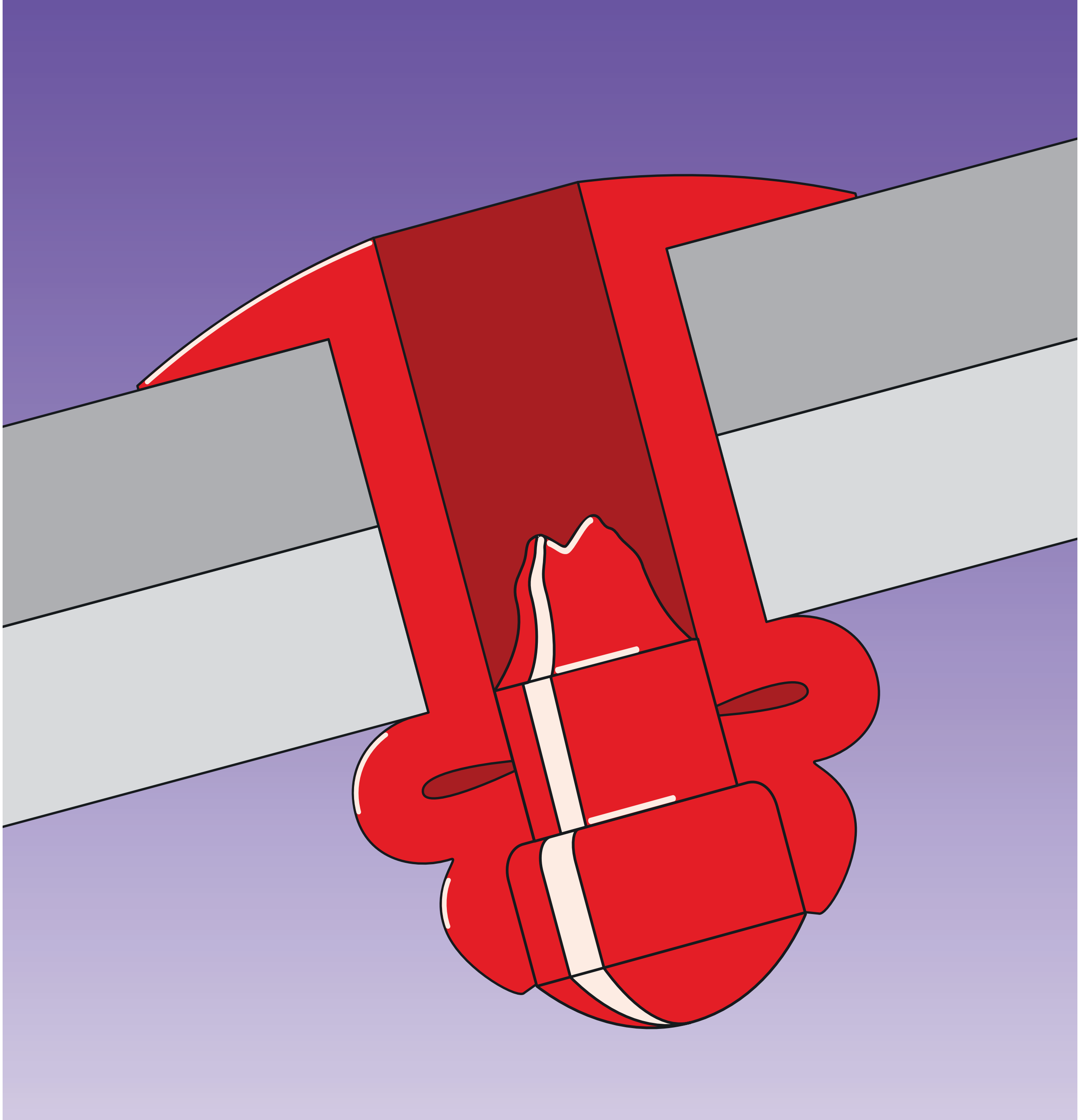
Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l *±0.5* [mm]	Head ø d_k *±0.3* [mm]	Head Height k *±0.2* [mm]	Mandrel ø d_m *nom* [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
4.0	4.2	– 6.4	17.5	8.0	1.2	2.3	700	900	**300 840**
		3.0 – 9.5	21.3	8.0	1.2	2.3	700	900	**300 841**
		5.0 – 12.0	25.0	8.0	1.2	2.3	700	900	**300 842**
4.8	5.0	– 6.4	17.5	9.5	1.5	2.7	1000	1400	**300 850**
		3.0 – 9.5	19.8	9.5	1.5	2.7	1000	1400	**300 851**
		5.0 – 12.0	23.5	9.5	1.5	2.7	1000	1400	**300 852**

[1] Minimum based on rivet failure

Large dome head on request.

