Norwegian University of Life Sciences

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Faculty of Environmental Science and Technology
Department of Mathematical Sciences and Technology

Development of a 60 L Mixer/Vacuum Coater

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Preface

6 months ago, we started working with our master thesis, which addresses the development of a ready to build 60-litre mixer/vacuum coater.

We would like to thank Dr. Carlos Salas Bringas for supervising us through the semester. He has provided guidance and has helped us with design decisions as well as comments on the thesis' final form.

We would like to thank Vladimir Jozin, the sales manager for Forberg International AS and Head engineer Janis Kalnins for providing us with 3D models of their mixers and vacuum coater.

We would also like to thank co-supervisor and head engineer Dejan Miladinovic and head engineer Ismet Nikqi at Fôrtek for discussing different design with us and showing us mixers used at Fôrtek.

Additionally, we would like to thank Dr. Geir Terjesen and head engineer Tore Ensby for discussing structural calculations as well as manufacturing methods.

Finally, we would like to thank the suppliers and manufacturers of the standard parts for the help they have provided and the knowledge they have shared with us.

Abstract

The development of a 60-litre mixer/vacuum coater was the main objective of this thesis. The mixer/vacuum coaters design is based on a 1-litre prototype created by Didrik Heidal Dolva and Eirik Madland Størdal at IMT/NMBU as well as existing products from Forberg International AS, a manufacturer of mixers and rotating vacuum coaters. The working principle for this machine originates from Fôrtek, the international centre for feed technology owned by NMBU, who in collaboration with IMT/NMBU have created the different inventive steps for the patent. The purpose of this work was to design a ready to build 60-litre version of the 1-litre prototype.

The mixer/vacuum coater consists of one main housing with two different lids: one de-agglomeration lid and one vacuum lid. The lids can be changed to perform either vacuum coating or mixing operations. Chain driven components are used to rotate the main housing for it to be able to execute filling, emptying, mixing/vacuum coating and cleaning. The mixer/vacuum coater consists of 77 self-made unique parts, countless standard parts and solutions provided by Forberg.

Structural analysis were executed on the components that was seen as critical for the machine to function safely and properly. The calculations were mainly performed for the parts that were subjected to the highest stress.
Required start torque and power for every motor/gearmotor and stress evaluation for the mixer rotor and the main housing is examples of calculations that were performed.

A list of possible production methods were executed to form the basis of the cost analysis. The cost of standard parts were obtained by contacting the different manufacturers while the manufacturing costs of the designed components were estimated based on communication with workshops and suppliers.

Sammendrag

Hovedmålet for denne mastergradsoppgaven var å utvikle en maskin som skulle kunne både mikse og vakuum «coate» en batch på opptil 60 liter. Oppgaven er basert på utviklingen av en 1 liter mixer/vacuum coater som er ble gjort i forbindelse med masteroppgaven til Didrik Heidal Dolva og Eirik Madland ved IMT/NMBU våren 2015. Maskinen som er blitt utviklet i denne masteroppgaven er blitt utviklet gjennom samarbeid med Forberg International AS, produsent av miksere og vacuum coatere og eier av den originale «twin-shaft»-mikseren, samt Fôrtek, senter for fôr-teknologi ved Norges miljø- og biovitenskapelige universitet. Sistnevnte utarbeidet arbeidsprinsippet og de forskjellige utviklingspunktene til mikser/vakuum coateren i samarbeid med IMT/NMBU. Den nye 60 liter mikser/vakuum coateren skulle være en oppskalering av fjorårets 1 liter maskin.

Mikser/vacuum coateren består av et hoved-hus som kan benyttes med to forskjellige lokk: ett med en de-agglomerator og ett vakuum-lokk. Lokkene kan byttes ut for å enten kunne utføre miksing eller vacuum coating. Kjededrevene komponenter er benyttet for å kunne rotere hoved-huset for at det skulle kunne bli utført påfylling, tømming, miksing/vacuum coating og rengjøring. Maskinen består av 77 egendesignede deler og en stor mengde standardkomponenter i tillegg til løsninger hentet fra Forberg.

Strukturanalyse har blitt utført på de komponentene som ble ansett som avgjørende for at maskinen skulle kunne utføre oppgavene den var ment til å uføre på et trygt og forsvarlig vis. Kalkulasjonene ble i all hovedsak utført på de delene som var sett på utsatt for høyest spenning.
Nødvendig startmoment og effekt for hver motor/gir-motor og spenningsberegninger på mikser-rotoren og hoved-huset er eksempler på beregninger som ble utført.

En liste med mulige produksjonsmetoder ble utformer for å danne grunnlaget til kostnadsanalysen. Kostnadene til standardkomponentene ble innhentet gjennom korrespondanse med leverandører, mens produksjonskostnadene av de selvdesignede delene ble estimert ved å ta utgangspunkt i kommunikasjon med verksted og leverandører.

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1. Introduction

1.1 Background

Last year, two students from NMBU sat out to design and test an idea for a mixer/vacuum coater which was generated by the Center for Feed Technology (Fôrtek) here at NMBU. The purpose of the thesis was to make a simpler, less complicated product compared to other similar products on the marked.

Throughout the thesis period, the two students in question designed and assembled a prototype that made it possible for them to perform testing. Through testing, the students proved the validity of the working principle by delivering satisfactory results in two out of three aspects. The third being the vacuum coating testing that was unfortunately declared inconclusive as the 3D-printet prototype had some constructional faults causing leaks. Seeing as both the mixing and the dispersion of fluid proved successful, it was decided that the working principle should be tested for an up-scaled version of the original mixer. (1)

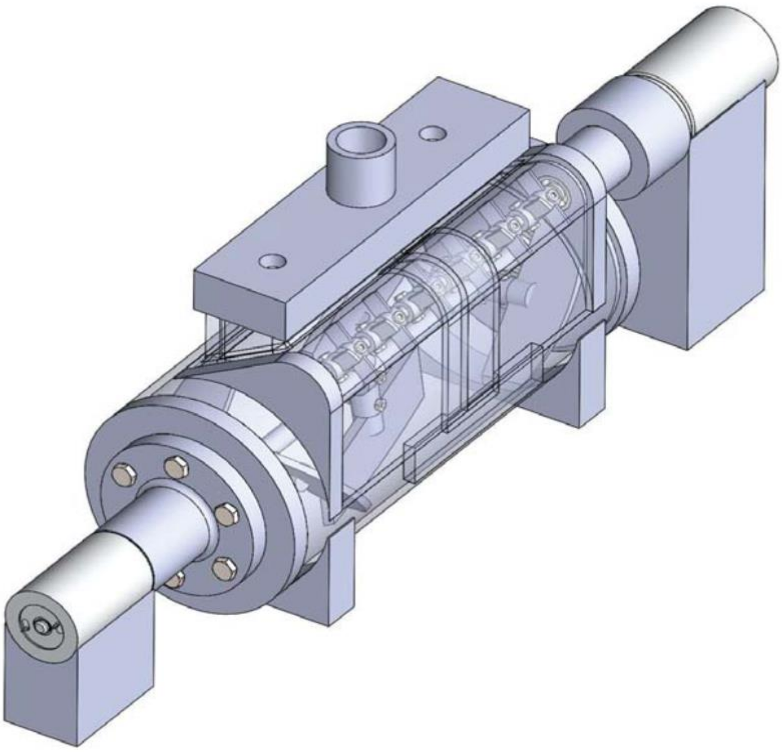


Figure 1.1 CAD-model of last year's Mixer/Vacuum Coater (1)

1.1.1 Vacuum Coating

Vacuum coating is a process that is commonly used in the feed industry to achieve an increased energy density of a pellet, enhanced flavour of a product, or to change its texture. The process takes place inside a chamber that is depressurized to achieve sub-atmospheric conditions (down to roughly 80 % vacuum (0,2 atm)). When the required pressure is reached, the air that would normally occupy the pores of the pellets will have been evacuated, leaving the pores empty. When initiating liquid addition when in the vacuum state, the added liquid will cover the surface of the pellets. When depressurising is initiated the liquid is slowly penetrating the pores. (1) (2)

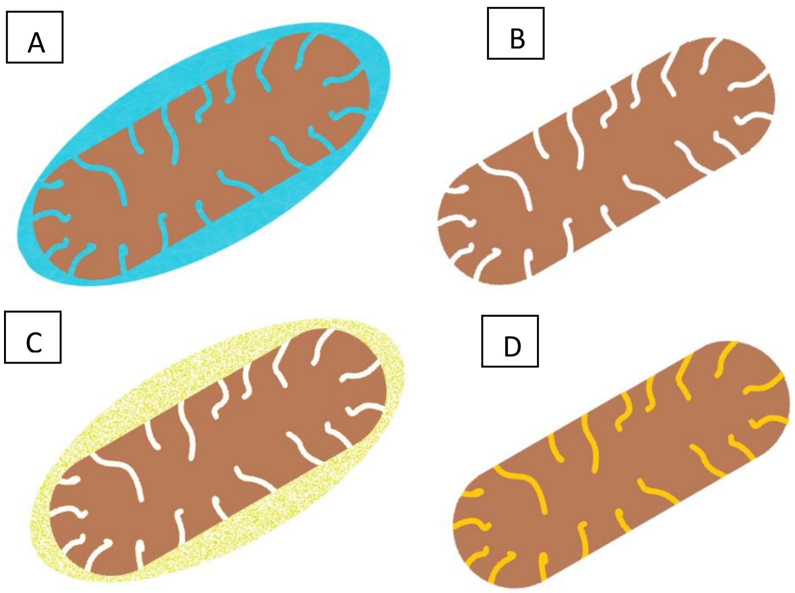


Figure 1.2 Vacuum Coating - Illustration and description

A: Pellets are added to the chamber under atmospheric pressure.

B: Sub-atmospheric environment is achieved and causes air to evacuate the pores.

C: Liquid is added while the pellets are being mixed, causing the added liquid to distribute evenly.

D: Liquid penetrates the pores as normal pressure is restored.

1.2 Scope of Thesis

The thesis will focus on the design of a single shaft paddle – mixer – de-agglomerator with vacuum coating ability. Through collaboration with Forberg International AS, the owner of the original Twin Shaft paddle mixer technology, and Fôrtek, the center for feed technology at NMBU, it was decided that the mixer/vacuum coater would have a batch capacity of 60 liter.

This thesis will mainly focus on the design of the mixer and the selection of standard parts to be implemented in the prototype that Forberg will manufacture and test.

Last year's thesis managed to provide data from testing that showed promising results in regards to the mixers working principle. The thesis also presented aspects of the mixer that needed improvement and other issues that should be addressed in the future.

1.3 Working principle

1.3.1 Mixing

The working principle of the mixer/vacuum coater designed in this thesis is the same as that of the mixer/vacuum coater designed in last year's thesis. This was a horizontal single shaft mixer with an added de-agglomerator that, in a short period of time, was to transform heterogeneous powders and particles into a loose, but homogenous solid-liquid matrix.

The geometry of the mixer rotor is to produce lifting of particles and powders towards the de-agglomerating zone which is equipped with a de-agglomerator. The de-agglomerator should, as a result of its high rotational speed and de-agglomerating elements, proceed to disperse any agglomerations before the particles and powder are forced towards the liquid addition zone. When in the liquid addition zone, the particles and powder should form a curtain beneath the spraying nozzle, resulting in an even dispersion of the added liquid. For the mixer to be able to mix a wide variety of powders and liquid additions, the rotational

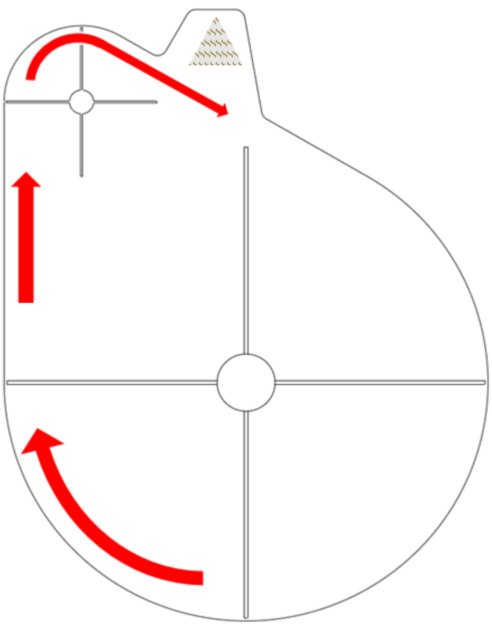


Figure 1.3 Demonstration of working principle when mixing. Red arrows show product movement

speed of the mixer rotor and the de-agglommerator is to be controlled separately from one another. This will enable the user to adjust the speeds according to the different liquid applications, and the different viscosities, powder size and cohesive properties of the particles being mixed. (3)

1.3.2 Vacuum coating

When vacuum coating, the mixer rotor will rotate at a reduced speed, which in turn will prevent the content of the mixer reaching the de-agglomeration zone. The geometry of the mixer rotor will instead cause the content of the mixer to be thrown around in an eight-figure pattern as illustrated in Figure 1.4. The way the pellets move when being vacuum coated will help distribute the liquid addition.

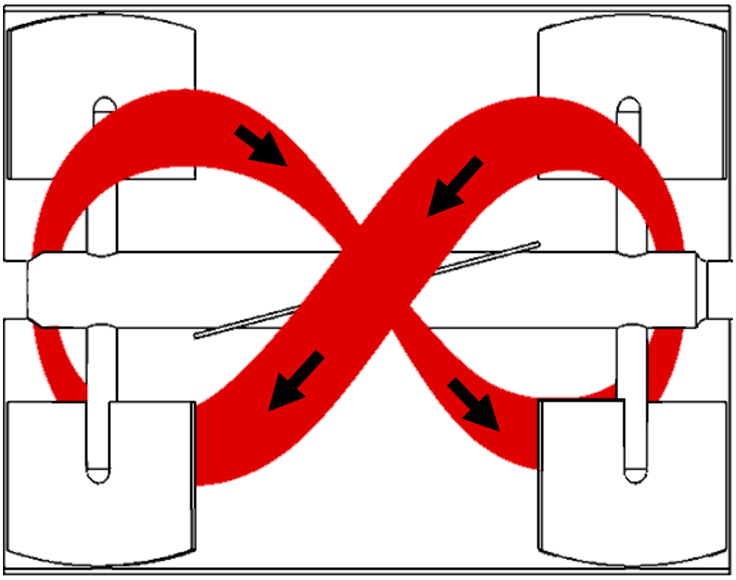


Figure 1.4 Demonstration of working principle when vacuum coating. Red 8 pattern and arrows show movement of product.

1.4 Competing solutions

To get a better understanding of the current market, it was performed a short analysis of products that work in a similar fashion or have approximately the same batch size as the mixer/vacuum coater designed in this thesis. The information on competitors gathered in this chapter will contribute to the concept generation in chapter 5.

1.4.1 Dinnissen Pegasus:

Figure 1.5: Dinnissen Pegasus. Courtesy of Dinnissen. (4)

The Pegasus is a twin shaft mixer where the shaft rotates in opposite directions to achieve a fluidized zone in the middle of the mixer, which eliminates segregation. A retractable shaft makes the mixer convenient to clean and easy to maintain. The mixer can be equipped with nozzles for liquid addition, as well as other components if the customer wants it. This mixer offers quick and effective mixing with a mixing time between 3-50 seconds. (5)

1.4.2 Andritz Optimix:

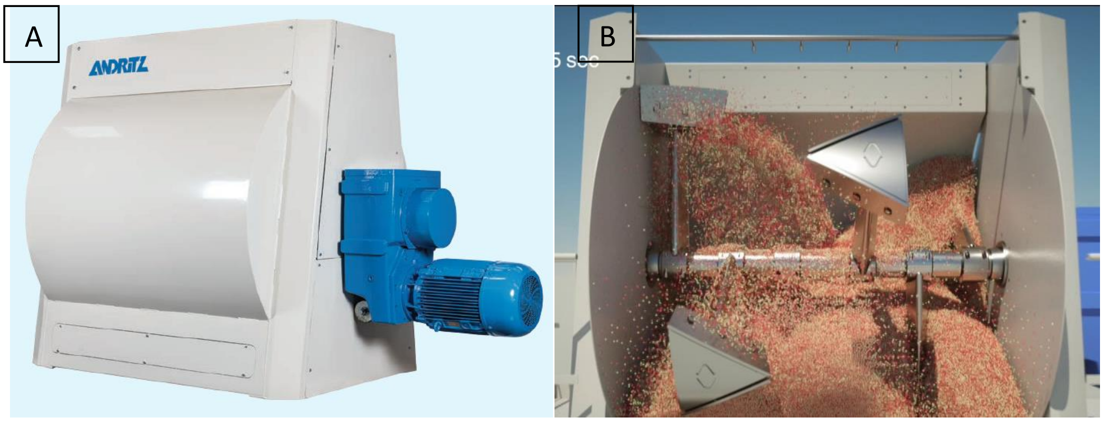


Figure 1.6: Andritz Optimix. Courtesy of Andritz. A: External view (6), B: Internal view. (7)

The Optimix is a single shaft mixer with focus on cleaning and maintenance. The paddles and the connections on the shaft are adjustable and replaceable. Maintenance of the nozzles is easily executed by entering a door at the end of the mixer. The shaft is rotated after each batch to achieve a better cleaning result, this is referred to as self-cleaning. The batch volume is up to 4000 litre and the mixing time is between 75-90 seconds. (8)

1.4.3 Bühler Sanimix:

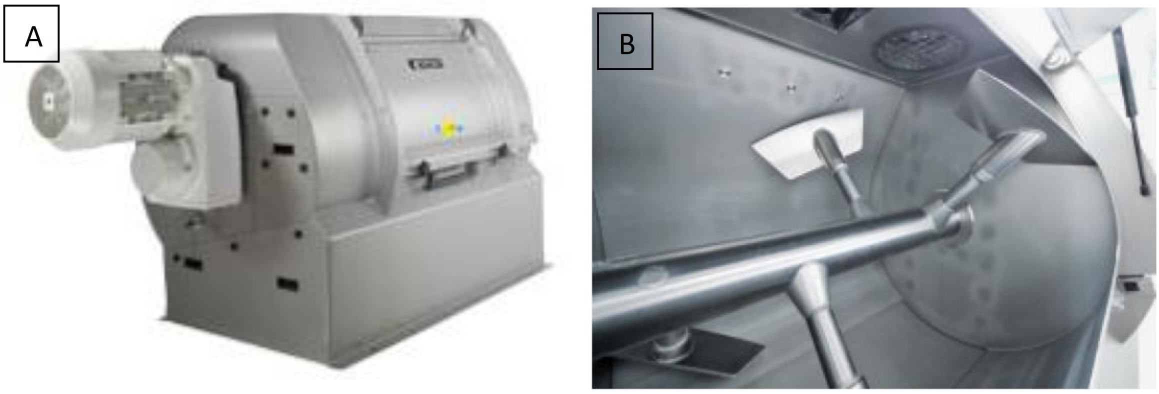


Figure 1.7: Bühler Sanimix. Courtesy of Bühler. A: External view (9), B: Internal view (10).

The Sanimix is a single shaft mixer with consistent mixing quality that and produce give a homogenic product. The Sanimix is easy to clean as a result of its large service door. There are two versions are available for this mixer: one for dry mixes and one for mixes that include liquid addition. The version with liquid addition has paddles that shear the product and choppers to crush chunks. (9)

1.4.4 Muyang double circle paddle mixer:

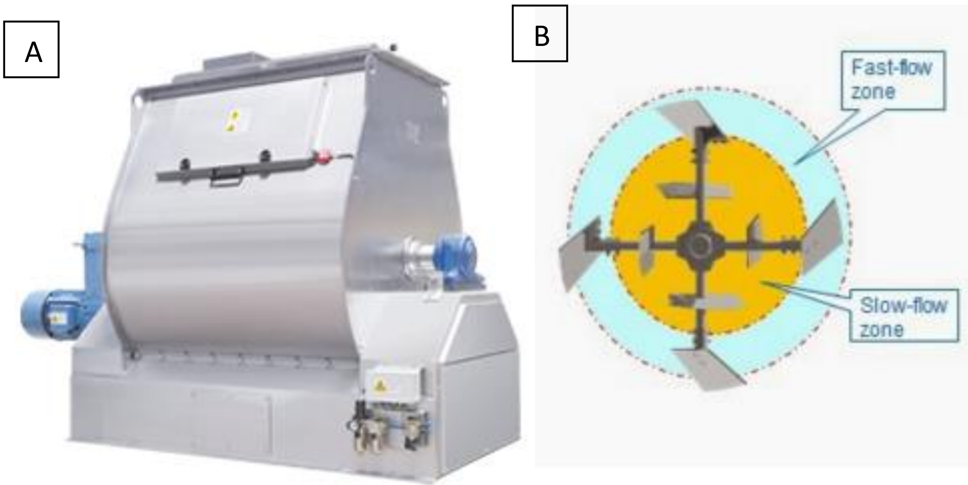


Figure 1.8: Muyang double circle paddle mixer. Courtesy of Muyang. A: External view (11), B: Paddle shape (12).

The double circle paddle mixer offers high mixing homogeneity and easy cleaning and maintenance due to its large service door. The double circle rotor moves product both at the fast flowing zone as well as the slow flowing zone as seen in Figure 1.8. The paddles are angled to move the product to the middle of the mixing chamber. The mixer has a mixing time of 60-90 seconds with a maximum of 3% liquid addition. (11)

1.4.5 Commentary regarding the competitors:

A large service door for cleaning seems to be a shared feature for all the competitors, as well as a quick mixing time with high homogeneity.

The Pegasus mixer is easy to clean because of the retractable shaft, but this comes at the expense of the required space for the mixer. It can be troublesome for production facilities who want to replace an existing mixer for the Pegasus in the same operating space.

The competitors mentioned here all have paddles that are small (compared to the batch volume) with an angle of about 45 degrees along the shaft. This is quite different from last year's prototype, which had big paddles with the middle paddles needing an angel of 15 degrees to provide enough lift so that the product could reach the de-agglomerator.

1.5 Potential

The prototype that this thesis bases itself on is a combination of a mixer and a vacuum coater, which in the industry would have been two separate dedicated machines. The advantage of having both functions in one machine is that it allows for testing of different types of products in mixing, and then use the same machine later on to vacuum coat the pellets. The reason why mixing and vacuum coating are done by two different machines today is that in a continuous production the mixing would happen at a different stage than the vacuum coating off pellets. The disruption of flow in the production process would not be optimal as one would have to clean the mixer before using it to coat the pellets. The mixer/vacuum coater will be developed to test if the working principle is scalable, and at a later stage, it can be considered if it is best to separate the machine into two machines, one mixer and one vacuum coater.

1.6 Design remarks

Before and during the design period of this thesis, there was a lot of correspondence with Fôrtek and Forberg regarding which features to include and which to avoid. Not all remarks written in this section was implemented to its fullest as the design evolved, but great effort was put into satisfying each of the requests.

- The housing needs to be airtight for the vacuum coating to be successful. A solution needs to be found to ensure that the leakage at the inlet/outlet and shaft bearings are negligible.
- Tests have been executed on last year's prototype and this thesis should not deviate too much from that design, keeping in mind the test results provided in said thesis.
- The prototype was 3D-printed, which gave them an advantage when producing the parts. As the new mixer/vacuum coater should handle a higher batch, the different parts now needs to be manufactured out of steel.
- Hatches on the bottom of the housing or any edges in the area where pellets are mixed and coated would cause crushing of pellets and is thus not desirable.
- An ideal approach is to use as many standard components as possible to minimize the production cost and to make it convenient to produce and assemble the mixer.
- Sharp edges are not desired within the mixer/vacuum coater, as this tend to cause local agglomeration, which in turn can lead to contamination of product.

2. Project Plan

This chapter will define the goals of the thesis and include a progress schedule and limitations for the thesis.

2.1 Objectives

2.1.1 Main goal

Development of a 60-litre mixer/vacuum coater based on last year's 1-litre prototype by Didrik Heidal Dolva & Eirik Madland Størdal (13).

2.1.2 Subgoals

- Product specification
- Complete 3D-model with manufacturing drawings
- Execute structural calculations
- Perform cost analysis
- Complete and deliver the Thesis

2.3 Limitations of the thesis

When developing a machine, as done in this thesis, there are lot of different aspects that needs to be taken into consideration. As time is a limited resource, the thesis will not go in depth in the following:

- Automation and system controls for the mixer/vacuum coater.
- Routing of pneumatic cables and electrical wiring.

3. Methods

3.1 Terminology, symbols and equations

Table 3.1: Explanation of terms used in this thesis.

Term	Explanation
Paddle	The plates moving the product that is being mixed in the mixer/vacuum coater.
De-agglomerator	Fast moving shaft with pins that crush lumps of product.
Mixer rotor	The assembly of the mixer shaft, rods and paddles.
Agglomeration	Clustering of masses.
Turn wheel	Wheel that is rotating on two smaller wheels.
RMVC	Rotating mixer/vacuum coater

Table 3.2: Symbol, description and unit.

Symbol	Description	Unit
$\boldsymbol{F}$	Force	N
$\boldsymbol{q}$	Distributed force	$\frac{N}{mm}$
$\boldsymbol{p}$	Pressure	Pa
$\boldsymbol{M}$	Moment	Nm
$\boldsymbol{\sigma}$	Stress	Pa
$\boldsymbol{\tau}$	Torsional stress	Pa
$\boldsymbol{E}$	Elastic modulus	Pa
$\boldsymbol{m}$	Mass	kg
$\boldsymbol{a}$	Acceleration	$\frac{m}{s^2}$
$\boldsymbol{g}$	Gravitational acceleration	$\frac{m}{s^2}$
$\boldsymbol{v}$	Velocity	$\frac{m}{s}$
$\boldsymbol{n}$	Rotational speed	RPM
$\boldsymbol{\omega}$	Rotational speed	$\frac{Rad}{s}$
$\boldsymbol{\mu}$	Friction coefficient	-
$\boldsymbol{V}$	Volume	L
$\boldsymbol{\rho}$	Density	$\frac{kg}{L}$
$\boldsymbol{d}$	Diameter	mm
$\boldsymbol{r}$	Radius	mm

Symbol	Description	Unit
t	Thickness	mm
l	Length	mm
b	Width	mm
h	Height	mm
A	Area	mm^2
P	Power	W
W	Section modulus	mm^3
$\boldsymbol{I}$	Second moment of inertia	mm^4
$\boldsymbol{R_e}$	Yield strength	MPa
$\boldsymbol{I}$	Moment of inertia	kgm^2
$\boldsymbol{\eta}$	Efficiency	-

Table 3.2: Overview of the equation used in this thesis.

Number & name	Equation	Description
1. Conservation of energy. Potential and kinetic (14)	$\frac{1}{2}mv_0^2 + mgh_0 = \frac{1}{2}mv^2 + mgh$	$v_0: Initial\ velocity$ $h_0: Initial\ heigth$ $m: Mass$ $v: Final\ velocity$ $h: Final\ heigth$ $g: Accelaration\ due\ to\ gravity$
2. Peripheral speed (15)	$v = \frac{d\pi n}{60}$	$v: Peripheral\ speed$ $n: Rotational\ speed$ $d: Diameter$
3. Volume of a cylindrical shell	$V = \frac{(r_a^2 - r_i^2)}{2} l$	$V: Volume$ $r_a: Outer\ radius$ $r_i: Inner\ radius$ $l: Length$
4. Mass	$m = V\rho$	$m: Mass$ $V: Volume$ $\rho: Density$
5. Force	$F = ma$	$F: Force$ $m: Mass$ $a: acceleration$
6. Distributed force (16)	$q = \frac{F}{l}$	$q: Distributed\ force$ $F: Force$ $l: Length\ of\ the\ distributed\ force$
7. Second moment of inertia for a	$I_x = \frac{bh^3}{12}$ $I_y = \frac{hb^3}{12}$	$I: Second\ moment\ of\ inertia$ $b: Width$ $h: Height$

Number & name	Equation	Description
rectangular cross-section (17)		
8. Deformation of a cantilever beam subject to a distributed force (16)	$y = \frac{ql^4}{8EI}$	$y: Deformation$ $l: Length\ of\ the\ beam$ $E: Elastic\ modulus$ $I: Second\ moment\ of\ inertia$
9. Moment of a cantilever beam subject to a distributed force (16)	$M_b = \frac{ql^2}{2}$	$M_b: Bending\ moment$ $q: Distributed\ force$ $l: Length\ of\ the\ beam$
10. Maximum bending stress (17)	$\sigma_b = \frac{M_b y}{I}$	$\sigma_{b,max}: Maximum\ bending\ stress$ $M_{b,max}: Maximum\ bending\ moment$ $y_{max}: Distance\ to\ the\ neutral\ axis$ $W: Section\ modulus$
11. Moment	$M = Fl$	$M: Moment$ $F: Force$ $L: Length$
12. Section modulus of a filled circular cross-section (17)	$W = \frac{\pi d^3}{32}$	$W: Section\ modulus$ $d: Diameter$
13. Maximum bending stress (17)	$\sigma_b = \frac{M_b}{W_b}$	$\sigma_b: Bending\ stress$ $M_b: Bending\ moment$ $W_b: Section\ modulus$
14. Polar section modulus of a filled circular cross-section (17)	$W_t = \frac{\pi d^3}{16}$	$W_t: Polar\ section\ modulus$ $d: Diameter$

Number & name	Equation	Description
15. Maximum shear stress (torsion) (17)	$\tau_{max} = \frac{M_t}{W_t}$	$\tau_{max}: Maximum\ shear\ stress$ $M_t: Torque$ $W_t: Polar\ section\ modulus$
16. S-N-curve (18)	$logN = \log \bar{a}_1 - m_1 k \times log\left(\frac{t}{t_{ref}}\right) - m_1 log\Delta\sigma$ $N = C \times \Delta\sigma^{-m}$	$t_{ref}: Reference\ thickness$ $t: Thickness\ of\ component$ $k: Correction\ factor$ $N: Number\ of\ cycles$ $C: Number\ of\ cycles$ $(forces\ not\ acting)$ $\Delta\sigma: Stress$ $m: Value\ from\ table$
17. Volume of a rectangular cuboid	$V = l \times b \times h$	$V: Volume$ $l: Length$ $b: Width$ $h: Height$
18. Volume of a cylinder	$V = \frac{\pi d^2}{4} l$	$V: Volume$ $d: Diameter$ $l: Length$
19. Second moment of inertia for a filled circular cross-section (17)	$I = \frac{\pi d^4}{64}$	$I: Second\ moment\ of\ inertia$ $d: Diameter$
20. Macaulay's method (17)	$EIy^{``} = -M(x)$ $EIy^{`} = -\int M(x)$ $EIy = -\iint M(x)$	$E: Elastic\ modulus$ $I: Second\ moment\ of\ inertia$ $M(x): Moment$ $y: Curvature$ $y^{`}: Deformation\ angle$ $y^{``}: Deformation$
21. Rayleigh's method for bending critical speed (19)	$n_{cr} = \frac{30}{\pi}\sqrt{\frac{9810 \times \sum m \times y}{\sum m \times y^2}}$	$n_{cr}: Critical\ speed$ $m: Mass$ $y: Deformation$
22. Moment of inertia rod about centre (20)	$I_r = \frac{ml^2}{12}$	$I_r: Moment\ of\ inertia$ $m: Mass$ $l: Length$

Number & name	Equation	Description
23. Parallel axis theorem (15)	$I_A = I_{CM} + me^2$	$I_A: Moment\ of\ inertia\ of\ an\ axis$ $I_{CM}: Moment\ of\ inertia\ about\ the\ center\ of\ mass$ $m: Mass$ $e: Distance\ between\ the\ axes$
24. Moment of inertia for a rectangular plate about central axis (20)	$I = \frac{ma^2}{12}$	$I: Moment\ of\ inertia$ $m: Mass$ $a: Width$
25. Moment of inertia for a solid cylinder (or disc) about central axis (20)	$I = \frac{mr_a^2}{2}$	$I: Moment\ of\ inertia$ $m: Mass$ $r_a: Radius$
26. Angular acceleration (15)	$\alpha = \frac{\pi \times n}{t \times 30}$	$\alpha: Angular\ acceleration$ $n: Rotational\ speed$ $t: Time$
27. Motor start torque (15)	$M_{start} = M_m + M_{aks,tot}$	$M_{start}: Start\ torque$ $M_m: Load\ torque$ $M_{aks,tot}: Accelaration\ torque$
28. Acceleration torque (15)	$M_{aks,tot} = \alpha_a \left(\frac{I_{tot}}{\eta i} + \frac{mr^2}{\eta i}\right)$	$M_{aks,tot}: Accelaration\ torque$ $\alpha_a: Rotational\ acceleration$ $I_{tot}: Total\ moment\ of\ inertia$ $m: Mass\ of\ load$ $r: Distance\ from\ rotational\ axis\ to\ load$ $i: Gear\ ratio$ $\eta: Efficiency$
29. Motor torque (15)	$M_m = \frac{M_L}{\eta_{tot} i_{tot}}$	$M_m: Motor\ torque$ $M_L: Load\ torque$ $\eta_{tot}: Total\ efficiency$ $i_{tot}: Total\ gear\ ratio$
30. Power (17)	$P = \frac{M\pi n}{30}$	$P: Power$ $M: Torque$ $n: Rotational\ speed$

Number & name	Equation	Description
31. Moment of inertia for a rectangular plate about perpendicular axis (15)	$$I = \frac{m(a^2 + b^2)}{12}$$	$I: Moment\ of\ inertia$ $m: Mass$ $a: Width$ $b: Length$
32. Moment of inertia for a cylinder about central diameter (20)	$$I = \frac{mr^2}{4} + \frac{ml^2}{12}$$	$I: Moment\ of\ inertia$ $m: Mass$ $r: Radius$ $l: Length$
33. Tangential stress. Pressure vessel (21)	$$\sigma_t = \frac{-p_y \times r_m}{s_0}$$	$\sigma_t: Tangential\ stress$ $p_y: Pressure$ $r_m: Mean\ radius$ $s_0: Thickness$
34. Axial stress. Pressure vessel (21)	$$\sigma_a = \frac{-p_y \times r_m}{2 \times s_0}$$	$\sigma_a: Axial\ stress$ $p_y: Pressure$ $r_m: Mean\ radius$ $s_0: Thickness$
35. Frictional force	$$F_R = \mu N$$	$F_R: Frictional\ force$ $\mu: Coefficient\ of\ friction$ $N: Normal\ force$
36. Moment of inertia for a thin cylinder about central axis (20)	$$I = mr^2$$	$I: Moment\ of\ inertia$ $m: Mass$ $r: Radius$
37. Moment of inertia for a hoop about central axis (20)	$$I = mr^2$$	$I: Moment\ of\ inertia$ $m: Mass$ $r: Radius$
38. Conversion equation for rotational speed (17)	$$\omega = \frac{\pi n}{30}$$	$\omega: Rotational\ speed$ $n: Rotational\ speed$

3.2 Development methods and computer tools

Pugh's method (22)**:**

A selection method that quantifies a final solution. This method is enable the user to make an objective decision.

Pugh's method follows these steps:

1. Insert concepts into a matrix with given criteria.
2. Give the concepts a weight dependent on the given criteria.
3. Summarize the weight and make a final decision.

Computer tools:

- Solidworks 2015/2016 Education edition (23)
- Ansys WB 16.2 (24)
- MS Word 2013 (25)
- MS Excel 2013 (26)
- Bosch Rexroth Scheme editor 6 2016 (27)

3.3 Process steps

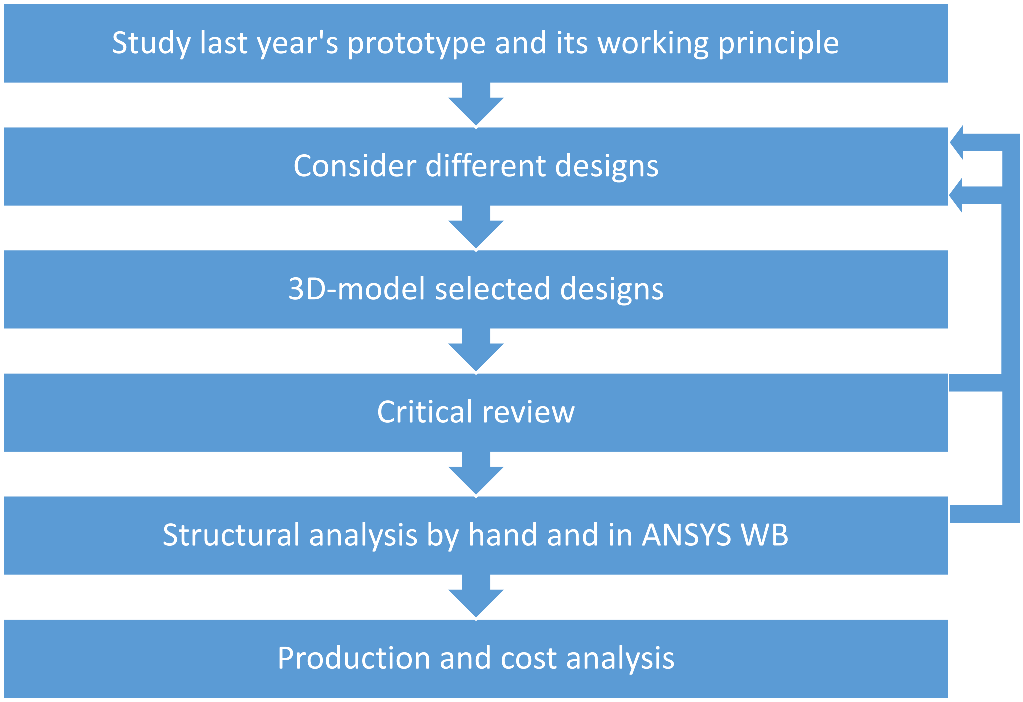


Figure 3.1 Description of the development process

Comments to Figure 3.1

The design process relies heavily on dialog with the thesis supervisor, Fôrtek and Forberg, which in turn means that the design might need to be revised through the thesis period. Parts would also need to be changed if the structural calculations were not satisfactory.

4. Product specifications

This chapter will state the product goal and the weighing of the different product properties.

4.1 Product goal

The product should be fully functional for both mixing and vacuum coating. The working principle must be preserved so that one can expect the same mixing result as the 1-liter prototype.

4.2 Rating of product properties

Table 4.1: Rating of the different properties for the mixer/vacuum coater.

Property	Rating
Functionality	5
User friendliness	4
Safety	5
Maintenance	4
Aesthetics	2
Cost	3

Comment to table 4.1:

The rating of properties ranges from 1 to 5, where 5 is the highest rating and 1 is the lowest rating.

Functionality:

Functionality is the most important factor as this is directly connected to the machines performance. The use of Forberg's existing solutions will increase the probability of a fully functioning machine.

User friendliness:

The automation of the different movements of the mixer/vacuum coater is beneficial for the operator.

Safety:

The operator of the machine should be shielded from moving components to avoid risk of injury. Safety switches and sensors is common for reducing the risk of damage to the mixer/vacuum coater and its operator. The rotating vacuum coaters produced by Forberg are usually surrounded by a safety cage.

Maintenance:

Maintenance is a factor that is crucial for the customer. Some parts are necessary to replace occasionally, but the main components (e.g. housing, mixer rotor and frame) of the assembly should be maintenance free. Rounded edges and grinding of the different components are optimal for the prevention of crack initiation.

Aesthetics:

This machine is going to be used in a production facility, therefore, the aesthetics is not of significant importance. Some mixers have sheet metal to cover up different parts of the machine so that it looks “cleaner”. Aforementioned aspect could be implemented at a later stage, and is therefore not viewed as critical for the machine’s success

Cost:

The ideal cost of the machine would be equal to the competitors’ mixers with similar or equal batch size, but seeing as this is a combination of a mixer and a vacuum coater, a higher cost is to be expected. The price of the mixer/vacuum coater should however not exceed the combined price of a separate mixer and vacuum coater.

5. Concept generation

This chapter address the different components and introduce, discuss and select the different concepts that will be implemented in the design.

5.2 Function alternatives

5.2.1 Housing

The housing is the part that contains what is being mixed and should allow both mixing and vacuum coating to be performed as the machine is to be used for both of these processes.

The inlet and outlet for filling and emptying was a challenge for this specific shape of the mixer/vacuum coater. The inlet/outlet had to be big enough for product to be inserted/emptied, while also remaining airtight when performing vacuum coating. The housing also had to avoid interfering with the paddles so that pellets would not get crushed against the edge of the inlet and/or the edges of the housing itself. A hatch at the bottom of the housing would cause problems when vacuum coating as the door would not be completely flush with the cylindrical wall of the housing, causing crushing of pellets. Forberg mentioned that they had experienced leakage of air when using hatches at the bottom of the mixer.

An air purged sealing for the shaft was available from Forberg, but only for shafts with diameter of 50 mm and larger. This is a good solution for the shaft when vacuum coating and mixing as the rotational speed is relatively low. The de-agglomerator, on the other hand, will be running at high speeds, and after a discussion with Forberg it was concluded that the air-purged sealing they use could not be used for the de-agglomerator.

Following solutions for the housing were generated:

1. **Funnel**

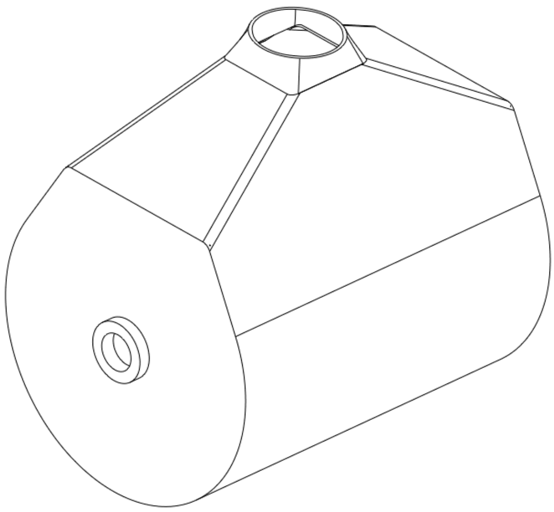


Figure 5.1: Funnel solution for the housing.

Advantages:

- The possibility of having a butterfly valve makes it easy to vacuum seal the housing.
- Filling and emptying is easily done with this type of valve. An existing solution by Forberg is to have different stations at the rotating path of the housing where filling, emptying and cleaning can be executed. As this is to be a single shaft mixer/vacuum coater, the housing can rotate about the shaft, which means that the motor can remain stationary when rotating the housing.

Disadvantages:

- The funnel would have to be in a position so that it does not interfere with the de-agglomerator. One would have to rotate the whole housing to empty the product inside.This can cause problems when there is a de-agglomerator installed as product might accumulate in the de-agglomerator region.
- The de-agglomerator and all its associated parts has to be airtight for this solution to function properly when vacuum coating.
- Cleaning for this type of housing is usually done in place with an own cleaning station. This is a more expensive solution than cleaning by hand.

2. Two-part housing with flanges

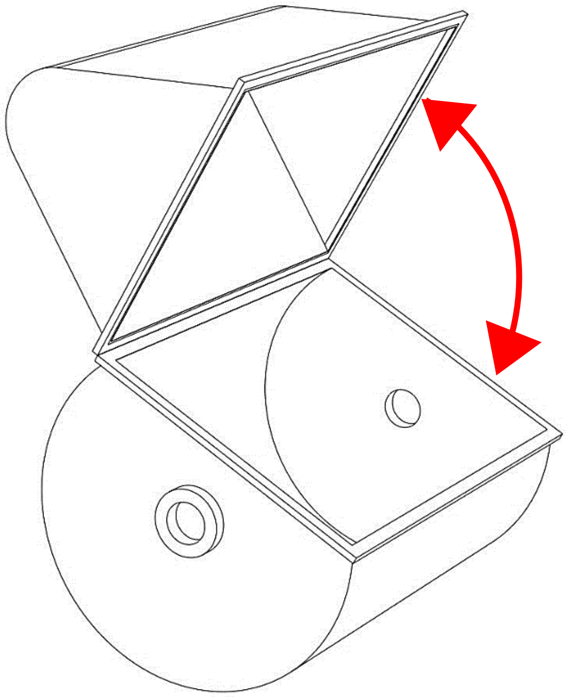


Figure 5.2: Two-part housing.

Advantages:

- This solution enables the opening to work as both an inlet and an outlet. The housing can rotate about the shaft, which means that the motor can remain stationary when rotating the bottom housing.
- Ability to have two different lids, one for mixing and one for vacuum coating.

Disadvantages:

- This solution requires rotation of the bottom housing with some sort of displacement mechanism for the top to refrain for obstructing the bottom part when it is rotating.
- The flanges can interfere with the path the product follows (see Figure 1.3) from the mixer rotor to the de-agglomerator, which in turn can lead to accumulation of product

3. **Hatch at end wall**

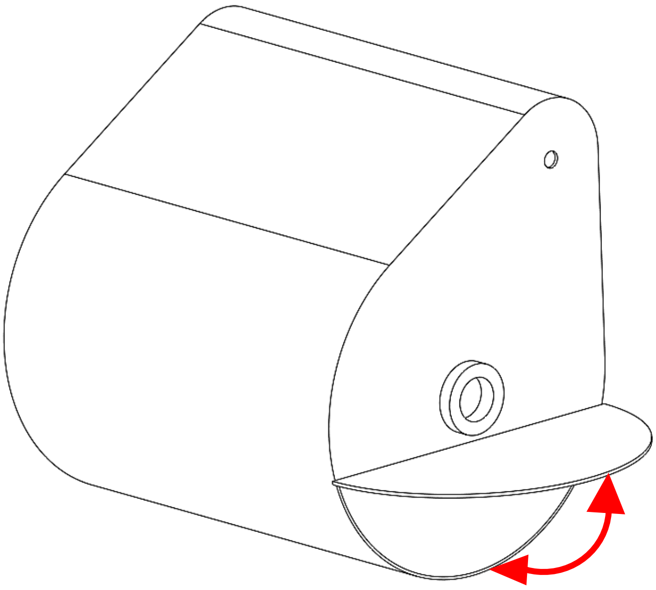


Figure 5.3: Housing with hatch at the end wall.

Advantages:

- The hatch can be used as both an inlet and an outlet.
- This option can have an opening on each end wall so the emptying and filling can be done in the same position.

Disadvantages:

- The hatch can be problematic when it comes to vacuum coating because of the edge it would create on the inside of the housing.
- Would demand the housing to tilt up and down, which is not beneficial because of the extra space this requires compared to rotating about the shaft.
- The de-agglomerator and all its associated parts has to be airtight for this solution to function properly when vacuum coating.

Explanation of the different criterion for the design of the housing:

The weight is measured on a scale from 1 to 5, where 1 is lowest and 5 is highest.

Functionality: The housing's main function is to contain whatever is being mixed and to not crush pellets when vacuum coating. It has to be airtight and have an outlet and an inlet that are easily accessible, emptied and filled. Preservation of the working principle is of the upmost importance.

Operational convenience: The filling, emptying and cleaning, as well as the rotation of the housing should be easily executable. The possibility of having a fully automated housing would be highly valued.

Durability: When vacuum coating; the housing must be able to withstand the pressure difference. The deformation and stress in the housing should be low enough to have an infinite* fatigue life. Sealings and other components that will need to be replaced through the lifespan of the mixer/vacuum coater will not be considered.

Manufacturing cost: The sheet metal work and the components required for the specific shape of the housing will be considered.

Table 5.1 : Weighing of the different criteria for the design of the housing (22).

Criteria	Weight	Funnel	Two-part housing with flanges	Hatch at end wall
Functionality	40 %	4	4	3
Durability	30 %	3	4	3
Operational convenience	20 %	4	3	4
Manufacturing cost	10 %	1	3	2
Sum	**100 %**	**3,4**	**3,7**	**3,1**

* Infinite in the sense that it will not succumb to structural failure in 10^7 cycles

5.2.2 Main rotor

Mixer rotors can have different paddles and different connection solutions between the parts. Some mixer manufacturers have the whole rotor assembled in a way that the rods and paddles can be replaceable, or in some cases, just the paddles. For testing purposes, an idea was to be able to change the angles and/or the shape of the paddles as well as being able to detach them with some sort of coupling. However, the risk of contamination outweighed this idea.

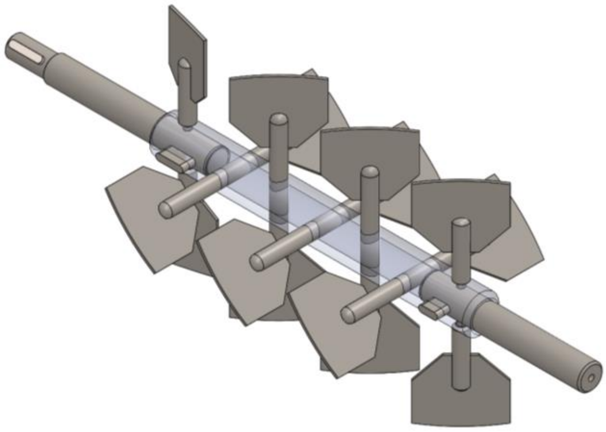


Figure 5.4: F-20 Twin Shaft mixing rotor assembly. Model provided by Forberg (28).

As seen from figure 5.4, this particular mixer rotor from Forberg consist of 14 paddles with angles of 45 degrees along the shaft. The rods go through the shaft and are welded to both the shaft and the paddles. The shaft consists of three parts, one external shaft and two internal shafts that are locked in place using keys.

To be able to replace or to perform maintenance on the shafts of a Forberg twin shaft mixer, one would have to cut the welded keys on both ends to disassemble the shaft arrangement, leaving the internal shafts free to slide out of the external shaft.

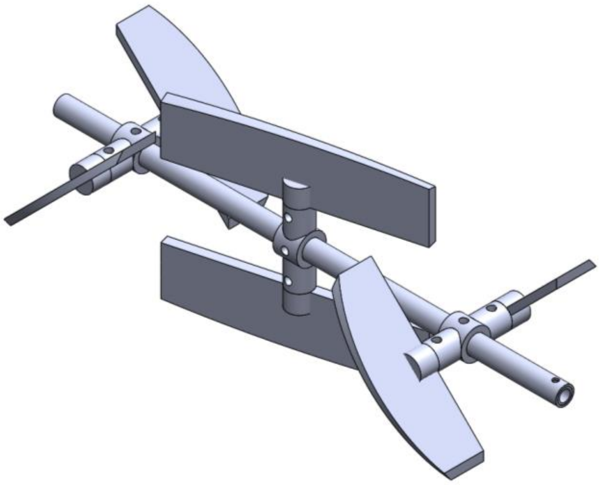


Figure 5.5: Last year's mixer rotor. Model provided by Didrik Heidal Dolva & Eirik Madland Størdal (13).

The mixer/vacuum coater rotor shown in Figure 5.5 consists of six paddles, where the middle paddles have an angle of 15 degrees along the shaft while the side paddles have an angle of 45 degrees along the shaft. The middle paddles purpose is to throw product into a de-agglomerator so that chunks will be crushed while the side paddles push product towards the middle paddle.

A direct upscaling of last year's prototype was desired, but as the length/diameter ratio needed to be smaller, according to Fôrtek, the same rotor ratio as last year's prototype could not be achieved. A smaller length/diameter ratio enabled the new rotor to have shorter paddles that extended further away from the shaft. This modification was beneficial in regards to stresses and deformation when applying the distributed load from the product on the paddle.

For the 60-litre mixer/vacuum coater the paddles were decided to be flat and wtih the same angle as last year's prototype. This was done to be able to better recreate the testing results from last year's thesis. The mixer rotor is to consist of a solid shaft that, through removal of one end wall of the housing, can be detached for maintenance or to be replaced. Forberg uses this solution for their 120 litre rotating vacuum coater.

5.2.3 De-agglomerator

When choosing the de-agglomerator design, it was important that the design stayed true to the working principle of the mixer/vacuum coater. The de-agglomerator has to be able to successfully de-agglomerate product that reaches the top housing. It should also contribute to the propulsion of product towards the spray zone, making the powder form the desired "curtain".

The de-agglomeration process is important as it often occurs clumping of product when mixing, which in turn leads to a batch with sub-par homogeneity. In Figure 5.6 there is shown an example of a de-agglomerator.

A de-agglomerator resolves said problem by running at a high RPM so that the chunks are crushed into smaller pieces. An idea from Fôrtek was that the pins should have an angle so that chunks would get thrown along the shaft as well as with the direction of the rotation. There was also a wish that the pins should "scrape" along the housing so that product would not stick to the surface, which is a common problem amongst mixers.

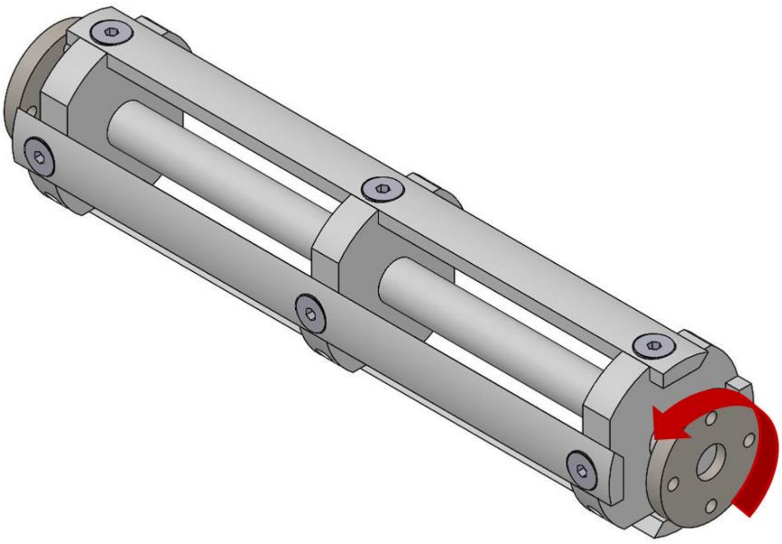


Figure 5.6: De-agglomerator from Forberg (28) F-20 mixer. The arrow represents product movement.

The following solutions for the de-agglomerator were generated:

De-agglomerator with paddles

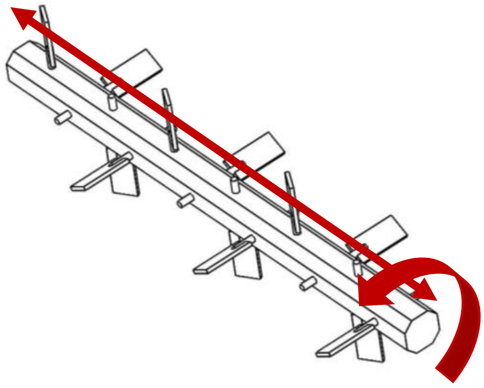


Figure 5.7 De-agglomerator with paddles. Product movement is represented by the arrows.

Advantages:

- Moves the product along the shaft so that it will be possible to hit chunks that are moving between the pins.
- The blades should provide movement of product towards the spray zone as well as an alternating movement of product along the rotational axis.

Disadvantages:

- The bolts and nuts can lead to accumulation of product, which in turn can lead to contamination.

De-agglomerator with bent flat steel

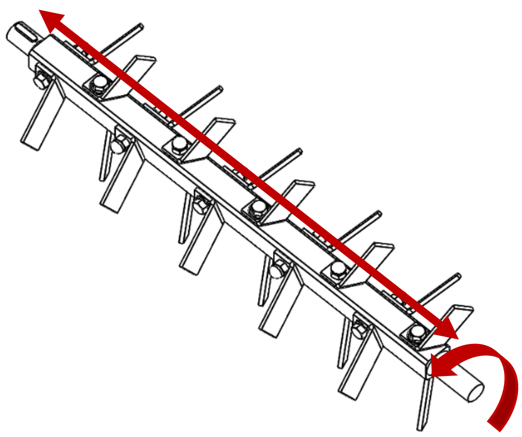


Figure 5.8: De-agglomerator with bent flat steel. Product movement is represented by the arrows.

Advantages:

- The “pins” on this de-agglomerator are easy to produce and are easy to change.
- The blades should provide movement of product towards the spray zone as well as alternating movement along the rotational axis.

Disadvantages:

- The bolts and nuts can lead to agglomeration of product on the shaft, which in turn can lead to contamination.
-

De-agglomerator with pins

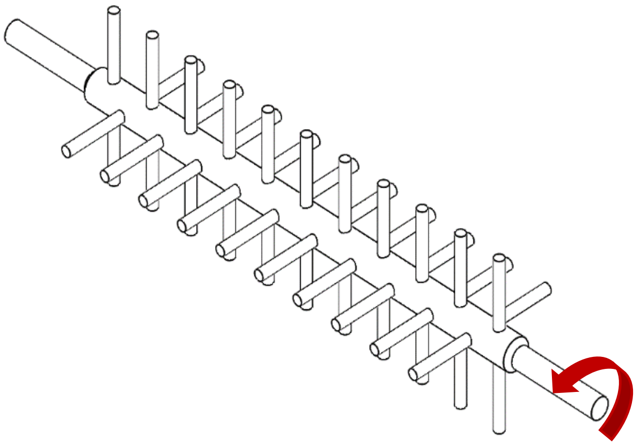


Figure 5.9 De-agglomerator with pins. Product movement is represented by the arrow.

Advantages:

- Easy to produce pins and shaft
- Will most likely de-agglomerate well

Disadvantages:

- Will not cause notable movement alongside the rotational axis
- Will not cause a lot of force towards the spray zone
- Fastening the pins to the shaft could lead to agglomeration of product

Preferred Solution: De-agglomerator with bent flat steel

The De-agglomerator with bent steel was chosen as it provided an adequate solution to most of the tasks it was intended to perform. By fastening the flat steel with bolts and nuts to the shaft, it will be possible to test different designs during the prototype testing period by replacing the flat steel with flat steel of a different angle or another type of paddle.

5.2.3 Lid displacement mechanism

With the housing separated in to two separate parts, it was important that, what from now on will be referred to as the lid did not interfere with the rotating housing. The displacement mechanism would also need to provide an adequate solution for the changing of lids, as there would need to be one lid for mixing with a de-agglomerator and one lid for vacuum coating. The following solutions were generated:

Rail system:

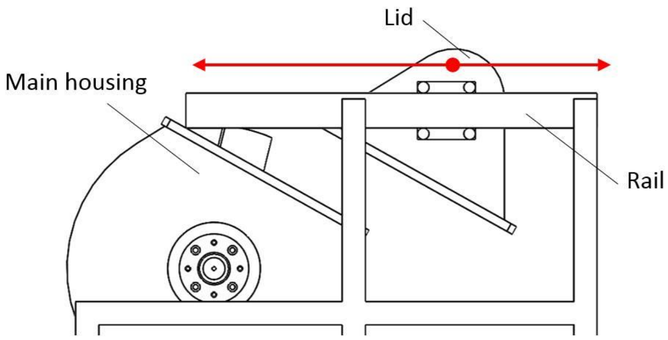


Figure 5.10: Rail system. The red line shows the desired movement of the lid.

Advantages:

- Can easily be operated by hand (no motors/pnemumatics).
- This solution makes it easy to change the two different lids.

Disadvantages:

- Requires space to move the lid so that the rotation of the housing is possible.
- The rail may interfere with the de-agglomerator and its associated parts.

Pivot point, arm and pneumatic piston:

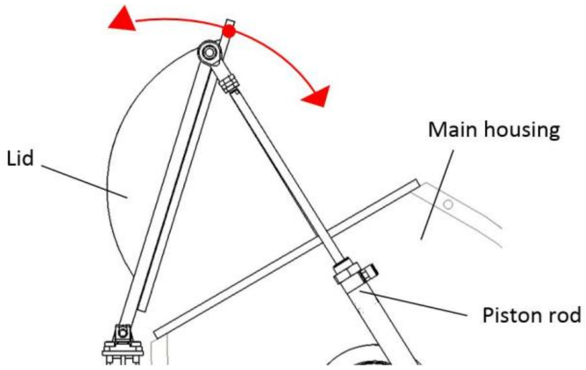


Figure 5.11: Pivot point, arm and pneumatic piston. The red line shows the desired movement of the lid.

Advantages:

- Requires little space to avoid the rotating housing.
- Adaptable flange connection between the housing and the lid.

Disadvantages:

- Requires a safety locking device if the pistons should fail.

Criteria:

1. Space: How much space does the solution require?
2. Accessibility: How easy is to access the lid for cleaning? How easy is it to attach/detach the different lids?
3. Complexity: Does the solution interfere with other parts of the assembly? Is it possible to add this solution without changing form and placement of other parts?

Preferred solution: Pivot point, arm and pneumatic piston

The reason behind this selection is that it requires less space than the rail system as well as the freer movement in the vertical direction, which makes it easier to fasten the lid to the housing for a better transition between the two. This solution does not interfere with the rest of the assembly and is more adaptable to fit the bottom housing. The rail system would have required some thought about the motor attachment for the de-agglomerator lid and requires more precision for fastening it to the bottom housing.

5.2.4 Rotation of the housing

A solution had to be chosen for the housing to be able to rotate about the mixer shaft. Forberg has existing solutions for this that they use for their vacuum coaters.

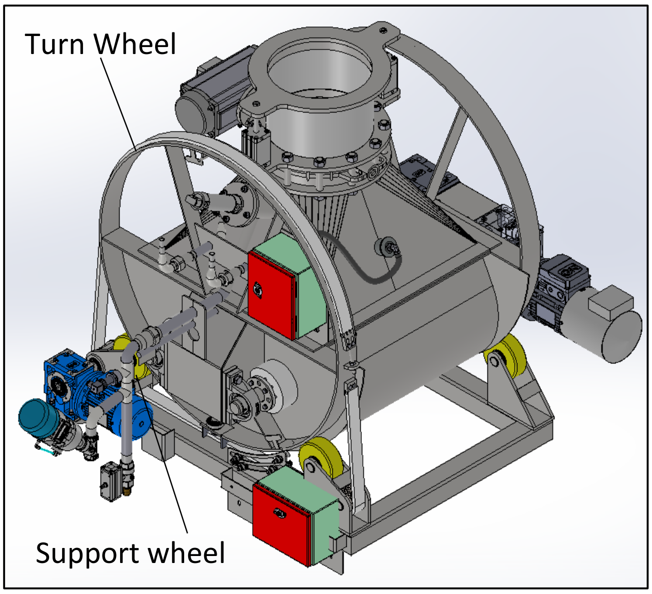


Figure 5.12: Forberg's 120-litre rotating vacuum coater (F-120-RVC). Model provided by Forberg (28).

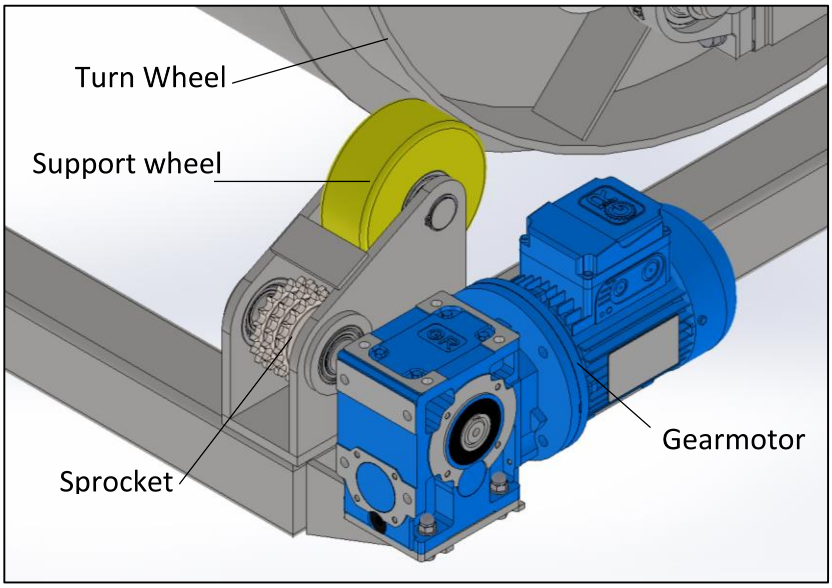


Figure 5.13: Close-up of the motor and support for the rotation of the housing. Model provided by Forberg (28).

As seen from figure 5.9 and 5.10, the housing rotates by using a gear motor to drive a chain that is mounted to a turn wheel. A similar solution would be ideal for the mixer/vacuum coater as this is convenient for the production facility and the design process.

Since the mixer/vacuum coater requires two lids, the turn wheel would have to be mounted on the end walls of the housing as shown in Figure 5.14

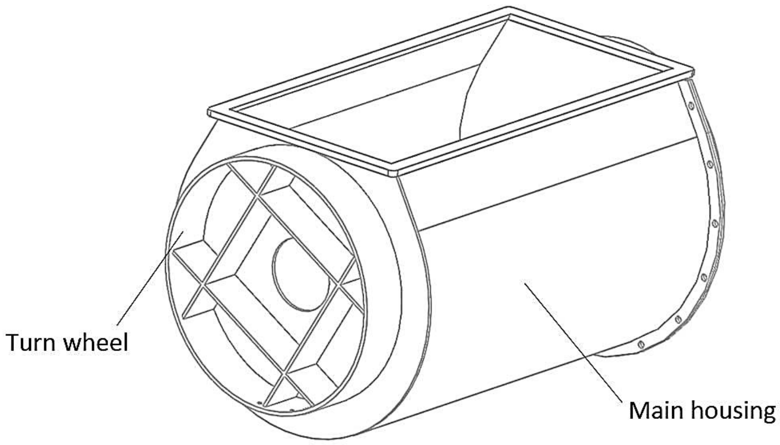


Figure 5.14: Housing with turn wheels mounted on the end walls. 60-litre mixer/vacuum coater.

The whole sprocket and support wheel assembly could be made almost identical as the 120-litre rotating vacuum coater from Forberg. The difference between the F-120-RVC (Forberg 120 Rotating Vacuum Coater) and the mixer/vacuum coater was that the F-120-RVC rotates the shafts and the motors, which in turn requires more power from the motor driving the sprocket/chain. For the single shaft mixer/vacuum coater, the housing rotates about the shaft itself and only needs power to rotate the housing and its content. The force from the content would only be the frictional force between the product being mixed and the housing. To stop the housing from drifting in the axial direction, ball bearings were attached to stop the housing from drifting.

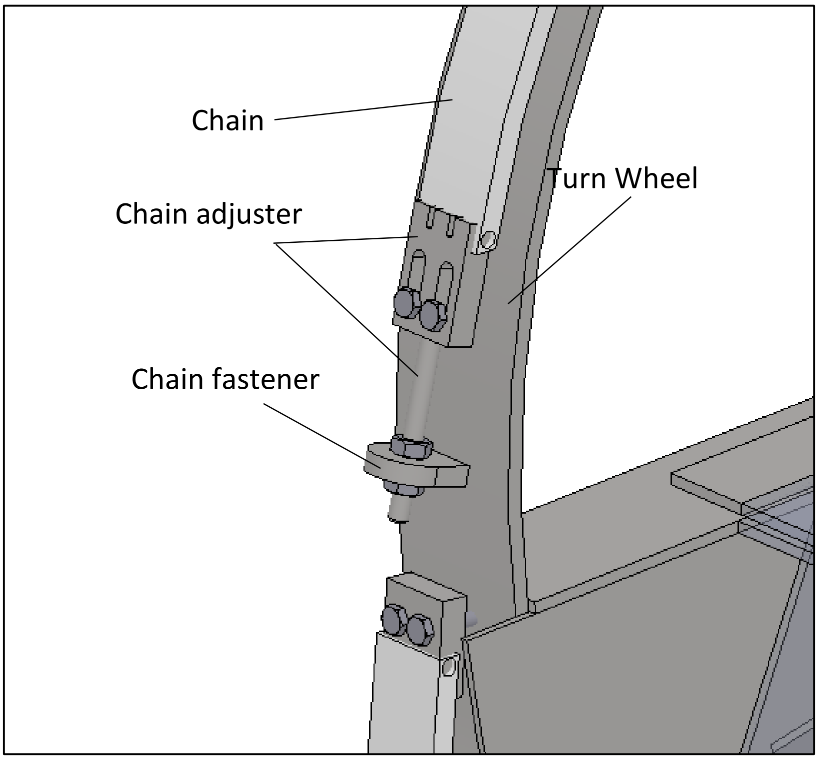


Figure 5.15: Chain adjuster and fastener. Model provided by Forberg (28).

As seen from Figure 5.15, the way the housing rotates is by mounting a chain fastener directly onto the turn wheel. This solution could be transferred to the mixer/vacuum coater, but it had to be taken into consideration that the housing would only be turned about 180 degrees before the chain fastener/adjuster would collide with the sprocket.

5.2.4 Sensor plate and safety switches

The housing has to stop at certain positions for the different actions to be executed (filling, emptying, mixing and cleaning). Steel plates are fastened to the housing at certain positions and triggers proximity sensors for the housing to stop at the desired positions. If the sensors for some reason fail to stop the rotation, safety switches will be in place to stop the housing from rotating too far. The safety switches will cut the power of the gearmotor driving the chain to avoid any damage to the mixer/vacuum coater that would happen if the chain-mounts collided with the sprockets.

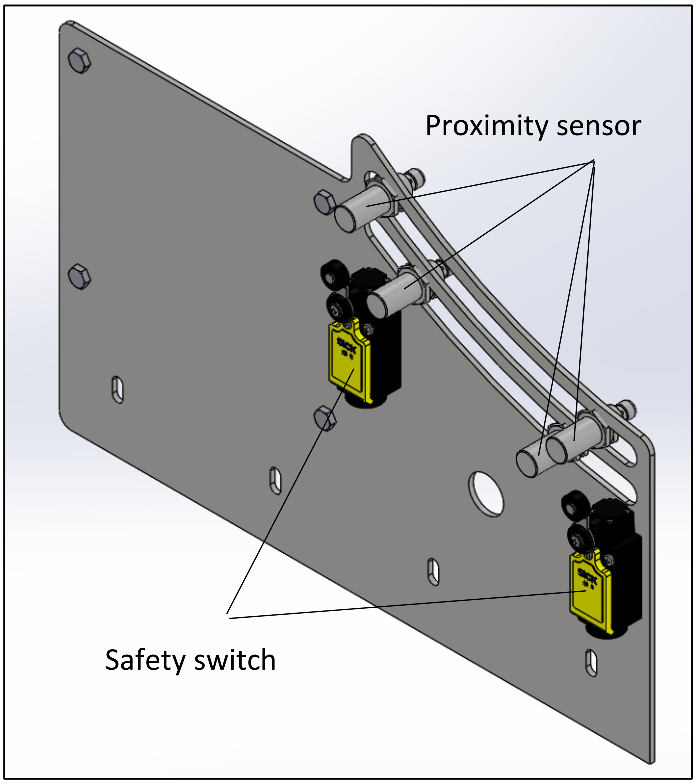


Figure 5.16: Sensors and safety switches mounting arrangement. Model provided by Forberg (28).

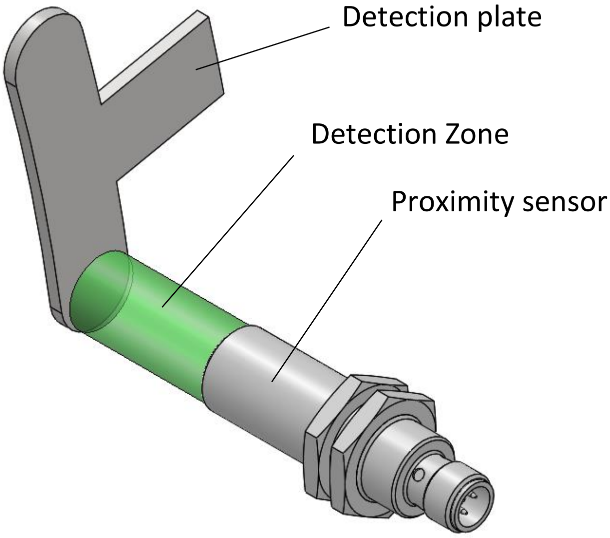


Figure 5.17: Proximity sensor and detection plate. Green represent the detection zone (not scaled). Sensor model provided by SICK (29).

Figure 5.17 shows the way the sensor is triggered. The sensing range for these sensors are 10 mm (29), which had to be taken into consideration when shaping the turn wheel for the housing so that the housing stops when the detection plates are registered by the sensors

5.2.5 Funnel and bin

For emptying the mixer/vacuum coater the initial thought was to rotate the housing to the point where the opening would be facing downwards, so that the product would be poured into a bin.

The housing has a maximum mixing capacity of 60 litres, while the bin could only hold 36 litres. Stopping the housing rotation at a certain point would enable the bin to be filled, emptied and inserted again for the rest of the product to be completely emptied once the housing rotates to the final emptying position.

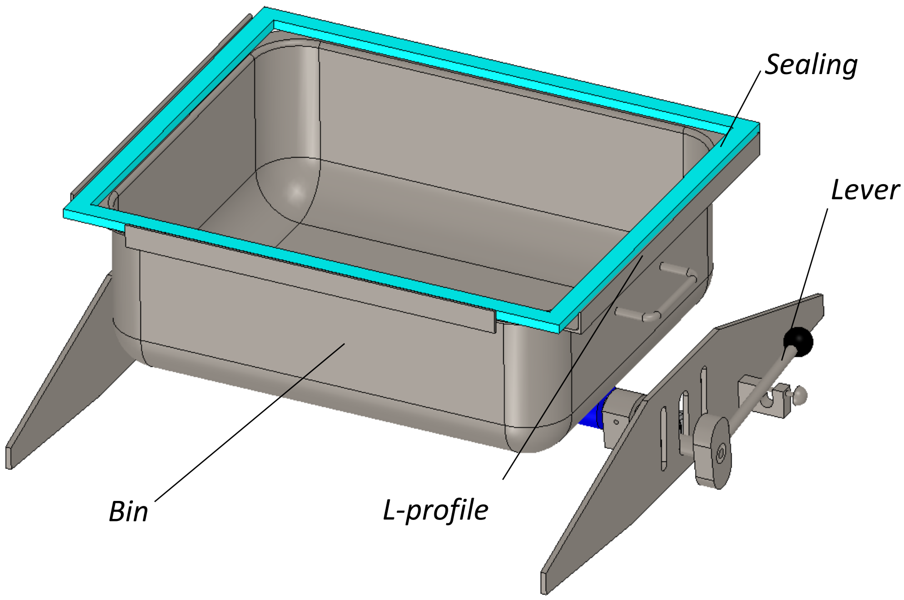


Figure 5.18: Bin with its associated parts. Model provided by Forberg (28).

For attaching the bin to the frame of the mixer/vacuum coater, Forberg's solution was chosen. The bin slides in between an L-profile and a sealing. To avoid product pouring out from the gaps between the bin and the frame there is a lever system that pushes the bin into the sealing for a tight fit.

5.2.6 Nozzle

When choosing a nozzle it has to be determined where the spray should hit the particles and in what fashion (cone spray/flat spray). The type of spray and the location of the nozzle is also important to avoid spraying the end walls of the mixer and the nozzle housing/holder as this would be wasteful. The optimal liquid addition is where the spray solely hits the particle curtain coming from the de-agglomerator. The spray should hit an area that is as wide as the middle paddle of the mixer rotor, as this paddle is the only component supposed to feed the de-agglomerator.

A two-substance nozzle is a nozzle that is able to create smaller droplets than a regular pressure nozzle. This is due to the use of high-pressure air to break the liquid into smaller droplets. The flow rate of a two-substance nozzle is usually much lower than that of a pressure nozzle due to the required air consumption. A large enough filter is also required for this type of nozzle due to the added air. The choice between a pressure nozzle and a two-substance nozzle depends on what liquid one is adding. For this machine, it should be an option to be able to replace one nozzle with another for testing purposes. (30)

When adding a small amount of liquid, the time it takes to add is usually longer than when adding a significantly bigger amount. The reason behind this is that all the particles in the mixer should have equal amount of liquid added to them, and this is only achieved when you have a slow and even addition of liquid. There can be added between 0,2 % to 30 % more volume by liquid addition than the initial product that is being mixed.

1. **Two hollow/full cone nozzles:**

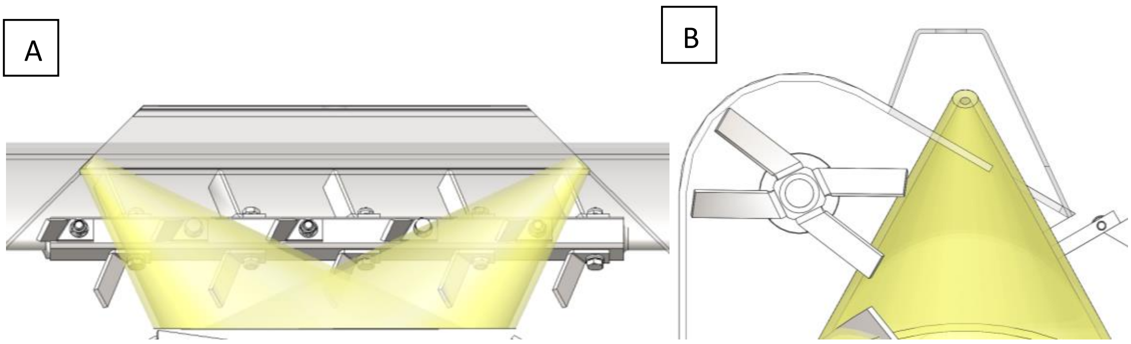


Figure 5.19: Two nozzles on each side spraying inwards. Yellow represents spray. A: Spray shown from the front of the mixer, B: spray shown from the side of the mixer.

From Figure 5.19 it is shown that the spray hits the de-agglomerator. This is not viewed as problematic as the de-agglomerator is running with a high RPM as the droplets will get thrown away from it. There may be a problem if the droplets hit the de-agglomerator lid, which can cause particles to agglomerate on these spots. A critical remark here is that the two sprays do not collide before it hits the particles coming from the de-agglomerator as this could lead to disruption of flow.

2. **One flat spray nozzle:**

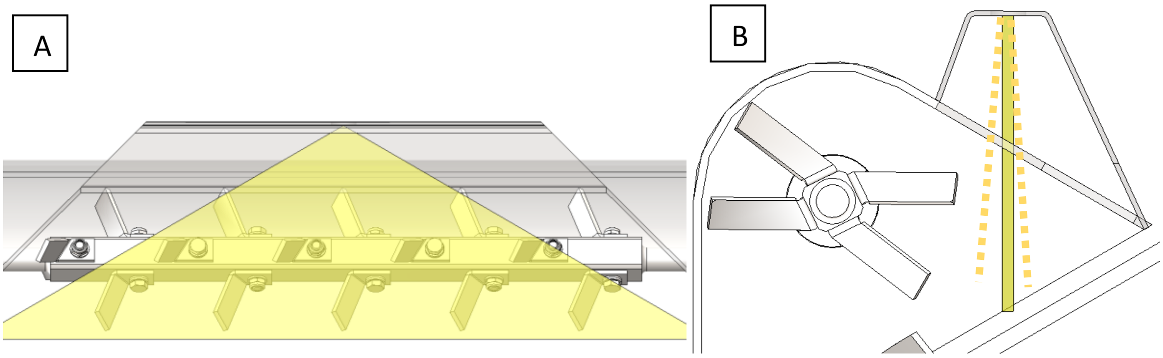


Figure 5.20: One flat spray nozzle in the middle. Yellow represents spray. A: Spray shown from the front of the mixer, B: spray shown from the side of the mixer.

Figure 5.20 shows how the flat spray avoids the pin mill and is directed vertically when mixing.

The benefit of using a flat spray nozzle is that you have more control over the area where liquid is added, seeing as this is a linear spray. However, the flow rate will be lower than that of a hollow/full cone spraying pattern. If one were to upscale the mixer, several flat spray nozzles in one line would be the optimal solution (31).

Through discussion with Fôrtek and Forberg it was concluded that the best choice would be a single flat spray nozzle for liquid addition. The reason behind this is that the nozzle offers more control when adding liquid, the solution is scalable and it does not hit the de-agglomerator.

Schlick, a nozzle manufacturer, was consulted regarding which nozzle to use. Forberg has their own supplier of nozzles, but the last year's prototype used a Schlick nozzle and the results were satisfying. It would be a good idea to have several options if the nozzle can improve the mixing results significantly.

For Schlick to be able to provide their best recommendations, a questionnaire was filled out (Appendix A).

Table 5.2: Recommended nozzles for the mixer/vacuum coater.

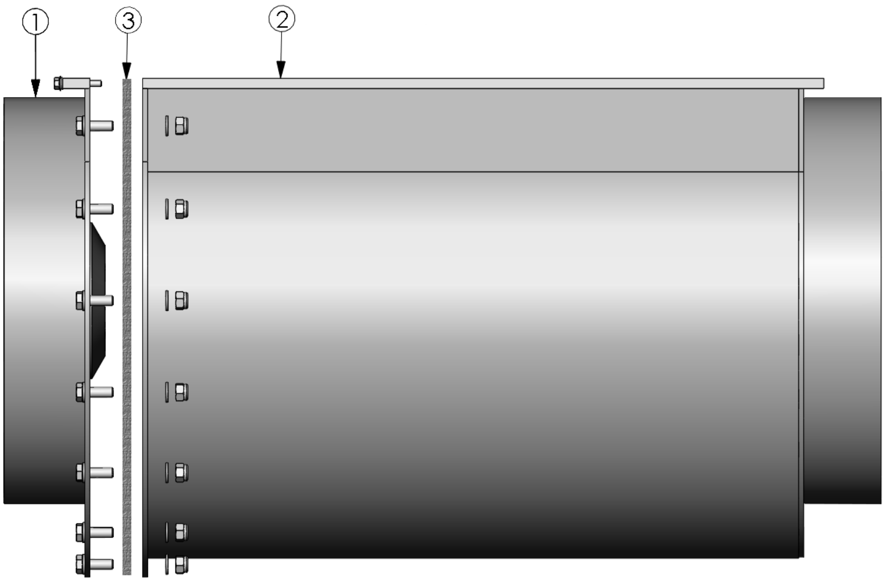
Name	Spray pattern	Spray angle	Capacity*	Price
Pressure nozzle Model 641 (32)	Circular hollow cone	40°, 60°, 90°, 120°, 140°	50 L/min at 3 bar	310 €
Two-substance nozzle Model 827 (33)	Circular full cone	30°	6 – 7 L/min	634 €
Pressure nozzle/Two-substance nozzle Model 700 (34)	Flat spray	20° -60°	Not specified	1246 €

* Measured with water at 16°C.

5.2. 7 Sealing

It is important that the housing remains airtight when performing vacuum coating. To ensure that the vacuum remains intact, all fittings needs to have some form of fitted gasket or sealant to make sure that there will not be any leaks. Forberg has a standardized vacuum sealing design for the main shafts that they use in their vacuum coaters. This patent will be implemented in our design.

To quote the Parker O-Ring Handbook *"All robust seals are characterized by the absence of any pathway by which fluid or gas might escape"* (35). The way the different form of seals are categorized is determined by how they obtain zero clearance. The different ways are normally divided in to two main groups, both of which will be used in the assembly of this machine. The first main category of sealants includes welding, soldering, brazing, ground fits or lapped finishes, which are a safe way to seal something permanently, while the other main category of sealants bases itself on the yielding of a softer material between two or more surfaces of a stiffer material. The latter is a method that is applicable for parts that will need to be able to reseal itself after use (e.g. doors). (35)



Item no.	Assembly/ component
1	Flanged End Wall
2	Main Housing
3	Liquid Alkoxy Silicone Sealing

Figure 5.21: Demonstration of the use of liquid sealant between the wall flanges with corresponding item descriptions.

When assembling the mixer, one of the end walls on the main housing will be welded onto the main housing ,while the second wall will be installed using flanges. The flanged wall is necessary, as two welded walls would not allow the main housing to be disassembled. The geometry of the housing prevents the mixer rotor from being removed from the mixer through the top opening, hence the necessity of the flanged wall. This is especially important for the prototype as design changes on the mixer rotor might be of interest. By welding the wall, the main housing will be without any gaps on the respective end, meaning it will not result in any leaks, thus remaining airtight. To ensure that the flanged wall will not have any leaks there will be used a liquid alkoxy silicone sealant between the flanges as shown in Figure 5.21. This will result in an airtight seal when bolts and nuts are fastened to apply pressure and to hold the wall in place.

The top part of the housing will be detached from the main housing each time the mixer is filled and emptied, meaning that welding the top part of the housing to the main part is not an option. To ensure that the housing remains airtight, there must be a form of sealing integrated in the flange connecting the top lid to the main housing. Through dialog with different sealing companies, different solutions were proposed. When reviewing the different solutions with Forberg, it was decided to go for a 10x10 mm D-profile made from silicone. There will be made a groove in the lid flange, making it possible for the D-profile to be fitted on the flange and fastened using glue. The sealing is elastic and thus resilient to permanent deformation, making it suitable for repetitive usage.

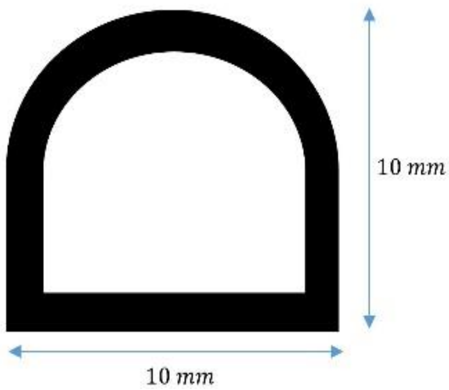


Figure 5.22 D-profile sealing for lid

5.3 Chosen solutions

Table 5.3: Chosen solutions.

Part	Solution
5.2.1 Housing	Two-part housing with flanges
5.2.2 Main rotor	Upscaling of last year's mixer rotor
5.2.3 De-agglomerator	Bolted angled flat steel with pneumatic installment.
5.2.3 Lid displacement mechanism	Pivot point, arm and pneumatic piston
5.2.4 Rotation of the housing	Turn wheel with sprocket and chain
5.2.5 Funnel and bin	Funnel with bin
5.2.6 Nozzle	Flat spray
5.2. 7 Sealing	Air purged sealing, silicone D-profile for lid and liquid silicon for end wall

6. Design

This chapter introduces the assembly of the mixer/vacuum coater and describes the different components it consists of.

6.1 Assembly

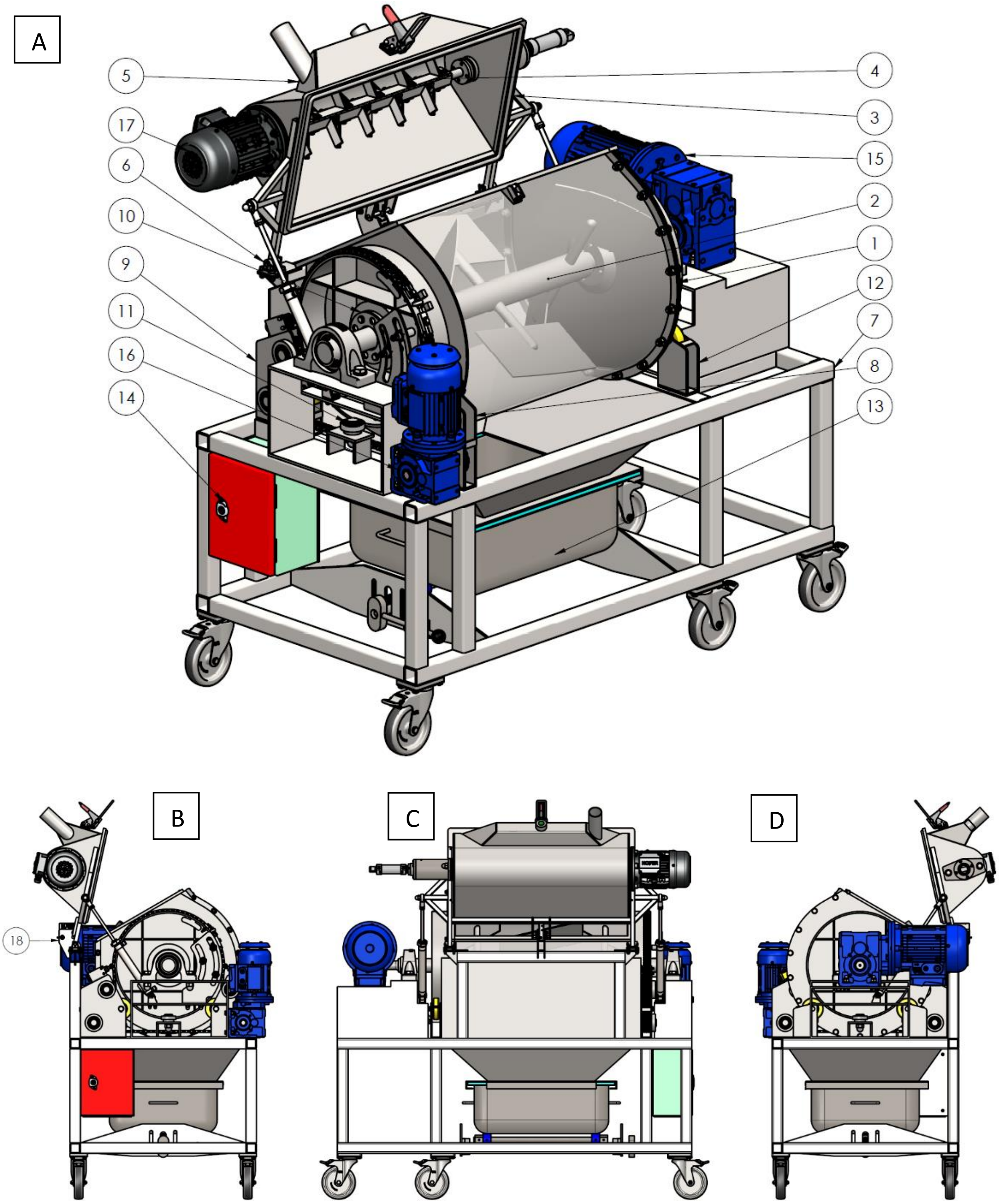


Figure 6.1: The Rotating Mixer Vacuum Coater with the mixer lid (with balloons). A: Isometric view, B: Left side, C: Back side, D: Right side

Table 6.1: List of balloon numbers from Figure 6.1 with corresponding components.

