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Master of Science

Re- design of a multipurpose snowmobile sled for Norwegian volunteer (SAR organizations).

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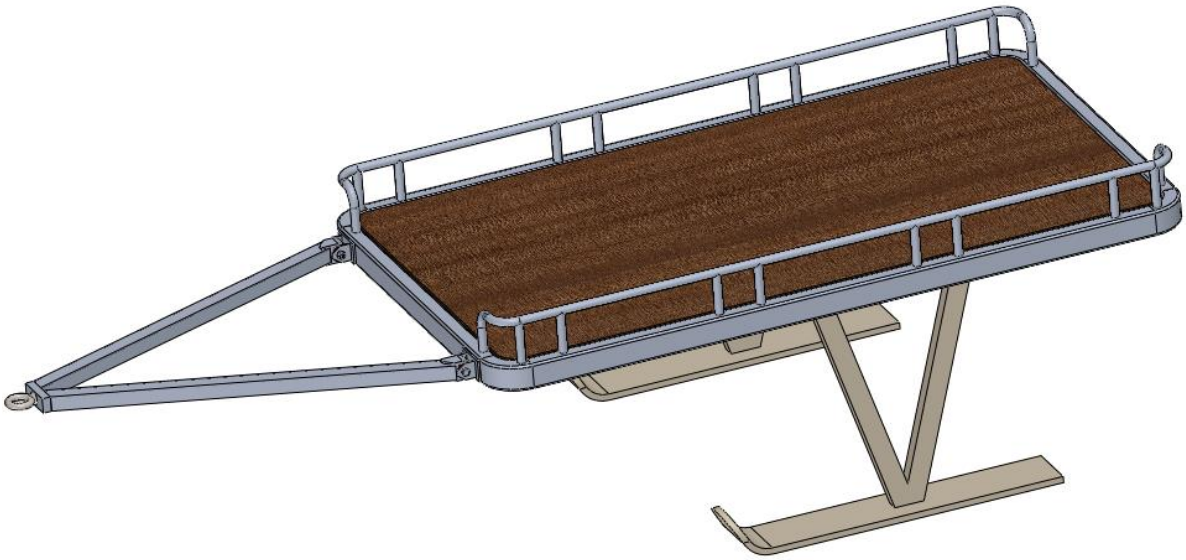
Abstract

This master thesis is written for the Norwegian volunteer organization "Hjelpekorpset" that is a search and rescue organization. The organization performs different kinds of activities in addition to rescue missions. During wintertime, they transport materials, furniture and other cargo to local huts to raise funds. This is the basis for the thesis, where the aim was to redesign a multipurpose snowmobile sled for both rescue missions and transportations jobs. Problem areas have been the towbar and the general design in terms of securing both stretchers and cargo.

The towbar have been reinforced by simplifying the design using fewer components and installing hingejoints in the transmission to the sled. Material selection was executed for the towbar rods and the top plate. This resulted in Aluminium alloy Al 6061 on the towbar, that was applied on the supporting bod structure and the railings as well. On the top plate, Plywood was determined to be the best choice of material. After conducting Finite Element Analysis on the system, the attachment ring is performed in a different, stronger material than the rest of the towbar; Titanium Alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr.

The design of the railings were altered so that they covers the two longitudinal sides, making it more convenient to secure a stretcher on the sled. A frame was designed that can be attached when needed to make it easier to transport cargo on the sled.

Objectives have been to strengthen the towbar and keeping the mass below 50 kg. This have been achieved with a thorough design process ending up on a final weight of the sled of 41.85 kg. Aesthetics of the design was examined by 3D printing a miniature prototype of the sled.



The final design of the snowmobile sled. Model drawn in SolidWorks

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1 Introduction

The aim of the project is to optimize the design for a multipurpose snowmobile sled that should be used both for transporting cargo and for rescue missions in difficult terrain. A preliminary project is performed which studied the existing snowmobile sleds on the market, and transformed the problem from the customer to specifications for the product. This lays the basis for the project where the design will be developed for an improved snowmobile sled.

The thesis is the final part of the Master of Science and will provide 30 student points and a diploma in Engineering Design. The formal date for delivery of the thesis is 6th of June 2017.

1.1 Background

In Norway, the need for volunteer organizations are different from countries where there is war or natural disasters. The organizations exists here as well, but their chores are drug- related, integrating new citizens, helping lonely souls or rescue operations in mountains when someone is lost or injured. In order for rescue operations in the mountains to be successful, it is crucial that the volunteers have the proper equipment. One of the main challenges they face is search and rescue in arctic environments. This includes winter climate when the mountains are covered in snow, ice and cold. Most of rescue operations during these conditions are proceeded by using snowmobiles with sleds that can reach almost anywhere.

The Norwegian Search and Rescue organizations (SAR) are mainly based on volunteer work (Hjelpekorpset is one of them). Some financing comes from the government but most of the financing the local SAR groups need to raise by them self. One way of raising funds is by doing transportation work by snowmobiles. Thus, there is a need for multipurpose sleds that can be used for all of the different operations/ work Hjelpekorpset do during the winter.

1.2 Problem Description

The sleds that exist today often have very specified area of application, there is a need for a sled that can be used for all operations/ transport missions that the Norwegian volunteer SAR organizations carries out. The sled must be reliable and easy to maneuver in difficult terrain. Area of application for the sled:

- Transport of various equipment for use during SAR- operation
- Transport of patients.
- General transportation of; firewood, gas, gasoline, furniture etc. (the volunteer SAR organizations in Norway often do transportation work to private huts etc.)

Hjelpekorpset are well experienced with snowmobile sleds used for rescue missions as well as transportation purposes. The specified problem- area is the transmission from the towbar to the sled itself, where there are weaknesses in the rods and bolts that need to be addressed. The complete problem description is presented in Appendix A.

1.3 Method

The design itself will be a product of the method described by Nigel Cross in his text course book "Engineering Design Methods" that have been frequently used in courses during the master program. This method consists of eight steps and is a guide to assure that the designer do not loose sight of the original demand during the process. For the material selections of the design, the method presented by Michael F. Ashby in his book "Materials Selection in Mechanical Design" and the program CES EduPack 2016 is used to ensure that the selection is as precise as possible.

When the design and materials are chosen, analyses will be performed on the object to make sure it will meet the demands and requirements set in the beginning of the project. If the design object do not pass this stage, it might be necessary to reconsider the design before prototyping it and performing numerical analysis.

The design will be divided into separate parts to make a systematic progress. System boundaries are set only around the sled itself, and no surrounding factors or organisms will affect it. The different parts are illustrated Figure 1-1 and the part of the report regarding the design will be divided into:

1. Railings
2. Top plate
3. Towbar
4. Skis
5. Supporting body structure

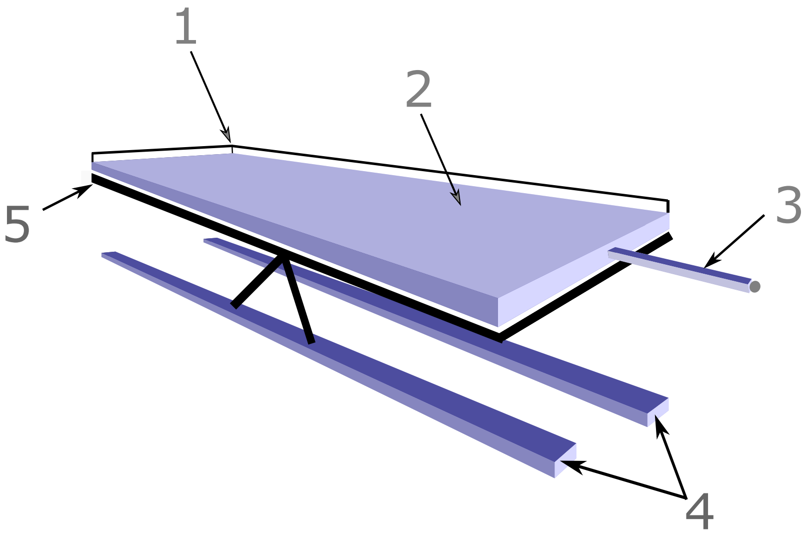


Figure 1-1: Sled divided into several parts for a systematic design process. Drawn in INKSCAPE 0.91.

2 The Design Process

As stated, the design process consists of eight steps from an idea or demand arises to a finished product. In order to design a product that is safe, reliable and satisfactory otherwise it is necessary to examine the demands for the design. This is performed regarding both physical conditions and what demands or wishes Hjelpekorpset have to determine the specifications.

2.1 Objectives

To clarify the objectives the information from the customer is crucial. Since the sled is intended for transportation of equipment and patients, it have to be able to fit large capacities in an effective way. It have to carry weight while driving in difficult and bumpy terrain where especially the attachment system from the snowmobile to the sled is an area of problems. The sled has to be stable and comfortable for injured patients in all kinds of snow and terrains. Both equipment and patients have to be easy to attach and release in a secure and simple matter. In order to organize the information given by the customer, Cross' objective tree method is utilized, as shown in Figure 2-1.

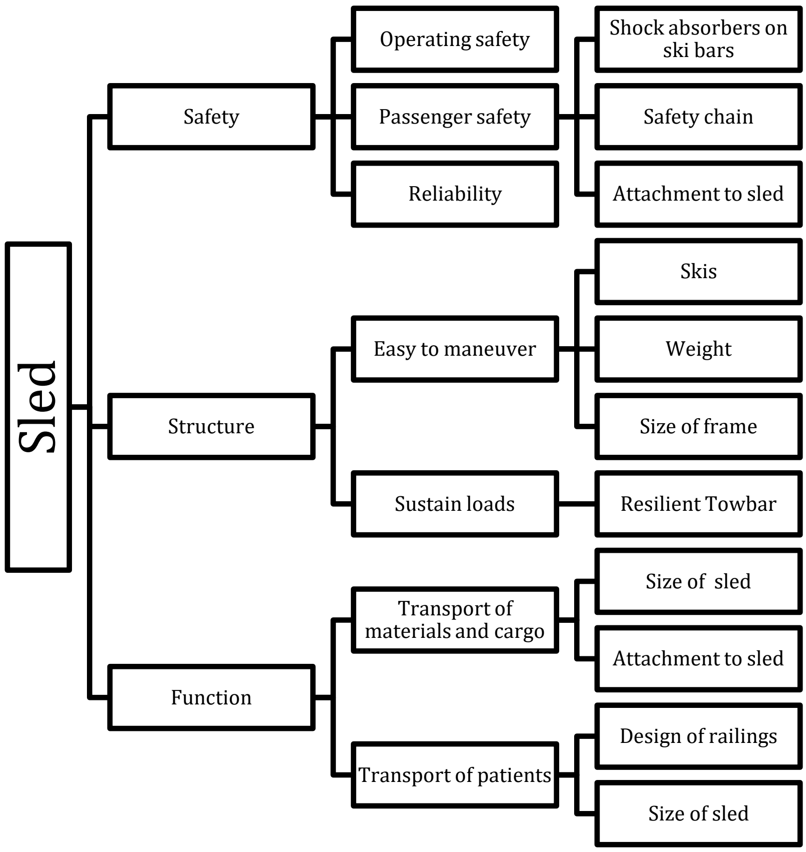


Figure 2-1: Objective tree for the snowmobile sled. Figure created with Word SmartArt.

2.2 Physical Requirements

A snowmobile sled is intended for outdoor use, and will be exposed to climate and weather changes. The sled is used during wintertime in low temperatures, on snow. During spring, summer and fall it is usually stored in a storage. The materials the sled is constructed of therefore have to be able to withstand both low temperatures during winter and higher temperatures during summer storage. The climatic requirements are:

- Winter, temperatures down to -50°C
- Summer storage, temperatures up to 40°C
- Ice, rain, sun

The sled is to be used both in Narvik and in the surrounding areas and are therefore often transported by car or train to the mountains. In order to manage this the persons handling the sled have to drag or carry the sled onto the transportation. The weight of the sled cannot exceed a weight that an average grown person can lift up. Based on an assumption that the persons involved in the rescue missions or other transport missions are in good physical health the limit for the total mass of the sled is set to 50 kg.

Since this is a sled for rescue operations and transportation of cargo, the design have to take into consideration the mass of load it will be carrying. In a rescue situation the sled have to withstand the mass of two or three persons including the patient and rescue team, assuming there is no more than one person in need of rescuing. The average weight of men of military age in Norway in 2010 were 76 kg (1). In addition to the persons, they might carry some equipment or heavy backpacks that have to be transported as well. Based on this the sled have to be design to withstand a load of at least 200 kg, and not dimensioned for more than 300 kg.

Additionally, the sled have to be long enough to transport a grown man without any problems. The average length of Norwegian men of military age in 2012 were about 1800 mm (2). If the cargo is longer than the sled this might cause problems in maneuvering the sled and the risk of the cargo falling off is greater. During a rescue operation, the patient will be attached to a stretcher that is stiff, and thus have support beyond the boundaries of the sled.

In Table 2-1, the physical requirements for the sled are summed up given a range on most values where the final decision depends on the final design attributes and how the sled will work.