We reserve the right to amend specifications at any time.

TIFAS® **multigrip** blind rivets



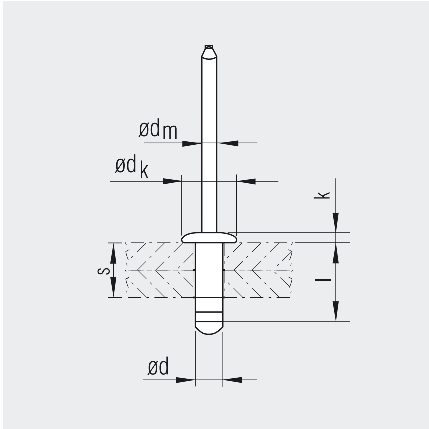
TITGEMEYER Tb1403GB(1011)1

Dome head

Material

Sleeve
Steel SAE 1006 or equivalent
zinc, passivate

Mandrel
Steel SAE 1018/1035
zinc, passivate

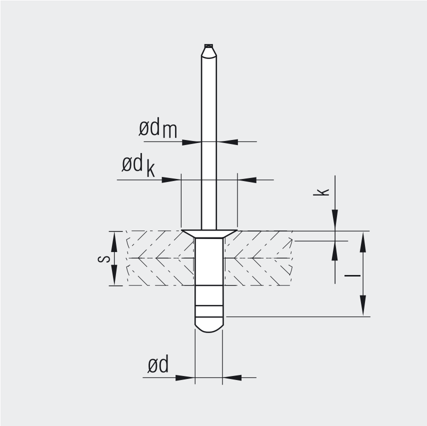


Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l *+0.4 -0.2* [mm]	Head ø d_k *±0.25* [mm]	Head Height k *±0.25* [mm]	Mandrel ø d_m *nom* [mm]	Strength[1] nominal Shear[3] [N]	Strength[1] nominal Tensile [N]	**Part No.**
3.2	3.3 – 3.4	1.0 – 4.0	9.0	7.2	0.85	2.1	1510	1717	**421 021**
		1.0 – 9.0	13.0	7.2	0.85	2.1	1510	1717	**421 023**[2]
4.0	4.1 – 4.2	1.4 – 5.0	11.0	8.1	1.20	2.7	1962	2355	**421028**
		1.4 – 8.0	14.0	8.1	1.20	2.7	1962	2355	**421 032**
4.8	4.9 – 5.0	1.0 – 4.0	9.0	9.8	1.45	2.9	4415	3826	**421 067**
		1.0 – 6.0	11.0	9.8	1.45	2.9	4415	3826	**421 068**
		1.0 – 9.0	14.0	9.8	1.45	2.9	4415	3826	**421 069**
		3.0 – 12.0	17.0	9.8	1.45	2.9	4415	3826	**421 072**
6.4	6.7 – 6.9	1.5 – 7.5	14.5	13.0	3.0	4.2	6867	4120	**–**

[1] *Minimum based on rivet failure*
[2] *Long mandrel 50 mm*
[3] *The shear strength is affected by the position of the broken mandrel on the shear plane*

On request:
- Other types
- Nominal size 4.8 mm with large head 14.0 mm
- Nominal size 4.8 mm with extra-large head 15.85 mm. e.g. Part No. 423 067
- Other surface coatings/proporties

We reserve the right to amend specifications at any time.



Countersunk head 120°

Material

Sleeve
Steel SAE 1006 or equivalent
zinc, passivate

Mandrel
Steel SAE 1018/1035
zinc, passivate

Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l +0.4 -0.2 [mm]	Head ø d_k ±0.25 [mm]	Head Height k ±0.20 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear[2] [N]	Strength[1] nominal Tensile [N]	**Part No.**
4.8	4.9 – 5.0	2.5 – 6.0	11.0	8.65	1.3	2.9	4415	3826	**421 073**
		3.0 – 9.0	14.0	8.65	1.3	2.9	4415	3826	**–**
		4.0 – 12.0	17.0	8.65	1.3	2.9	4415	3826	**–**
		9.0 – 17.0	22.0	8.65	1.3	2.9	4415	3826	**421 071**