Item no.	Assembly/component
1	Main Housing
2	Mixer Rotor
3	De-agglomerator Lid
4	De-agglomerator
5	Nozzle Housing (welded to the de-agglomerator lid)
6	Pivot point, arm and pneumatic piston
7	Pneumatic Piston
8	Wheel Support Driver
9	Wheel Support Driven
10	Air Purged Sealing
11	Axial Displacement Restrictor
12	Wheel Support
13	Bin System
14	Control Cabinet
15	Gear Motor for Mixer Rotor
16	Gear Motor for Rotation of Main Housing
17	Motor for De-agglomerator
18	Safety Lock

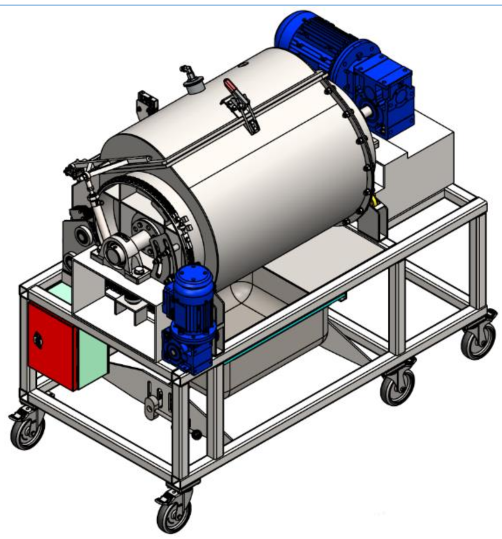


Figure 6.2: Rotating Mixer Vacuum Coater with vacuum lid

6.1.1 De-agglomerator lid with de-agglomerator

To be able to install and detach the de-agglomerator, the shaft will be equipped with pin couplings on each side. On one of the end walls of the de-agglomerator housing there will be installed a module which is used in the F-20 mixer from Forberg. This module consists of two bearings installed in a cylinder that is free to move in the axial direction. At the end of this module there is installed a double-acting pneumatic piston than enables the de-agglomerator to be pressed against the motor coupling and locked in place.

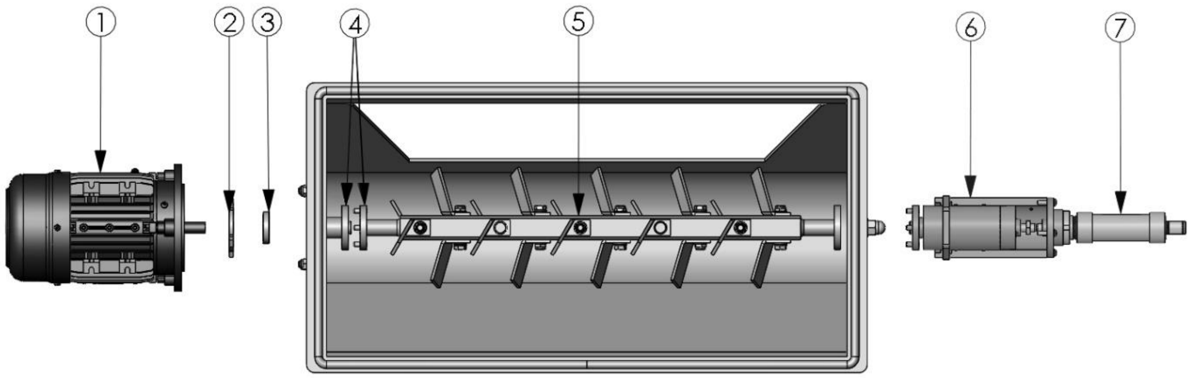


Figure 6.3: Exploded view of De-agglomerator lid without nozzle housing

Table 6.2: List of balloon numbers from Figure 6.3 with corresponding components.

Item no.	Assembly/Component
1	Motor
2	Sealing Housing
3	Sealing
4	Pin Coupling (same as that of the F-20 mixer)
5	De-agglomerator
6	Bearing Cylinder same as that of the F-20 mixer (section view)
7	Pneumatic Piston

On the motor side of the de-agglomerator housing there will be a sealing that prevents product from reaching the cavity between the motor and the housing wall. The sealing will be installed within a housing that can be locked in place by slipping it past four gaps before rotating it, locking it in the axial direction. Set screws will be used to restrain the sealing housing from rotating.

6.1.2 Chain drive for rotation of the housing

The rotation of the main housing is made possible with the components shown in Figure 6.4.

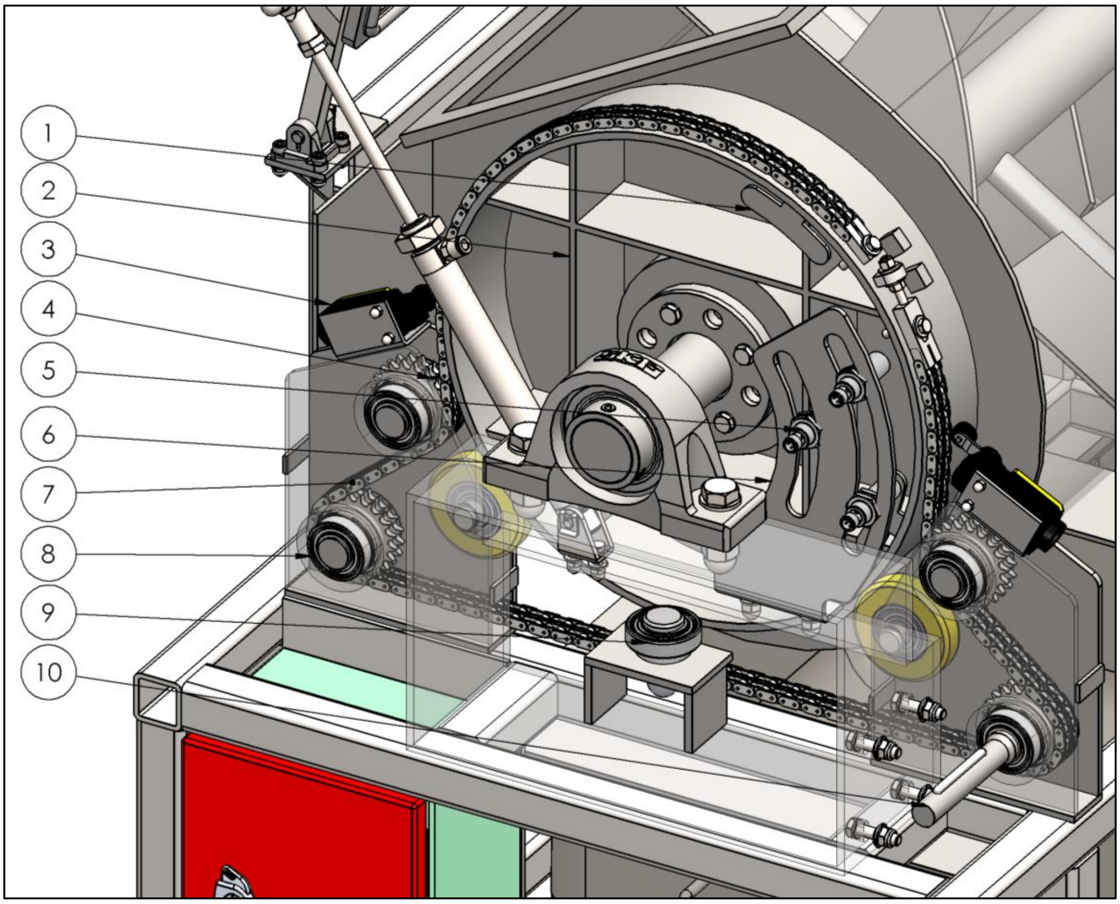


Figure 6.4: Overview of the rotating system (with balloons)

Table 6.3: List of balloon numbers from Figure 6.4 with corresponding components.

Item no.	Assembly/component
1	Detection Plate
2	Turn Wheel
3	Safety Switch
4	Chain
5	Proximity Sensor
6	Sensor Holder
7	Pneumatic Piston
8	Bearing
9	Axial Displacement Restrictor
10	Driver Shaft for Sprocket

6.1.3 Safety locking of lid

There has been implemented a safety lock that will lock the lid in place when in the open position. This has been done to prevent damage to personnel and the machine if the pneumatic pistons for some reason were to fail. The lock (Electronic Rotary Latch (36)) can be controlled electronically, but it also have the possibility of manual release in case of power failure.

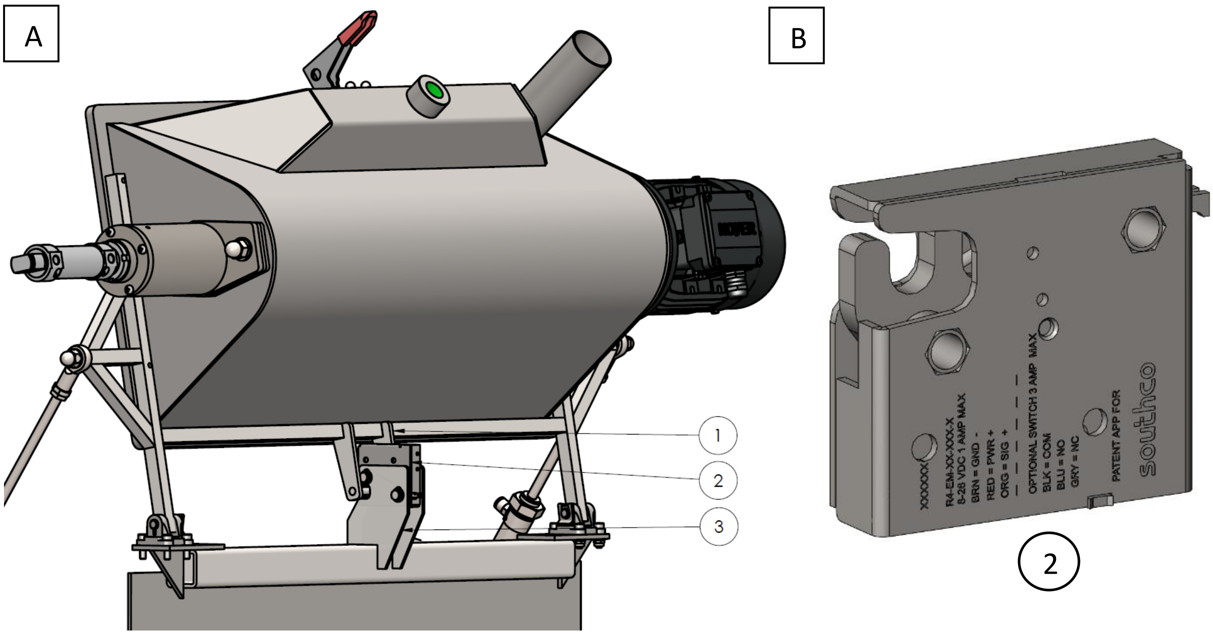


Figure 6.5: A: Overview of the safety lock installment (with balloons), B: detailed picture of the rotary latch model provided by Southco (36).

Table 6.4: List of balloon numbers from Figure 6.5 with corresponding components

Item no.	Assembly/component
1	Pin Holder
2	Electronic Rotary Latch
3	Lock Holder

6.1.4 Overview over the mixers movement for performing the different actions:

In the following figures, the mixer is equipped with the mixer lid. The machine will have the same different positions when equipped with the vacuum lid.

1. *Filling/cleaning*

   The filling/cleaning position is achieved by rotating the housing from the emptying position to the filling position. The housing stops when it triggers the proximity sensor.

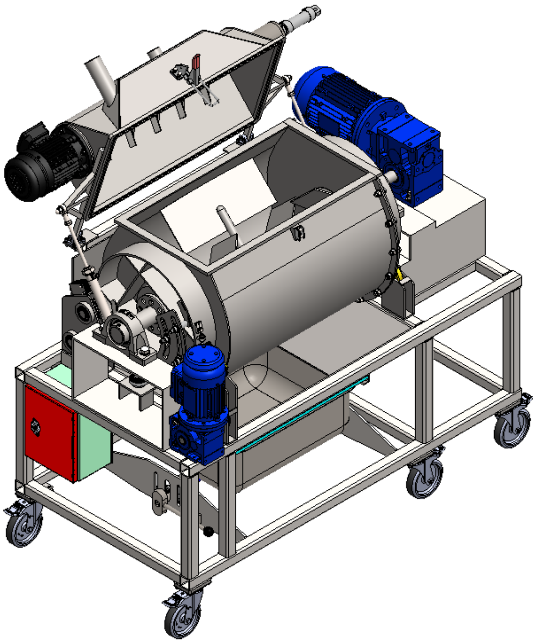


Figure 6.6: The mixer/vacuum coater in the filling/cleaning position

2. *Mixing*

   From the filling position, the housing rotates until the proximity sensors are triggered. The locking mechanism for the lid is opened and the piston rods starts retracting. When the flanges of the lid and housing meet, the piston will help push the flange sealing tight in addition to the clamp installed on the lid.

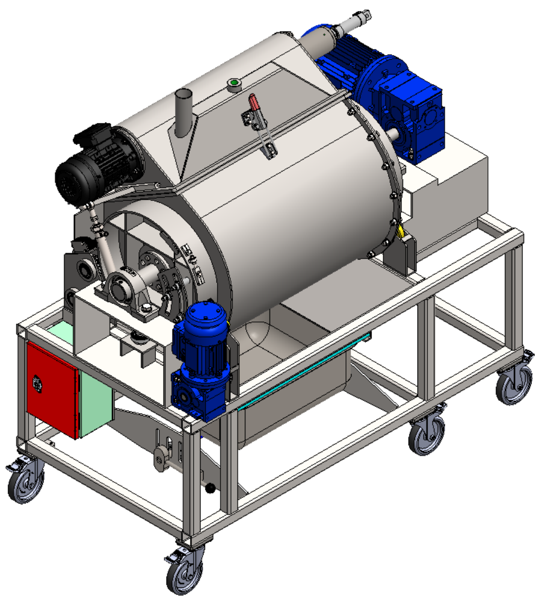


Figure 6.7: The mixer/vacuum coater in the mixing/vacuum coating position

3. *Emptying*

   For emptying the housing, the clamp is opened and the piston rods start extending until the lid has reached the rotary latch. The housing then rotates until proximity sensors stops it. This is done for both of the emptying positions.

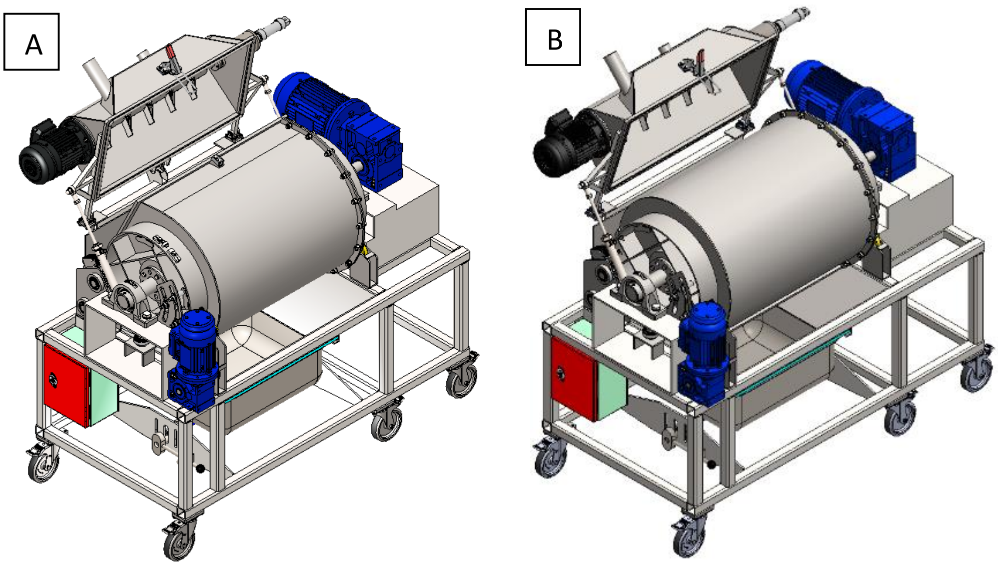


Figure 6.8 A: First emptying position, B: Second emptying position.

6.2 Standard components

Mixer rotor gearmotor (MR CI 64UO3A 24x200 10,4):

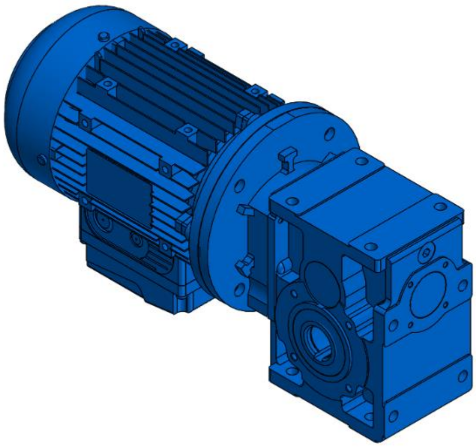


Figure .6.9: Mixer rotor gearmotor. Model provided by Rossi-group (39).

Table 8.1: Specifications for the mixer rotor gearmotor **(37)**.

Specifications	Data
Power	2,2 kW
Rotational speed	135 RPM
Nominal torque	149 Nm
Start torque **(38)**	477 Nm
Gear ratio	10,4
Mounting	B8

Chain gearmotor (MR CI 40UO3A 11x140 13,7):

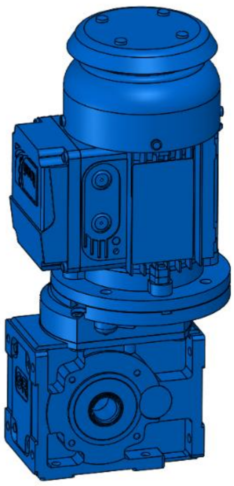


Figure 6.10: Chain gearmotor Model provided by Rossi-group (39).

Table 8.2: Specifications for the chain gearmotor **(37)**

Specifications	Data
Power	0,09 kW
Rotational speed	65,9 RPM
Torque	12,5 Nm
Start torque **(38)**	134 Nm
Gear ratio	13,7
Mounting	B6

De-agglomerator motor:

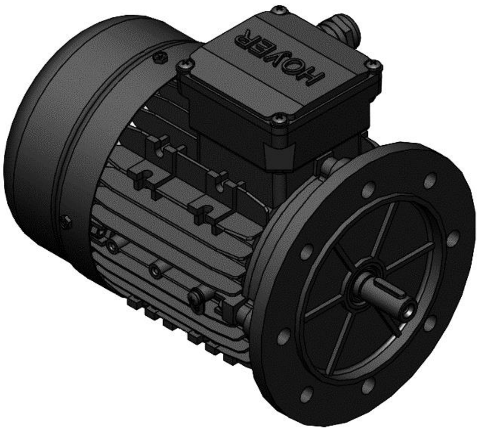


Figure 6.11: De-agglomerator motor. Model provided by Hoyer Motors (41).

Table 8.3: Specifications for the de-agglomerator motor **(40)**.

Specifications	Data
Power	0,25 kW
Rotational speed	1500 RPM
Torque	1,7 Nm
Start torque	3,74 Nm
Mounting	B5

Pneumatic driver (25x150 PPV-A):

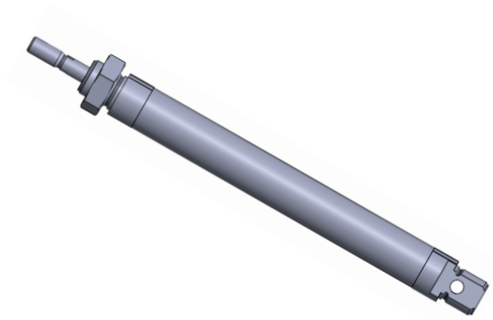


Table 8.4: Specifications for the pneumatic driver **(42)**

Specifications	Data
Stroke length	150 mm
Force at 6 bar	294,5 N

Figure 6.12: Pneumatic driver. Model provided by Festo (43).

Vacuum pump:

Table 8.5: Specifications for the vacuum pump **(44)**.

Specifications	Data
Power	1,5 kW
Capacity	$50 \frac{m^3}{t}$

Figure 6.13: Vacuum pump V-VC 50 (45).

Reaches 0,2 bar in 12 seconds for a vacuum chamber of 120 litres.

7. Structural analysis

The stresses and fatigue life for the necessary components are evaluated in this chapter. Start moment and torque required for the different motors are calculated. ANSYS results were added for some of the components for assurance.

7.1 Materials

The material that Forberg uses for mixers and vacuum coaters are stainless steel of AISI 304 (46). AISI 304 is commonly used in food processing for most containers, pipework and food contact equipment (47). For components that are not exposed to the product being mixed, S355 steel will be used, as this is a stronger and cheaper metal.

Table 7.1: Properties for AISI 304 (48).

Properties	Value
Density	$8\ kg/L$
Tensile strength, yield	$215\ MPa$
Tensile strength, ultimate	$505\ MPa$
Elongation modulus	$2 \times 10^5\ MPa$

Safety factor against yielding, SF:

$$SF = 2$$

The stresses found in this chapter should not override this given value:

$$\frac{215\ MPa}{2} = 107{,}5\ MPa$$

7.2 Mixer rotor

7.2.1 Peripheral speed of the mixer rotor

For the mixer to be able to follow the working principal, the paddles on the mixer rotor must have a high enough speed to successfully throw the product up into the de-agglomerator.

The necessary rotor speed was calculated using the law of conservation of energy (eq. 1) to estimate the required peripheral speed of the middle paddle.

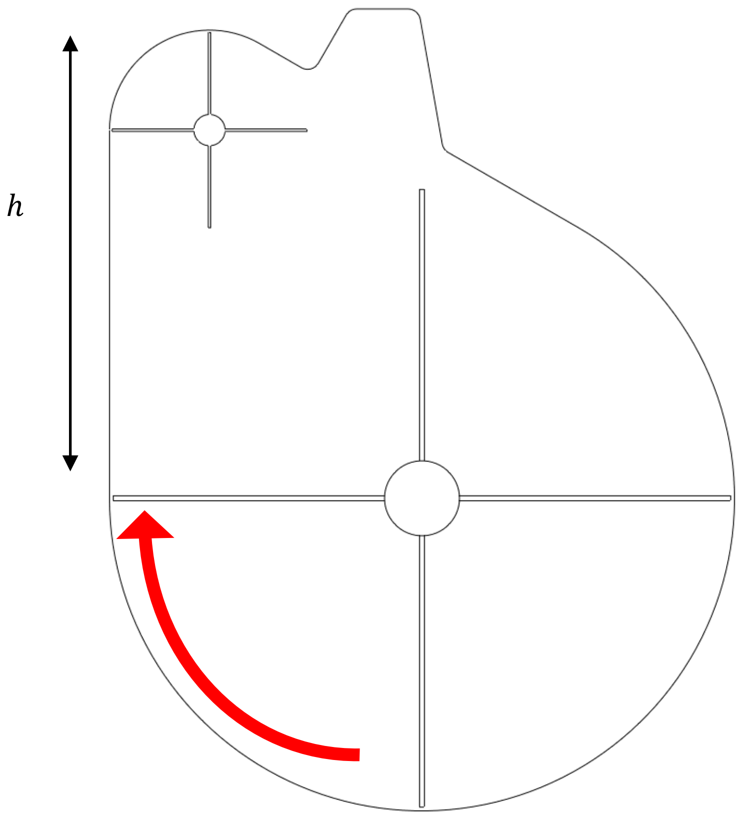


Figure 7.1: Side view of the mixer configuration. Red arrow shows mixer rotor movement.

The product is moved by a paddle that has a slight angle, making the product trajectory diverge from a straight vertical path. The height used in the following calculation was set to a higher numerical value than the height shown in Figure 7.1, this was done to compensate for said factor.

$$h = 295\, mm, \quad h_{throw} = 500\, mm, \quad g = 9{,}81\, m/s^2$$

Conservation of energy (eq. 1)

$$mgh = \frac{1}{2}mv^2 \quad \rightarrow \quad gh = \frac{1}{2}v^2$$

$$v = \sqrt{2gh_{throw}} = 3{,}13\,{}^{m}/_{s}$$

Converting speed from ${}^{m}/_{s}$ to RPM (eq.2):

$$n = \frac{60 \times v}{D \times \pi} = 121\ RPM$$

7.2.2 Forces applied on the mixer rotor paddles

Calculating the forces applied on the paddles:

From conversations with Forberg it was concluded that the heaviest bulk density the mixer would operate with was 1 kg/l.

A conservative way to approach the structural calculations is to view the volume defined by the paddles area and the path it takes in half a revolution, and regard this as the mass it has to "push" (*see*Figure 7.2*)*. By multiplying this volume with the maximum bulk density and the gravitational pull, an approximated force can be calculated.

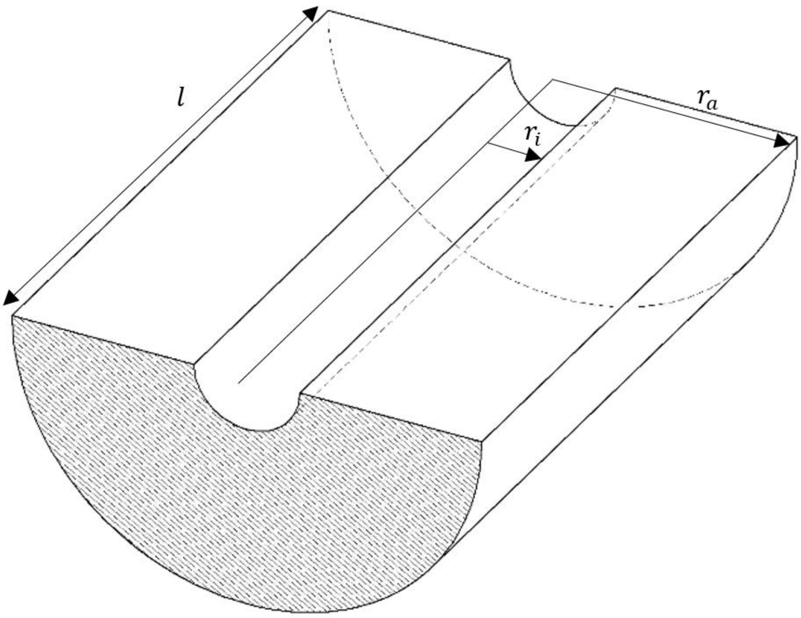


Figure 7.2: Swept volume created by a paddle.

End paddle

As the end paddles are orientated at a 45-degree angle alongside the shaft, the cathetus of the paddle (as shown in figure 7.2) was used as the paddles length in the volume calculations

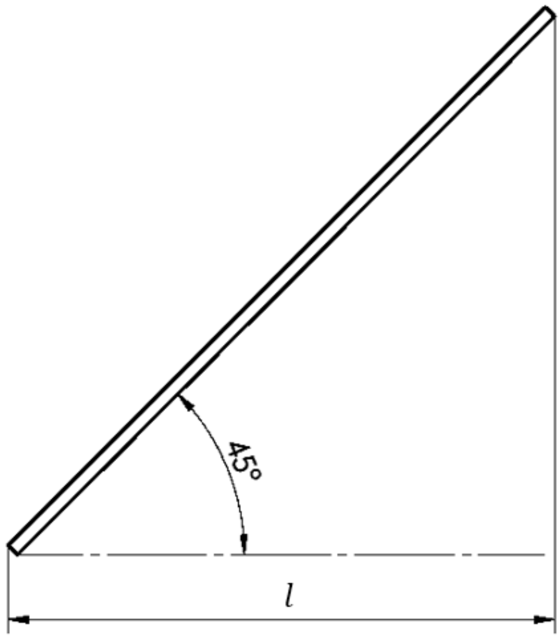


Figure 7.3: End paddle oriented at a 45 degree angle.

$r_a = 247\ mm \qquad r_i = 100\ mm \qquad l = 168\ mm$

Calculating the swept volume of the end paddle according to eq. 3:

$$V_{sweep} = \frac{(r_a^2 - r_i^2) \times \pi}{2} \times l = 13{,}46 \times 10^6\ mm^3$$

As a conservative approach, liquid addition of 30% of swept volume:

$$V_{add} = V_{sweep} \times 1{,}3 = 17{,}50 \times 10^6\ mm^3$$

Calculating the mass of the swept volume (eq. 4):

$$\rho_{max} = 1 \frac{kg}{L}$$

$$m_{bulk} = V_{add} \times \rho_{max} = 17{,}5\ kg$$

Calculating the force exerted on the paddle (eq. 5):

$$F_{bulk} = m_{bulk} \times g = 171{,}7\ N$$

Middle paddle

$$r_a = 247\ mm \qquad r_i = 100\ mm \qquad l = 310\ mm$$

As the middle paddle is orientated at a 15-degree angle alongside the shaft, the longest cathetus of the paddle (as shown in Figure 7.4)was used as the paddles length in the volume calculations.

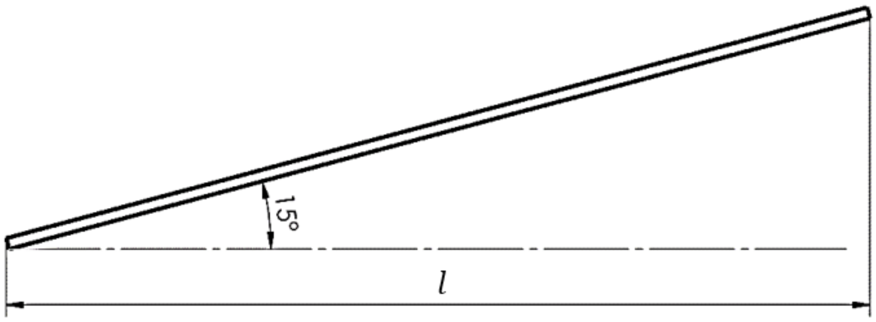


Figure 7.4: Middle paddle oriented at a 15 degree angle.

Calculating the sweep volume of the paddles path (eq. 3):

$$V_{sweep} = \frac{(r_a^2 - r_i^2) \times \pi}{2} \times l = 24{,}84 \times 10^6\ mm^3$$

$$V_{add} = V_{sweep} \times 1{,}3 = 32{,}29 \times 10^6\ mm^3$$

Calculating the mass of the swept volume (eq. 4):

$$\rho_{max} = 1\ {}^{kg}/_{l}$$

$$m_{bulk} = V_{add} \times \rho_{max} = 32{,}29\ kg$$

Calculating the force exerted on the paddle according to equation 5:

$$F_{bulk} = m_{bulk} \times g = 316{,}8\ N$$

7.2.3 Deformation and stresses on the middle paddle

The force is evenly distributed on the paddle as shown in figure 7.4.

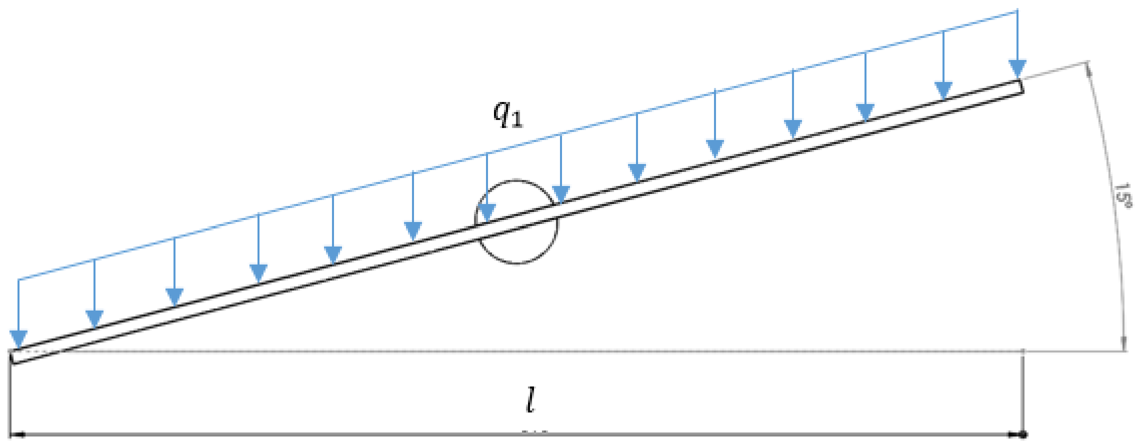


Figure 7.5: Distributed force acting on the middle paddle angled at a 15 degree angle..

Distributed force along the middle paddle (eq. 6):

$$F_{paddle} = 316{,}8\ N, \qquad l = 310\ mm$$

$$q_1 = \frac{F_{paddle}}{l} = 1{,}02\,\frac{N}{mm}$$

To simplify the deformation and stress calculations, the force exerted on the paddle was considered working perpendicular on the paddle as shown in Figure 7.6

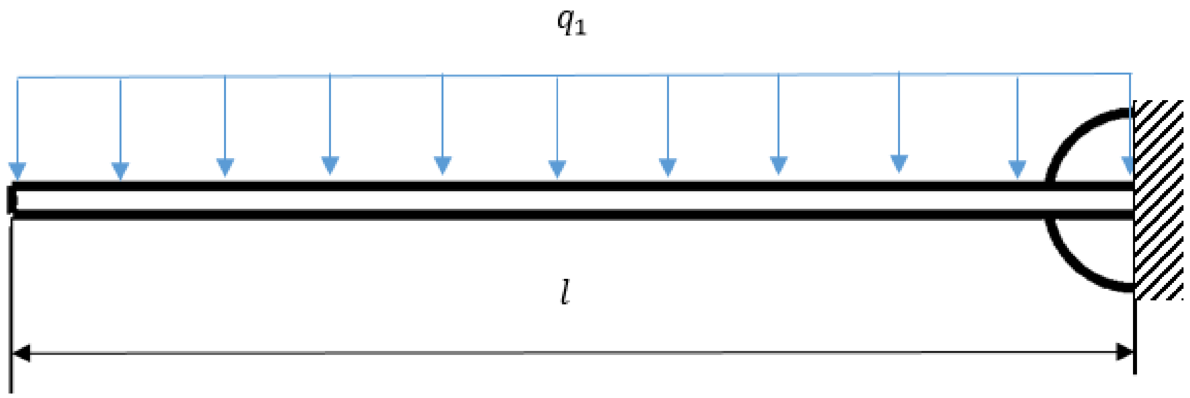


Figure 7.6: Distributed force acting perpendicular on the middle paddle.

Calculating the second moment of inertia for the width section of the paddle, using thickness h and width b of the paddle (eq. 7):

$$b = 147\ mm, \qquad h = 4\ mm, \qquad l = 160\ mm, \qquad E = 2{,}0 \times 10^5\ MPa,$$

$$I_1 = \frac{bh^3}{12} = 784\ mm^4$$

Calculating the deformation of the paddle (eq. 8):

$$y_1 = \frac{q_1 l^4}{8EI_1} = 0{,}53\ mm$$

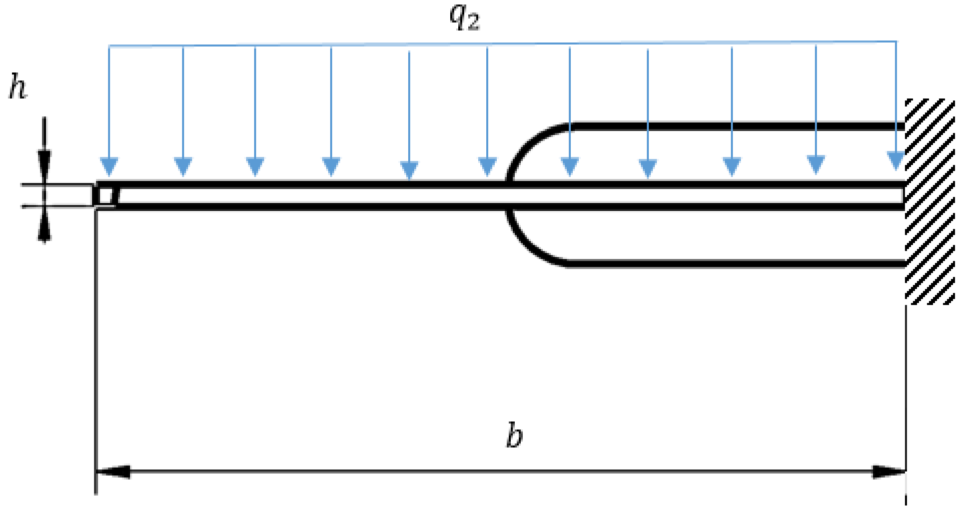


Figure 7.7: Distributed force acting on the middle paddle.

Distribute force across the middle paddle (eq. 6):

$$F_{paddle} = 316{,}8\ N, \qquad b = 147\ mm$$

$$q_2 = \frac{F_{paddle}}{b} = 2{,}15 \frac{N}{mm}$$

Calculating the second moment of inertia for the length section of the paddle, using thickness h and width w:

$$h = 4\ mm, \qquad w = 320\ mm, \qquad b = 147\ mm, \qquad E = 2{,}0 \times 10^5 MPa$$

$$I_2 = \frac{wh^3}{12} = 1706{,}67\ mm^4$$

$$y_2 = \frac{q_2 b^4}{8EI_2} = 0{,}35\ mm$$

$$y_{max} = y_1 + y_2 = 0{,}89\ mm$$

Calculating the moment working on the middle paddle (eq. 9):

$$l = 160\ mm$$

$$M_{max} = \frac{q_1 l^2}{2} = 13{,}1\ Nm$$

Calculating the resulting bending stress from the moment (eq. 10):

$$y = \frac{h}{2} = 2\ mm$$

$$\sigma_b = \frac{M_{max} y}{I_1} = 33{,}31\ MPa$$

7.2.4 Calculating the bending stress where the middle rod meets the mixer shaft

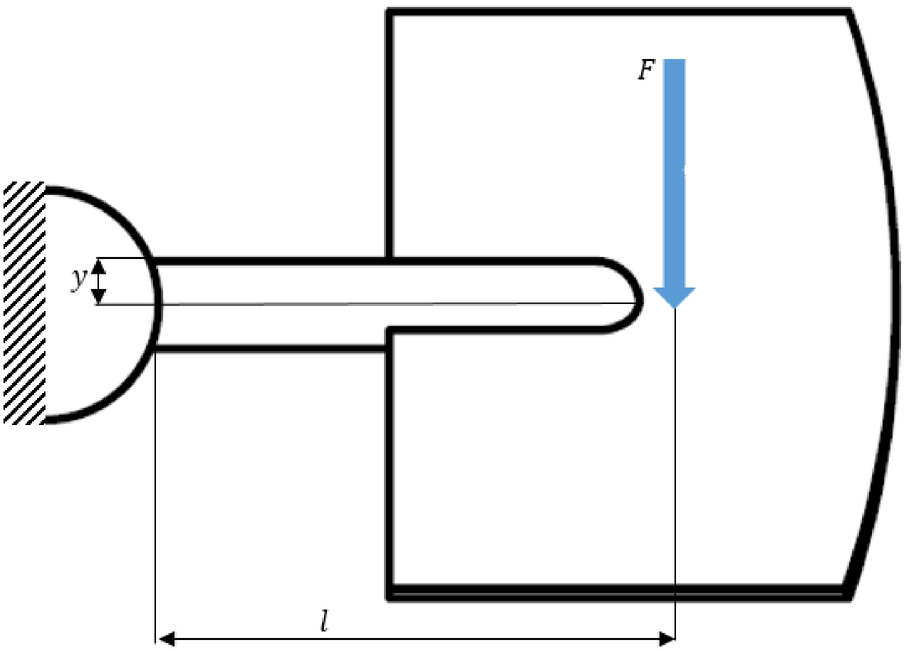


Figure 7.8: Resultant force acting on the middle paddle.

Calculating the moment on the rod from the force exerted on the middle paddle (eq. 11):

$$l = 140\ mm, \qquad F = 316{,}8\ N$$

$$M = Fl = 44{,}35\ Nm$$

Calculating the section modulus of the rod (eq. 12):

$$d = 25\ mm$$

$$W = \frac{\pi d^3}{32} = 1534\ mm^3$$

Calculating the bending stress at the edge of the rod (eq. 13):

$$\sigma_b = \frac{M}{W} = 28{,}9\ MPa$$

$$\sigma_b = 28{,}91\ MPa$$

An approximation for the stress concentration factor using chart 3.4: Stress concentration factor K_t for bending of a stepped bar of circular cross section with a shoulder fillet (49).

$$K_t = 1{,}4$$

$$\sigma_{b,SCF} = \sigma_b \times K_t = 40{,}5\ MPa$$

ANSYS Workbench (24) **deformation and stress results:**

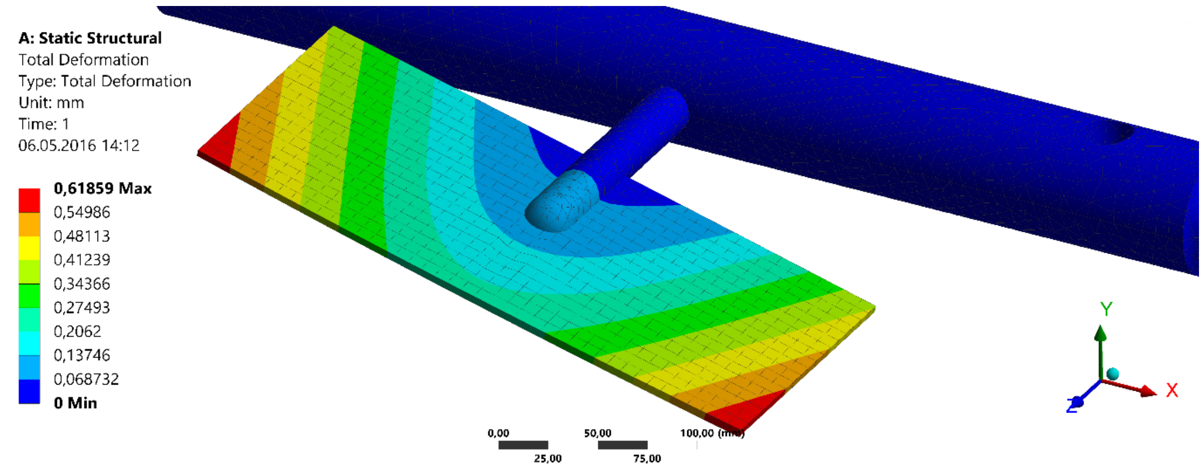


Figure 7.9: Deformation of the middle paddle. Maximum deformation 0,62 mm.

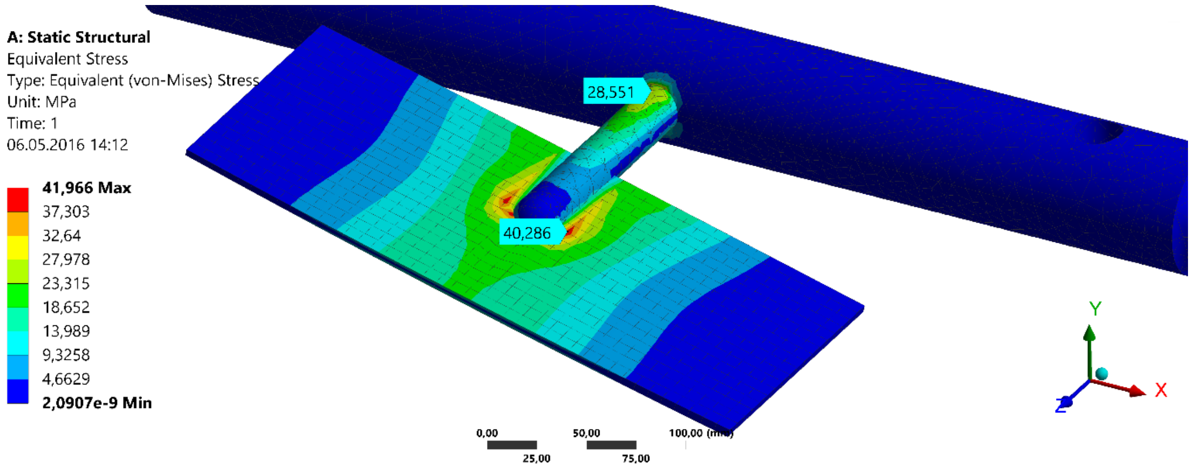


Figure 7.10: Equivalent stress on the middle paddle. Maximum stress 42 Mpa.

There is a difference between the ANSYS stress results compared to the hand calculations, which was expected. The stress concentration factors used in the hand calculations were roughly approximated in addition to the 3D model lacking fillet welds between the parts.

7.2.5 Torsional stresses

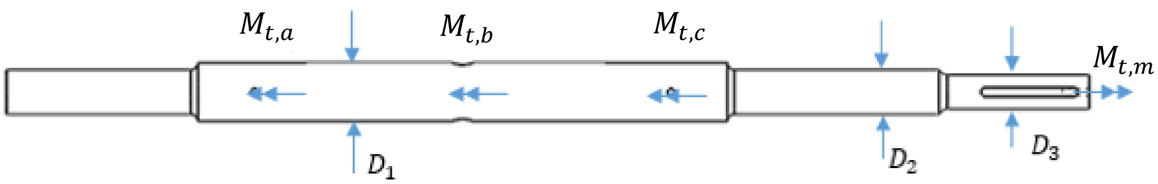


Figure 7.11: Torsion and diameters for the mixer shaft.

$$D_1 = 66\ mm, \qquad D_2 = 50\ mm, \qquad D_3 = 32\ mm$$

The torsion about the shaft is calculated using the forces exerted on the paddles with the distance from the resultant force to the centre of the shaft (eq.11).

$M_{t,a}$,$M_{t,c}$: Torsion about the shaft generated by the end paddles.

$M_{t,b}$: Torsion about the shaft generated by the middle paddle.

$$M_{t,a} = 29{,}8\ Nm, \qquad M_{t,b} = 54{,}9\ Nm, \qquad M_{t,c} = 29{,}8\ Nm,$$

$$M_{t,m} = M_{t,a} + M_{t,b} + M_{t,c} = 114{,}5\ Nm$$

Calculating the shear stress on D_2 using equation 14 and 15, with torque $M_{t,m}$ and the polar section modulus for D_2:

$$\tau_{D2} = \frac{16M_{t,m}}{\pi D_2^3} = 4{,}67\ MPa$$

Calculating the shear stress on D_3 using equation 14 and 15, with torque $M_{t,m}$ and the polar section modulus for D_3:

$$\tau_{D3} = \frac{16M_{t,m}}{\pi D_3^3} = 17{,}8\ MPa$$

The transition between the diameters all have a fillet radius r and stress concentration factors had to be found.

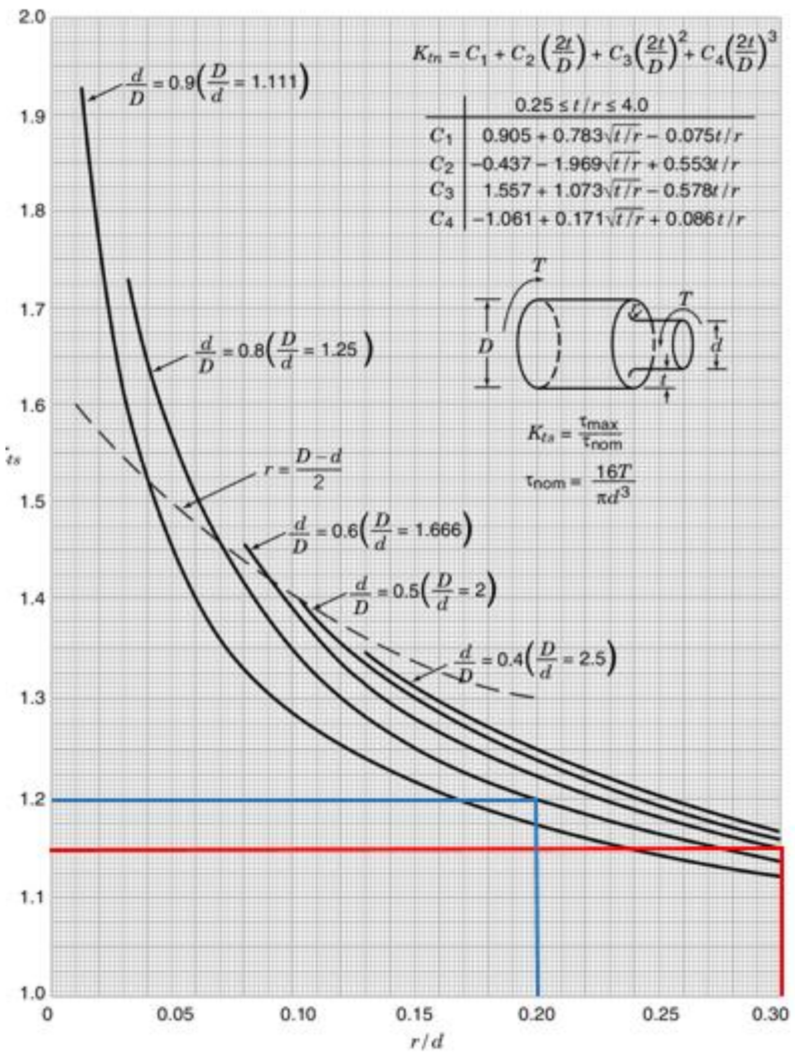


Figure 7.12: Torsion of shoulder fillet bar of circular cross-section (50).

The red line in Figure 7.12 indicates the following stress concentration factor based on given relationships in the geometry:

$$r = 10\ mm, \qquad \frac{r}{D_3} = 0{,}3125, \qquad \frac{D_3}{D_2} = 0{,}64, \qquad K_{ts} = 1{,}15$$

The maximum shear stress at the fillet radius in the transition between $D_2 and\ D_3$:

$$\tau_{maxD2} = \tau_{D3} \times K_{ts} = 20{,}5\ MPa$$

The blue line in Figure 7.12 indicates the following stress concentration factor based on given relationships in the geometry:

$$r = 10\ mm, \qquad \frac{r}{d} = 0{,}2, \qquad \frac{d}{D} = 0{,}76, \qquad K_{ts} = 1{,}2$$

The maximum shear stress at the fillet radius in the transition between $D_1 and\ D_2$:

$$\tau_{maxD1} = \tau_{D2} \times K_{ts} = 5{,}60\ MPa$$

The stress concentration factors for the keyway also had to be found:

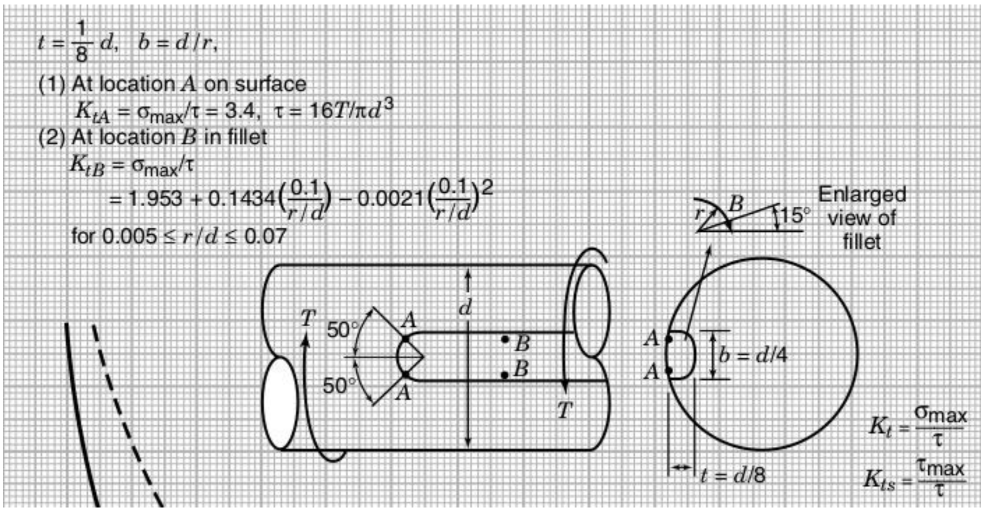


Figure 7.13: Stress concentration factors for a torsion shaft with a semicircular end keyseat (51).

Calculating the stress at location A from Figure 7.13:

$$\tau_{maxD1}, \qquad K_{tA} = 3{,}4$$

$$\sigma_{max} = K_{tA} \times \tau_{D3} = 60{,}5\ MPa$$

Calculating the stress at location B from Figure 7.13:

$$r = 0{,}3\ mm$$

$$K_{tB} = 1{,}953 + 0{,}1434\left(\frac{0{,}1}{r/D_3}\right) - 0{,}0021\left(\frac{0{,}1}{r/D_3}\right)^2 = 3{,}24$$

The equation above is valid for $0{,}005 \leq \mathrm{r/d} \leq 0{,}07 \;\; \rightarrow \; \mathrm{r/D_3} = 0{,}00938$

$$\sigma_{max} = K_{tB} \times \tau_{D3} = 57{,}7\ MPa$$

ANSYS workbench (24) **results:**

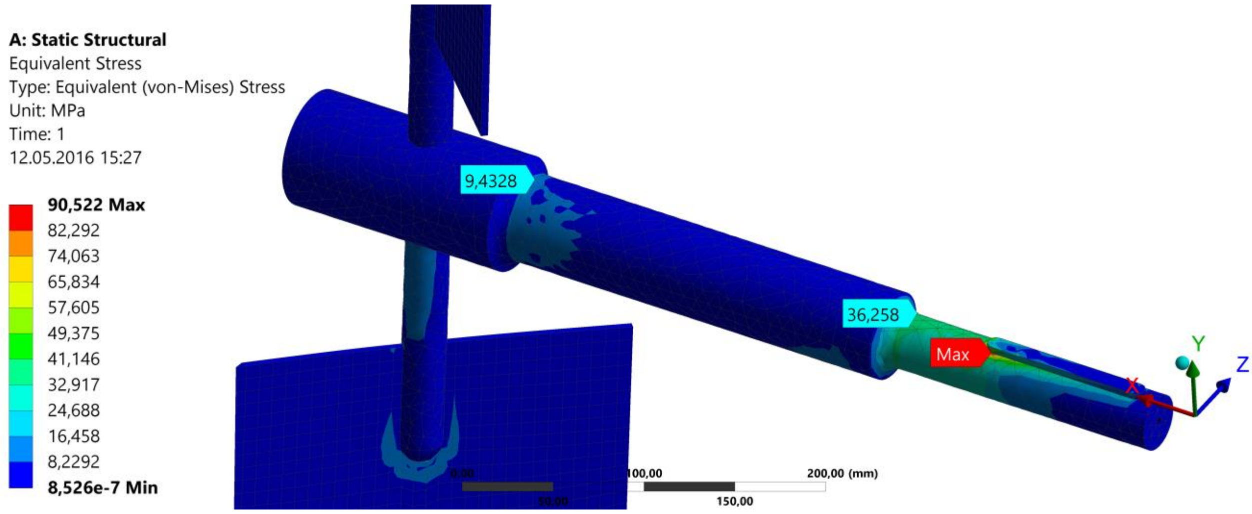


Figure 7.14: Mixer shaft stresses. Maximum value 90,5 MPa.

The ANSYS results shown in the figure above indicates higher stresses than calculated by hand. There can be faults in the supports added or to the mesh added in the program (Appendix B). Another source of error could be the stress concentration factor calculated for the key. However, the stresses found is below set yield strength limit.

7.2.6 Fatigue

A conservative approach is to choose the strictest curve for non-welded details from DNV-RP-C203 (18)

C-curve for thickness D_3:

$N \leq 10^7 cycles$

$$log\bar{a}_1 = 12{,}592, \qquad m_1 = 3, \qquad k = 0{,}15, \qquad t_{ref} = 25\,mm,$$

Using equation 15 to determine the curve and fatigue limit at $10^7 cycles$:

$$logN = \log\bar{a}_1 - m_1 k \times log\left(\frac{D_3}{t_{ref}}\right) - m_1 log\Delta\sigma$$

$$N = 3{,}497 \times 10^{12} \times \Delta\sigma^{-3}$$

$$\Delta\sigma = 70{,}45\ MPa$$

$N > 10^7 cycles$

$$log\bar{a}_2 = 16{,}320, \qquad m_2 = 5, \qquad k = 0{,}15, \qquad t_{ref} = 25\,mm$$

Using equation 15 to determine the curve and fatigue limit at $10^7 cycles$:

$$logN = \log\bar{a}_2 - m_2 k \times log\left(\frac{D_3}{t_{ref}}\right) - m_2 log\Delta\sigma$$

$$N = 1{,}736 \times 10^{16} \times \Delta\sigma^{-5}$$

$$\Delta\sigma = 70{,}45\ MPa$$

As seen from these calculations the stress limit is 70,45 MPa for the diameter D_3 for an infinite fatigue life.

Keyway (90,5 MPa from ANSYS):

$$N = 3{,}497 \times 10^{12} \times \Delta\sigma^{-3} = 4{,}7 \times 10^6\ cycles$$

C-curve for thickness D_1:

$N \leq 10^7 cycles$

$$log\bar{a}_1 = 12{,}592, \qquad m_1 = 3, \qquad k = 0{,}15, \qquad t_{ref} = 25\,mm,$$

Using equation 15 to determine the curve and fatigue limit at $10^7 cycles$:

$$logN = \log\bar{a}_1 - m_1 k \times log\left(\frac{D_1}{t_{ref}}\right) - m_1 log\Delta\sigma$$

$$N = 2{,}525 \times 10^{12} \times \Delta\sigma^{-3}$$

$$\Delta\sigma = 63{,}2\ MPa$$

$N > 10^7 cycles$

$$log\bar{a}_2 = 16{,}320, \qquad m_2 = 5, \qquad k = 0{,}15, \qquad t_{ref} = 25\,mm$$

Using equation 15 to determine the curve and fatigue limit at $10^7 cycles$:

$$logN = \log\bar{a}_2 - m_2 k \times log\left(\frac{D_1}{t_{ref}}\right) - m_2 log\Delta\sigma$$

$$N = 1{,}009 \times 10^{16} \times \Delta\sigma^{-5}$$

$$\Delta\sigma = 63{,}2\ MPa$$

As seen from these calculations the stress limit is 63,2 MPa for the diameter D_1 for an infinite fatigue life. All of the stressed components for this diameter are below this value.

7.2.7 Volume and masses of the paddles

Middle paddle:

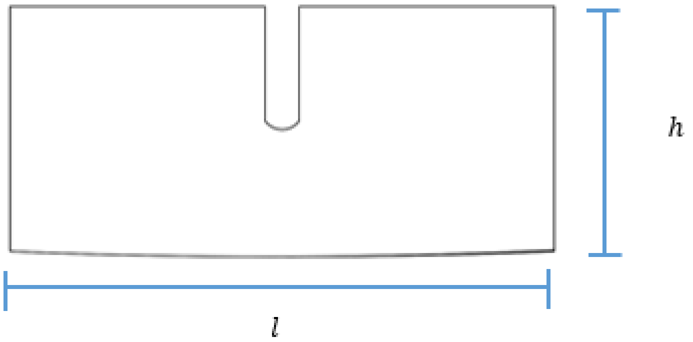


Figure 7.15: Middle paddle. Height and length illustrated.

$$l = 320\ mm, \qquad h = 147\ mm, \qquad t = 4\ mm, \qquad \rho = 8\ kg/L$$

$$V_{mid} = l \times h \times t = 0{,}188\ L$$

$$m_{mid} = V \times \rho = 1{,}5\ kg$$

End paddle:

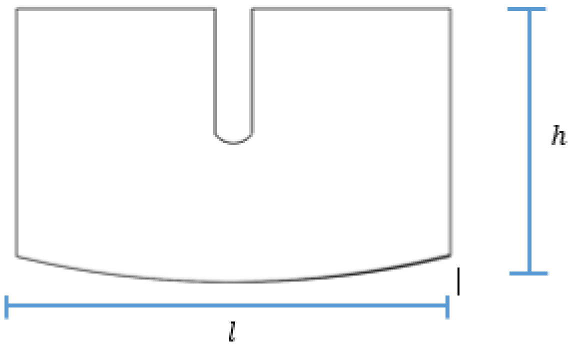


Figure 7.16: End paddle. Height and length illustrated.

$$l = 236\ mm, \qquad h = 147\ mm, \qquad t = 4\ mm, \qquad \rho = 8\ kg/L$$

$$V_{end} = l \times h \times t = 0{,}139\ L$$

$$m_{end} = V \times \rho = 1{,}1\ kg$$

Rod:

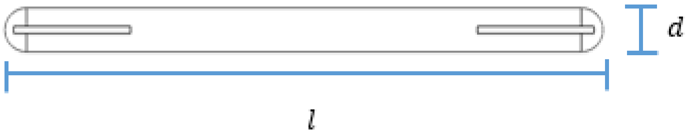


Figure 7.17: Rod. Length and diameter illustrated.

$$l = 345\ mm, \qquad d = 25\ mm, \qquad \rho = 8\frac{kg}{L}$$

$$V_{rod} = \frac{\pi \times d^2}{4} \times l = 0{,}1694\ L$$

$$m_{rod} = V \times \rho = 1{,}36\ kg$$

Shaft:

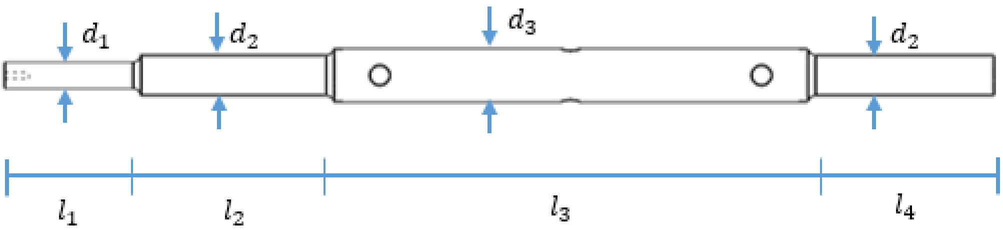


Figure 7.18: Mixer shaft. Lengths and diameters illustrated.

$$l_1 = 170\ mm, \qquad l_2 = 240\ mm, \qquad l_3 = 590\ mm, \qquad l_4 = 232\ mm$$

$$d_1 = 32\ mm, \qquad d_2 = 50\ mm, \qquad d_3 = 66\ mm$$

Calculating the volumes for the different parts of the shaft using equation 18:

$$V_1 = \frac{\pi \times d_1^2}{4} \times l_1 = 0{,}137\ L$$

$$V_2 = \frac{\pi \times d_2^2}{4} \times l_2 = 0{,}471\ L$$

$$V_3 = \frac{\pi \times d_3^2}{4} \times l_3 = 2{,}02\ L$$

$$V_4 = \frac{\pi \times d_2^2}{4} \times l_4 = 0{,}456\ L$$

$$V_{tot} = V_1 + V_2 + V_3 + V_4 = 3{,}08\ L$$

$$m_{shaft} = V_{tot} \times \rho = 24{,}6\ kg$$

7.2.8 Deformation and critical speed

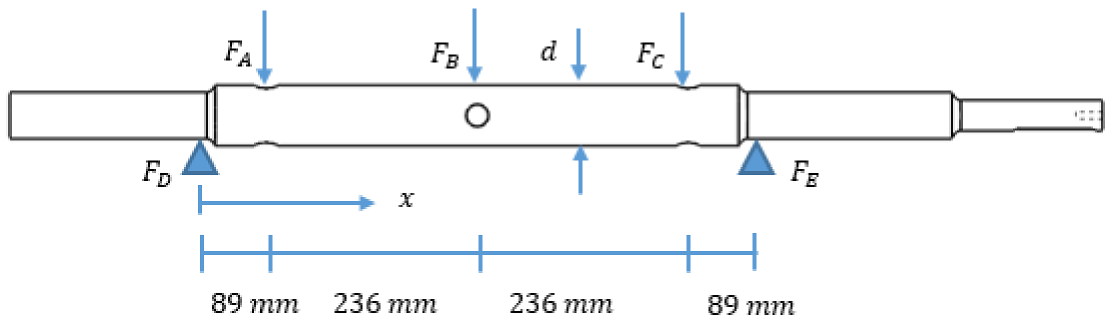


Figure 7.19: Forces acting on the mixer shaft from the paddles and rods.

$$E = 2{,}0 \times 10^5\ MPa, \qquad d = 66\ mm, \qquad I = \frac{\pi d^4}{64} = 931420\ mm^4, \qquad g = 9{,}81\frac{m}{s^2}$$

Forces acting on the shaft by the paddles and rods (eq. 5):

$$F_A = F_C = (2 \times m_{side} + m_{rod}) \times g = 34{,}9\ N$$

$$F_B = (2 \times m_{mid} + m_{rod}) \times g = 42{,}8\ N$$

Forces from the shaft support:

$$F_D = F_E = \frac{F_A + F_B + F_C}{2} = 56{,}3\ N$$

Calculating the deformations using Macaulay's method (eq. 20):

$$M(x) = 56{,}3 < x > - 34{,}9 < x - 89 > - 42{,}8 < x - 325 > - 34{,}9 < x - 561 >$$

$$EIy'' = -M(x)$$

$$EIy' = -\frac{56{,}3 < x >^2}{2} + \frac{34{,}9 < x - 89 >^2}{2} + \frac{42{,}8 < x - 325 >^2}{2} + \frac{34{,}9 < x - 561 >^2}{2} + C_1$$

$$EIy = -\frac{56{,}3 < x >^3}{6} + \frac{34{,}9 < x - 89 >^3}{6} + \frac{42{,}8 < x - 325 >^3}{6} + \frac{34{,}9 < x - 561 >^3}{6} + C_1 < x > + C_2$$

$$x = 0 \ \rightarrow y = 0 \rightarrow C_2 = 0$$

$$x = 650 \rightarrow y = 0$$

$$-\frac{56{,}3 \times 650^3}{6} + \frac{34{,}9 \times 561^3}{6} + \frac{42{,}8 \times 325^3}{6} + \frac{34{,}9 \times 89^3}{6} + C_1 \times 650 = 0$$

$$C_1 = 2001449$$

$$y(89) = y(561) = \left(-\frac{56{,}3 \times 89^3}{6} + 2001449 \times 89\right)\frac{1}{EI} = 9{,}21 \times 10^{-4}\ mm$$

$$y(325) = \left(-\frac{56{,}3 \times 325^3}{6} + \frac{34{,}9 \times 236^3}{6} + 2001449 \times 325\right)\frac{1}{EI} = 2{,}17 \times 10^{-3}\ mm$$

Rayleigh’s method for bending critical speed (eq. 21) using the deformations calculated above:

$$n_{kr} = \frac{30}{\pi}\sqrt{\frac{9810 \times \sum m \times y}{\sum m \times y^2}} = 23223\ RPM$$

Estimated masses for the paddles, rods were used to calculate the deformations for the shaft. The critical speed were found to be way above the mixing speed, as this is about 121 RPM.

7.2.9 Start torque and required power for the mixer rotor

For determining the start torque for the gearmotor, the moment of inertia for the different parts connected to the shaft had to be calculated:

Rod (eq. 22):

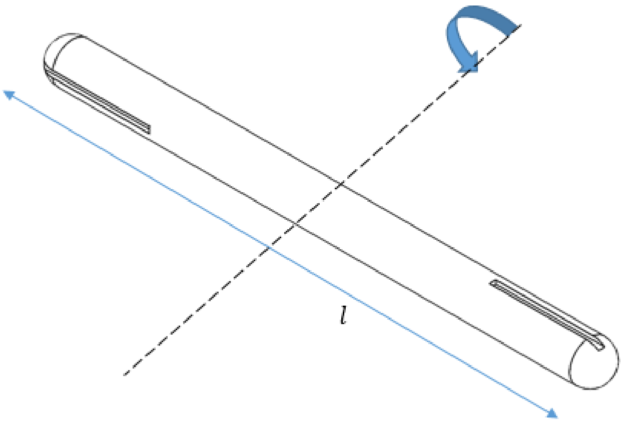


Figure 7.20: Rod. Dashline represent the rotational axis.

$$m_{rod} = 1{,}36\ kg, \qquad l = 345\ mm$$

$$I_r = \frac{m_{rod} l^2}{12} = 0{,}013\ kgm^2$$

Three rods:

$$I_{rods} = 3I_r = 0{,}039\ kgm^2$$

Middle paddle (eq. 22 & 23):

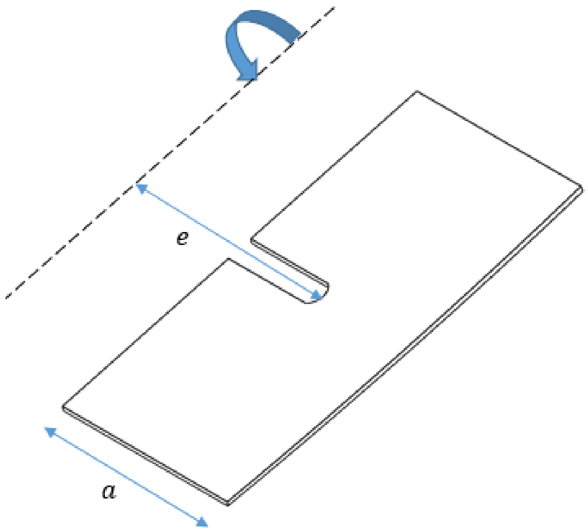


Figure 7.21: Middle paddle. Dashline represents the roational axis. Distance not Scaled.

$$m_{mid} = 1{,}5\ kg, \qquad a = 147\ mm, \qquad e = 173{,}5\ mm$$

$$I_{mp} = \frac{m_{mid}a^2}{12} + m_{mid}e^2 = 0{,}048\ kgm^2$$

2 middle paddles:

$$I_{m,paddles} = 2I_{mp} = 0{,}096\ kgm^2$$

End paddle (eq. 22 & 23):

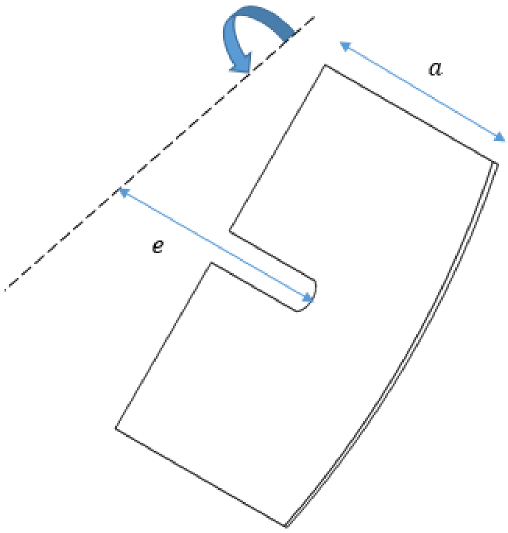


Figure 7.22: End paddle. Dashline represent the rotational axis. Distance not scaled.

$$m_{end} = 1{,}1\ kg, \qquad a = 147\ mm, \qquad e = 173{,}5\ mm$$

$$I_{ep} = \frac{m_{end}a^2}{12} + m_{end}e^2 = 0{,}035\ kgm^2$$

Four end paddles:

$$I_{e,paddles} = 4I_{ep} = 0{,}14\ kgm^2$$

Shaft:

Calculated with the whole shaft as 66 mm diameter (eq. 25):

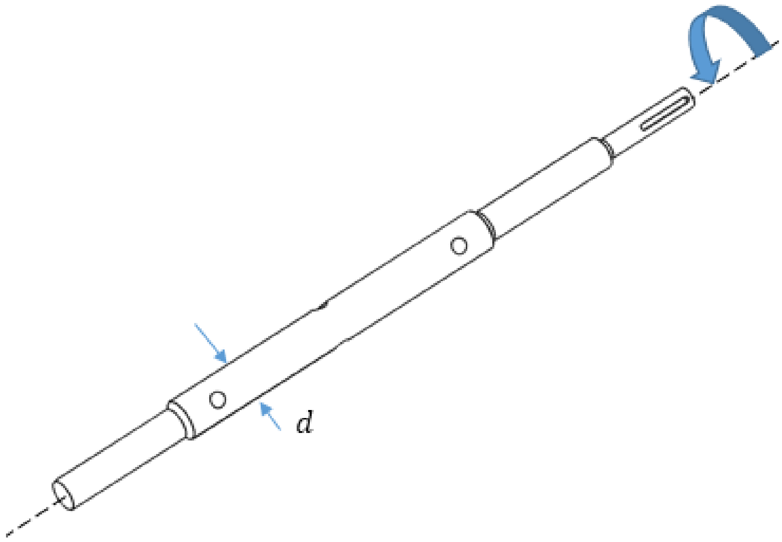


Figure 7.23: Shaft. Dashline represents the rotational axis.

$$m_{shaft} = 24{,}6\ kg, \qquad d = 66\ mm, \qquad r_a = \frac{d}{2}$$

$$I_{shaft} = \frac{m_{shaft} r_a^2}{2} = 0{,}013\ kgm^2$$

Total moment of inertia for the mixer rotor:

$$I_{tot} = I_{rods} + I_{m,paddles} + I_{e,paddles} + I_{shaft} \ = 0{,}288\ kgm^2$$

As calculated before , the necessary rotational speed is 121 RPM, n. An acceleration from 0 to 121 RPM in 0,5 seconds (t) is used to calculate the required starting torque for the gearmotor (eq. 26).

$$\alpha_A = \frac{\pi \times n}{t \times 30} = 25{,}3 \frac{rad}{s^2}$$

The required start torque for the mixer rotor is estimated by adding the load torque and the torque required to accelerate the masses (eq. 27 and 28). The load torque $M_{t,m}$ consist of the swept force created by the paddles with an arm r from the central axis of the shaft.

$$M_{t,m} = 114{,}5\ Nm, \qquad r = 173{,}5\ mm, \qquad g = 9{,}81 \frac{m}{s^2}$$

$$m = \frac{M_{t,m}}{g \times r} = 67{,}3\ kg$$

$$M_{aks} = \alpha_A (I_{tot} + m \times r^2) = 58{,}5\ Nm$$

$$M_{start} = M_{t,m} + M_{aks,tot} = 173\ Nm$$

The required power (eq. 30):

$$P = \frac{M_m \times \pi \times n}{30} = 1451\ W$$

Estimated moments of inertias for the rotating parts of the mixer motor as well as the torque from the product being mixed were used to determine the necessary start torque and the required power for the gearmotor. Moment of inertia for the ball bearings and the frictional force from the air purged sealing were excluded from these calculations.

7.2.10 Thermal expansion

There was a concern that the paddles could hit the main housings walls when adding heated liquid to the mix. An analysis were executed with a temperature difference of 78 °C

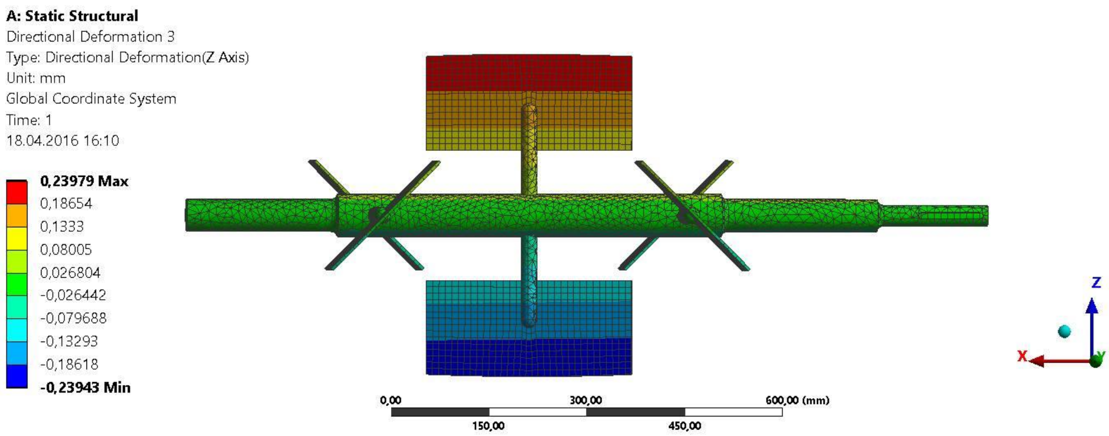


Figure 7.24: Thermal expansion analysis from ANSYS WB (24). Maximum value 0,24 mm and minimum value -0,24 mm.

7.3 De-agglomerator

7.3.1 Start torque and required power

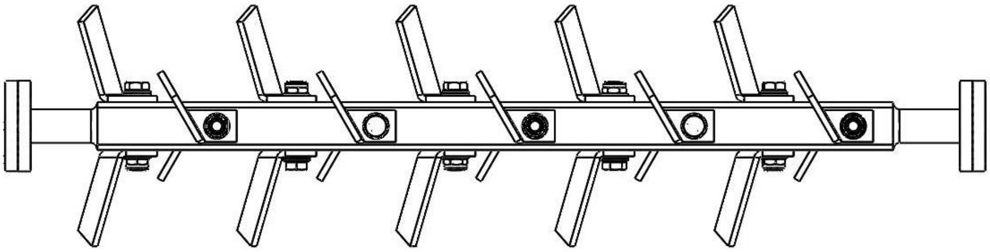


Figure 7.25: De-agglomerator.

Seeing as Forberg uses Hoyer motors on their F-20 mixers, it was reasonable to use them as well. Hoyer delivers a wide range of high quality electrical motors in both aluminium and cast iron. The Hoyer IE2 motors comes in three different speeds: 2800, 1400 and 700 (RPM). It was decided that it was beneficial to go for a motor of 1400 RPM.

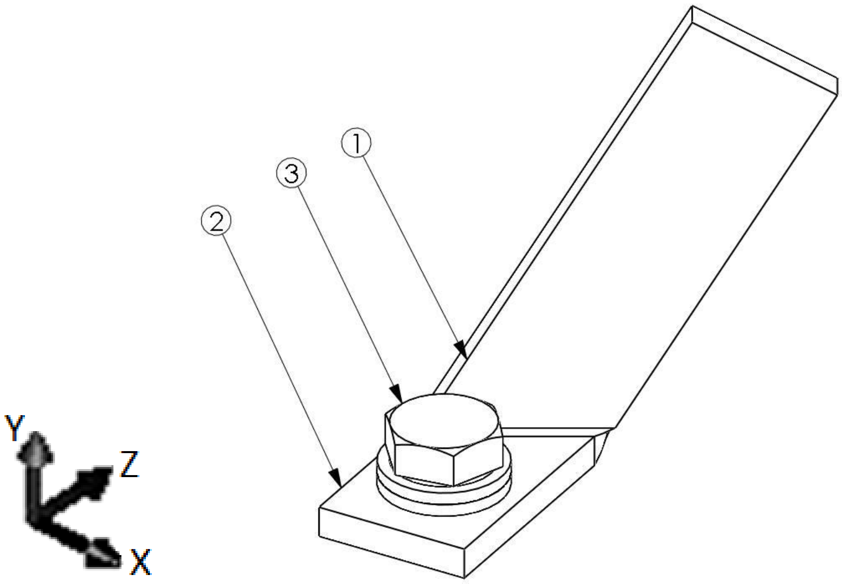


Figure 7.26: Bent flat steel seen as two separate parts, while bolt head and washers are seen as one solid part.

Mass part no. 1:

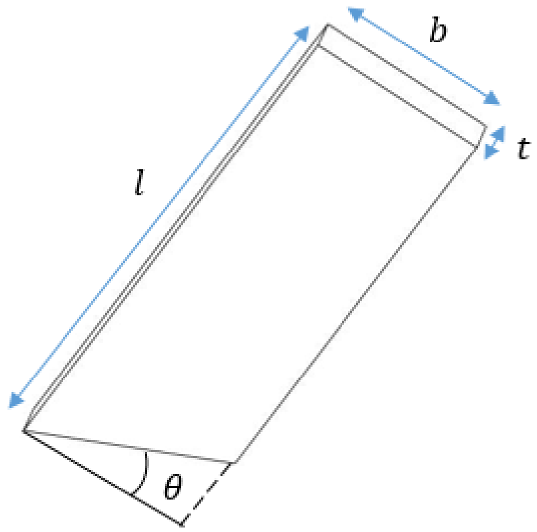


Figure 7.27: Measurements for part no. 1.

Estimating the mass for part 1 of the de-agglomerator flat steel (eq. 17 and 4):

$$l = 65\ mm \qquad b = 20\ mm \qquad \theta = 30^{\circ}$$

$$\rho = 8000\frac{kg}{m^3}, \qquad t = 4\ mm$$

$$m_1 = \left(l \times b - \frac{b^2 \times \tan\theta}{2}\right) \times t \times \rho = 37{,}9 \times 10^{-3}\ kg$$

Mass part no. 2:

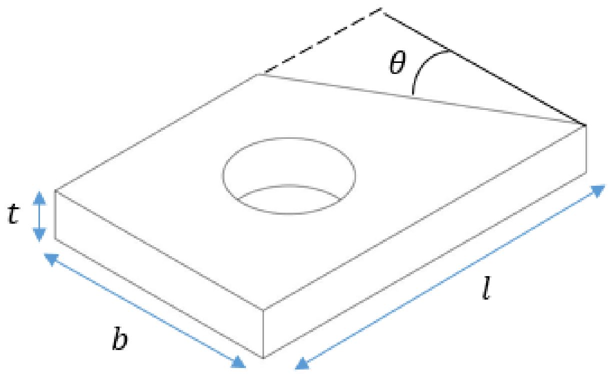


Figure 7.28: Measurements for part no. 2.

In favour of the calculations in this section, part no. 2 of the assembly was considered to be solid without the clearance hole for the bolt. As the bolt (DIN 6921) and the de-agglomerator share the same density ρ ($8000\, {}^{kg}/_{m^3}\ vs. 8030\, {}^{kg}/_{m^3}$) , the section of the bolt that passes through part no. 2 was seen as non existent and calculations in respect of the bolt was only performed on the bolt-head.

$$l = 31\, mm, \qquad b = 20\, mm, \qquad t = 4\, mm, \qquad \theta = 30°$$

$$m_2 = l \times \left(b \times t - \frac{b^2 \tan\theta}{2}\right) \times \rho = 18{,}71 \times 10^{-3}\, kg$$

Mass part no. 3:

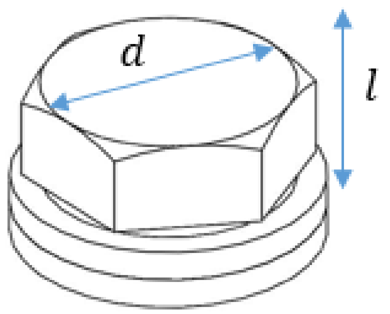


Figure 7.29: Measurements for part no. 3.

Calculating the mass of bolt head and washers (eq. 18 and 4):

$$d = 16\, mm, \qquad l = 8{,}5\, mm$$

$$m_3 = \frac{\pi d^2}{4} l = 13{,}6 \times 10^{-3}\, kg$$

Rectangular NO. 1 (1 on Figure 7.26)**:**

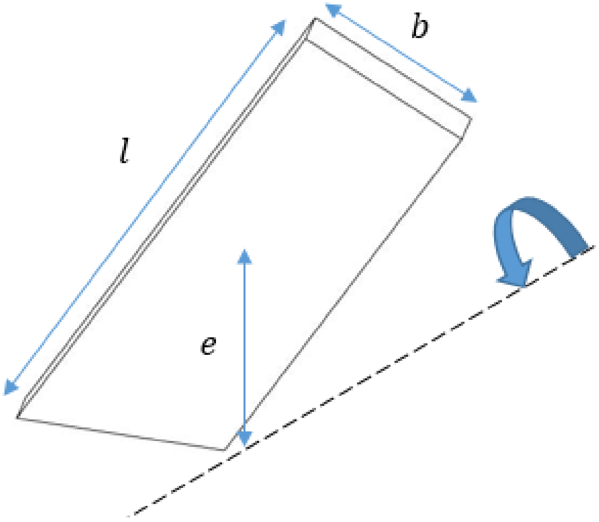


Figure 7.30: Part no.1. Dashline represents the rotational axis. Not scaled.

Moment of inertia (eq. 31 and 23):

$$l = 65\ mm, \qquad b = 20\ mm, \qquad e = 50{,}5\ mm$$

$$I_1 = \frac{m_1}{12}(l^2 + b^2) + m_1 e^2 = 1{,}11 \times 10^{-4}\ kgm^2$$

mRectangular NO. 2 (2 on Figure 7.26)**:**

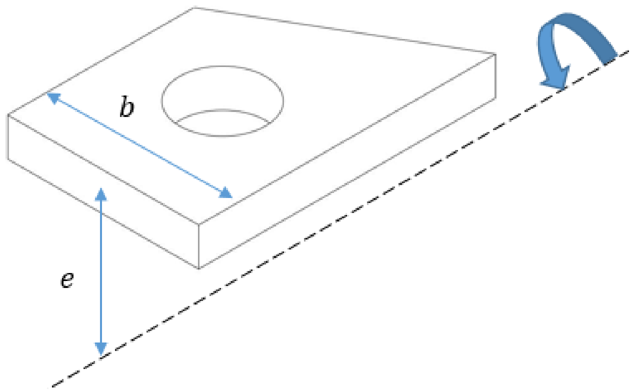


Figure 7.31: Part no. 2. Dashline represents the rotational axis. Not scaled.

$$b = 20\ mm, \qquad e = 17\ mm$$

Estimating the moment of inertia about rotational axis (eq. 24 and 23):

$$I_2 = \frac{m_1 \times b^2}{12} + m_1 e^2 = 6{,}03 \times 10^{-6}\ kgm^2$$

Bolt head (3 on Figure 7.26) **moment of inertia (eq. 32 and 23):**

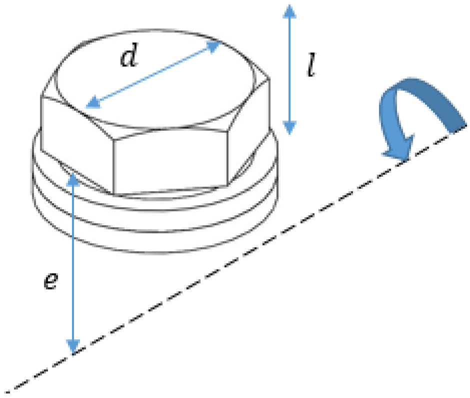


Figure 7.32: Part no.3. Dashline represents the rotational axis. Not scaled.

$$d = 16\,mm, \qquad r = \frac{d}{2}, \qquad l = 8{,}5\,mm, \qquad e = 23{,}25\,mm$$

$$I_3 = \frac{m}{12}(3r^2 + l^2) + me^2 = 7{,}65 \times 10^{-6}\,kgm^2$$

Shaft:

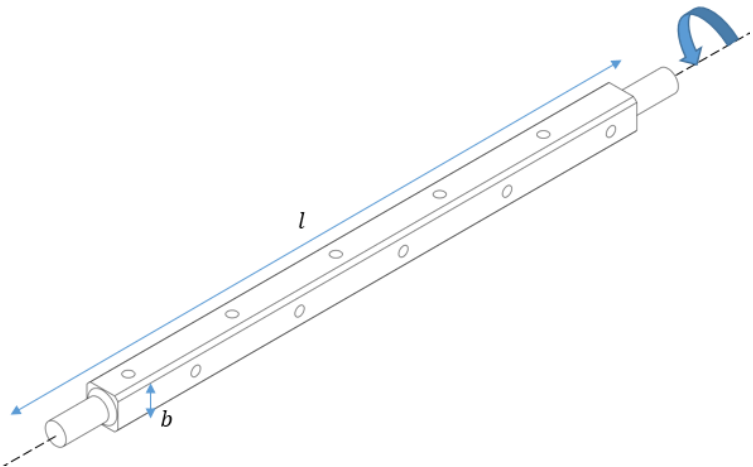


Figure 7.33: De-agglomerator shaft. Dashline represents the rotational axis.

$$l = 500\,mm, \qquad b = 30\,mm$$

Calculated mass assumed as solid square through all (eq. 17 and 4):

$$m_{sq} = b^2 \times l \times \rho = 3{,}6\,kg$$

Estimated moment of inertia (eq. 31):

$$I_{sq} = \frac{m_{sq} \times 2 \times b^2}{12} = 5{,}4 \times 10^{-4}\,kgm^2$$

Couplings:

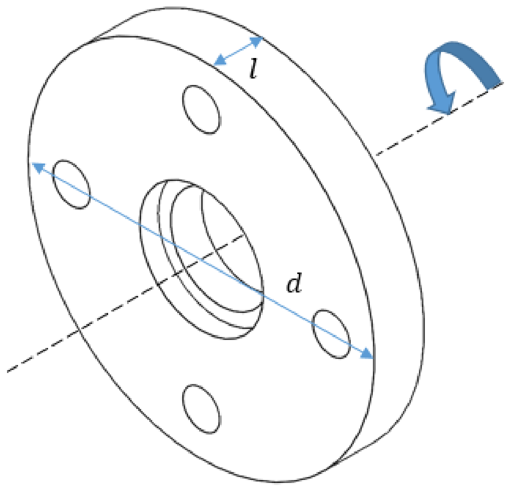


Figure 7.34: De-agglomerator coupling. Dash line represents rotational axis.

$$d = 56\,mm, \qquad r = \frac{d}{2}, \qquad l = 8\,mm$$

Mass assumed as solid cylinder (the pins from the corresponding coupling would fill the holes of the coupling) (eq. 4):

$$m_{cp} = \frac{\pi d^2}{4} l \times \rho = 0{,}158\,kg$$

Estimated moment of inertia for four couplings (eq. 25):

$$I_{cp} = 4\frac{mr^2}{2} = 2{,}48 \times 10^{-4}\,kgm^2$$

Calculating the total moment of inertia:

$$I_{tot} = 20I_1 + 20I_2 + 20I_3 + I_{sq} + I_{cp} = 3{,}28 \times 10^{-3} kgm^2$$

The mass properties function in SolidWorks was used as a way to verify the calculations. In SolidWorks the moment of inertia of the de-agglomerator was said to be $2{,}9 \times 10^{-3}\,kgm^2$. The results for SolidWorks had a lower value than what was calculated in this section, putting the calculations on the conservative side.