Table 2-1: Physical requirements for the snowmobile sled

Requirement	Minimum	Maximum
Weight of sled	-	50 kg
Load weight	200kg	300 kg
Length (top plate)	1600 mm	2200 mm
Load length	-	15-30 % of final Design length
Width	900 mm	1000 mm
Temperature	-50°C	40°C

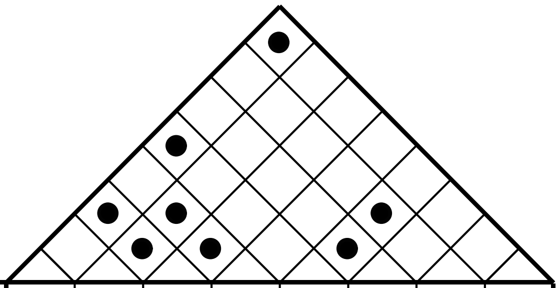
2.3 Determining Characteristics

To determine the importance of the engineering characteristics of the product it is necessary to get overview of the relations between the customers' demands and the specifications of the product. This is obtained by using the "Quality Function Deployment Analysis" (QFDA) (Cross, 2008). The method results in a "House of Quality" (HOQ) where the specifications are rated after the relevance to the demands for the product, and the characteristics are determined.

In Figure 2-2, HOQ is presented and shows that the strength of the towbar and the size of the top plate are the key characteristics for the sled. In the mid table, the customer objectives are related to the engineering characteristics and rated from 1-3 on the relationship between them, where 3 is the strongest relationship. The customer objectives are weighted based on the importance where 0 is worst and 10 is most important. In the summation the rank and the weight are multiplied and summed up.

On the top of the table the engineering characteristics are compared to each other, and marked with a black dot if they are related. To the left of the table two existing products are compared to the customer objectives and ranked with values from 1-3 where three is the highest score.

By comparing existing products to the objectives, it is possible to exploit the strong attributes on the models in order to gain inspiration for the design process. The two models scores the same, but have different strengths and weaknesses. Model 1 is in this case the cargo sled J830 by Montana Trailers that is similar to the one that Hjelpekorpset uses today (3). This model scores high on sustaining loads and is easy to operate, which are two of the most important objectives for the design. Model 2 is a sled from Altapulken that is intended for rescue missions. This model is specialized in comfort for patients with a door made for entering stretchers, and heater to keep the sled warm (4). It scores high on comfort and passenger safety.



Objectives	Weight	Total mass	Strength of towbar	Damping on towbar	Stiffness of structure	Size of top plate	Stiffness of top plate	Strength of top plate	Damping on skies	Model 1	Model 2
Sustain loads	9		3	2	1	2	2	2	2	3	2
Maneuverability	6	3	1	1	2	2	1		1	2	1
Reliability	7		3			1	1	2		2	2
Passenger safety	6		2	2		2		2	1	1	3
Comfort	3			3	2	2	1	2	2	1	3
Easy to operate	8	3			1	3	1			3	2
Maintenence	8	1	3	1			1	1	1	2	1
Stability	5	3		2	3	1	2	1	3	2	2
Unit		kg	Pa	Pa	mm/g	mm	mm/g	Pa	Pa		
SUM		**65**	**108**	**63**	**50**	**84**	**60**	**63**	**59**	**16**	**16**

Figure 2-2: House of Quality. Roof: Engineering characteristics are compared and a black dot symbolizes that the one characteristic is dependent on the other. Middle: Customer objectives relative to engineering characteristics are rated from 1- 3 where 3 is best, multiplied with the weight of the objectives and summed up. Right: Two competing snowmobile sleds are compared to each other. Drawn in INKSCAPE 0.91.

2.4 Alternatives

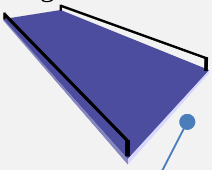
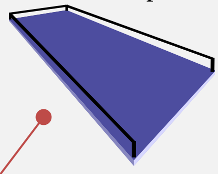
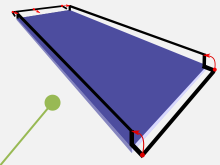
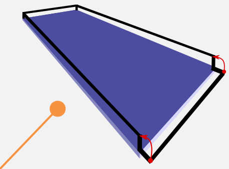
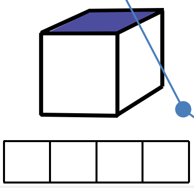
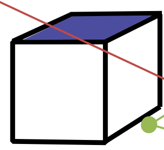
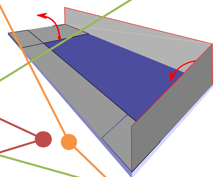
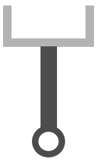
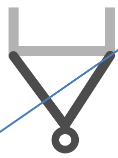
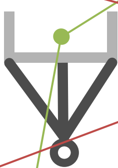
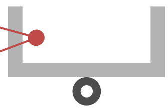
In order to generate the best suitable alternative designs for the design, "the morphological chart method" by Nigel cross is used. "*The aim of the morphological chart method is to generate the complete range of alternative design solutions for a product, and hence to widen the search for potential new solutions"* (5)

The railings surrounding the sled is not satisfactory as they appear today. When placing a stretcher on the sled, the railings is a hurdle in the top and rear end of the sled. However, the railings can not be removed completely since there is a need for some kind of railings to secure cargo, stretchers, equipment and persons. Additionally, the sled should have some extra security for cargo, preferably as a frame that is removable and easy to attach to the sled when needed.

The towbar is the part of the sled that "Hjelpekorpset" have experienced the most problems with, and need to be improved. The new design needs to make a sustainable solution that requires minimum maintenance and is less likely to fail than the sled in use today. To obtain this it is natural to have as few components as possible in a strong, solid construction. The profile of the components as well as how they are fastened to the sled will be essential.

Additionally, the mass have to be considered as the whole system can not exceed 50 kg. The alternatives for the features and suggested solutions are presented in Table 2-2. The solutions are expressed in paths of different colors.

Table 2-2: Generated alternatives and solutions for railing, frame and towbar on top plate. Illustrations drawn in INKSCAPE 0.91 if references not are given.

Features	Alternative 1	Alternative 2	Alternative 3	Alternative 4
RAILING	Only on longitudinal sides 	On longitudinal sides and top 	Detachable in top and rear end 	Detachable in rear end 
Lock	None	Manual lock  (6)	Click lock  (7)	
Attachment -loose end	None	Reattach completely	Hang loose at ends of sled	Stops at 90°
FRAME	Open loop of 4 foldable plates 	Closed loop of 4 foldable plates 	Frame attached to sled, foldable 	
Attachment	Free, supported by railings	Locked onto railing	“Clicked” into railing (railings and frame design to fit)	Tied onto railing
TOWBAR	Simple rod attached to body structure 	Triangular attached to body structure 	Triangular attached to body structure and ski 	Simple ring to directly attach to snowmobile 
Attachment to sled	Welded	Screwed	Joint	

2.5 Evaluation

The different solutions (colored lines) in Table 2-2 got different qualities. To make sure the best solution for the problem is selected, "The Weighted Objectives Method" by Nigel Cross is used. This method uses the objectives of the product to measure the different solutions. By giving each of the solutions a weighted number, it is easier to make a scientific approach for comparing the solutions rather than guessing and assuming.

Design Objectives

In Chapter 2.3 HOQ was presented and the objectives for the whole sled listed. Some of these objectives applies directly to the railings, frame, and towbar, but there are also some objectives that are not listed in the HOQ. The total objectives are listed below with an assigned letter:

A. Light weight
B. Reliability
C. Passenger safety
D. Easy to operate with gloves
E. Easy maintenance
F. Small number of components
G. Optimal design for transport of stretcher
H. Optimal design for transport of cargo
I. Good maneuverability

In order to set weights for the objectives, they have to be compared to each other. In Table 2-3, this is done by setting the objectives as both rows and columns, and comparing them to each other. If for instance A and B are being compared, and B is the more important of the two, B will be assigned 1 and A assigned 0. All results then are summed up for each objective and assigned weights accordingly equation 2-1 and ranked.

$$\text{Relative weight} = \frac{\text{Resulting sum for objective}}{\text{Total resulting sums for all objectives}} \tag{2-1}$$

Table 2-3: Objectives for railings and frame with weights

	A	B	C	D	E	F	G	H	I	Result	Weight
A	-	0	1	0	0	1	1	1	1	5	0.14
B	1	-	1	1	1	0	0	0	1	5	0.14
C	0	0	-	0	1	1	1	1	0	4	0.11
D	1	0	1	-	0	1	0	0	0	3	0.08
E	1	0	0	1	-	0	0	1	1	4	0.11
F	0	1	0	0	1	-	0	0	1	3	0.08
G	0	1	0	1	1	1	-	1	0	6	0.17
H	0	1	0	1	0	1	0	-	0	3	0.08
I	0	0	1	1	0	0	1	1	-	3	0.08
								Sum		**36**	**1.00**

Evaluation

In order to find a rational and feasible solution, the different suggested solutions have to be compared using the found objectives. In Table 2-4 the solutions are compared according to a five- step scale:

0. Inadequate
1. Weak
2. Satisfactory
3. Good
4. Excellent

To find the best solution the results are multiplied with the relative weights of the objectives and the blue solution from Table 2-2 stands out as the optimal solution.

Table 2-4: Evaluation of solutions for railings and frame

	Blue	Red	Green	Orange
Light weight (0.14)	3	3	1	2
Reliability (0.14)	3	2	2	1
Passenger safety (0.14)	2	2	4	4
Easy to operate with gloves (0.11)	3	2	1	0
Easy maintenance (0.11)	2	2	1	1
Small number of components (0.07)	3	2	1	1
Transport of stretcher (0.18)	4	2	4	2
Transport of cargo (0.11)	2	3	4	4
Good maneuverability (0.08)	3	0	4	1
SUM	**2.86**	**2.06**	**2.47**	**1.81**

2.6 Details

2.6.1 Railings

The railings have to be a simple, supporting structure for passengers to hold on to, or to fasten cargo, the frame or stretchers to. It will be welded onto the body structure to ensure stability. The design should be as simple as possible to ensure minimum mass but at the same time strong enough to be secure. Since it will be railings only on the two longitudinal sides of the sled, they lose some of the support they have today from being a closed loop. Hence, some measure have to done to ensure the stability of the structure. A simple solution is to have the railing curve around the corners of the top plate, but not cover the short sides. The suggested raildesign is shown in Figure 2-3.

2.6.2 Top plate

The function of the top plate is simply to support cargo and persons. It needs to withstand the load and impacts while driving in difficult terrain. Since the total mass of the sled is set to 50 kg, it is important to regard the mass of the plate as well.

The size of the top plate affects the mass, which should be kept to a minimum. The length and width therefor will be set to the minimum measures in Table 2-1, respectively 1600 mm x 900 mm. Additionally, the material, which will be decided later on in the process, and structure of the top plate will be essential for the total mass.

Figure 2-3: Illustration of top plate and railings. Drawn in SolidWorks 2015.

2.6.3 Towbar

Since the towbar is the feature on the sled that is the most troubled today, it is subject for different evaluation than the rest of the features. The mass is important, but the most important requirement is that it needs to be strong, reliable, and contribute to the sled being easy to maneuver and stable. The blue solution in Table 2-2 suggests that a triangular construction with attachment in the body structure of the sled itself, as illustrated in Figure 2-4. This will be one of the heaviest solutions, but it will fill the requirements the best. To try to get the mass down the profile of the rods used in the towbar have to be subject for investigation.

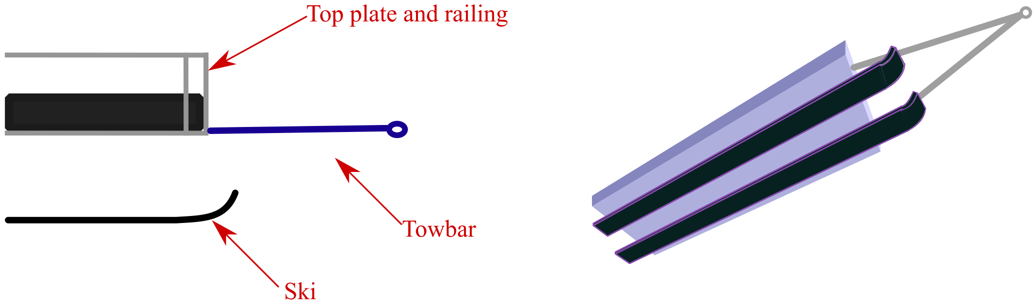


Figure 2-4: Suggested design for towbar. Illustration created in INKSCAPE 0.91.

2.6.3.1 Features

In the blue solution in Table 2-2, the attachment method to the sled is welding. A welded joint will cause the resulting forces that occurs when the snowmobile breaks, accelerates or turns to propagate to the rest of the system and could cause weaknesses in the design. It is not desirable to have moment or axial forces spreading throughout the structure and in order to avoid this situation it is necessary to explore the other attachment options.

The best option to avoid the case of propagating forces are to have a joint that is rotational in one or more directions like the alternatives illustrated in Figure 2-5. As the figure illustrates, the balljoint is rotational in all three directions while the hingejoint is rotational only in one direction. While riding the sled, the towbar will move in all directions relevant to the attachment to the snowmobile, and some rotational freedom in all directions will be preferred and could spare the rest of the system from damage. Installing a balljoint on the sled, however, is an intricate process. A hingejoint with bearing can be, if not rotational, tolerant to movements in all directions and damp impacts. The bearing is easy to replace if wore down, as well as other parts in a hingejoint rather than a balljoint. This is a standard component that many production companies are producing today, and will be outsourced to an established company rather than produced.