[1] Minimum based on rivet failure
[2] The shear strength is affected by the position of the broken mandrel on the shear plane

On request:
- Other types
- Other surface coatings/proporties

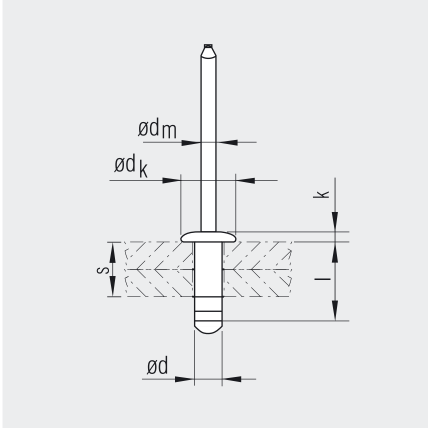
We reserve the right to amend specifications at any time.

Dome head

Material

Sleeve
Aluminium AlMg 2/2.5

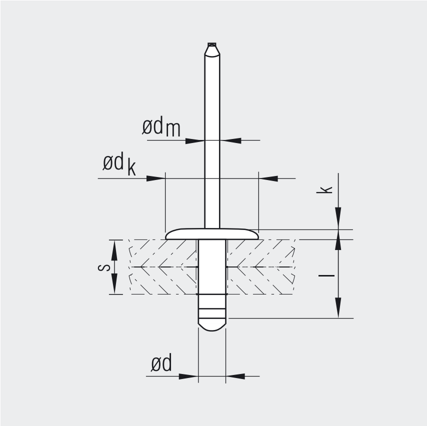
Mandrel
Steel zinc



Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l *+0.4 -0.2* [mm]	Head ø d_k *±0.25* [mm]	Head Height k *±0.1* [mm]	Mandrel ø d_m *nom* [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
3.2	3.3 – 3.4	0.8 – 4.8	8.0	6.4	0.95	1.8	700	1000	**421 121**
		4.0 – 8.0	11.0	6.4	0.95	1.8	700	1000	**421 122**
4.0	4.1 – 4.2	1.3 – 3.8	7.0	7.9	1.20	2.2	1100	1700	**421 134**
		1.2 – 6.5	10.0	7.9	1.20	2.2	1100	1700	**421 130**
		4.0 – 9.5	12.7	7.9	1.20	2.2	1100	1700	**421 132**
		8.0 – 13.5	17.0	7.9	1.20	2.2	1100	1700	**421 129**
4.8	4.9 – 5.0	1.6 – 6.4	10.3	9.8	1.45	2.8	1500	2300	**421 141**
		4.8 – 11.1	15.0	9.8	1.45	2.8	1500	2300	**429 127**
		7.5 – 12.0	16.9	9.8	1.45	2.8	1500	2300	**421 143**
		9.0 – 15.0	19.5	9.8	1.45	2.8	1500	2300	**421 149**
		12.7 – 19.8	24.8	9.8	1.45	2.8	1500	2300	**421 144**

[1] Minimum based on rivet failure

We reserve the right to amend specifications at any time.



Large dome head

Material

Sleeve
Aluminium AlMg 2/2.5

Mandrel
Steel zinc

Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l +0.4 -0.2 [mm]	Head ø d_k ±0.3 [mm]	Head Height k ±0.15 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
4.0	4.1 – 4.2	3.2 – 7.9	11.1	11.0	1.5	2.2	1100	1700	**423 132**
4.8	4.9 – 5.1	1.6 – 6.4	10.0	16.0	1.8	2.8	1500	2300	**423 150**
		6.4 – 12.7	16.0	16.0	1.8	2.8	1500	2300	**423 152**
		12.0 – 20.0	24.8	16.0	1.8	2.8	1500	2300	**423 154**

[1] *Minimum based on rivet failure*

Nominal size 4.0 mm with stainless steel mandrel e.g. Part No. 423 232 on request.

We reserve the right to amend specifications at any time.