Calculating the acceleration required to reach max speed of 1400 RPM in 0,5 seconds (eq. 26.):

$$\alpha = \frac{n \times 2 \times \pi}{\Delta t \times 60} = 293{,}22 \, {}^{rad}/_{s^2}$$

Calculating the load from the powder acting upon the de-agglomerator, using the same sweep approach as the mixer paddles (eq. 3 and 4):

$$r_a = 75\,mm, \qquad r_i = 15\,mm, \qquad b = 12\,mm, \qquad \rho = 1\frac{kg}{L}$$

$$m_{sweep} = \frac{(r_a^2 - r_i^2)}{2} \times b \times \pi \times \rho = 0{,}105\,kg$$

Calculating the moment created by the powder for 10 pieces of bent flat steel with the distance r_p, from the rotational axis to their centre of mass (eq. 5 and 11):

$$r_p = 45\,mm, \qquad g = 9{,}81\frac{m}{s^2}$$

$$M_L = 10 \times m_{sweep} \times r_p \times g = 0{,}46\,Nm$$

Calculating required start torque (eq. 27, 28 and 29)

$$M_{aks} = \alpha_p \left(I_{tot} + 10 \times m_{p_{sweep}} \times r_p^2 \right) = 1{,}57\,Nm$$

$$M_{start} = M_L + M_{aks} = 2{,}03\,Nm$$

Required power from the motor (eq. 30):

$$P = \frac{M_L \times \pi \times n}{30} = 67{,}44\,W \approx 0{,}067kW$$

The required motor size was determined by calculating the necessary start torque, which in turn was determined by the applied load from the product, the total moment of inertia of the rotating masses and the acceleration.From these calculations it is concluded that the motor needs to be able to provide at least a start torque of 2,03 Nm and 0,067 kW of power

7.4 Housing

7.4.1 Vacuum

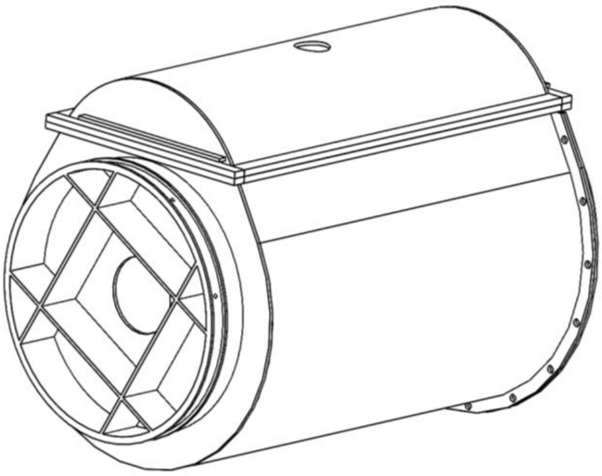


Figure 7.35:Isometric view of the main housing and vacuum lid.

For the calculation of this problem, we assume that the vacuum chamber is cylindrical with an inner diameter of 500 mm.

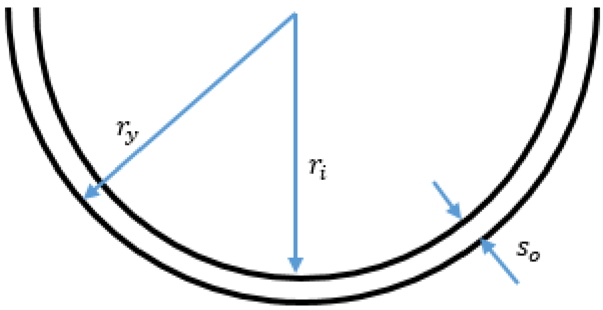


Figure 7.36: Vacuum chamber cross-section with illustrated measurements.

$$r_i = 250\ mm, \qquad r_y = 255\ mm, \qquad s_0 = 5\ mm$$

$$r_m = \frac{(r_y + r_i)}{2} = 252{,}5\ mm$$

Thin walled theory can be used when (21):

$$\frac{s_0}{r_m} \leq \frac{1}{10}$$

$$\frac{s_0}{r_m} = \frac{5\ mm}{252{,}5\ mm} = 0{,}02$$

For thin walled pressure vessels, the radial stress is set to zero. $\sigma_r = 0$.

Pressure difference 20% vacuum:

$$p_{atm} = 0{,}101325\ MPa, \qquad p_v = 0{,}2p_{atm}$$

$$\Delta p = p_y = p_{atm} - p_v = 0{,}8p_{atm} = 0{,}08106\ MPa$$

Tangential stress (eq. 32):

$$\sigma_t = \frac{-\, p_y \times r_m}{s_0} = -4{,}10\ MPa$$

Axial stress (eq. 33):

$$\sigma_a = \frac{-\, p_y \times r_m}{2 \times s_0} = -2{,}05\ MPa$$

For the housings end walls and flat surfaces, the stresses and deformations were analysed in ANSYS Workbench (24):

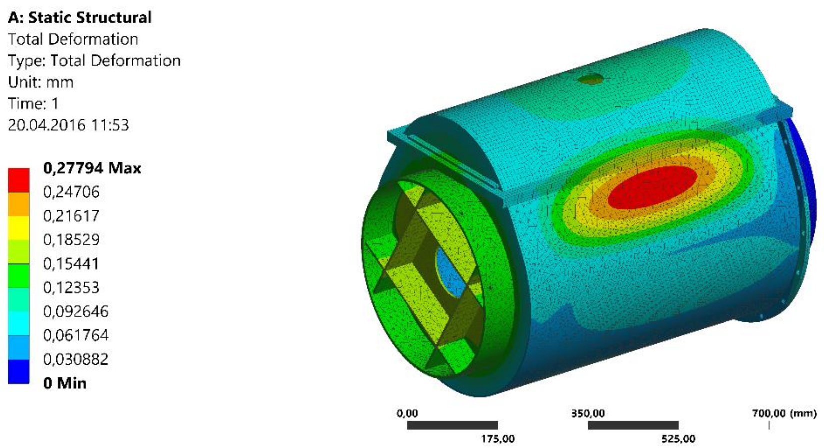


Figure 7.37: Deformation when vacuum is applied. Maximum deformation 0,28 mm.

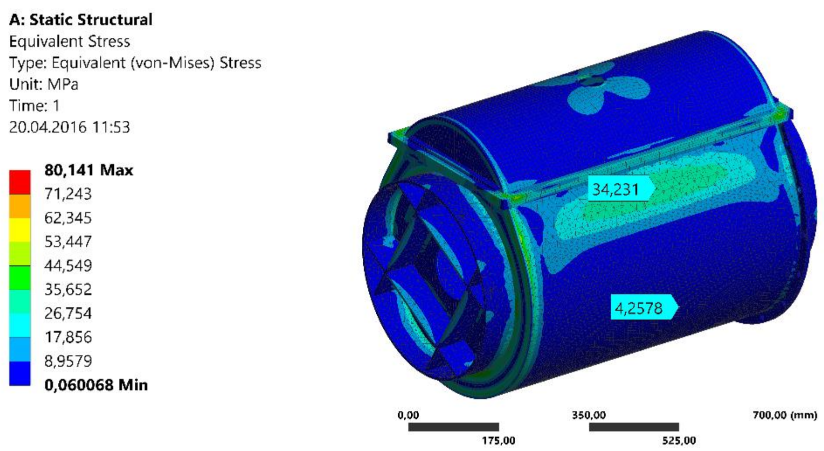


Figure 7.38: Equivalent stress when vacuum is applied. Maximum stress 80 MPa.

The maximum value shown in Figure 7.38 is a negligible value as this is a stress singularity due to limited mesh elements.

7.4.2 Required start torque and power for rotating the housing

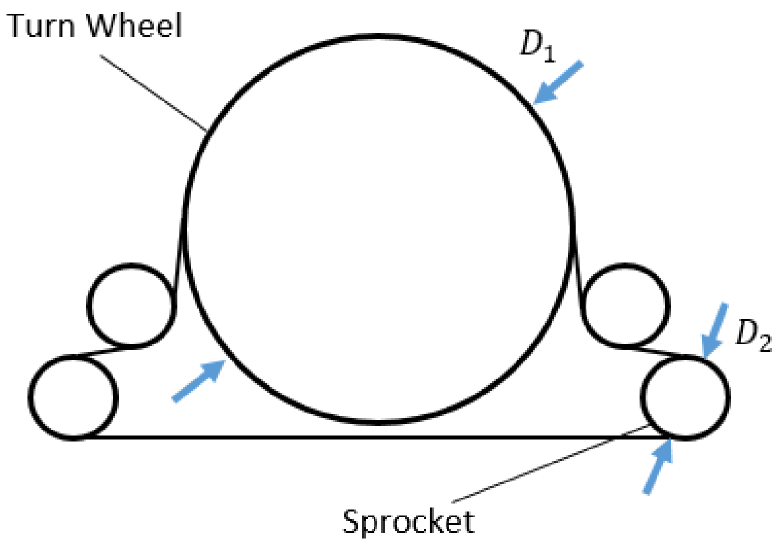


Figure 7.39: Turn wheel and sprocket arrangement for rotation of the housing. Not scaled

$$D_1 = 402\ mm, \qquad D_2 = 60\ mm$$

$$i = \frac{D_1}{D_2} = 6{,}7$$

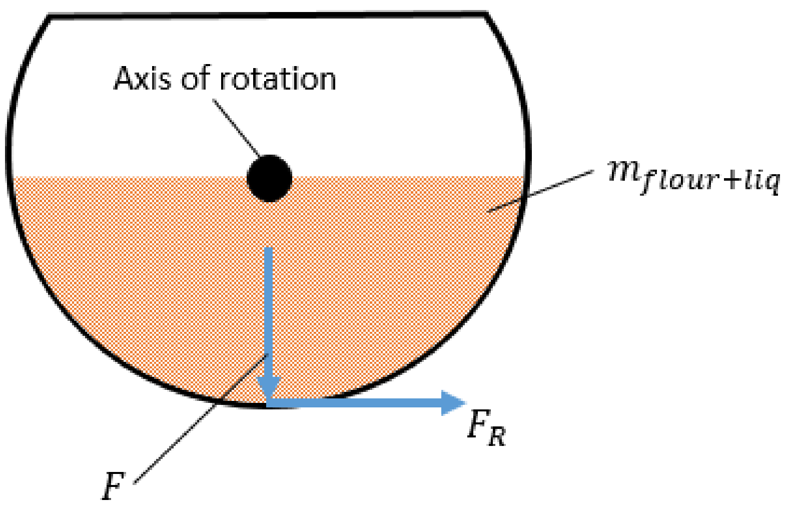


Figure 7.40: Frictional force caused by rotating the housing.

μ : Friction between grain and steel (52)

$$\mu = 0{,}2, \qquad g = 9{,}81\,\frac{m}{s^2}, \qquad m_{flour+liq} = 80\ kg$$

$$F = m_{flour+liq} \times g = 785\ N$$

Frictional force caused by rotation of the housing (eq. 34):

$$F_R = \mu F = 157\ N$$

Moment caused by the frictional force with the distance r from the central axis to the force (eq. 11):

$$r = 250\ mm$$

$$M_R = F_r \times r = 39{,}24\ Nm$$

Estimated moment of inertia cylindrical shell(eq. 35):

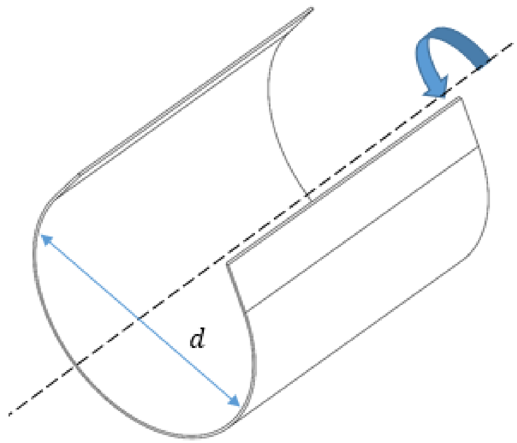


Figure 7.41: Cylindrical shell. Dashline represents the rotational axis.

$$d = 500\,mm, \qquad r = \frac{d}{2}, \qquad m = 7{,}6\,kg$$

$$I_h = mr^2 = 2{,}125\,kgm^2$$

Estimated moment of inertia for the two end walls of the housing (eq. 25):

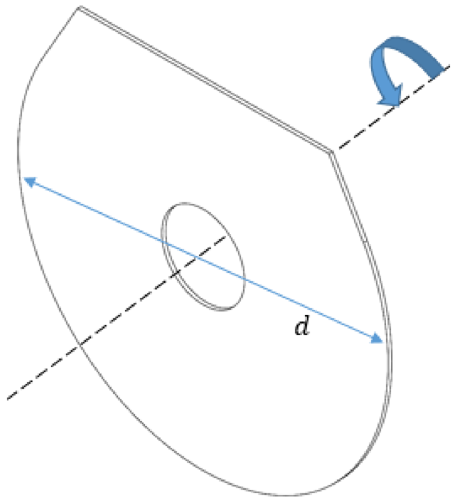


Figure 7.42: End wall. Dashline represents the rotational axis.

$$d = 510\,mm, \qquad r = \frac{d}{2}, \qquad m = 7{,}5\,kg$$

$$I_e = 2 \times \frac{mr^2}{2} = 0{,}98\,kgm^2$$

Moment of inertia for two turn wheels. Estimates all mass as a hoop (eq. 36):

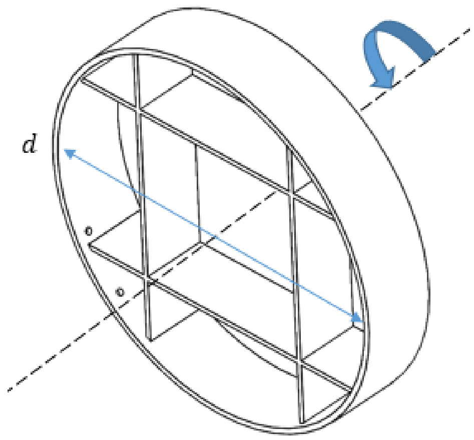


Figure 7.43: Turn wheel. Dashline represents the rotational axis.

$$d = 402\ mm, \qquad r = \frac{d}{2}, \qquad m = 8{,}5\ kg$$

$$I_r = 2 \times mr^2 = 0{,}69\ kgm^2$$

Total moment of inertia housing:

$$I_{tot,housing} = I_h + I_e + I_r = 3{,}795\ kgm^2$$

Estimated moment of inertia for 4 sprocket (eq. 25):

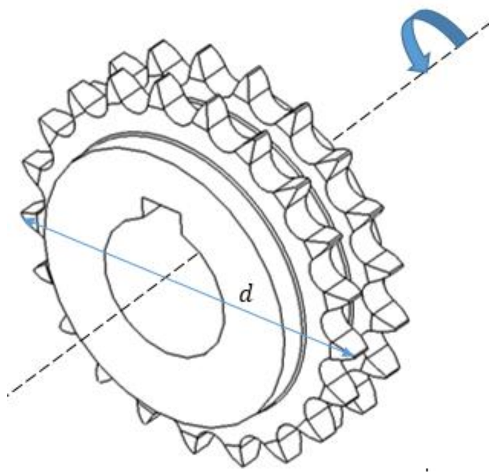


Figure 7.44: Sprocket. Dashline represents the rotational axis.

$$d = 69\ mm, \qquad r = \frac{d}{2}, \qquad m = 0{,}4\ kg$$

$$I_s = 4 \times \frac{mr^2}{2} = 9{,}522 \times 10^{-4}\ kgm^2$$

Estimated moment of inertia for the sprocket shaft. The whole shaft is calculated with one diameter, d (eq. 25):

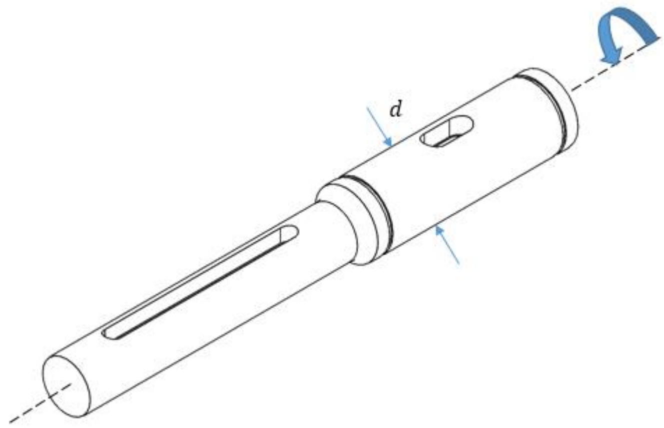


Figure 7.45: Sprocket shaft. Dashline represents the rotational axis.

$$m = 0{,}54\ kg, \qquad d = 25\ mm, \qquad r_a = \frac{d}{2}$$

$$I_{shaft} = \frac{mr_a^2}{2} = 4{,}22 \times 10^{-5}\ kgm^2$$

Total moment of inertia for the sprockets and shaft:

$$I_{tot,shaft} = I_s + I_{shaft} = 9{,}94 \times 10^{-4}\ kgm^2$$

Frictional force working on the turn wheel with radius r as mass forced by gravity (eq. 5):

$$r = 201\ mm, \qquad g = 9{,}81 \frac{m}{s^2}, \qquad F_{R,tw} = \frac{M_R}{r} = 195\ N$$

$$m = \frac{F_{R,tw}}{g} = 20\ kg$$

The housing have to rotate 180 degrees to empty. The rotational speed of the turn wheel n_1, and the sprocket n_2 will be calculated with 4 seconds t_s to rotate and 1 second t_a to accelerate (eq. 26 & 38):

$$n_1 = \frac{0{,}5}{4\ s} \times 60\ s = 7{,}5\ RPM, \qquad n_2 = n_1 \times i = 50{,}25\ RPM$$

$$\omega = \frac{n_2 \times \pi}{30} = 5{,}26 \frac{rad}{s}$$

$$\alpha_a = \frac{\omega}{t_a} = 5{,}26 \frac{rad}{s^2}$$

The required start torque for the gearmotor (eq. 27 – 29) :

$$M_{aks} = \alpha_a \left(\frac{I_{tot,housing}}{i^2} + I_{tot,shaft} + \frac{mr^2}{i^2} \right) = 0{,}545\ Nm$$

$$M_m = \frac{M_R}{i} = 5{,}86\ Nm$$

$$M_{start} = M_{aks} + M_m = 6{,}4\ Nm$$

The power required (eq. 30) :

$$P = \frac{M_m \times \pi \times n_2}{30} = 31\ W$$

Estimations for the moments of inertia were used to calculate the required start torque and power for the rotation of the housing. The moment of inertia for the wheel supports and the chain as well as the friction from the air purged sealing were excluded from these calculations.

7.5 Piston rod

It was necessary to determine the moment about the pivot point from the de-agglomerator lid to evaluate if the piston rods could move the lid.

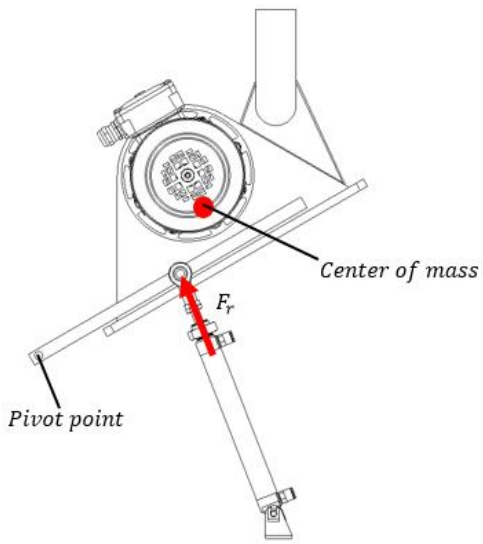


Figure 7.46: The de-agglomerator lid and piston rod assembly. The center of mass is an approximation.

$$F_r: Force\ from\ the\ piston\ rod$$

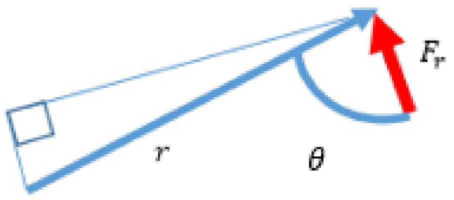


Figure 7.47: Piston force and arm arrangement.

$$r = 197{,}5\ mm, \qquad \theta = 81\ °$$

Moment from the piston rod (eq. 11):

$$M = r \times \sin(81) \times F_r$$

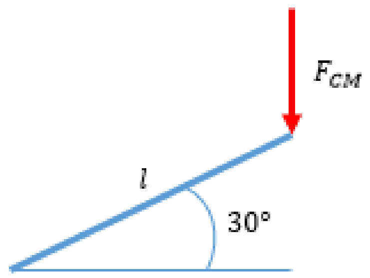


Figure 7.48: Force from the center of mass arrangement.

The mass of the de-agglomerator lid were estimated using Solidworks and hand calculations.

$$m = 42\ kg, \qquad l = 265\ mm, \qquad g = 9{,}81\ \frac{m}{s^2}, \qquad F_{CM} = mg = 412\ N$$

Calculating the moment from the centre of mass about the pivot point (eq. 11):

$$M_{CM} = F_{CM} \times l \times \cos(30) = 94{,}6\ Nm$$

Required force from the piston rod:

$$M_{CM} = M$$

$$F_r = \frac{M_{CM}}{r \times \sin(81)} = 485\ N \rightarrow For\ both\ pistons$$

The piston rods chosen, can handle a force up to 294,5 N at 6 bar each (53) .

7.4 Other

Calculations were done for other component as well, along with the concept generation and design process. These were done to assure that the stresses were below half of the yield strength for parts that were looked upon as “weak”.

8. Manufacture and cost

This chapter will discuss the manufacturing methods for every part and use this as a basis for a cost analysis.

8.1 Coding of the parts and assemblies

To have control over the parts and assemblies for the mixer/vacuum coater, there had to be made a numbering system:

$$\underbrace{A}_{Type} - \underbrace{XXX}_{Assembly\ no.} - \underbrace{XXX}_{Part\ no.}$$

Every self-made part in this thesis is indexed with the letter N at the start of the code.

$$\underbrace{N}_{New\ part} - \underbrace{002}_{Mixer\ shaft} - \underbrace{003}_{Middle\ paddle}$$

Solutions provided by Forberg will start with the letter F.

$$\underbrace{F}_{Solution\ provided\ by\ Forberg} - \underbrace{001}_{Air\ purged\ sealing} - \underbrace{\dots}_{Blank}$$

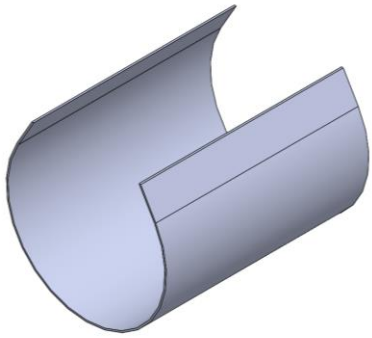
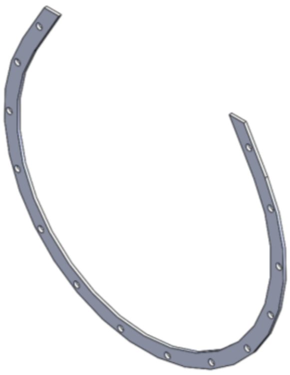
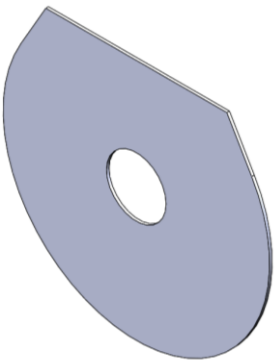
If there is only one numbered area, this means that it is an assembly.

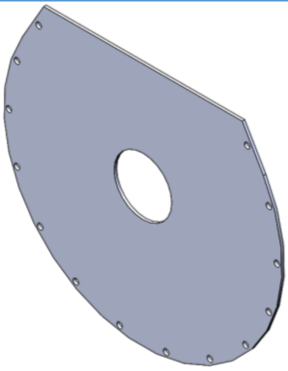
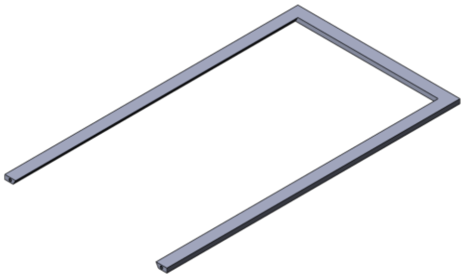
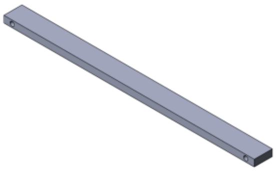
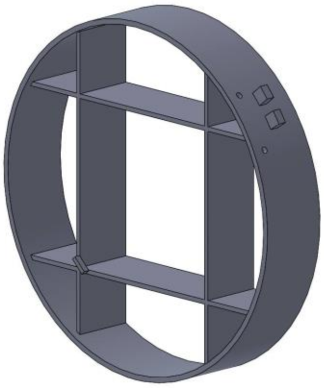
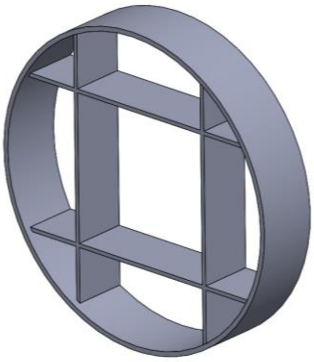
Standard parts are represented with their own name.

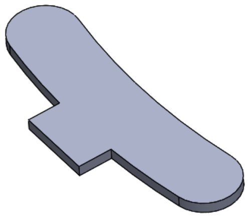
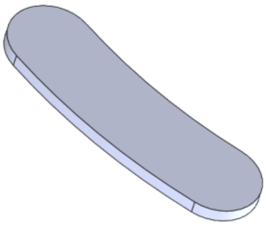
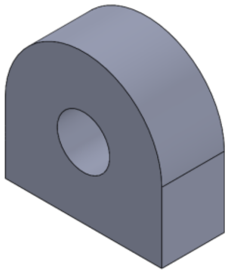
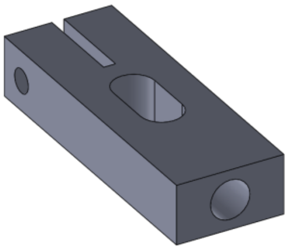
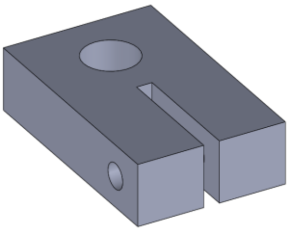
8.2 Production methods

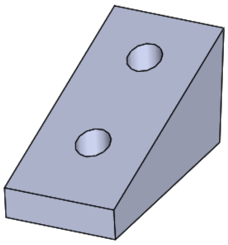
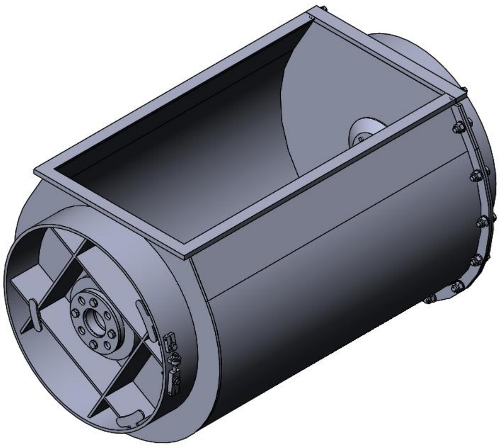
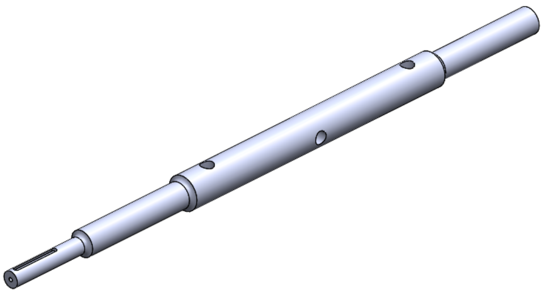
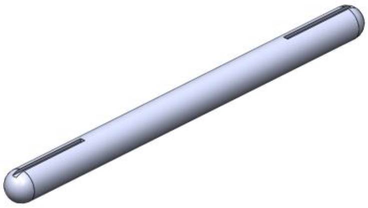
This chapter addresses the production methods in brief for each part that is created for this specific mixer/vacuum coater. The methods discussed will be the basis of the cost analysis. Manufacturing drawings can be seen in Appendix C.

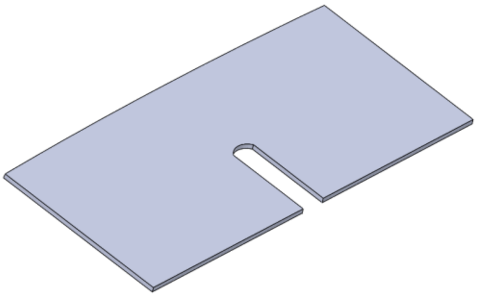
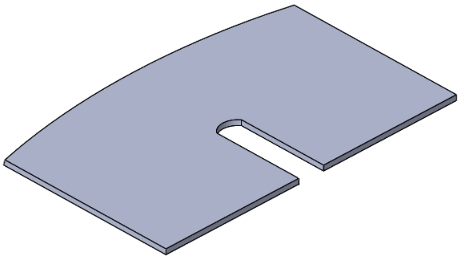
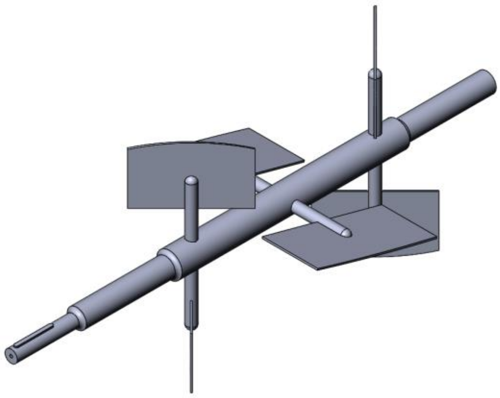
Table 8.1: Production methods.

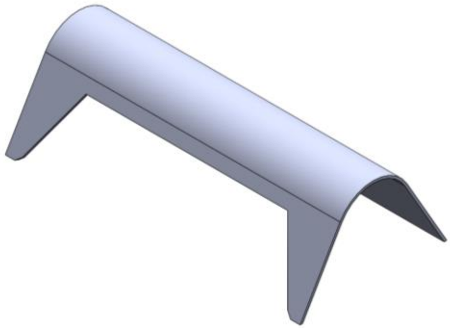
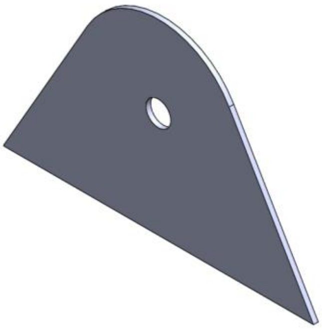
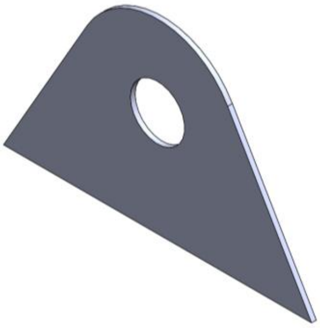
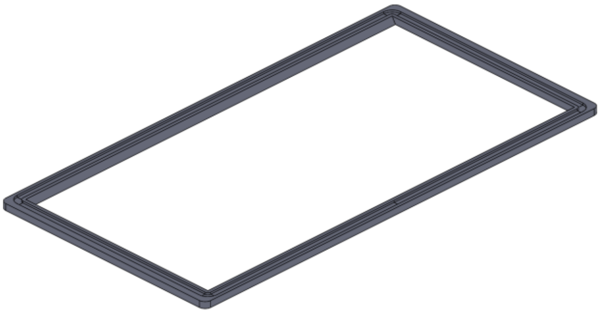
Name/Number	Figure	Production methods
Semi-cylindrical wall N-001-001		- Shear cutting - Roll bending
Semi-cylindrical flange N-001-002		- Plasma cutting - Drilling
End wall N-001-003		- Plasma cutting

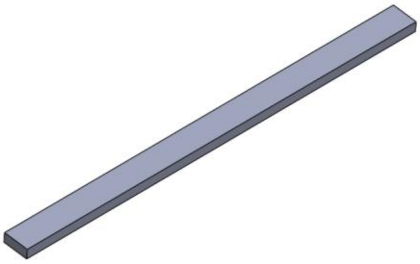
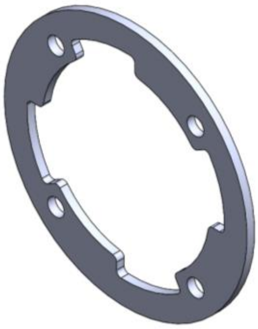
Name/Number	Figure	Production methods
End wall flanged **N-001-004**		- Plasma cutting - Drilling
Main flange **N-001-005**		- Plasma cutting - Drilling - Threading
End flange **N-001-006**		- Plasma cutting - Drilling
Turn wheel A **N-001-007**		- Shear cutting - Roll bending - Welding - Drilling
Turn wheel B **N-001-008**		- Shear cutting - Roll bending - Welding

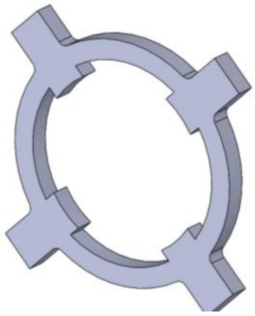
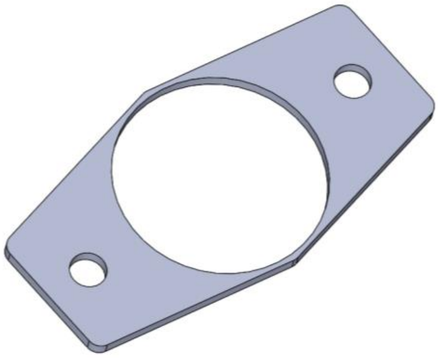
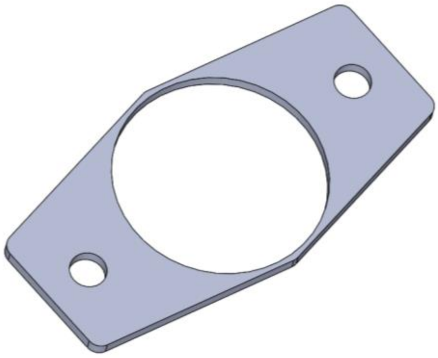
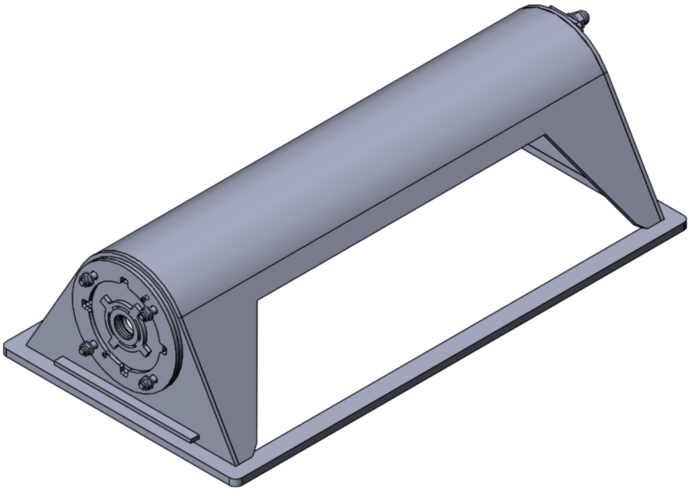
Name/Number	Figure	Production methods
Detection plate A N-001-009		- Plasma cutting
Detection plate B N-001-010		- Plasma cutting
Chain tightener B N-001-011		- Plasma cutting - Drilling
Chain tightener A N-001-012		- Plasma cutting - Drilling - Milling
Chain fastener N-001-013		- Plasma cutting - Drilling

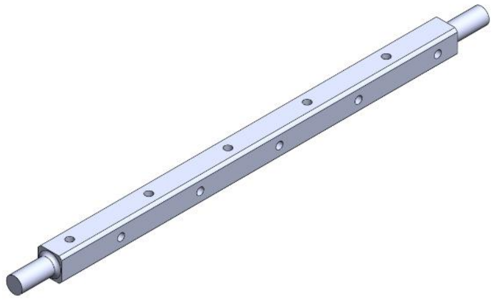
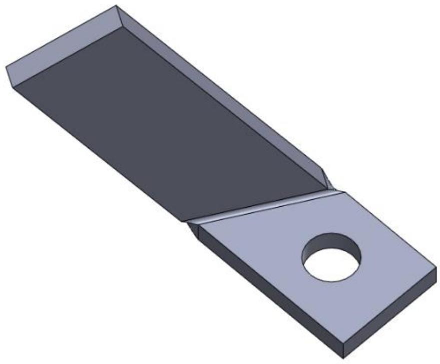
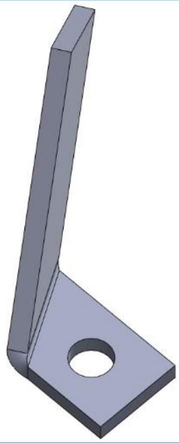
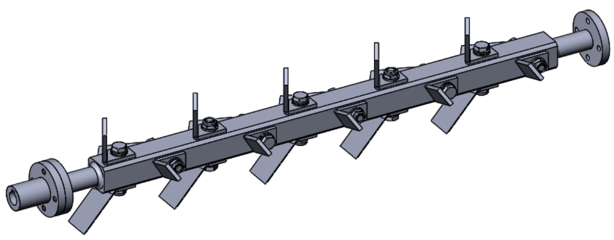
Name/Number	Figure	Production methods
Clamp mount **N-001-014**		- Plasma cutting -Drilling
Housing assembly **N-001**		- Welding - Bolting
Shaft **N-002-001**		- Lathe - Drilling - Milling
Middle rod **N-002-002**		- Lathe - Milling

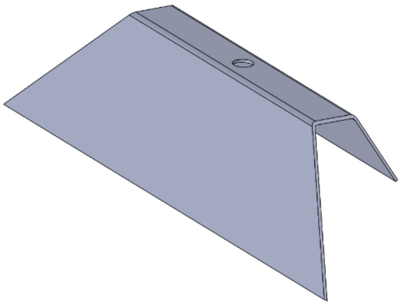
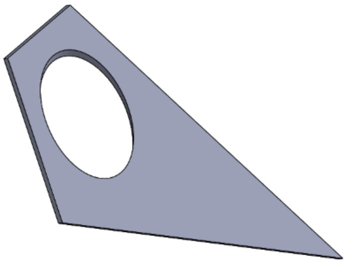
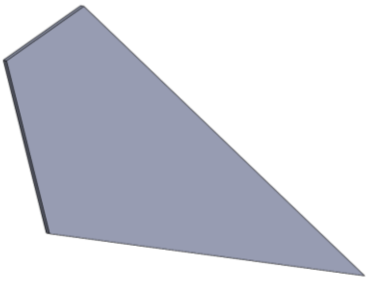
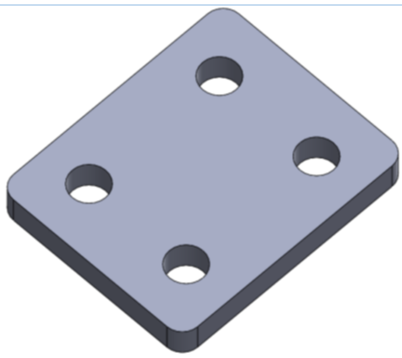
Name/Number	Figure	Production methods
Middle paddle **N-002-003**		- Shear cutting - Plasma cutting
End rod **N-002-004**		- Lathe - Milling
End paddle **N-002-005**		- Shear cutting - Plasma cutting
Mixer rotor **N-002**		- Welding - Grinding - Heat treatment

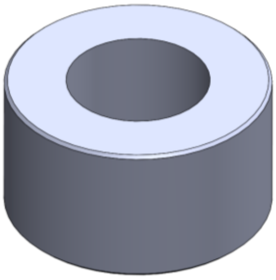
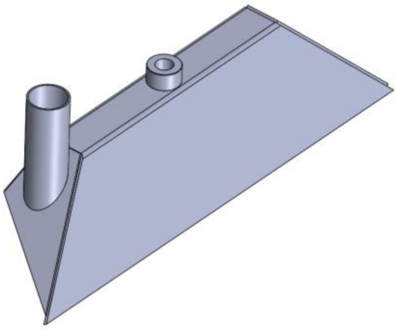
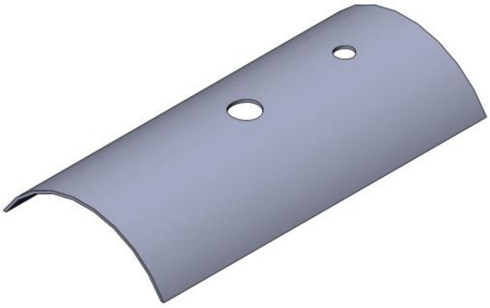
Name/Number	Figure	Production methods
Semi-cylindrical wall N-003-001		- Shear cutting - Plasma cutting - Roll bending
End wall A N-003-002		- Plasma cutting - Drilling
End wall B N-003-003		- Plasma cutting - Drilling
Grooved flange N-003-004		- Plasma cutting - Milling

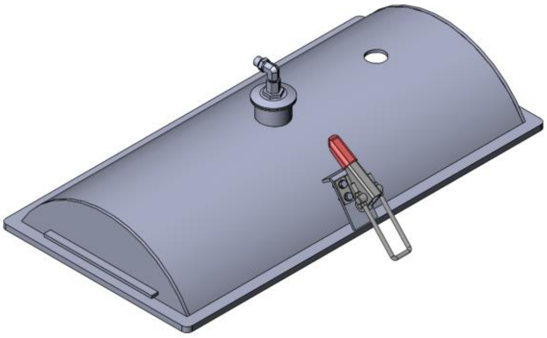
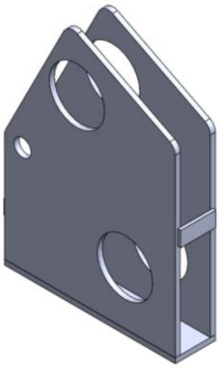
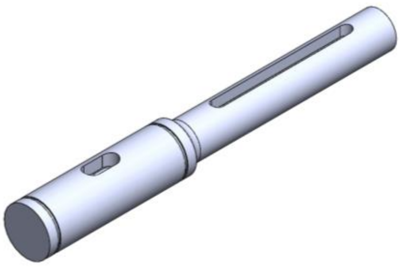
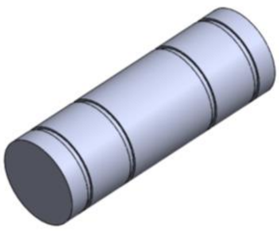
Name/Number	Figure	Production methods
Mounting rail **N-003-005**		- Shear cutting
Stud plate **N-003-006**		- Plasma cutting - Drilling
Buffer plate **N-003-007**		- Plasma cutting - Drilling - Threading
Locking plate **N-003-008**		- Plasma cutting
Sealing housing **N-003-009**		- Lathe

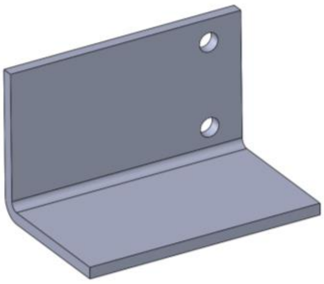
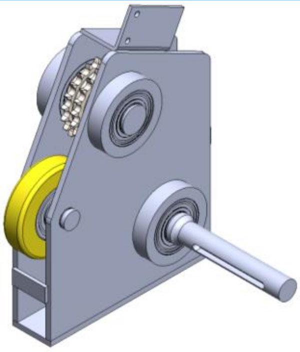
Name/Number	Figure	Production methods
Moment cross N-003-010		- Plasma cutting
Modified Forberg plate A N-003-011		- Plasma cutting - Drilling
Modified Forberg plate B N-003-012		- Plasma cutting - Drilling
De-agglomerator lid N-003		- Welding - Bolting - Gluing the sealing into the grooved flange

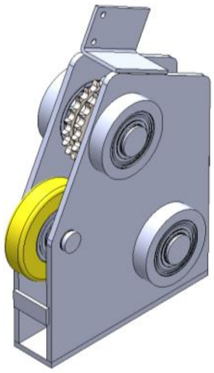
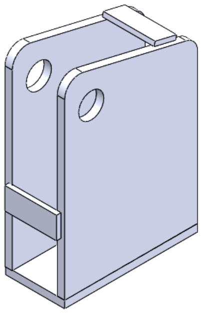
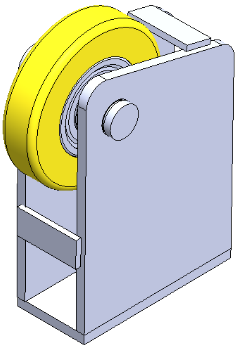
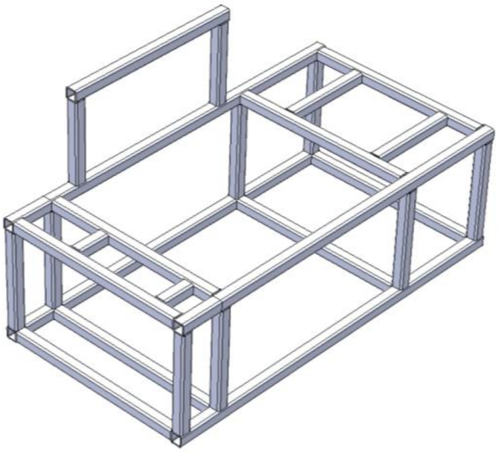
Name/Number	Figure	Production methods
Shaft **N-004-001**		- Milling - Lathe - Drilling
Bent flat steel A **N-004-002**		- Shear cutting - Bending - Drilling
Bent flat steel B **N-004-003**		- Shear cutting - Bending - Drilling
De-agglomerator **N-004**		- Bolting - Welding

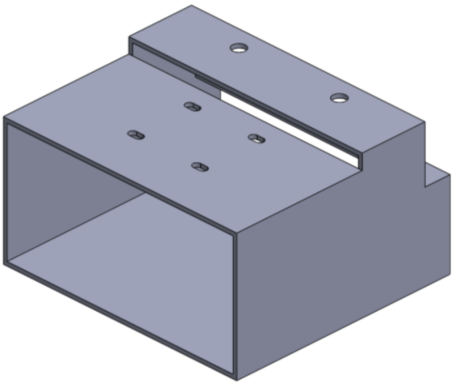
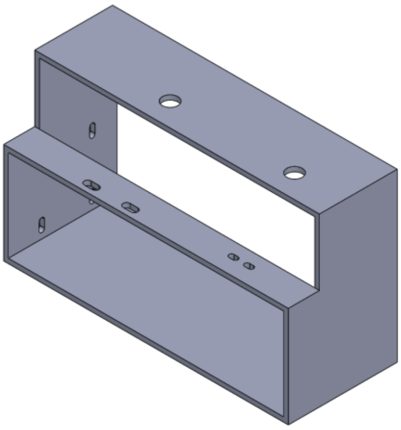
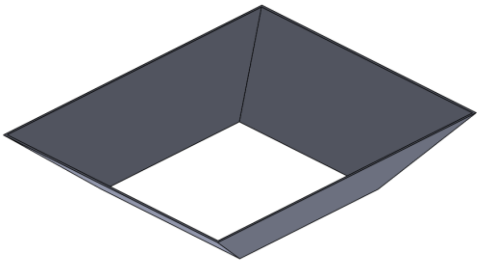
Name/Number	Figure	Production methods
Bent **N-005-001**		- Plasma cutting - Bending - Drilling
End wall A **N-005-002**		- Plasma cutting
End wall B **N-005-003**		- Plasma cutting
Filter holder **N-005-004**		- Plasma cutting
Stud plate **N-005-005**		- Plasma cutting - Drilling

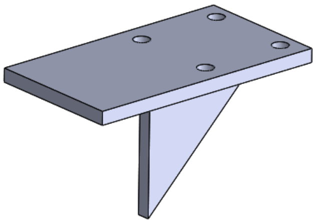
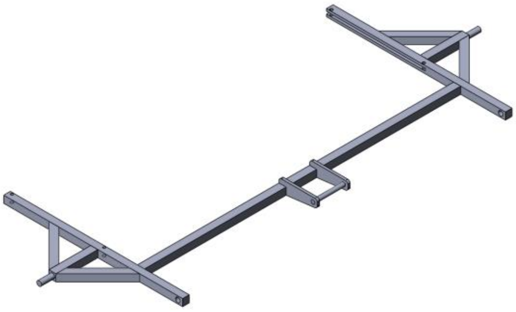
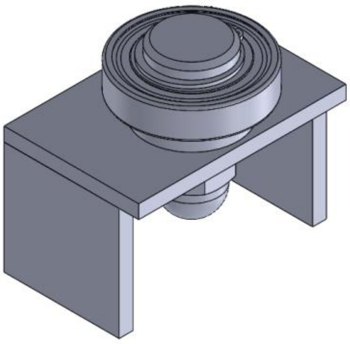
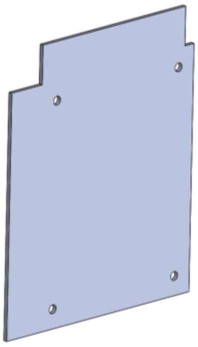
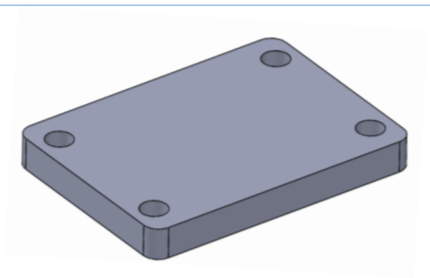
Name/Number	Figure	Production methods
Nozzle holder **F-003**		- Lathe
Nozzle housing **N-005**		- Welding
Semi-cylindrical wall **N-006-001**		- Shear cutting - Drilling
End wall **N-006-002**		- Plasma cutting
Vacuum stud plate **N-006-003**		- Shear cutting - Drilling - Bending

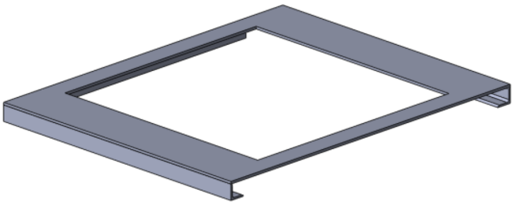
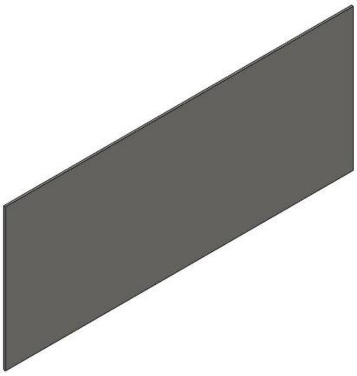
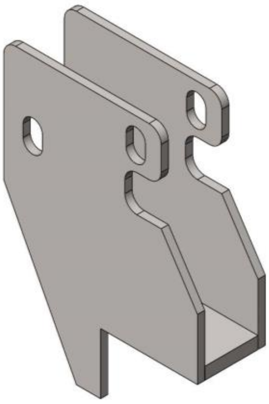
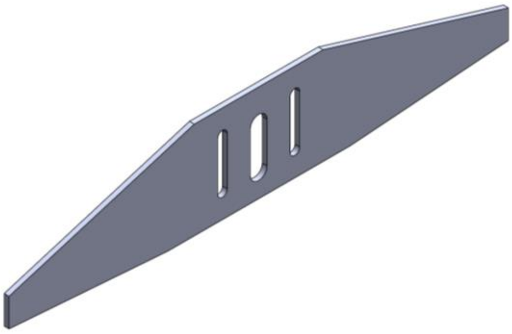
Name/Number	Figure	Production methods
Vacuum lid **N-006**		- Welding - Bolting - Gluing the sealing into the grooved flange
Wheel support frame A **N-008-001** **N-008-002** **N-008-003**		- Plasma cutting - Drilling - Welding
Axle **N-008-006**		- Lathe - Milling
Sprocket rod **N-008-007**		- Lathe - Milling
Wheel rod **N-008-009**		- Lathe

Name/Number	Figure	Production methods
Wheel **N-008-008**		- Lathe
Ball bearing house **N-008-006**		- Lathe
Actuator plate **N-008-007/N-009-001**		- Shear cutting - Bending - Drilling
Wheel support driver **N-008**		- Welding - Insert ball bearings, sprockets and circlips.

Name/Number	Figure	Production methods
Wheel support driven N-009		- Welding - Insert ball bearings, sprockets and circlips.
Wheel support frame B N-010-001 N-010-002		- Plasma cutting - Drilling - Welding
Wheel support N-010		- Insert ball bearing and circlips
Main frame N-007-001		- Plasma cutting - Welding

Name/Number	Figure	Production methods
Box A **N-007-002**		- Shear cutting - Drilling - Welding
Box B **N-007-003**		- Shear cutting - Drilling - Welding
Funnel **N-007-004**		- Shear cutting - Welding
Sensor plate **N-007-005**		- Plasma cutting - Bending - Drilling

Name/Number	Figure	Production methods
Pivot mounting plate **N-011**		- Shear cutting - Drilling - Welding
Pivot arm **N-012**		- Plasma cutting - Drilling - Milling - Welding
Axial displacement restrictor **N-013**		- Shear cutting - Drilling - Welding
Cabinet plate **N-007-006**		- Shear cutting - Drilling
Mounting plate for frame wheels **N-007-007**		- Shear cutting - Drilling - Grinding

Name/Number	Figure	Production methods
Funnel flange **N-007-008**		- Shear cutting - Plasma cutting - Welding
Side wall **N-007-009**		- Shear cutting
Lid lock mount **N-007-010**		- Plasma cutting - Welding
Bin mount (modified) **F-005-001**		- Plasma cutting

8.3 Cost analysis

Through conversation with the workshop at NMBU, it was concluded that the cost analysis would be a rough estimate of the actual cost of the machine produced in Norway. However, the machine is to be made in Latvia. The assembly and production of components of a new machine are usually not without errors, as it can occur small faults in the design, which means that modifications has to be done.

For AISI 304 the price per kilogram is about 100 NOK/kg (54), S355 is about 15 NOK/kg (55) and 450 NOK for the hourly wage of the workers producing the parts is used. The prices differ with quantity and different profiles (e.g. bar, sheet metal etc.).

Table 8.2: Overview over components and cost.

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
Main Housing		1		8	3600
	Semi-cylindrical wall N-001-001	1	33,5	1	3800
	Semi-cylindrical flange N-001-002	1	1	2	1000
	End wall N-001-003	1	7,5	0,5	975
	End wall flanged N-001-004	1	8,4	2	1740
	Main flange N-001-005	1	3,0	0,5	525
	End flange N-001-006	1	0,8	0,5	305
	Air purged sealing F001 5008525-550	2	7,5	3	4200
	Turn wheel A N-001-007	1	8,5	3	2200

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	Turn wheel B N-001-008	1	8,5	3	2200
	Detection plate A N-001-009	2	0,04	0,5	458
	Detection plate B N-001-010	1	0,05	0,5	230
	Chain tightener B N-001-011	1	0,02	0,3	137
	Chain tightener A N-001-012	1	0,06	1	456
	Chain fastener N-001-013	1	0,03	1	453
	Clamp mount N-001-014	1	0,03	1	453
Mixer rotor		1		4	1800
	Shaft N-002-001	1	23,9	2	3290
	Middle rod N-002-002	1	1,3	2	1030
	Middle paddle N-002-003	2	1,4	1,5	1630
	End rod N-002-004	2	1,3	2	2060
	End paddle N-002-005	4	1,0	1,5	3100
De-agglomerator lid				6	2700
	Semi-cylindrical wall N-003-001	1	10,5	1	1500
	End wall motor	1	1,6	0,5	385

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	N-003-002				
	End wall pneumatic N-003-003	1	1,5	0,5	375
	Grooved flange N-003-004	2	3,3	3	3360
	Mounting rail N-003-005	4	0,1	0,1	220
	Stud plate N-003-006	1	0,3	1	480
	Buffer plate N-003-007	1	0,4	1	490
	Locking plate N-003-008	1	0,3	0,5	255
	Sealing housing N-003-009	1	0,02	1	452
	Moment cross N-003-010	1	0,06	1	456
	Modified Forberg plate A N-003-011	1	0,2	0,5	245
	Modified Forberg plate B N-003-012	1	0,2	0,5	245
	Pneumatic drive with ball bearing housing and flanges F-002	1	800	2	1700
De-agglomerator				5	2250
	Shaft	1	3,6	4	2160

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	N-004-001				
	Bent flat steel A N-004-002	10	0,05	0,5	2300
	Bent flat steel B N-004-003	10	0,05	0,5	2300
Nozzle housing				3	1350
	Bent wall N-005-001	1	2,5	1,5	925
	End wall A N-005-002	1	0,2	0,2	110
	End wall B N-005-003	1	0,2	0,2	110
	Filter holder N-005-004	1	0,3	0,2	120
	Stud plate N-005-005	1	0,03	0,2	93
	Nozzle holder F-003	1	0,2	0,5	245
Vacuum lid				3	1350
	Semi-cylindrical wall N-006-001	1	10,0	0,5	1225
	End wall N-006-002	2	0,9	0,2	270
	Nozzle F-004	1			1000
	Vacuum stud plate N-006-003	1	0,3	0,5	255
Frame				16	7200
	Main frame (56) N-007-001	1	64	4	3000

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	Box A N-007-002	1	17,9	2	1169
	Box B N-007-003	1	7,3	1,5	785
	Bin assembly F-005	1	18,0	3	3150
	Funnel N-007-004	1	14,4	2	2340
	Wheel support driver N-008	1	3,4	6	2751
	Wheel support driven N-009	1	3,4	6	2751
	Wheel support N-010	2	1,5	2	1845
	Sensor plate N-007-005	1	0,7	1	461
	Safety switch plate N-007-006	2	0,1	0,3	290
	Pivot mounting plate N-011	2	0,5	0,2	98
	Pivot arm N-012	1	2,5	4	1838
	Axial displacement restrictor N-013	2	0,5	1	1000
	Cabinet mounting plate N-007-006	1	2,2	0,5	258
	Wheel mounting plate N-007-007	6	0,46	0,3	851
	Funnel flange	1	3,3	1,5	1005

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	N-007-008				
	Side wall N-007-009	1	7,3	0,2	820
	Lid lock mount N-007-010	1	0,27	1,5	679
	Standard parts				
	Ball bearing mixer shaft (57) SKF SYJ 50 TF1	2			2452
	Ball bearing wheel support (58) SKF 62303-2RS1	4			1060
	Ball bearing sprocket (58) SKF W 6005-2RS1	6			600
	Ball bearing axial displacement restrictor (58) SKF 6006-2RS1	2			182
	Sprocket (59) DIN 8192 C 21Z06B-2	4			1788
	Chain (59) 2 meter DIN 8781 06B-2	1			715
	Circlip (60) DIN 471 17 x 1	16			128
	Circlip (60) DIN 472 47 x 1.75	8			376
	Circlip (60) DIN 471 25 x 1.2	8			136

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	Hex screws and nuts (61)	88			766
	Washers (62)	160			224
	Cabinet (63) GN252015	1			328
	Pneumatic driver (64) FESTO DSNU-25-150-PPV-A	2			680
	Mounting for pneumatic driver (64) FESTO LBN-20_25	2			80
	Rod eye (64) FESTO SGS-M10X125	2			240
	Pivot point (64) FESTO SNC-32	2			180
	Magnetic sensor (65) SICK_IM18-10BPS-NC1	3			2400
	Electro mechanical safety switch (65) Sick i10RA213	2			500
	Electronic rotary latch (66) R4-EM-R13-131				728
	Frame wheel (67) LKPXA-TPA_126G	6			2628
	Vacuum pump (44) V-VC 50	1			17500
	Mixer motor (68)	1			21509

Assembly	Part Part No.	Qty.	Amount of material [kg]	Production time [hours]	Sum [NOK]
	MR CI 64 24x200 90LB 4-poles B8 mounting				
	Chain motor (68) MR CI 40 11x140 63A 6-poles B6 mounting	1			8344
	De-agglomerator motor HMA2 71 1-4 4-poles	1			922
Mixer/vacuum coater					**161 325**

Commentary to table 8.2:

Some of the ball bearing prices were not available for some of the ball bearings. The cost of these components were approximated by looking at bearings of the same dimensions.

A compressor is needed for the mixer/vacuum coater to be able to move the lid as well as being able to fasten the de-agglomerator. The cost of this compressor is excluded from the cost analysis. It is presumed that a compressor would already be in available as it is commonplace to have pumps like these at production sites.

9. Presentation

This chapter introduces rendered images of the mixer/vacuum coater as well as technical descriptions.

9.1 Rendered images

Figure 9.1: Mixer/vacuum coater with the de-agglomerator lid.

Figure 9.2: Mixer/vacuum coater with the de-agglomerator lid. Section-cut housing.

Figure 9.3: Mixer configuration and vacuum coater configuration.

Figure 9.4: Mixer configuration in a production environment. Human (James) model provided by Sergio Skaletti (69)

9.2 Technical descriptions

9.2.1Positioning of the housing

The positioning of the housing will be automated with sensors to achieve the desired position for the mixer/vacuum coater when execute different tasks.

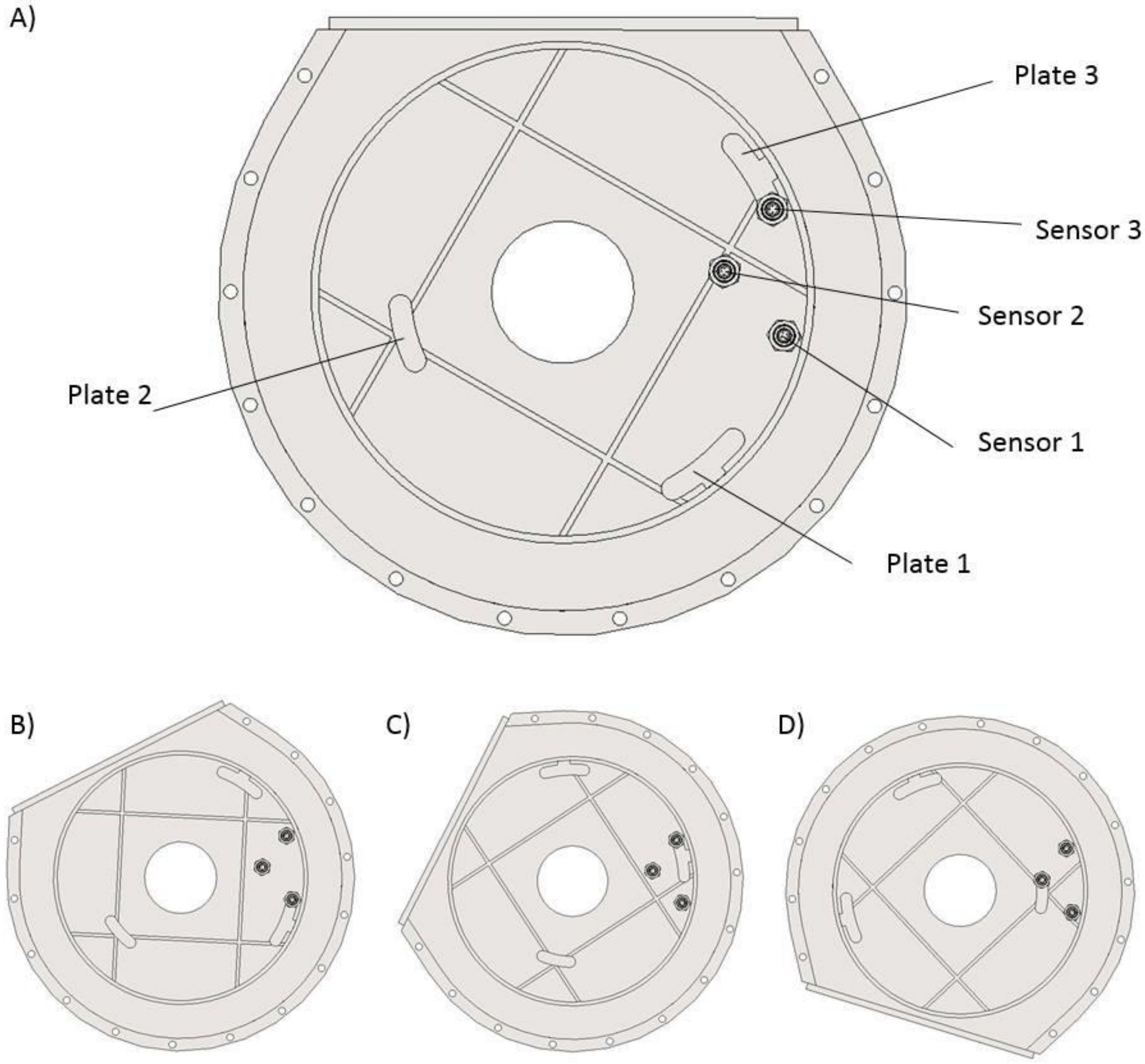


Figure 9.5: Overview over the mixer/vacuum positioning by sensors and plates. A) Filling/cleaning position, B) Mixing position, C) First emptying position, D) Second emptying position

Table 9.1: Overview over the mixer/vacuum positioning by sensors and plates.

Position	Sensor	Plate
Filling/cleaning	3	3
Mixing	1	1
First emptying position	3	1
Second emptying position	2	2

9.2.3 Pneumatic schematic

For lifting the two lids for the mixer/vacuum coater, pneumatic piston rods are used. Using the program Scheme editor 6 (27) and studying other pneumatic schematics (70) the following schematic will work as a suggestion.

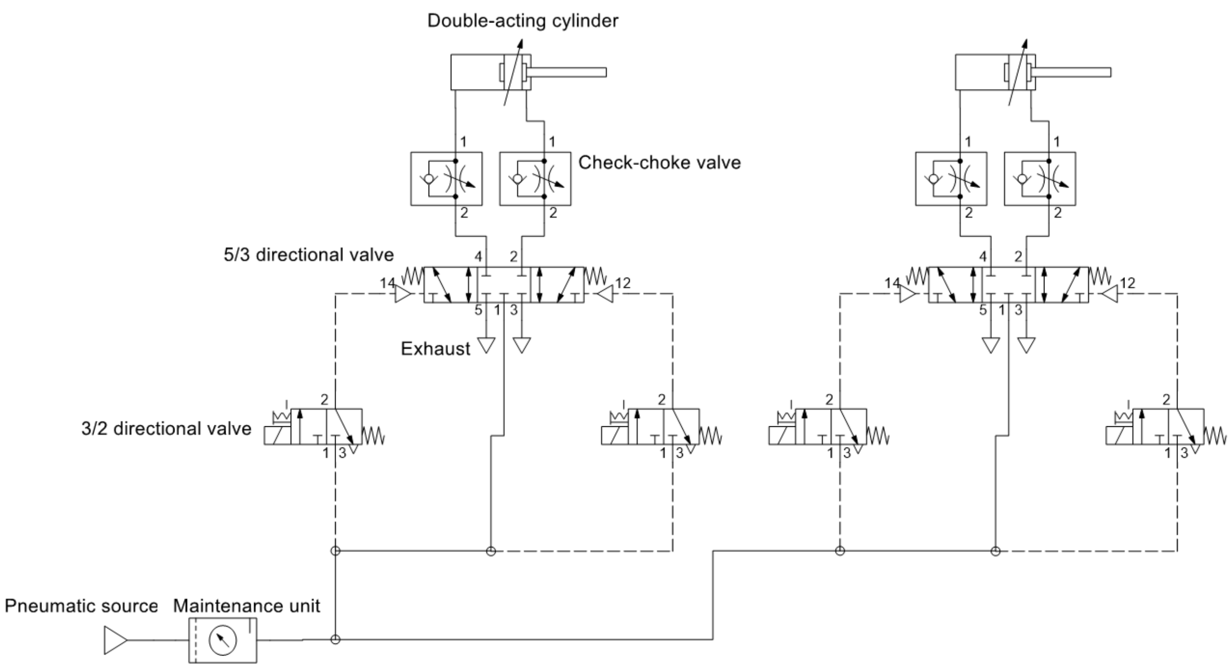


Figure 9.6: Pneumatic scheme for lid movement.

Components:

1. Pneumatic source
2. Maintenance unit. Pressure regulator, manometer, lubricator and filter.
3. 3/2 directional valve. Single solenoid with spring return.
4. 5/3 directional valve. Pneumatically operated, closed mid position with spring return.
5. Check-choke valve. Strainer on the return air from the double-acting cylinder.
6. Double-acting cylinder. Adjustable cushioning.

As seen in Figure 9.6, there are two identical arrangements for the piston rods. The 3/2 valves are used for controlling the pneumatically operated 5/3 valve, this is indicated by dashed lines. The strainers are used for controlling the speed, in both directions, for the double –acting cylinder.

10. Discussion

At the start of the thesis, the working principle of the machine were assessed as well as some competitive mixers. A meeting with Fôrtek was held to discuss different shapes for the mixer rotor and housing in addition to being able to look at the mixers they use. Some design remarks were made regarding the combination of a mixer and a vacuum coater, which set the boundaries for what solutions the mixer/vacuum had to exclude/include.

The concept generation process was started by studying the working principle, competitors and the 1-litre prototype from last year made by Didrik Heidal Dolva and Eirik Madland Størdal. Initially, an up-scaled version of the prototype were modelled, but the main dimensions of the mixer were changed due to unwanted stresses and deformations. A meeting with Forberg were held to introduce the main parts of the mixer/vacuum coater and to acquire comments on the design at an early stage. 3D models of three of Forberg's machines were obtained to study how they function and how to optimize the mixer/vacuum coater for a convenient production by using some of their solution as well as their suppliers of standard parts. Parts that contribute to the aesthetics of the machine was not modelled due to the limited timeframe of the thesis.

The mixer/vacuum coater would benefit from being two dedicated machines (chapter 11.1.1.) instead of a combination of the two. In a production process, one is interested in batches per hour and quality of mixed product the machine can offer. For a combination of mixing and vacuum coating, one is reducing the batches per hour by a significant amount due to the lid changing and cleaning in between mixing and vacuum coating. The machine developed in this thesis is foremost a test machine to assure that the working principle have potential in the feed industry.

The structural analysis chapter consist of calculated stresses, deformation, start torque and power for the components seen as crucial. An approach to approximate the force acting on the mixer rotor was to sweep the area the paddles make in half a rotation and considering the swept volume as the mass the paddles have to move. This assessment was used throughout the calculations. For start torque of the motors, estimations for the moments of inertias were calculated and later verified in Solidworks. Some quick calculations were also done alongside the 3D modelling process to assure that the stresses were below the set yield strength limit.

In chapter 8, the production methods and costs for the different parts were evaluated. The production time for the components were roughly estimated while the cost of some standard parts were set as equal to components of a similar form. For every newly created part, AISI 304 or S355 were set as the material of choice.

11. Conclusion

The main objective of this thesis was to develop and design a 60-litre mixer with vacuum coating capability. The mixer/vacuum coater design was to be based on last years' 1-litre prototype that was developed, constructed and tested by M.Sc Didrik Heidal Dolva and M.Sc Eirik Madland Størdal. The preservation of the working principle used in said mixer was of great importance for the current thesis as the tests conducted by the aforementioned students showed promising results.

For the mixer/vacuum coater to be able to perform both mixing and vacuum coating it was decided that it would be beneficial for the mixer to have two separate lids: one with a de-agglomerator for mixing, and one for vacuum coating. It was also decided that it would be favourable to empty the housing by rotation, as bottom hatches in vacuum coaters was strongly discouraged by Forberg. This configuration of the original design would make it possible to make a prototype that could be used for testing of the working principle for both vacuum coating and mixing.

All parts in contact with the powders and particles being mixed will be of AISI 304 stainless steel. The housing is to be made out of 5 mm sheet metal as this will make the mixer able to obtain vacuum conditions within the mixer without suffering from structural fatigue.

When the prototype of the mixer is manufactured, the subsequent testing will help determine the potential of the working principle and to what extent the original design is scalable.

If the mixer/vacuum coater is to be scaled to suit an even higher batch volume, the possibility of splitting the mixer in to one dedicated mixer and one dedicated vacuum coater is strongly recommended as this would make each of the designs less complicated and thus making them easier to produce and sell.

11.1 Further work

- Instructions for assembling the machine.
- Routing for pneumatics, vacuum, liquid addition, air purged sealing and electronics.
- Balancing and vibration control of the de-agglomerator.
- Experimentation with different angles for the de-agglomerator's bent flat steel.

11.1.1. Separate machines

When testing of the mixer/vacuum coaters performance is completed, one can consider the possibility of developing two separate machines. The basis of these two machines would be the main components presented in this thesis as well as the performance for the mixer/vacuum coater.

Mixer:

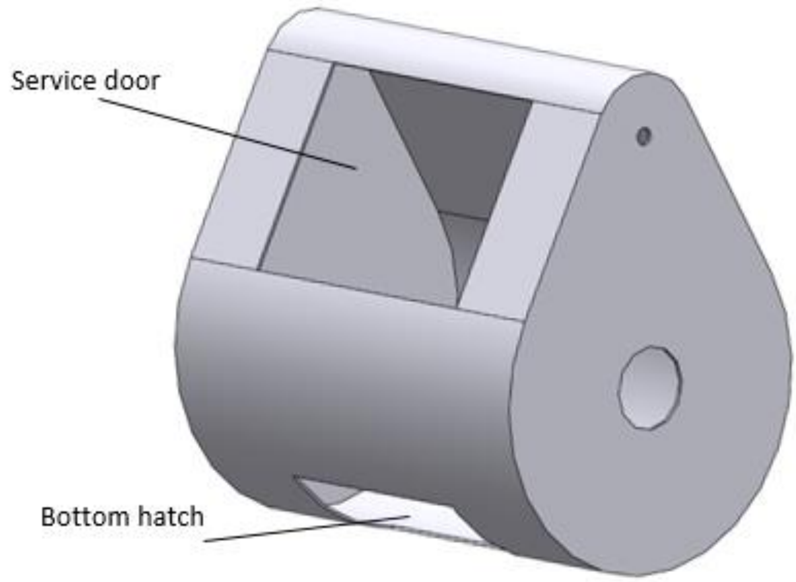


Figure 11.1: Mixer housing.

As seen in the figure above, the mixer would consist of one housing with a service door and a bottom hatch for discharge. Rotation of the whole housing would not be necessary, as this is only common for vacuum coater (bottom hatch results in crushed pellets). One of the end walls could be a flange coupling with the rest of the housing or one could consider a clamp coupling to enable the possibility of a retractable shaft. This solution offers a compact design, as well as easier operation than the mixer/vacuum coater.

The components that could be excluded as a result of making a dedicated mixer would be the following components:

- Chain drive associated components required to rotate the housing.
- Pneumatic piston rods for movement of the different lids.

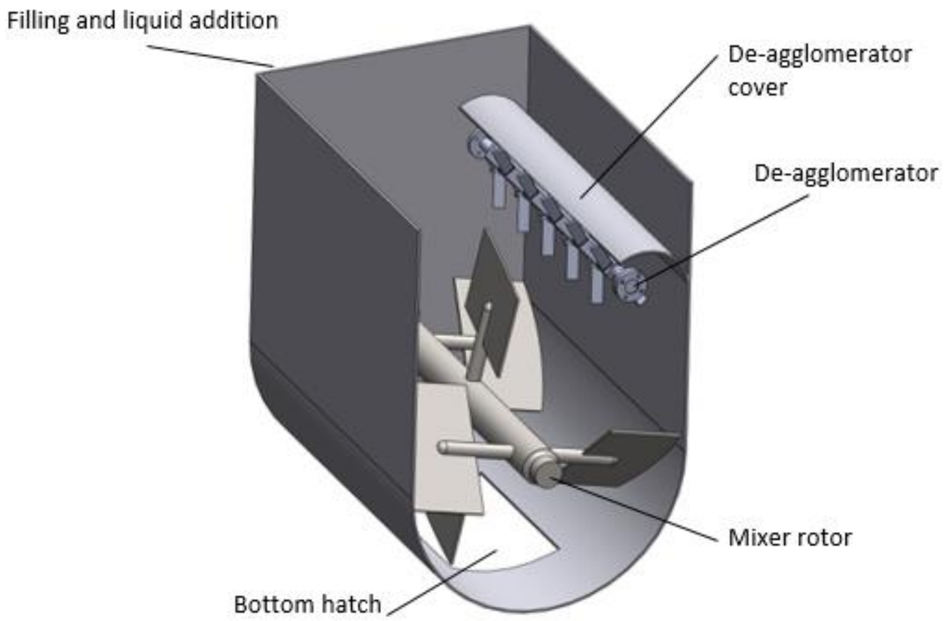


Figure 11.2: Smaller version of the mixer.

For smaller mixers one can consider a solution with a de-agglomerator cover, shown in the figure above. This enables the use of a large opening for filling, cleaning and liquid addition.

Vacuum coater:

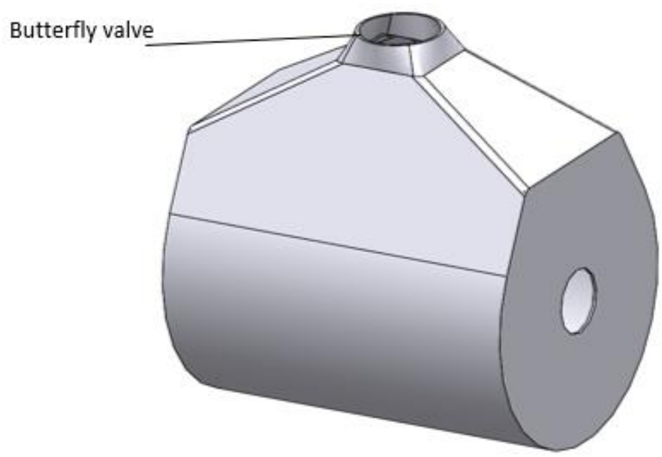


Figure 11.3: Vacuum housing.

The vacuum coater would consist of a funnel with a butterfly valve as this makes for a good vacuum seal. The housing would have to rotate to stop at different station for filling and emptying. The possibility of also adding a station for cleaning through the butterfly valve would be possible, as Forberg does on their rotating vacuum coater.

The components that could be excluded as a result of making a dedicated mixer would be the:

- De-agglomerator associated components.
- Pneumatic piston rods for movement of the different lids.

This dedicated vacuum coater could be cheaper than a twin shaft vacuum coater, by a significant amount. The twin shaft rotating vacuum coater now has two shaft which each has its own gear and they are synchronized with an axle between the two. For bigger vacuum coaters, the two shafts are powered by a gearmotor each. As we can see from the cost analysis the cost of the mixer/vacuum coaters gearmotor is 21000 NOK, but there is of course less power required for each motor for the two shafts compared to the single shaft. As we understand the gears are the most expensive component on the gearmotor. By only having single shaft, the production will be cheaper as well as the material and standard components. The housing can rotate about its shaft which in return requires less power than rotating two shaft, since it is centered. The housing is in a more compact fashion compared to the twin shaft housing.

Table 11.1: Difference in number of components between a twin shaft and single shaft vacuum coater.

Component	Single shaft	Twin shaft
Bottom hatch	1	2
Air purged sealing	2	4
Gearmotor (mixing and rotation)	2	3
Shaft	1	2

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Appendix A

www.duesen-schlick.de

Schlick
Atomizing technologies
Living for Solutions.

Düsen-Schlick GmbH
Hutstraße 4
96253 Untersiemau/Coburg
Germany

Zerstäubungsdüsen . *Atomizing Nozzles*

Firma . *Company*	Ansprechpartner . *Contact*	Telefon . *Phone*
Forberg International	Felix Lerengen	+47 48156620
Straße . *Street*	**Ort . Town / City**	**Fax . *Fax***
Kajaveien 15	Aas	
Postleitzahl . *Post Code*	**E-mail . *E-mail***	
1432	chle@nmbu.no	

1. Einsatzgebiet (Anwendung) . *Area of Application (applications)*

Was möchten Sie mit den Düsen erreichen? . *What is to be achieved with the nozzles?*

Adding a percentage of fluid to a mixing process for feed and food production.

Adding molasses is the worst case.

2. Sprühbild . *Spray pattern*

- ☐ Vollkegel . *Full-cone*
- ☐ Hohlkegel . *Hollow-cone*
- ☐ Flachstrahl . *Flat jet*
- ☐ Glattstrahl (Vollstrahl) . *Smooth-jet*

3. Stoffspezifische Kenngrößen der Flüssigkeit . *Type of fluid:*

Dichte . *Density*	1,4 g/ml
Viskosität . *Viscosity*	4 Pa s
Rheologie . *Rheology*	Pseudoplastic, tixotropic
Oberflächenspannung . *Surface tension*	
Temperatur . *Temperature*	max 70 degrees celsius

4. Flüssigkeitsmenge . *Fluid Quantity*

Maximal . *Maximum* 36 kg/min
Minimal . *Minimum* 6 kg/min

5. Flüssigkeitsdifferenzdruck / Treibmitteldruck . *Fluid pressure*

Δp Flüssigkeit bar . *Pressure drop available (Δp) in bar*

bei Zweistoffdüsen max. vorhandener Treibmitteldruck , z. B. Dampf/Luft, bar (ü) .

with two-substance nozzles also existing pressure, e. g. steam/gas, bar (g)

6. Streukegel / Streuwinkel . *Angular size of dispersion cone*

- ☐ 15°
- ☐ 30°
- ☐ 45°
- ☑ 60°
- ☑ 78°
- ☑ 90°
- ☑ 120°
- ☐ °

oder Düsenabstand zur Fläche und Sprühkreis Ø

or distance of nozzle from surface and spray diameter or spray width

7. Zerstäubungsfeinheit . *Fineness of atomisation*

gewünschte Tropfengröße in Mikrometer (z. B. Sauter Ø, volumetrisch mittlerer Ø) . *Size of drops*

0,5 mm to 1,5 mm. 0,5 mm is preferable. Adding molasses to flour is the worst case

8. Umgebungseinflüsse / Verunreinigungen . *Environmental of influences / Impurities present the fluid*

At low temperature molasses can form sugar crystals

9. Materialvorauswahl . *Material*

- ☑ Edelstahl (säurefest) . *Stainless steel (acid-resistant)*
- ☑ Edelstahl (hitzebeständig) . *Stainless steel (heat-resistant)*
- ☐ Hartmetall . *Hard metal*
- ☐ Hastelloy . *Hastelloy*
- ☐ Inconel . *Inconel*
- ☐ Keramik . *Ceramic*
- ☐ Messing . *Brass*
- ☐ PP . *PP*
- ☐ PTFE . *PTFE*
- ☐ PVC . *PVC*
- ☐ PVDF . *PVDF*
- ☐ RCH1000 . *RCH1000*
- ☐ SiSiC . *SiSiC*
- ☐ Sonstige . *Others*

70 degree celsius is the maximum temperature

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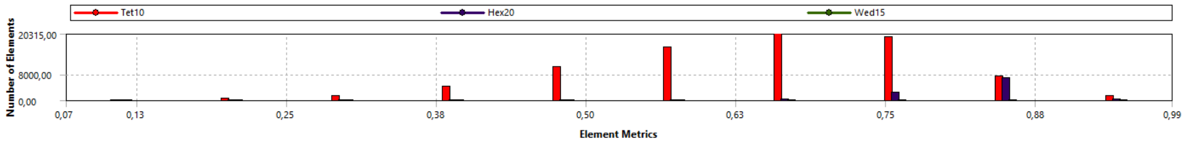
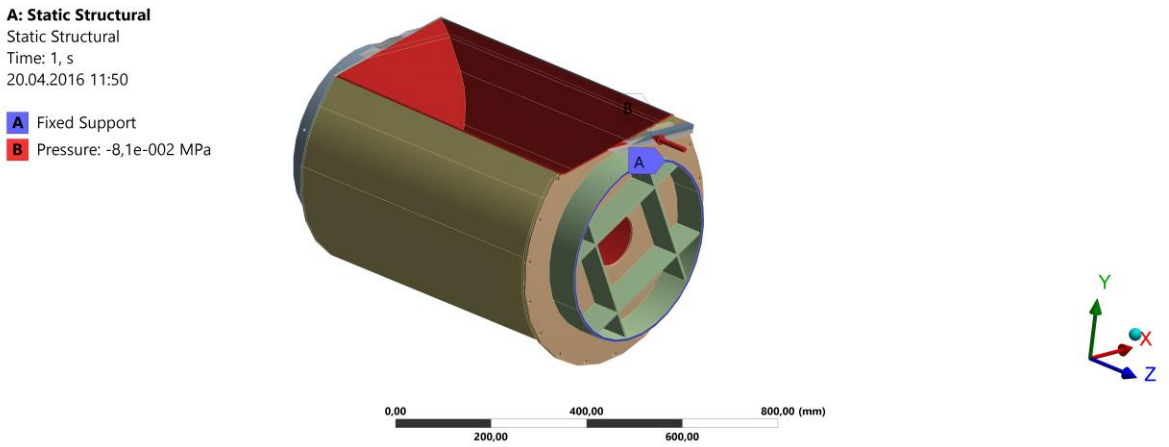
Appendix B

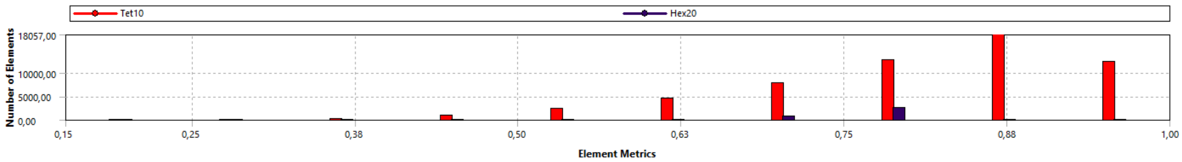
Ansys mesh quality and support/forces applied.