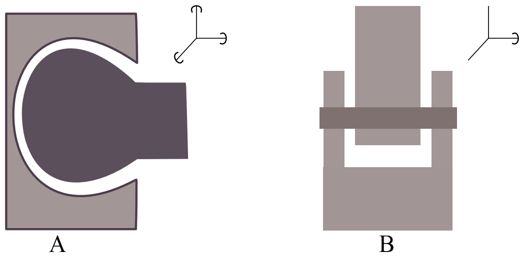


Figure 2-5: Cross sections of A: Balljoint and B: Hingejoint with rotational axis. Drawn in INKSCAPE 0.91.

For the comfort, as well as preventing damage to the towbar and ease the attaching and detaching of the sled to the snowmobile it is desirable with a rotational attachmentring. This could be solved by installing a hallow rod connecting the triangle structure with the attachmentring in the end, as illustrated in Figure 2-6.

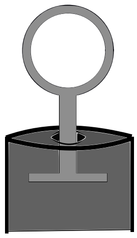


Figure 2-6: Rod and rotational attachmentring on towbar. Drawn in INKSCAPE 0.91.

2.6.3.2 Analyses and Dimensioning

In order to set the dimensions of the structure, the worst-case scenario of forces acting on the sled are considered. The possible situations where forces are acting on the sled are when the snowmobile accelerates, brakes, turns, accelerates & turns simultaneously or brakes & turns simultaneously. In order to determine which are the worst case scenario, the situation in Figure 2-7 is studied where the force F is the behavior of the snowmobile.

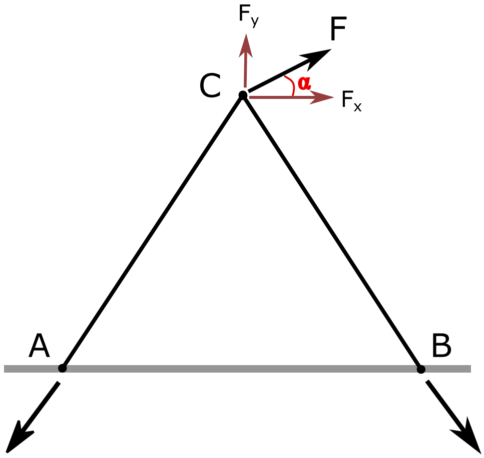


Figure 2-7: The triangular towbar structure ABC with applied snowmobile- force F. Drawn in INKSCAPE 0.91.

The resulting forces in A and B will, as in the case of F, get resulting forces in x and y directions with an angle depending on α and the angle between the rods AC and BC. To find the worst-case scenario the sum of the forces in x and y direction are evaluated as follows.

$$\sum F_x = 0 \rightarrow F_x - A_x + B_x = 0 \rightarrow F\cos\alpha - A_x + B_x = 0$$

$$\sum F_y = 0 \rightarrow F_y - A_y - B_y = 0 \rightarrow F\sin\alpha - A_y - B_y = 0$$

This shows that the resulting force in x direction in A will become largest and will increase as Fcosα increases which gives $|\alpha| = 0, \pi, 2\pi, 3\pi$ .... The results shows that the situation will have the same magnitude in the opposite direction if the snowmobile are breaking instead of accelerating.

In order to determine the angle between AC and BC the rods are isolated and a diagram of the free bodies evaluated. Each of the rods are affected by two forces, and will seek equilibrium which will lead to the forces being equally big but opposite directed as illustrated in Figure 2-8 (8).

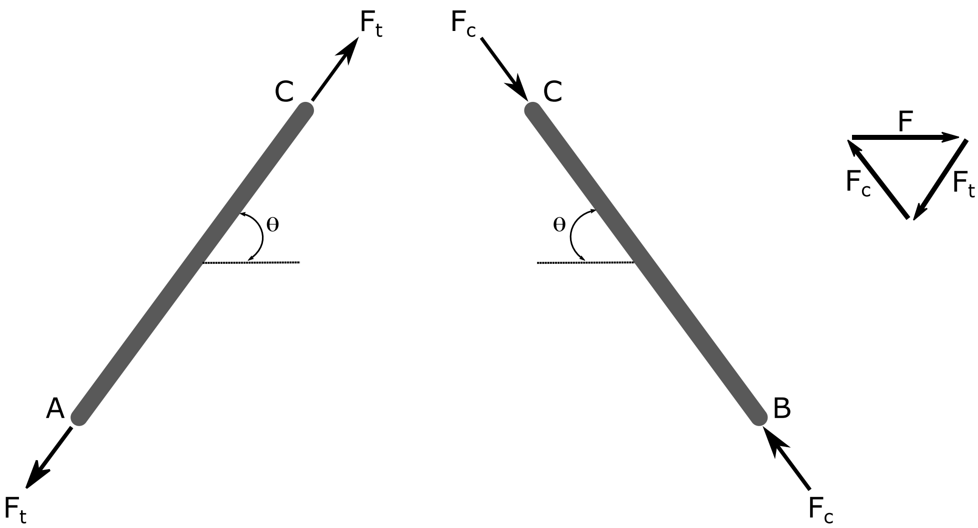


Figure 2-8: Rods AC and BC of the towbar in equilibrium where F_c= compressive forces and F_t= tension forces. Drawn in INKSCAPE 0.91.

The figure illustrates the case when the link in C is in equilibrium and the forces acting on AC are tension forces (F_t), while the forces acting on BC are compressive forces (F_c), and the diagram of the free bodies becomes as in the upper corner of Figure 2-8. By comparing the sums of the forces for this case, it is possible to find the angle θ.

$$\sum F_x = 0 \rightarrow Tcos\theta - Scos\theta + F_x = 0 \rightarrow F_x + cos\theta(T - S) = 0$$
$$\sum F_y = 0 \rightarrow -Tsin\theta - Ssin\theta = 0 \rightarrow sin\theta(T + S) = 0$$
$$\Rightarrow T = -\frac{F_x}{2cos\theta}, \qquad S = \frac{F_x}{2cos\theta}, \qquad 0 < \theta < \frac{\pi}{2}$$

This proves that F_t and F_c are larger the more θ grows. It suggests that the angle between AC and BC, which increases with decreasing θ, should be as big as possible, hence the distance between A and B should be as wide as the sled itself. The length of the rods should be as small as possible for minimum resulting forces passing on to the sled, but still long enough to ensure stability and best possible maneuverability. Stability and maneuverability cannot be calculated since it is human experienced properties, and the rods are set to be half the length of the top plate, which gives a length of 900 mm.

2.6.4 Skis

The function of the skis are to make the sled slide on snow and support the sled so it stays above ground. Skidesign are important for the maneuverability and safety in difficult terrain or different kinds of snow and ice. A wider ski will make the sled more stable and better afloat in deep snow, and a thinner ski assures that less energy is required to steer the sled in snow and can make it more stable on hard, icy snow. The mass of the skis should be considered as well to maintain as low total mass as possible.

2.6.4.1 Alternatives and evaluation

The skis will be outsourced to a manufacturing company that already produces skis. In
Table 2-5, three types of skis have been described, compared and evaluated. The skis are chosen since they all have cross section profiles that offers qualities to make them stable and avoid darting. Alternative 3 from KIMPEX seems like the best choice based on this information since it is the lightest option, seems to have good maneuverability and comes with mount kit included in the price.

Table 2-5: Alternative solutions for skis

Feature	Alternative 1	Alternative 2	Alternative 3

Manufacturer	C&A PRO (9)	Ultimate Snowmobile Skis & Parts (USI) (10)	KIMPEX (11)
Illustration			
Weight (pair)	6.24 kg	6.8 kg	3.62 kg
Width	184.15 mm	304.8 mm	127 mm
Mount kit included	No	No	Yes
Price	2147 NOK	3723 NOK	2463 NOK
Maneuverability	Plastic Keel Pebbled sides	Metal Keel Pebbled sides Pebbled underneath	Metal Keel Raised rear portion Side edge underneath

2.6.4.2 Details

To improve the stability, a possibility is to install two skis per side of the sled. This will add considerable mass to the system with a total of 4 ski- systems (skis, suspensions and shock absorbers). The estimated mass for one ski- system is 5 kg.

With two skis on each side, the sled will have a large contact area with the substrate and will acquire more energy for the snowmobile to turn around, and cause less maneuverability. The arguments of mass and maneuverability are higher prioritized in this situation, thus there will be only one ski-system on each side of the sled.

The suspensions are designed as a simple, triangular construction where the shock absorbers will be installed as well. In the technical drawings, the shock absorbers are not included, and a simplified model of the skis are attached only for the illustrative purposes.

2.6.5 Supporting body structure

The supporting body structure have only one function: to keep the sled together. It needs to connect all other features in a satisfying matter, which makes it a simple, rectangular structure where the top plate rests, the towbar joints and the railings and ski-systems are welded onto. Since the maximum mass of the sled is set to 50 kg, it is important that the body structure is as simple as possible with a material and profile that is both strong and light.

2.6.6 Detachable Frame

For the frame to be as easy and practical as possible, the chosen design is an open loop. In Table 2-2 the suggested design consists of four sides. In order to make the frame foldable and easier to handle since the sled not is squared but rectangular, the design is changed to five sides connected through hinges as illustrated in Figure 2-9. As before, the mass are to be kept to a minimum and the frame have to be easy to attach or detach to the railing. The structure have to be strong enough to secure the cargo and resist weather changes, equal to the top plate, and the material for the two will be the same in the drawings. The walls need to be high enough to keep cargo from falling out of the sled, and are set to 500 mm. Length and width are the same as for the sled itself so it can fit directly into the sled and the design should be as simple as possible.

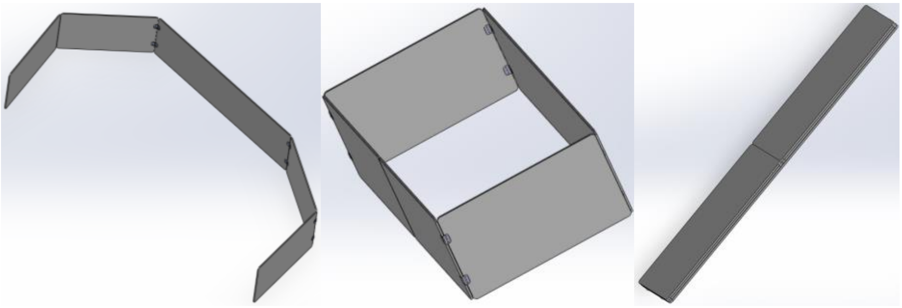


Figure 2-9: The frame structure open, closed and folded. Illustration created in SolidWorks.

Outdoor during winter time, especially in the mountains, the temperatures drops real low, and it is a big advantage to be able to handle all aspects of the sled with gloves on, the frame as well. Locks of various kinds, or tying ropes will be difficult under such conditions. A alternative solution for locking the loop is to have a click- solution, that requires minimum operations as illustrated in Figure 2-10.

Detailed drawings of the frame are presented in Appendix B.

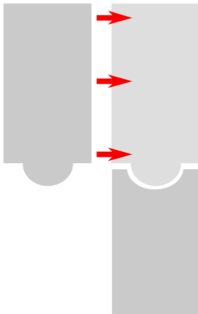


Figure 2-10: Click-lock solution for frame- loop. Drawn in INKSCAPE 0.91.

3 Material Selection

The method for the material selection is the method presented in the book "Material selection in mechanical design" by Michael F. Ashby. This method systematically goes through the stages from idea to finished design via three stages.

The concept phase and parts of the Embodiment phase in Figure 3-1 is conducted previously in the design process. One of the main physical properties that have to be prioritized for both the towbar and the top plate is the total mass of the sled as well as the performance in different weather conditions and temperatures and the ability to resist applied forces. For the material selection itself, material indexes are calculated and applied to material charts using the software CES EduPack 2016.

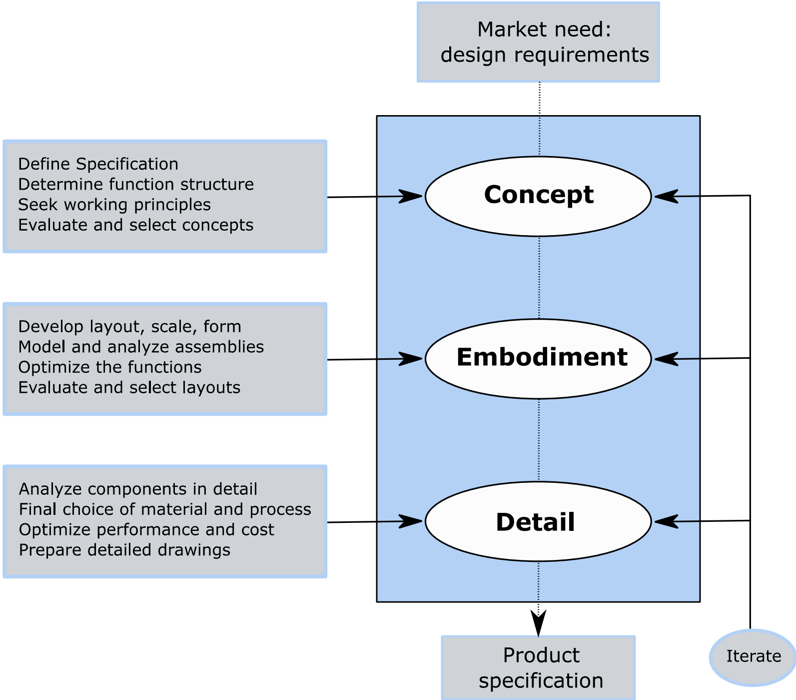


Figure 3-1: The Design Flow Chart (12). Drawn in INKSCAPE 0.91.

3.1 Towbar

It is decided that the towbar it should be a triangular construction that is attached to the sled through a hingejoint, and to the snowmobile through a rotational ring.