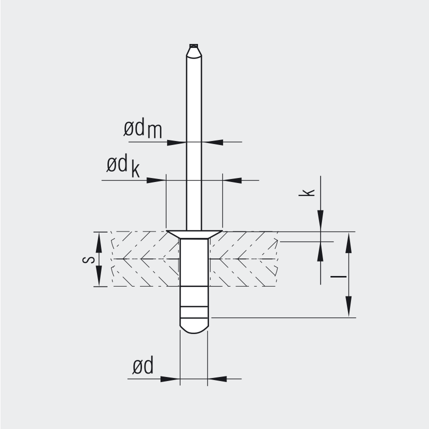
TIFAS® multigrip blind rivets

Countersunk head 120°

Material

Sleeve
Aluminium AlMg 2/2.5

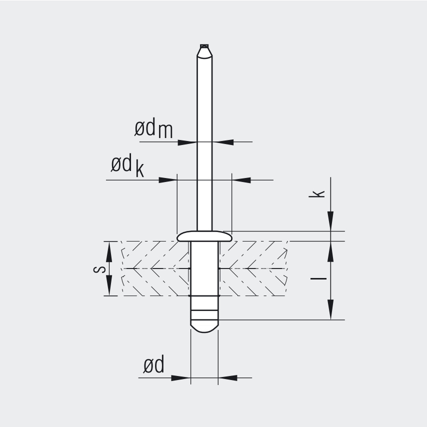
Mandrel
Steel zinc



Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l +0.4 -0.2 [mm]	Head ø d_k ±0.15 [mm]	Head Height k ±0.1 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
4.8	4.9 – 5.0	3.2 – 7.9	12.1	8.8	1.35	2.8	1500	2300	**422 140**
		6.4 – 12.7	16.9	8.8	1.35	2.8	1500	2300	**422 142**

[1] *Minimum based on rivet failure*

We reserve the right to amend specifications at any time.



Dome head

Material

Sleeve
Aluminium AlMg 2/2.5

Mandrel
Stainless steel AISI 434
1.4113

Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l +0.4 -0.2 [mm]	Head ø d_k ±0.25 [mm]	Head Height k ±0.1 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	Part No.
3.2	3.3 – 3.4	0.8 – 4.8	8.0	6.4	0.95	1.8	700	1000	**421 221**
4.0	4.1 – 4.2	1.3 – 6.3	9.5	7.9	1.20	2.2	1100	1700	**421 230**
		4.5 – 8.5	12.7	7.9	1.20	2.2	1100	1700	**421 232**
		6.4 – 13.0	16.9	7.9	1.20	2.2	1100	1700	**421 233**
4.8	4.9 – 5.0	1.6 – 6.3	10.3	9.8	1.45	2.8	1500	2300	**421 243**
		4.8 – 11.1	15.1	9.8	1.45	2.8	1500	2300	**421 244**

[1] *Minimum based on rivet failure*

We reserve the right to amend specifications at any time.

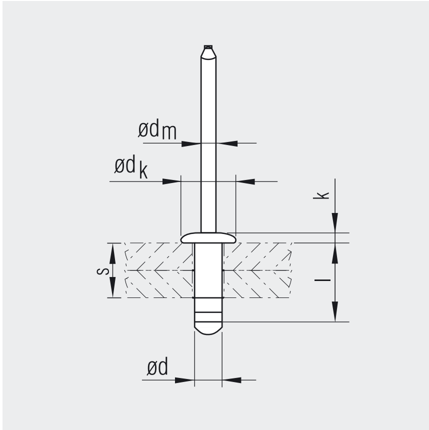
Dome head

Material

Sleeve
Stainless steel AISI 304

Mandrel
Stainless steel AISI 434

EDELSTAHL Rost frei



Nominal size-ø d [mm]	Hole-ø [mm]	Grip range s [mm]	Sleeve length l +0.4 -0.2 [mm]	Head ø d_k ±0.25 [mm]	Head Height k ±0.25 [mm]	Mandrel ø d_m nom [mm]	Strength[1] nominal Shear [N]	Strength[1] nominal Tensile [N]	**Part No.**
4.8	4.9 – 5.0	1.5 – 6.0	10.3	9.8	1.85	3.4	6475	5003	**421 741**
		2.5 – 7.5	12.7	9.8	1.85	3.4	6475	5003	**421 742**

[1] *Minimum based on rivet failure*

Other types on request.

We reserve the right to amend specifications at any time.