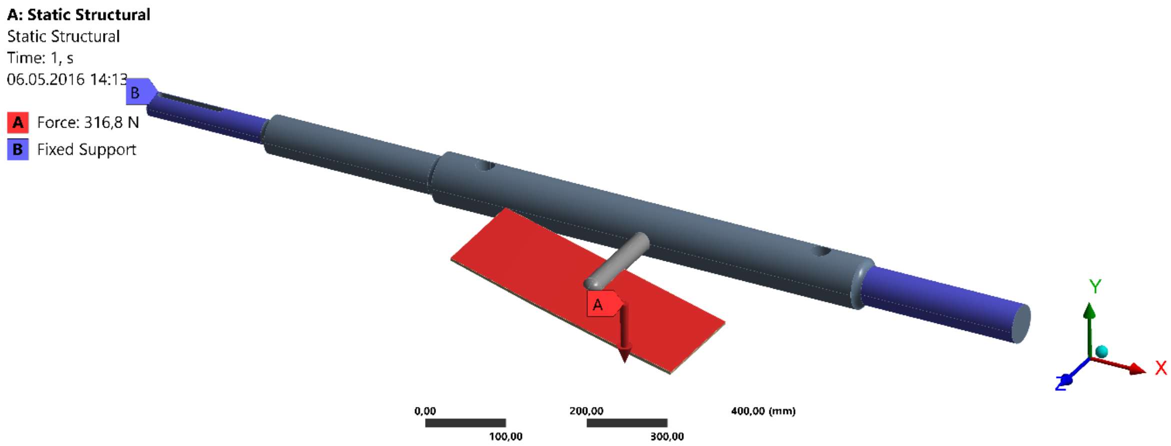
Vacuum:



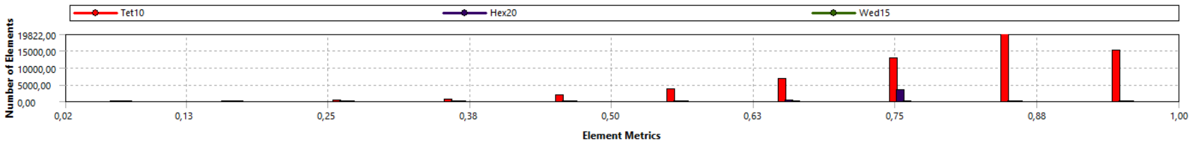


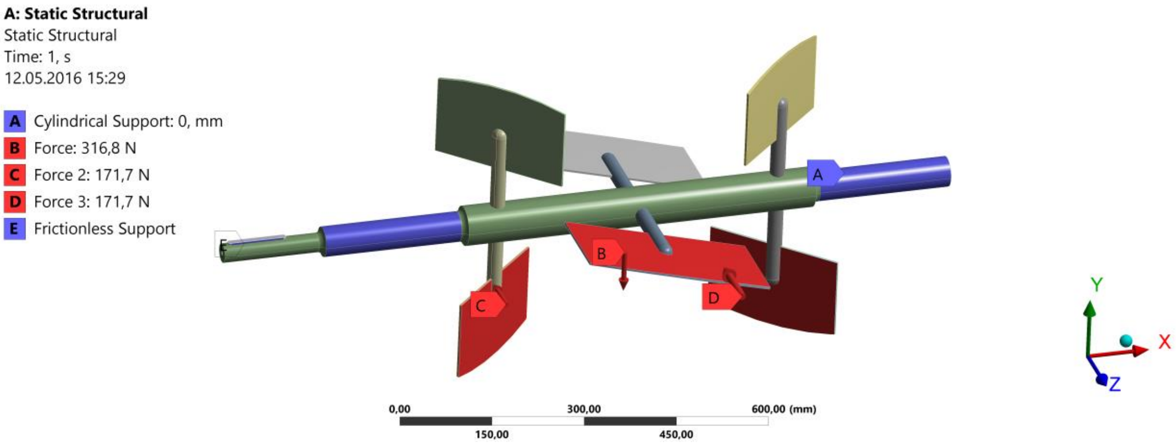
Paddle:



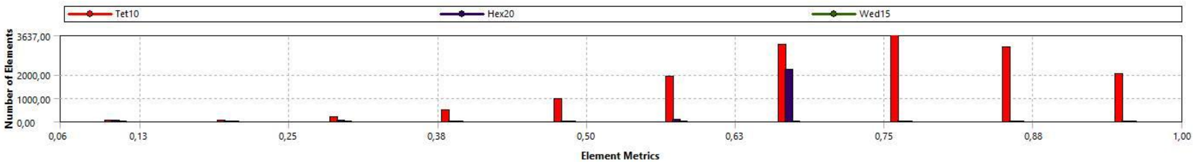


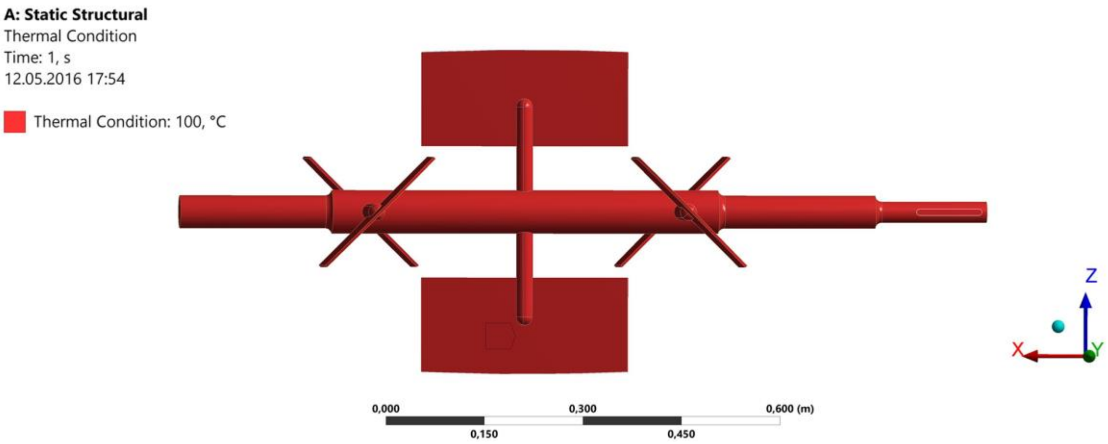
Shaft:





Thermal expansion:





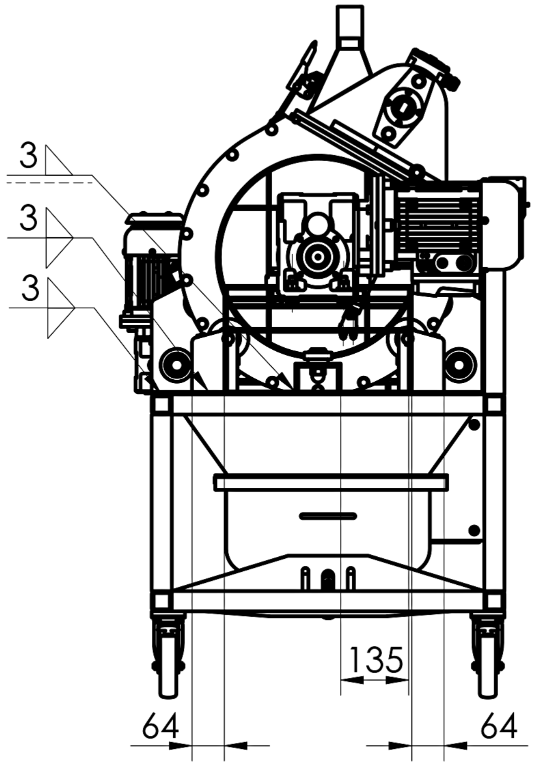
Appendix C

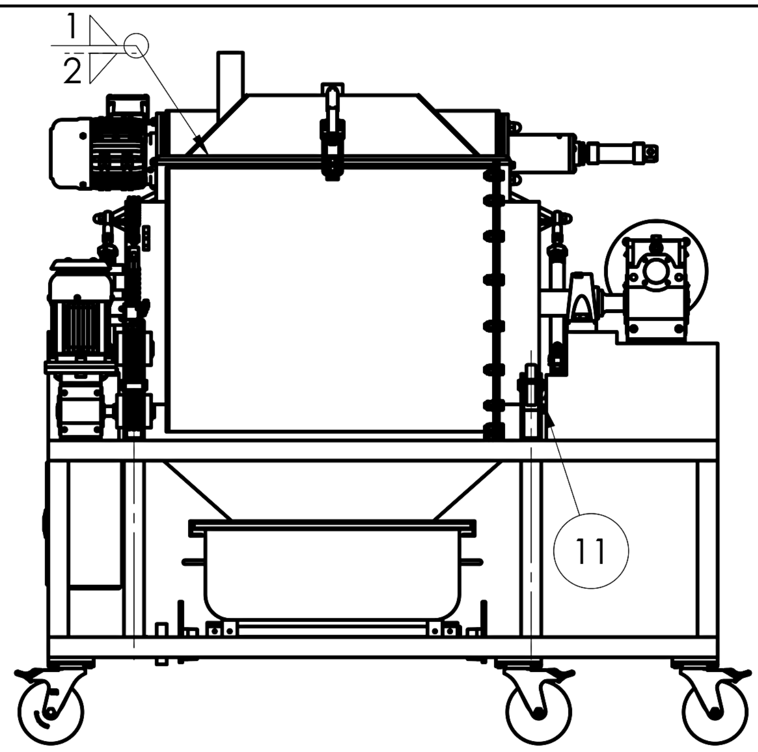
The manufacturing drawings was made in A3 format.The printed version of this thesis will however have the majority of the drawing on A4 paper. The scale-field on the drawings that are printed on A4 paper are to be disregarded as these were made for A3 paper.

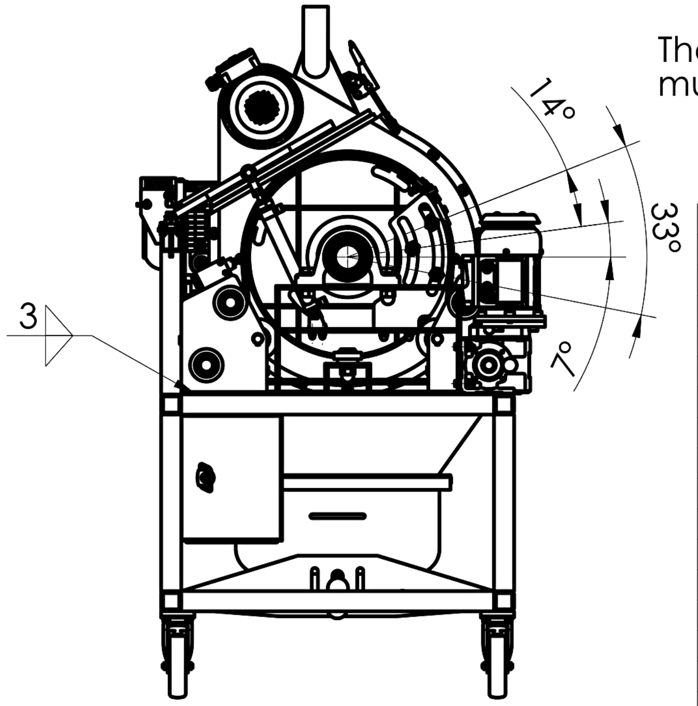
Order	Order of which the manufacturing drawings are presented.		
1.**Exploded complete** assembly RMVC	15.Chain fastener N-001-013	29.Stud plate N-003-006	43.End wall A N-005-002
2.Main Housing N-001	16.Clamp mount N-001-014	30.Buffer plate N-003-007	44.End wall B N-005-003
3.Semi-cylindrical wall N-001-001	**17.Mixer Rotor N-002**	31.Locking plate N-003-008	45.Filter holder N-005-004
4.Semi-cylindrical flange N-001-002	18.Shaft N-002-001	32.Sealing housing N-003-009	46.Stud plate N-005-005
5.End wall N-001-003	19.Middle rod N-002-002	33.Moment cross N-003-010	**47.Vacuum lid N-006**
6.Flanged wall N-001-004	20.Middle paddle N-002-003	34.Modified Forberg plate A N-003-011	48.Vacuum top wall N-006-001
7.Main flange N-001-005	21.End rod N-002-004	35.Modified Forberg plate B N-003-012	59.Vacuum end wall N-006-002
8.End flange N-001-006	22.End paddle N-002-005	**36.De-agglomerator N-004**	50.Vacuum stud plate N-006-003
9.Turn wheel A N-001-007	**23.De-agglomerator lid N-003**	37.Shaft N-004-001	**51.Frame N-007**
10.Turn wheel B N-001-008	24.Semi cylindrical wall N-003-001	38.Bent flat steel A N-004-002	52.Main frame N-007-001
11.Detection plate A N-001-009	25.End wall A N-003-002	39.Bent flat steel B N-004-003	53.Box A N-007-002
12.Detection plate B N-001-010	26.End wall B N-003-003	40. Motor coupling N-004-004	54.Box B N-007-003
13.Chain tightener B N-001-011	27.Grooved flange N-003-004	**41.Nozzle housing N-005**	55.Funnel N-007-004
14.Chain tightener A N-001-012	28.Mounting rail N-003-005	42.Bent wall N-005-001	56.Sensor plate N-007-005

Continuation of the table above:

Order			
57.Cabinet mounting plate N-007-006	65.Flat steel stiffener N-008-002	**73.Wheel support driven** **N-009**	81.Rod eye N-012-002
58.Wheel mounting plate N-007-007	66.Flat steel base N-008-003	74.Actuator plate N-009-001	82.Arm stiffener N-012-004
59.Funnel flange N-007-008	67.Bearing housing N-008-004	**75.Wheel support** **N-010**	83.Pin holder N-012-006
60.Side wall N-007-009	68.Actuator plate N-008-005	76.Wheel support plate N-010-001	**84.Axial displacement restrictor** **N-013**
61.Lid lock mount N-007-010	69.Sprocket driver shaft N-008-006	77.Flat steel base N-010-002	85.Flat steel vertical N-013-001
62.Bin mount (modified) F-005-001	70.Sprocket shaft N-008-007	**78.Pivot mounting plate** **N-011**	86.Flat steel horizontal N-013-002
63.Wheel support driver **N-008**	71.Wheel N-008-008	**79.Pivot arm** **N-012**	
64.Wheel support plate N-008-001	72.Wheel shaft N-008-009	80.Lifting arm N-012-001	

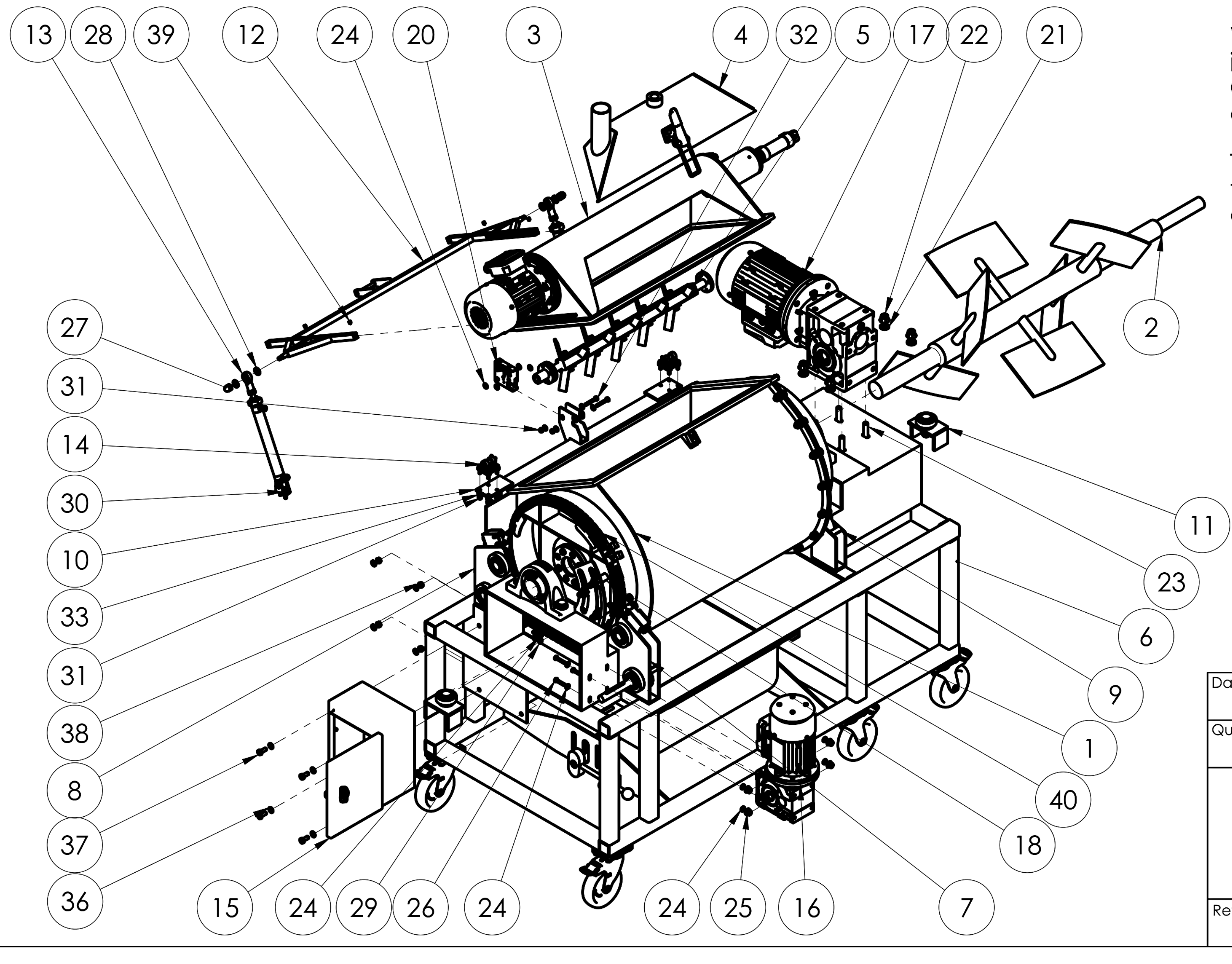






The angles of the proximity sensors must be calirbrated after assembly

Pos.	QTY.	Part Name
41		DIN 8781 06B-2
39	4	DIN 914 - M6 x 8-N
38	4	DIN EN ISO 10511 - M8 - N
37	4	ISO 4017 - M8 x 20-N
36	8	Washer DIN 125 - A 8.4
33	8	Washer DIN 125 - A 6.4
32	2	ISO 4017 - M6 x 40-N
31	10	DIN EN ISO 10511 - M6 - N
30	4	ISO 4017 - M6 x 20-N
29	4	DIN 1587 - M6 --NNU
28	4	Washer DIN 125 - A 10.5
27	2	DIN 1587 - M10 --NNU
26	4	ISO 4017 - M6 x 35-N
25	4	DIN EN 1663 - M8 - N
24	24	Washer DIN 125 - A 7.4
23	4	ISO 4017 - M12 x 50-N
22	4	DIN EN 1663 - M12 - N
21	8	Washer DIN 125 - A 13
20	1	Southco - R4-EM-R13-131
18	3	SICK - IM18-10BPS-NC1-Order_no_6027577_2_03
17	1	ROSSI - MRCI64UO3A24x20010.4B8HB-Standard motor90TB0LC4ErPIE3B5
16	1	ROSSI - MRCI40UO3A11x14013.7B3HB-Standard motor63TB0C4-B5PP
15	1	CONJUNTOS - GN252015
14	2	FESTO - 174383_SNC-32
13	2	FESTO - 193991_DSNU-25-250-P
12	1	N-012 - Pivot Arm
11	2	N-013 - Axial Displacement Restrictor
10	2	N-011 - Pivot Mounting Plate
9	2	N-010 - Wheel Support
8	1	N-009 - Wheel Support Driven
7	1	N-008 - Wheel Support Driver
6	1	N-007 - Frame
5	1	N-004 - De-agglomerator
4	1	N-005 - Nozzle Housing
3	1	N-003 - De-agglomerator Lid
2	1	N-002 - Mixer Rotor
1	1	N-001 - Main Housing



When assembeling this machine, it is recommended to have the CAD-model avalible to get a better overview.

The Mixer Rotors paddles shall have the same distance from each of the end walls.

Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:15	NMBU
Quantity: 1	Material:	Unit of measure: mm		Replacement for: / Replaced by:

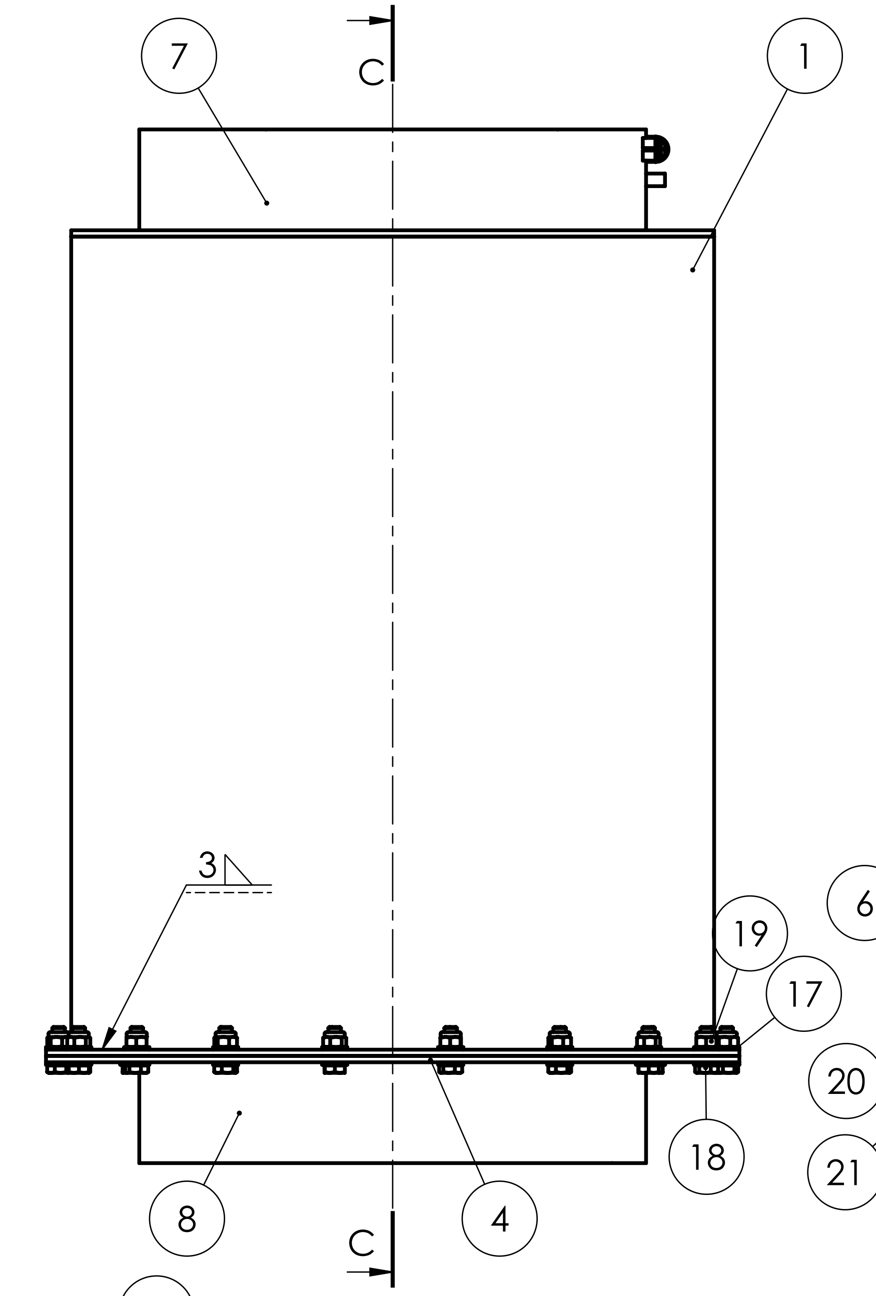
Rotating Mixer Vacuum Coater

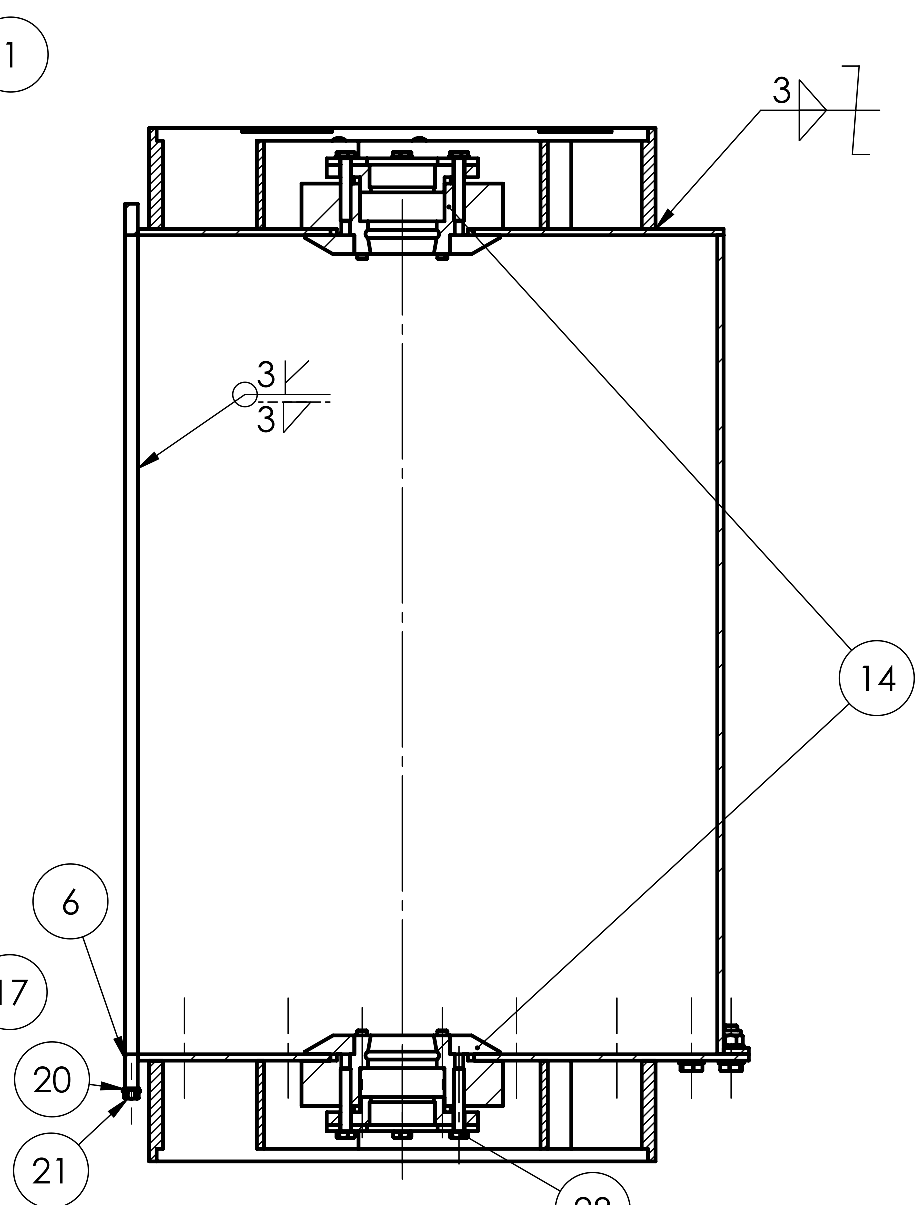
60 litre

RMVC

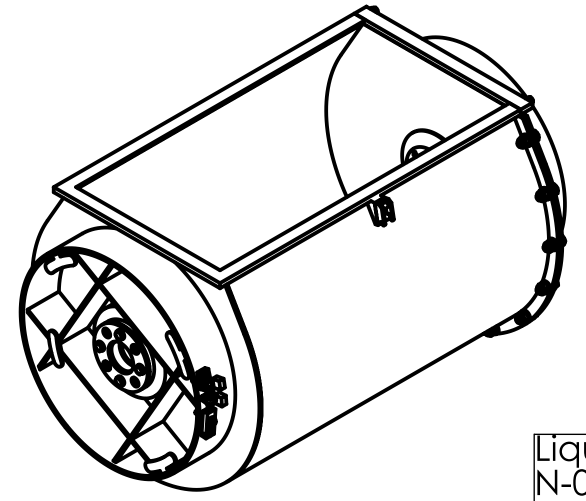
Referral:

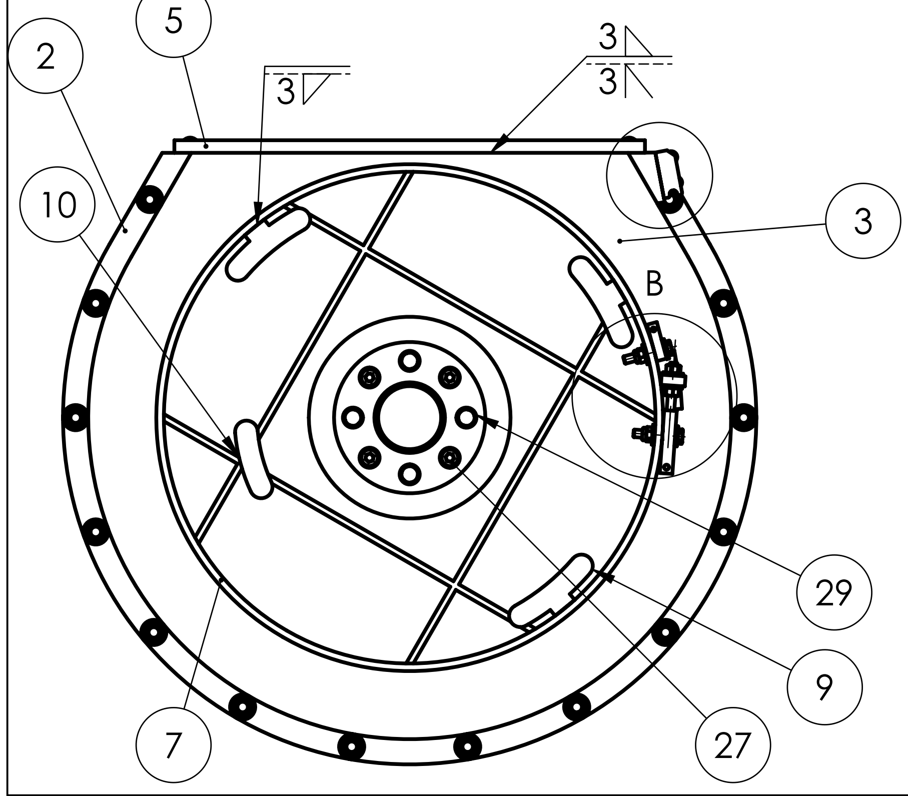
Calculation: F.L & H.G

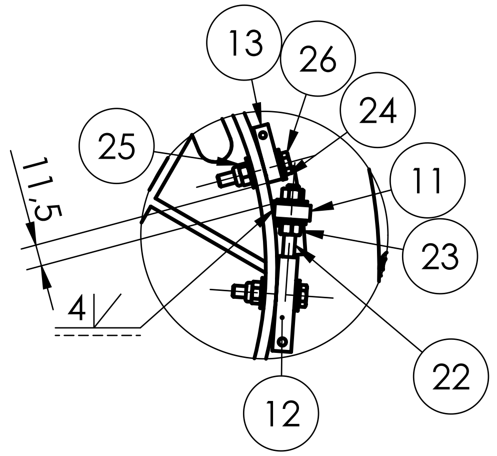




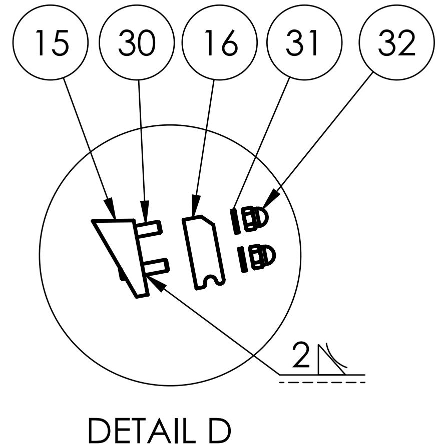
SECTION C-C
SCALE 1 : 6







DETAIL B
SCALE 1 : 4



DETAIL D
SCALE 1 : 4

Liquid Alkoxy Siloce is to be applied between N-001-002 and N-001-004 as sealant

Pos.	Aty.	Part Name	Material
32	2	DIN 1587 - M6 --NNU	AISI 304
31	2	Washer DIN 125 - A 6.4	AISI 304
30	2	din 976-1 -- m6 x 25 a-- n	AISI 304
29	4	Washer DIN 125 - A 8.4	AISI 304
28	8	ISO 4014 - M8 x 50 x 22-N	AISI 304
27	8	ISO 4762 M8 x 60 --- 28C	AISI 304
26	2	ISO 4014 - M6 x 35 x 35-C	AISI 304
25	2	DIN EN ISO 7040 - M6 - N	AISI 304
24	6	DIN 6902-A7.4	AISI 304
23	2	Hexagon Nut ISO 4034 - M6 - N	AISI 304
22	1	DIN 976-2 -- MFS M6 x 50 --- C	AISI 304
21	2	DIN 6921 - M6 x 40 x 40-N	AISI 304
20	2	Washer DIN 126 - 6.6	AISI 304
19	14	DIN EN ISO 7040 - M10 - N	AISI 304
18	14	iso 4017 - m10 x 30-n	AISI 304
17	28	Washer DIN 126 - 11	AISI 304
16	1	Speedyblock - 320_T3X4 Base	AISI 304
15	1	N-001-014 - Clamp Mount	AISI 304
14	2	F-001 - Air Purged Sealing	AISI 304
13	1	N-001-013 - Chain Fastener	AISI 304
12	1	N-001-012 - Chain Tightener - A	AISI 304
11	1	N-001-011 - Chain Tightener - B	AISI 304
10	1	N-001-010 - Detection Plate - B	AISI 304
9	3	N-001-009 - Detection Plate - A	AISI 304
8	1	N-001-008 - Turn Wheel - B	AISI 304
7	1	N-001-007 - Turn Wheel - A	AISI 304
6	1	N-001-006 - End Flange	AISI 304
5	1	N-001-005 - Main Flange	AISI 304
4	1	N-001-004 - Flanged Wall	AISI 304
3	1	N-001-003 - End Wall	AISI 304
2	1	N-001-002 - Semi-Cylindrical Flange	AISI 304
1	1	N-001-001 - Semi-Cylindrical Wall	AISI 304

Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:6	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for: / Replaced by:

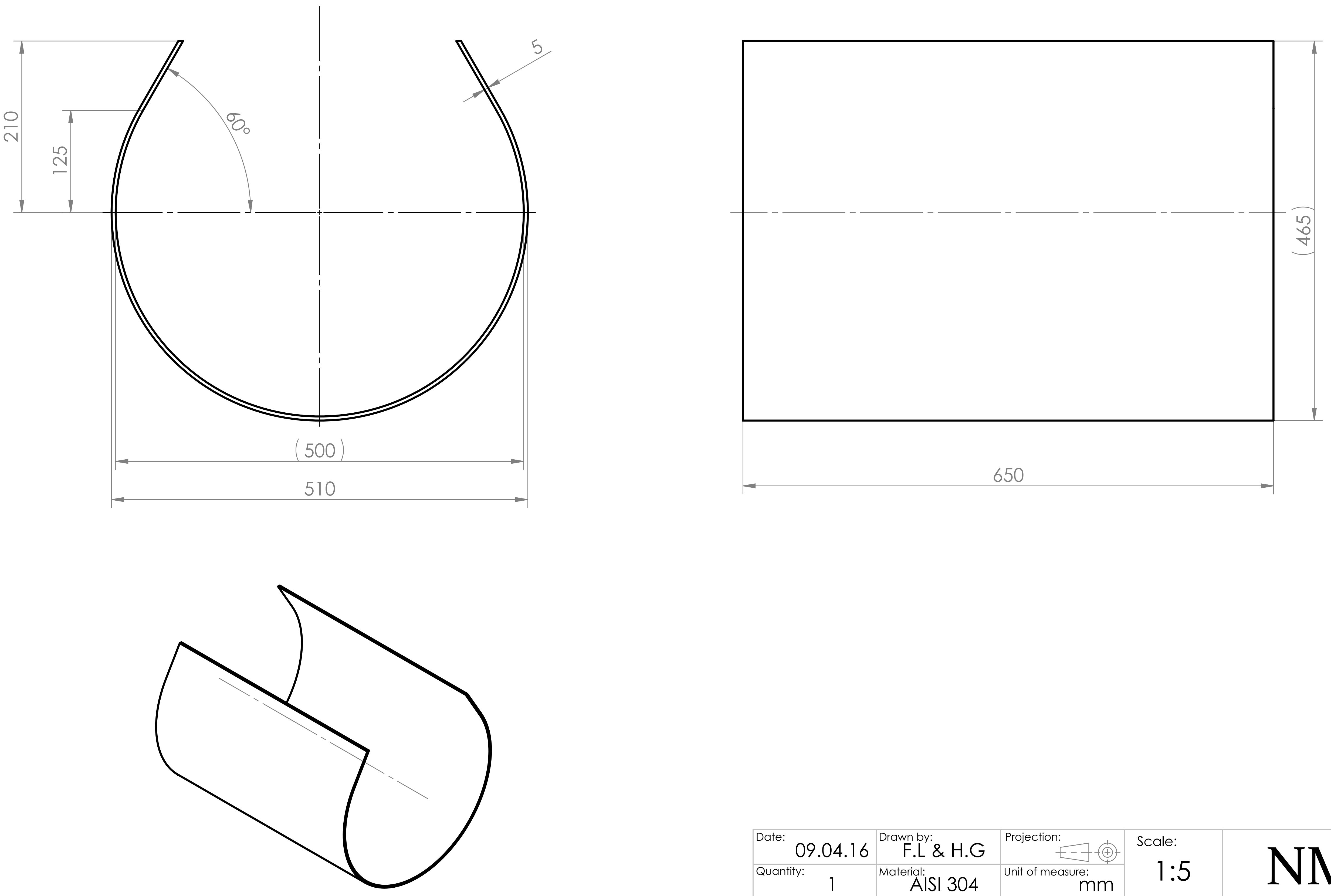
Main Housing

RMVC

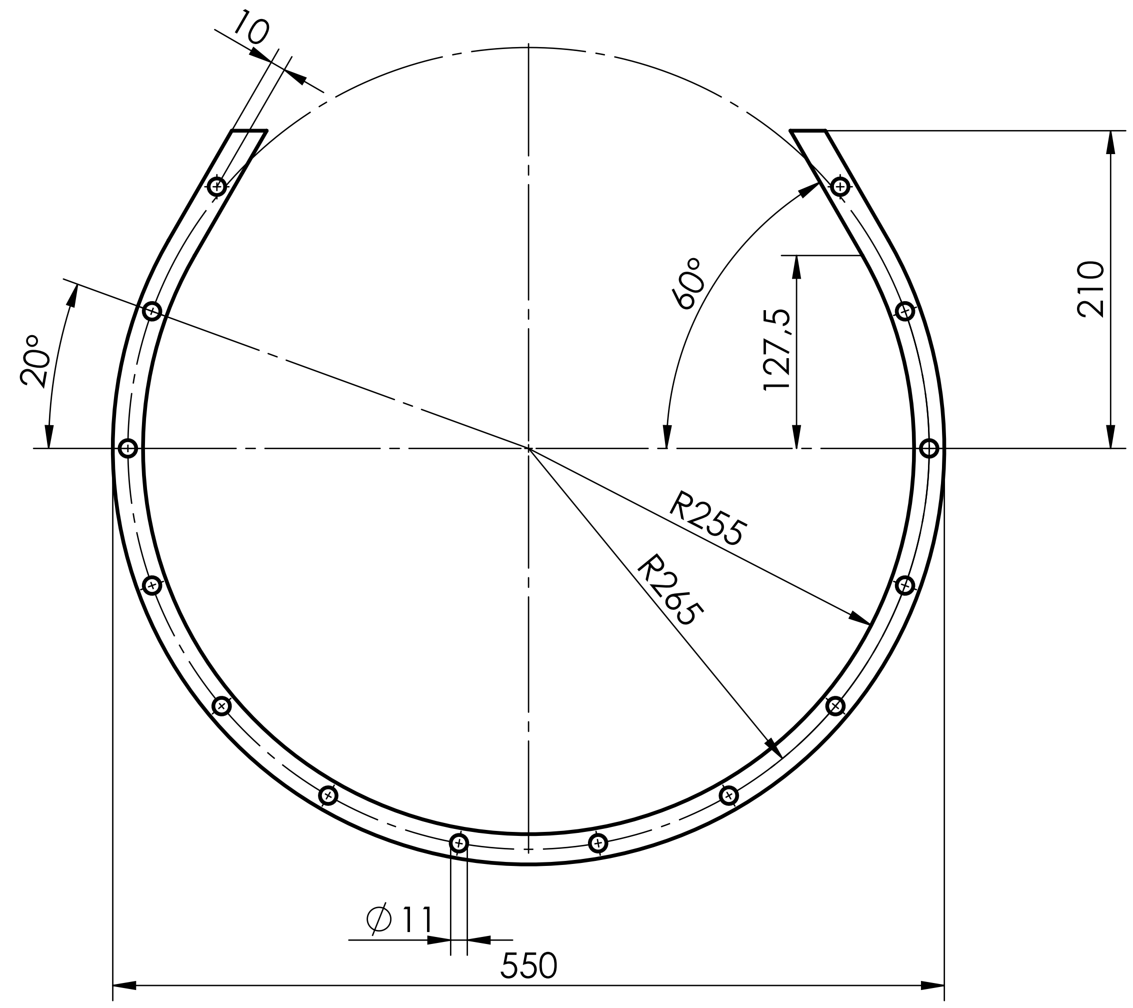
N-001

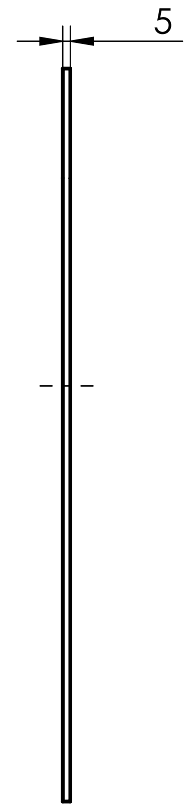
Referral:

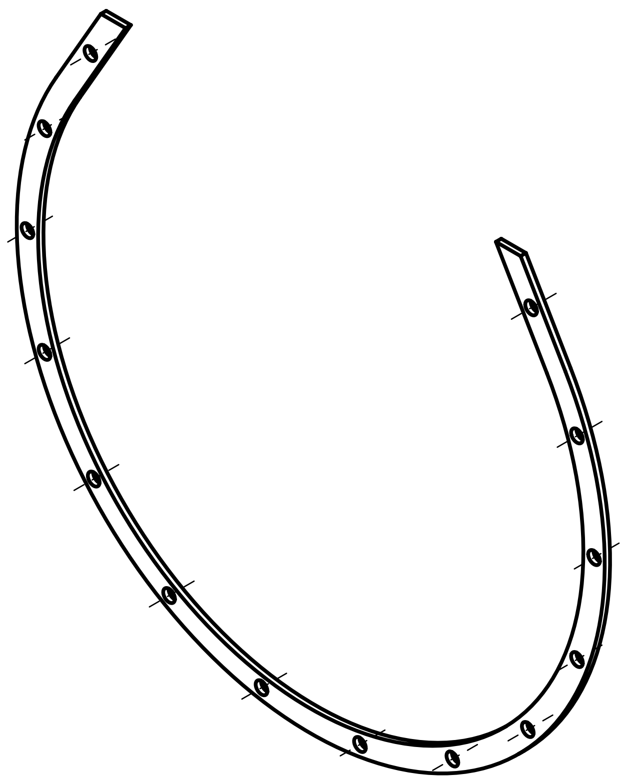
Calculation: F.L & H.G



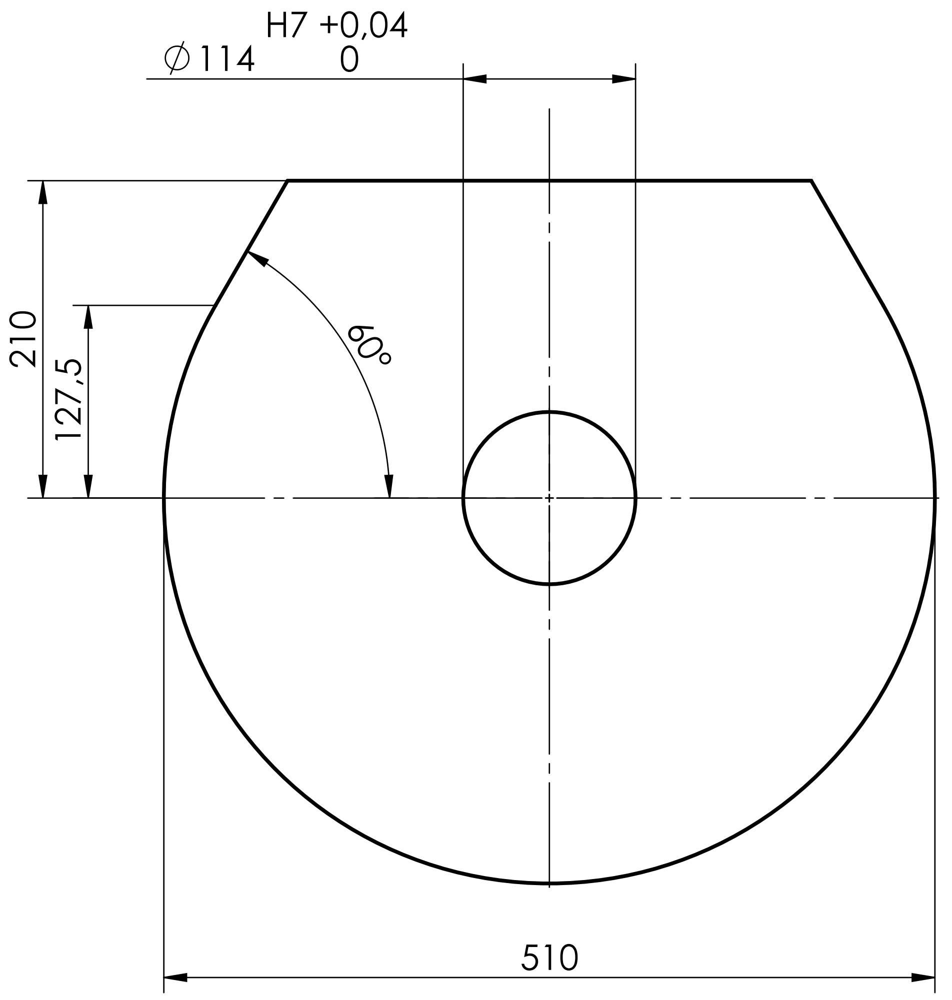
Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Semi-Cylindrical Wall				Replacement for: / Replaced by:
Main Housing				N-001-001
Referral:	Calculation: F.L & H.G			

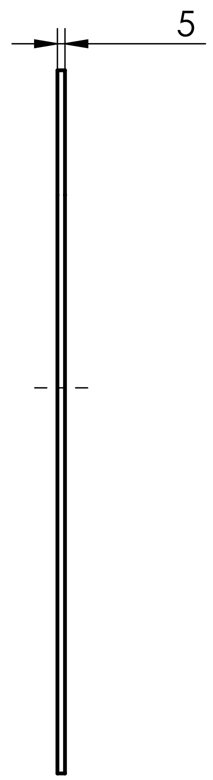


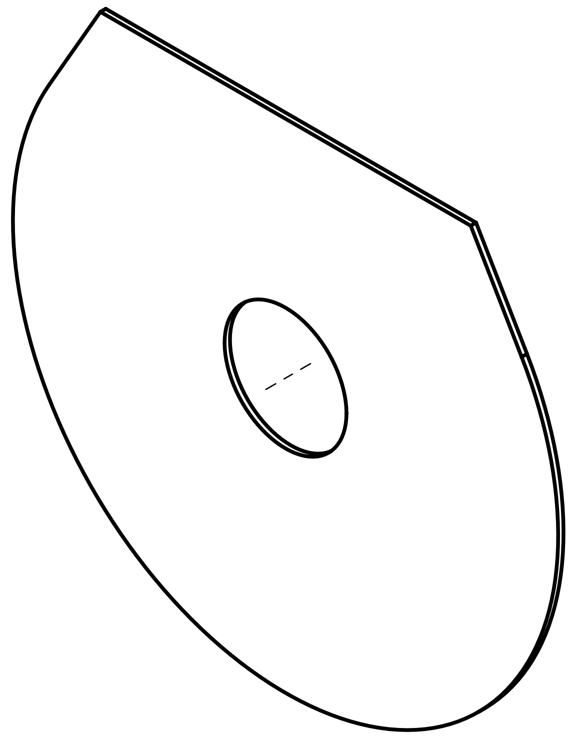




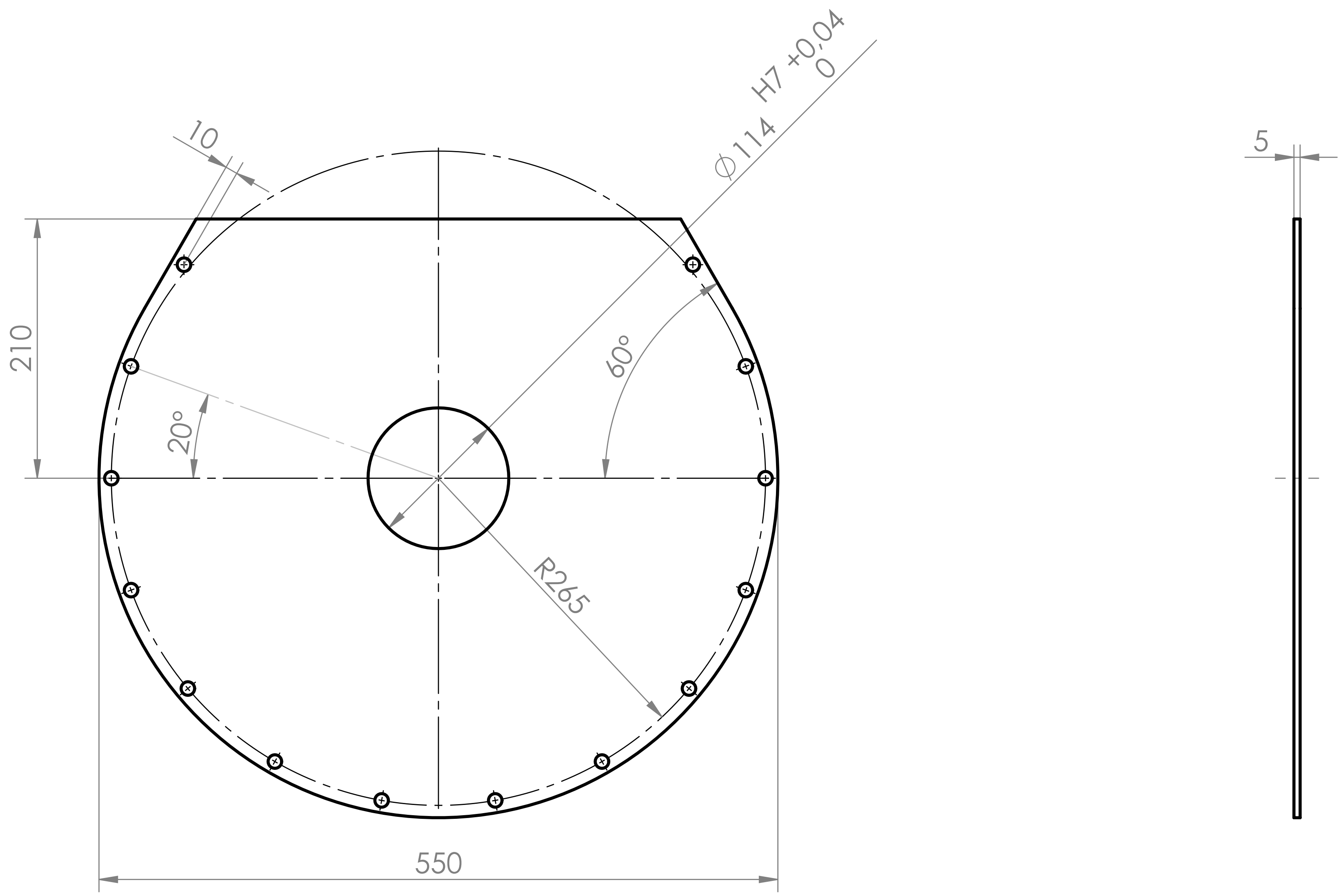
Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Semi-Cylindrical Flange				Replacement for: / Replaced by:
Main Housing				N-001-002
Referral:		Calculation: F.L & H.G		

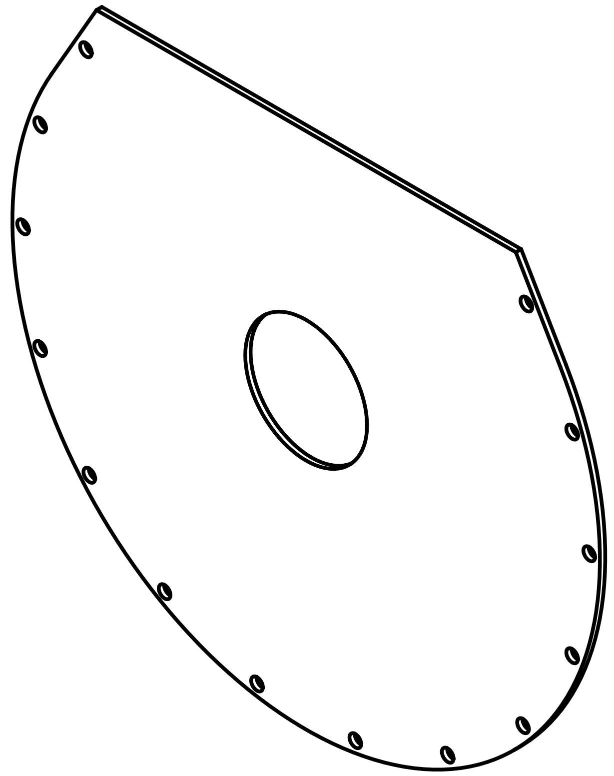






Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
End Wall Main Housing				Replacement for: / Replaced by: N-001-003
Referral:	Calculation: F.L & H.G			





Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

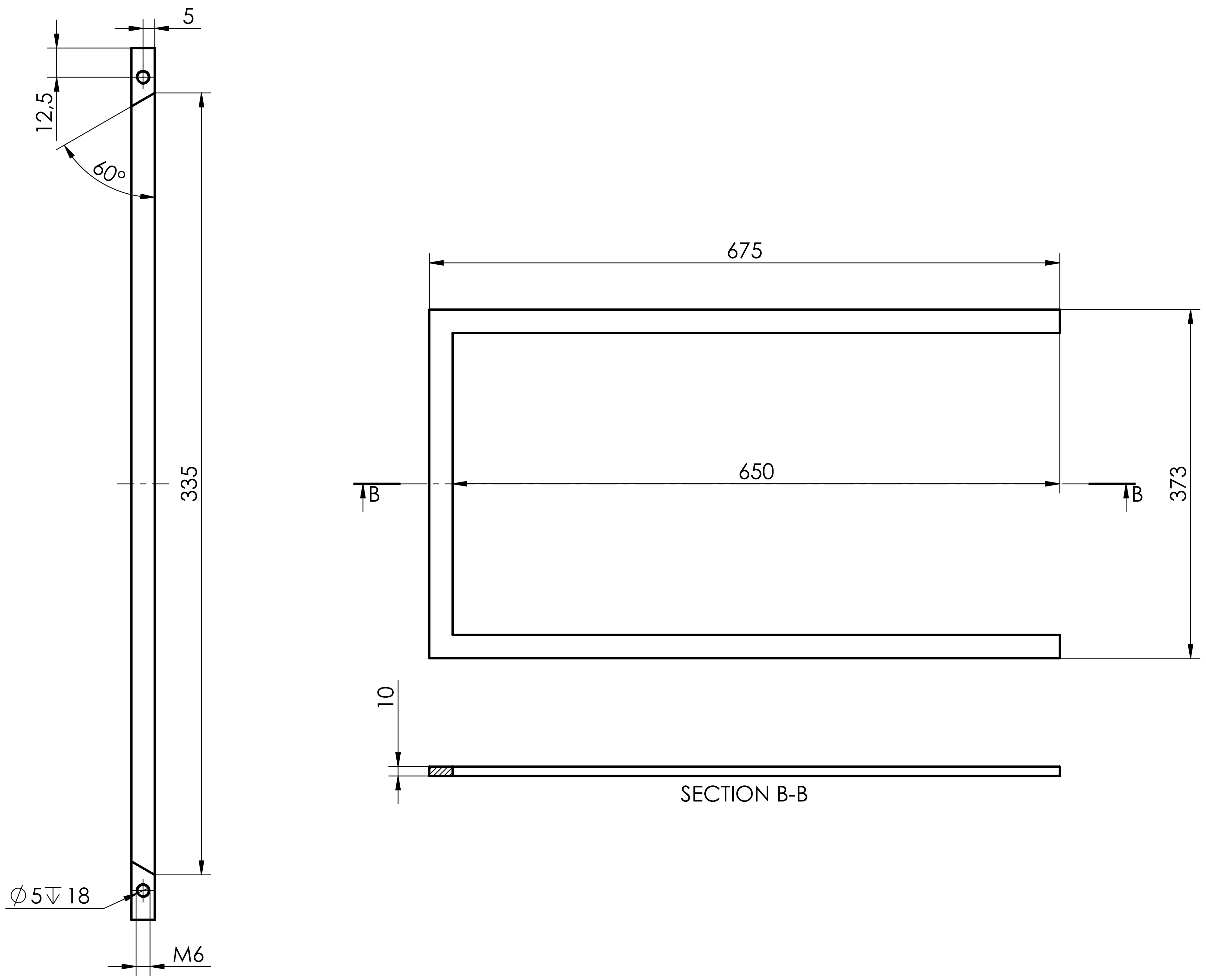
Flanged Wal

Main Housing

Replacement for: | Replaced by:

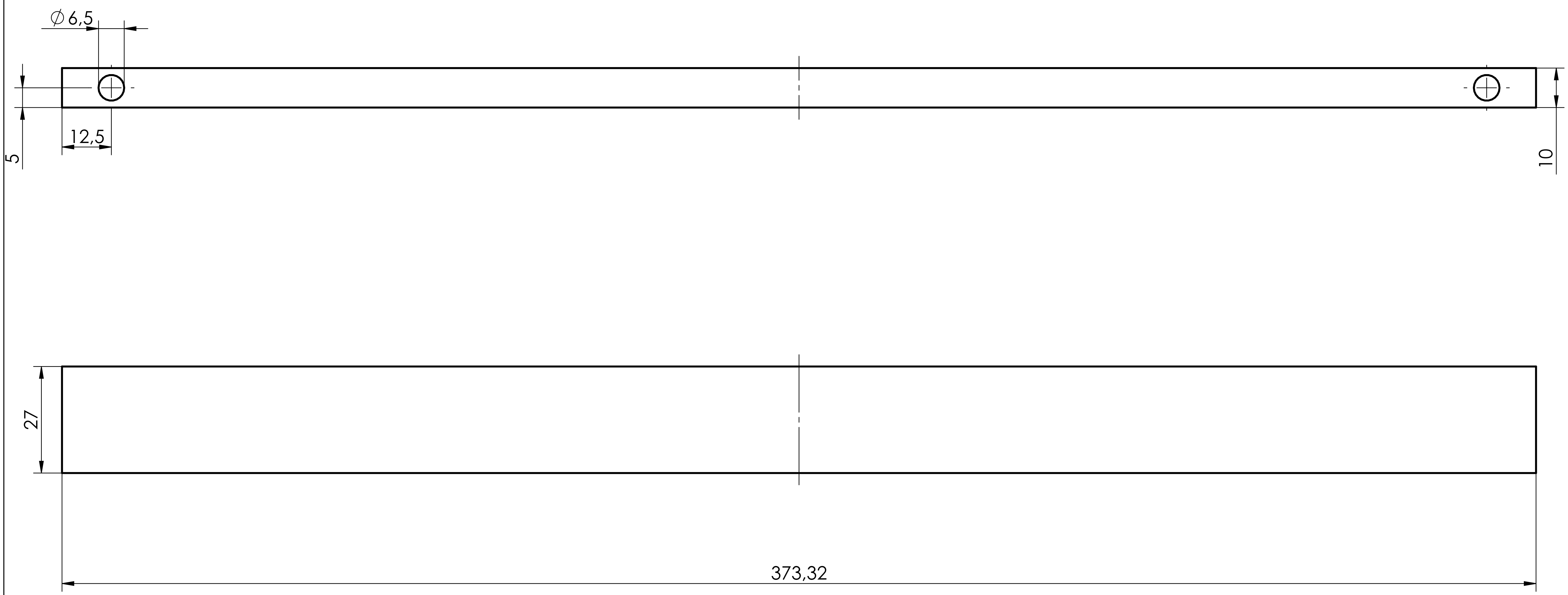
N-001-004

Referral: | Calculation: F.L & H.G

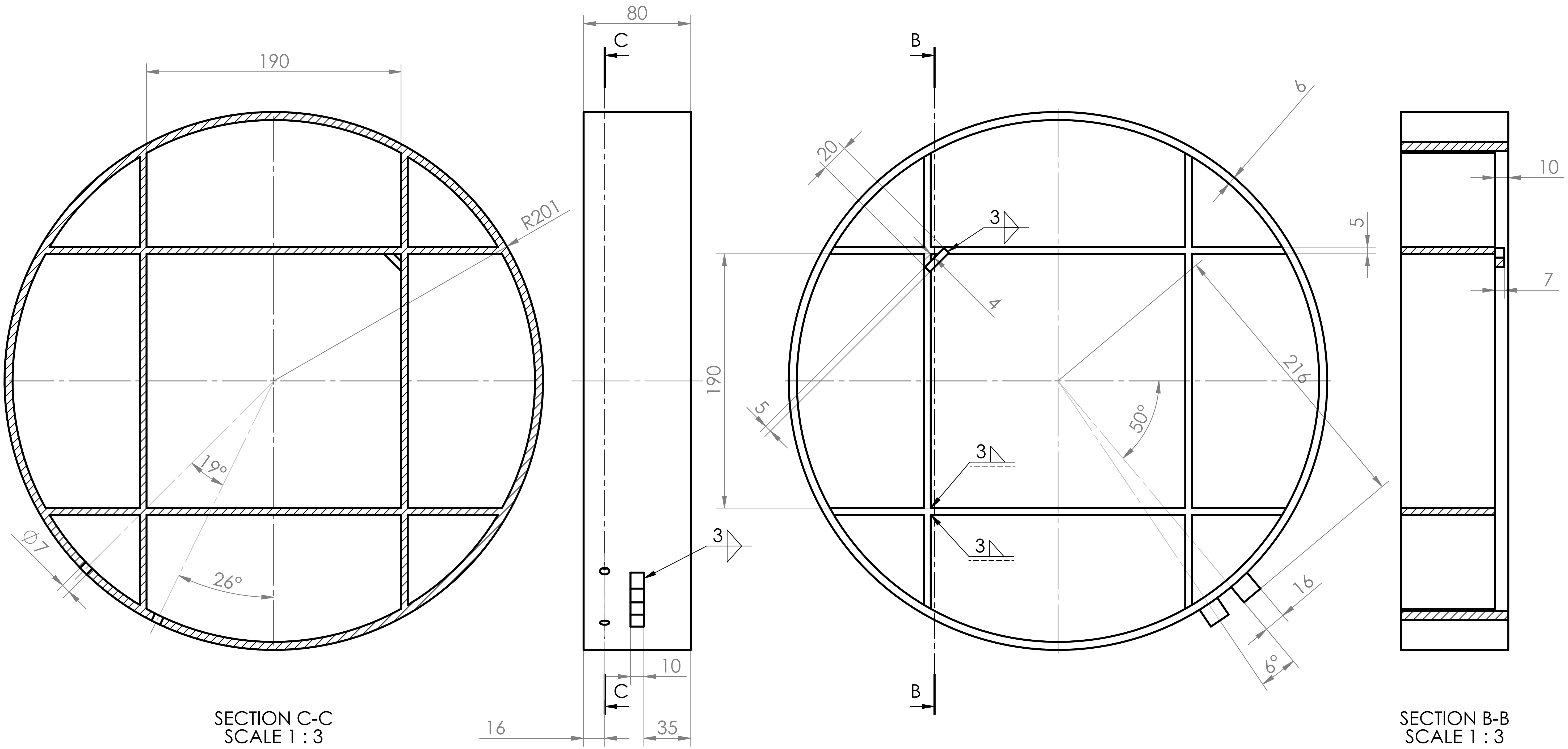


SCALE: 1:2

Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Main Flange				Replacement for: / Replaced by:
Main Housing				N-001-005
Referral:		Calculation: F.L & H.G		

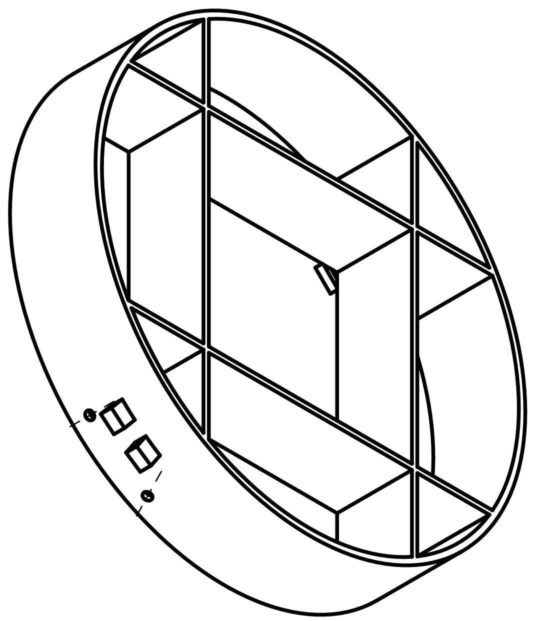


Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
End Flange Main Housing				Replacement for: / Replaced by:
				N-001-006
Referral:		Calculation: F.L & H.G		



SECTION C-C
SCALE 1 : 3

SECTION B-B
SCALE 1 : 3



Date: 11.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1: 3	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

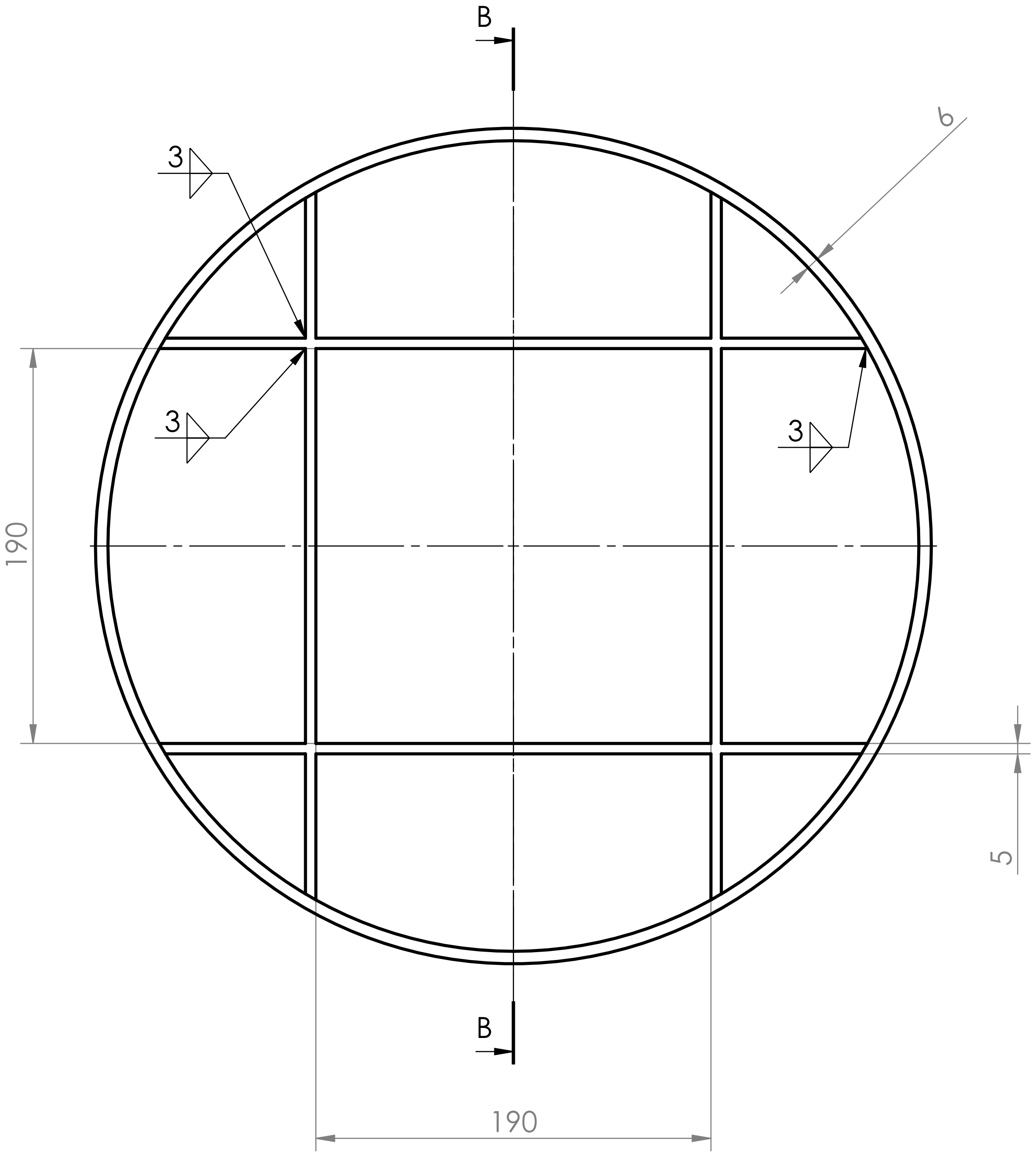
Turn Wheel - A

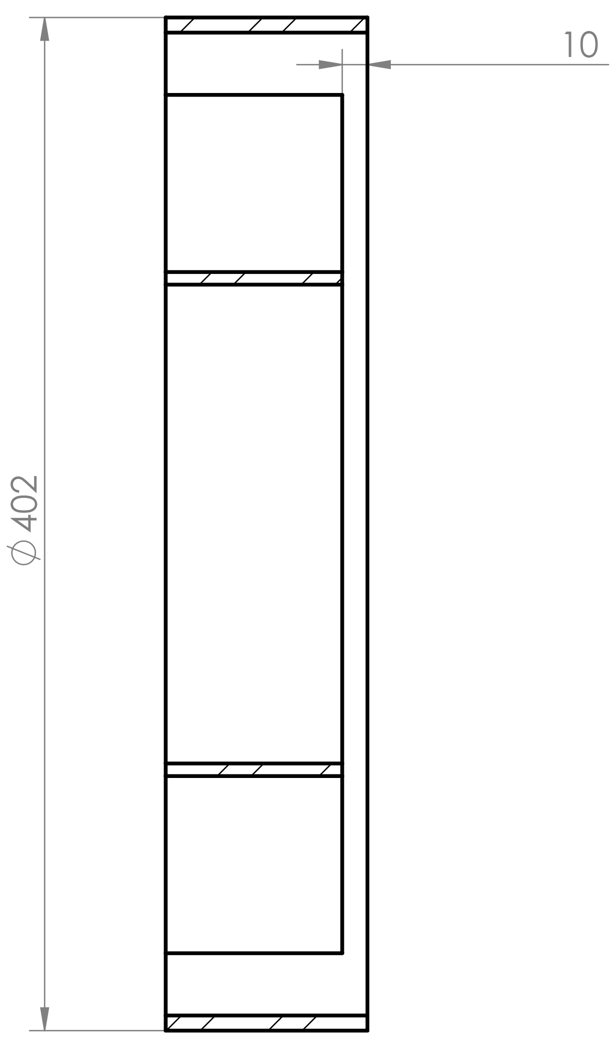
Main Housing

Replacement for:	Replaced by:

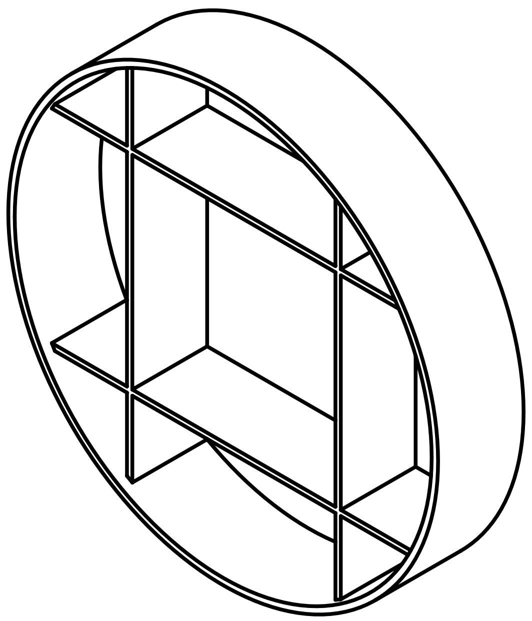
N-001-007

Referral:	Calculation: F.L & H.G

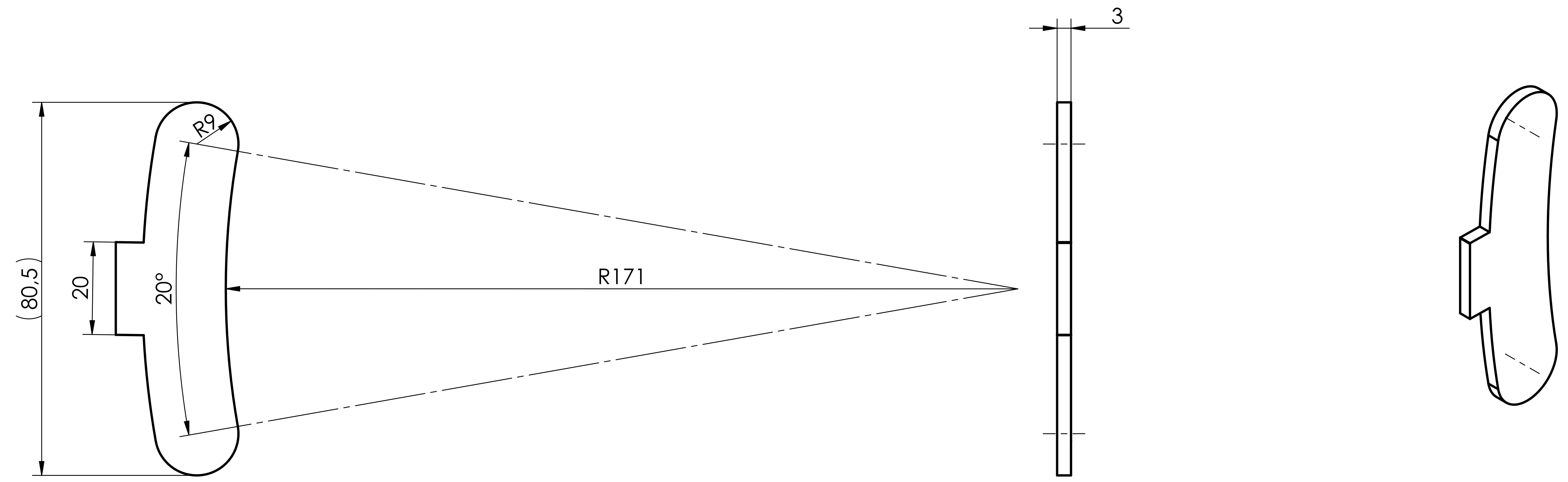




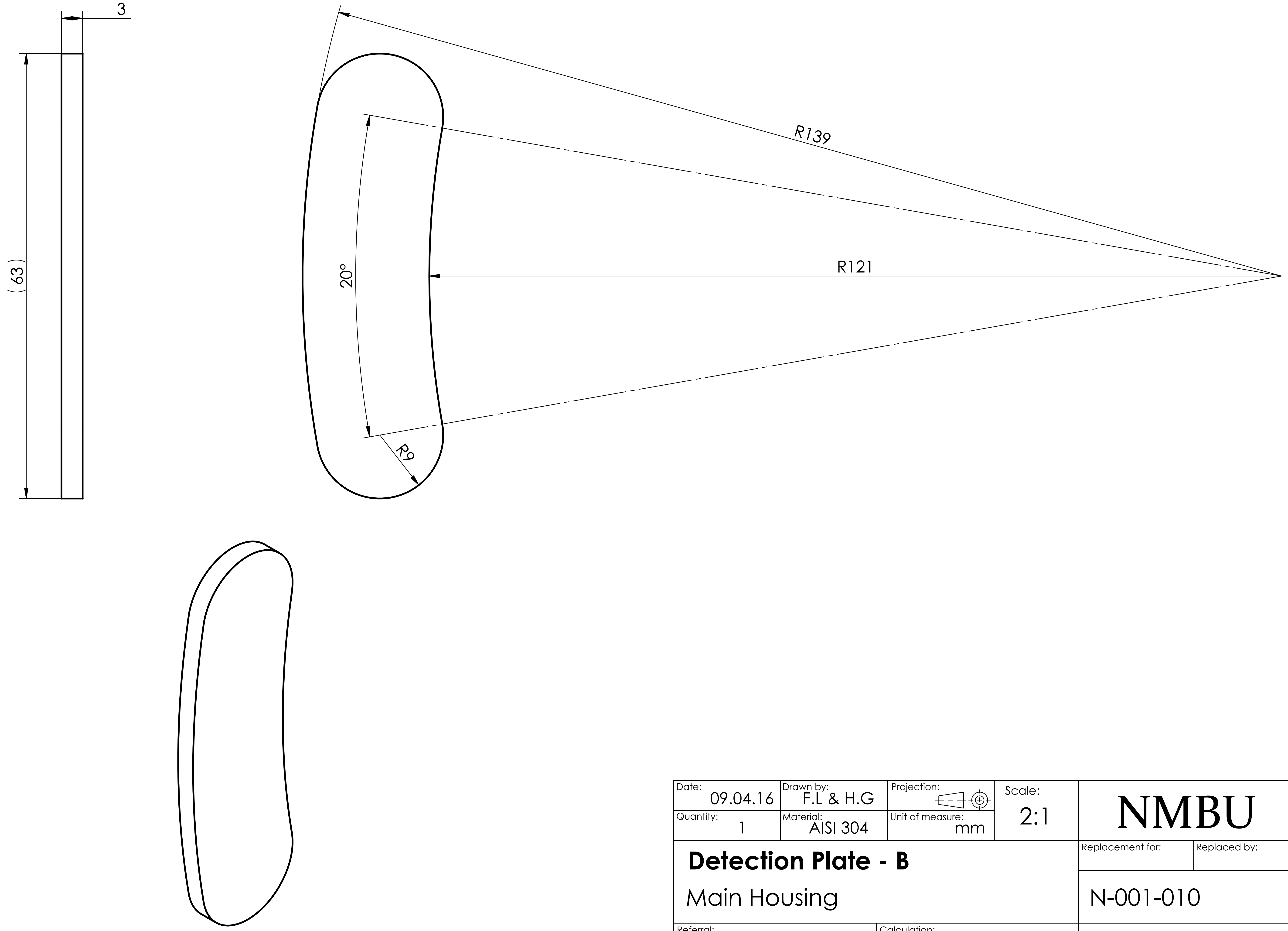
SECTION B-B
SCALE 1 : 3



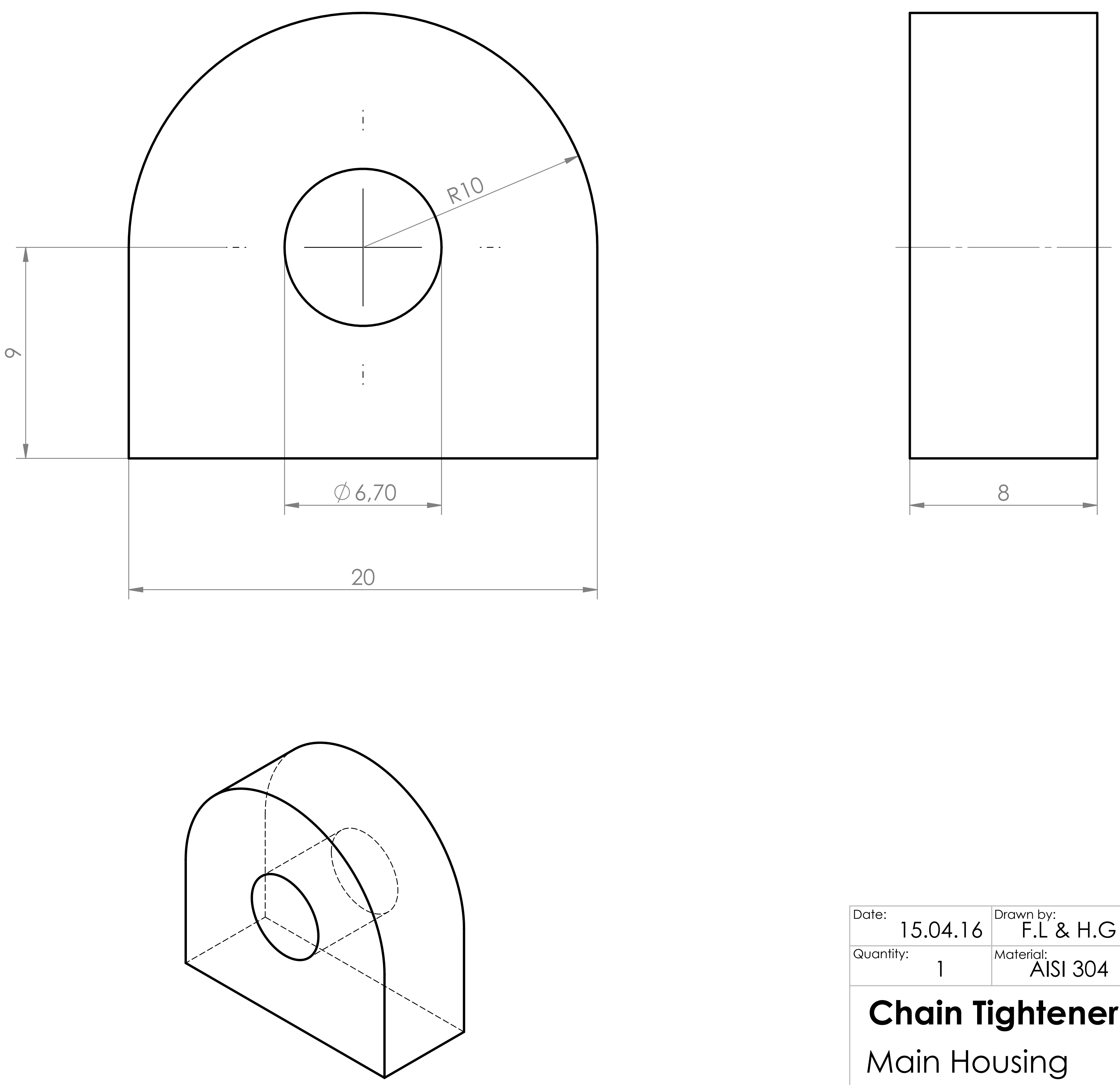
Date: 15.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:3	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Turn Wheel - B				Replacement for: / Replaced by:
Main Housing				N-001-008
Referral:	Calculation: F.L & H.G			



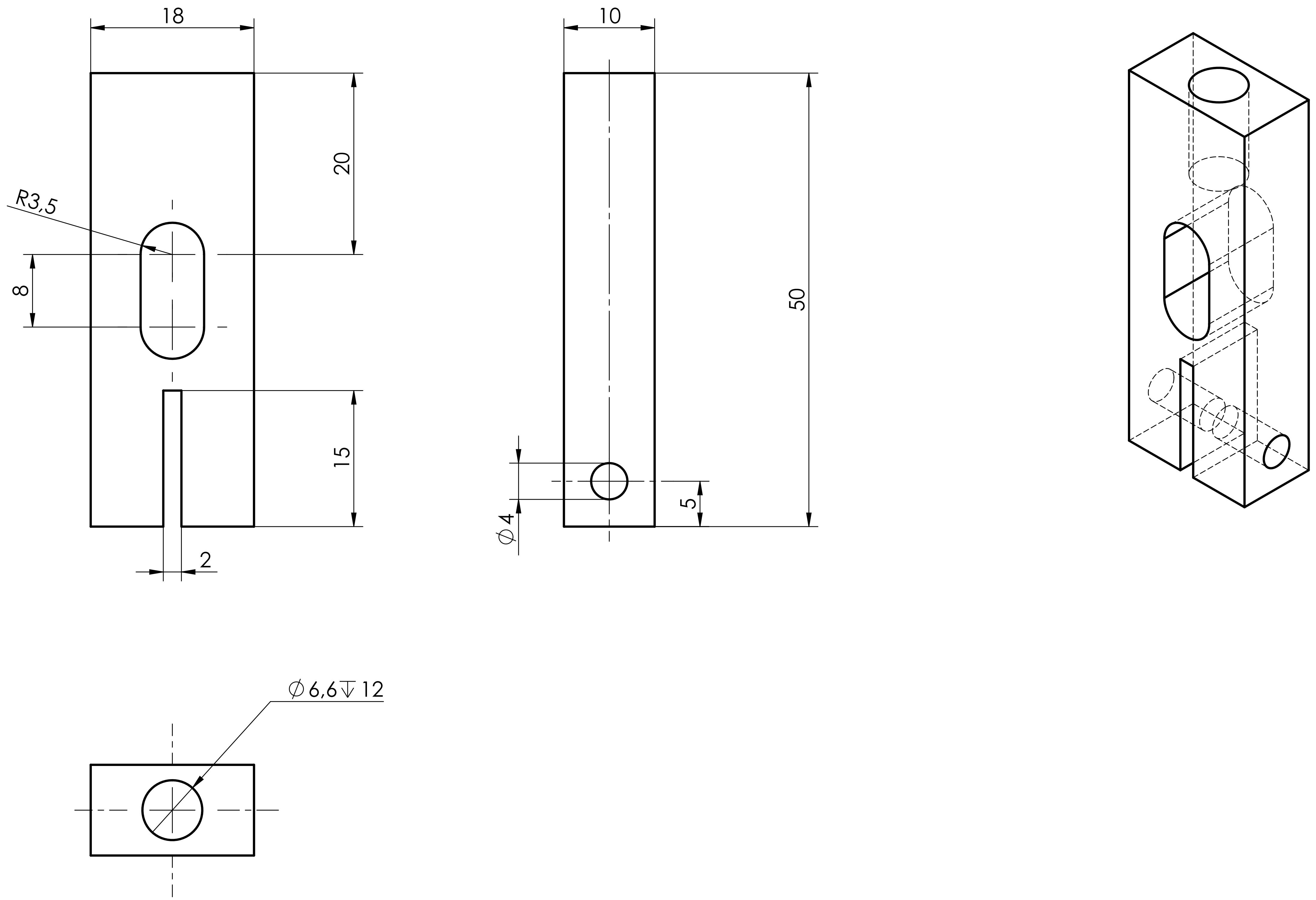
Date: 12.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 3	Material: AISI 304	Unit of measure: mm		
Detection Plate - A				Replacement for: / Replaced by:
Main Housing				N-001-009
Referral:		Calculation: F.L & H.G		



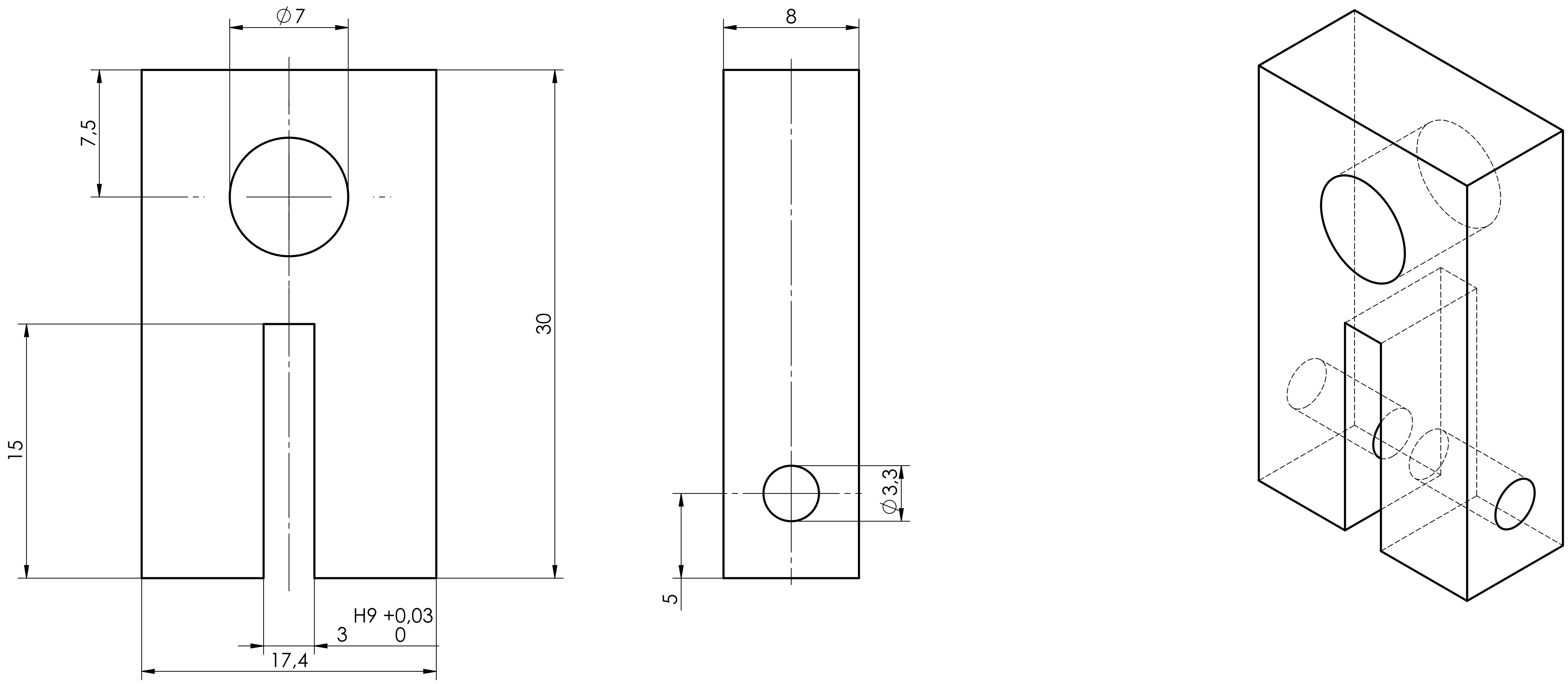
Date: 09.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Detection Plate - B				Replacement for: / Replaced by:
Main Housing				N-001-010
Referral:		Calculation: F.L & H.G		



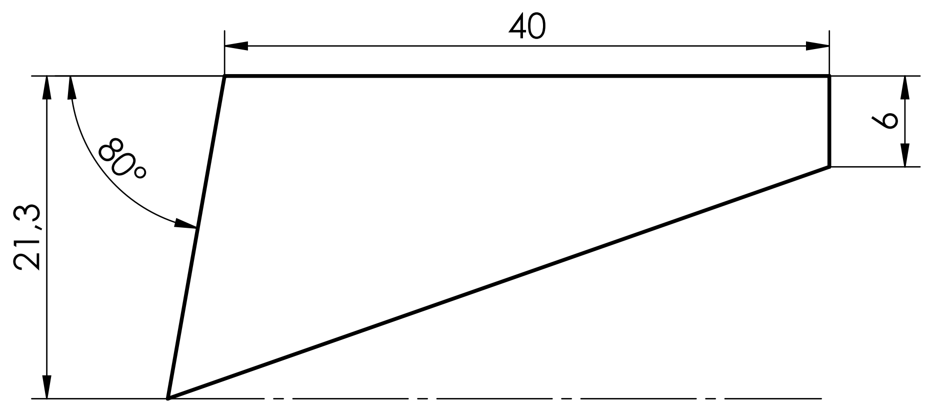
Date: 15.04.16	Drawn by: F.L & H.G	Projection:	Scale: 5 :1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Chain Tightener - B				Replacement for: / Replaced by:
Main Housing				N-001-011
Referral:	Calculation: F.L & H.G			

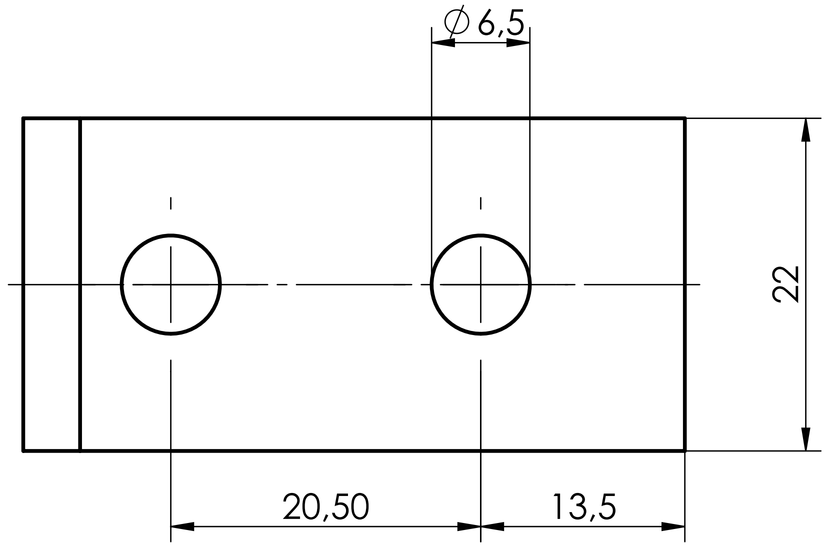


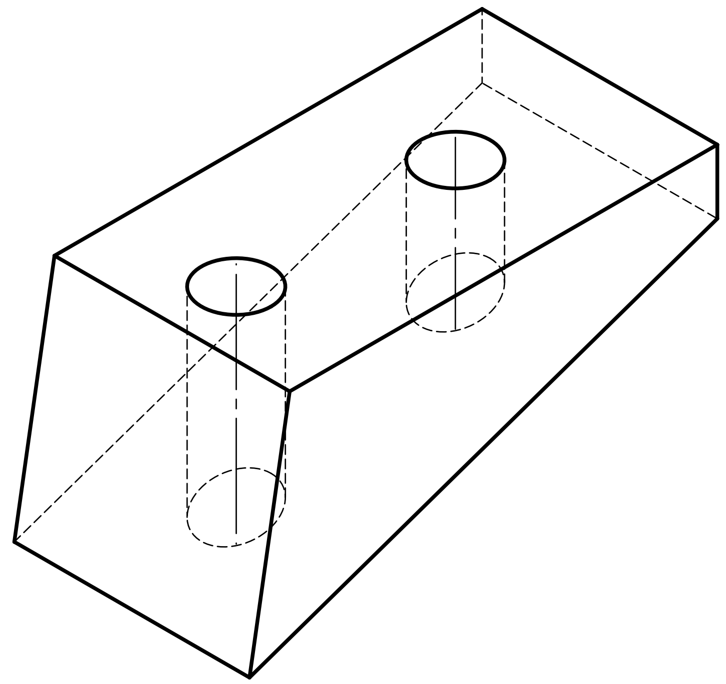
Date: 15.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2 : 1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Chain Tightener - A				Replacement for: / Replaced by:
Main Housing				N-001-012
Referral:		Calculation: F.L & H.G		



Date: 15.04.16	Drawn by: F.L & H.G	Projection:	Scale: 4 : 1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Chain Fastener				Replacement for: / Replaced by:
Main Housing				N-001-013
Referral:		Calculation: F.L & H.G		







Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

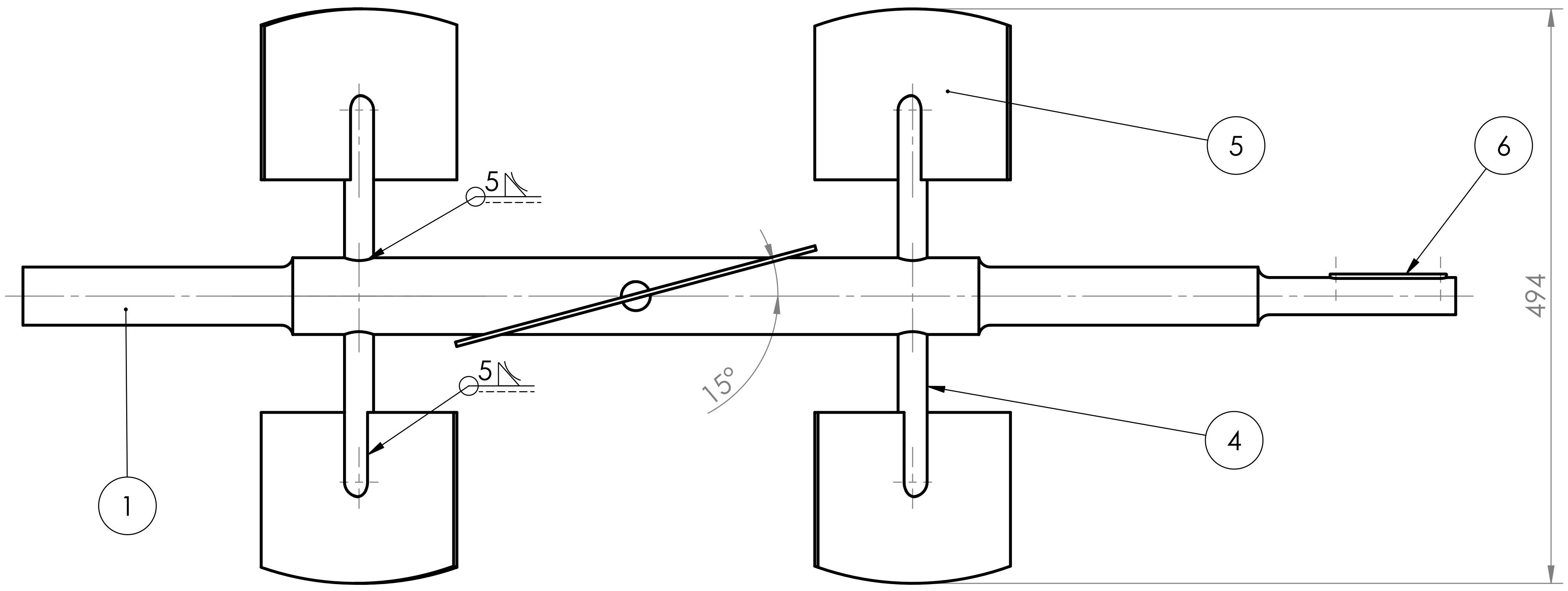
Clamp Mount

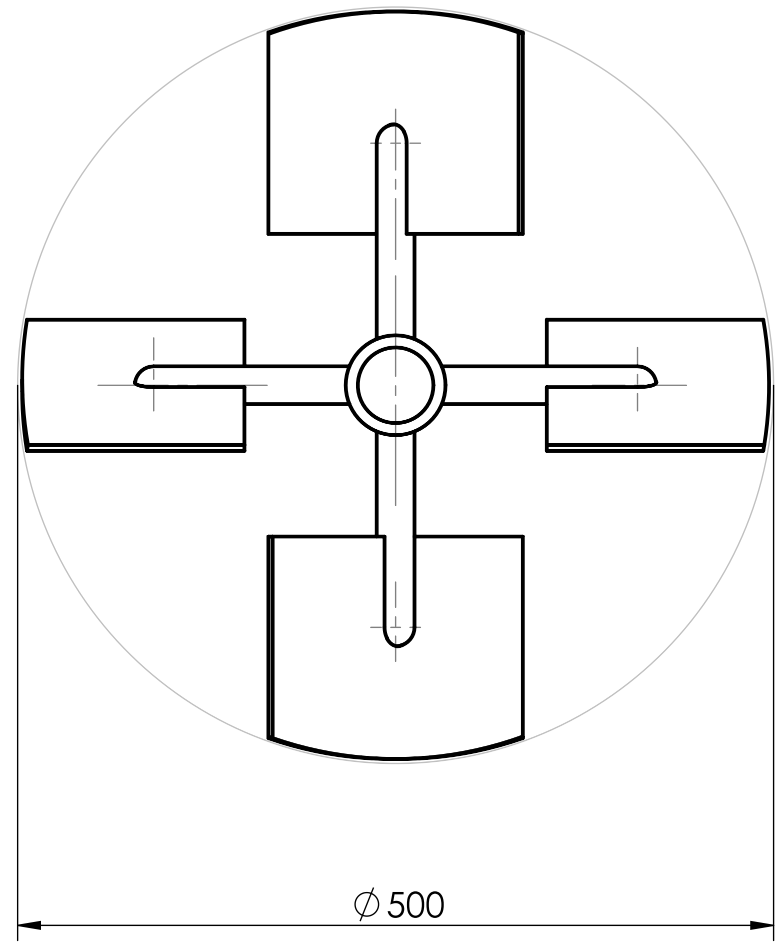
Main Housing

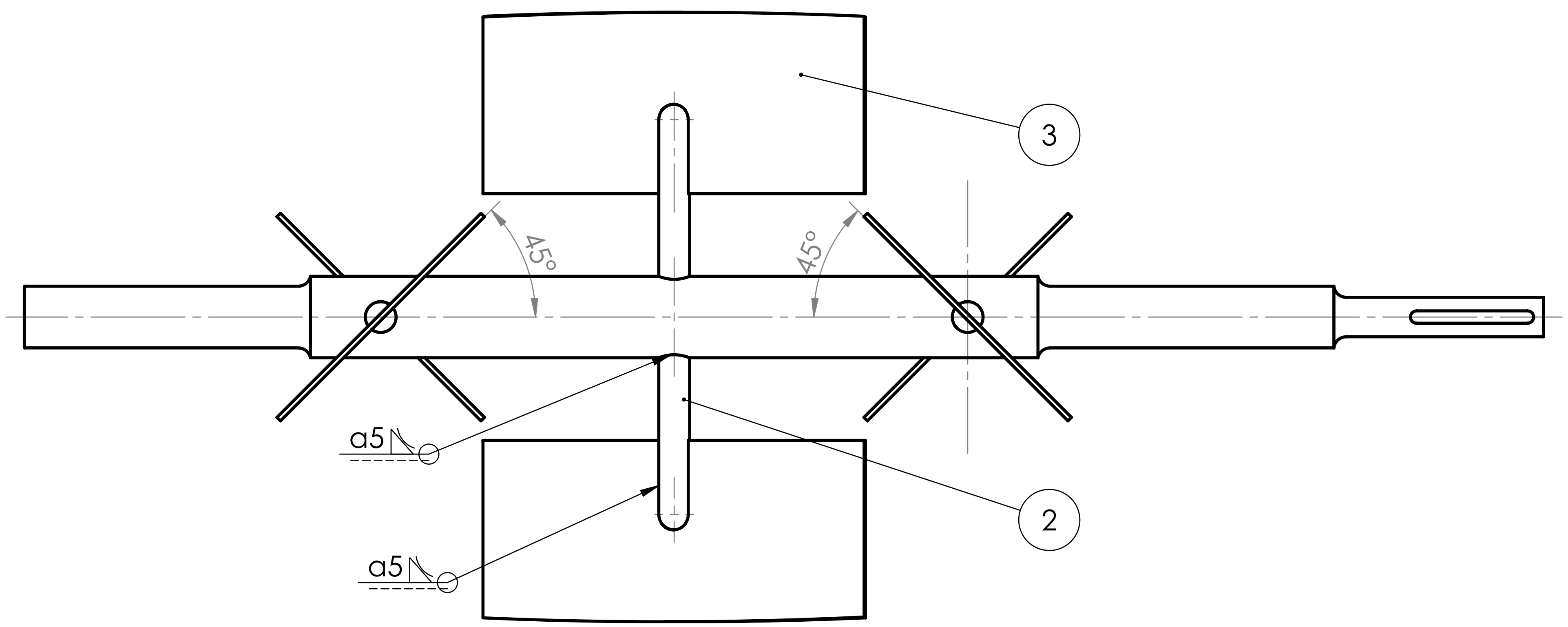
Replacement for:	Replaced by:

N-001-014

Referral:	Calculation: F.L & H.G







The Mixer Shaft is to be installed inside a cyllinder with a diameter of 500 mm.