3.1.1 Material indexes

As stated in chapter 2.6.3, details of the towbar design; even though the weight of the sled is important, the most important thing for the towbar is that it needs to be strong, reliable, and contribute to the sled being easy to maneuver and stable. The length of the rods are set to 900 mm, and the width should be as long as the width of the sled. The profile of the rods should be as thin as possible but at the same time be strong enough to withstand the forces acting on the system. The design requirements for the light beam are presented in Table 3-1.

Table 3-1: Requirements towbar beam for material selection

Function:	Towbar beam
Constraints:	a) Length= 900 mm b) Support bending load F without failing by yield or fracture
Objective:	Minimize mass
Free variable:	a) Cross- section area b) Choice of material

This gives the objective function

$$m = AL\rho \tag{3-1}$$

Where m is mass, A is cross- section area, L is length and ρ is the density of the material.

In Figure 3-2 the situation when accelerating is illustrated on a small part of one rod as a beam with length L and applied tensile force F and elongation, ε.

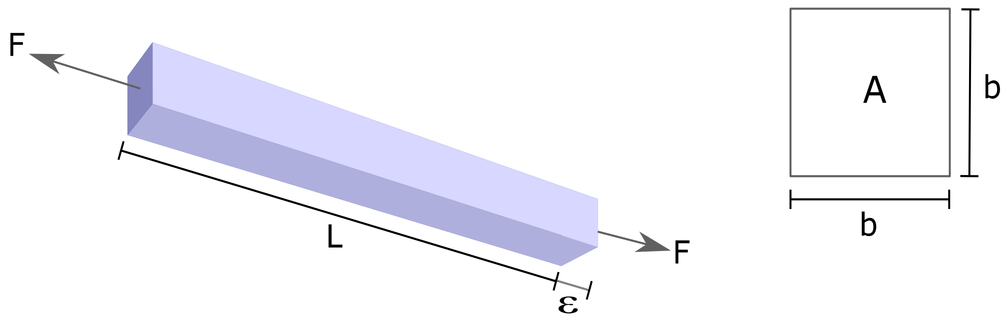


Figure 3-2: Towbar illustrated as a simple beam of length L, elongation ε, cross- section A and applied tensile force F. Drawn in INKSCAPE 0.91.

Both F and L are fixed, and the cross- section area have to be sufficient to support the tensile load. The failure strength of a material can be expressed as in equation 3-2, and rewritten to make sure the cross –section is large enough for the applied force.

$$\sigma_f = \frac{F}{A} \tag{3-2}$$

$$A \geq \frac{F}{\sigma_f}$$

Combined with equation 3-1 this gives

$$m = AL\rho \geq \left(\frac{F}{\sigma_f}\right) L\rho \ \Rightarrow m \geq FL\left(\frac{\rho}{\sigma_f}\right)$$

Where the last bracket containing the density and the failure strength is the one related to the material properties. This gives the material index in equation 3-3 that is inserted in the material chart presented in Figure 3-3.

$$M_1 = \frac{\sigma_f}{\rho} \tag{3-3}$$

In addition to the tensile strength, the compressive strength of the beam is important in the case of the snowmobile breaking and the towbar have to be strong enough to withstand the weight of the sled being pressed towards the snowmobile. Euler's buckling describes how a beam behaves when applied a compressive force (13). In equation 3-4, it is the case when both ends are pinned.

$$F = \frac{\pi^2 EI}{L^2} \tag{3-4}$$

Where E is the modulus of elasticity of the material and I is are moment of inertia of the cross section. I in the case of the beam is expressed in equation 3-5.

$$I = \frac{b^4}{12} \tag{3-5}$$

Combined with equation 3-1 this gives

$$b^2 = \left(\frac{12FL^2}{\pi^2 E}\right)^{\frac{1}{2}} = \frac{m}{L\rho} \Rightarrow m = (12F)^{\frac{1}{2}}\left(\frac{L^2}{\pi}\right)\left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

Resulting in the second material index expressed in equation 3-6 and inserted in Figure 3-4.

$$M_2 = \frac{E^{\frac{1}{2}}}{\rho} \quad (3\text{-}6)$$

After these selections, it still remains too many materials to choose from that are relevant candidates. In order to narrow the selection down further, the price per kg of the materials are compared in Figure 3-5 and a limit is set on 50 NOK/kg.

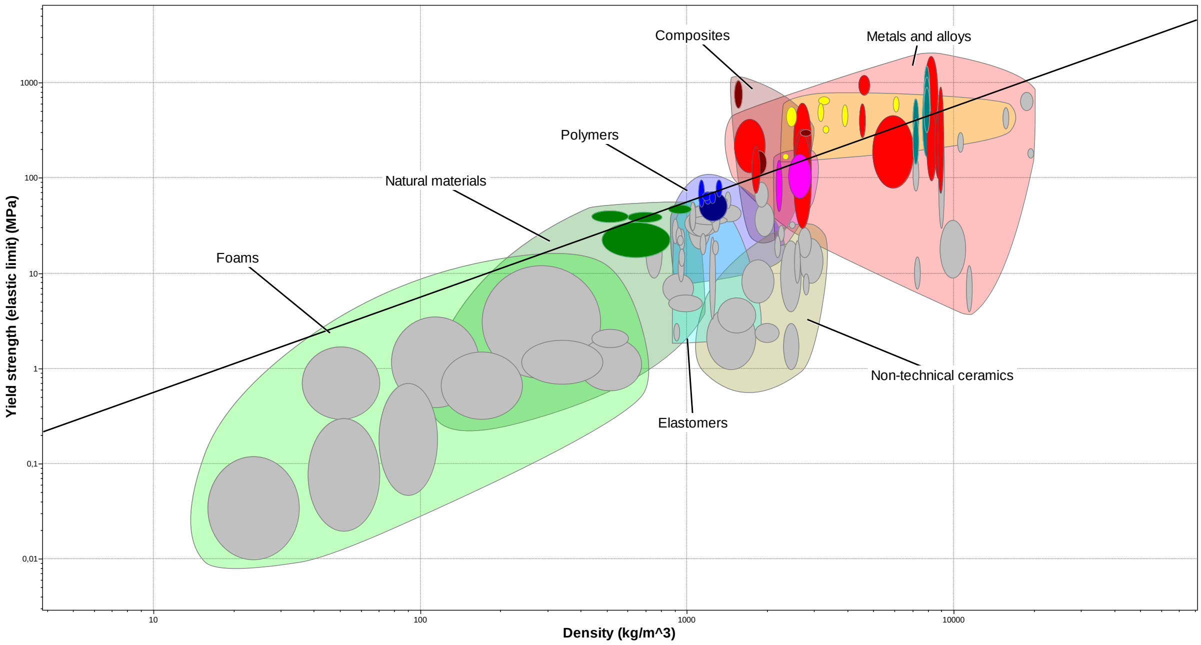


Figure 3-3: Material chart Yield strength/ Density for the material selection of the towbar. The chart is created in CES EduPack 2016.

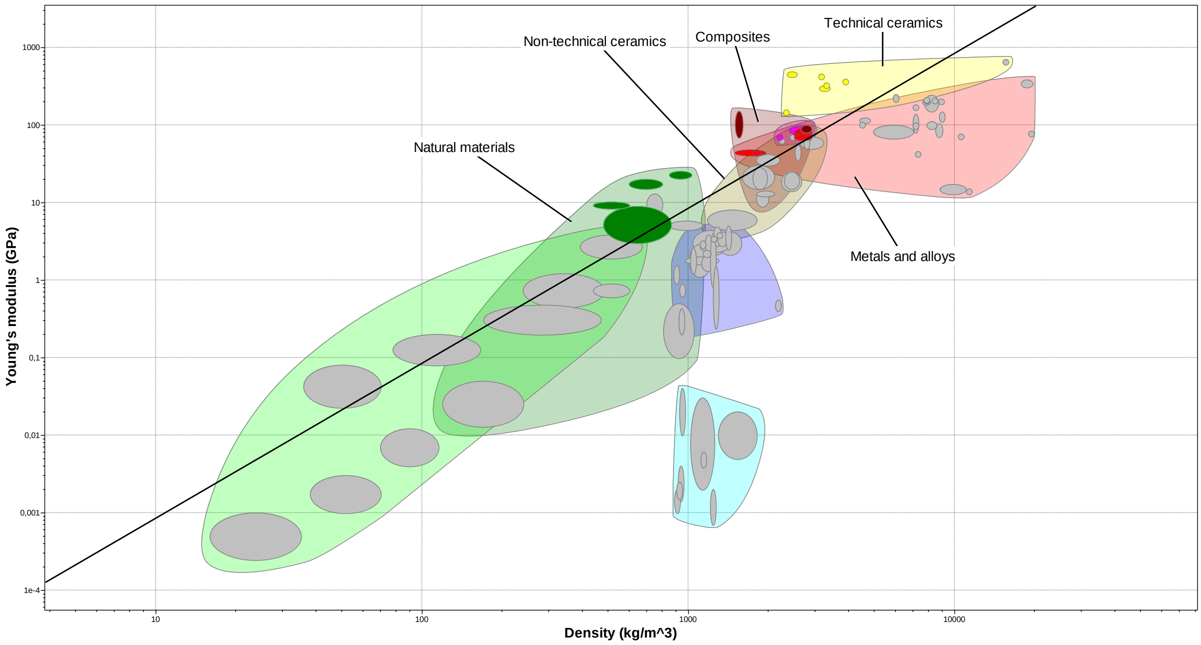


Figure 3-4: Material chart Young's modulus/ Density for the material selection of the towbar. The chart is created in CES EduPack 2016.

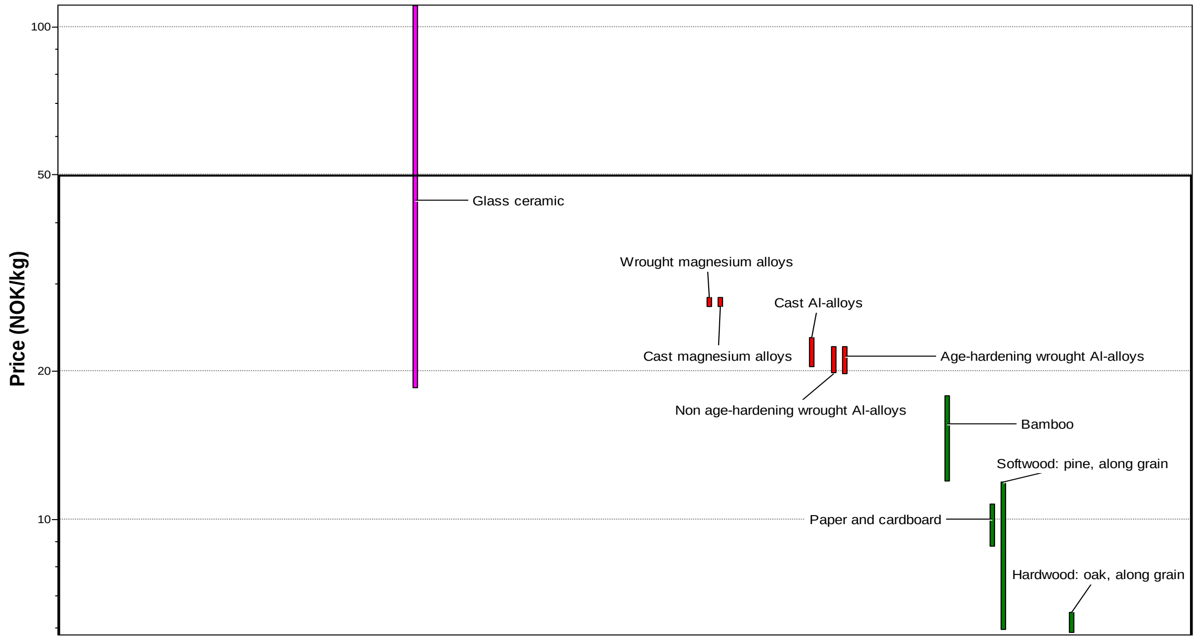


Figure 3-5:Material chart price per kg material for the material selection of the towbar. The chart is created in CES EduPack 2016.

3.1.2 Evaluation

These three stages leaves five relevant materials in the metals and alloys family that is listed in Table 3-2. In order to compare the materials the different properties have been given a value from 1-5 where 1 is best relative to the other materials. The values are summed up in Table 3-3, and the material that scores the best are age-hardening wrought al- alloys. Further investigations in the data sheet in Appendix C shows that the Aluminium 6000 series are typically used in general engineering and automotive such as connecting rods.

The railings and body structure of the sled will be designed as rods as well, and have to withstand impacts and imposed forces. Aluminium 6000 series are common to use for such purposes, and are considered as a good fit for these parts as well.