BOND LAMINATES
Materials designed to improve

TEPEX® dynalite Glas/PA-RG600(x)/47%:

Symbol	Einheit	Bezeichnung	Wert	Prüfnorm
E_1	[GPa]	E-Modul in Kettrichtung	23,65	DIN EN ISO 527-4
E_2	[GPa]	E-Modul in Schussrichtung	23,43	DIN EN ISO 527-4
E_3	[GPa]	E-Modul in Dickenrichtung	5,4[a]	-
G_{12}	[GPa]	Schubmodul k/s	3,1	DIN EN ISO 14129
G_{13}	[GPa]	Schubmodul k/z	2,1[b]	-
G_{23}	[GPa]	Schubmodul s/z	2,1[c]	-
ν_{12}	[-]	Querkontraktionszahl k/s	0,16	DIN EN ISO 527-4
ν_{13}	[-]	Querkontraktionszahl k/z	**	-
ν_{23}	[-]	Querkontraktionszahl s/z	**	-
R^z_1	[MPa]	Zugfestigkeit in Kettrichtung	472	DIN EN ISO 527-4
R^d_1	[MPa]	Druckfestigkeit in Kettrichtung	250***	DIN 65380
R^z_2	[MPa]	Zugfestigkeit in Schussrichtung	425	DIN EN ISO 527-4
R^d_2	[MPa]	Druckfestigkeit in Schussrichtung	280***	DIN 65380
R^z_3	[MPa]	Zugfestigkeit in Dickenrichtung	63[d]	-
R^d_3	[MPa]	Druckfestigkeit in Dickenrichtung	63[e]	-
R_{12}	[MPa]	Scherfestigkeit k/s	91	DIN EN ISO 14129
R_{13}	[MPa]	Scherfestigkeit k/z	47[f]	-
R_{23}	[MPa]	Scherfestigkeit s/z	47[g]	-

1 = Kettrichtung (k); 2 = Schussrichtung (s); 3 = Dickenrichtung (z)

*** = Diese Werte sind extrem schwer experimentell zu ermitteln, da Knickgefahr während der Versuche. Reale Werte müssen deutlich höher sein.

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[a] berechnet mit: $E_3 = E^*_m \cdot \frac{(1+0{,}85\cdot\varphi^2)}{\left[(1-\varphi)^{1{,}25} + \varphi \cdot \frac{E^*_m}{E_f}\right]}$ $\quad E^*_m = \frac{E_m}{(1-\nu^2_m)}$

[b] berechnet mit: $G_{13} = G_m \cdot \frac{1+0{,}6\cdot\sqrt{\varphi}}{\left[(1-\varphi)^{1{,}25} + \varphi \cdot \frac{G_m}{G_f}\right]}$

[c] berechnet mit: $G_{23} = G_m \cdot \frac{1+0{,}6\cdot\sqrt{\varphi}}{\left[(1-\varphi)^{1{,}25} + \varphi \cdot \frac{G_m}{G_f}\right]}$

[d] berechnet mit: $R^z_3 = R^z_m \cdot \left[1+(\varphi-\sqrt{\varphi})\cdot\left(1-\frac{E_m}{E_{f,quer}}\right)\right]$

[e] berechnet mit: $R^d_3 = R^d_m \cdot \left[1+(\varphi-\sqrt{\varphi})\cdot\left(1-\frac{E_m}{E_{f,quer}}\right)\right]$

[f] berechnet mit: $R_{13} = R^s_m \cdot \left[1+(\varphi-\sqrt{\varphi})\cdot\left(1-\frac{G_m}{G_f}\right)\right]$

[g] berechnet mit: $R_{23} = R^s_m \cdot \left[1+(\varphi-\sqrt{\varphi})\cdot\left(1-\frac{G_m}{G_f}\right)\right]$

** ergibt sich aus Schubmodul und E-Modul

	Glass	PA
E_1 E-Modul in Hauptrichtung [N/mm²]	*73.000 (nicht erforderlich)*	*3000 (nicht erforderlich)*
E_2 E-Modul quer zur Hauptrichtung [N/mm²]	*73.000*	*3000*
G Schubmodul [N/mm²]	*30.000*	*735 (μ=0,36)*
μ_{12} Querkontraktion [-]	*0,22*	*0,36*
R_3^z Zugfestigkeit in Dickenrichtung [N/mm²]		*80*
R_3^d Druckfestigkeit in Dickenrichtung [N/mm²]		*80*
R^s Scherfestigkeit		*60*

Die obigen Angaben gelten für einen Faservolumenanteil von 47%. Für andere Glasgehalte schlagen wir ein Hoch- bzw. Runterrechnen mit folgenden Gleichungen vor:

Module:

$$E,G = x \cdot \varphi_{Glas} \cdot E,G_{Faser} + (1-\varphi_{Glas}) \cdot E,G_{Matrix}$$

Festigkeiten:

$$R = x \cdot \varphi_{Glas} \cdot R_{Faser}$$