The Mixer Rotor is to be heat treated for stress relief purposes.

6	1	Parallel key A10 x 8 x 100 DIN 6885	AISI 304
5	4	N-002-005 - End Paddle	AISI 304
4	2	N-002-004 - End Rod	AISI 304
3	2	N-002-003 - Middle Paddle	AISI 304
2	1	N-002-002 - Middle Rod	AISI 304
1	1	N-002-001 - Shaft	AISI 304
Pos.	Qty.	Part Name	Material

Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material:	Unit of measure: mm		

Mixer Rotor

RMVC

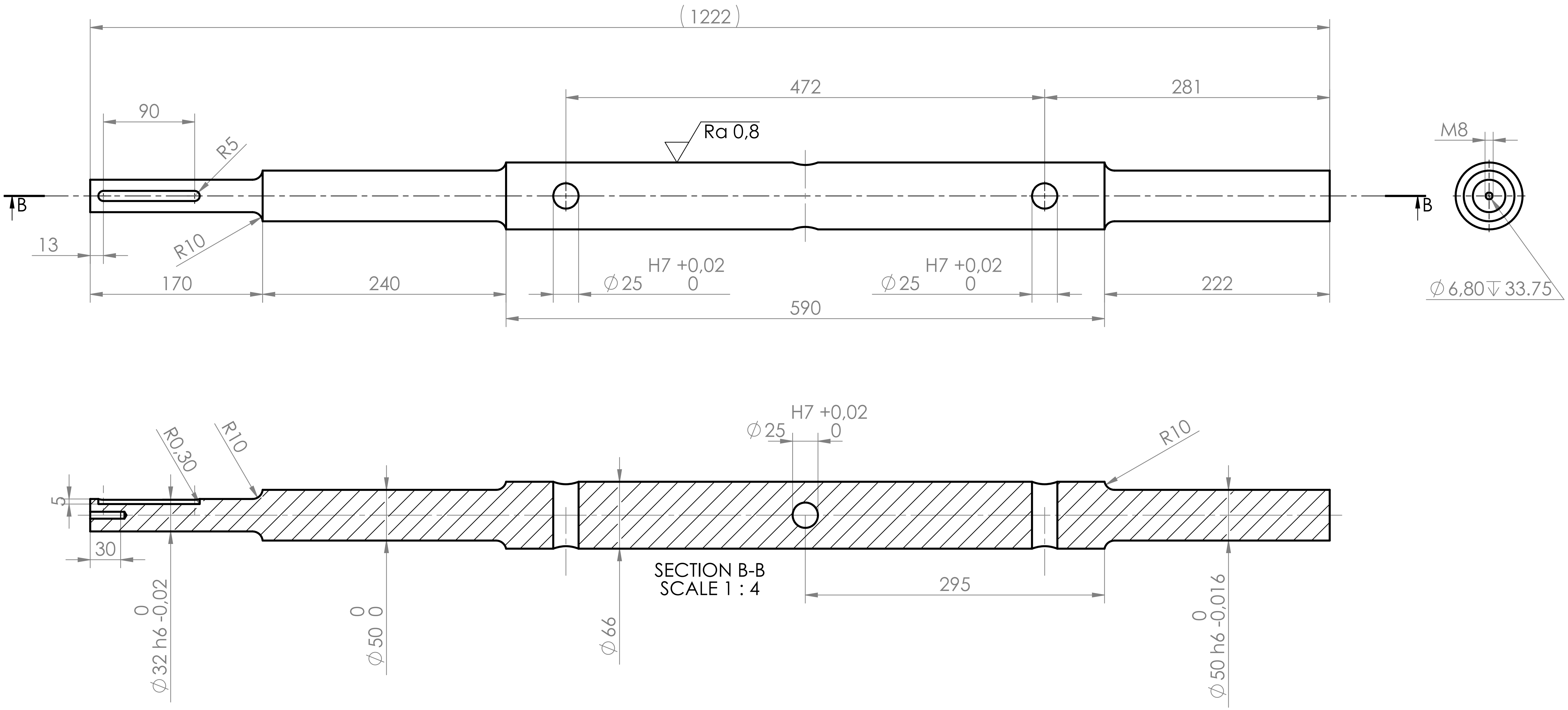
Replacement for:

Replaced by:

N-002

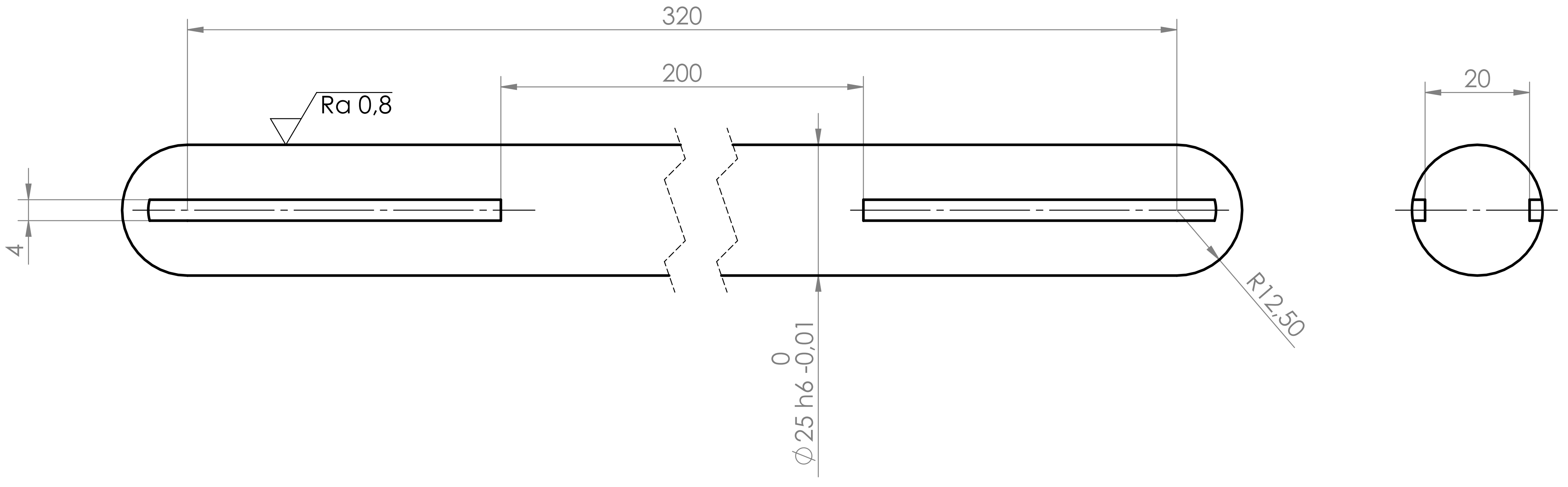
Referral:

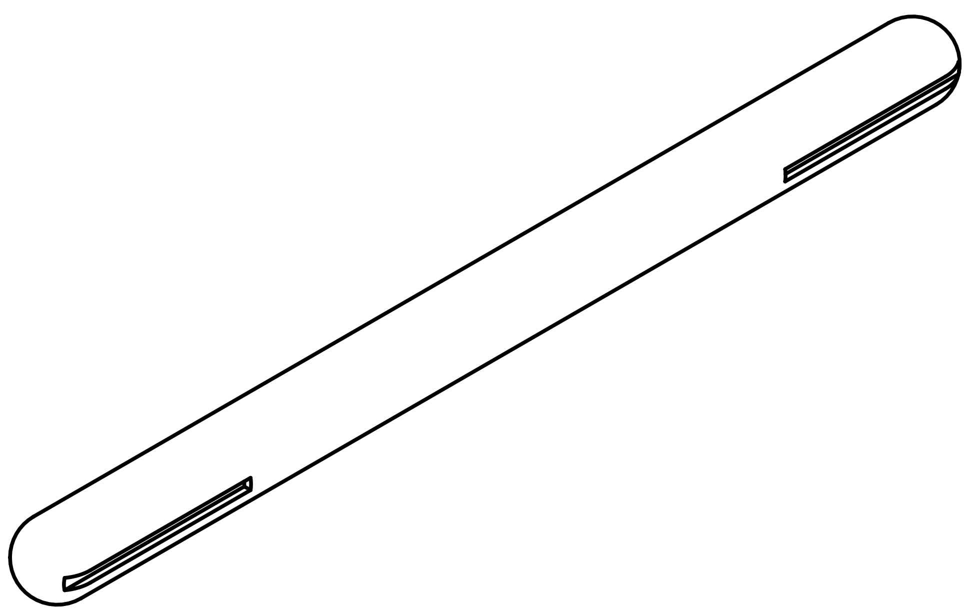
Calculation: F.L & H.G



The mentioned surface finsih applies to all of the exterior surfaces.

Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:4	NMBU	
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for:	Replaced by:
Shaft Mixer Rotor				N-002-001	
Referral:	Calculation: F.L & H.G				





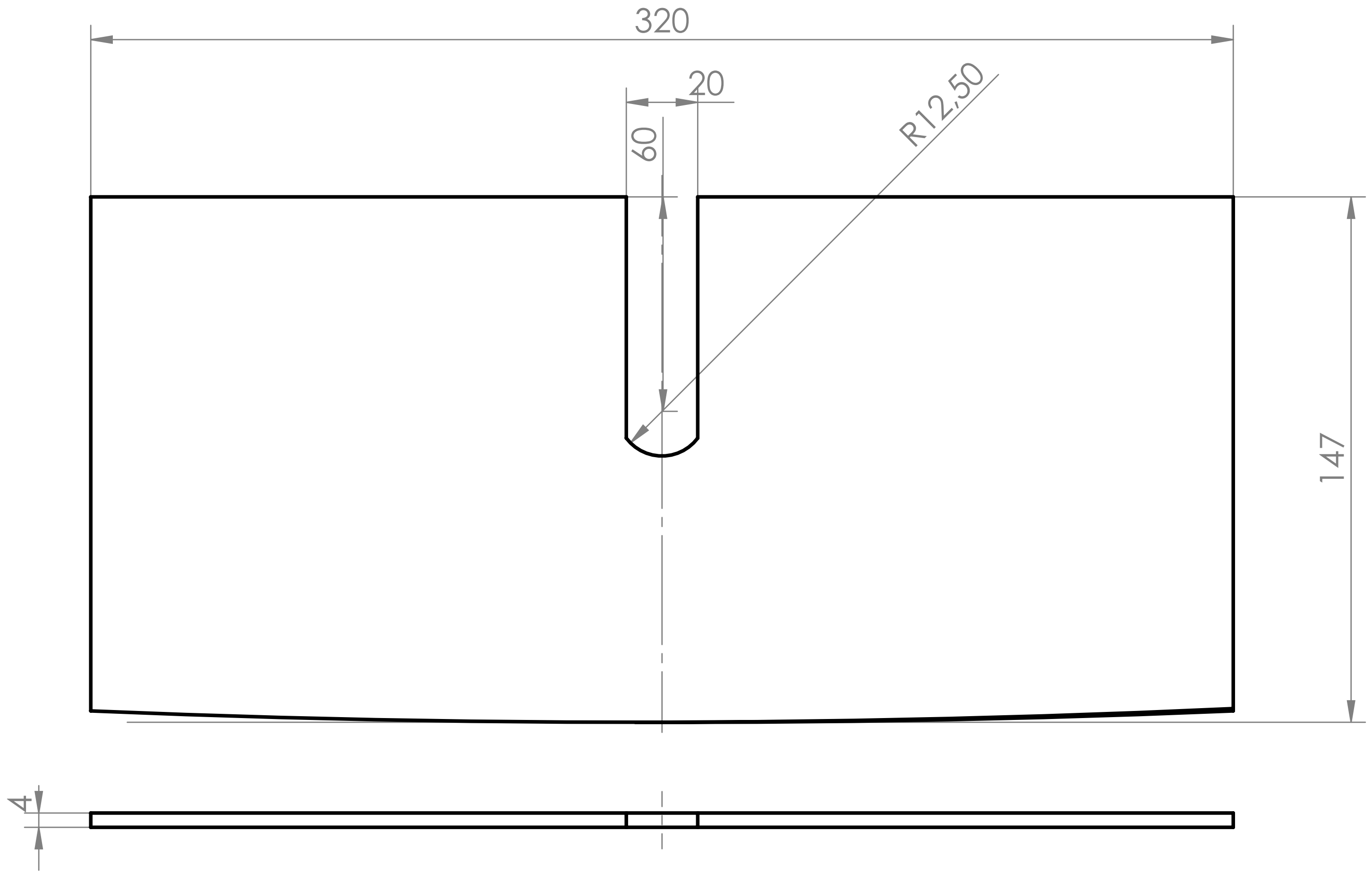
Date: 05.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for: / Replaced by:

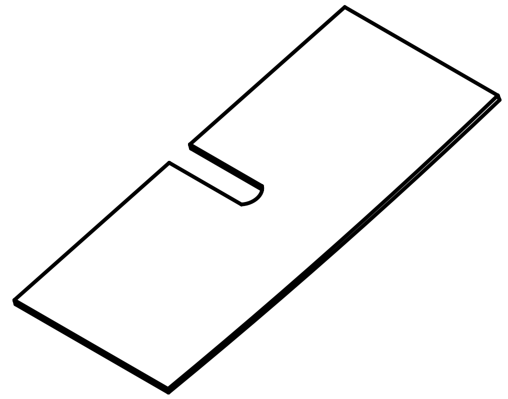
Middle Rod

Mixer Rotor

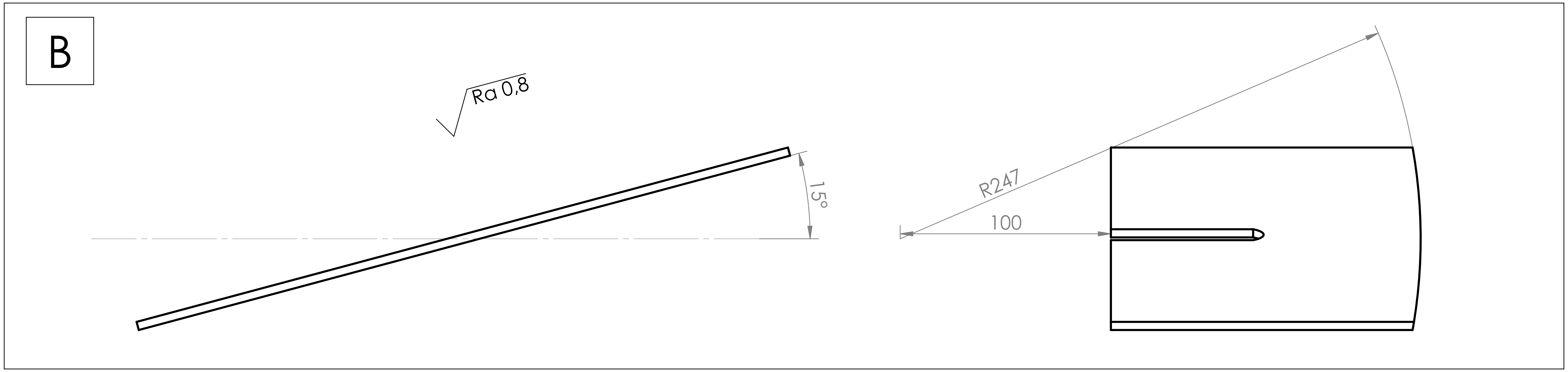
N-002-002

Referral:	Calculation: F.L & H.G

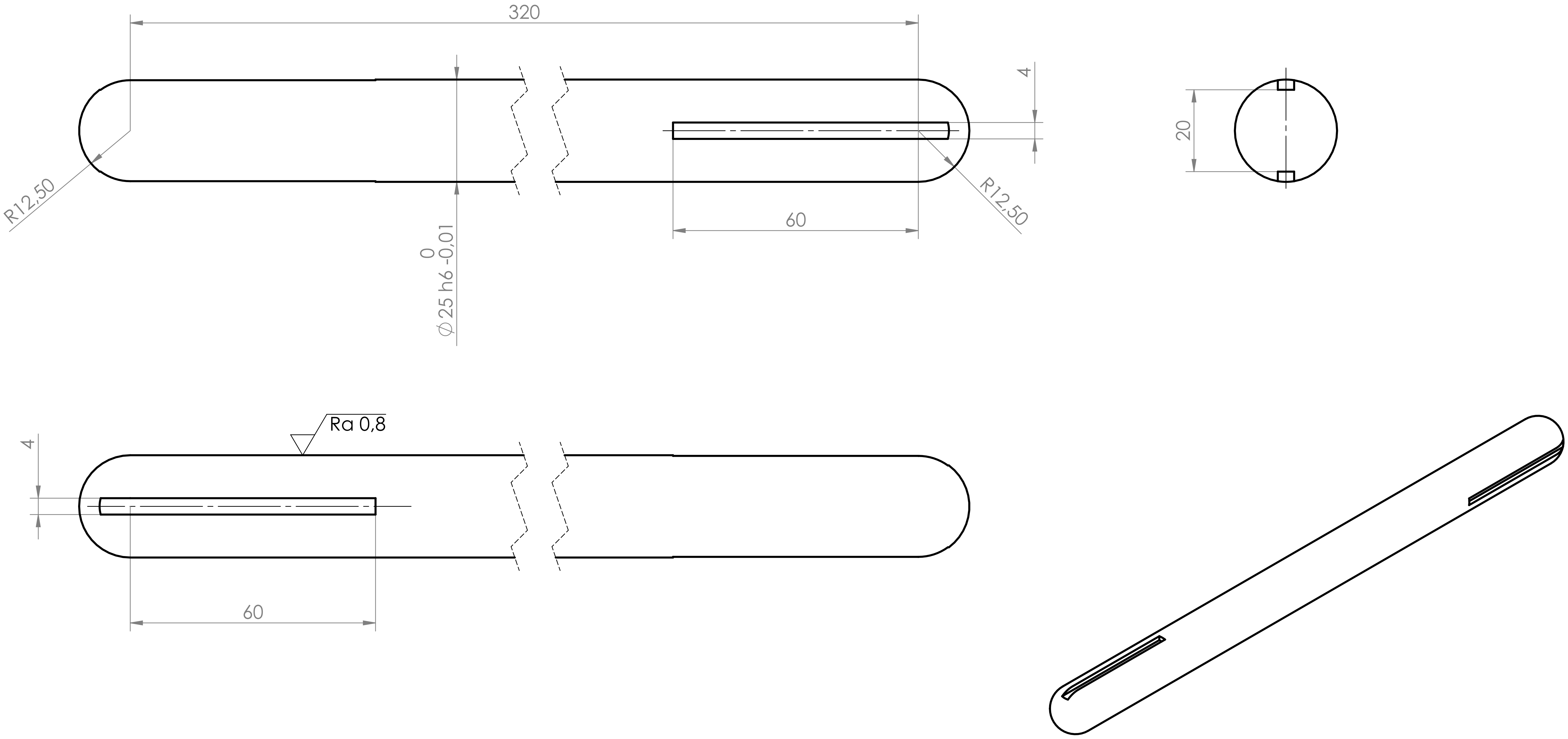




The Paddle is to mounted at 15 degree angle when assembeled with the rest of the mixer shaft.
As a result the paddle will have to be cut/grinded in a simerlar fashion as shown in section B, making the outer edge twist around itself.

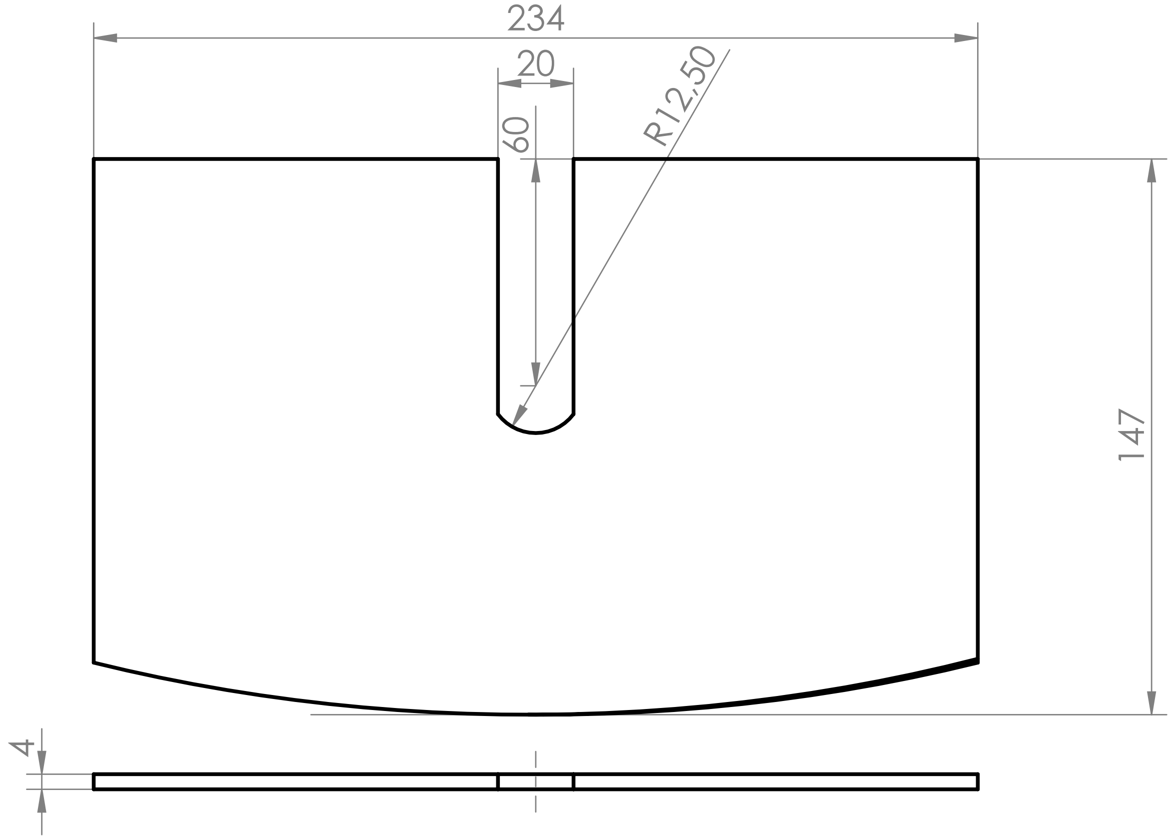


Date : 11.03.16	Drawn bt : F.L & H.G	Projection	Scale: 1: 2	NMBU
Quantity: 2	Material: AISI 304	Unit of measure: mm		
Middle Paddle				Replacement for: / Replaced by:
Mixer Rotor				N-002-003
Refferal:		Calculation: F.L & H.G		

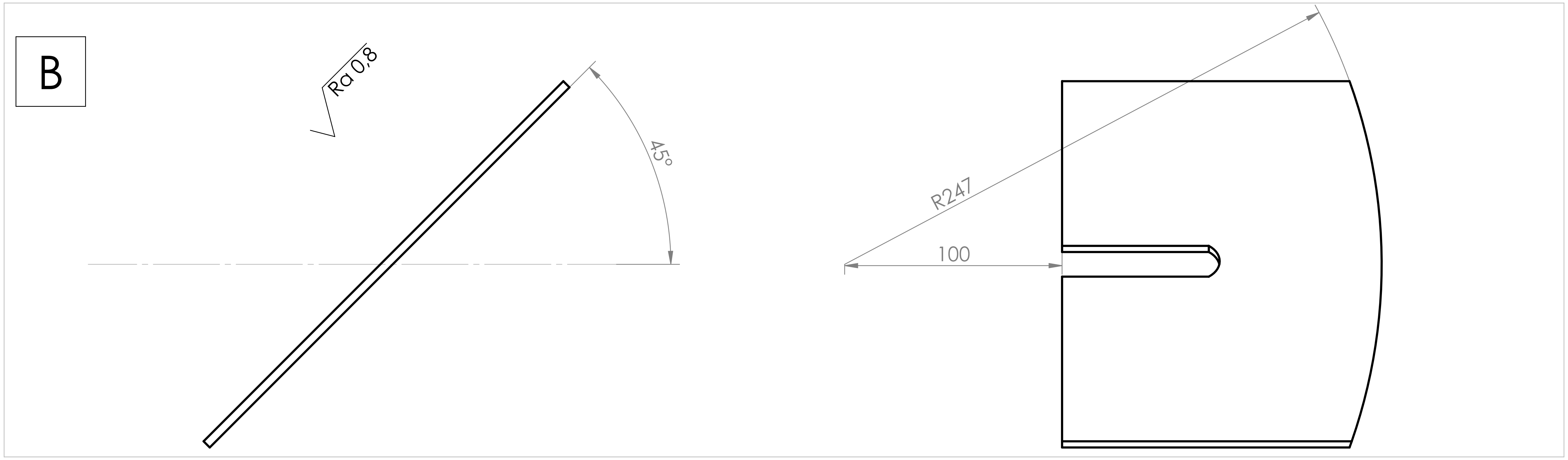


Date: 05.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 2	Material: AISI 304	Unit of measure: mm		

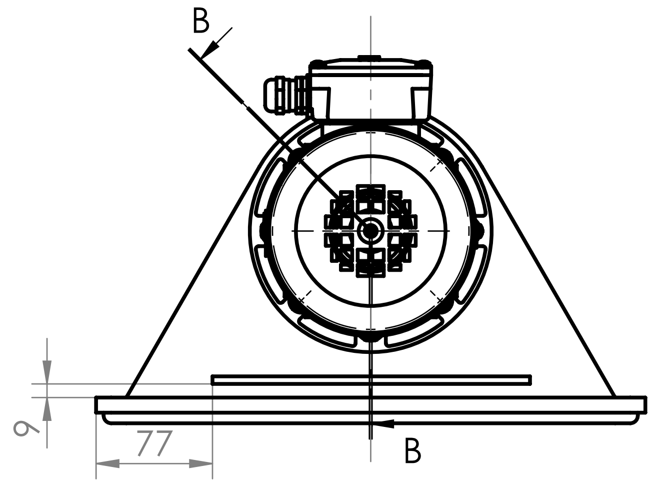
End Rod	Replacement for:	Replaced by:
Mixer Rotor	N-002-004	
Referral:	Calculation: F.L & H.G	



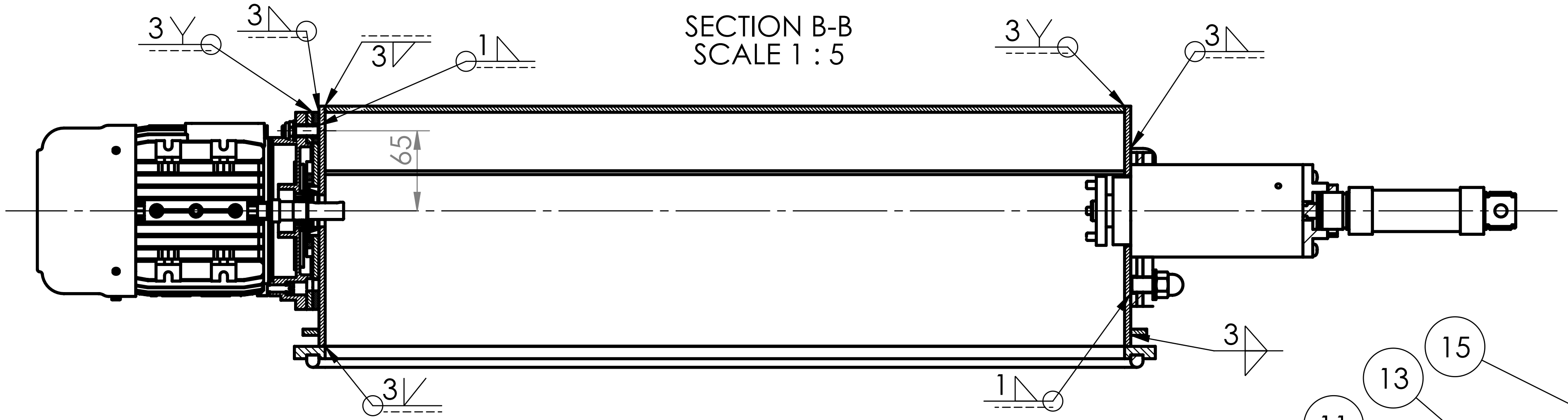
The Paddle is to mounted at 15 degree angle when assembeled with the rest of the mixer shaft.
As a result the paddle will have to be cut/grinded in a simerlar fashion as shown in section B, making the outer edge twist around itself.



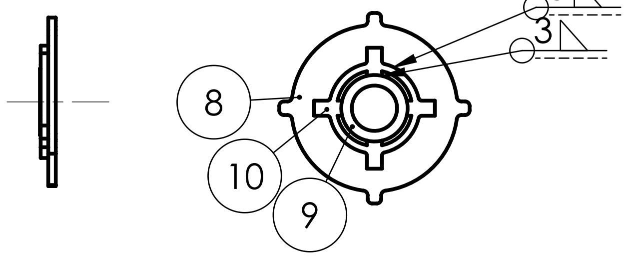
Date: 11.03.16	Drawn by: F.L & H.G	Projection:	Scale: 1: 2	NMBU
Quantity: 4	Material: AISI 304	Unit of measure: mm		
End Paddle				Replacement for: / Replaced by:
Mixer Rotor				N-002-005
Referral:	Calculation: F.L & H.G			

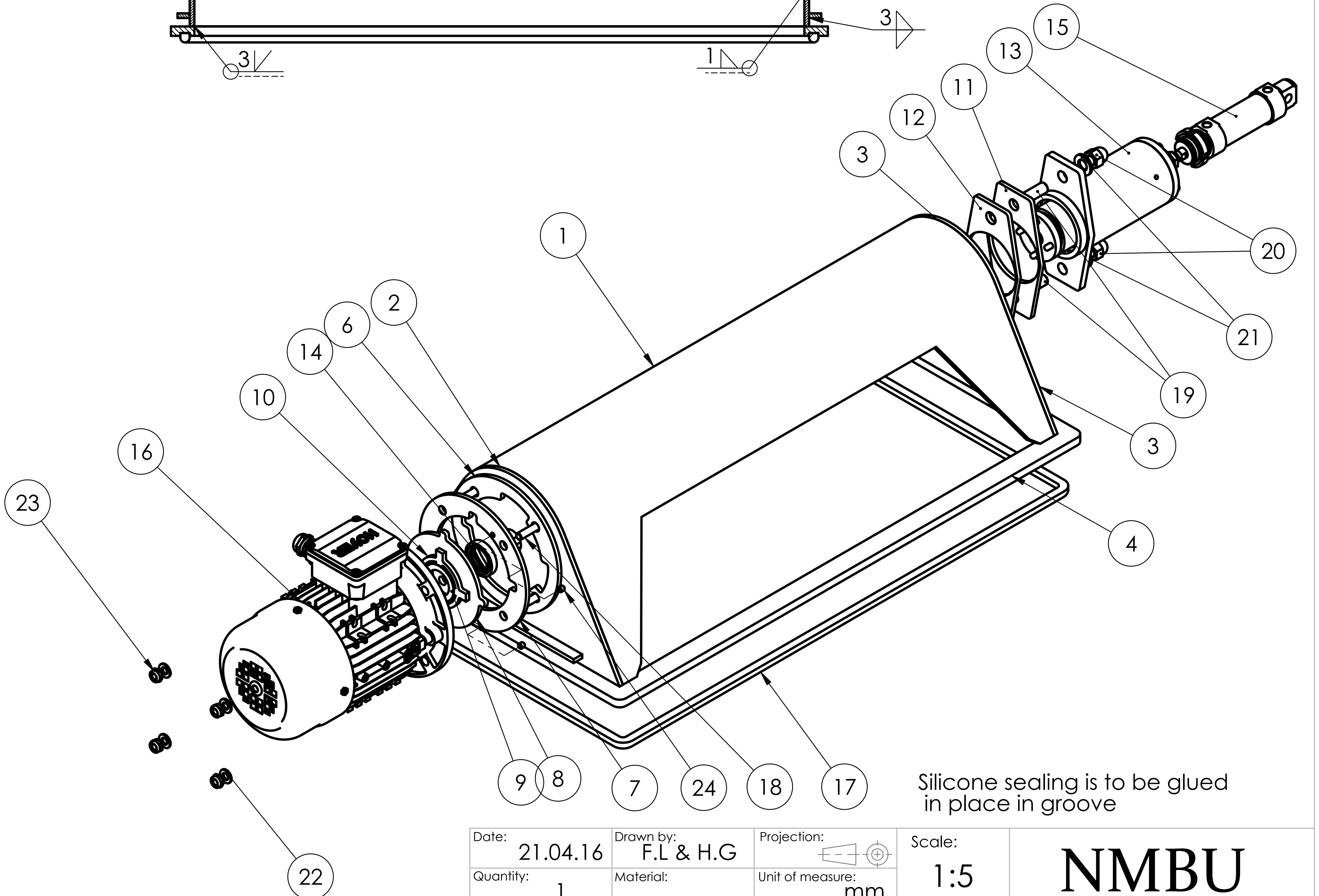


SECTION B-B
SCALE 1 : 5



Sealing Housing sub-assembly





Silicone sealing is to be glued in place in groove

Pos.	QTY.	Part Name	Material
24	2	DIN 916 - M6 x 6-N	
23	4	DIN EN ISO 10511 - M8 - N	
22	4	Washer DIN 125 - A 8.4	
21	2	washer din 125 - a 13	
20	2	DIN 1587 - M12 --NUC	
19	2	din 976-1 -- m12 x 35 a-- n	
18	4	DIN 976-1 -- M8 x 30 A-- N	
17	1	Silicone Sealing D 10x10	Silicone
16	1	HOYER - HMA2-71-B5-708801	
15	1	FESTO - 196021_DSNU-32-40-PPV-A_2_14a	
14	1	SKF - 26X40X8 HMS1 R	
13	1	F-002 - Pneumatic Drive System	
12	1	N-003-012 - Modified Forberg Plate -B	AISI 304
11	1	N-003-011 - Modified Forberg Plate -A	AISI 304
10	1	N-003-010 - Moment Cross	AISI 304
9	1	N-003-009 - Sealing Housing	AISI 304
8	1	N-003-008 - Locking Plate	AISI 304
7	1	N-003-007 - Buffer Plate	AISI 304
6	1	N-003-006 - Stud Plate	AISI 304
5	2	N-003-005 - Mounting Rail	AISI 304
4	1	N-003-004 - Grooved Flange	AISI 304
3	1	N-003-003 - End Wall - B	AISI 304
2	1	N-003-002 - End Wall - A	AISI 304
1	1	N-003-001 - Semi Cylinfrical Wall	AISI 304

Date: 21.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material:	Unit of measure: mm		

De-agglomerator Lid

RMVC

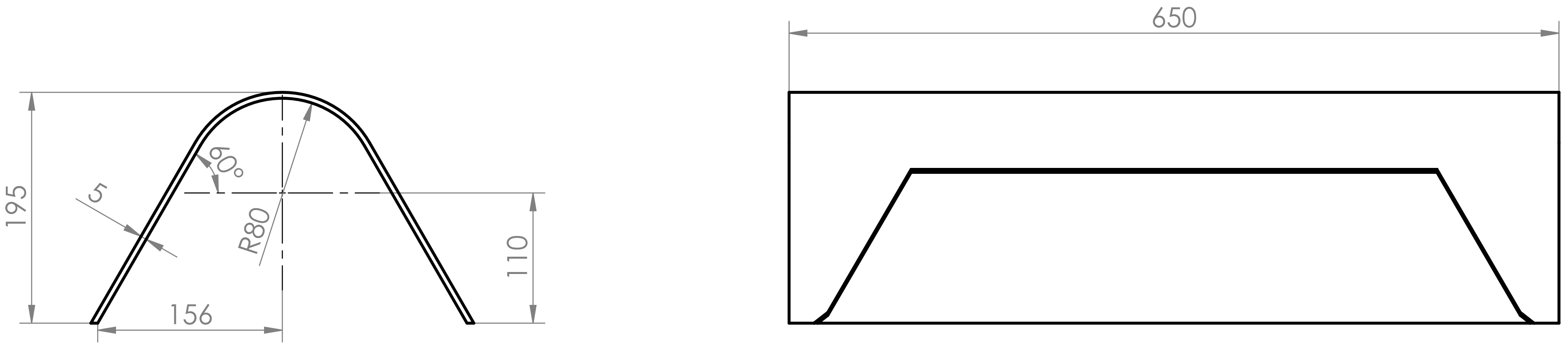
Replacement for:

Replaced by:

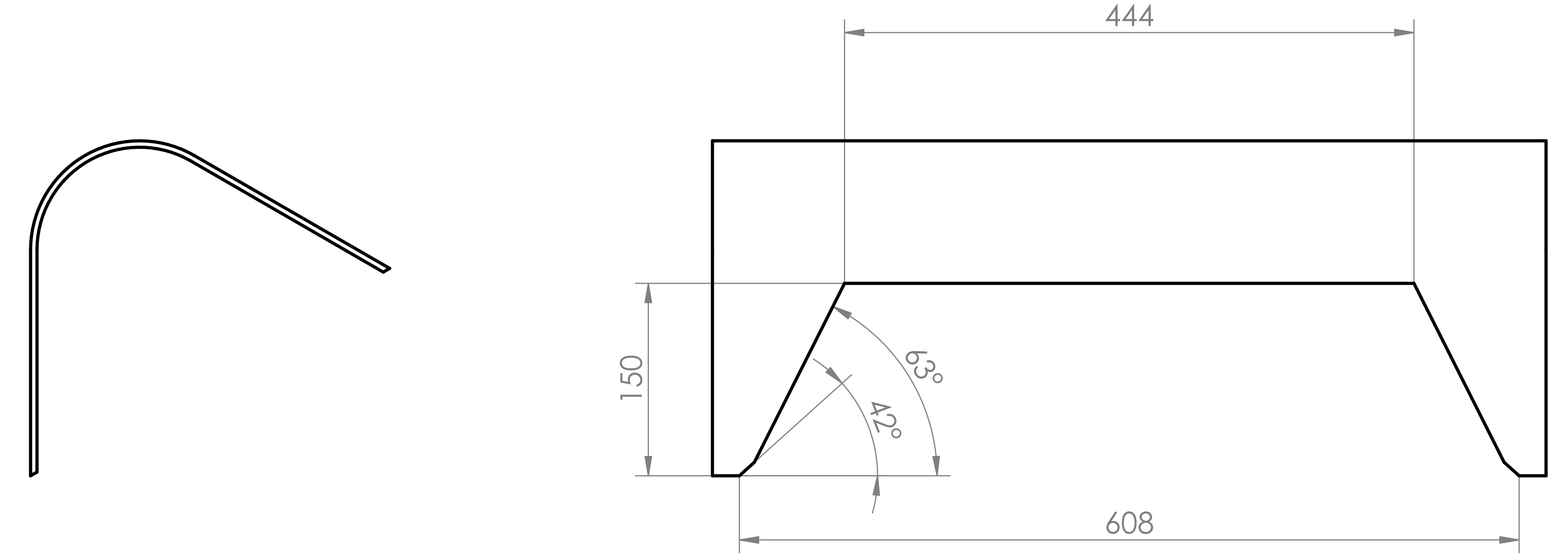
N-003

Referral:

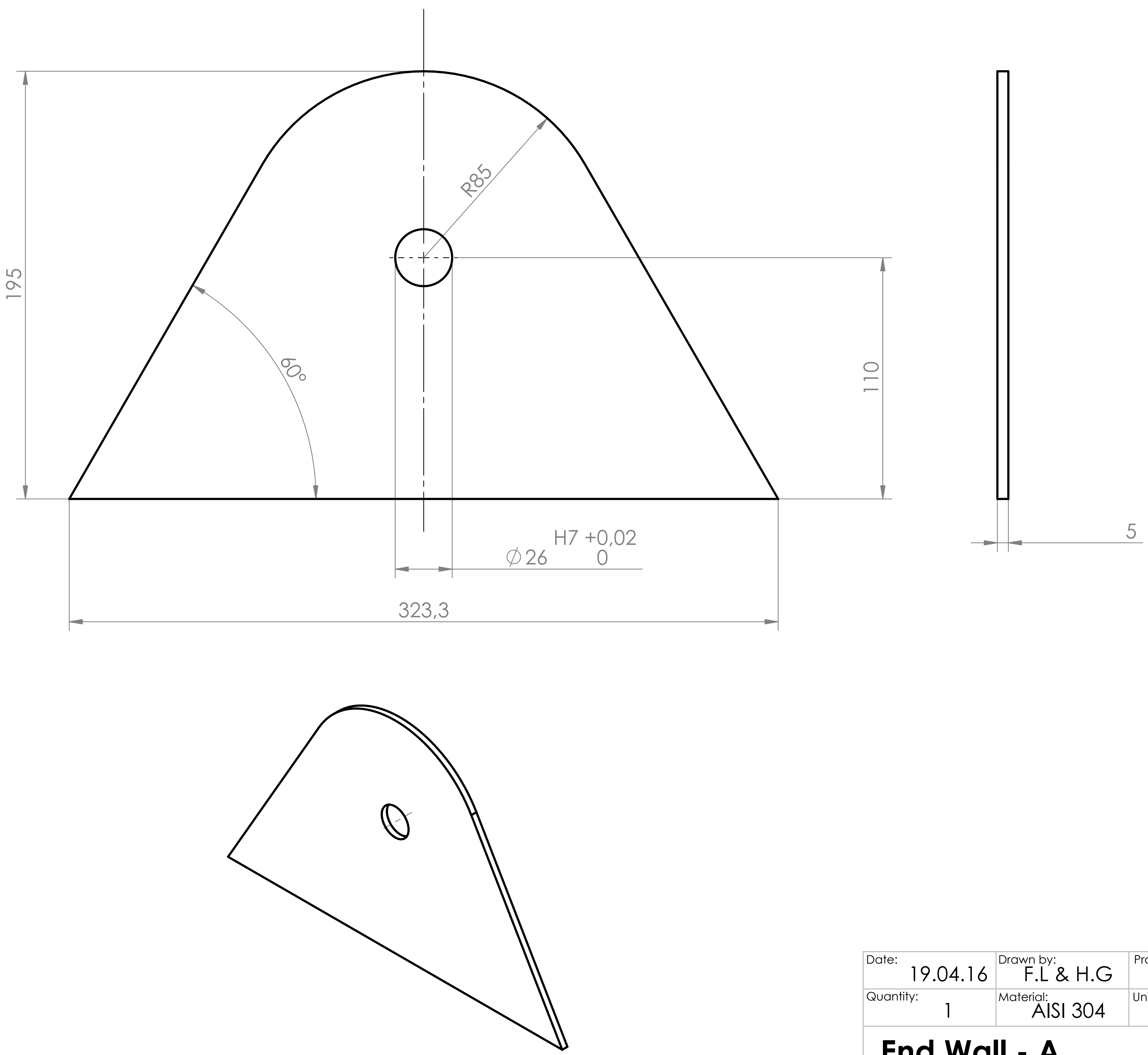
Calculation: F.L & H.G



Rotated 30 degrees

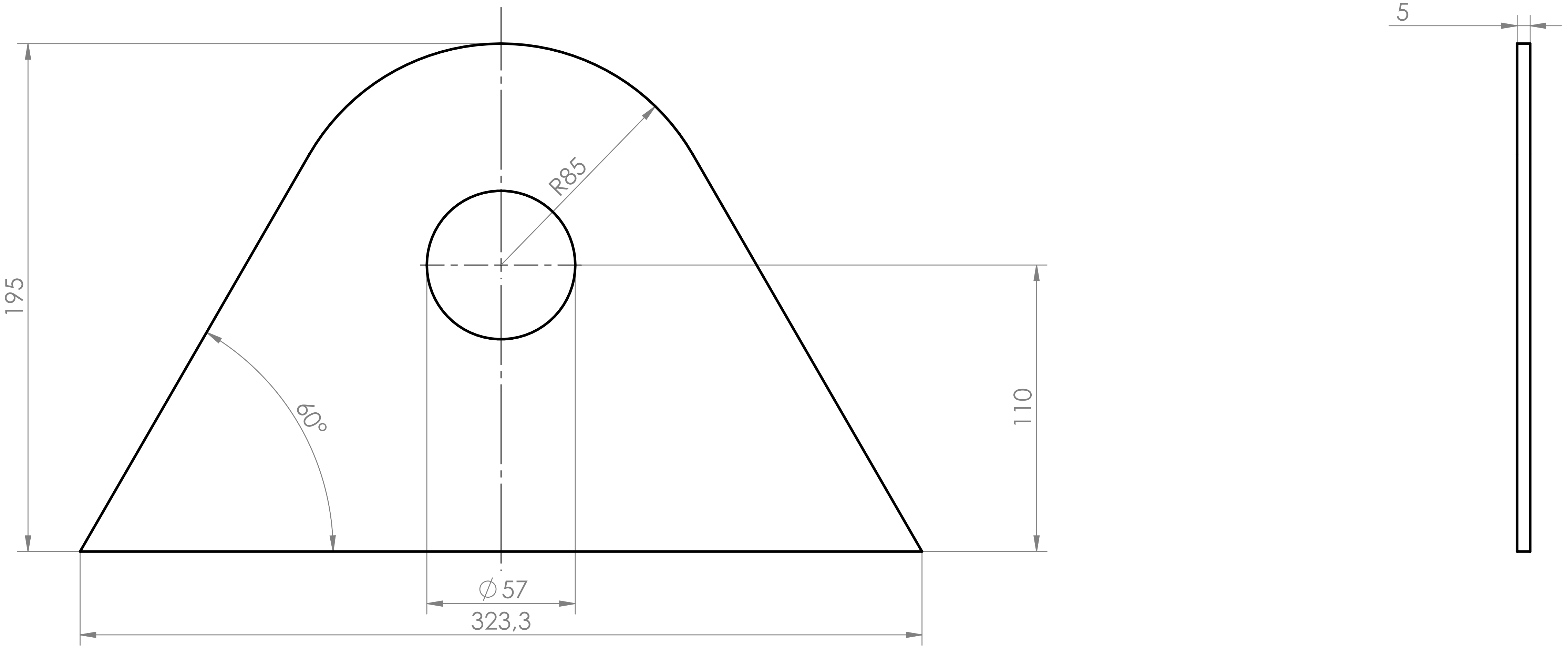


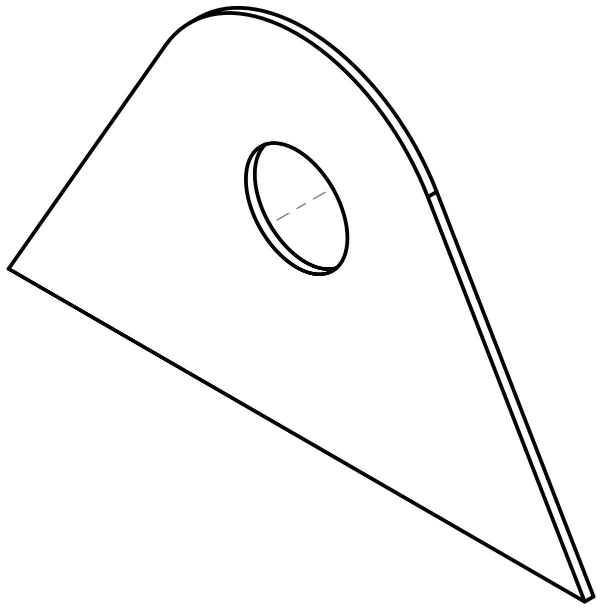
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Semi Cylindrical Wall				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-001
Referral:		Calculation: F.L & H.G		



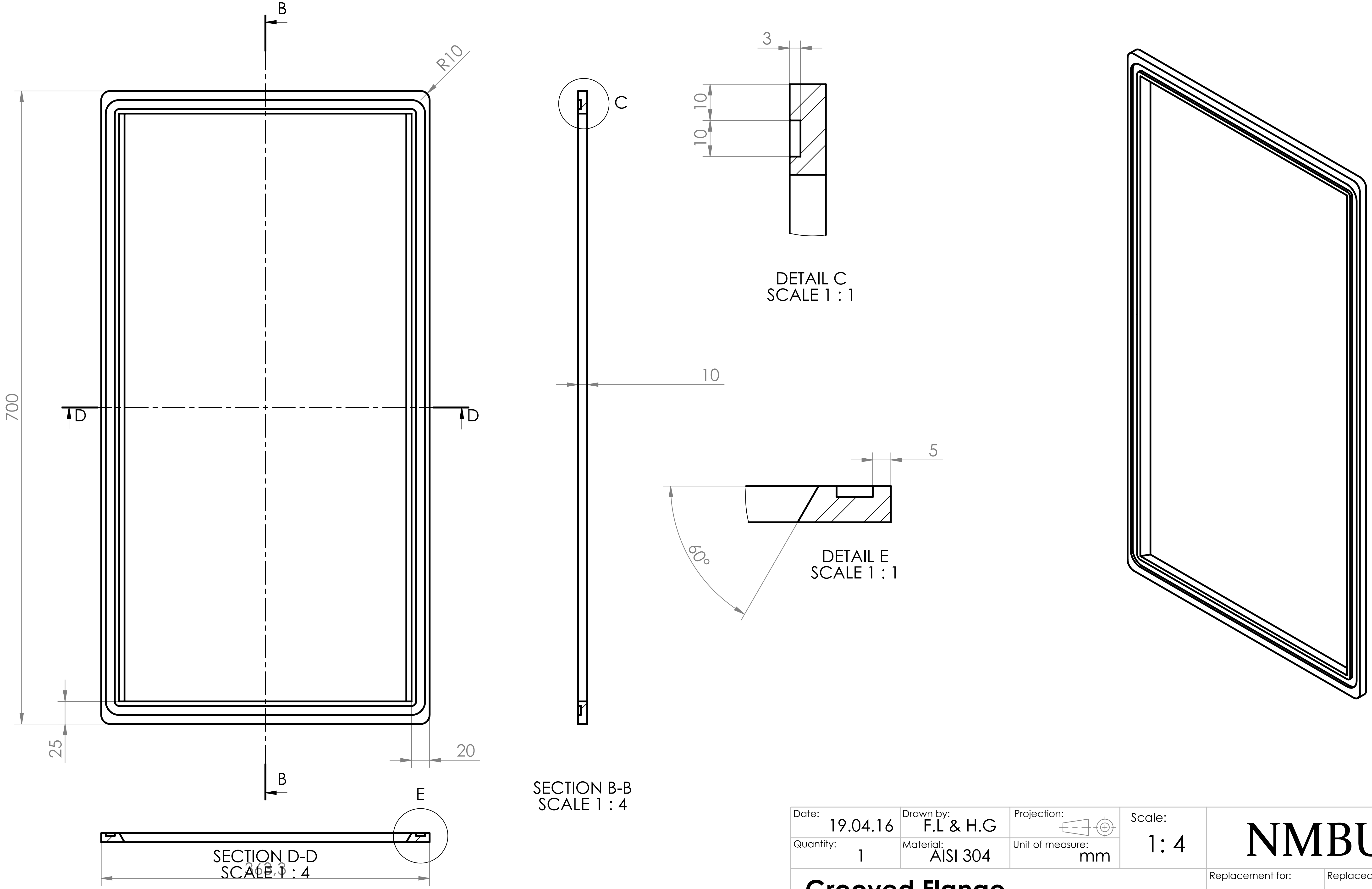
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1: 2	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

End Wall - A De-agglomerator Lid	Replacement for: / Replaced by: N-003-002
Referral:	Calculation: F.L & H.G

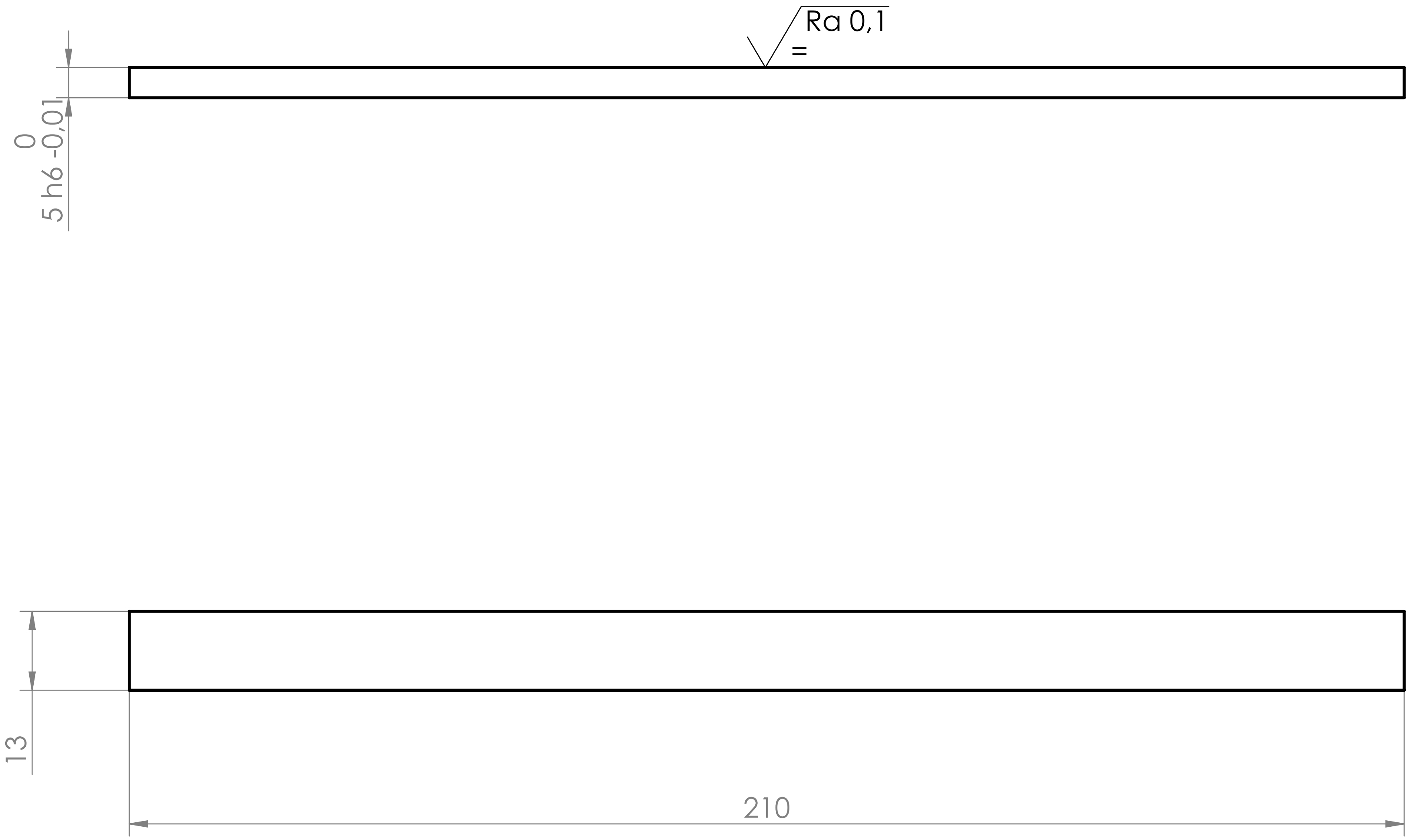




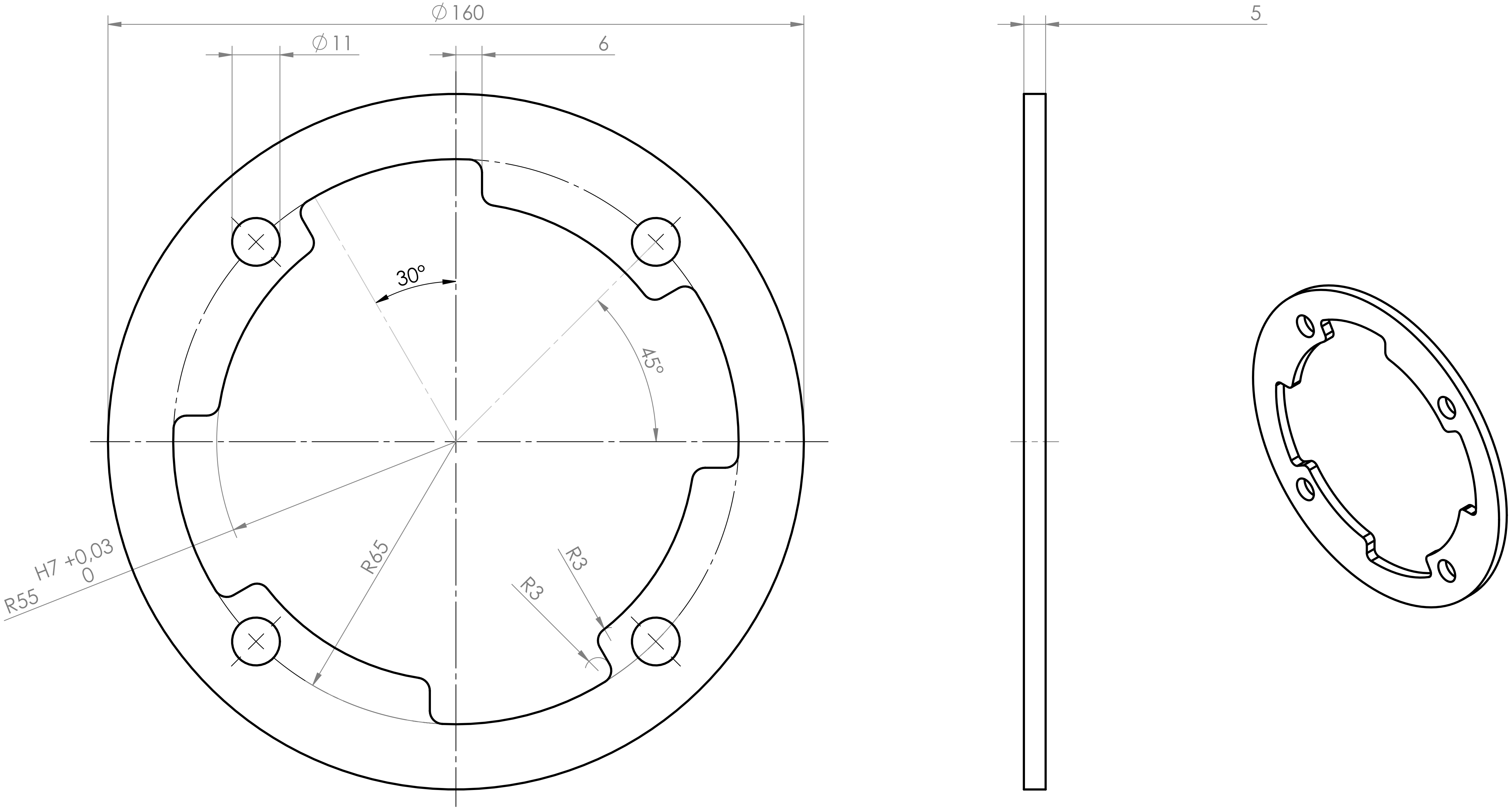
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1: 2	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
End Wall - B				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-003
Referral:		Calculation: F.L & H.G		



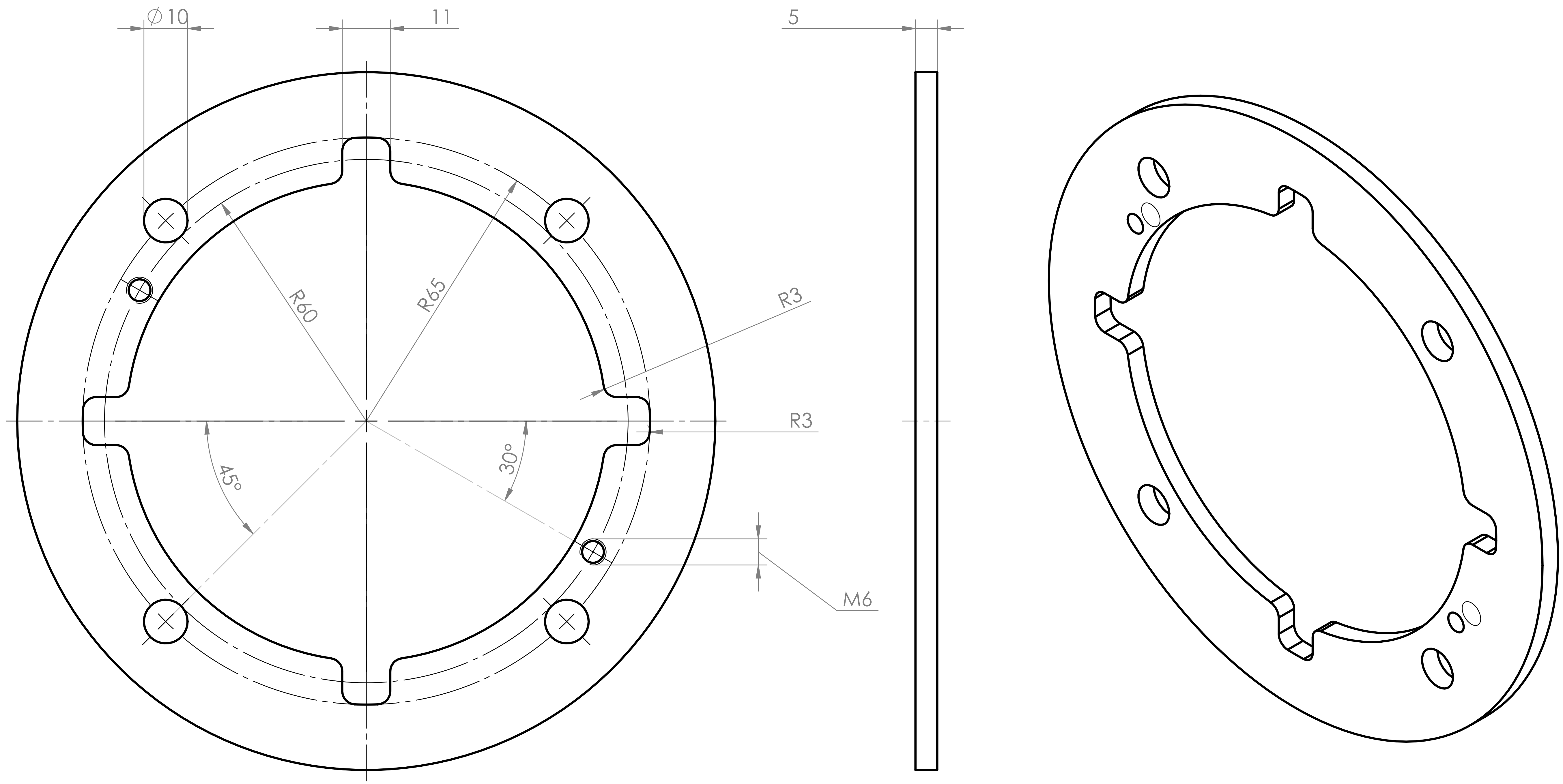
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1: 4	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for: / Replaced by:
Grooved Flange De-agglomerator Lid				N-003-004
Referral:	Calculation: F.L & H.G			



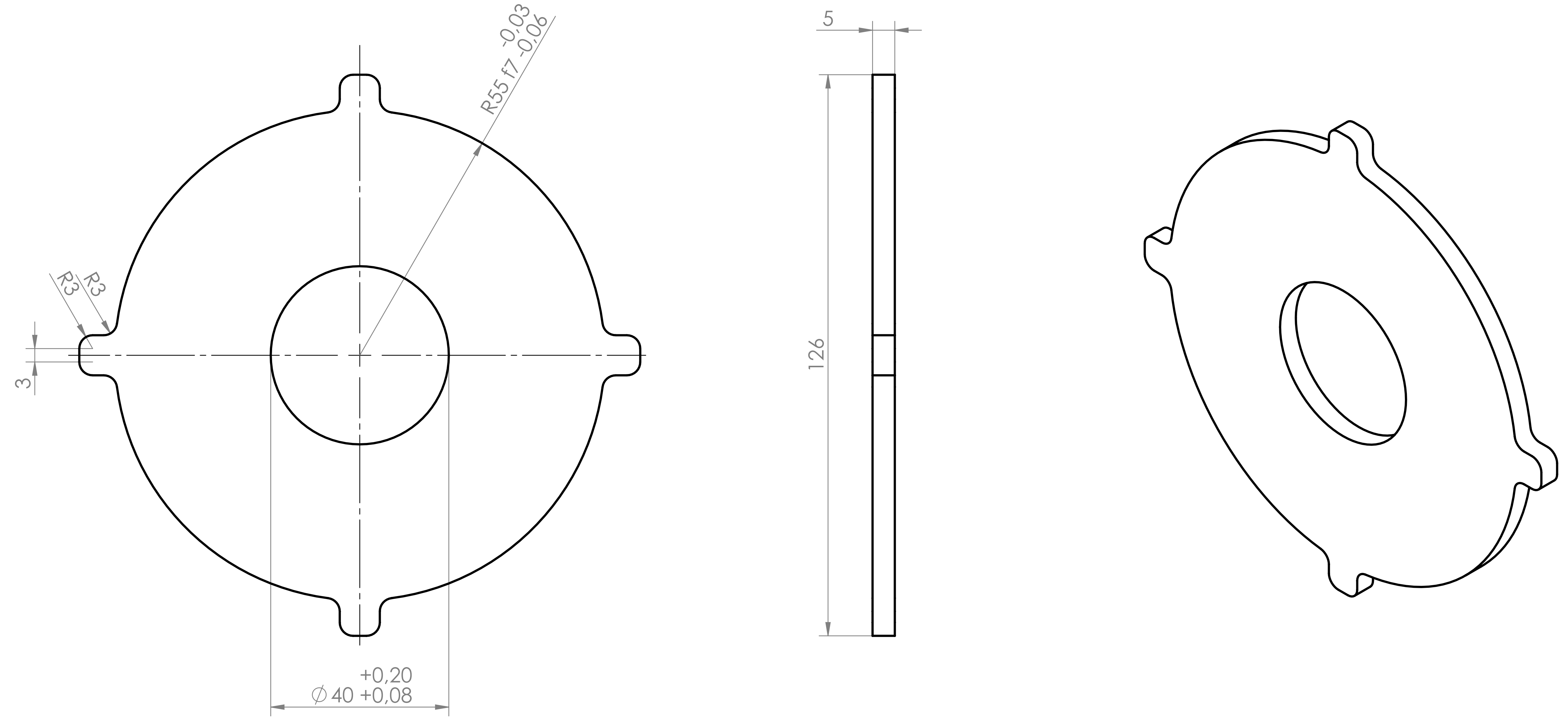
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 2	Material: AISI 304	Unit of measure: mm		
Mounting Rail				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-005
Referral:		Calculation: F.L & H.G		



Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Stud Plate				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-006
Referral:		Calculation: F.L & H.G		



Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Buffer Plate				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-007
Referral:	Calculation: F.L & H.G			



Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

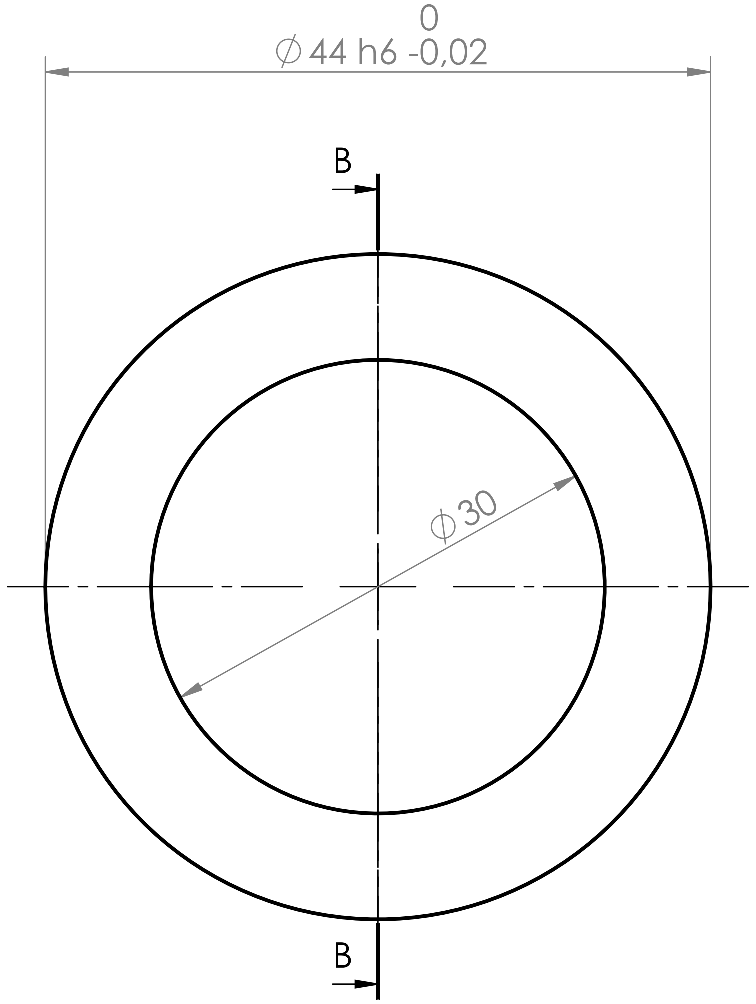
Locking Plate

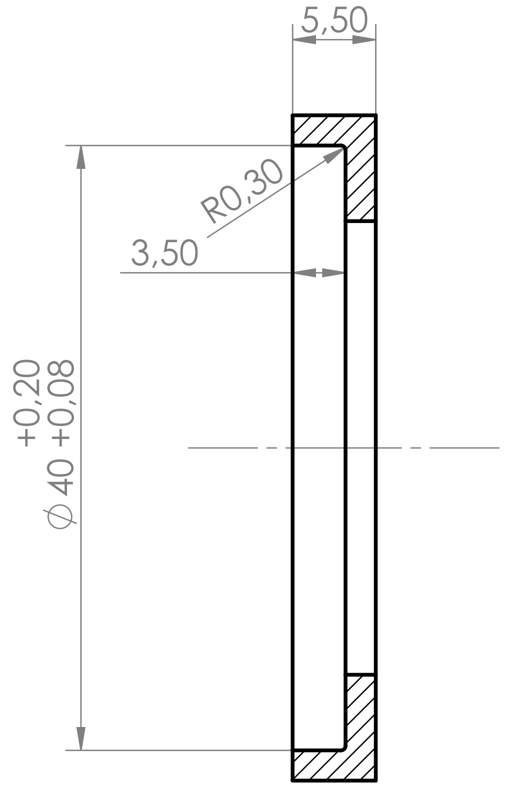
De-agglomerator Lid

Replacement for:	Replaced by:

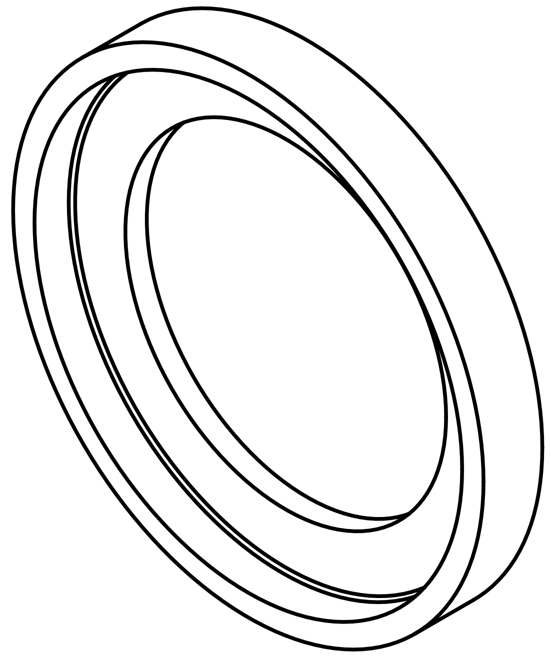
N-003-008

Referral:	Calculation: F.L & H.G

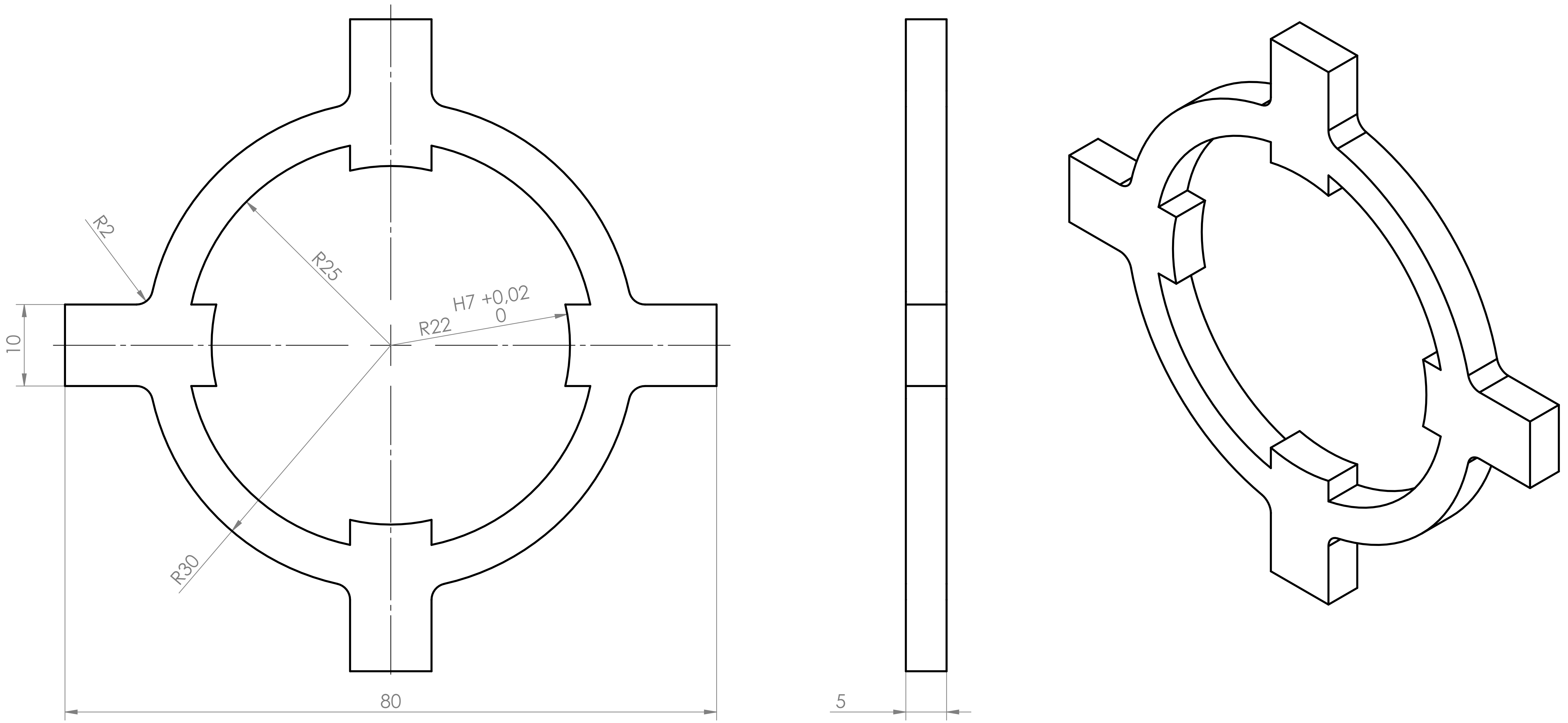




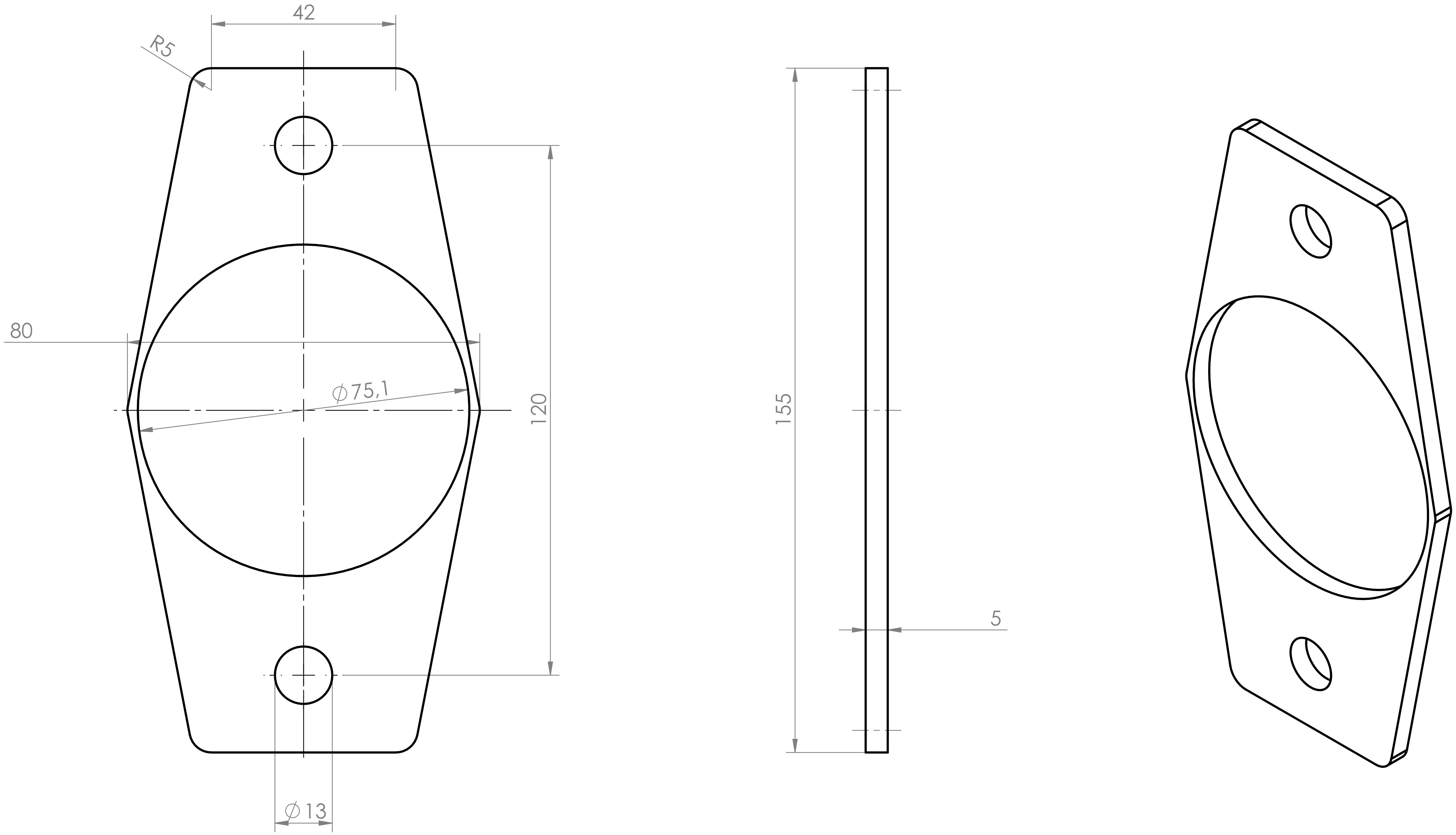
SECTION B-B
SCALE 2 : 1



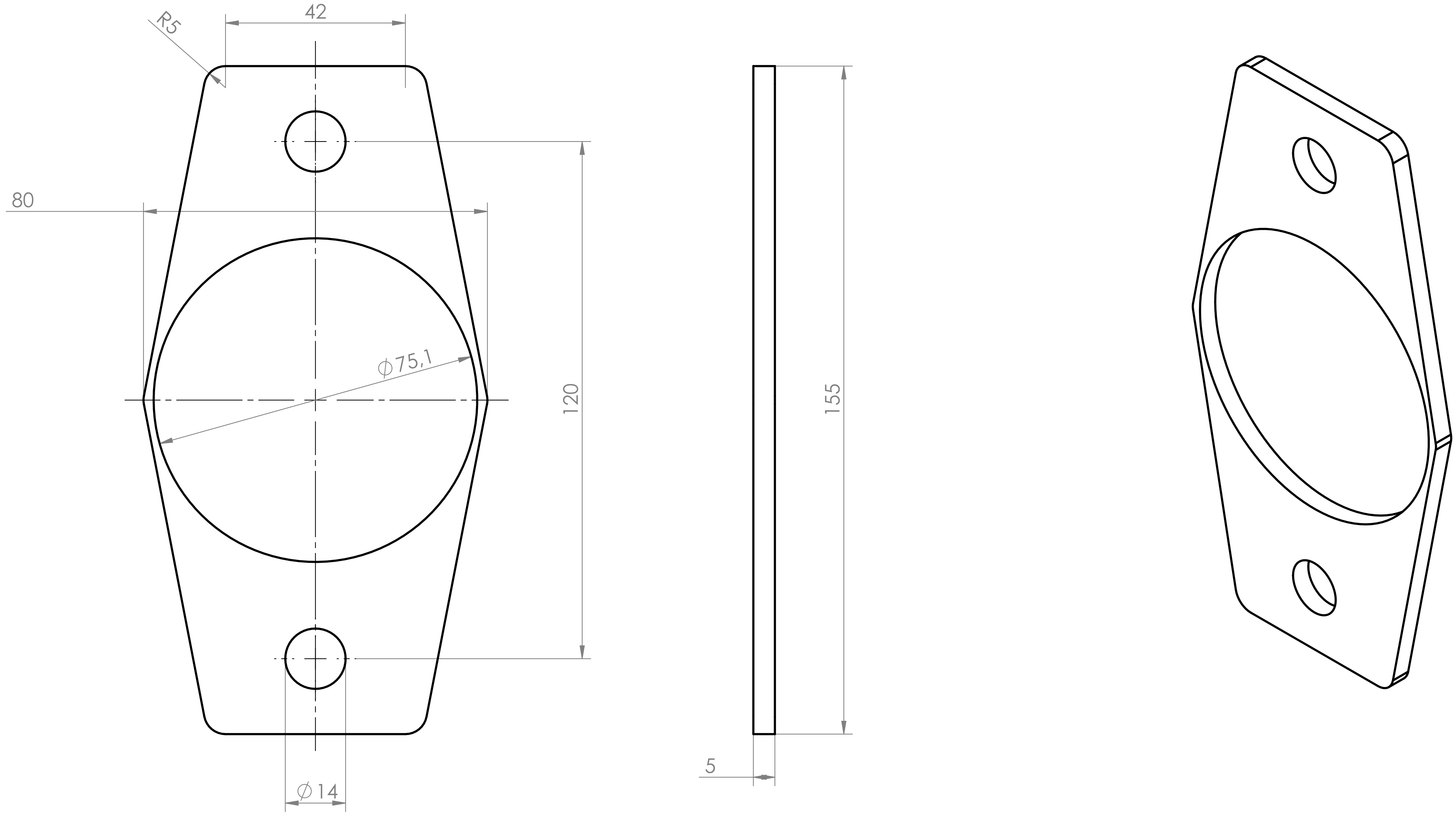
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Sealing Housing				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-009
Referral:		Calculation: F.L & H.G		



Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Moment Cross				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-010
Referral:	Calculation: F.L & H.G			



Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Modified Forberg Plate - A				Replacement for: / Replaced by:
De-agglomerator Lid				N-003-011
Referral:	Calculation: F.L & H.G			



Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

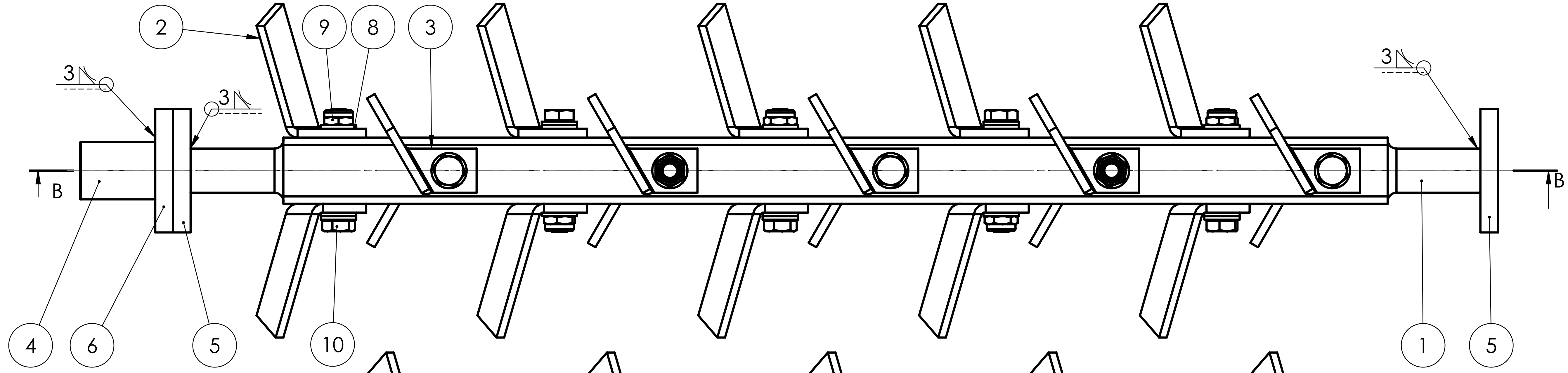
Modified Forberg Plate - B

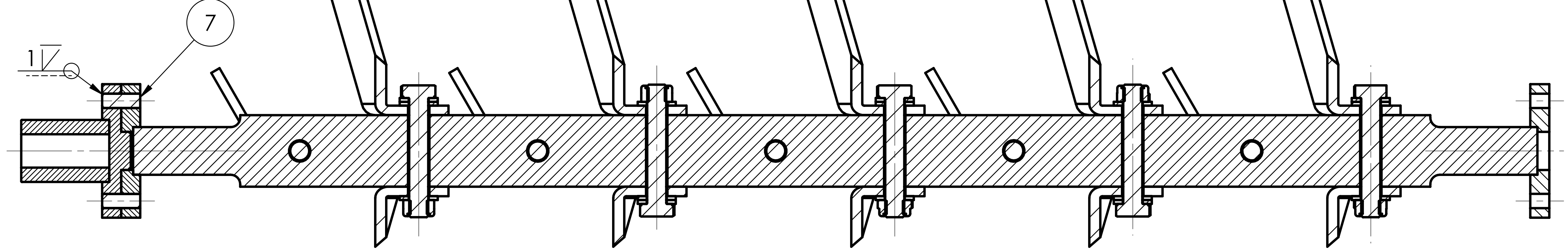
De-agglomerator Lid

Replacement for:	Replaced by:

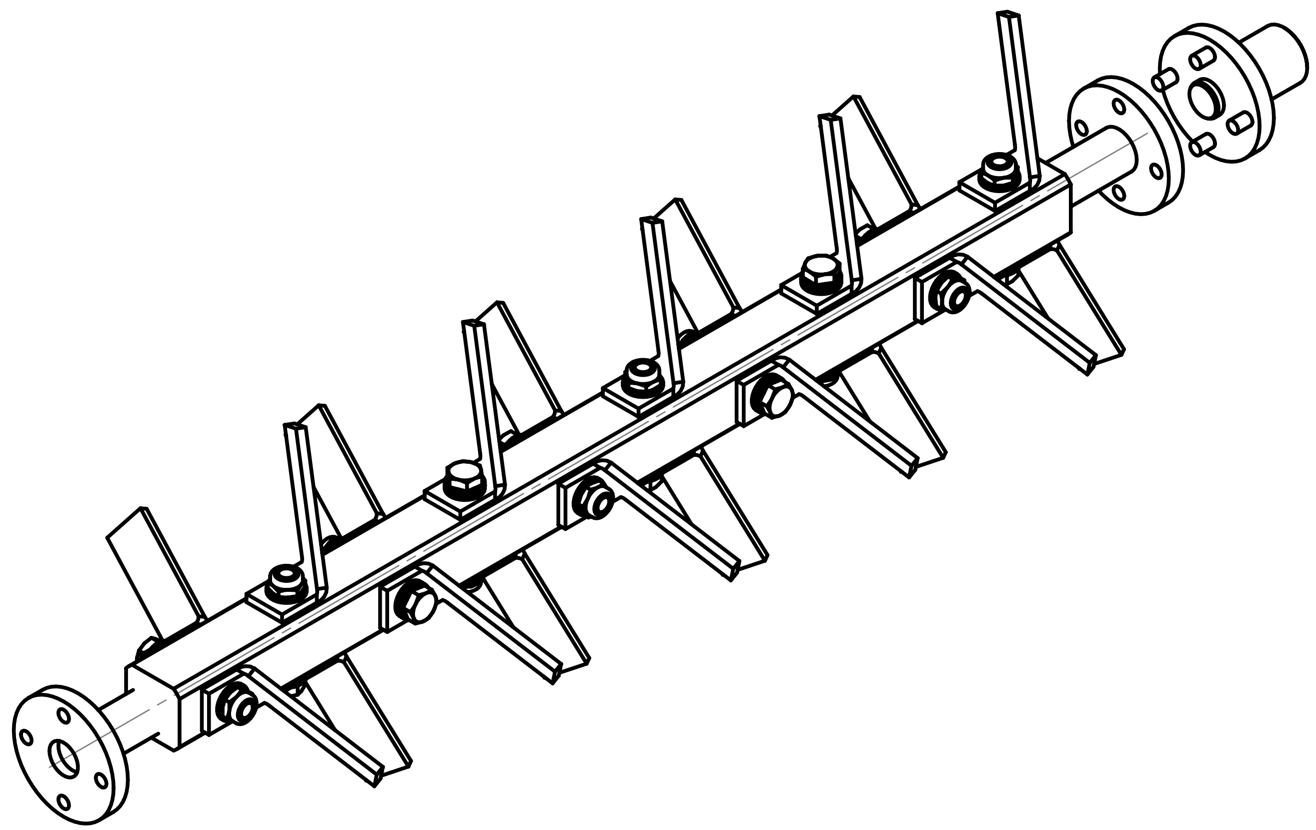
N-003-012

Referral:	Calculation: F.L & H.G





SECTION B-B
SCALE 1 : 2



Flange D56-2 shall not be welded to Flange D56 as this should be easily detachabale

Pos.	Qty.	Part Name	Material
10	10	ISO 4014 - M8 x 50 x 22-N	AISI 304
9	10	DIN EN ISO 10511 - M8 - N	AISI 304
8	30	Washer DIN 125 - A 8.4	AISI 304
7	4	F-005 - Part D6 L16	AISI 304
6	1	F-004 - Flange D56-2	AISI 304
5	2	F-003 - Flange D56	AISI 304
4	1	N-004-004 - Motor Coupling	AISI 304
3	10	N-004-003 - Bent Flat Steel - B	AISI 304
2	10	N-004-002 - Bent Flat Steel - A	AISI 304
1	1	N-004-001 - Shaft	AISI 304

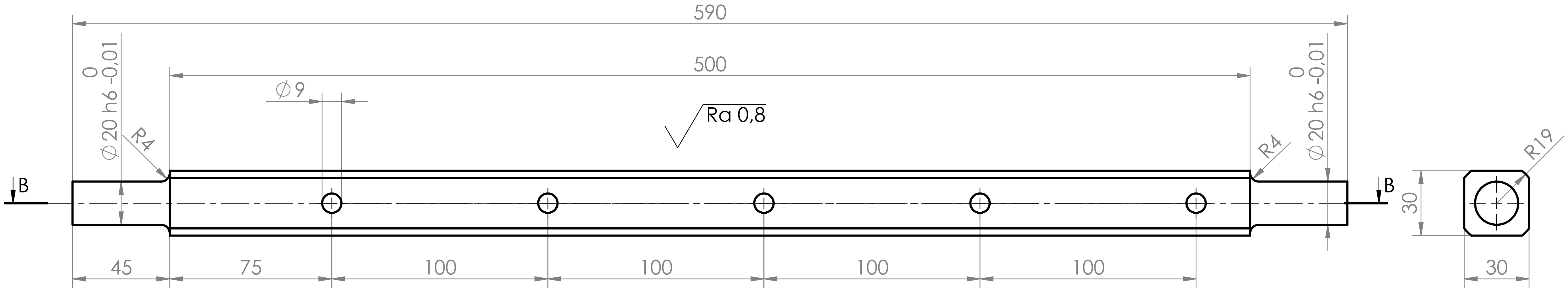
Date: 11.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

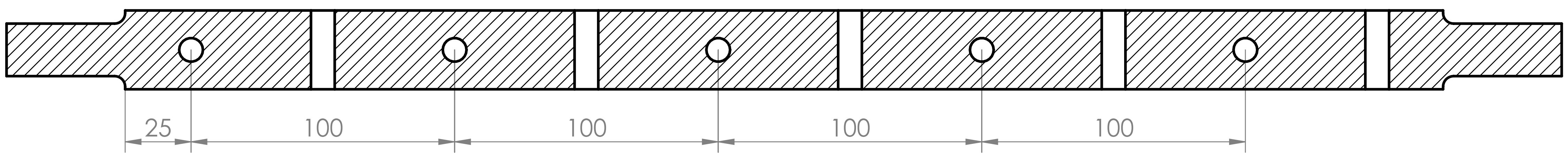
De-agglomerator

RMVC

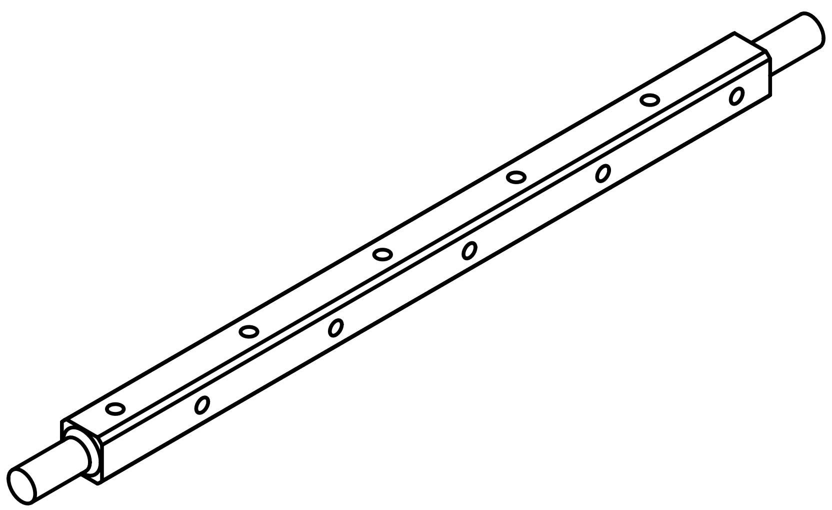
Replacement for:	Replaced by:
N-004	

Referral:	Calculation: F.L & H.G

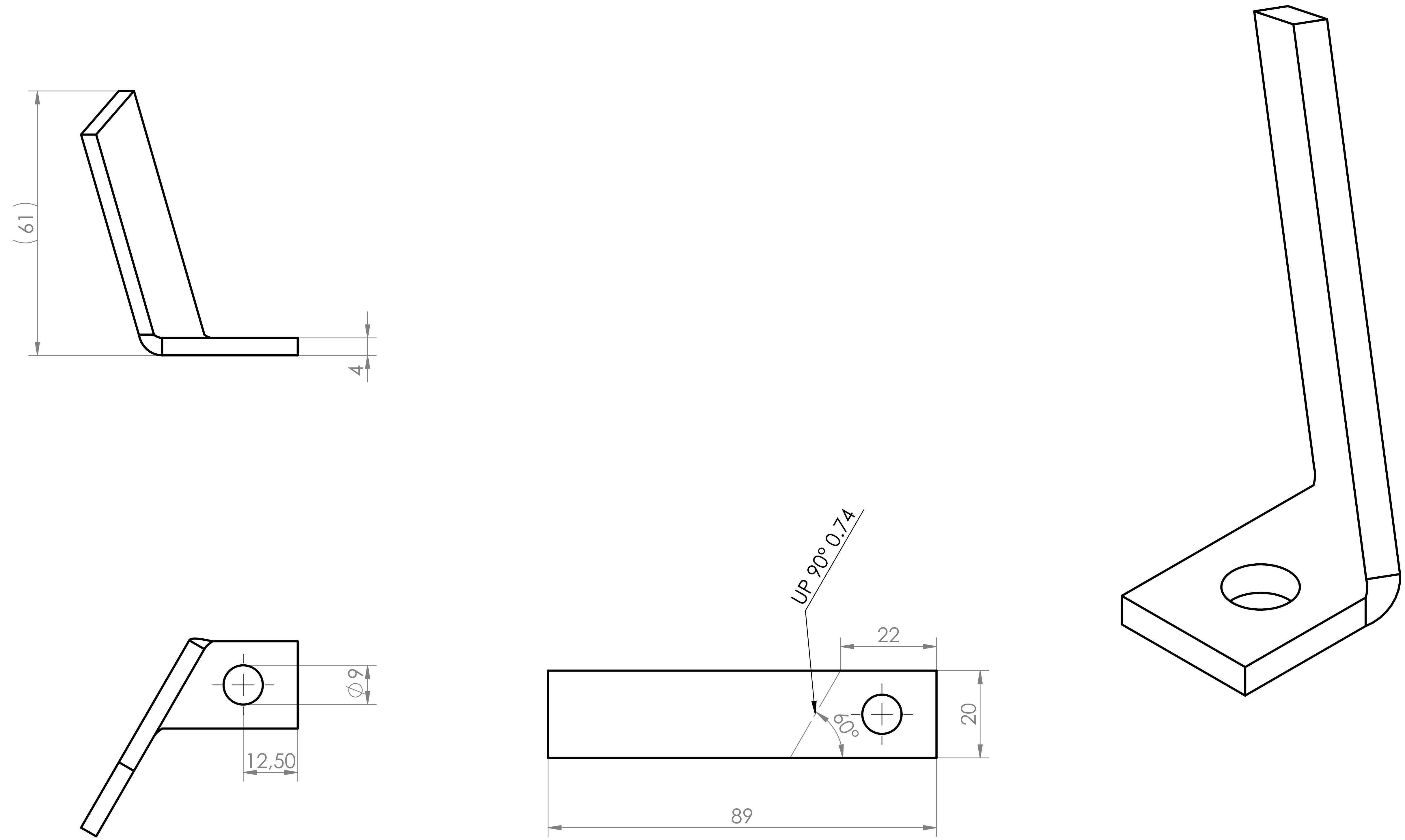




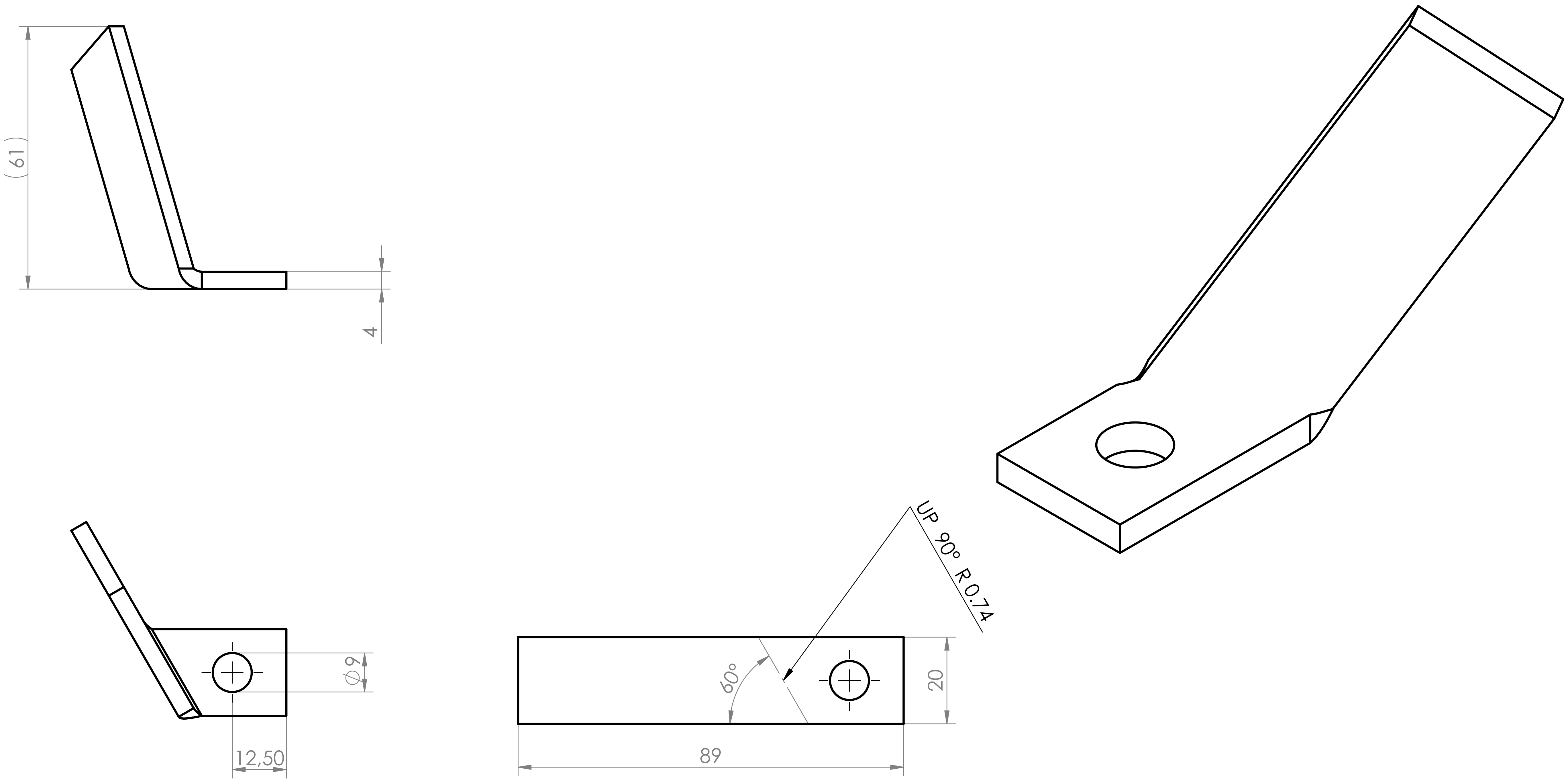
SECTION B-B
SCALE 1 : 2



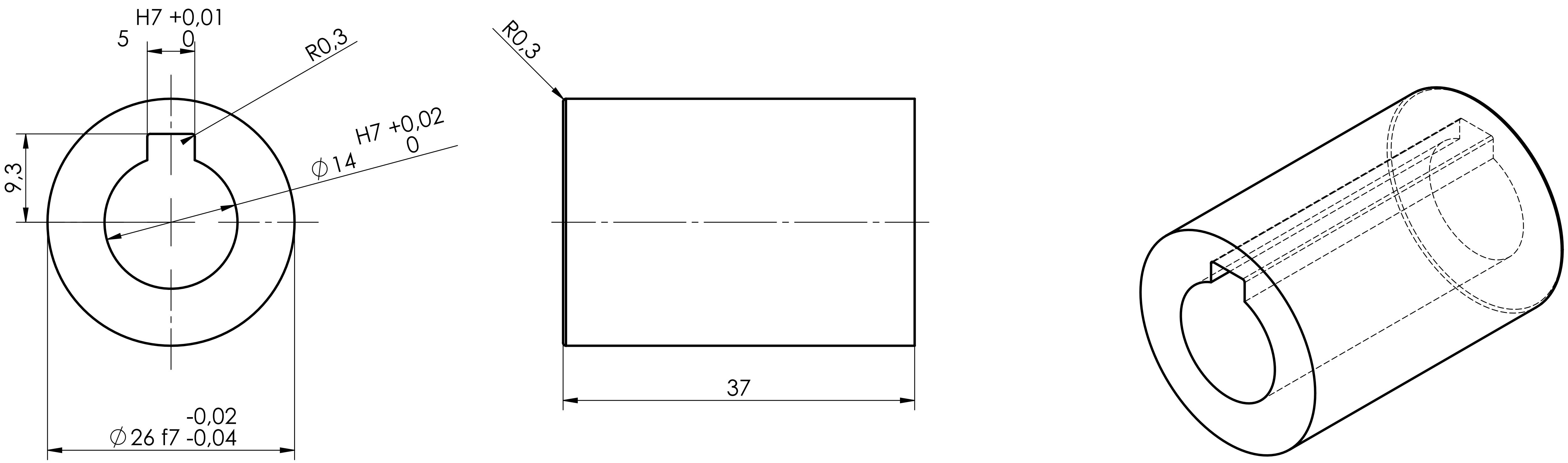
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Shaft				Replacement for: / Replaced by:
De-agglomerator				N-004-001
Referral:	Calculation: F.L & H.G			



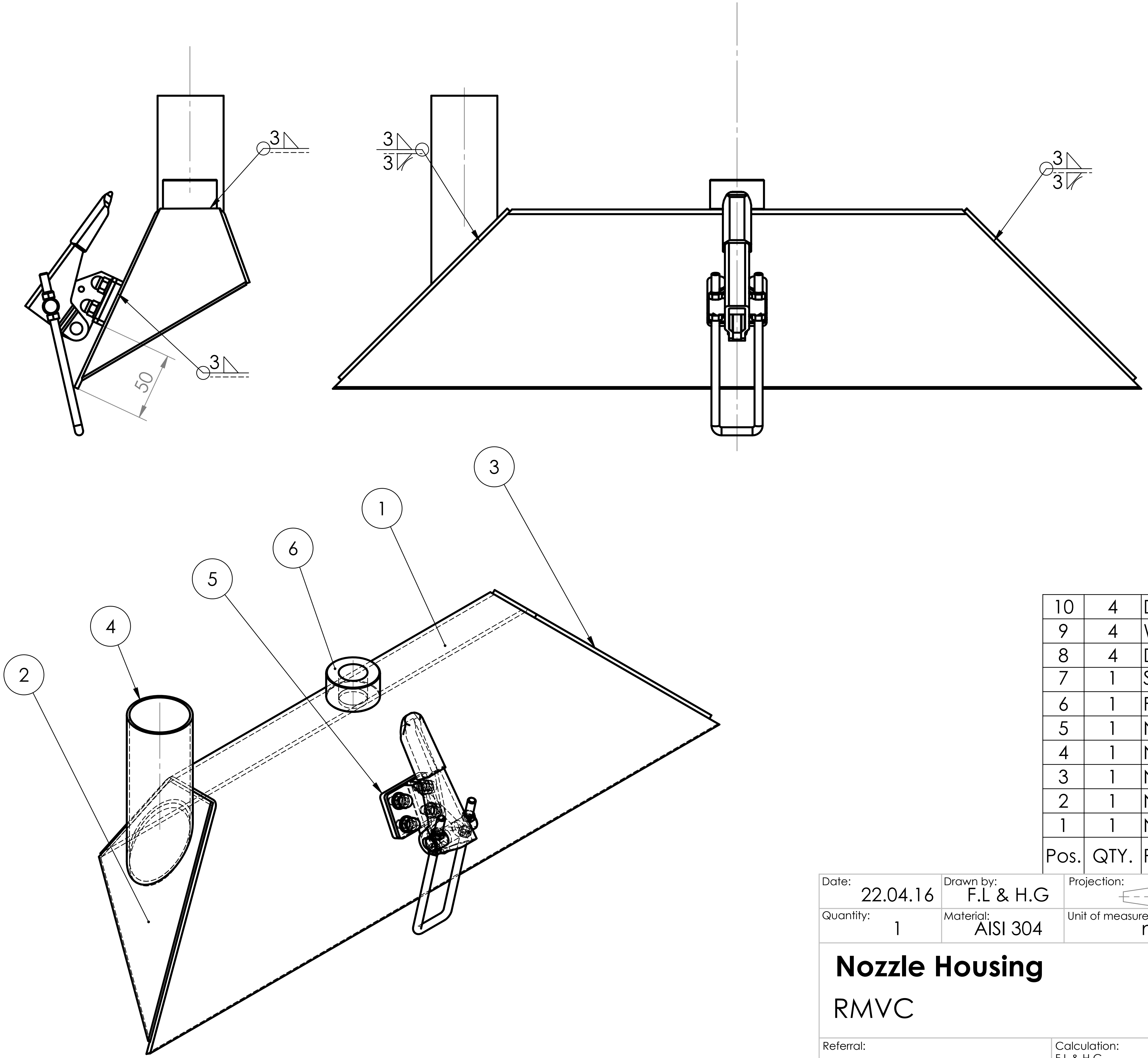
Date: 20.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 10	Material: AISI 304	Unit of measure: mm		
Bent Flat Steel A				Replacement for: / Replaced by:
De-agglomerator				N-004-002
Referral:	Calculation: F.L & H.G			



Date: 20.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 10	Material: AISI 304	Unit of measure: mm		
Bent Flat Steel - B				Replacement for: / Replaced by:
De-agglomerator				N-004-003
Referral:		Calculation: F.L & H.G		

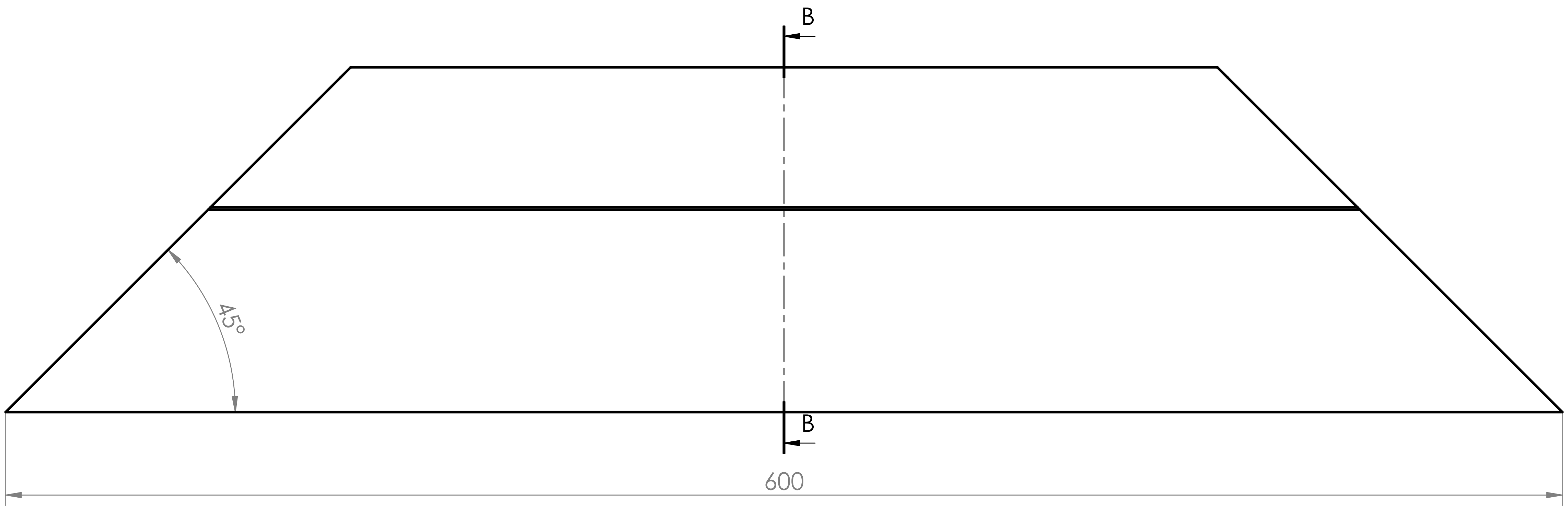


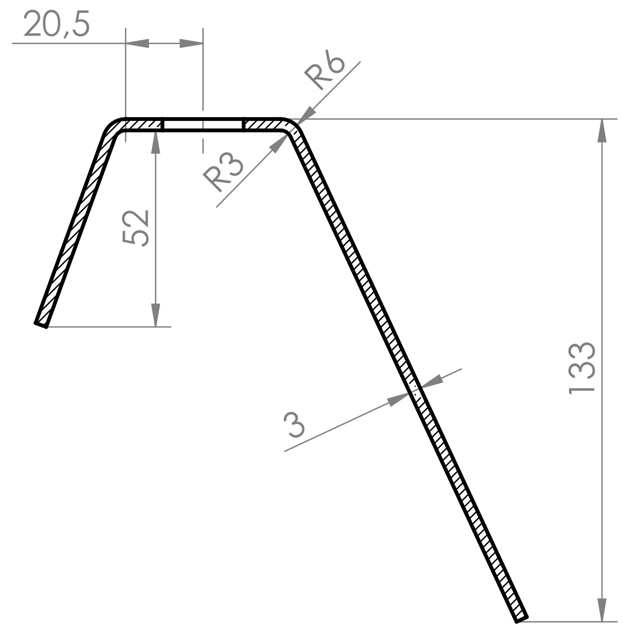
Date: 20.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Motor Coupling				Replacement for: / Replaced by:
De-agglomerator				N-004-004
Referral:		Calculation: F.L & H.G		



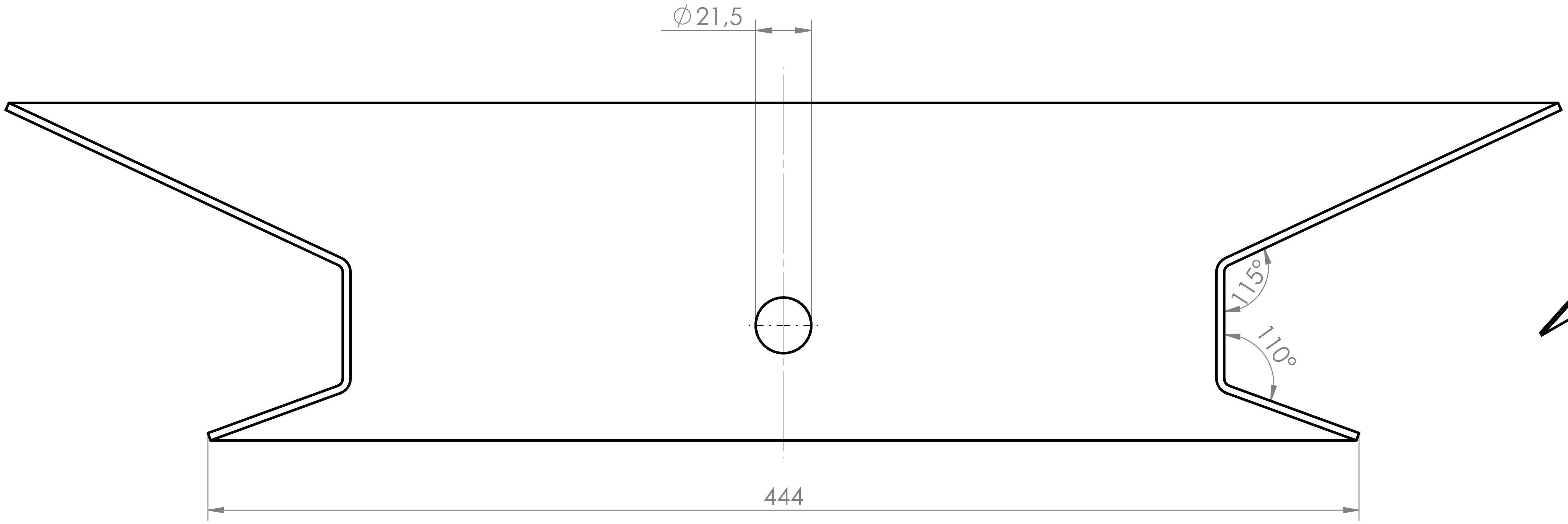
Pos.	QTY.	Part Name	Material
10	4	DIN 1587 - M6 --NNU	AISI 304
9	4	Washer DIN 125 - A 6.4	AISI 304
8	4	DIN 976-1 -- M6 x 16 A-- N	AISI 304
7	1	Speedyblock - AS535 - 320-T3X	
6	1	F-003 - Nozzle Holder	
5	1	N-005-005 - Stud Plate	AISI 304
4	1	N-005-004 - Filter Holder	AISI 304
3	1	N-005-003 - End Wall - B	AISI 304
2	1	N-005-002 - End Wall - A	AISI 304
1	1	N-005-001- Bendt Wall	AISI 304

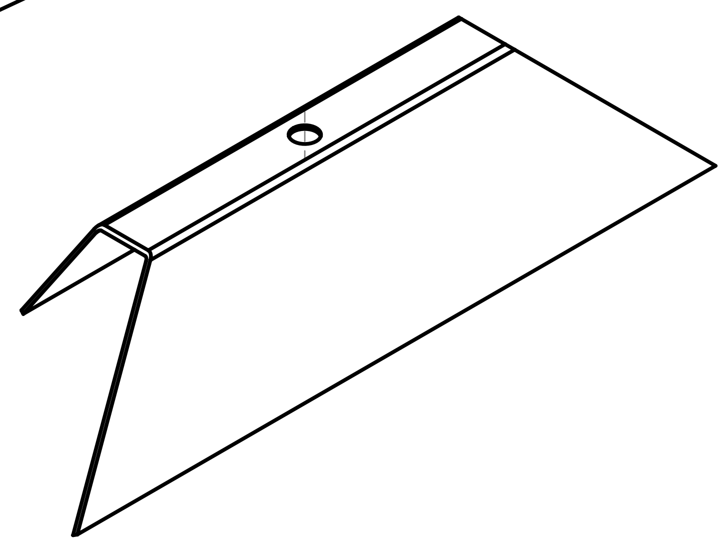
Date: 22.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:3	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Nozzle Housing RMVC				Replacement for: / Replaced by: N-005
Referral:		Calculation: F.L & H.G		



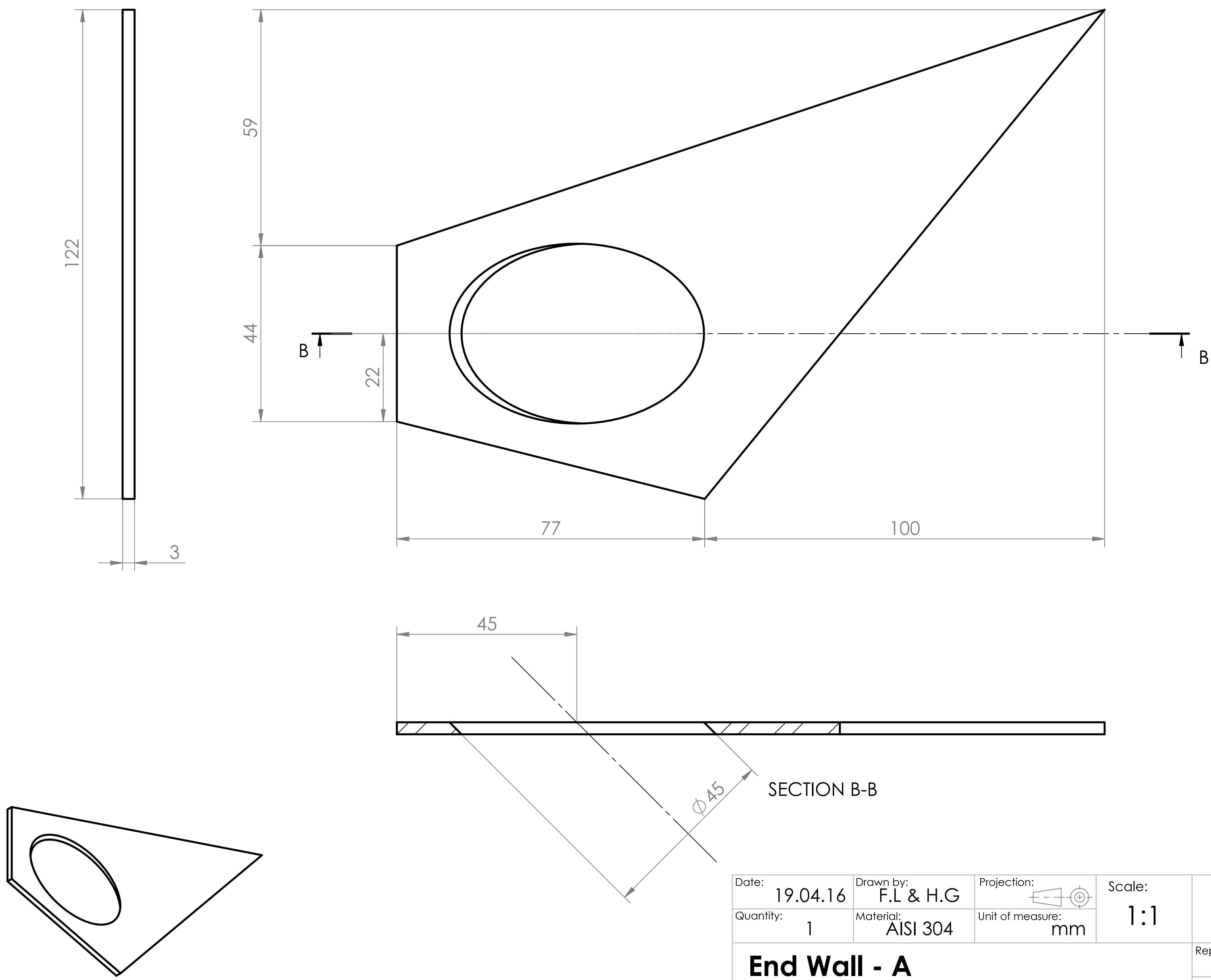


SECTION B-B
SCALE 1 : 2

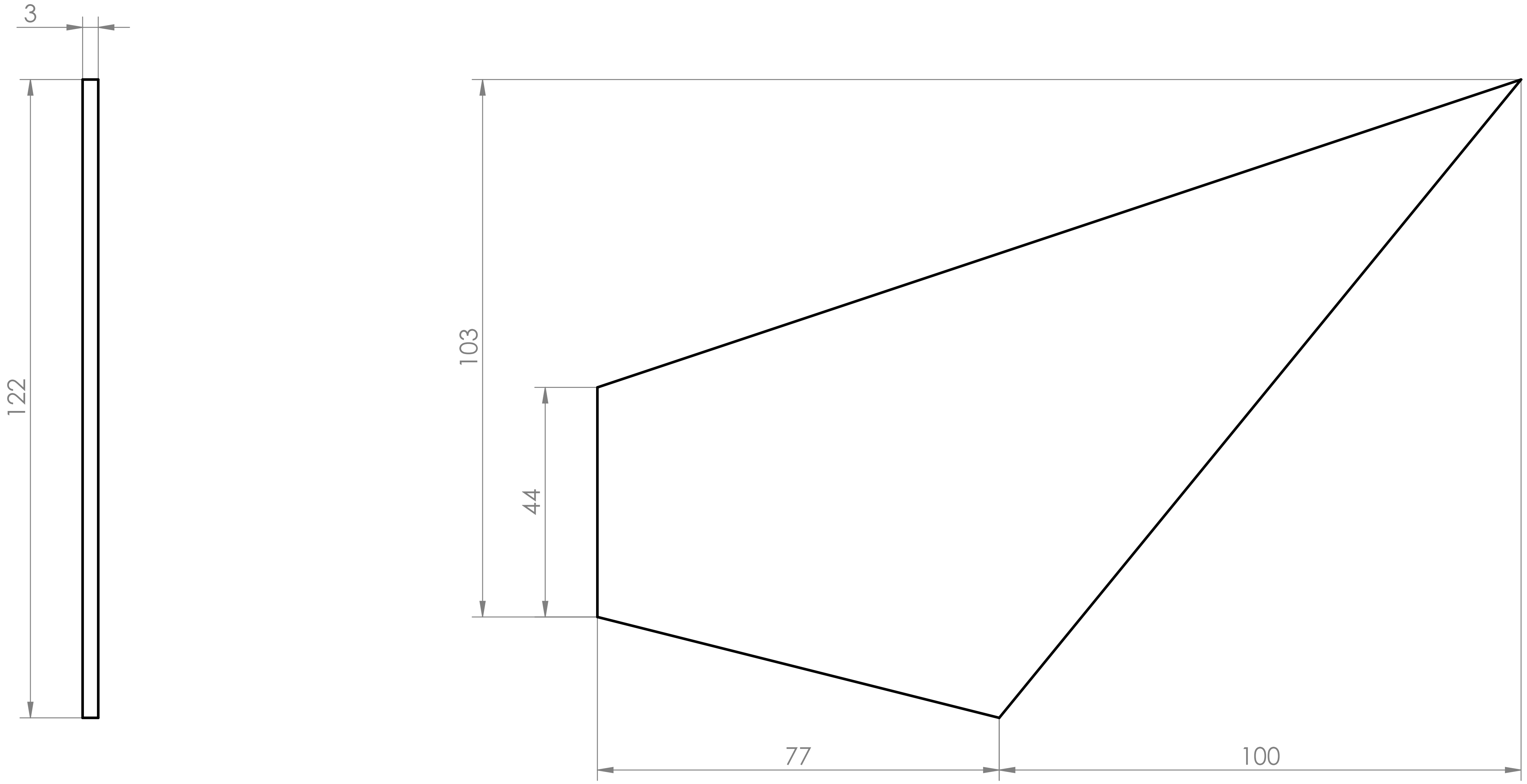




Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Bent Wall				Replacement for: / Replaced by:
Nozzle Housing				N-005-001
Referral:		Calculation: F.L & H.G		



Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
End Wall - A				Replacement for: / Replaced by:
Nozzle Housing				N-005-002
Referral:	Calculation: F.L & H.G			



Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

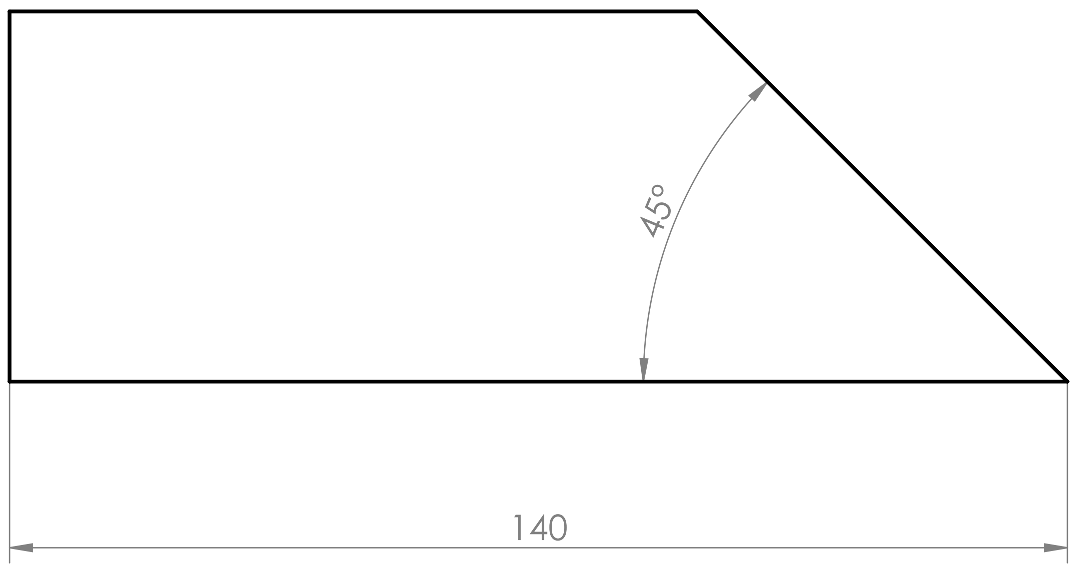
End Wall - B

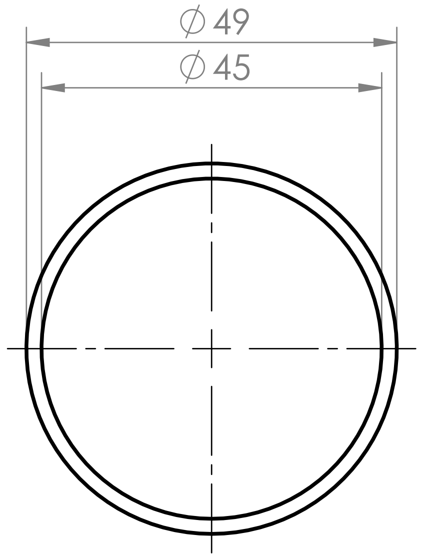
Nozzle Housing

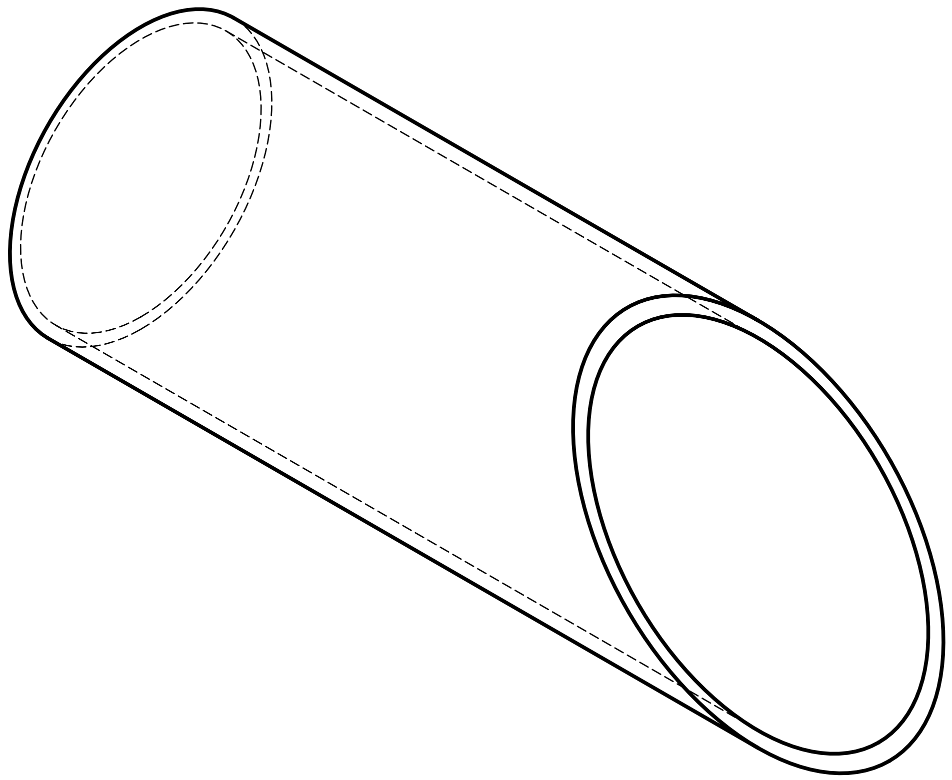
Replacement for:	Replaced by:

N-005-003

Referral:	Calculation: F.L & H.G







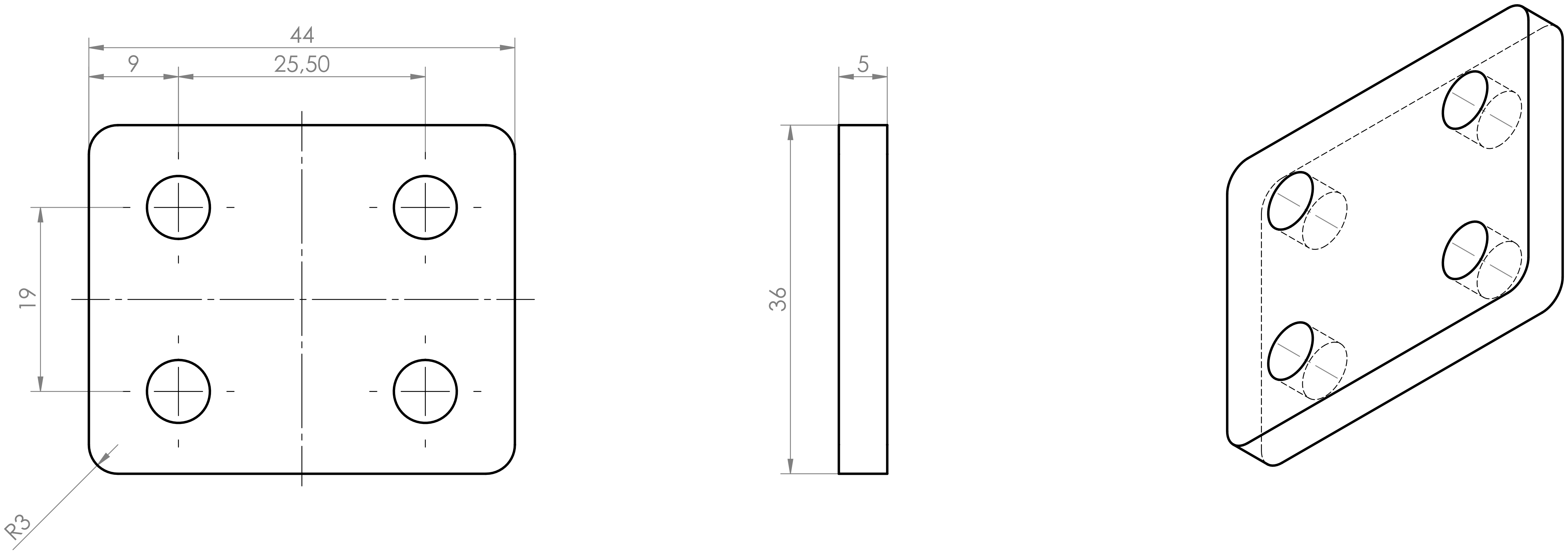
Date: 19.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU	
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for:	Replaced by:

Filter Holder

Nozzle Housing

N-005-004

Referral:	Calculation: F.L & H.G



Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

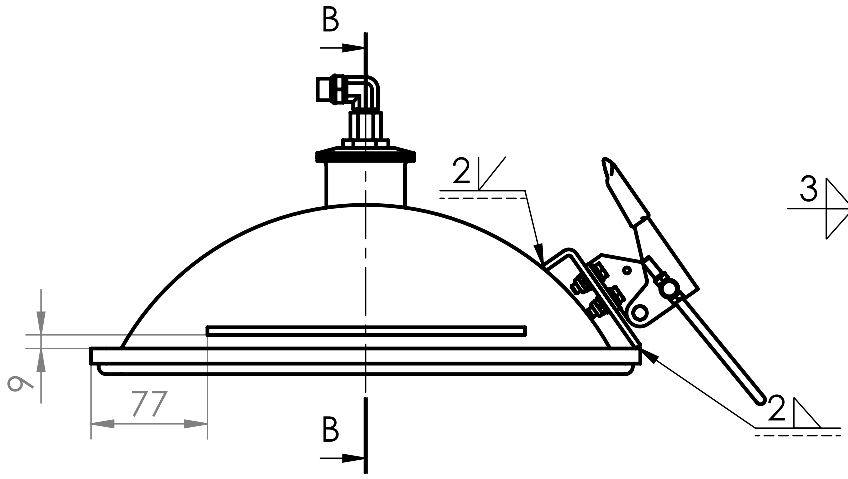
Stud Plate

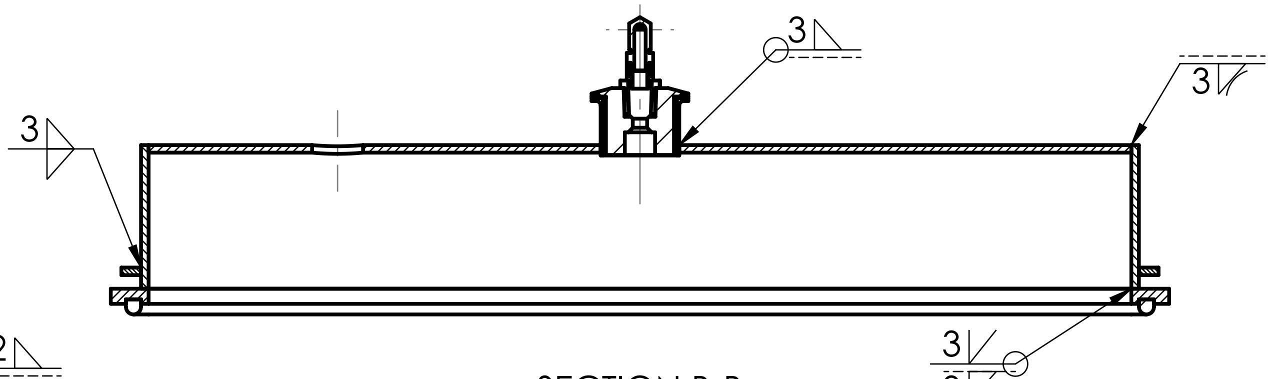
Nozzle Housing

Replacement for:	Replaced by:

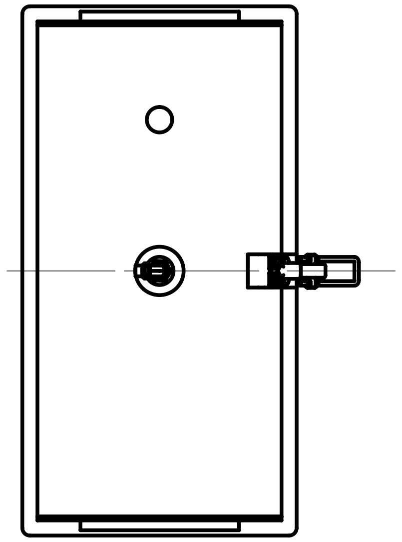
N-005-005

Referral:	Calculation: F.L & H.G

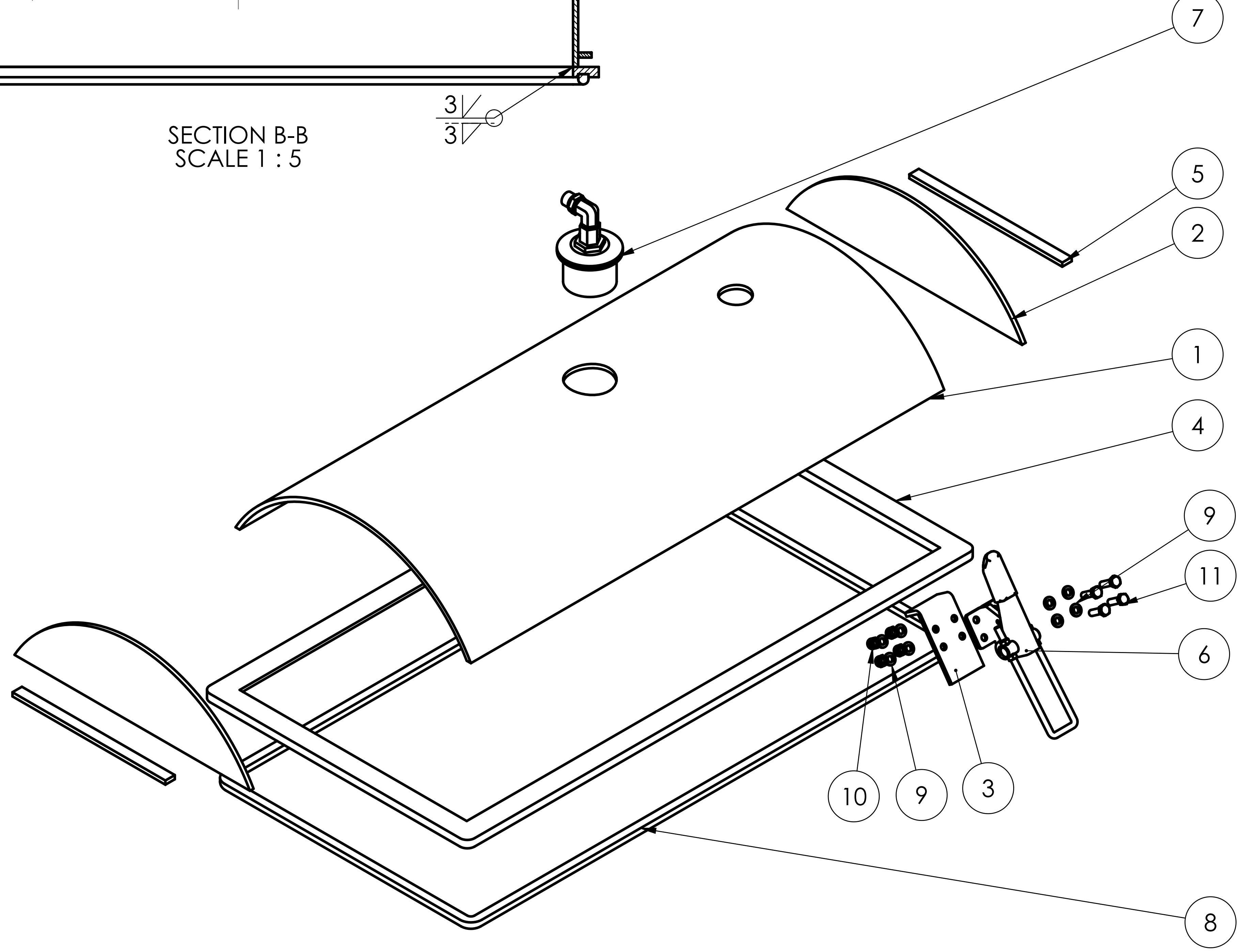




SECTION B-B
SCALE 1 : 5

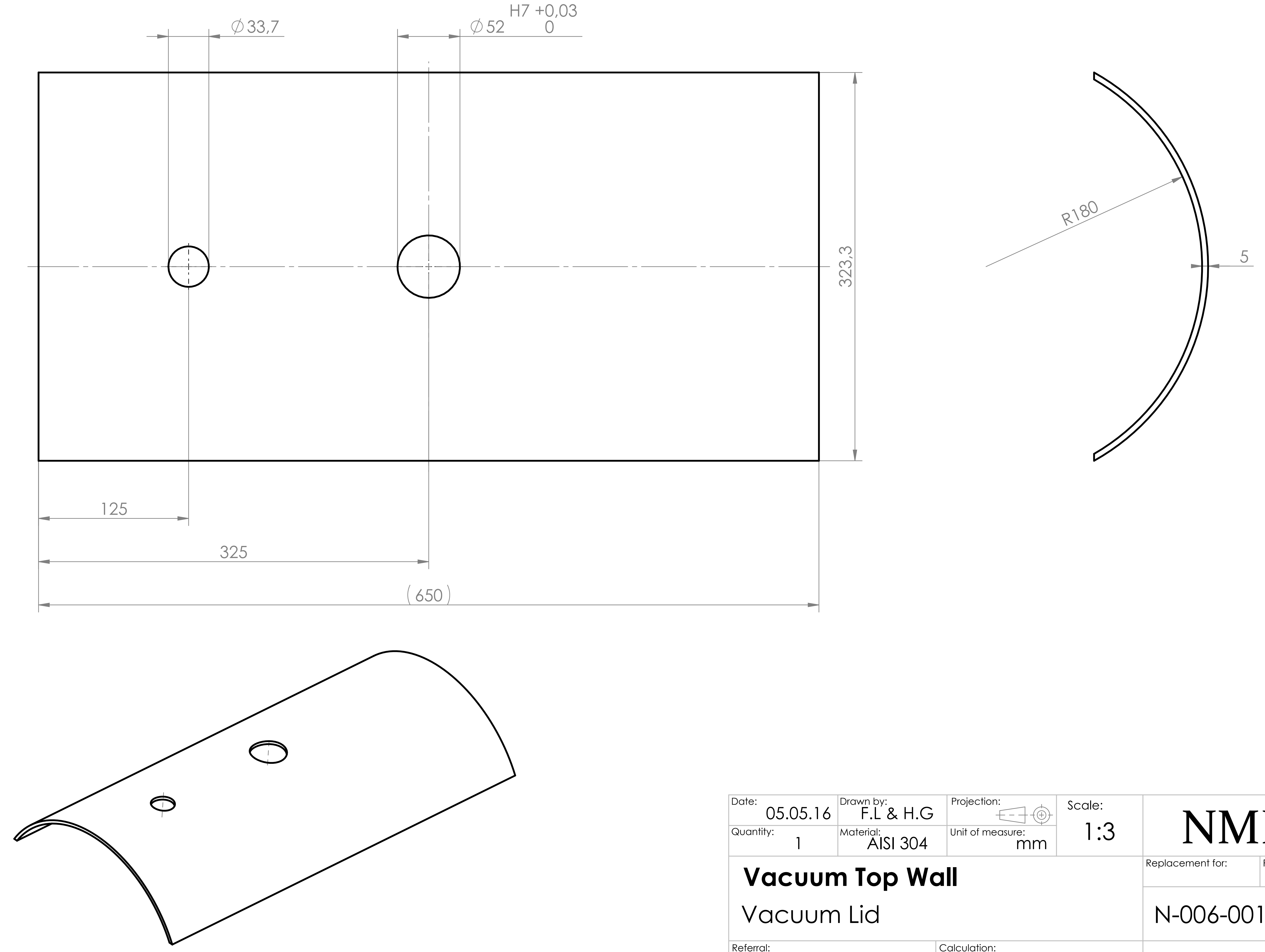


SCALE 1 : 10

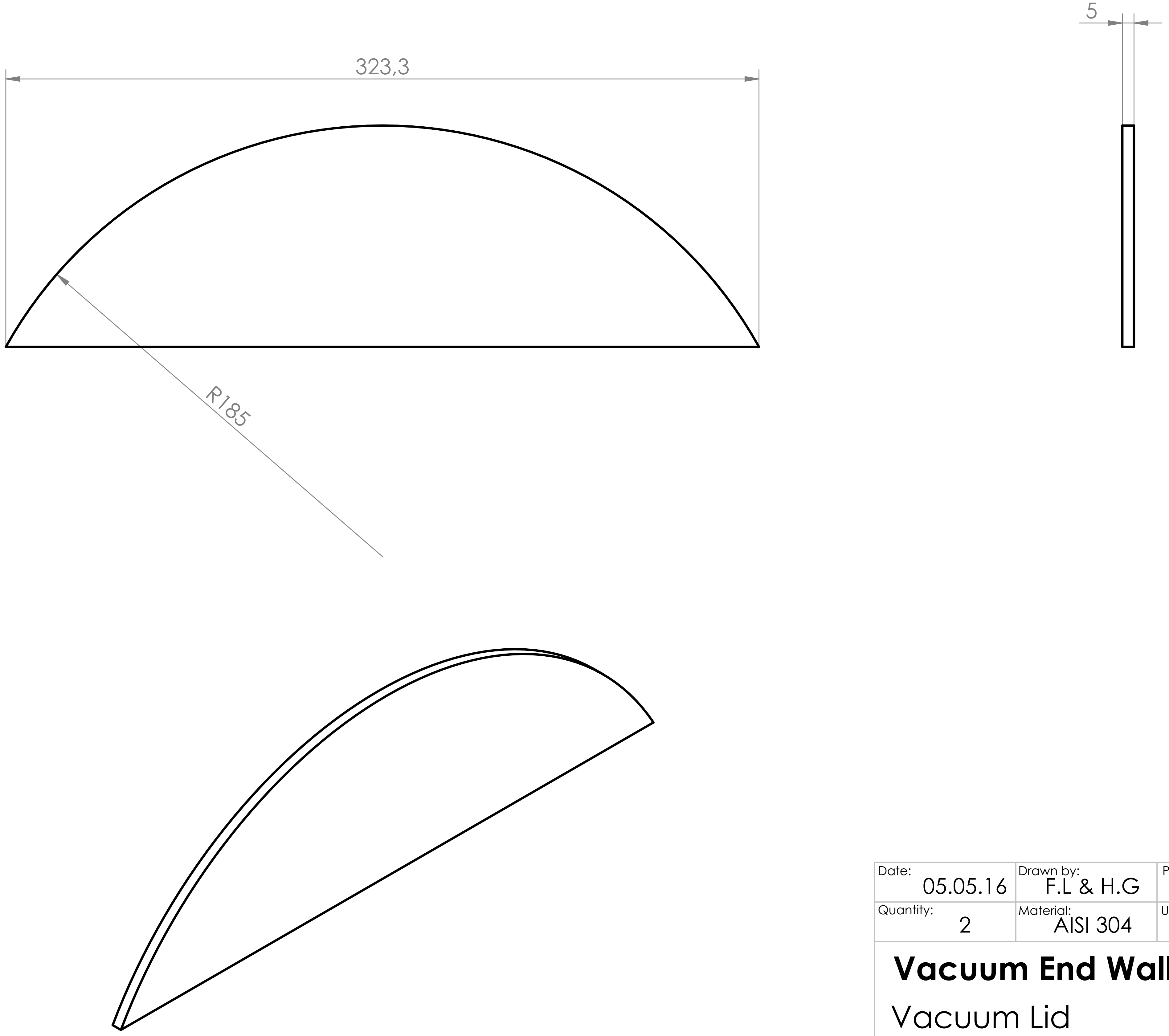


Pos.	QTY.	Part Name	Material
11	4	ISO 4017 - M6 x 20-N	AISI 304
10	4	DIN EN ISO 10511 - M6 - N	AISI 304
9	8	Washer DIN 125 - A 6.4	AISI 304
8	1	Silicone Sealing D 10x10	Silicon
7	1	F-004 - 10003154-300 Nozzle	AISI 304
6	1	Speedy Block - AS535 - 320/T3X	AISI 304
5	2	N-003-005 - Mounting Rail	AISI 304
4	1	N-003-004 - Grooved Flange	AISI 304
3	1	N-006-003 - Vacuum Stud Plate	AISI 304
2	2	N-006-002 - Vacuum End Wall	AISI 304
1	1	N-006-001 - Vacuum Top Wall	AISI 304

Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material:	Unit of measure: mm		Replacement for: / Replaced by:
Vacuum Lid RMVC				N-006
Referral:	Calculation: F.L & H.G			



Date: 05.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:3	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for: / Replaced by:
Vacuum Top Wall Vacuum Lid				N-006-001
Referral:		Calculation: F.L & H.G		



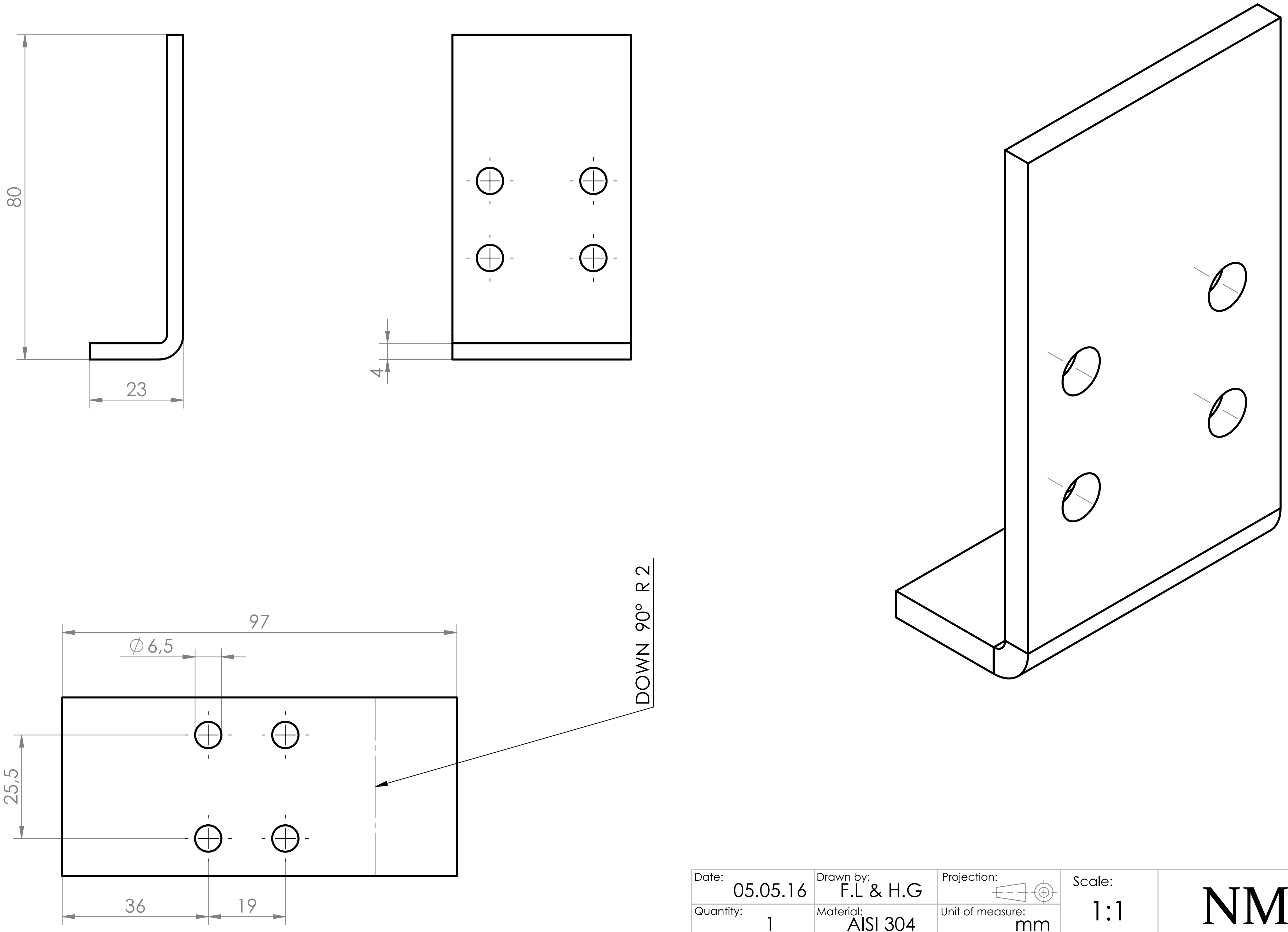
Date: 05.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 2	Material: AISI 304	Unit of measure: mm		

Vacuum End Wall

Vacuum Lid

Replacement for:	Replaced by:
N-006-002	

Referral:	Calculation: F.L & H.G



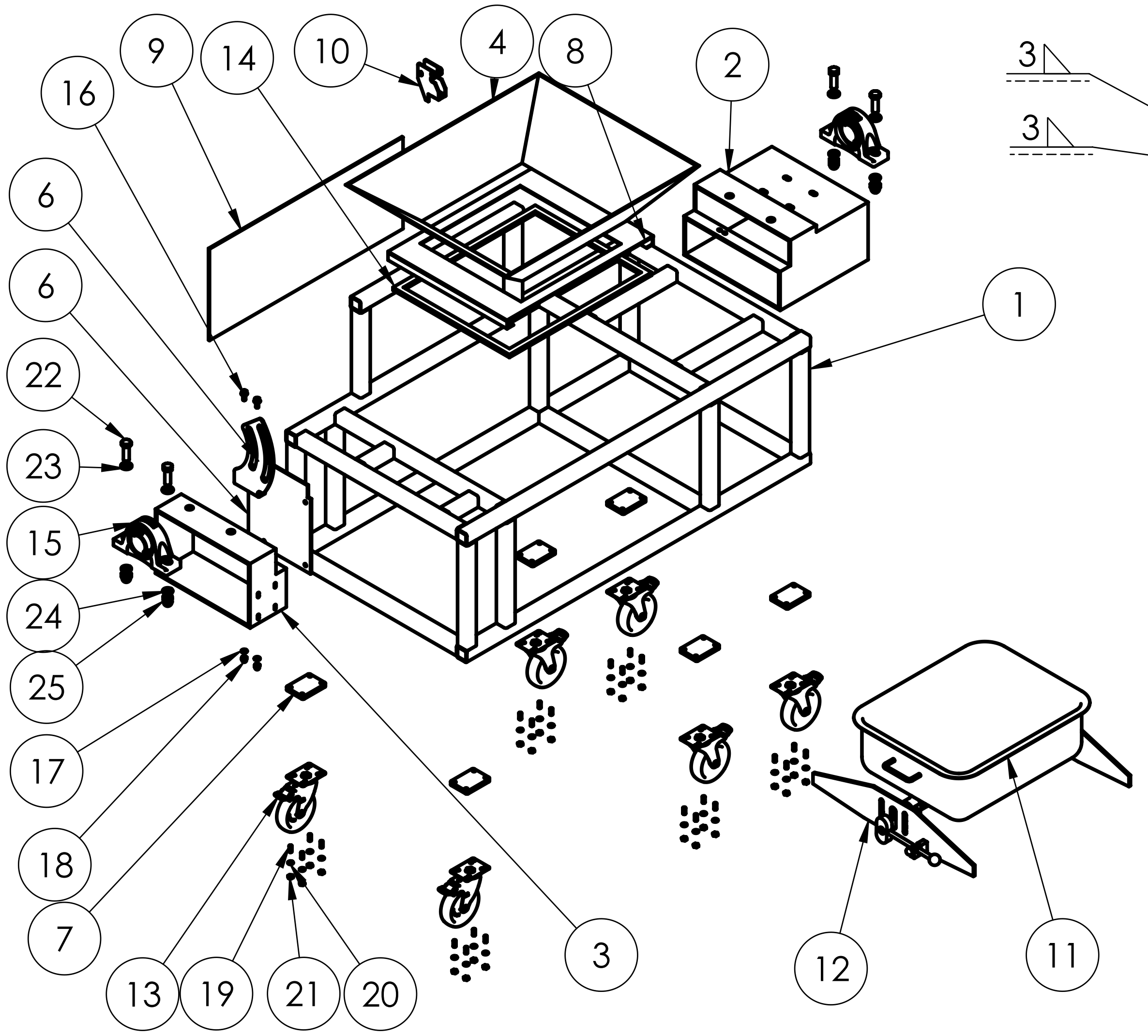
Date: 05.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

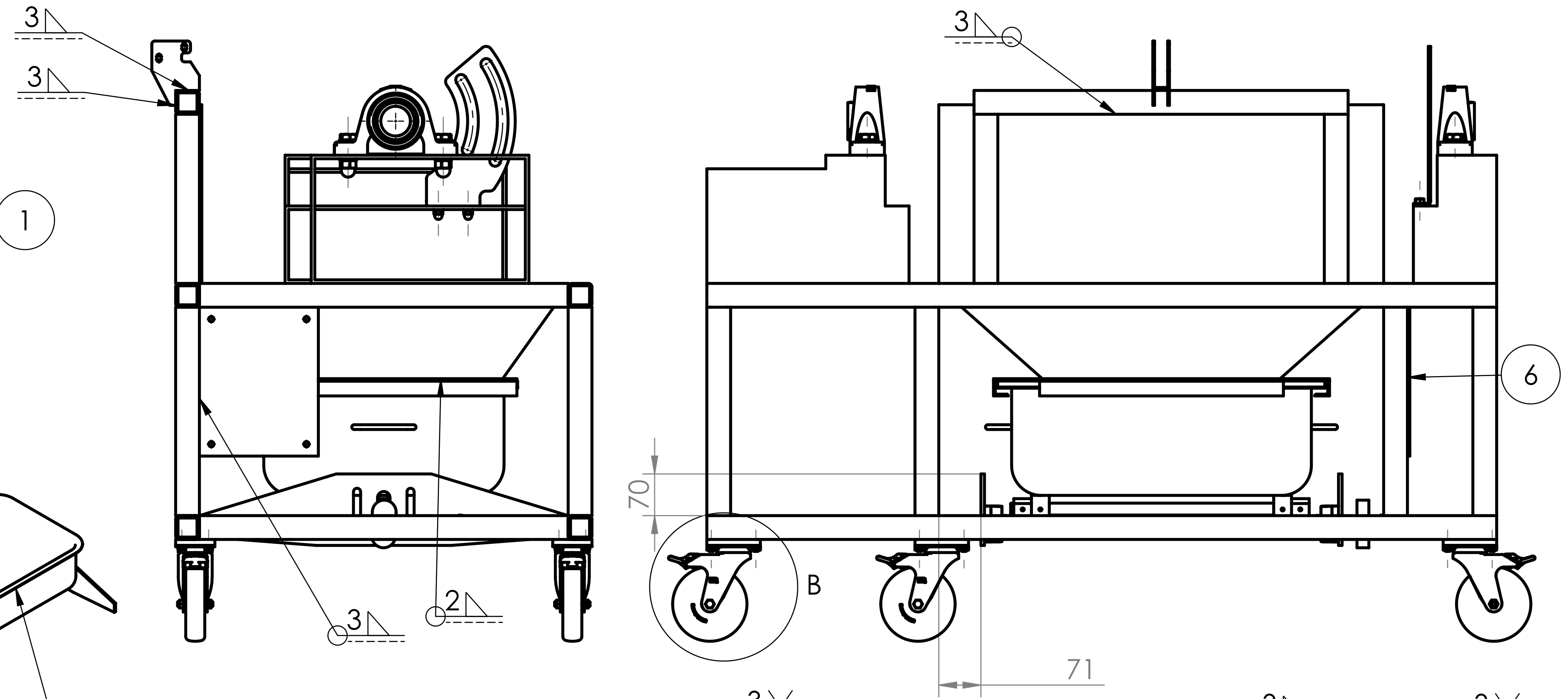
Vacuum Stud Plate

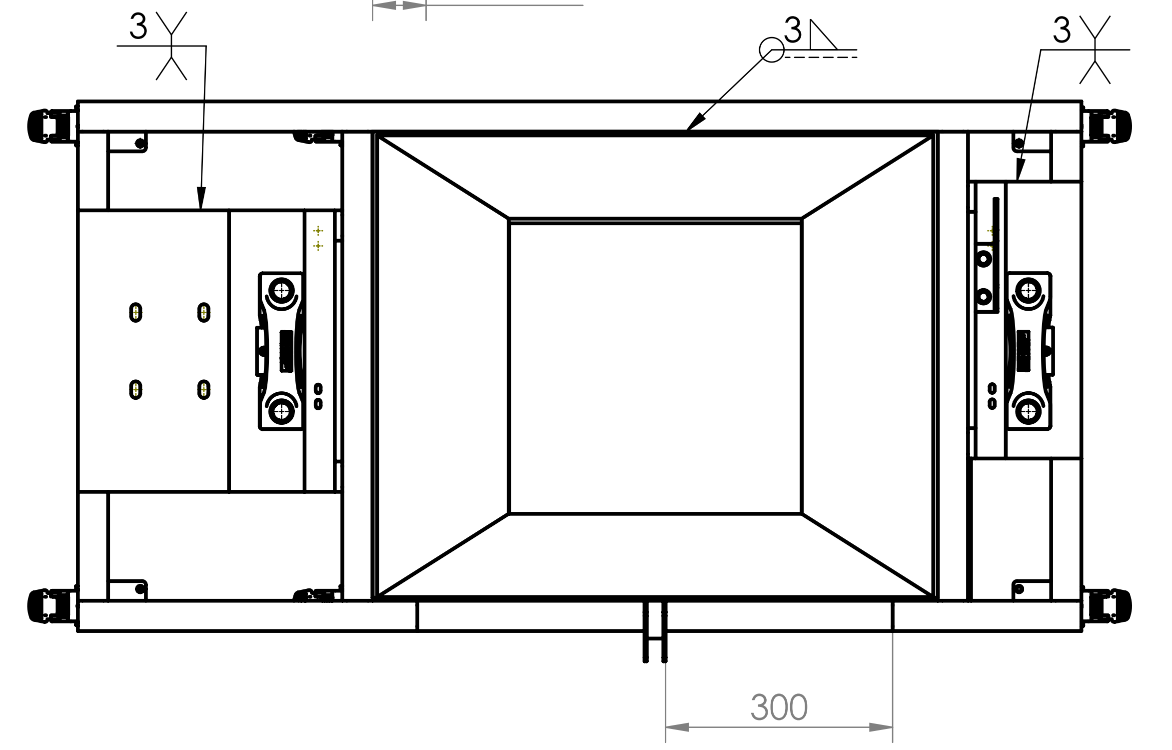
Vacuum Lid

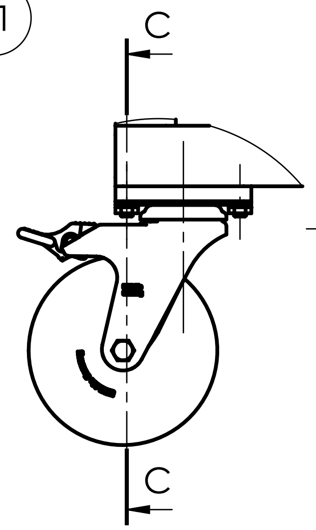
Replacement for:	Replaced by:
N-006-003	

Referral:	Calculation: F.L & H.G

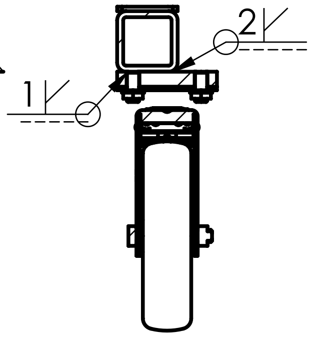








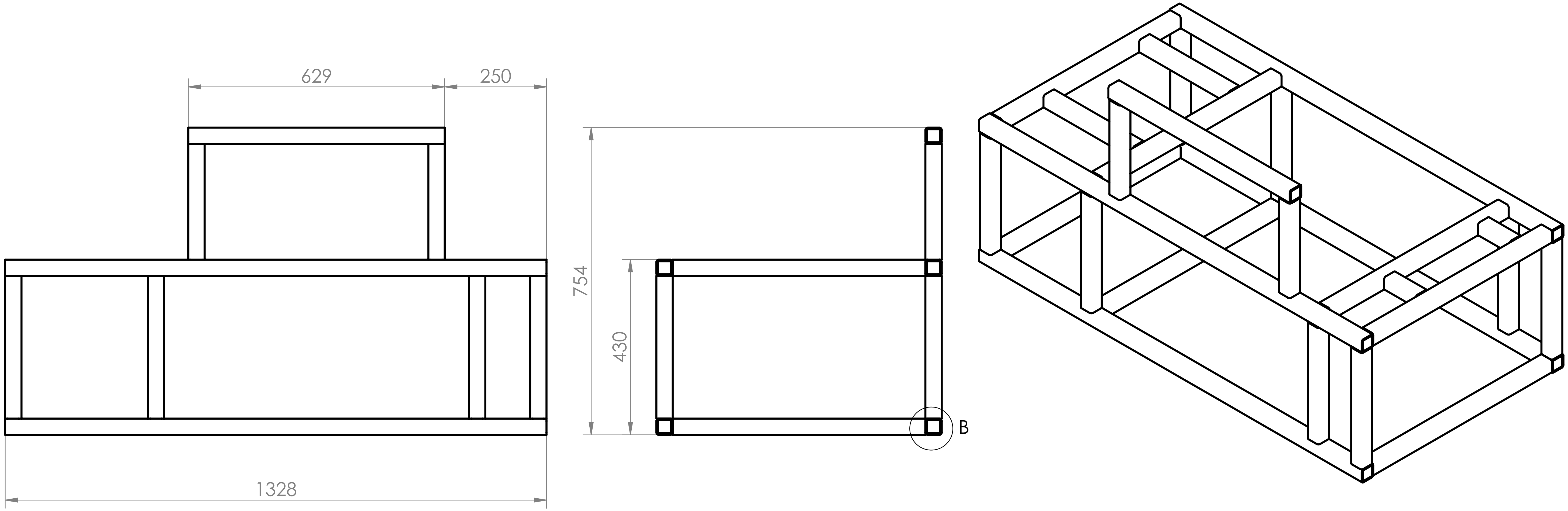
DETAIL B
SCALE 1 : 5

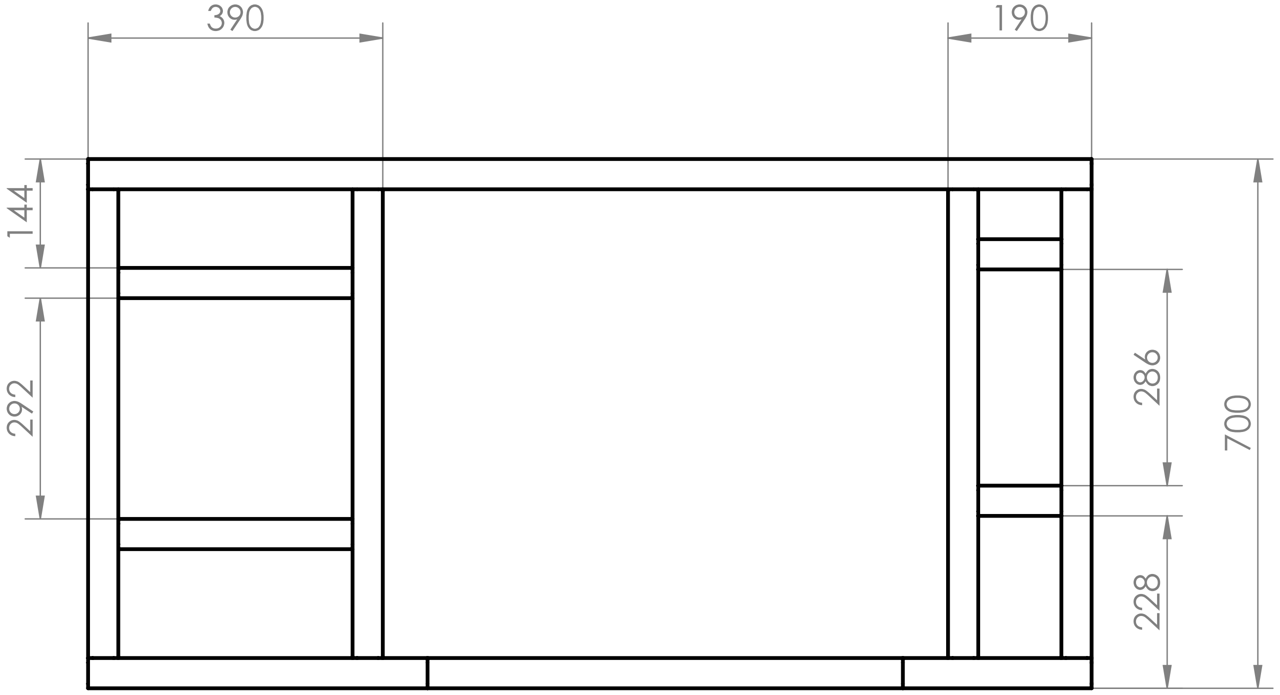


SECTION C-C
SCALE 1 : 5

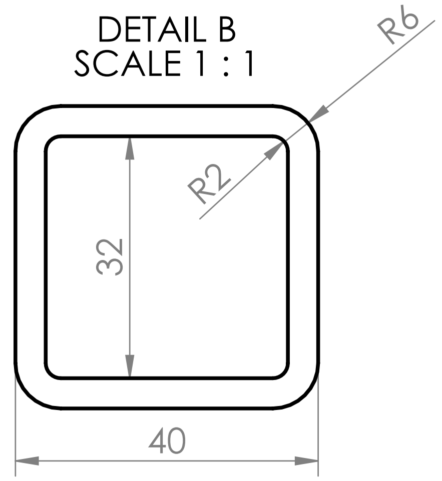
Pos.	QTY.	Part Name	Material
25	4	DIN 1587 - M16 --NUC	S355
24	4	Spring washer DIN 128 - A16	S355
23	4	Washer DIN 125 - A 17	S355
22	4	ISO 4017 - M16 x 50-N	S355
21	24	Hexagon Nut ISO 4036 - M8 - N	S355
20	24	Spring washer DIN 128 - A8	S355
19	24	DIN 976-1 -- M8 x 20 A-- N	S355
18	2	DIN 1587 - M8 --NNU	S355
17	2	Washer DIN 125 - A 8.4	S355
16	2	DIN 6921 - M8 x 20 x 20-N	S355
15	2	SKF - SYJ 50 TF1	
14	1	Sealing (same as Forberg uses in F-20 mixer)	
13	6	Blickle LKPXA-TPA_126G-FI_527135-203	
12	2	F-005-001 - Bin Mount (Modified)	S355
11	1	F-005 - Bin System F-120 with modified bin mounts	
10	1	N-007-010 - Lid Lock Mount	S355
9	1	N-007-009 - Side Wall	AISI 304
8	1	N-007-008 -Funnel Flange	AISI 304
7	6	N-007-007 - Wheel Mounting Plate	S355
6	1	N-007-006 - Cabinet Mounting Plate	S355
5	1	N-007-005 - Sensor Plate	S355
4	1	N-007-004 - Funnel	AISI 304
3	1	N-007-003 - Box - B	S355
2	1	N-007-002 - Box - A	S355
1	1	N-007-001 - Main Frame	S355