Table 3-2: Material properties of the remaining five materials for the towbar (14) (15) (16) (17) (18)

Property / Material	Density $\left[10^3 \frac{kg}{m^3}\right]$	Young's modulus [GPa]	Yield strength [MPa]	Price [NOK/kg]
Wrought magnesium alloys	1.5-1.95	42-47	115-410	26.9-28.2
Cast magnesium alloys	1.75-1.87	42-47	70-215	26.9-28.1
Cast al- alloys	2.5-2.9	72-89	50-330	20.3-23.3
Non age-hardening wrought al- alloys	2.5-2.9	68-72	30-286	19.7-22.4
Age-hardening wrought al-alloys	2.5-2.9	68-80	95-610	19.6-22.4

Table 3-3: Material properties of the remaining materials for the towbar in values relative to each other where 1 is best and 5 is worst

Property / Material	Density	Young's modulus	Yield strength	Price	Sum
Wrought magnesium alloys	1	4	2	5	**12**
Cast magnesium alloys	2	4	5	4	**15**
Cast al- alloys	3	1	3	3	**10**
Non age-hardening wrought al- alloys	3	3	4	2	**12**
Age-hardening wrought al-alloys	3	2	1	1	**7**

3.1.3 Dimensioning

Knowing the material properties, the cross- section area and width of the rod is calculated in Appendix D. In the calculations, it is assumed that the material have the highest density and lowest young's modulus (worst-case scenario) for age-hardening wrought al- alloys presented in Table 3-2. The force applied to the system are calculated from assumption of acceleration of 0-100 km/t on 1.5 s and total a weight of the system of 1000 kg. This cross section area will give a side width of only 23 mm, and in order to make it more robust but not adding weight, the profile of the towbar rods is hollow. The calculated area will be the same, but the width of the sides will differ. The inner widths are set to 15 mm and make the outer widths 27.3 mm. this gives a mass of 1.34 kg per rod using Al alloy of the 6000 series, which have a density of 2700 kg/m^3. Such a low mass allows for larger dimensions to ensure that the construction will be strong for even worse cases than the one calculated.

3.2 Top Plate and detachable frame

The dimensions of the top plate are set to 1600 mm x 900 mm and it have to sustain the maximum mass of 300 kg. The supporting body structure will relieve some of the impact, but the plate have to be strong enough not to brake or crack under the force of the impact that may occur in bumps or when loading the sled.

The detachable frame will have the same requirements as the top plate for the material choice to withstand some impacts with the cargo, and both the top plate and the frame have to be as light as possible. The dimensions for the sides of the frame are 900 mm x 500 mm and 1800 mm x 500 mm, while the thickness for both the frame and the top plate are free variables.

The design requirements for the top plate are presented in Table 3-4. Requirements for the frame would be the same as for the top plate.

Table 3-4: Requirements Top plate for material selection

Function:	Top plate
Constraints:	a) Length= 1600 mm b) Width= 900 mm c) Support impact with cargo load F without failing by yield or fracture
Objective:	Minimize mass
Free variable:	a) Cross- section area b) Choice of material

This gives the objective function that is presented in equation 3-1.

The Young's modulus, E is a measure of the elasticity or impact strength of the material, and are directly related to the stress, σ and strain, ε in a material as shown in equation 3-7.

$$E = \frac{\sigma}{\varepsilon} \tag{3-7}$$

By combining equations 3-1, 3-2 and 3-7, knowing that V= At for a plate where t is the thickness, this gives:

$$\frac{m}{\rho \cdot t} = \frac{F}{E \cdot \varepsilon}$$

Since the thickness is a free variable in this case, the expression is rewritten and gives a material index as follows:

$$t = \frac{m \cdot \varepsilon}{F} \left(\frac{E}{\rho}\right)$$

$$\Downarrow$$

$$M = \frac{\rho}{E}$$

The material index is inserted in Figure 3-6, where it becomes clear that several material groups are relevant based on this. However, since the total mass of the sled is important, the limit for the density is set to 1500 kg/m^3.

Since the sled is going to be used as passenger or patient transport in low temperatures, it is important that the top plate does not get too cold; hence, the thermal conductivity is investigated in Figure 3-7. A limit at 1 W/m°C is set to narrow down the selection.

The cost is always a subject of interest in the design processes, and in Figure 3-8 the price per kg material is compared with the density of the material. This leaves the natural materials as the best choice for this purpose, and plywood fits the requirements and area of use for the top plate which can be read about in Appendix E; datasheet of plywood.

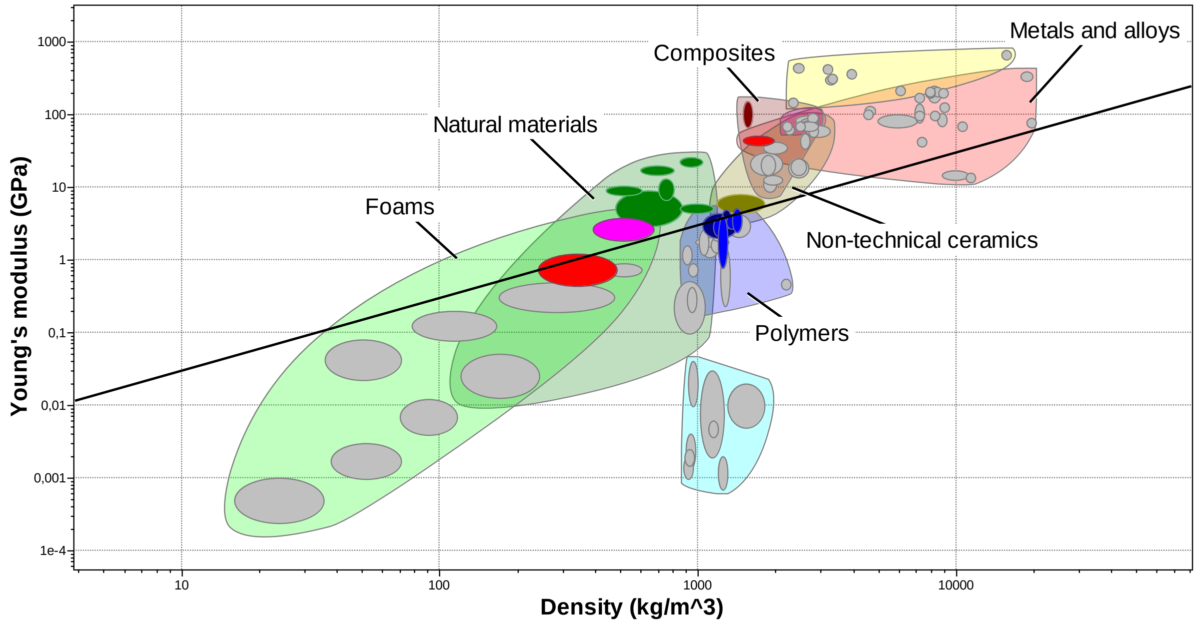


Figure 3-6: Material chart Young's modulus/ density for the material choice of the top plate inserted with material index ρ/E and limit for the density at 1500 kg/m^3. The chart is created with CES EduPack 2016.

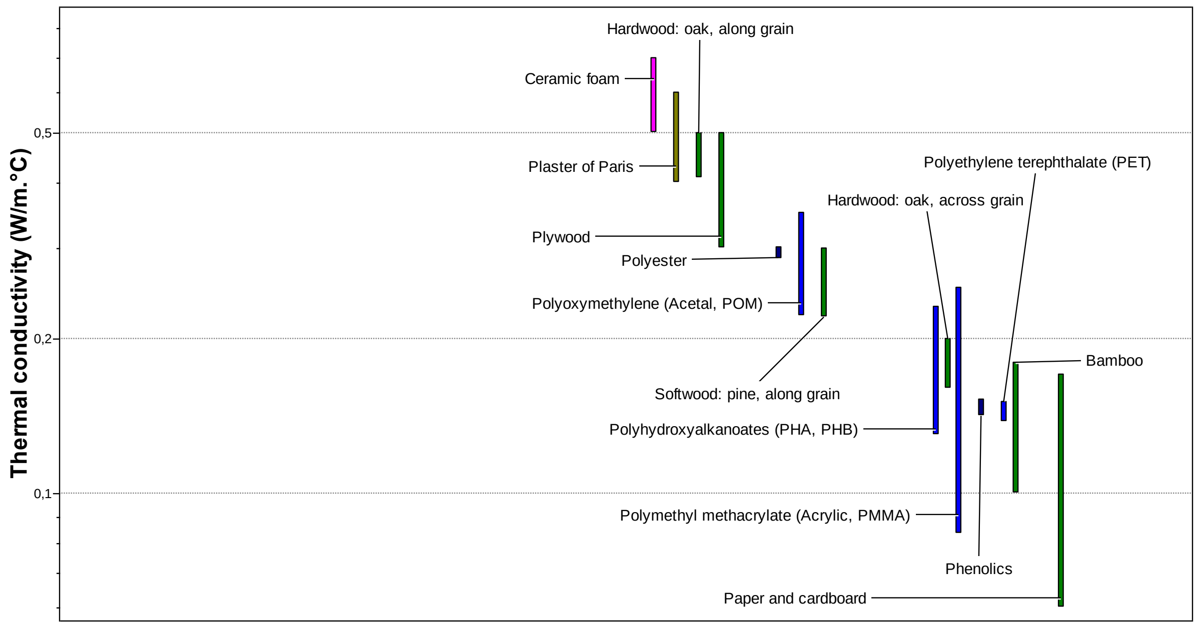


Figure 3-7: Material chart Thermal conductivity for the material choice of the top plate inserted a limit at 1 W/m°C. The chart is created with CES EduPack 2016.

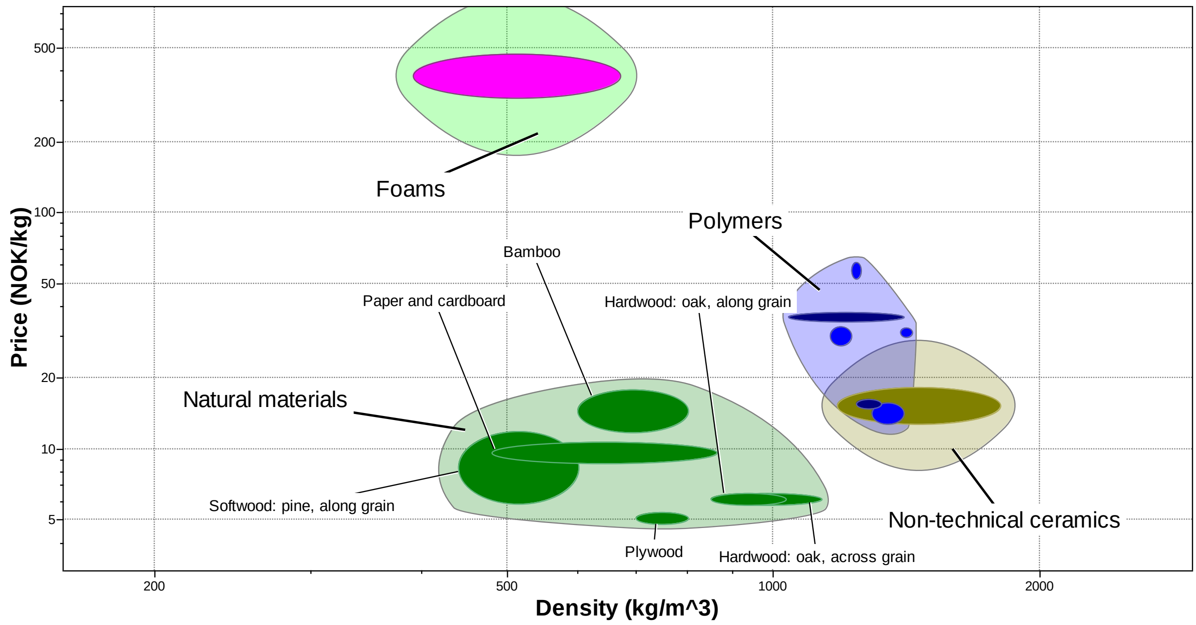


Figure 3-8: Material chart Price/ density for the material choice of the top plate. The chart is created with CES EduPack 2016.

4 Production methods

Age- hardening wrought Al- alloys are created by heating the material to a temperature where it is still solid, but makes the alloying elements dissolve, and then cooled down rapidly. After this the material is heated once more, but not to temperatures as high as in the dissolving phase, for several hours so that it ages and obtain its mechanical properties of high strength and corrosion resistance. This process leaves a low weight material but with constrains in the processability properties (19). The best methods of processing are, accordingly the datasheet in Appendix C, casting and machining.

Casting is a production method where the material is shaped in liquid state. The material is poured into a mold and cooled down to solid phase temperature. Centrifugal casting is used for casting of cylindrical shaped metals and includes die casting, investment casting, permanent mold, sand casting and shell mold casting (20).

When machining a material the component is shaped by material removal such as turning, drilling, boring and mashing (20).

For this case, CES EduPack 2016 is used to help choose the production method. Figure 4-1 shows that investment casting are among the best methods for non- ferrous metals such as aluminium alloy Al6061 and are economically attractive for small batches. Figure 4-2 shows that this method offers a low limit for the tolerance of the dimensions as well, which is useful for the accuracy of the design. To create the figures, limits were set for the relative equipment costs at medium and relative tooling cost at low. The datasheet of the investments casting are presented in Appendix F where it states that this production method can be used for both solid parts, and hollow components.

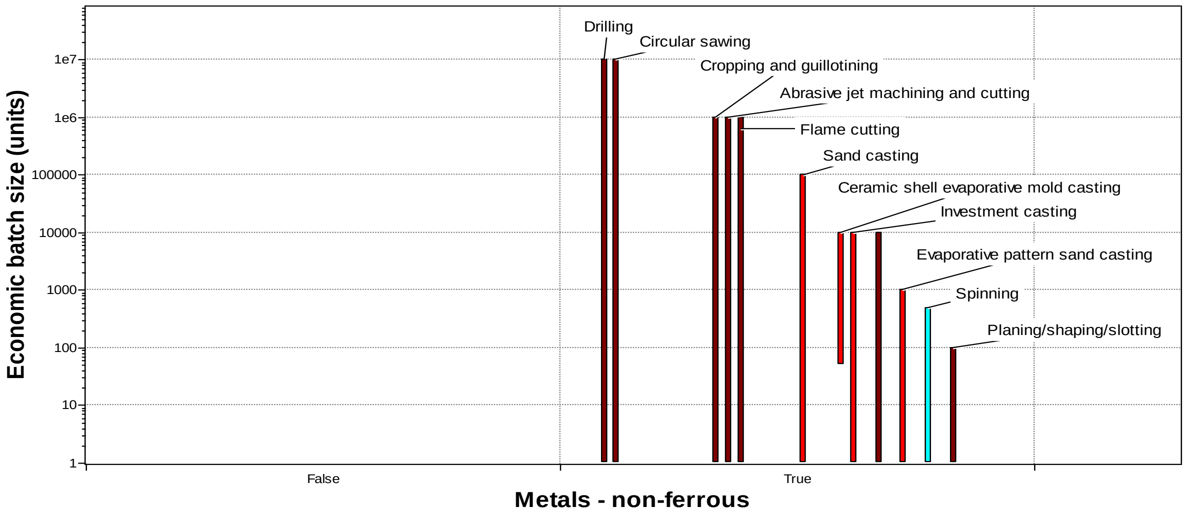


Figure 4-1: Process chart of economic batch size/ non- ferrous metals. The chart is created with CES EduPack 2016.

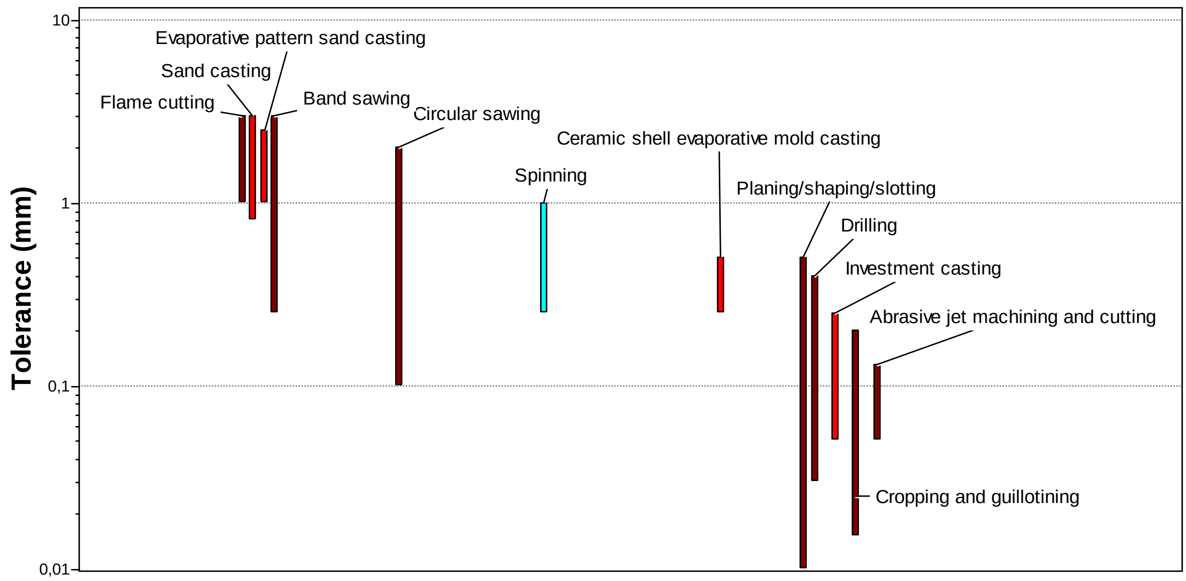


Figure 4-2: Process chart of tolerance [mm]. Limits are set for the relative equipment cos and the relative tooling cost at medium and low, respectively. The chart is created with CES EduPack 2016.

5 Finite element analysis

Finite element analysis (FEA) are mainly used in engineering problems regarding strength or temperature tolerances in a structure or material exposed to loads, pressure or extreme temperatures. Such analysis are done by Partial differential equations (PDE) that usually are too complicated for analytical analysis. To perform such analysis, numerical approximations are performed, such as FEA. Today several software facilitates the process for the engineer (21).

5.1 Strength analysis

A snowmobile sled will be subjected to forces applied by the snowmobile itself while driving as well as the cargo on the sled and possible uneven terrain. The largest force will occur when the snowmobile is accelerating while turning 90° and cause the largest amount of stress on the towbar. Even though the towbar rods are dimensioned for these stresses, other components or the rods could give in under extreme conditions and need to be tested.

When the snowmobile turns, this will give both compressive and tension forces that could lead to the material giving in and be permanently deformed. A measure of the elasticity of the material is the yield strength that gives a measure of the tolerance of the material until deformation occurs. Von Mises stress are stresses that occurs in the material and are considered a safe measure for engineering problems. If the von Mises stress exceeds the yield strength, the material will have plastic deformation and are more likely to fail. Hence, the aim is that all parts of the towbar should experience a lower von Mises stress than the given yield strength (22).

If the structure is not dimensioned for the applied forces, it might be deformed into a state where the structure can no longer be used for the purpose it is intended for. In addition to von Mises stress, the strain that occurs in the material can be a good indicator of whether the design is acceptable or not. The strain and deformation are directly linked together as shown in equation **Feil! Fant ikke referansekilden.** where ϵ is the engineering strain, ΔL is the change in length when exposed to forces, and l_0 is the initial length. This connection makes it important to keep the strain to a minimum (23).

$$\epsilon = \frac{\Delta L}{l_0} \tag{5-1}$$

5.2 SolidWorks

The towbar, with hingejoints, rods and attachment ring were subject for the linear structural analysis in SolidWorks simulation add- in. This add- in allows the 3D CAD drawing to be analyzed directly.

In the original design, all parts except for the plastic sides and the rubber tubes of the hingejoints were done in Aluminium alloy Al6061. The attachment ring were set to a profile of 10 mm, and were a free variable. In chapter 2.6.3 it became clear the ring should be rotational to ease handling. The dimensioning of the hingejoints were set according to the bodystructure of the sled as well as the calculated dimensions of the towbar- rods.

High quality, fine mesh was applied to the model, and a force of 20 kN simulating maximum acceleration while turning 90° were applied to the attachmentring. Since the analysis is worst-case scenario, the hingejoints were fastened as if the sled were stuck while the snowmobile is accelerating. The meshing, forces, materials etc. are described in detail in the report in Appendix G produced after the final analysis.

The analysis showed that the dimensioning of the attachment ring needed redesigning due to large displacement and high Von Mises stress. The first analysis showed that it was the attachmentring that was the weak point at the structure and the main focus of the further analysis. The displacement were much larger than what is acceptable, and the ring were deformed due to the applied force thus the ring were subject for redesigning. The redesigning of the attachment ring and the rods were done in several iterations, as presented in table 5-1.

After altering the profile of the ring and the rods, the design of the ring, how it was attached to the towbar as well as the material of the ring; the stress, strain and displacement became satisfactory. Figure 5-1 shows the deflection of the towbar, and illustrates how the attachment ring is the weakest link. The rods themselves seems to handle the forces well, and that the calculated profiles from the analysis in Chapter 3.1 are sufficient for this case.

Table 5-1: Iterations of analysis of the towbar in Solid Works with changes in design done in each iteration and resulting Von Mises stress, displacement and strain.

Iteration	**Changes in design**	**Von Mises [pa]**	**Displacement [mm]**	**Strain**
1	N/A	$4.24529 \cdot 10^9$	27.9361	0.252238
2	Dimensions for the profile of the attachment ring enlarged by 5 mm. Profile of the rods altered so that they are solid bodies, and not hallow.	$7.55718 \cdot 10^9$	10.3241	0.048519
3	Rod on the attachment ring were shortened down to 15 mm. Cross section of the main rods were enlarged from 35x35 mm to 35x40 mm, keeping the same cross section area.	$2.4318 \cdot 10^9$	8.2837	0.0377143
4	Material of attachment ring changed from 6061 Aluminium alloy to 201 Annealed stainless steal	$2.58224 \cdot 10^9$	4.68902	0.0127025
5	Length of ring changed from 15 mm to 12 mm	$1.19966 \cdot 10^9$	4.09967	0.0117419
6	Changed the profile of the rod on the ring from 14.5 mm to 15 mm wide Material of attachment ring changed to Titanium alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si (SS) that got high yield strength.	$1.142 \cdot 10^9$	4.666	0.01494
7	The design of the ring altered so that the ring is welded directly onto the towbar, and the attachmentring rod that made it rotational was deleted.	$3.7023 \cdot 10^8$	3.44939	0.00503221

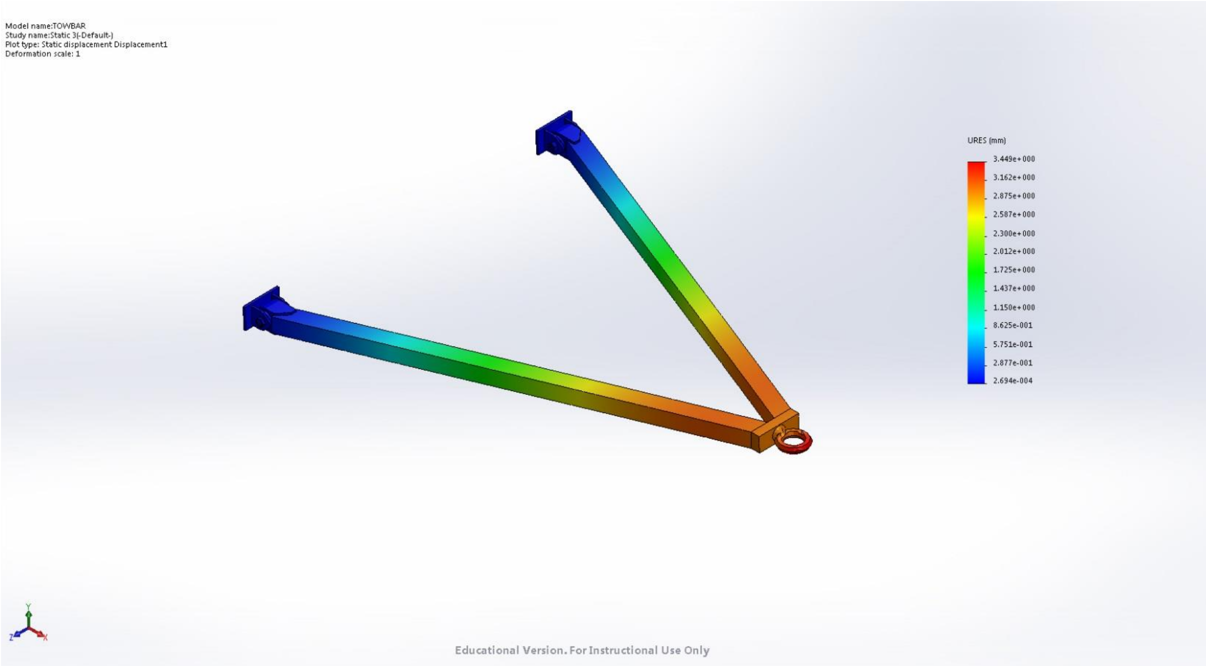


Figure 5-1: Deflection of the towbar after performing FEA analysis. Maximum displacement 3.44939 mm.

6 Prototyping

A design process requires several steps, and iterations. This leaves the designer with a clear idea of how the product should look and feel like; however, this might not be consistent with the real case. In order to get a clearer idea of how the dimensions of the different components are relative to each other an alternative is to print a downscaled model of the design in a 3D- printer.

The printer that were used is a Cubepro duo by 3D systems, which prints in PLA (Polylactid acid), ABS (Acrylonitrile Butadiene Styrene) and dissolvable natural PLA using Layer manufacturing technology (LMT) (24). This technique is divides a 3D model into 2D layers, and prints the model layer by layer to a complete 3D model as can be studied in Figure 6-1 that is a close- up photograph of the skis and shows the layers (25).

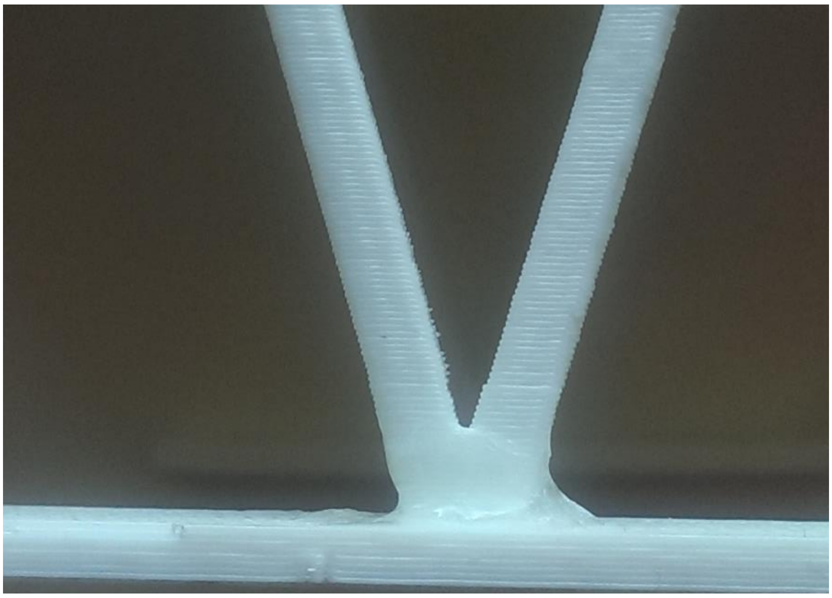


Figure 6-1: Close- up of the ski in the 3D printed model. Lines on the rods and ski shows the effect of LMT.
Photo: Kari W. Johansen

The model were downscaled to approximately 8% of the original size, making the total length 213 mm in ABS. To make the model robust, it was necessary to enlarge some of the rod dimensions and simplify the design:

- Profiles of railings were increased to 50 mm diameter.
- Profile of body structure frame were increased to 60x60 mm.
- Hingejoint were cut since there are some weak connections that are complicated to enlarge.
- The profiles of the rods of the towbar were done rigid and increased to 50x50 mm.
- Railings and skis were printed separately and glued onto the model of the sled.