Date: 27.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:10	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		
Frame				Replacement for: / Replaced by:
RMVC				N-007
Referral:		Calculation: F.L & H.G		

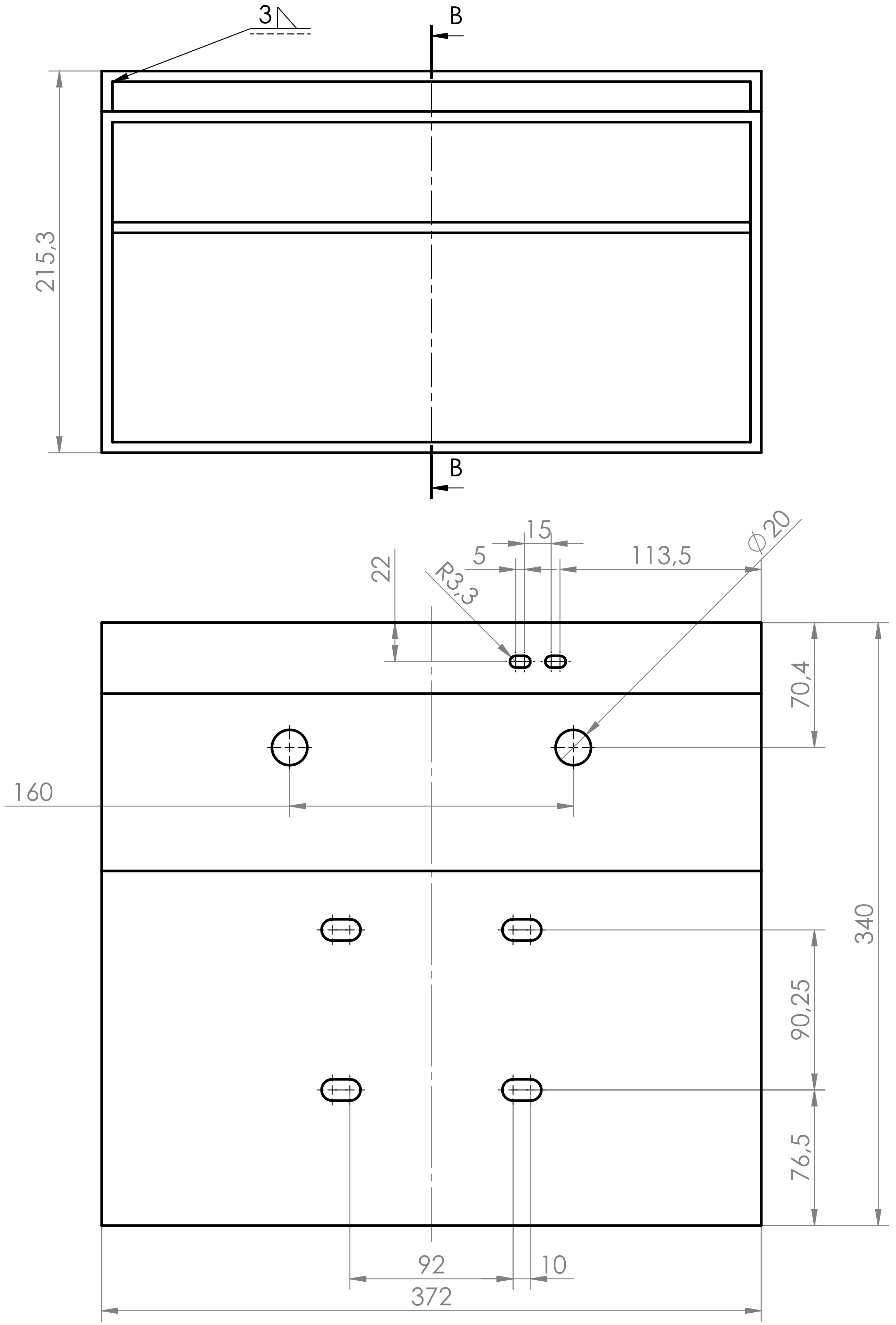


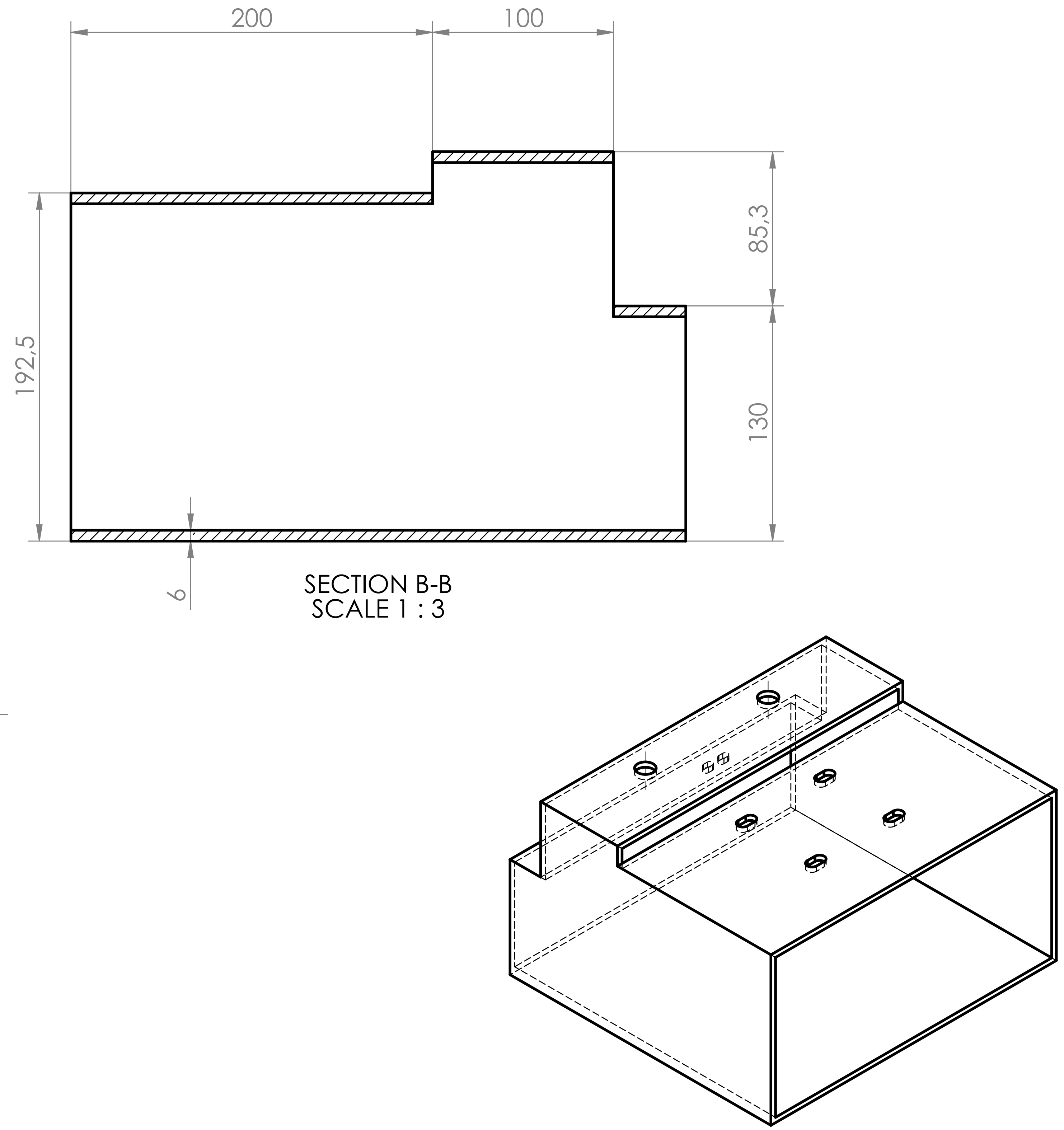


DETAIL B
SCALE 1 : 1

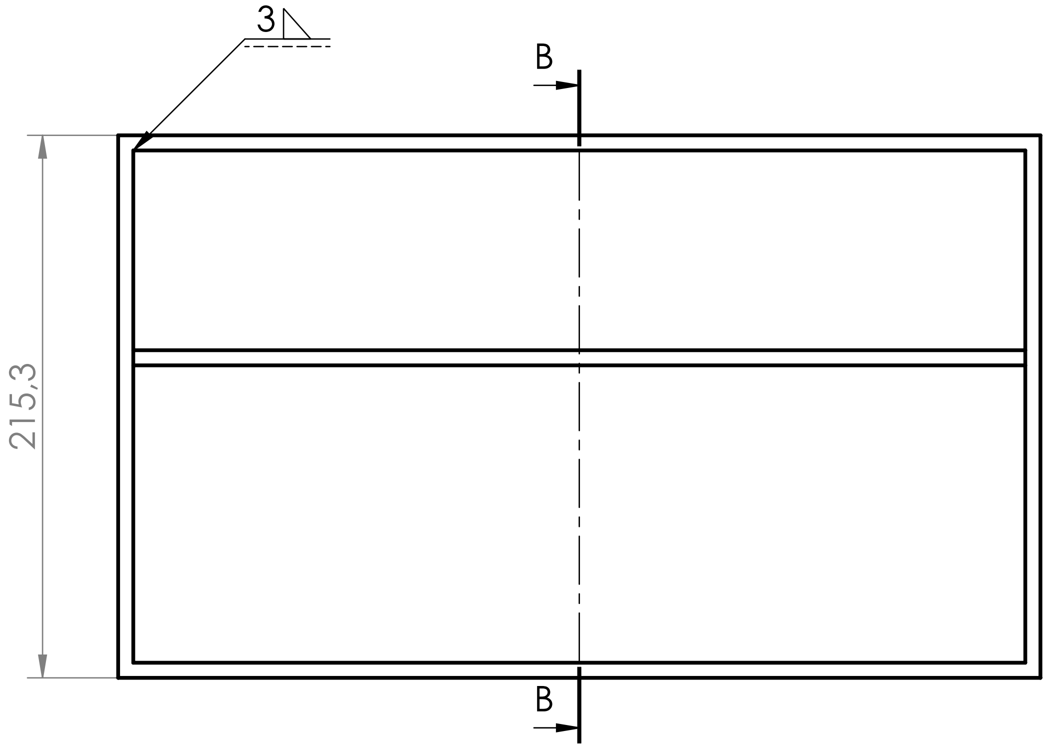


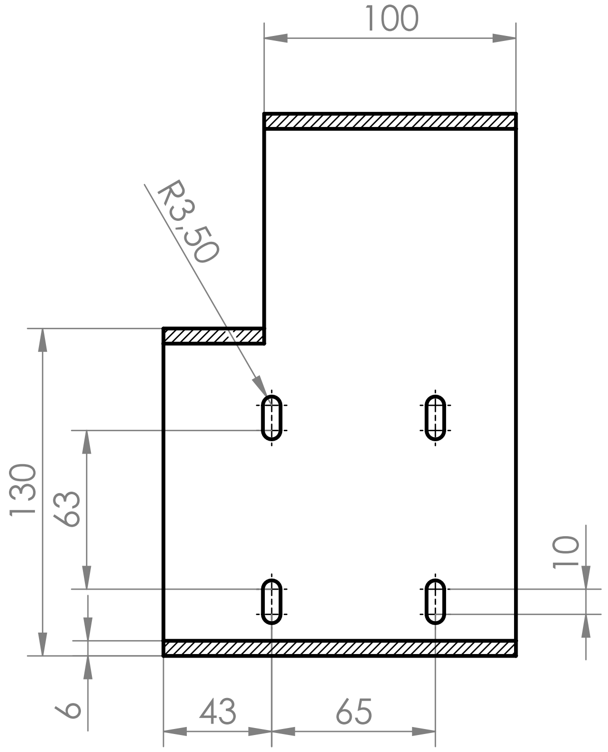
Date: 22.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:10	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		
Main Frame				Replacement for: / Replaced by:
Frame				N-007-001
Referral:	Calculation: F.L & H.G			



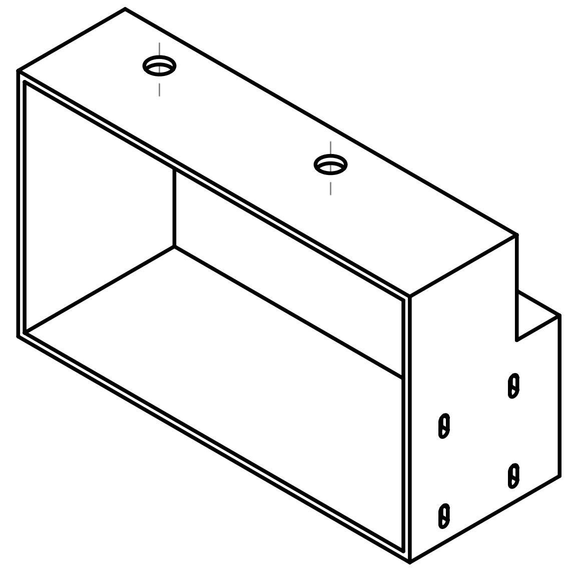


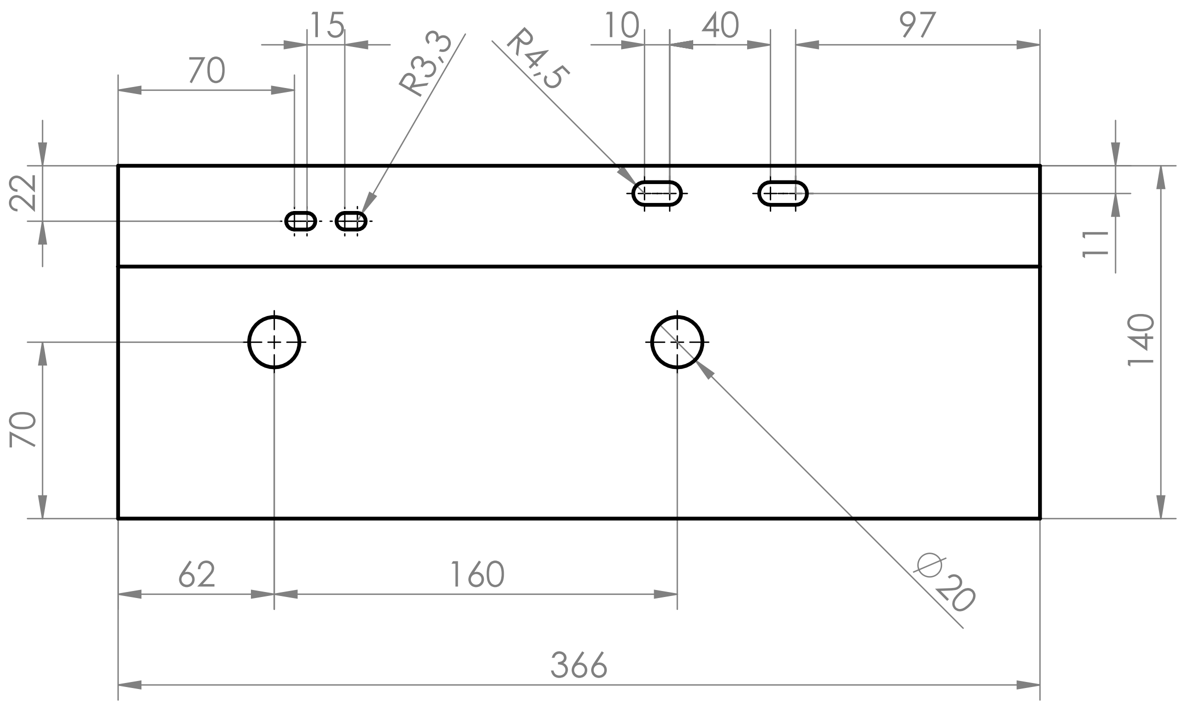
Date: 22.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:3	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		
Box - A Frame				Replacement for: / Replaced by: N-007-002
Referral:	Calculation: F.L & H.G			



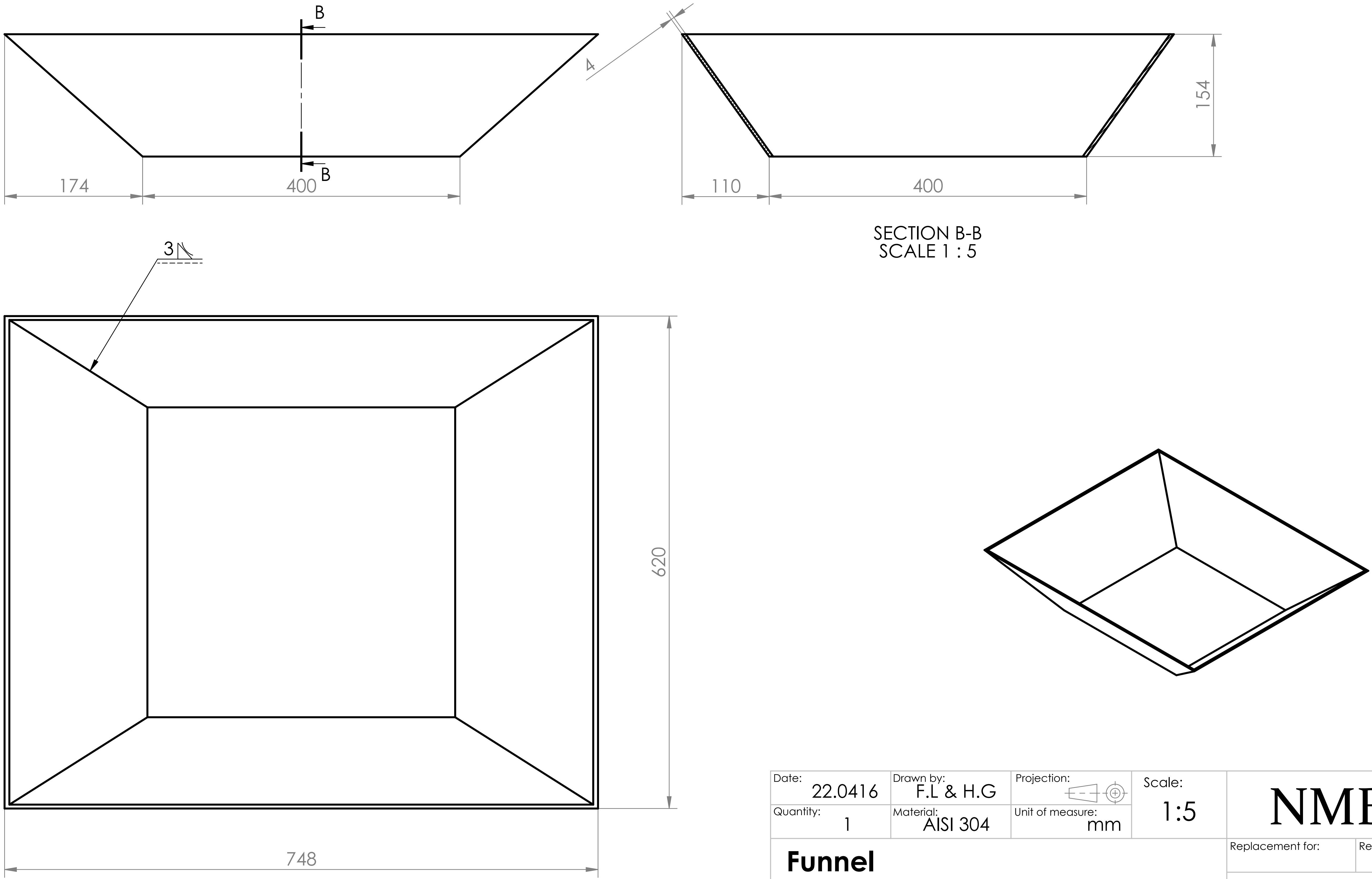


SECTION B-B
SCALE 1 : 3

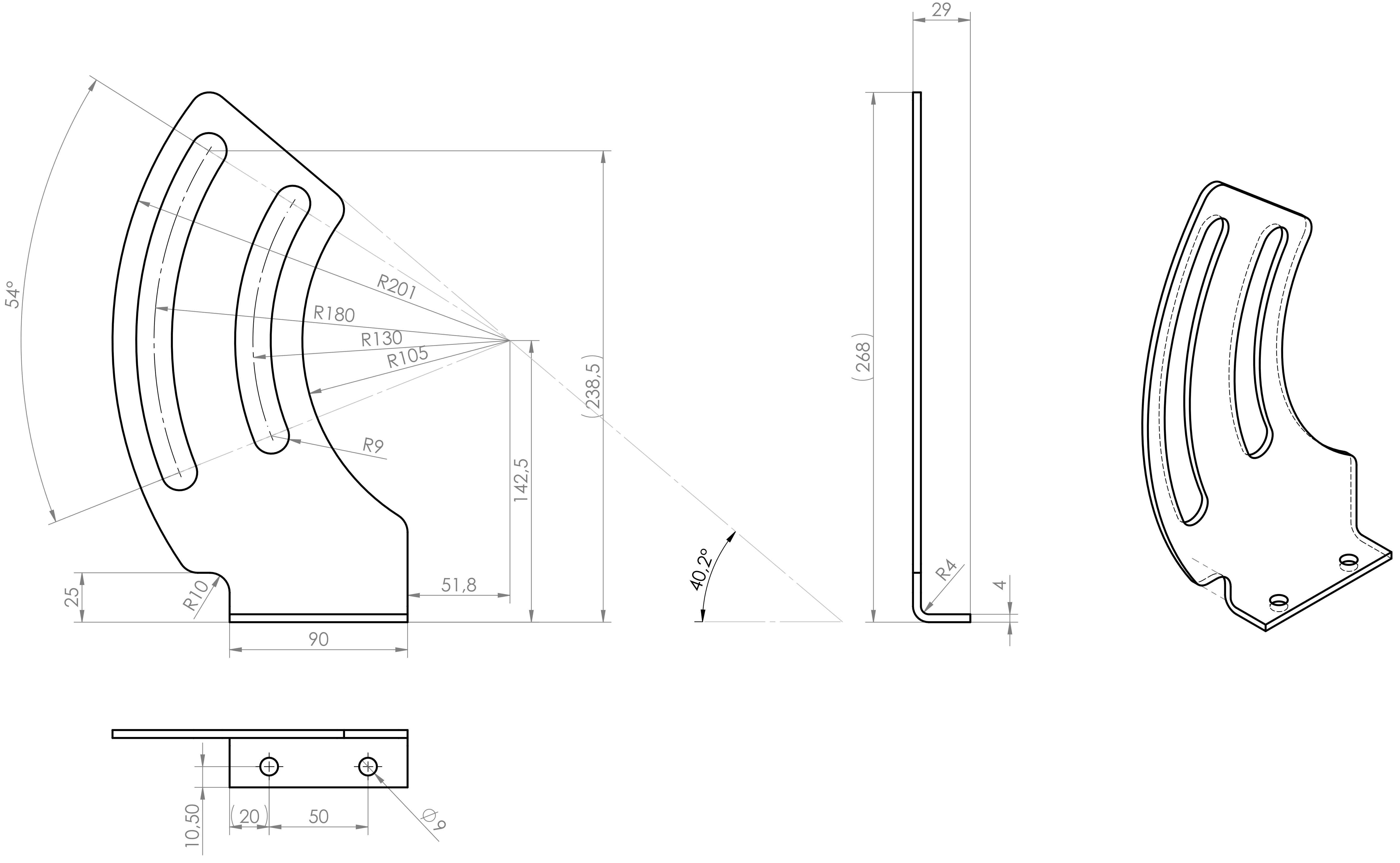




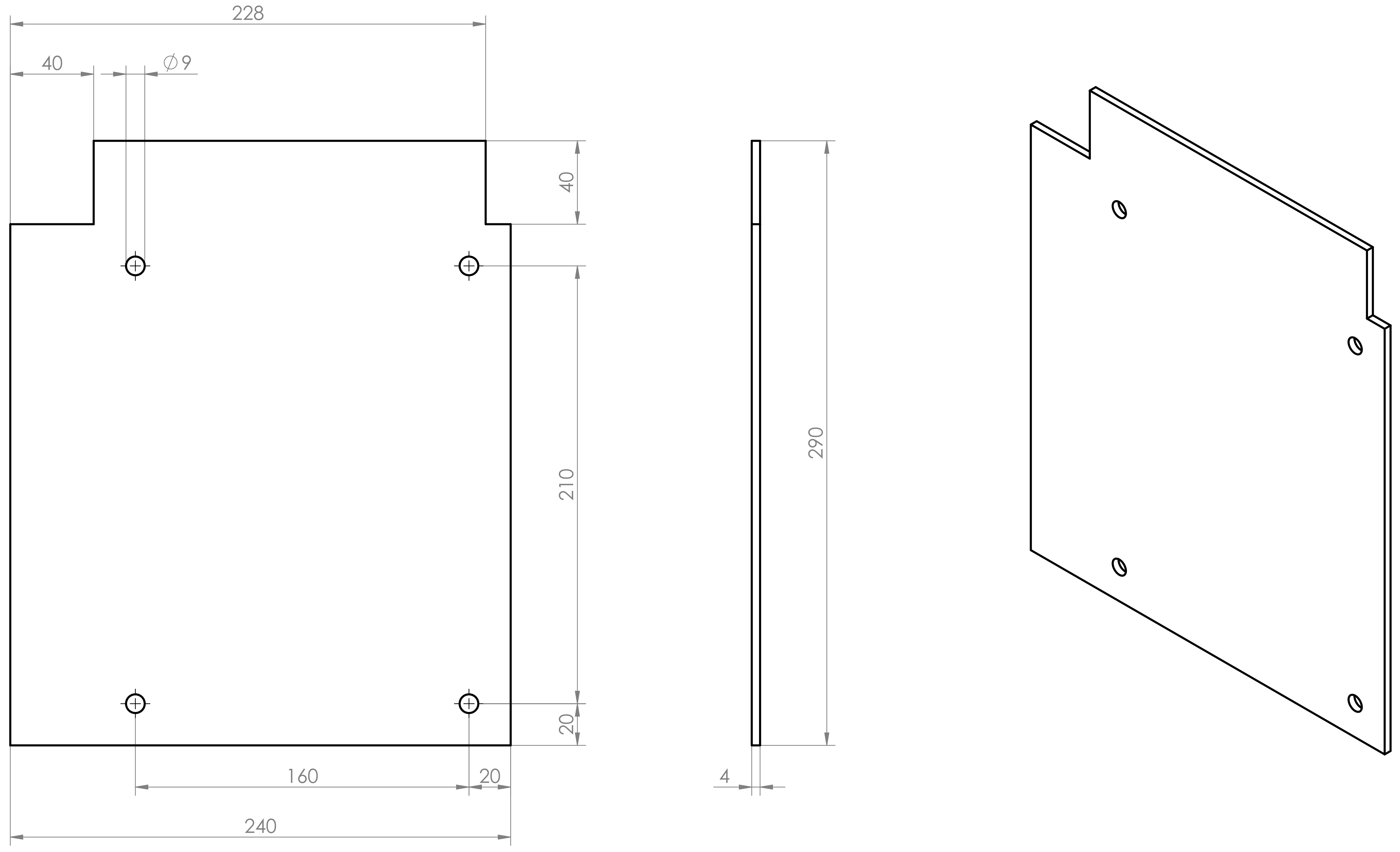
Date: 22.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:3	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		
Box - B				Replacement for: / Replaced by:
Frame				N-007-003
Referral:		Calculation: F.L & H.G		



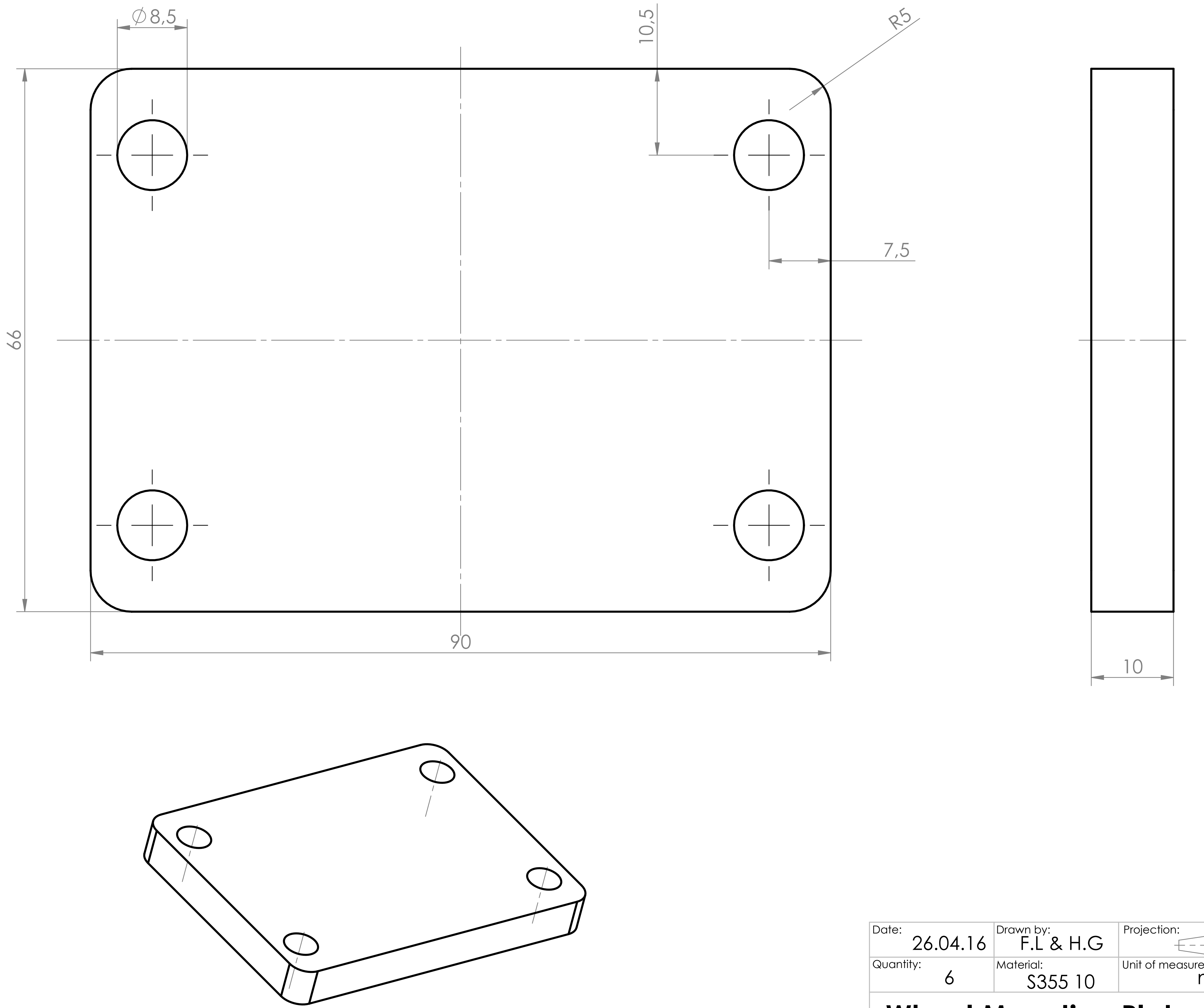
Date: 22.0416	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		Replacement for: / Replaced by:
Funnel Frame				N-007-004
Referral:		Calculation: F.L & H.G		



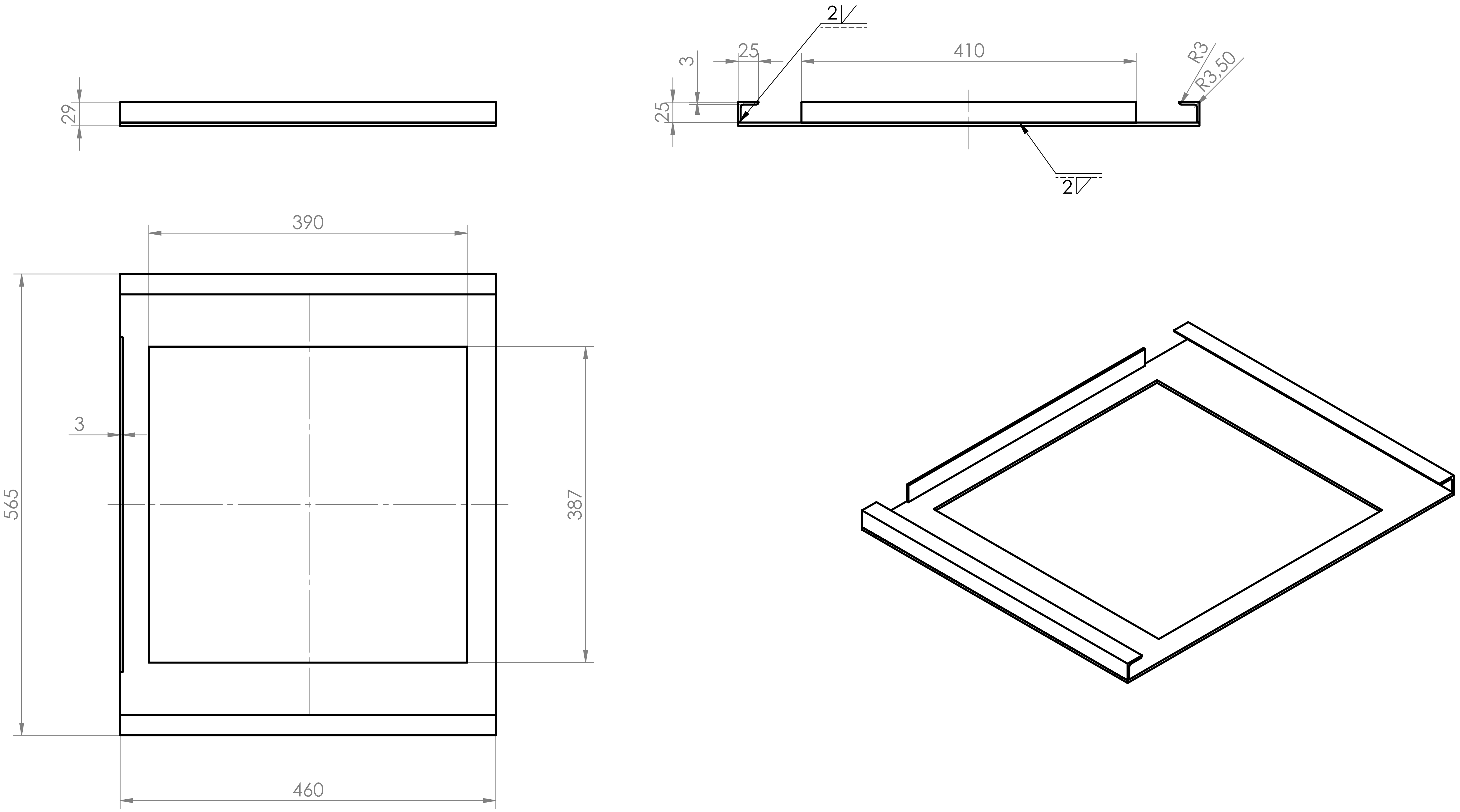
Date: 16.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		
Sensor Plate				Replacement for: / Replaced by:
Frame				N-007-005
Referral:		Calculation: F.L & H.G		



Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU	
Quantity: 1	Material: S355	Unit of measure: mm			
Cabinet Mounting Plate				Replacement for:	Replaced by:
Frame				N-007-006	
Referral:		Calculation: F.L & H.G			



Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 6	Material: S355 10	Unit of measure: mm		
Wheel Mounting Plate				Replacement for: / Replaced by:
Frame				N-007-007
Referral:		Calculation: F.L & H.G		



Date: 27.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

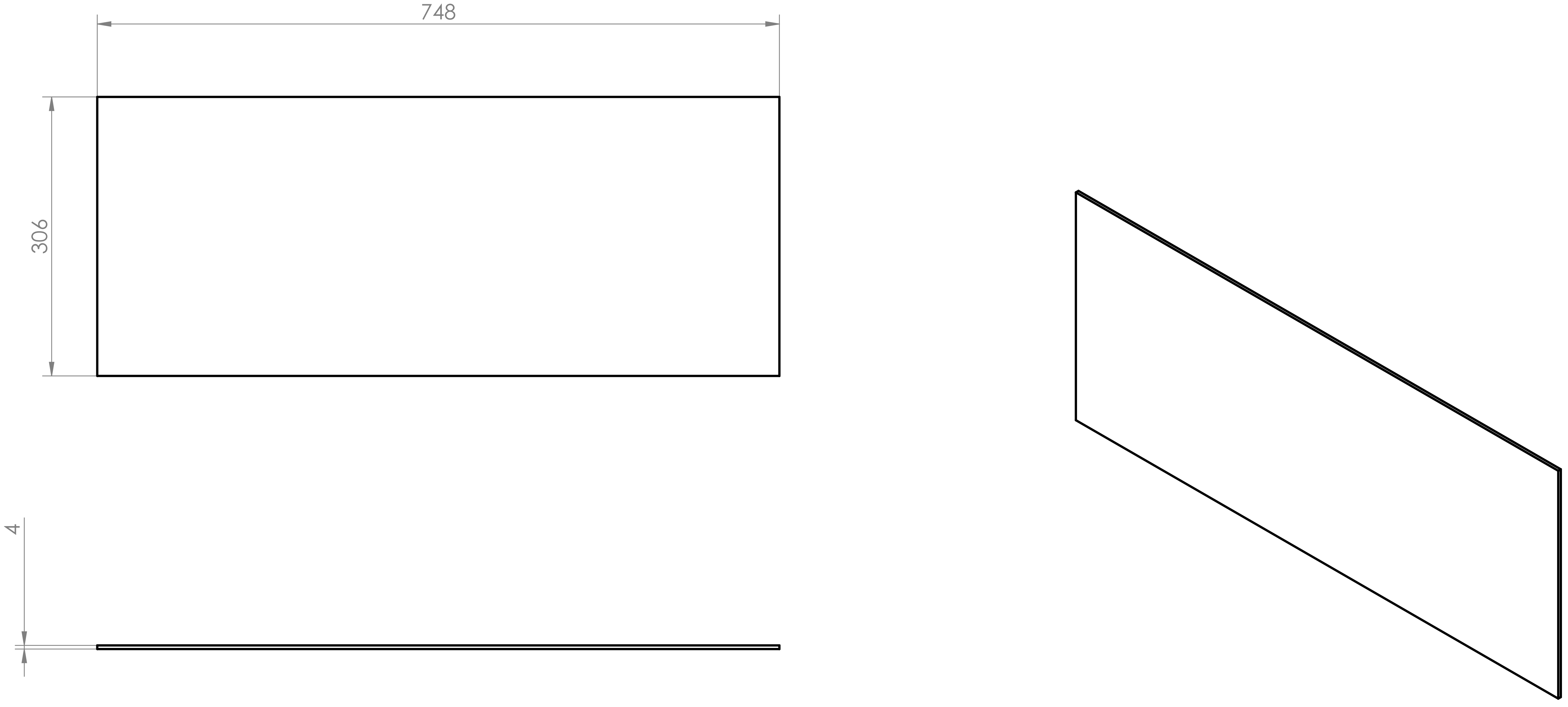
Funnel Flange

Frame

Replacement for:	Replaced by:

N-007-008

Referral:	Calculation: F.L & H.G



Date: 27.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:5	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

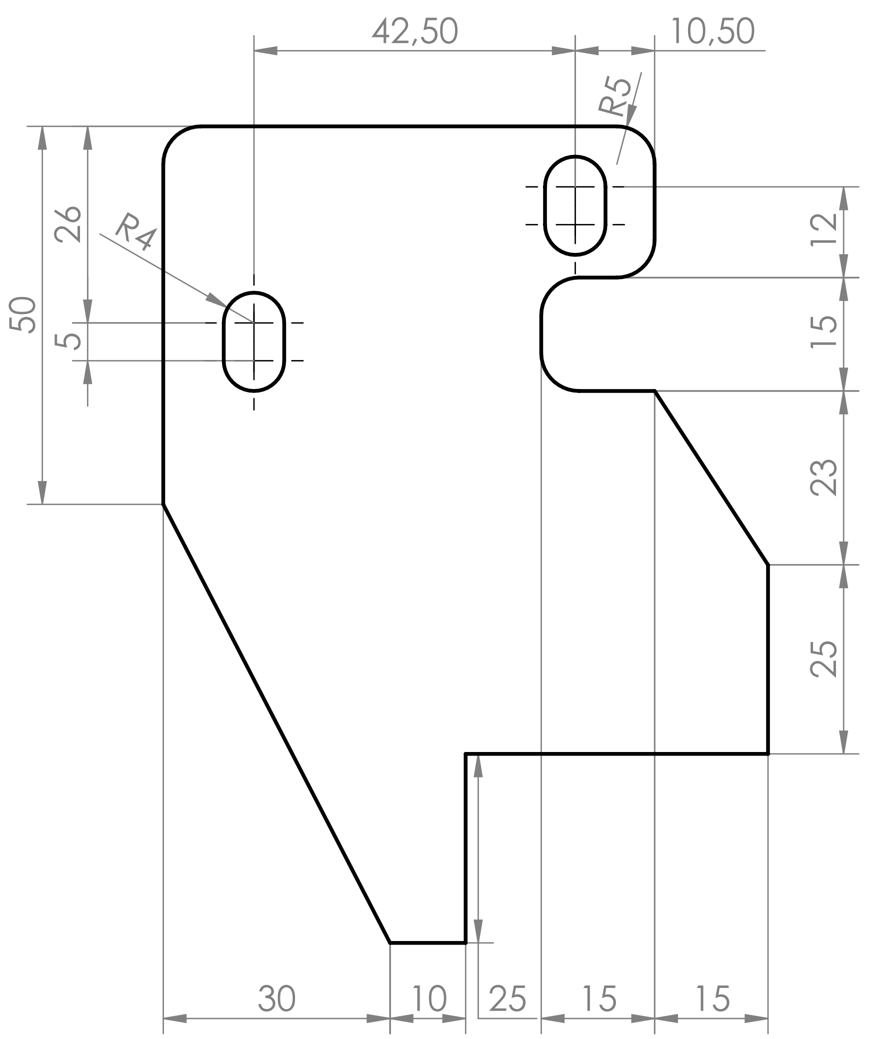
Side Wall

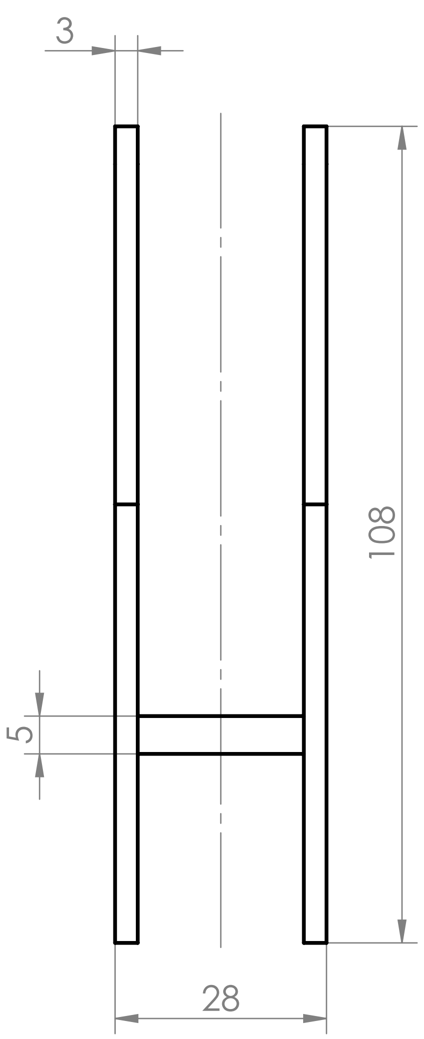
Frame

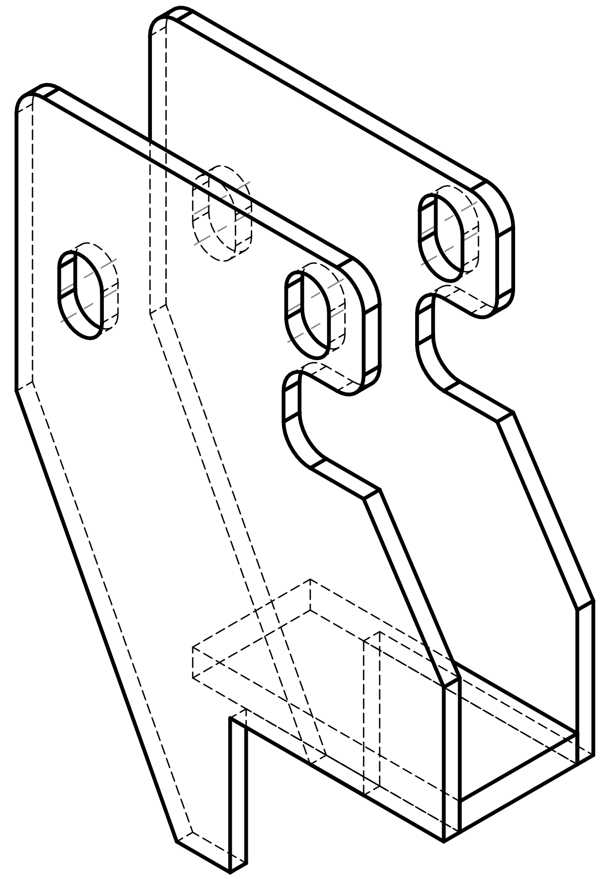
Replacement for:	Replaced by:

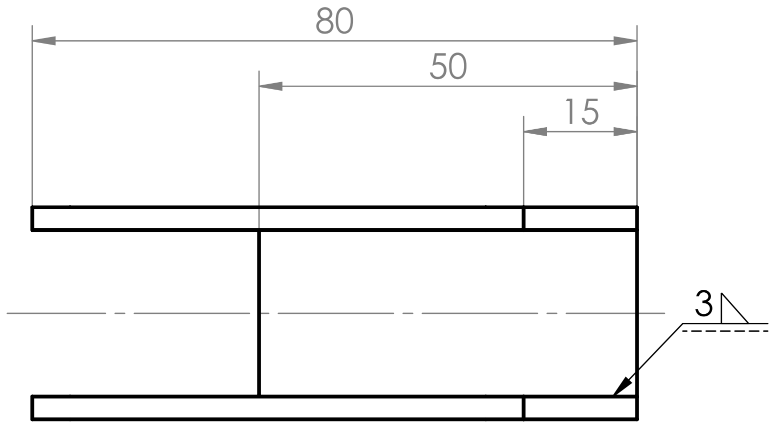
N-007-009

Referral:	Calculation: F.L & H.G









Date: 06.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU	
Quantity: 1	Material: S355	Unit of measure: mm		Replacement for:	Replaced by:

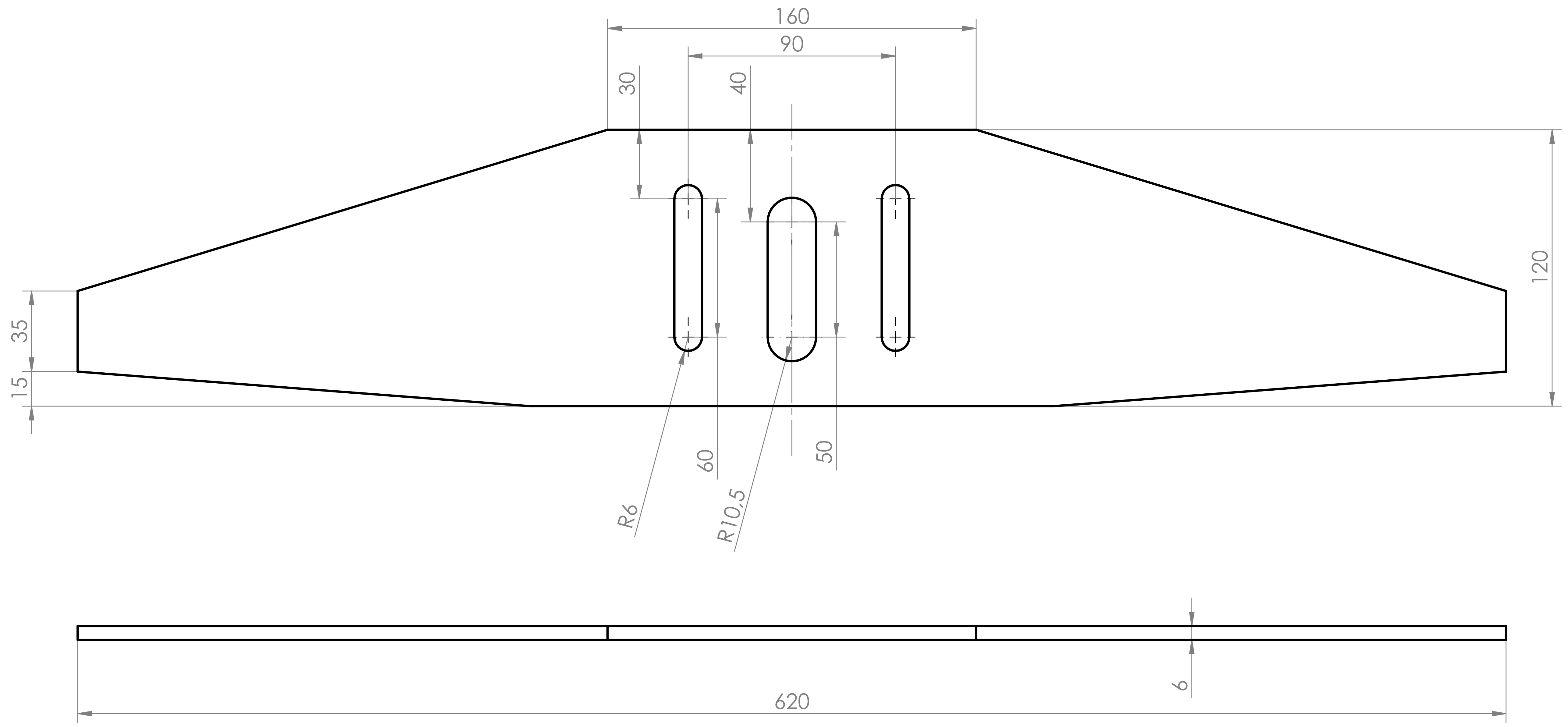
Lid Lock Mount

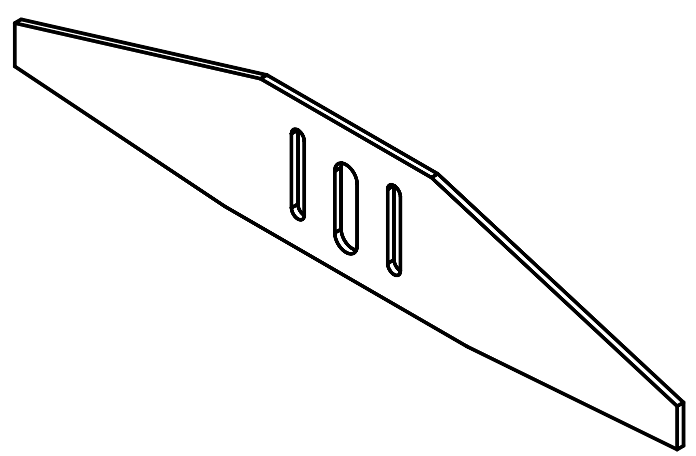
Frame

N-007-010

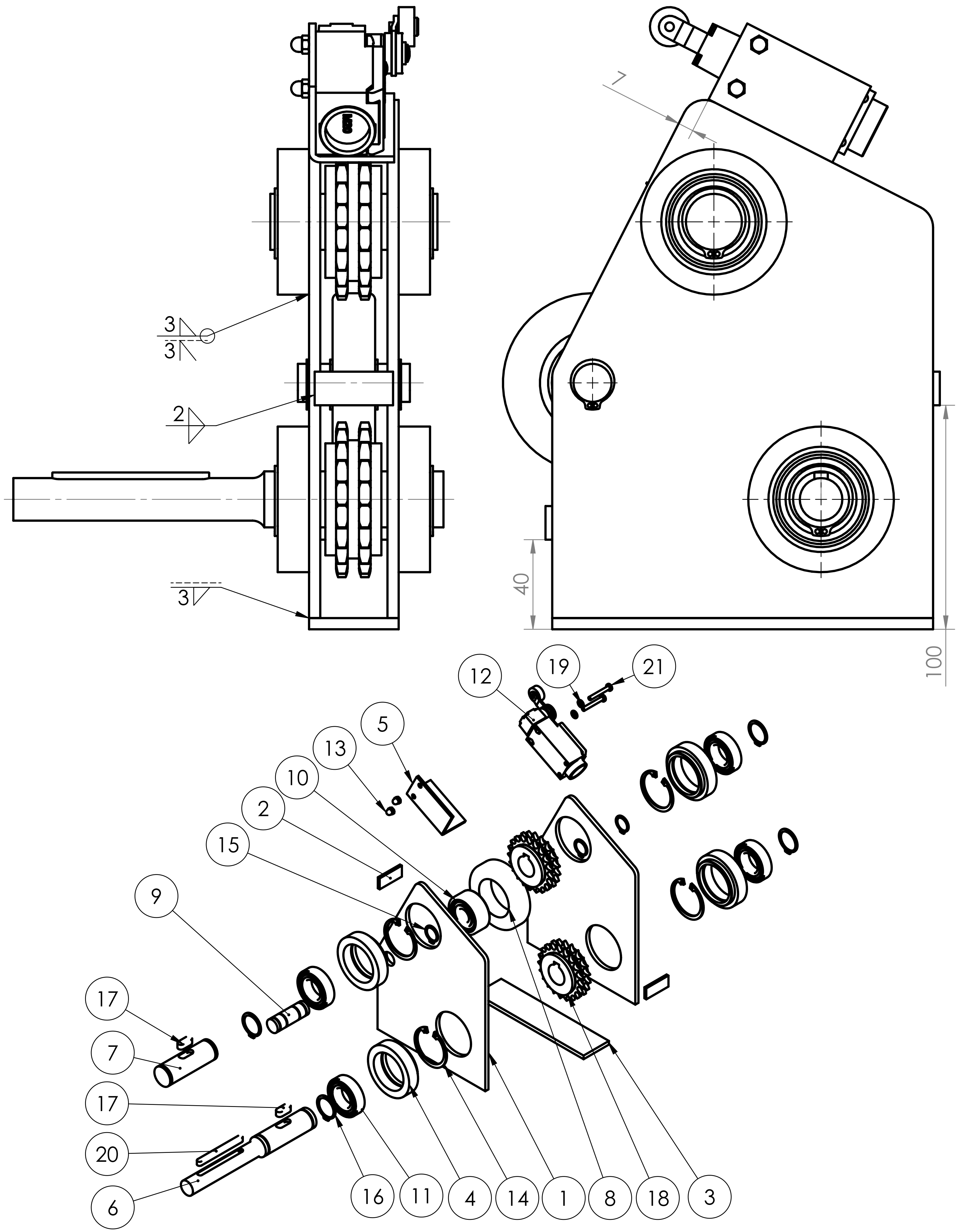
Referral:

Calculation: F.L & H.G



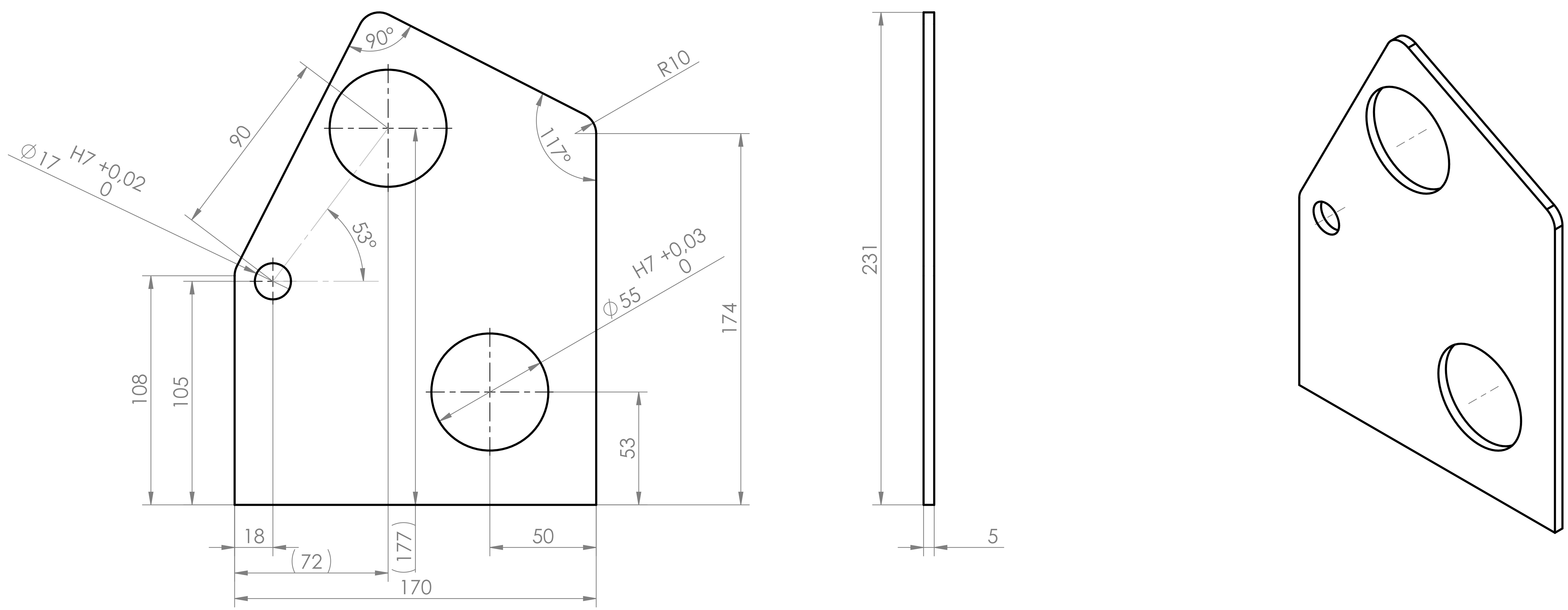


Date: 22.04.2016	Drawn by: Forberg	Projection:	Scale: 1:2	NMBU
Quantity: 2	Material: S355	Unit of measure: mm		
Bin Mount (modified)				Replacement for: / Replaced by:
Bin System				F-005-001
Referral:		Calculation: F.L & H.G		

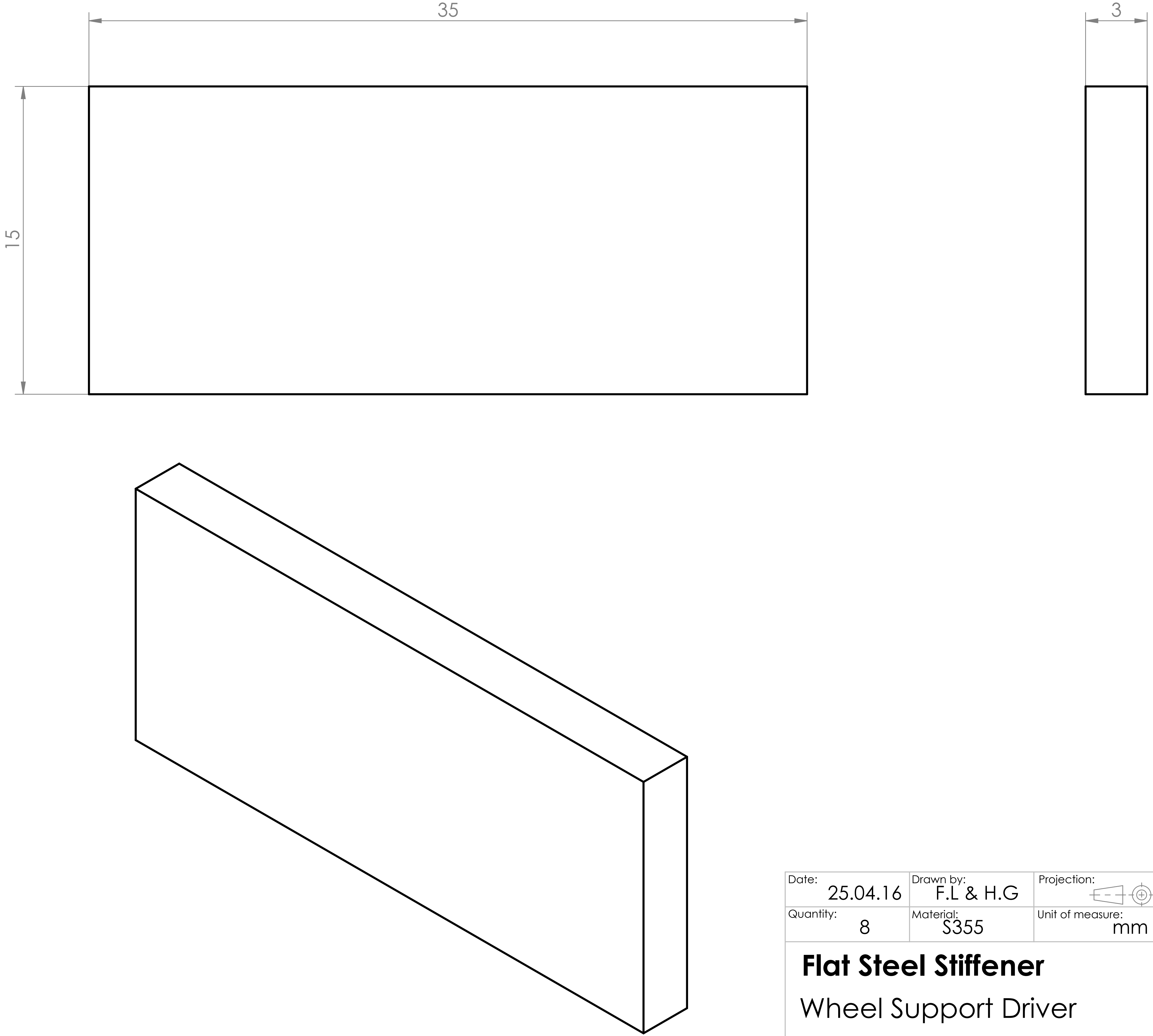


21	2	ISO 7045 - M4 x 30 - Z --- 30N	S355
20	1	Parallel key A6 x 6 x 70 DIN 6885	S355
19	2	Pan Head Cross Recess Screw ISO 7045 - M4x30	S355
18	2	Chain wheel DIN 8192 - C 21Z 06B-2 --21SC50H25L25R1	S355
17	2	Parallel key A8 x 7 x 20 DIN 6885	S355
16	4	Circlip DIN 471 - 25 x 1.2	
15	4	Circlip DIN 471 - 17 x 1	
14	4	Circlip DIN 472 - 47 x 1.75	
13	2	Chain Wheel DIN 8192 C 21Z06B-2	S355
12	1	SICK - i10_RA213	
11	4	SKF - W 6005-2RS1	
10	1	SKF - 62303-2RS1	
9	1	N-008-009 - Wheel Shaft	S355
8	1	N-008-008 - Wheel	S355
7	1	N-008-007 - Sprocket Shaft	S355
6	1	N-008-006 - Sprocket Driver Shaft	S355
5	1	N-008-005 - Actuator Plate	S355
4	4	N-008-004 - Bearing Housing	S355
3	1	N-008-003 - Flat Steel Base	S355
2	2	N-008-002 - Flat Steel Stiffener	S355
1	2	N-008-001 - Wheel Support Plate	S355
Pos.	QTY.	Part Name	Material

Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 1	Material:	Unit of measure: mm		
Wheel Support Driver				Replacement for: / Replaced by:
RMVC				N-008
Referral:		Calculation: F.L & H.G		



Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 4	Material: S355	Unit of measure: mm		
Wheel Support Plate				Replacement for: / Replaced by:
Wheel Support Driver				N-008-001
Referral:		Calculation: F.L & H.G		



Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 5:1	NMBU
Quantity: 8	Material: S355	Unit of measure: mm		

Flat Steel Stiffener

Wheel Support Driver

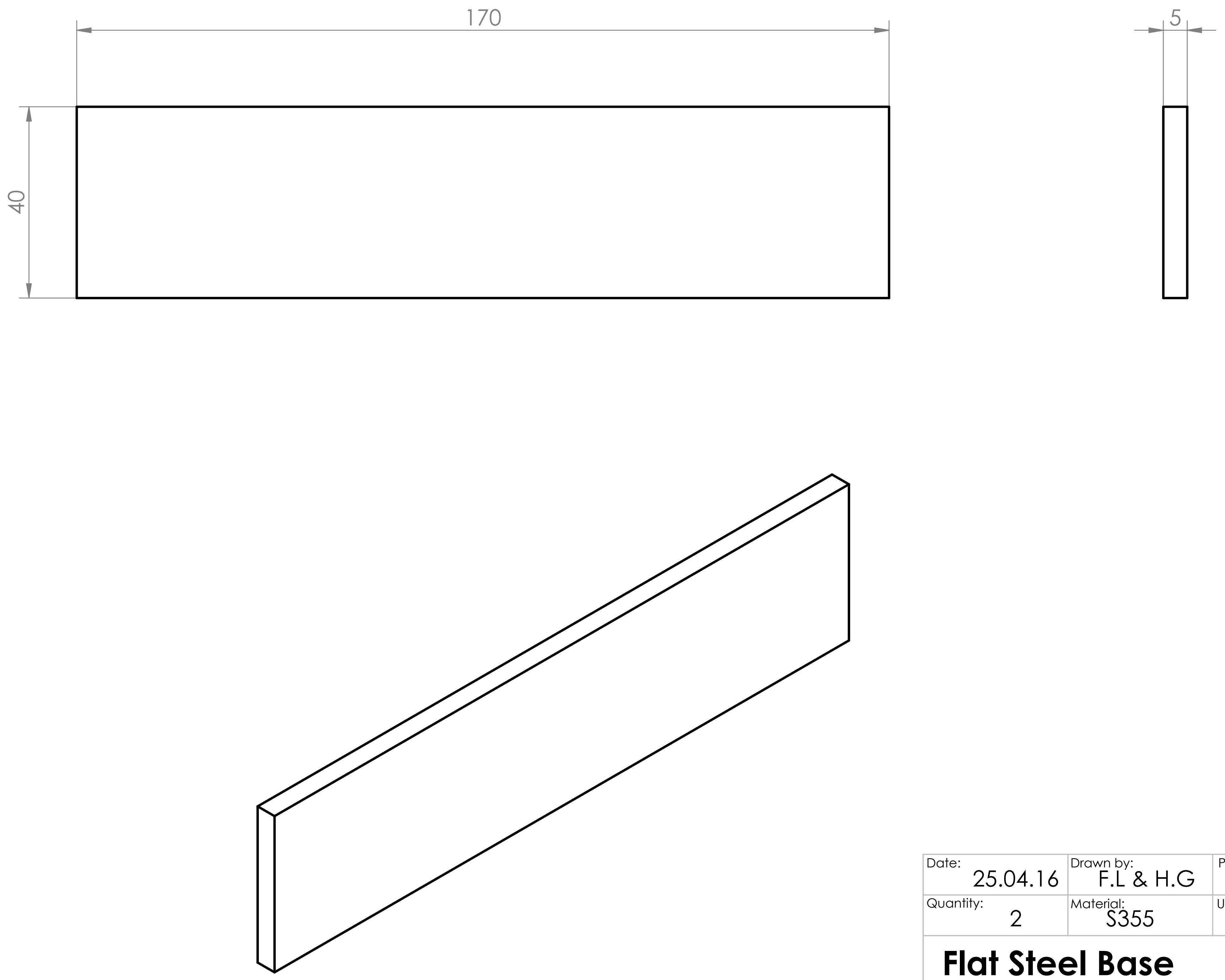
Replacement for:

Replaced by:

N-008-002

Referral:

Calculation: F.L & H.G



Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 2	Material: S355	Unit of measure: mm		

Flat Steel Base

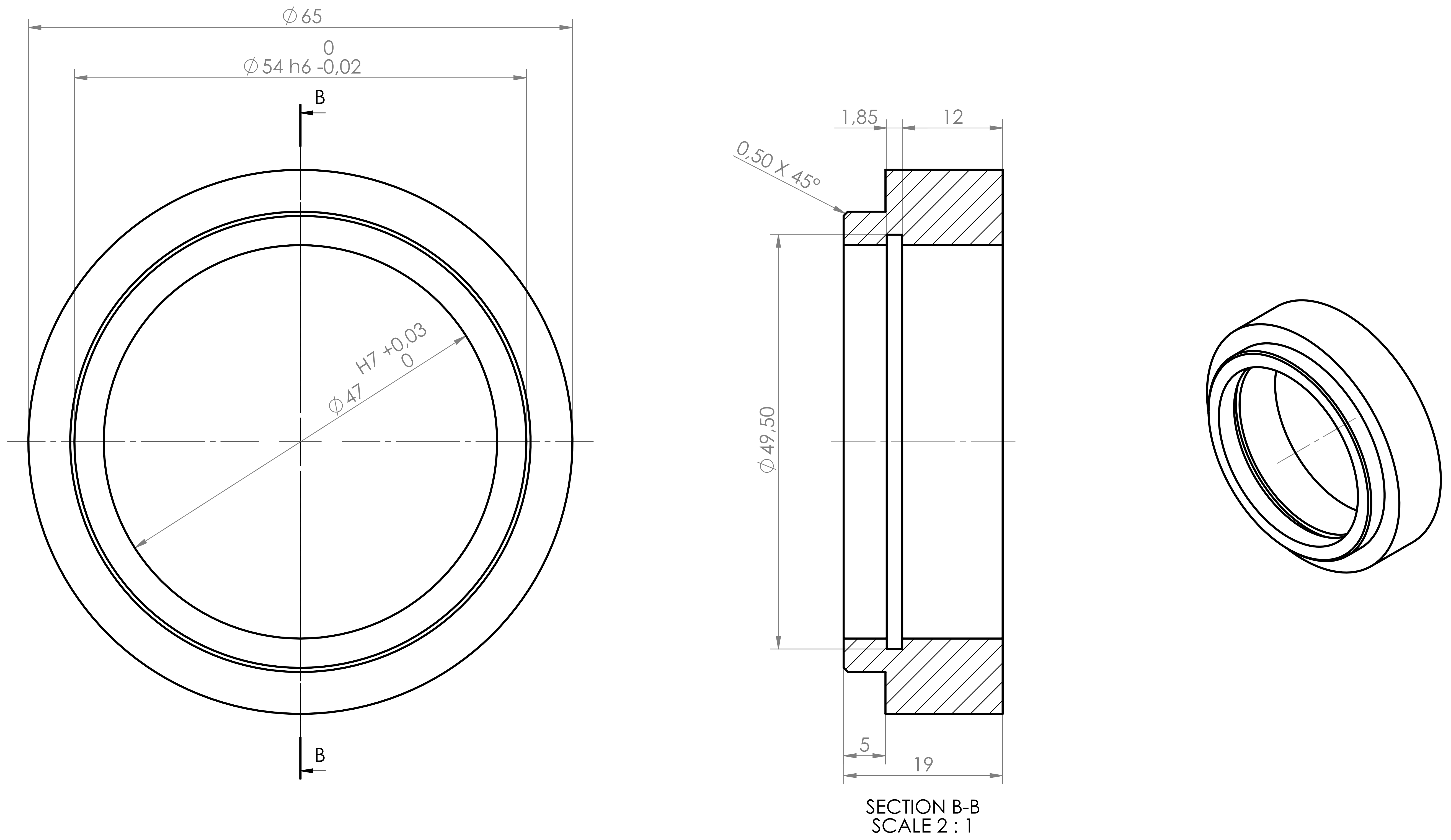
Wheel Support Driver

Replacement for:	Replaced by:

N-008-003

Referral:

Calculation: F.L & H.G



Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 8	Material: S355	Unit of measure: mm		

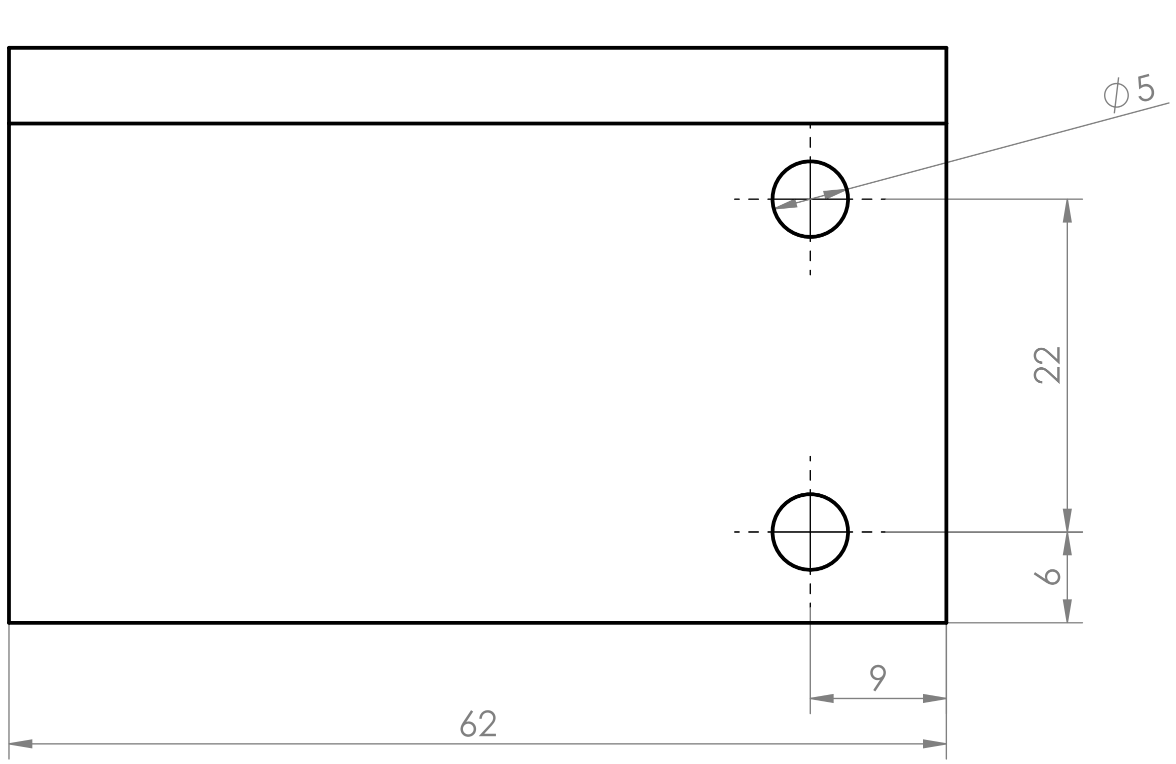
Beraing Housing

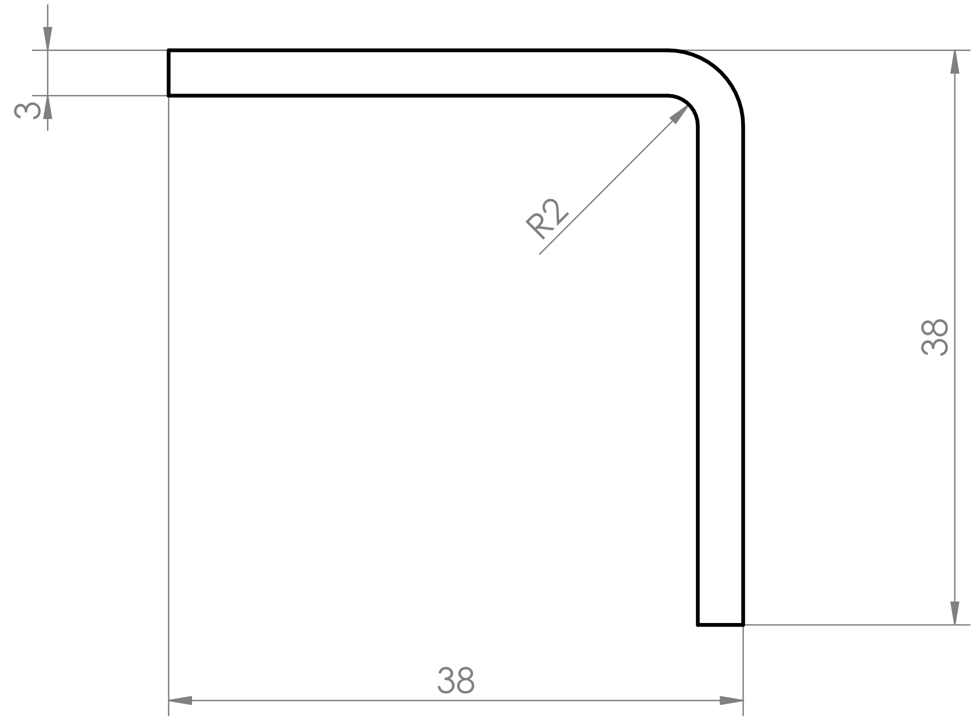
Wheel Support Driver

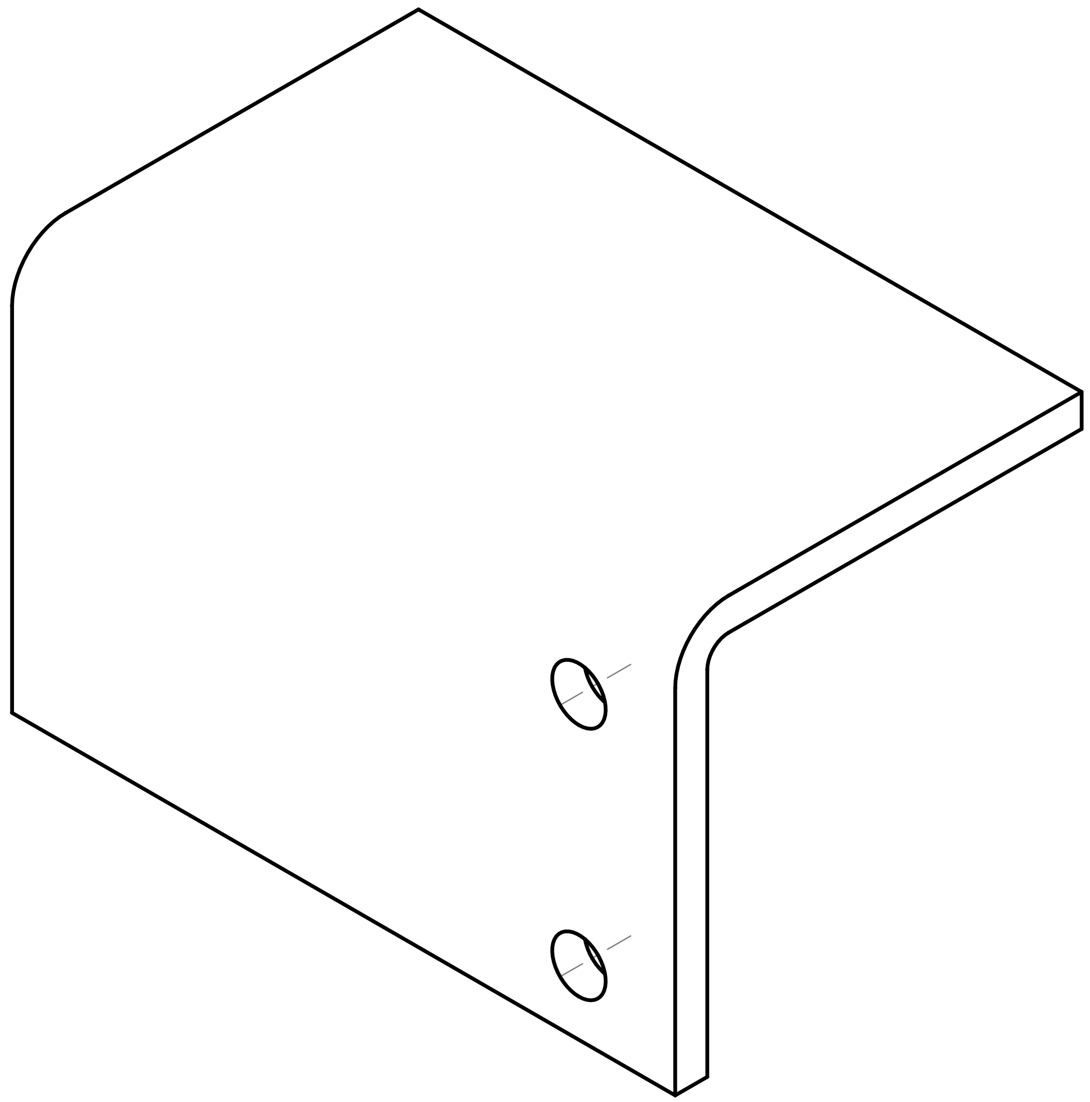
Replacement for: | Replaced by:

N-008-004

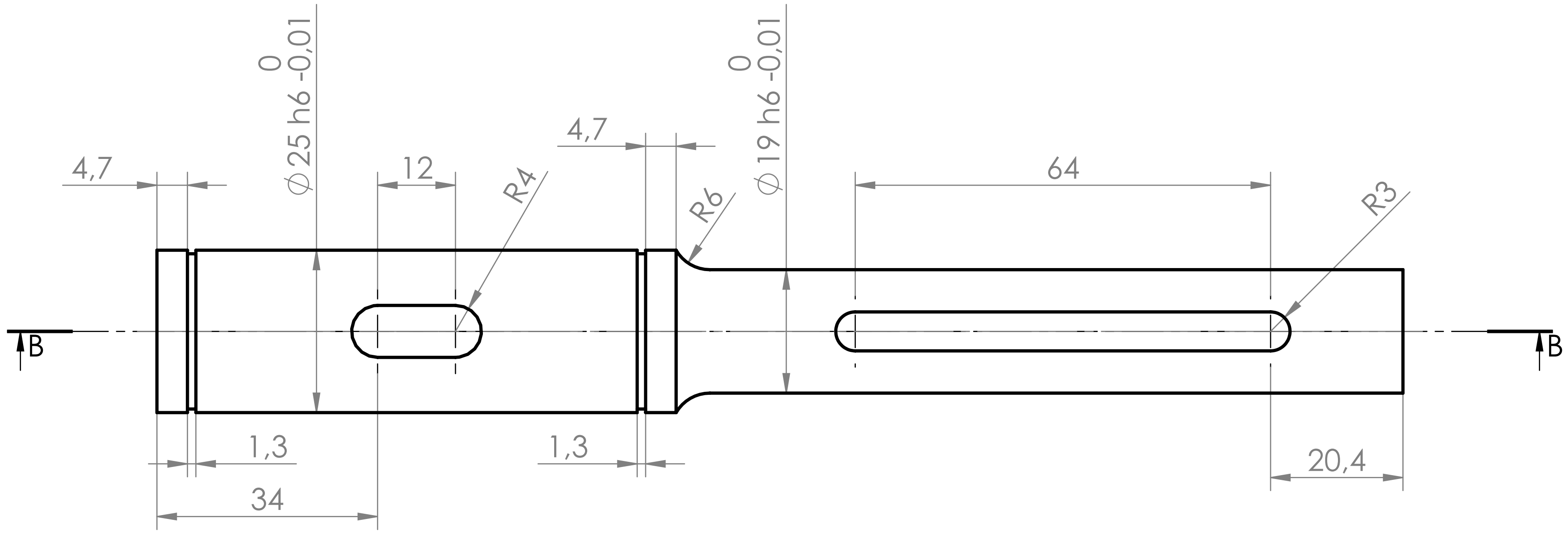
Referral: | Calculation: F.L & H.G

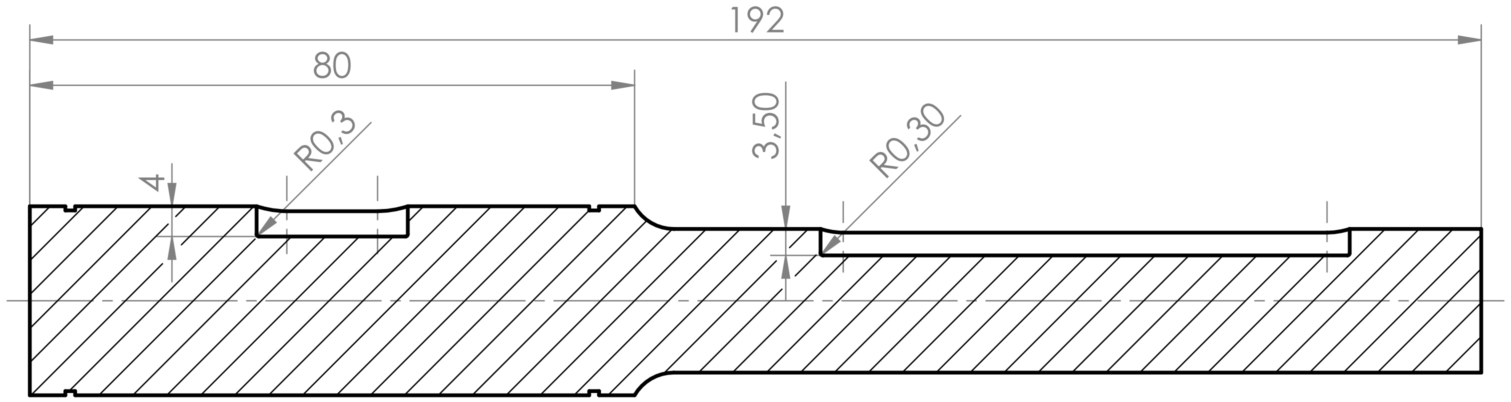




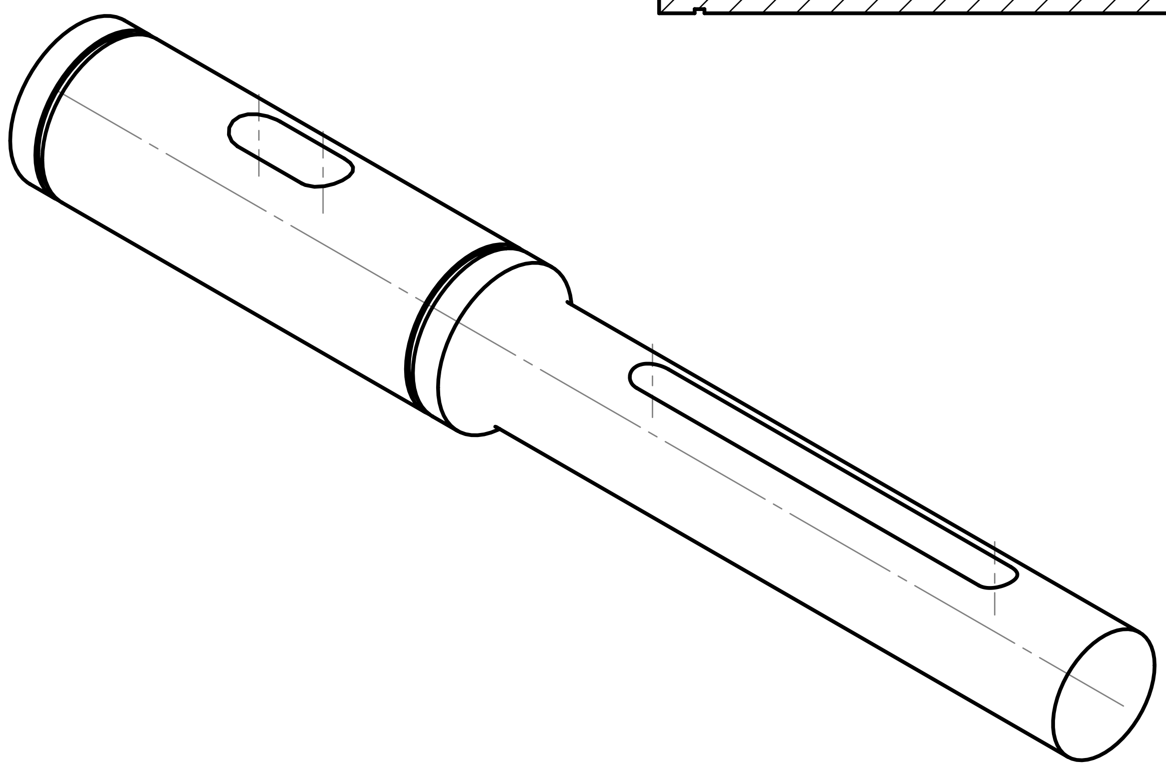


Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		
Actuator Plate				Replacement for: / Replaced by:
Wheel Support Driver				N-008-005
Referral:	Calculation: F.L & H.G			

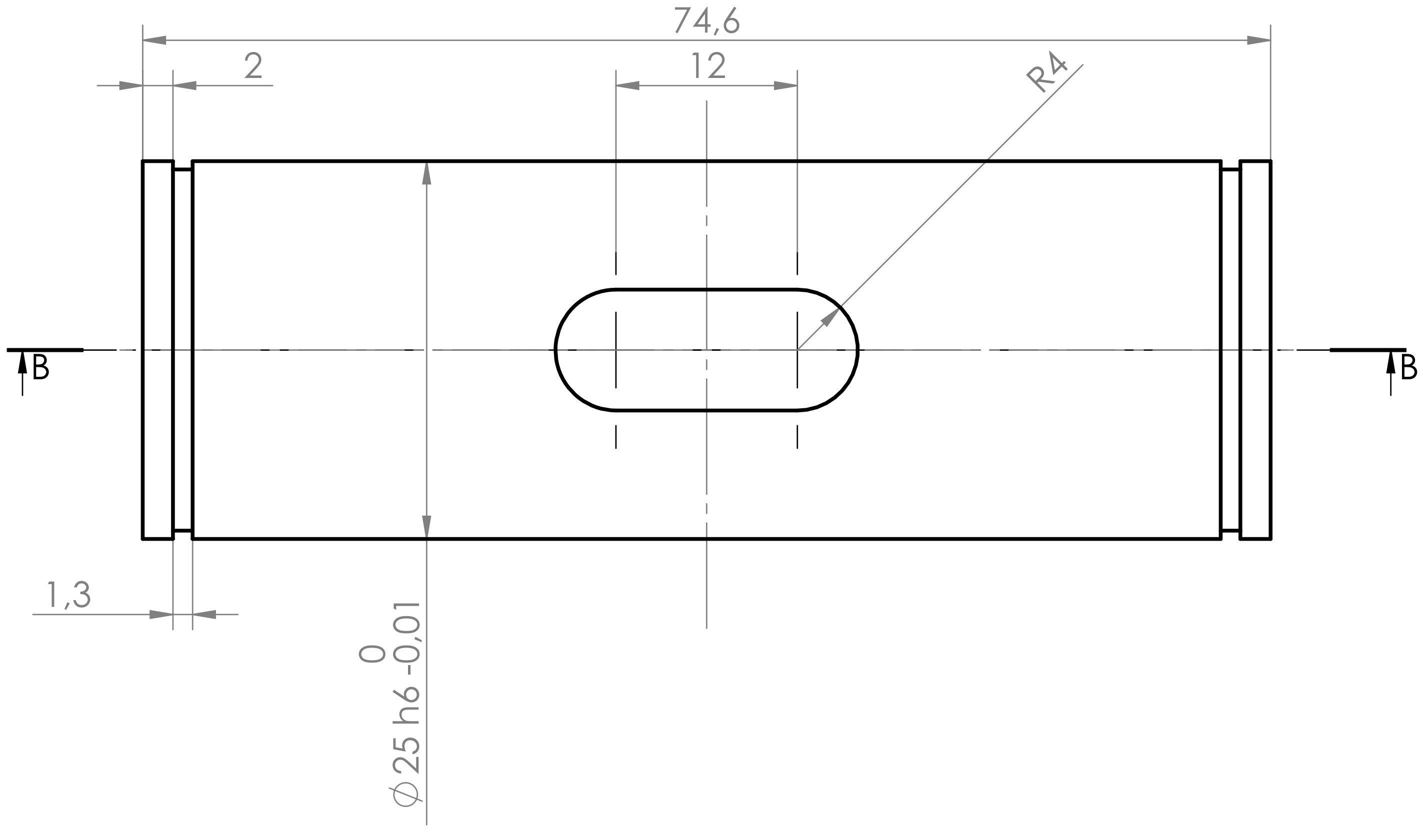


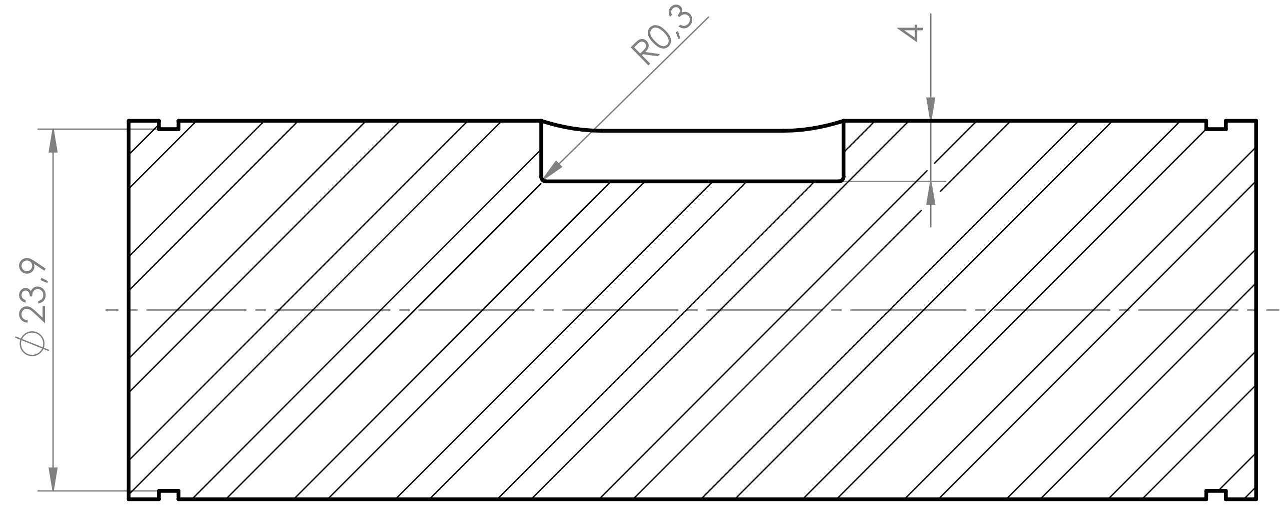


SECTION B-B
SCALE 1 : 1

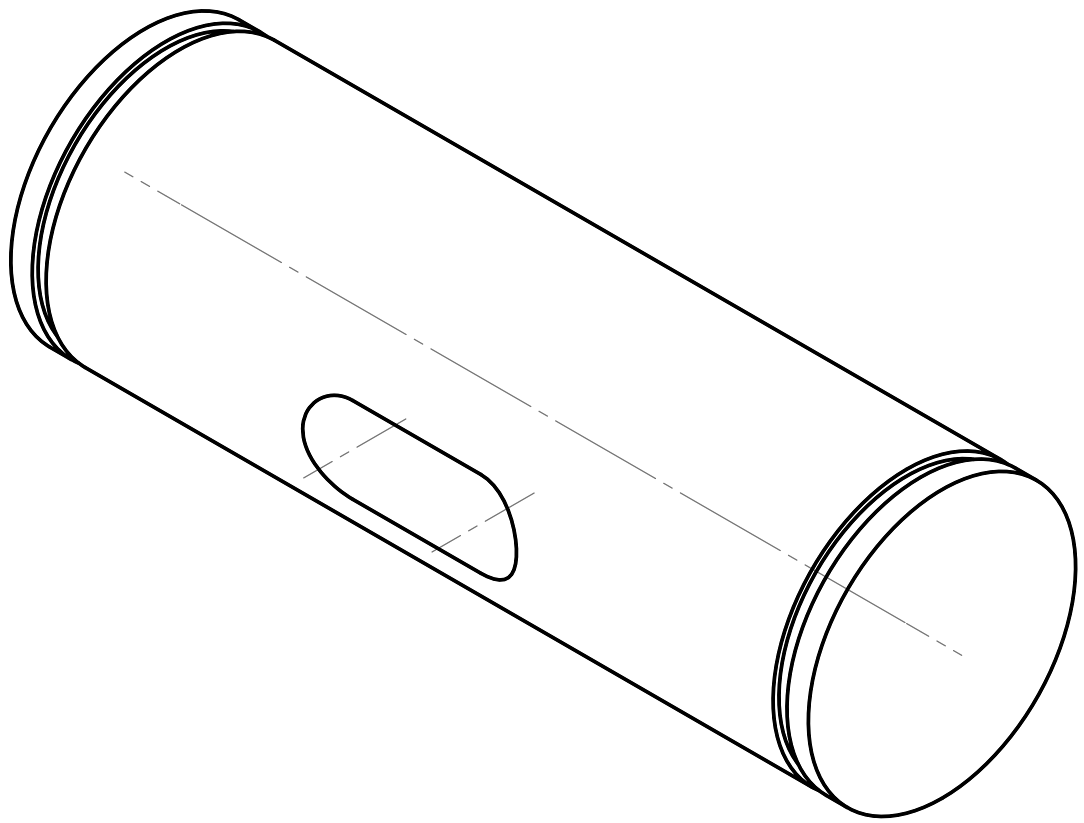


Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		
Sprocket Driver Shaft				Replacement for: / Replaced by:
Wheel Support Driver				N-008-006
Referral:	Calculation: F.L & H.G			

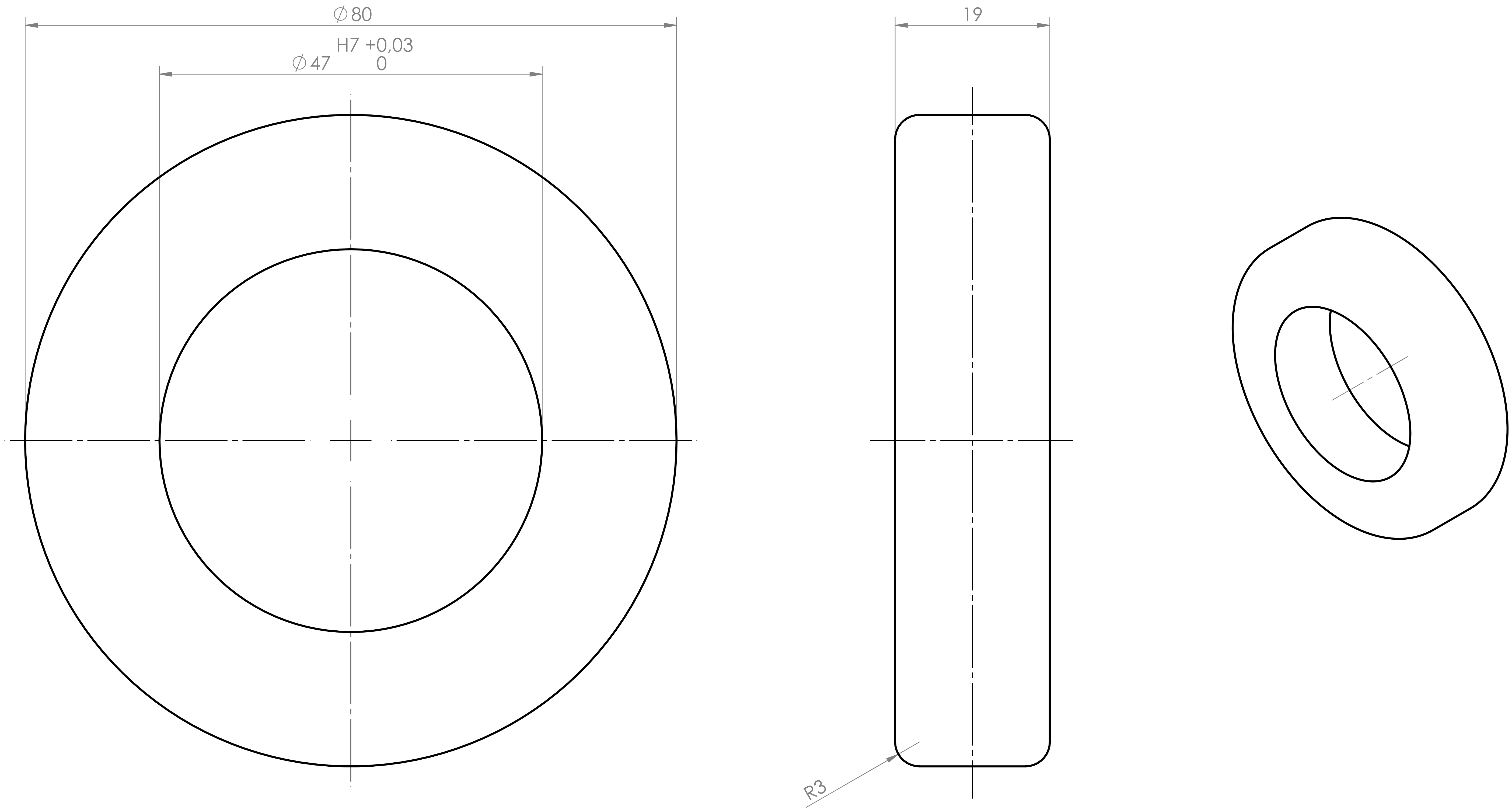




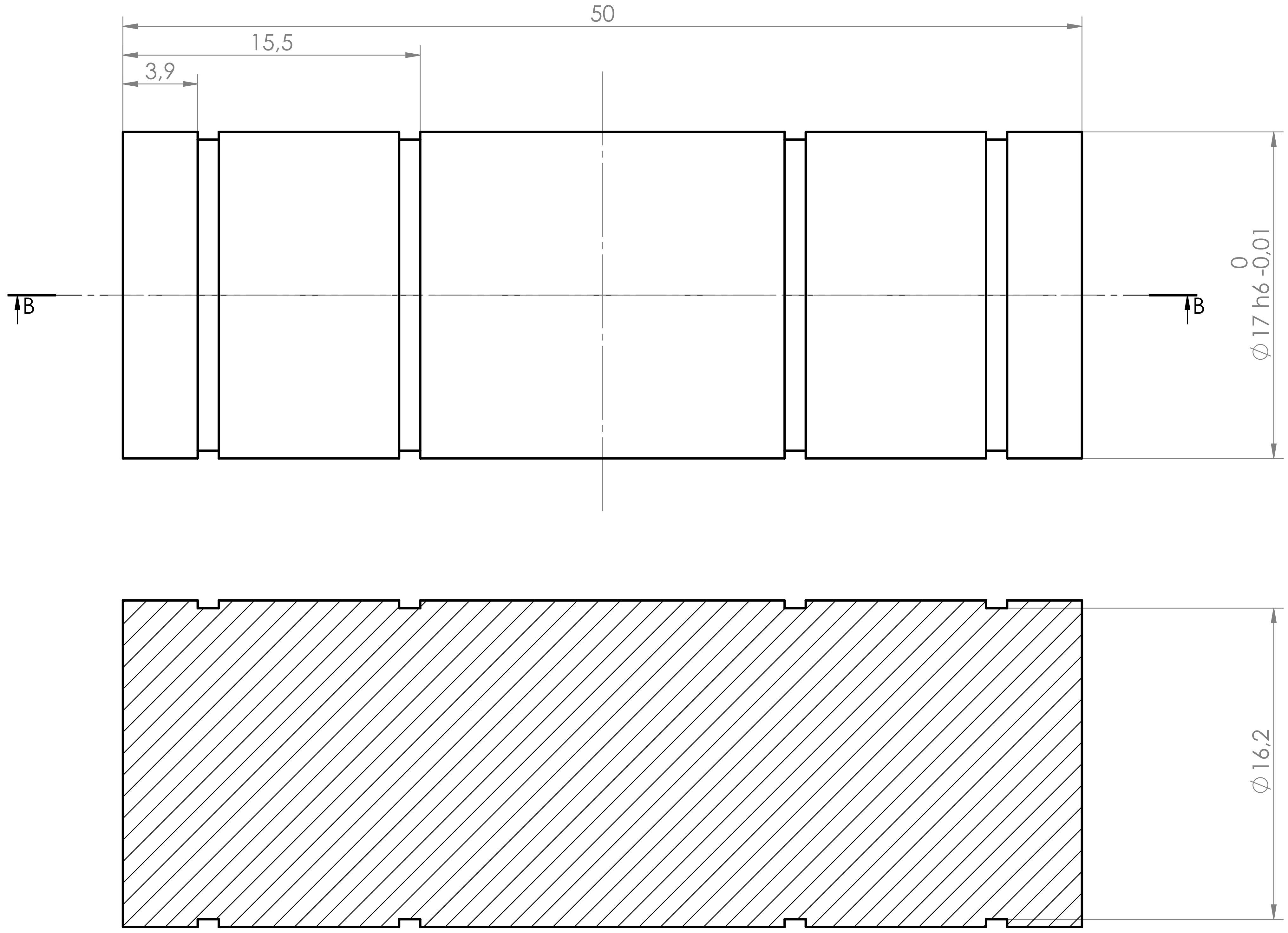
SECTION B-B
SCALE 2 : 1

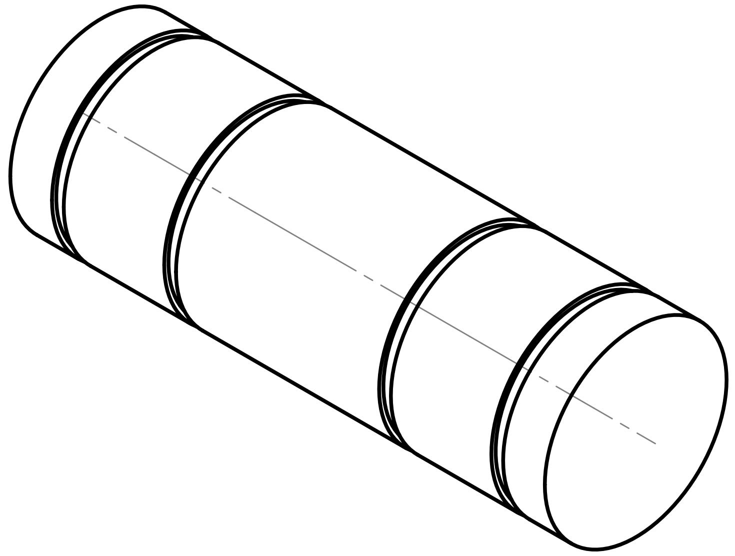


Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 3	Material: S355	Unit of measure: mm		
Sprocket Shaft				Replacement for: / Replaced by:
Wheel Support Driver				N-008-007
Referral:	Calculation: F.L & H.G			



Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU	
Quantity: 4	Material: S355	Unit of measure: mm		Replacement for:	Replaced by:
Wheel					
Wheel Support Driver				N-008-008	
Referral:	Calculation: F.L & H.G				



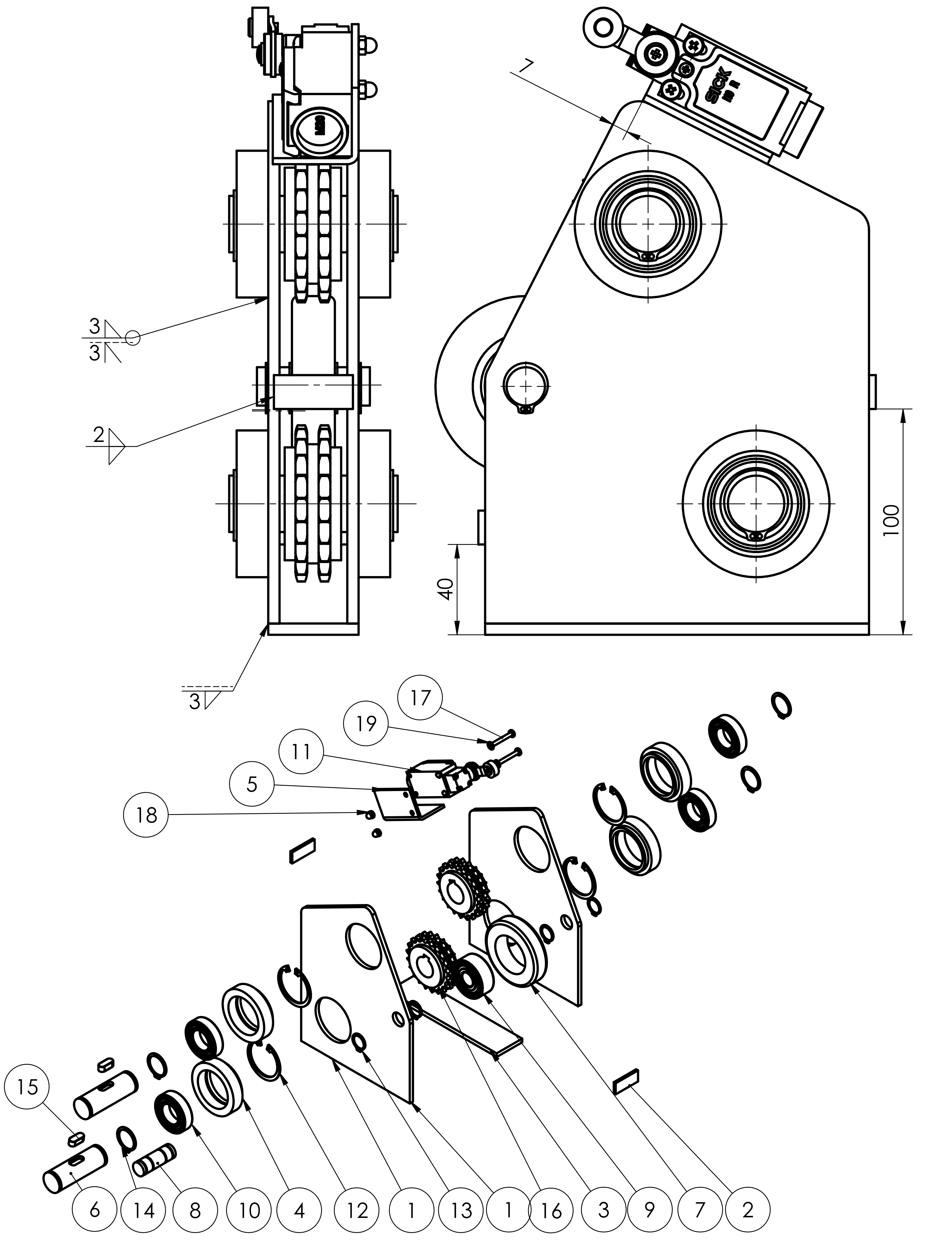


SECTION B-B
SCALE 4 : 1

Date: 25.04.16	Drawn by: F.L & H.G	Projection:	Scale: 4:1	NMBU
Quantity: 4	Material: S355	Unit of measure: mm		

Wheel Shaft Wheel Support Driver	Replacement for:	Replaced by:
	N-008-009	

Referral:	Calculation: F.L & H.G	



Pos.	QTY.	Tittel/benevning/dim.	Material
19	2	Washer DIN 125 - A 4.3	S355
18	2	DIN 1587 - M4 --NNU	S355
17	2	Pan Head Cross Recess Screw ISO 7045 - M4X30	S355
16	2	Chain Wheel DIN 8192 C 21Z06B-2	S355
15	2	Parallel key A8 x 7 x 20 DIN 6885	S355
14	4	Circlip DIN 471 - 25 x 1.2	
13	4	Circlip DIN 471 - 17 x 1	
12	4	Circlip DIN 472 - 47 x 1.75	
11	1	SICK - i10_RA213	
10	4	SKF - W 6005-2RS1	
9	1	SKF - 62303-2RS1	
8	1	N-008-009 - Wheel Shaft	S355
7	1	N-008-008 - Wheel	S355
6	2	N-008-007 - Sprocket Shaft	S355
5	1	N-009-001 - Actuator Plate	S355
4	4	N-008-004 - Bearing Housing	S355
3	1	N-008-003 - Flat Steel Base	S355
2	2	N-008-002 - Flat Steel Stiffener	S355
1	2	N-008-001 - Wheel Support Plate	S355

Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 1	Material: AISI 304	Unit of measure: mm		

Wheel Support Driven

RMVC

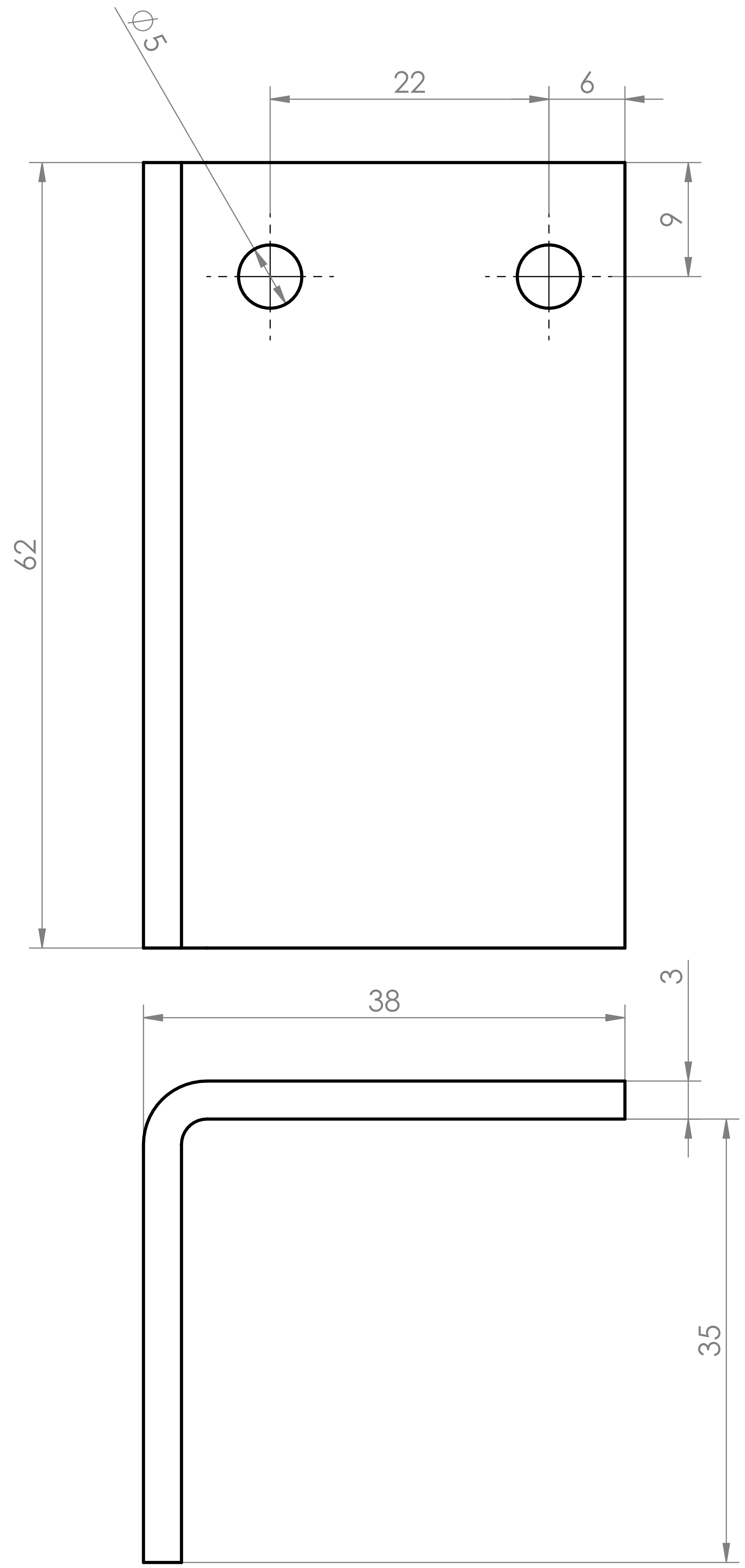
Replacement for:

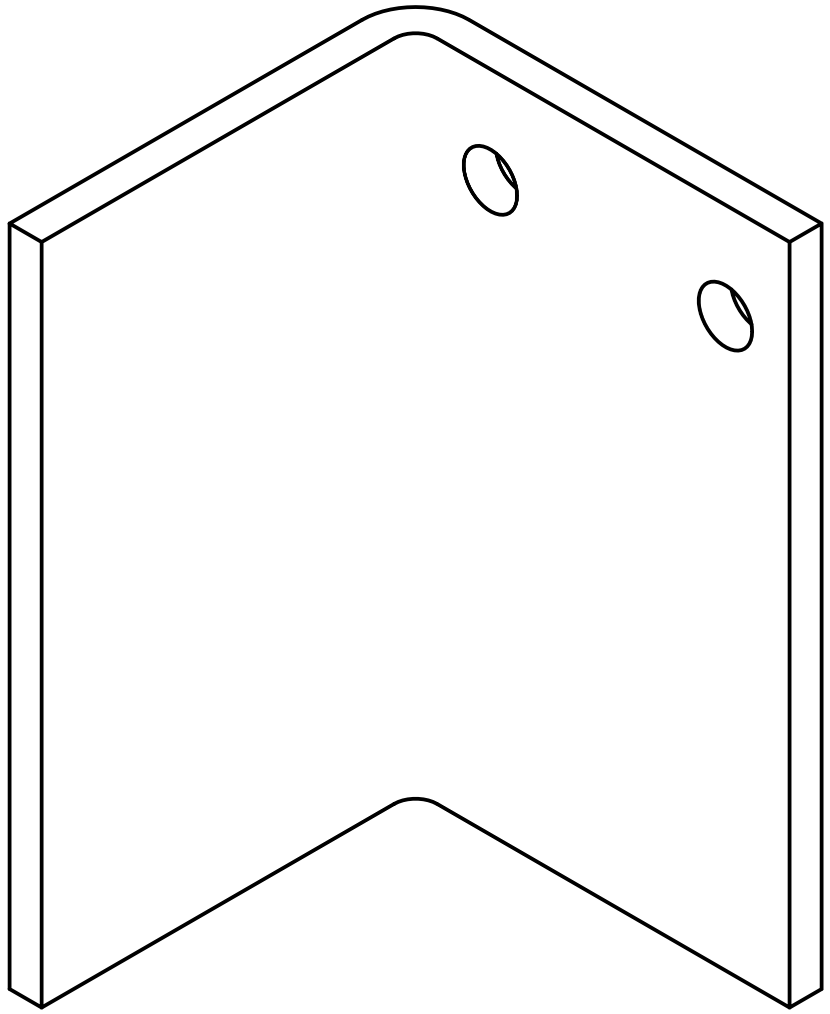
Replaced by:

N-009

Referral:

Calculation: F.L & H.G





Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 1	Material: S355	Unit of measure: mm		

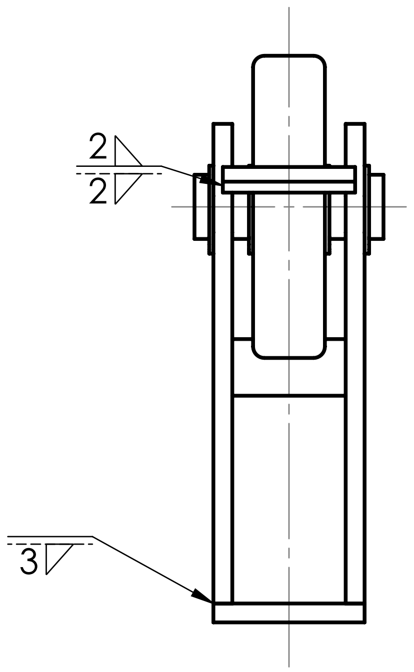
Actuator Plate

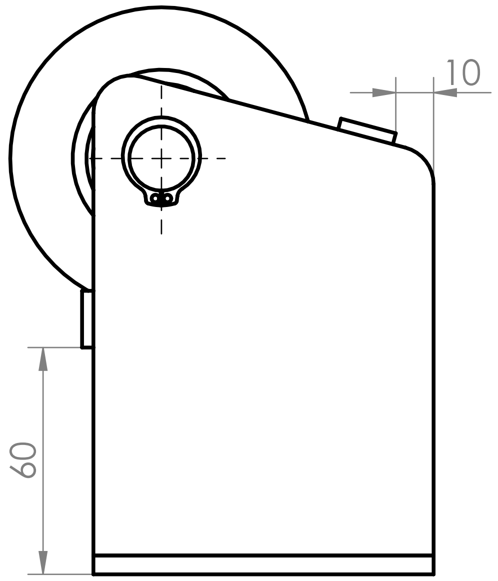
Wheel Support Driven

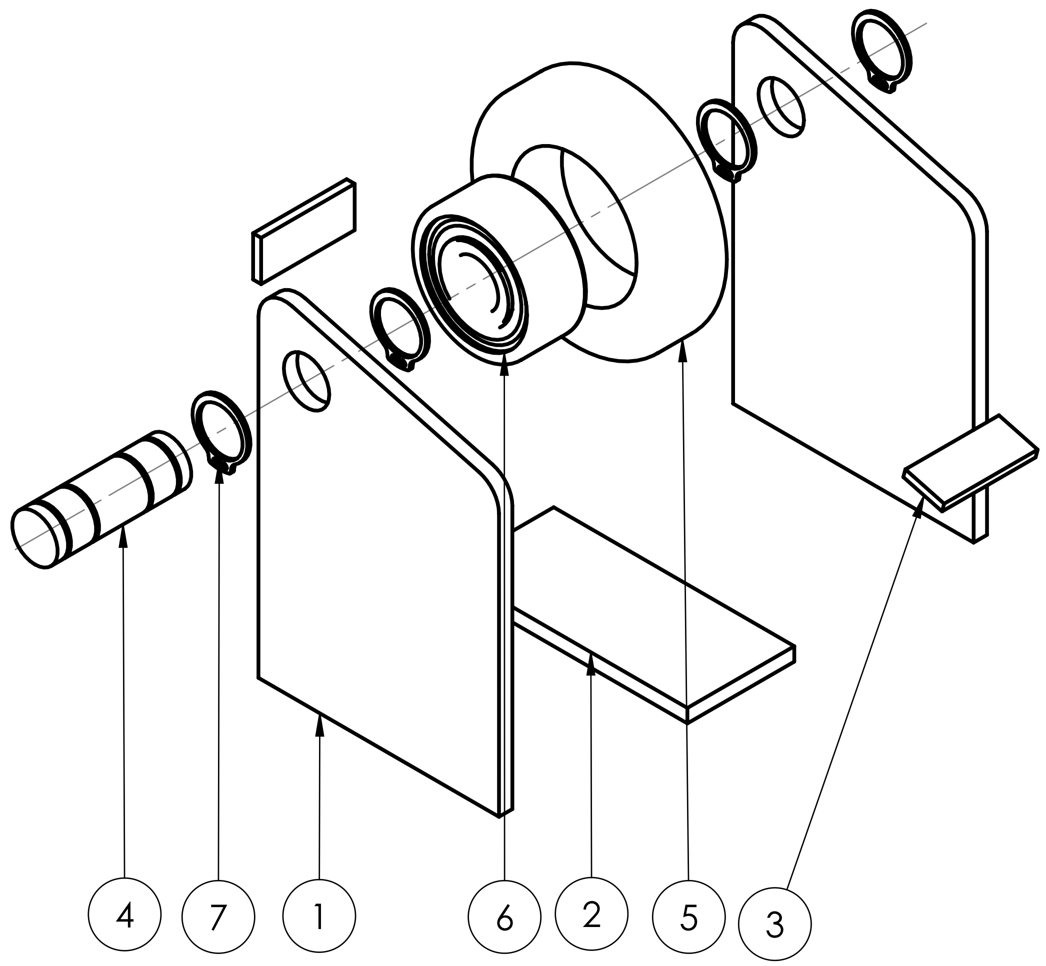
Replacement for:	Replaced by:

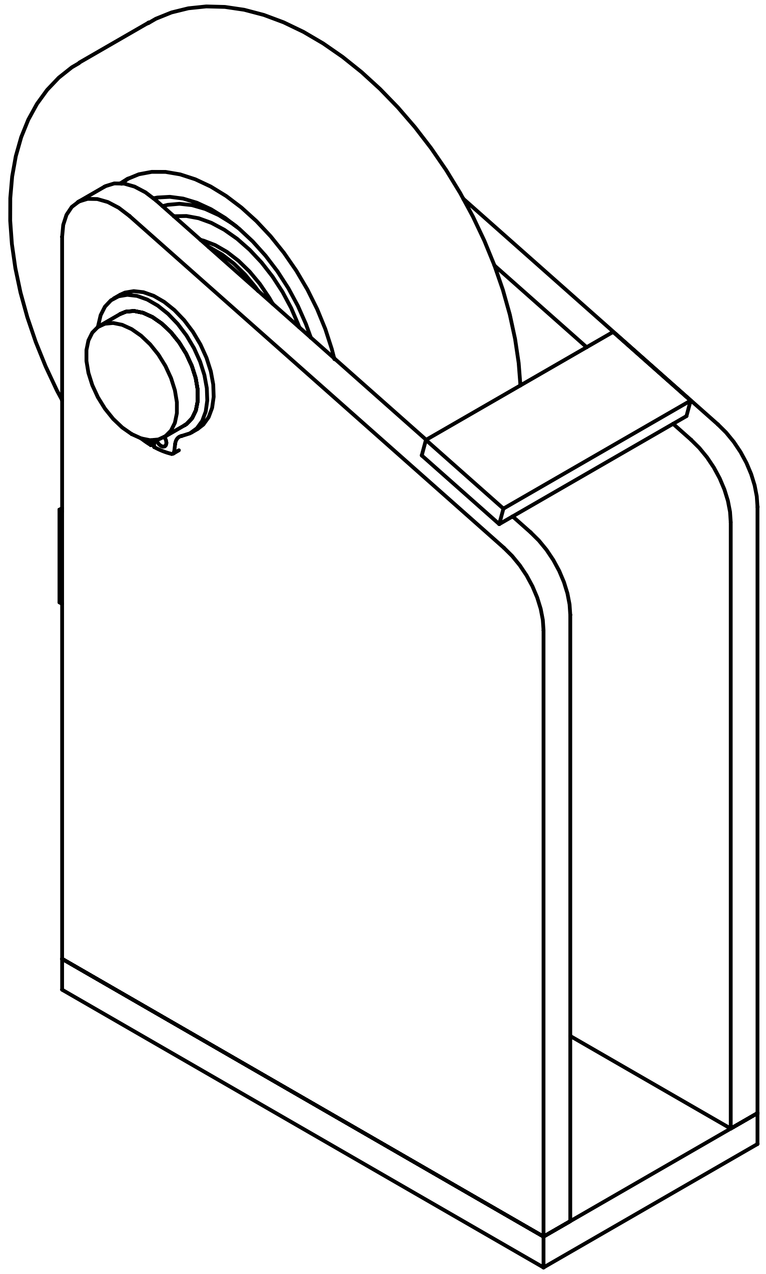
N-009-001

Referral:	Calculation: F.L & H.G









Pos.	QTY.	Part Name	Material
7	4	Circlip DIN 471 - 18 x 1.2	
6	1	SKF - 62303-2RS1	
5	1	N-008-008 - Wheel	S355
4	1	N-008-009 - Wheel Shaft	S355
3	2	N-008-002 - Flat Steel Stiffener	S355
2	1	N-010-002 - Flat Steel base	S355
1	2	N-010-001 - Wheel Support Plate	S355

Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 2	Material:	Unit of measure: mm		

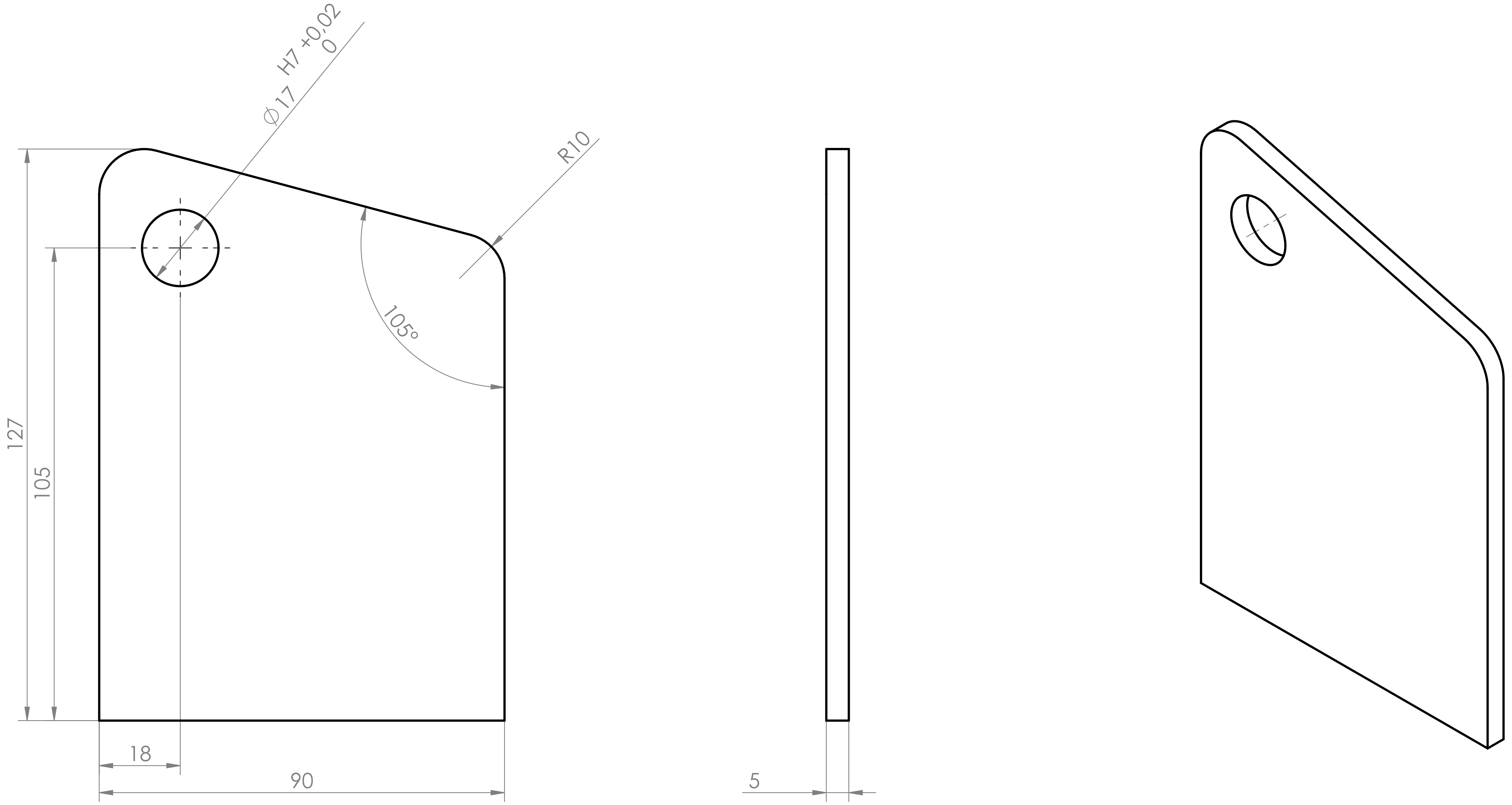
Wheel Support

RMVC

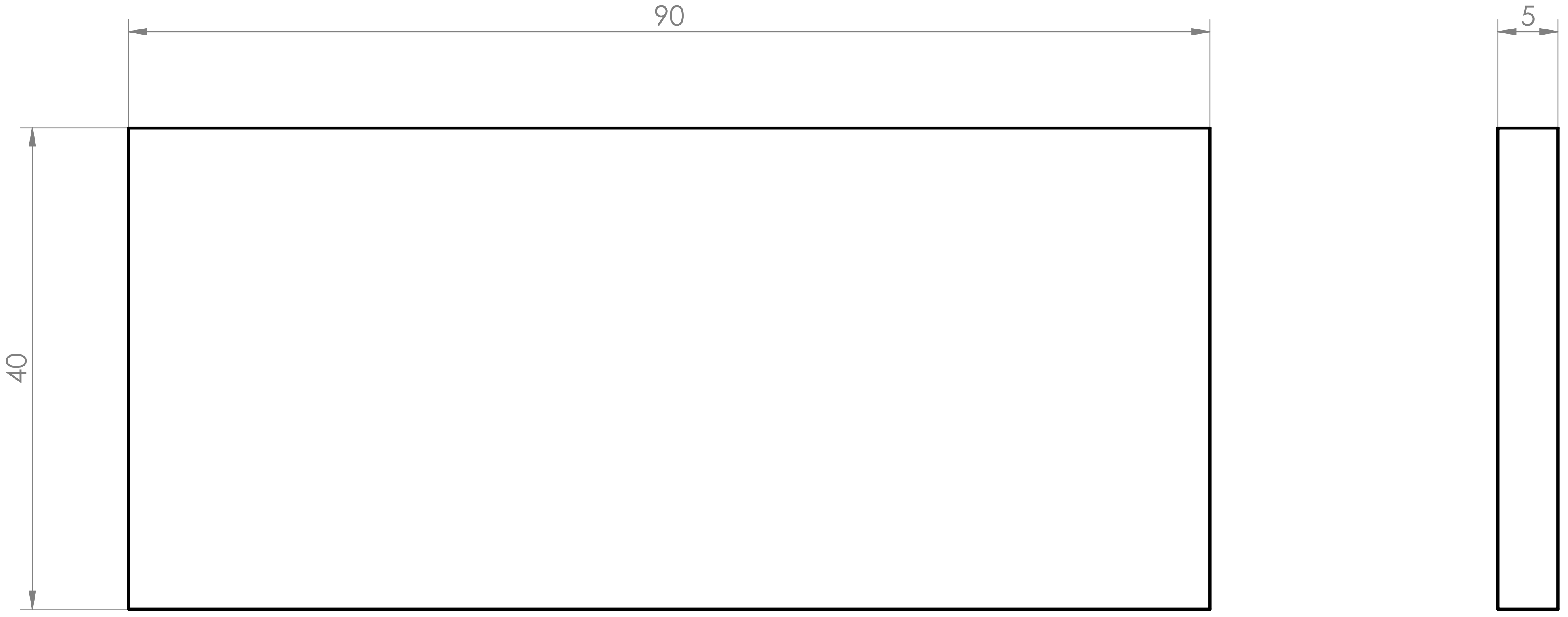
Replacement for:	Replaced by:

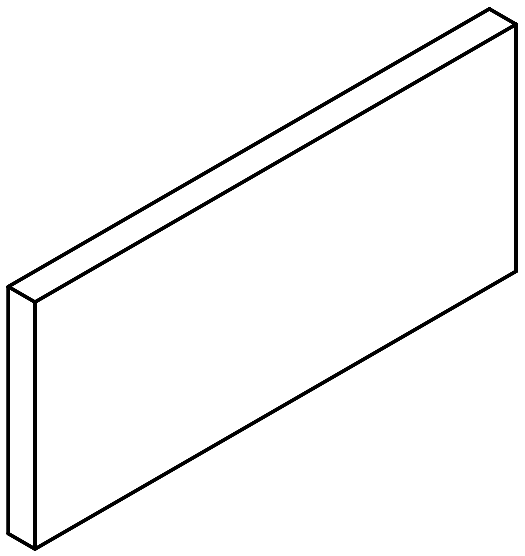
N-010

Referral:	Calculation: F.L & H.G



Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU	
Quantity: 4	Material: S355	Unit of measure: mm			
Wheel Support Plate				Replacement for:	Replaced by:
Wheel Support				N-010-001	
Referral:		Calculation: F.L & H.G			





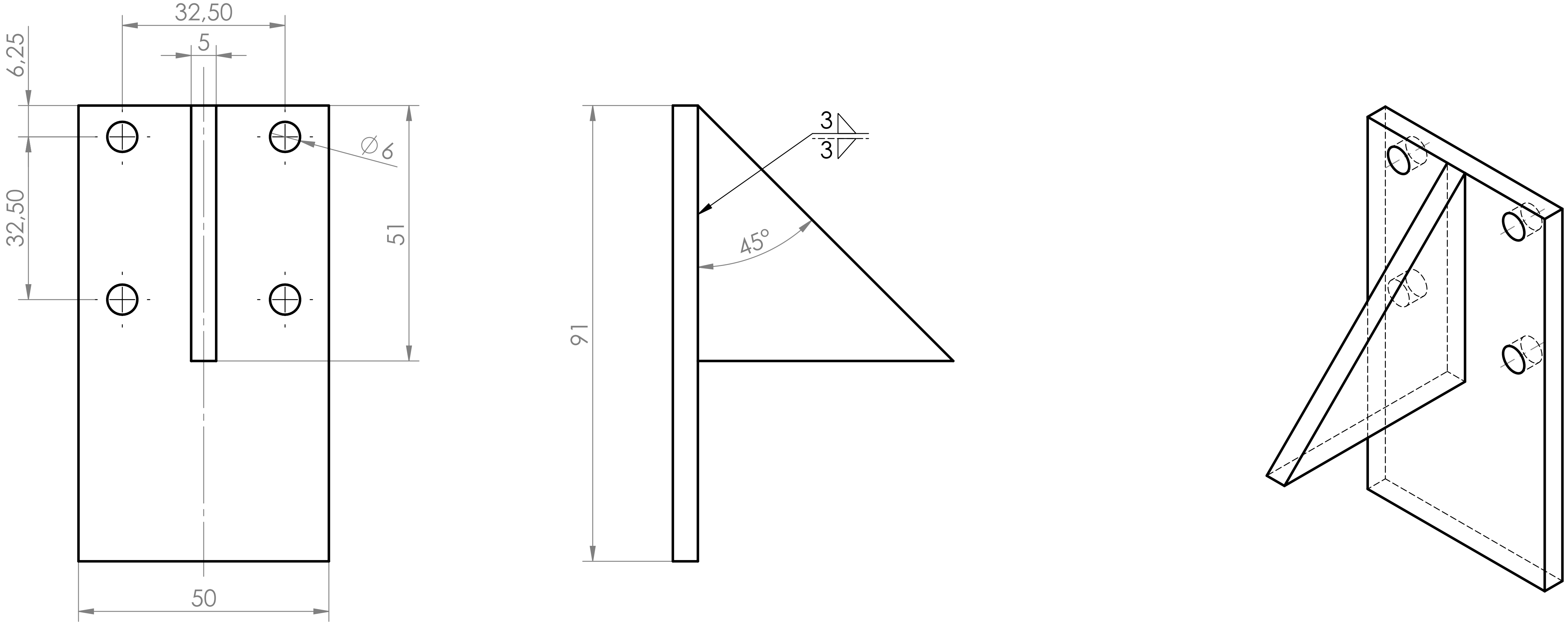
Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU	
Quantity: 2	Material: S355	Unit of measure: mm		Replacement for:	Replaced by:

Flat Steel Base

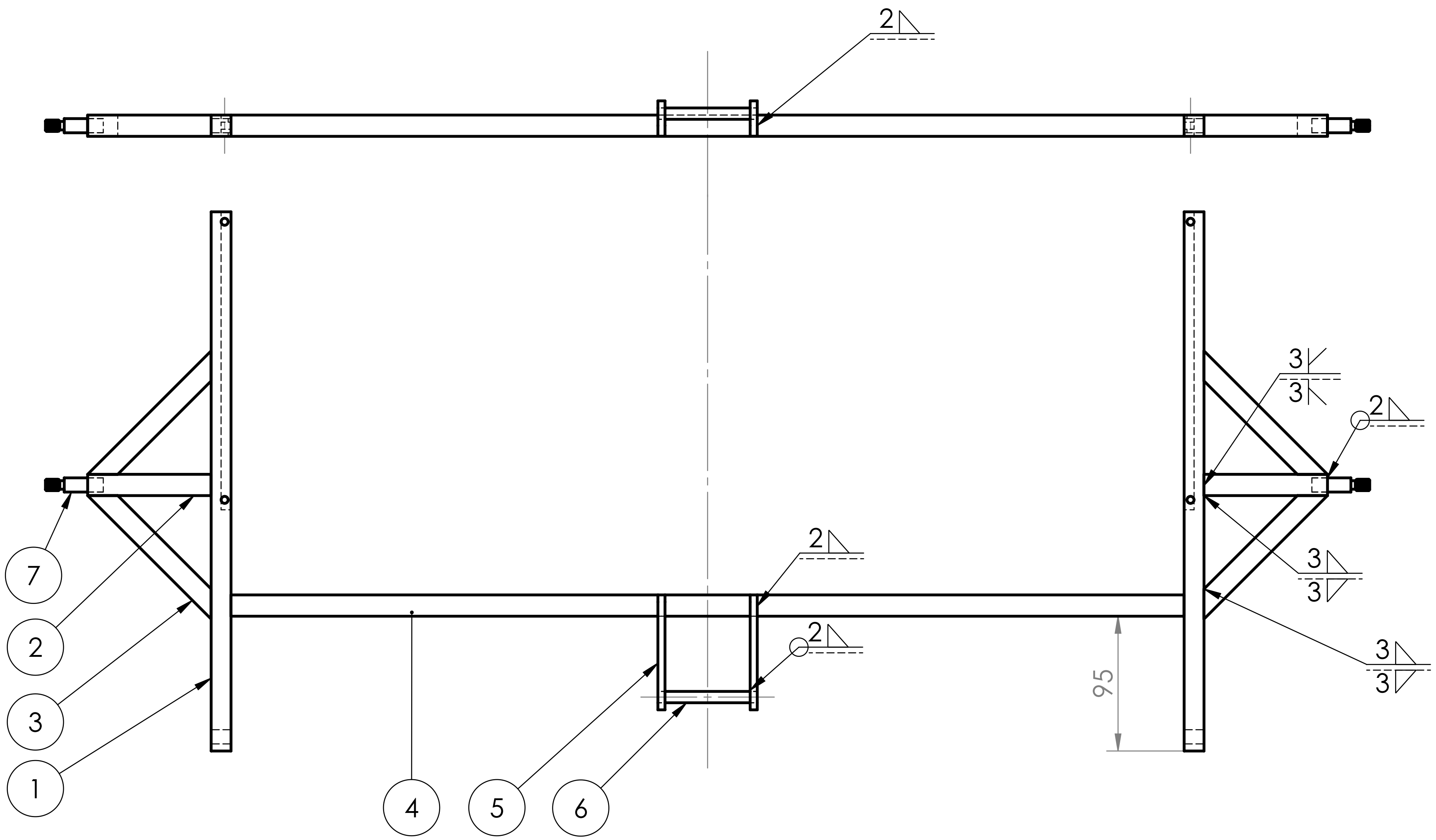
Wheel Support

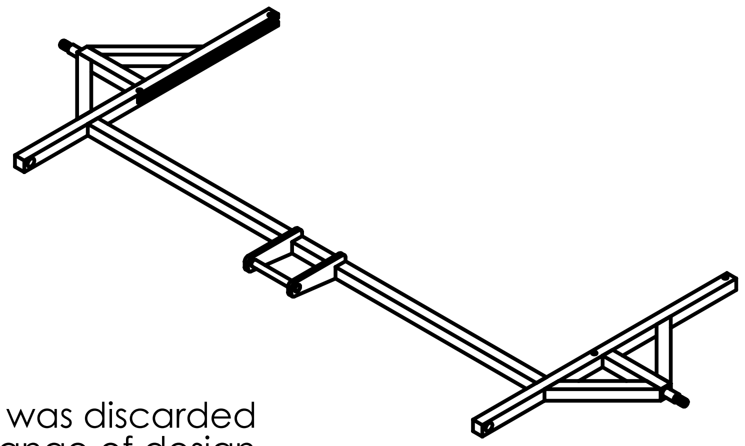
N-010-002

Referral:	Calculation: F.L & H.G

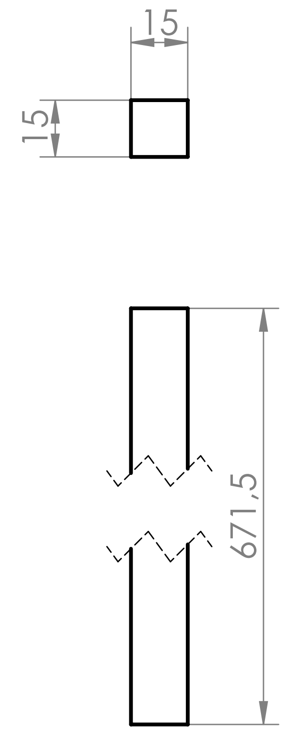


Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 2	Material: S355	Unit of measure: mm		
Pivot Mounting Plate				Replacement for: / Replaced by:
RMVC				N-011
Referral:		Calculation: F.L & H.G		



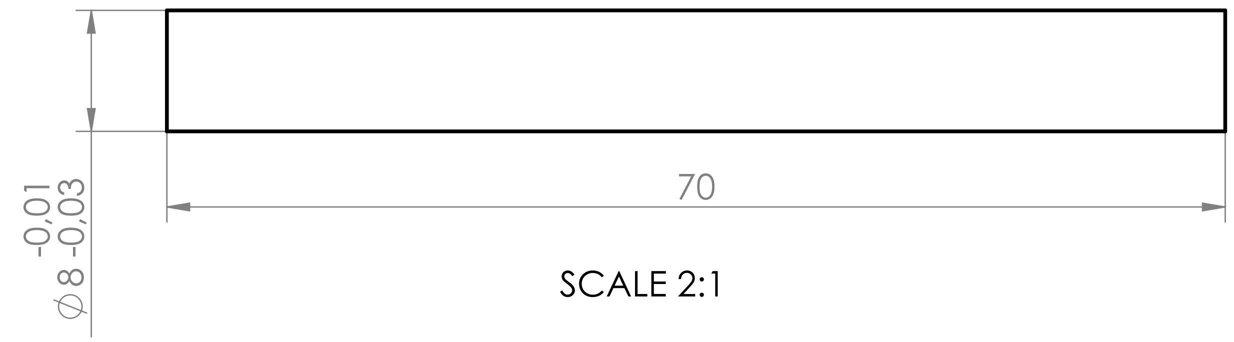


N-012-005 - Arm Connector



SCALE 1:2

N-012-007 - Pin



SCALE 2:1

N-012-003 was discarded
due to change of design

Pos.	QTY.	Part Name	Material
7	2	ISO 7379 - 10 x 30 --- N (Head Removed)	S355
6	1	N-012-007 - Pin	S355
5	2	N-012-006 - Pin Holder	S355
4	1	N-012-005 - Arm Connector	S355
3	4	N-012-004 - Arm Stiffener	S355
2	2	N-012-002 - Rod Eye	S355
1	2	N-012-001 - Lifting Arm	S355

Date: 06.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:4	NMBU
Quantity: 1	Material:	Unit of measure: mm		Replacement for: / Replaced by:

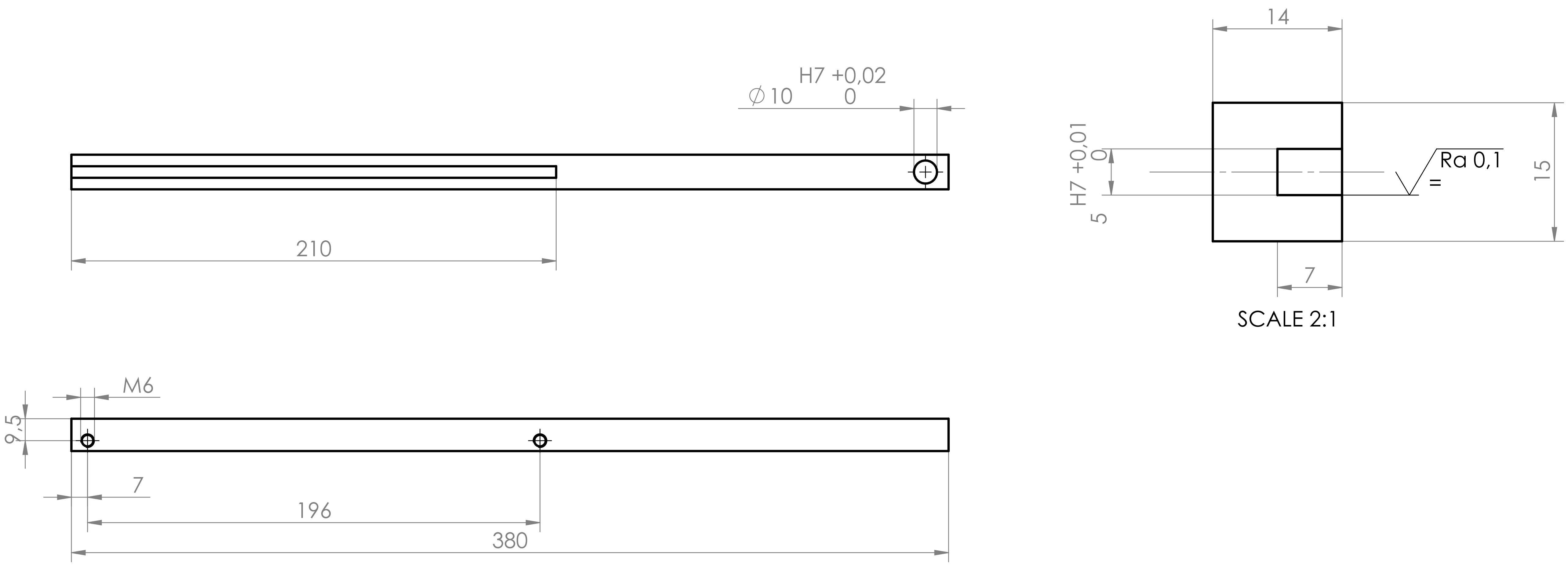
Pivot Arm

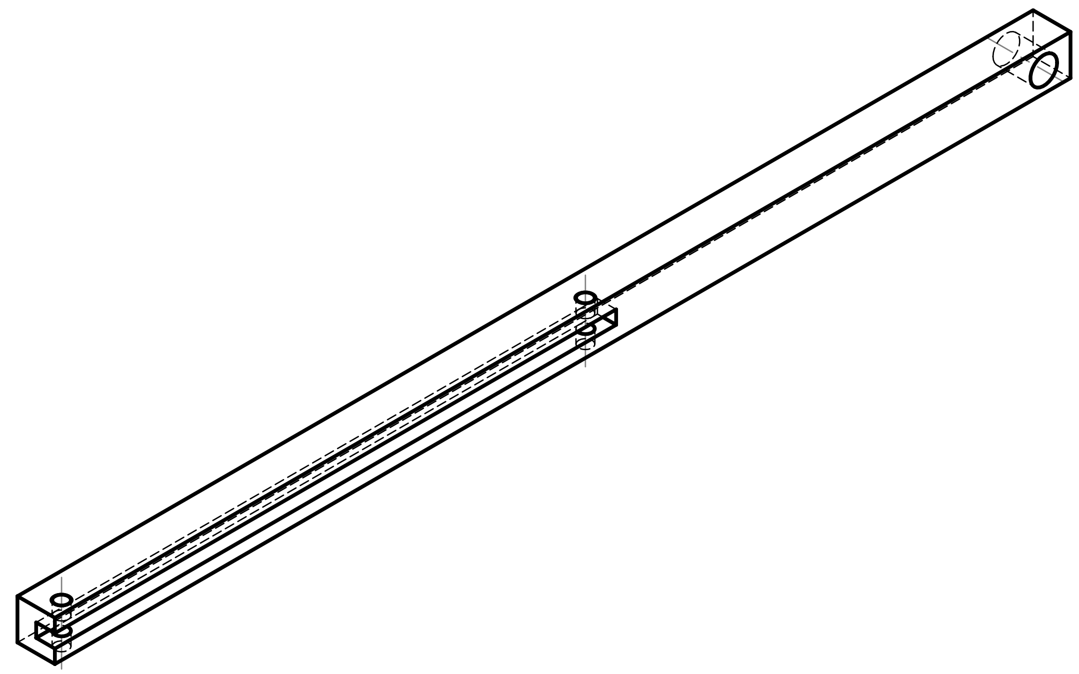
RMVC

N-012

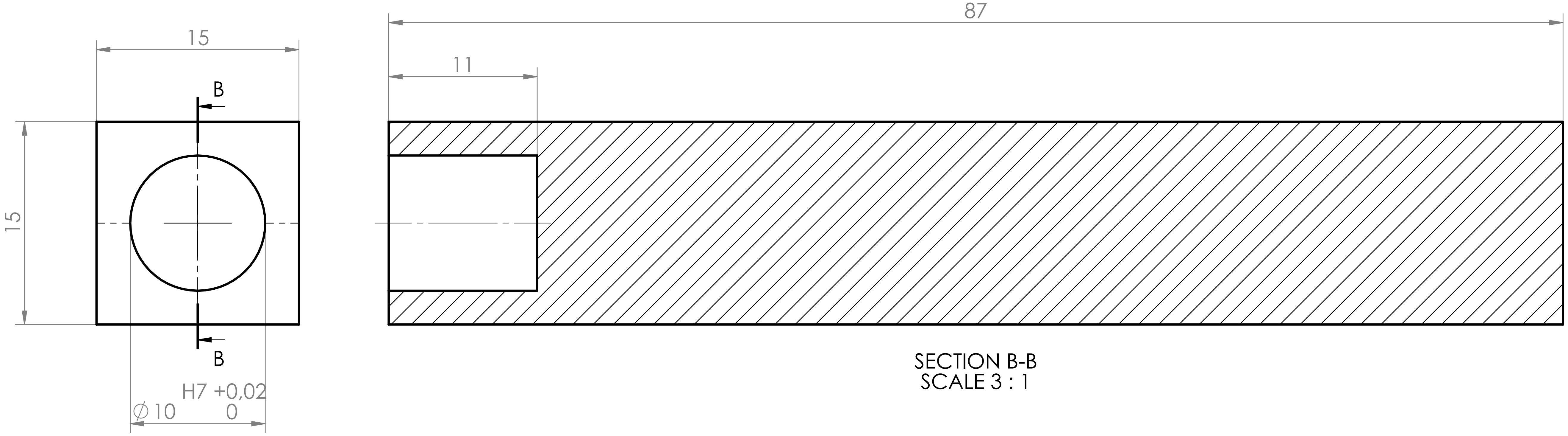
Referral:

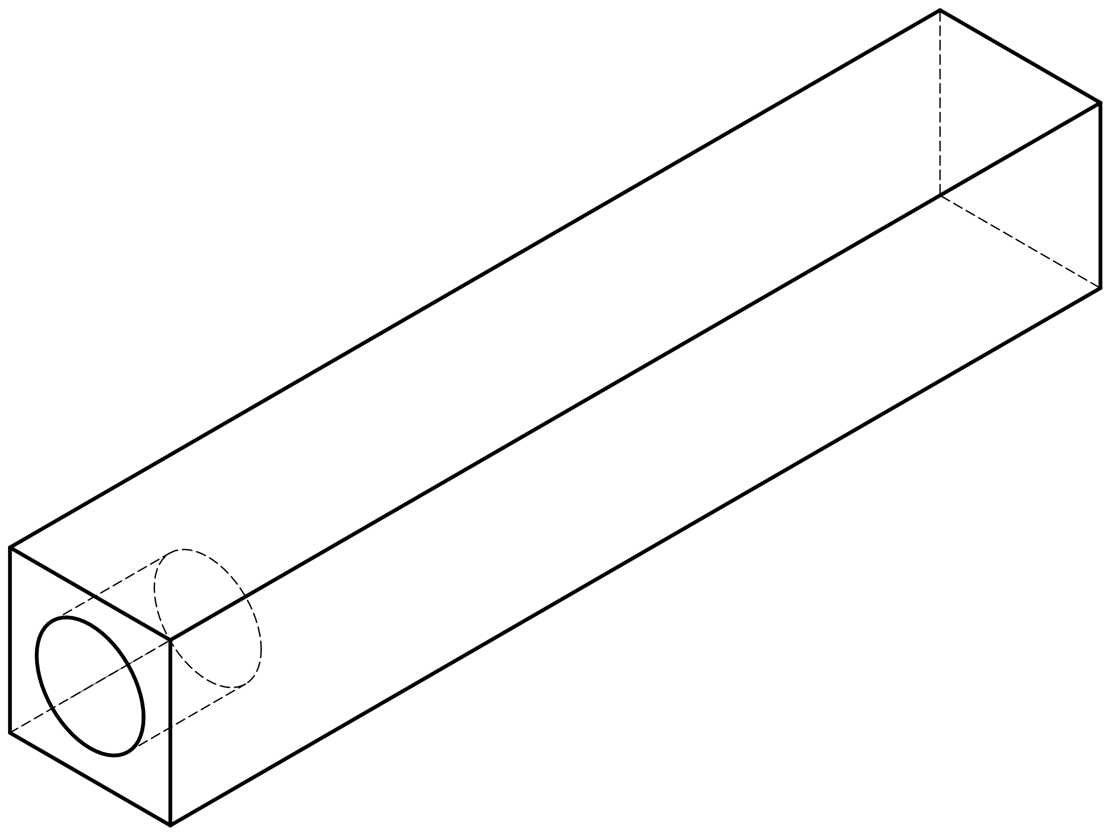
Calculation: F.L & H.G



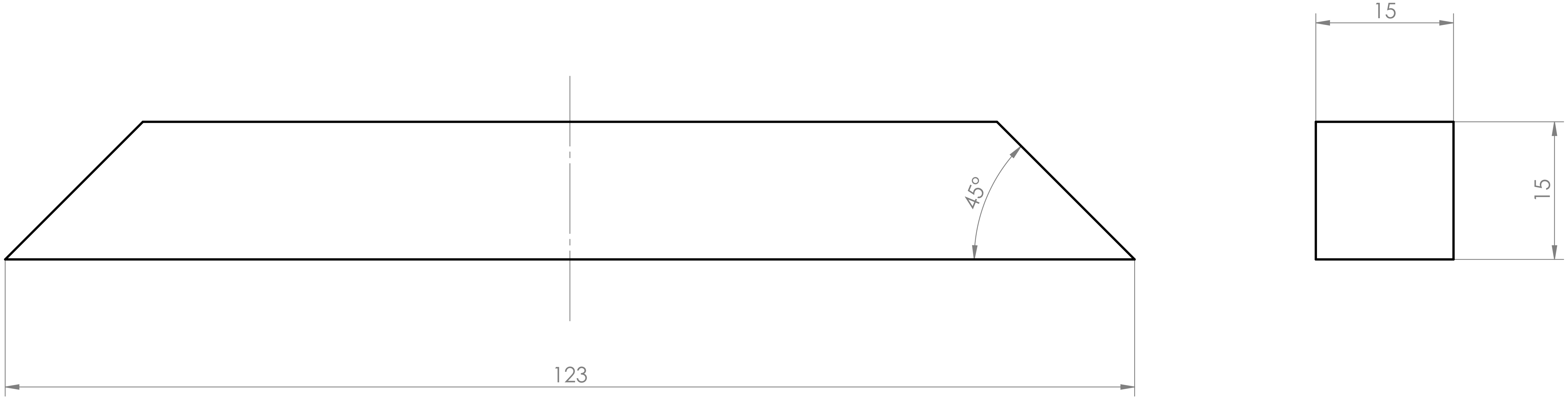


Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:2	NMBU
Quantity: 2	Material: S355	Unit of measure: mm		
Lifting Arm				Replacement for: / Replaced by:
Pivot Arm				N-012-001
Referral:		Calculation: F.L & H.G		

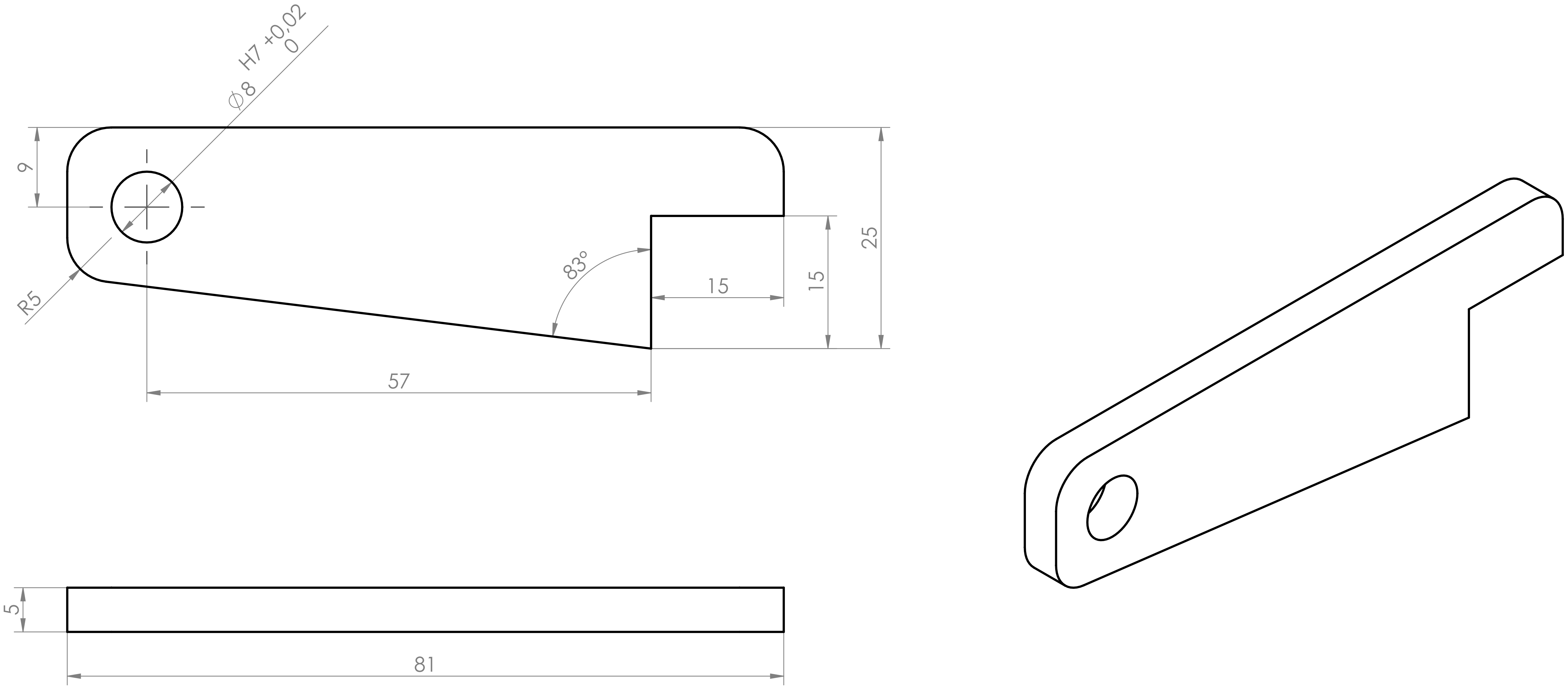




Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 3:1	NMBU
Quantity: 2	Material: S355	Unit of measure: mm		
Rod Eye				Replacement for: / Replaced by:
Pivot Arm				N-012-002
Referral:	Calculation: F.L & H.G			

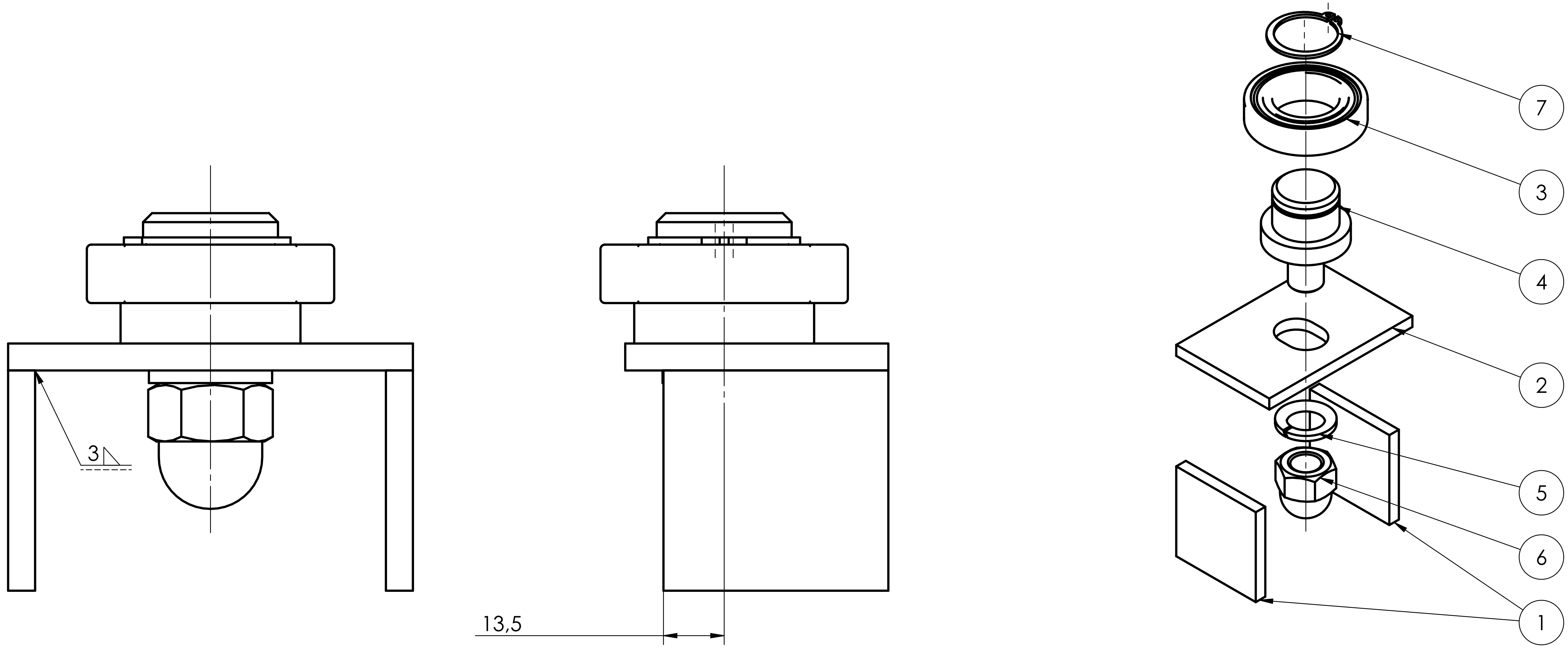


Date: 06.05.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 4	Material: S355	Unit of measure: mm		
Arm Stiffener				Replacement for: / Replaced by:
Pivot Arm				N-012-004
Referral:	Calculation: F.L & H.G			



Date: 06.05.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 2	Material: S355	Unit of measure: mm		

Pin Holder	Replacement for: / Replaced by:
Pivot Arm	N-012-006
Referral:	Calculation: F.L & H.G



Pos.	Ant.	Part Name	Material
7	1	DIN 471 30x1,5	
6	1	DIN 1587 M16	S355
5	1	DIN 128 A16	S355
4	1	F-006 - 10003154-150-70-3	
3	1	SKF-6006-2RS1	
2	1	N-013-002 - Flat Steel Horizontal	S355
1	2	N-013-001 - Flat Steel Vertical	S355

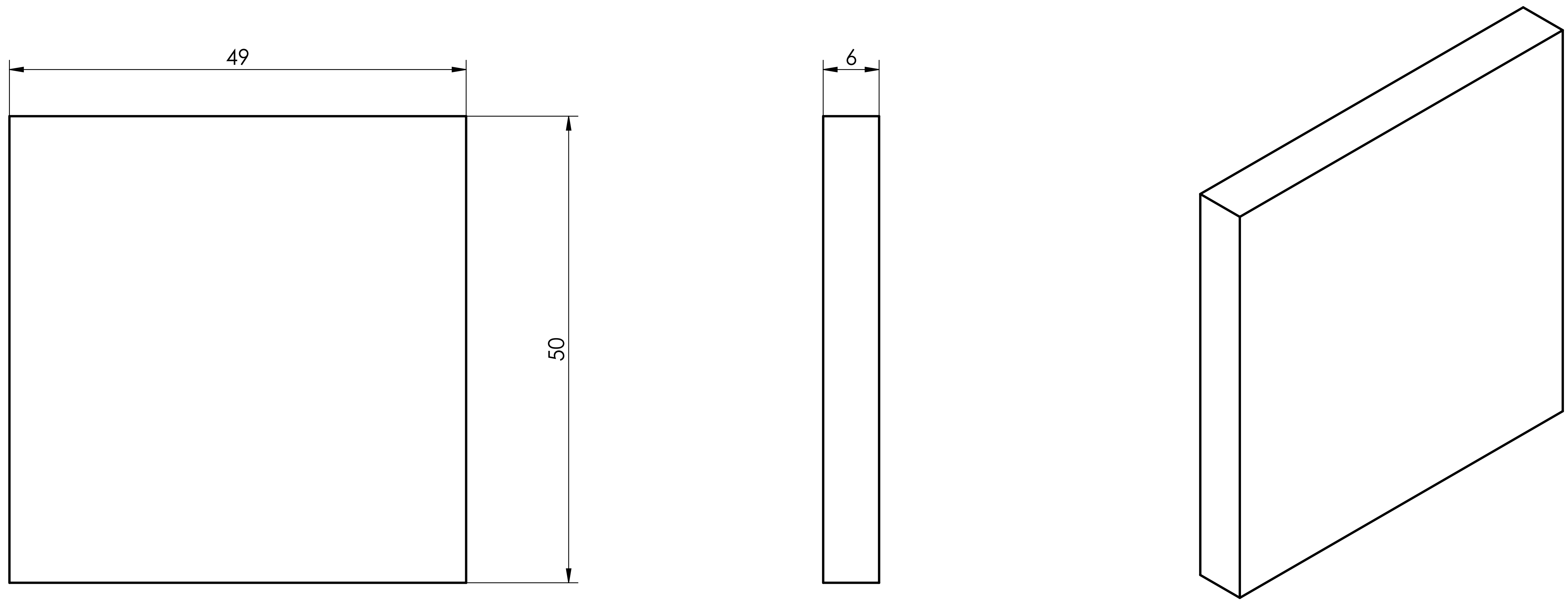
Date: 12.05.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU
Quantity: 2	Material:	Unit of measure: mm		

Axial Displacement Restrictor

RMVC

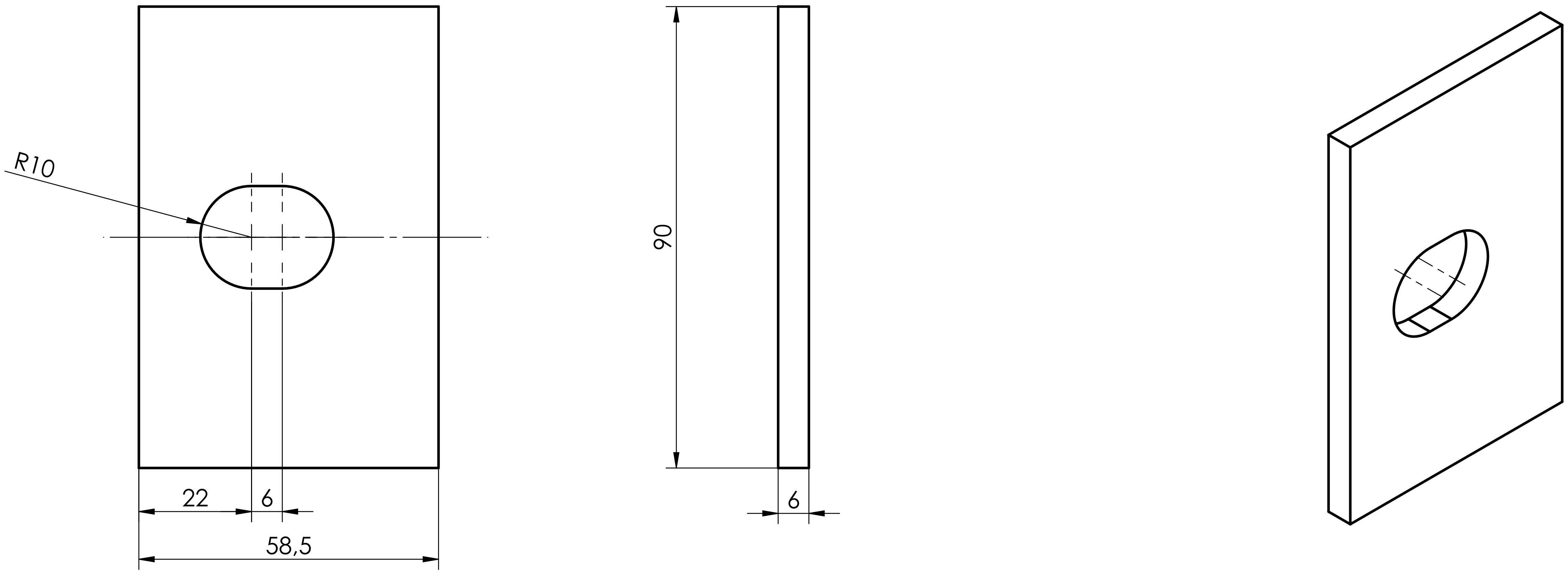
Replacement for:	Replaced by:
N-013	

Referral:	Calculation: F.L & H.G



Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 2:1	NMBU
Quantity: 4	Material: S355	Unit of measure: mm		

Flat Steel Vertical Axial Displacement Restrictor	Replacement for: / Replaced by: N-013-001
Referral:	Calculation: F.L & H.G



Date: 26.04.16	Drawn by: F.L & H.G	Projection:	Scale: 1:1	NMBU	
Quantity: 2	Material: S355	Unit of measure: mm			
Flat Steel Horizontal				Replacement for:	Replaced by:
Axial Displacement Restrictor				N-013-002	
Referral:		Calculation: F.L & H.G			

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