In Appendix H technical drawings of the 3D printed model are presented.

Since the sled not is printed in the calculated dimensions or materials, it is not suitable for testing of forces or environmental challenges; the area of application is aesthetics. In Figure 6-2 a photograph of the model is presented.

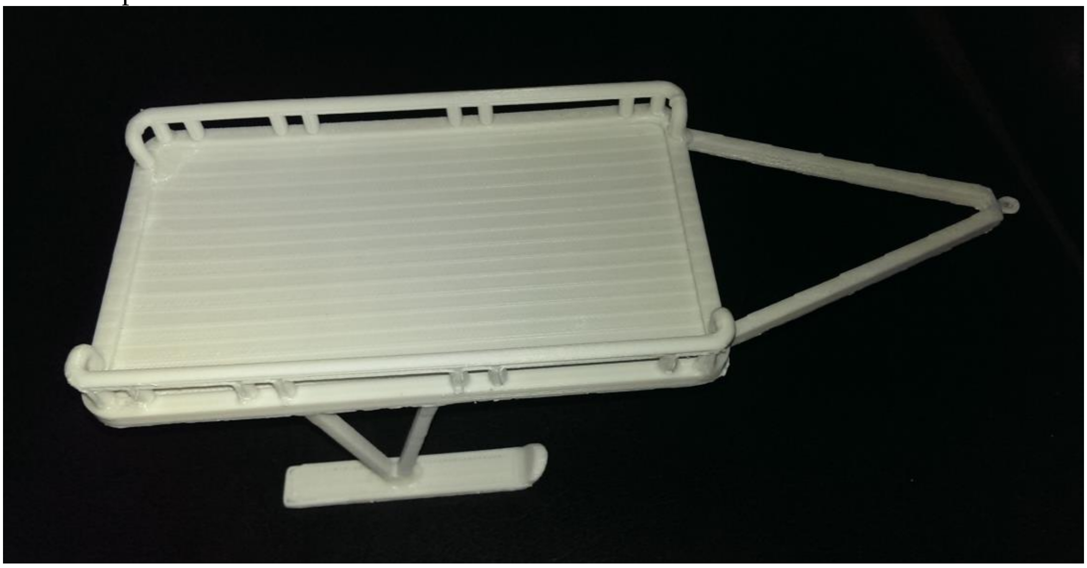


Figure 6-2: photo of 3D printed model of the sled. Photo: Kari W. Johansen

7 Final Design

From using design methods by Nigel Cross and material selection methods by Michael F. Ashby, the sled have been redesigned to better meet the requirements set in Chapter 2. In Appendix I detailed drawings of the sled is presented, in table 7-1 a summary of components with material and weight are listed and in Figure 7-1 the final design is illustrated.

The design deals with resulting forces that spreads throughout the sled by installing hingejoints with bearings in the transmission from the towbar to the sled. This way the sled will last longer and require less maintenance than today. The hingejoints are easy to change parts in, and if they are ordered from a known manufacturer, the costs would not be large in replacing parts.

To lower the maintenance, the objective have been to have a simple design with few parts. The towbar have been the focus, and designed to consist of two hallow rods attached to a ring for towing. The structure have been subject for finite element analysis and over several iterations, the design was adjusted to resist the applied force. This resulted in a ring that is welded directly onto the towbar structure, and different material on the ring than the rest of the structure.

Sleds used today have railings surrounding the top plate. The design of the railings have been altered to better fit the area of use with railings only on the longitudinal sides of sled, making the sled suitable for both stretchers with patients and transporting cargo.

As for the hingejoints, the skis are outsourced as described in chapter 2.6.4.

Table 7-1: Components of the final design with material and weight

Component	Material	Weight [g]
Railings x2	Al6061 alloy	2277.04
Towring	Ti-6Al-2Sn-2Zr-2Mo-2Cr	188.92
Top plate	Plywood	10048.18
Towbar	Al6061 alloy	1828.31
Supporting body structure	Al6061 alloy	14760.27
Hingejoint x2	N/A	234.42
Skisystem x2	N/A	5000
TOTAL		41848.6

It was desired by the customer to have some additional frame for protection of cargo that can be attached when needed. The detachable frame are set to be produced in plywood as the top plate in Chapter 3.2. The dimensions are set according to the sled itself. In Appendix B detailed 2D drawings of the frame with dimensions are presented.

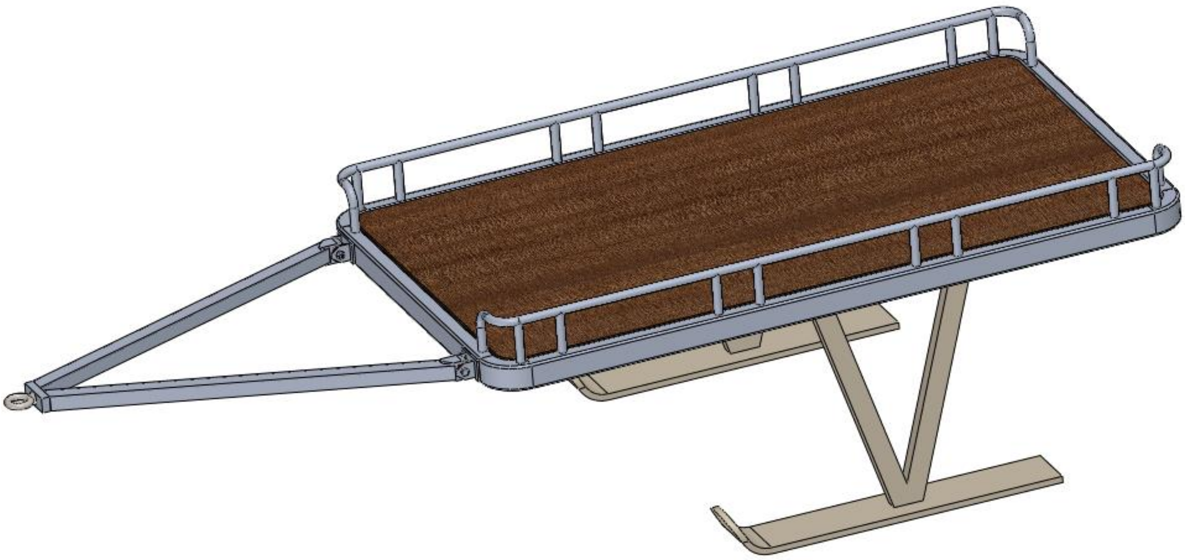


Figure 7-1: The final design of the snowmobile sled. Model drawn in SolidWorks

7.1 Design restrictions

Even though the design have been subject for analysis, there are components and parameters that are not tested which could affect the performance of the product under extreme conditions. The analysis are executed using computer software and approximates how the system would behave in a real situation based on assumptions and calculations. Approximations can not predict the behavior of the system with certainty and are not to be considered a guarantee for the design.

The material choices are done using the software CES EduPack. This version of the software have a limited database of materials to choose from, and other materials could have changed the resulting design.

7.2 Further work

There are still work to be executed until the sled is ready to be produced:

- A 1:1 prototype in the chosen materials and profiles should be tested in the situations the sled is intended for. Tests like these should look into the strength of the whole system, the comfort and security for passengers and patients.
- As the front of the skis are not attached to the sled or towbar in any way, the stability of the skis are uncertain since they haven’t been tested and should undergo 1:1 tests in different terrains and snow types.

- The detachable frame have not been subject for any analysis, and the whole system should be analyzed for the worst-case scenarios that can occur while using it before producing them. Since the frame have a weight of 17 kg, the material choice and profiles should be analyzed as well to minimize the mass and weight.
- Analysis of the profiles of the railings need to be executed before producing since they have not undergone any strength analysis, and it is not certain they will sustain the applied forces.
- The profile of the top plate should be analyzed before producing to test for applied forces that will occur when being loaded with cargo and patients while driving in different terrains. The plate should be subject for analysis regarding the mass as well.
- Even though the towbar system as a whole have been analyzed, the hingejoints have not been looked into specifically. The ring and rods are dimensioned to withstand the worst-case scenario for the structure, however, the hingejoints should undergo analysis to determine if they can withstand repeating forces from the sides.
- In case the sled loosens from the snowmobile while driving, there are not installed any safety measures such as a safety line in the design as it occurs today. This should be installed for security means.
- Cost analysis of the production, shipping and mounting of the system.

Acknowledgements

The master thesis marks the end of five years at UiT, campus Narvik. It is the competence of the university as well as the student community in Narvik that have made these years as wonderful as they have been, and the management of the school deserves a big thank you!

Further, my supervisors Guy Mauseth and Andreas Seger have been a great support during these months and always ready to help or guide if there was a struggle. Together with the rest of the team on the engineering design department, they have created a learning environment and passed their knowledge on. Thanks to the whole team of lecturers, and a special thanks to my supervisors.

At last, I want to thank my classmates of 5ID that have been helpful, understanding and caring. We have pulled through these two years together.

Appendices

The following documents are attached to the report:

A. Problem Description
B. Technical 2D drawing with measures detachable frame
C. Datasheet age-hardening wrought al- alloys
D. Calculations of towbar profile
E. Datasheet plywood
F. Datasheet investment casting
G. Report Finite Element Analysis in SolidWorks
H. Technical 2D drawing with measures 3D model of the sled
I. Technical 2D drawing with measures final design of the snowmobile sled

External files:

J. STEP file of the CAD file of the sled

Software

Developing the product different software were used, that are listed below.

SolidWorks

SolidWorks is a 3D CAD software and is developed by Dassault Systèmes SA. It is used to produce 3D-models, technical drawings, FEM- analysis, illustrations, simulations, animations etc.

CES

CES is developed by Granta Design and CES EduPack is a teaching resource that contains a large database of materials and production methods as well as material software for material selection.

Inkscape

InkScape 0.91 is open-source vector graphics editor that allows making 2D illustrations in scalable vector graphics.

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References

1. Kjelvik, Julie. Skråblikk på statistikk- Vernepliktige opp i vekt. Statistisk sentralbyrå- Statistics Norway. [Online] 28 02 2011. [Cited: 23 02 2017.] https://www.ssb.no/helse/artikler-og-publikasjoner/vernepliktige-opp-i-vekt.

2. Statistics Norway. 109 Egenrapportert høyde, vekt og svømmeferdigheter for sesjonspliktige, etter fylke. 2012. Statistisk sentralbyrå- Statistics Norway. [Online] 2012. [Cited: 23 02 2017.] http://www.ssb.no/a/aarbok/tab/tab-109.html.

3. Montana Trailers. Norsk Maskinutvikling. [Online] [Cited: 17 01 2017.] http://www.maskinutvikling.no/slede-doning-kjelke.

4. Redningspulken. Altapulken- Det sikreste valget! [Online] [Cited: 25 01 2017.] http://altapulken.no/redningspulken.

5. Cross, Nigel. The Quality Function Deployment Method. Engineering Design Methods fourth edition. 4. Edition. s.l. : John Wiley & sons Ltd, 2000, 8.

6. Biltema. Lemlås. Biltema. [Online] [Cited: 21 03 2017.] http://www.biltema.no/no/Bil---MC/Laste-og-Trekke/Tilhenger/Tilbehor/Lemlas-2000019435/ .

7. ISC. BU182 / BU182 45mm Klick-lock Buckle & Sliding Tang Set. ISC Solutions in Metal. [Internett] [Sitert: 21 03 2017.] http://www.iscwales.com/Products/Showcase/BU182-45mm-Klick-lock-Buckle-Sliding-Tang-Set/0/ .

8. Irgens, Fridtjov. Likevekt for plane kraftsystemer. Statikk. 7. Trondheim : Tapir akademisk forlag, 2005, 3, p. 44.

9. BX. C&A PRO. [Online] VoyageurWeb, Mankato, MN. [Cited: 21 03 2017.] https://www.caproskis.net/bx.

10. USI- SPX Snowmobile Ski. USI. [Online] [Cited: 21 03 2017.] http://usiskis.com/ski_bottom/spx_ski.html.

11. KIMPEX Rush Ski Complete Kit. KIMPEX. [Internett] [Sitert: 22 03 2017.] https://www.kimpex.com/en-ca/products/snowmobile/skis-and-accessories/skis/kimpex-rush-ski-complete-kit.

12. Ashby, Michael F. Materials Selection in Mechanical Design. 3. Edition. Burlington : Pergamon Press, 2005, 2, p. 13.

13. Haugan, John. Fasthetslære. Formler og tabeller. 2. Bekkestua : NKI Forlaget, 2011, p. 101.

14. CES EduPack 2016. Datasheet Wrought Magnesium Alloys. s.l. : CES EduPack, 2016.

15. CES EduPack 2016. Datasheet Cast Magnesium Alloys. s.l. : CES , 2016.

16. CES EduPack 2016. Datasheet Cast Al- Alloys. s.l. : CES, 2016.

17. CES EduPack 2016. Datasheet Non Age- Hardening Wrought Al- Alloys. s.l. : CES, 2016.

18. CES EduPack 2016. Datasheet Age- Hardening Wrought Al- Alloys. s.l. : CES, 2016.

19. Metals AG. Precipitation Hardening of ALuminium Alloys. Total Materia The world's most comprehensive materials database. [Online] [Cited: 22 04 2017.] http://www.totalmateria.com/page.aspx?ID=CheckArticle&site=ktn&NM=235.

20. Lukkassen, Dag and Midell, Annette. Fabrication Processes. Advanced Materials and Structures and some computational methods. Narvik : UiT The Arctic University in Engineering Design, Book manuscript, 2016, V, p. 242.

21. Lukkassen, Dag. Elementmetoden (FEM). Generell teori. Partielle differensiallikninger. Narvik : s.n., 2016. pp. 144-150.

22. Irgens, Fridtjov. Mises- kriteriet for flytning. Fasthetslære. 7. edition Trondheim : Tapir Akademisk Forlag, 2006, 14.3, ss. 101-106.

23. Smith, William F. og Hashemi, Javad. Engineering Stress and Engineering Strain. Foundations of material science and engineering. 5. New York : McGraw-Hill, 2011, 6.2.2, equation (6.4), s. 227.

24. 3D systems. CubePro. 3D Systems. [Internett] [Sitert: 01 06 2017.] https://www.3dsystems.com/shop/cubepro/techspecs.

25. Lukkassen, Dag and Midell, Annette. Layer Manufacturing Technology (LMT). Advanced Materials and Structures and some computational methods. Narvik : UiT The Arctic University in Engineering Design, Book manuscript, 2016, pp. 263-265.

Bibliography

Cross, Nigel. Engineering Design Methods fourth edition. 4. Edition. s.l. : John Wiley & sons Ltd, 2000
Ashby, Michael F. Materials Selection in Mechanical Design. 3. Edition. Burlington : Pergamon Press, 2005
Irgens, Fridtjov. Statikk. 7. Trondheim : Tapir akademisk forlag, 2005
Irgens, Fridtjov. Fasthetslære. 7. edition Trondheim : Tapir Akademisk Forlag, 2006

UiT THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Engineering Science and Technology

Department of Computer Science and Computational Engineering, Narvik

Appendix A: Problem Description

Re-design of a multipurpose snowmobile sled for Norwegian volunteer (SAR organizations).

—

Kari Wilhelmsen Johansen

Master thesis in Engineering Design … Spring 2017

Background

The "Hjelpekorps" emergency response extends well beyond patrolling the mountains at Easter. Every year "Hjelpekorps" help over 1000 people who get lost or injured during outdoor activities. One of the main challenges the Hjelpekorps have is search and rescue in arctic environment.

The Norwegian Search and Rescue organizations (SAR) are mainly based on volunteer work (Hjelpekorpset is one of them), some financing comes from the government but most of the financing the SAR groups need to raise by them self. One way of raising funds is by doing transportation work by snowmobiles. Thus, there is a need for multipurpose sleds that can be used for all of the different operations/ work Hjelpekorpset do during the winter.

Problem description

Short about the problem: The sleds that exist today have often very specified area of application, there is a need for a sled that can be used for all operation/transport mission that the Norwegian volunteer SAR organizations carries out.
The sled must be reliable, easy to maneuver in difficult terrain. Area of application for the sled:

- Transport of various equipment for use during SAR-operation
- Transport of patients.
- General transportation of; firewood, gas, gasoline, furniture etc. (The volunteer SAR organizations in Norway often do transportation work to private huts etc.)

The work shall include:

1. **A literature study** both in terms of finding state-of –the art for these types of products, existing equipment on the market and potential competitors, as well as other literature that is necessary with a view to solving the problem (regulations, standards for materials, patents etc.). Existing equipment described with respect to behaviour, structure, performance, weight, and size.
2. **Develop a specification** for the product based on demands for performance under the given physical conditions, requirements for stiffness, strength, weight, reliability, comfort, regulations and other requirements and demands of the customer.
3. **Conduct a systematic design** ending up with a final proposal to the technical solution for the product/system.
4. **Analysis of the product/system** shall be made in order to determine which aspects/ parts of the system/ product should undergo numerical and analytical calculations.
5. **Modelling of the system** in a 3D parametric CAD system and simulation/visualization of for instance movements. A set of 2D drawings should be generated. These drawings should include assembled drawings of the system in open and closed position and complete part production drawings with tolerances.
6. **Modelling and numerical analysis** of the product/ system will (also) be carried out using an appropriate numerical calculation tool (such as Ansys) and should be compared with the analytical calculations of the product / system.
7. **Construction/making** a (physical) prototype or a model of the product/system/structure.
8. **Suggestions** for future work and description of remaining work

The solution of the task should be based on typical engineering design methods and areas of study for the Master Program Engineering Design at UiT – campus Narvik.

General information

This master thesis should include:

- ❄ Preliminary work/literature study related to actual topic
  - A state-of-the-art investigation
  - An analysis of requirement specifications, definitions, design requirements, given standards or norms, guidelines and practical experience etc.
  - Description concerning limitations and size of the task/project
  - Estimated time schedule for the project/ thesis
- ❄ Selection & investigation of actual materials
- ❄ Development (creating a model or model concept)
- ❄ Experimental work (planned in the preliminary work/literature study part)
- ❄ Suggestion for future work/development

Limitations of the task/project

Eventual ownership of product and documentation, restrictions and closure to be filled up here.

Preliminary work/literature study

After the task description has been distributed to the candidate a preliminary study should be completed within 4 weeks. It should include bullet pints 1 and 2 in "The work shall include", and a plan of the progress. The preliminary study may be submitted as a separate report or "natural" incorporated in the main thesis report. A plan of progress and a deviation report (gap report) can be added as an appendix to the thesis.

In any case the preliminary study report/part must be accepted by the supervisor before the student can continue with the rest of the master thesis. In the evaluation of this thesis emphasis will be placed on the thorough documentation of the work performed.

Reporting requirements

The thesis should be submitted as a research report and should include the following parts; Abstract, Introduction, Material & Methods, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References and Appendices. Choices should be well documented with evidence, references, or logical arguments.

The candidate should in this thesis strive to make the report survey-able, testable, accessible, well written, and documented.

Materials which are developed during the project (thesis) such as software/codes or physical equipment are considered to be a part of this paper (thesis). Documentation for correct use of such information should be added, as far as possible, to this paper (thesis).

The text for this task should be added as an appendix to the report (thesis).

The report (Abstract, Introduction, Material & Methods, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References) should not exceed 50 pages. Any additional material should be included in the appendix.

General project requirements

If the tasks or the problems are performed in close cooperation with an external company, the candidate should following the guidelines or other directives given by the management of the company.

The candidate does not have the authority to enter or access external companies' information system, production equipment or likewise. If such should be necessary for solving the task in a satisfactory way a detailed permission should be given by the management in the company before any action are made.

Any travel cost, printing and phone cost must be covered by the candidate themselves, if and only if, this is not covered by an agreement between the candidate and the management in the enterprises.

If the candidate enters some unexpected problems or challenges during the work with the tasks and these will cause changes to the work plan, it should be addressed to the supervisor at the UiT Campus Narvik or the person which is responsible, without any delay in time.

Submission requirements

This thesis should result in a final report with an electronic copy (i.e. CD/DVD, memory stick) of the report included appendices and necessary software codes, simulations and calculations. The final report with its appendices will be the basis for the evaluation and grading of the thesis. The report with all materials should be delivered in one signed loose-leaf copy, together with three bound. If there is an external company that needs a copy of the thesis, the candidate must arrange this. A standard front page, which can be found on the UiT Campus Narvik internet site, should be used. Otherwise, refer to the "General guidelines for thesis" and the subject description for master thesis.

The final report with its appendices should be submitted no later than the decided final date. The final report should be delivered to the adviser at the office of the Department of Computer Science and Computational Engineering.

Date of distributing the task:	6.6.2017
Date for submission (deadline):	6.6.2017

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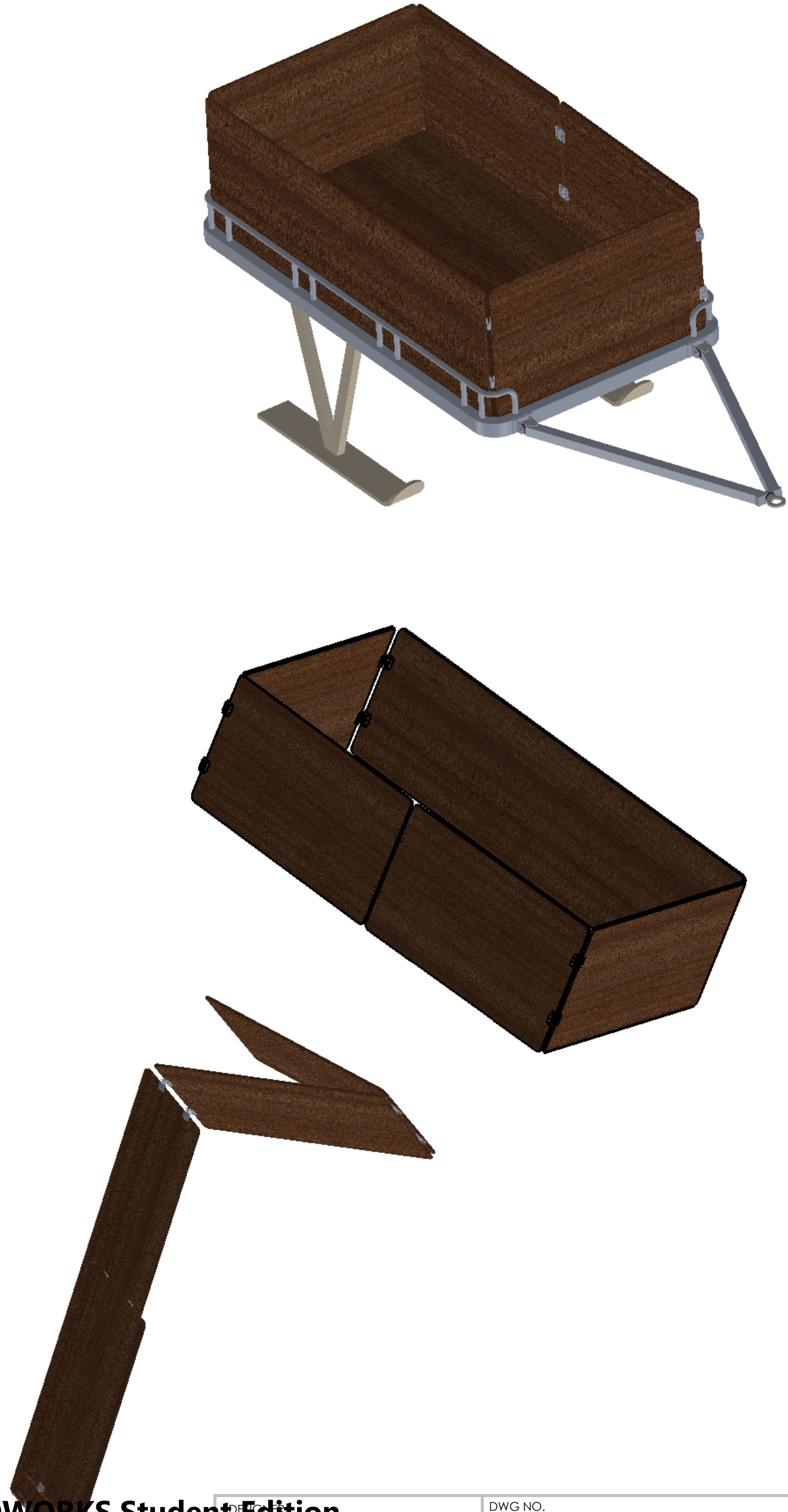
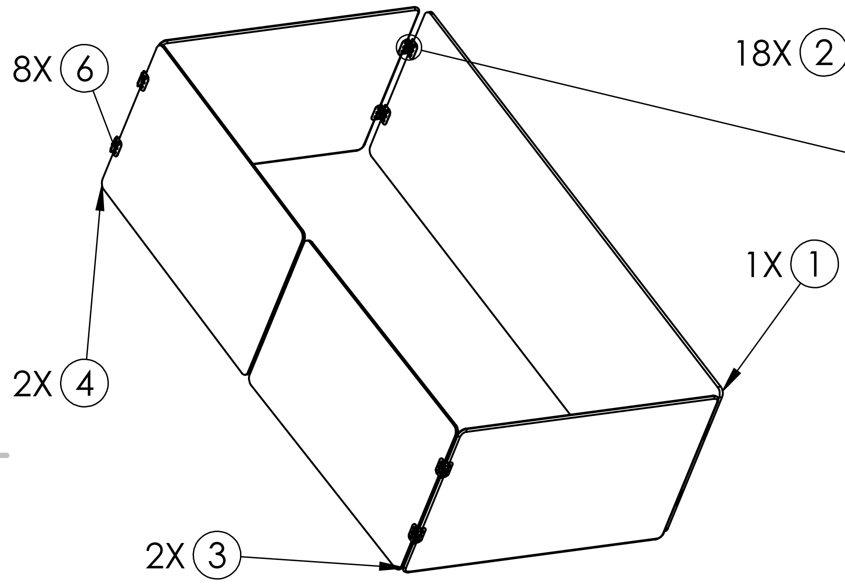
Appendix B

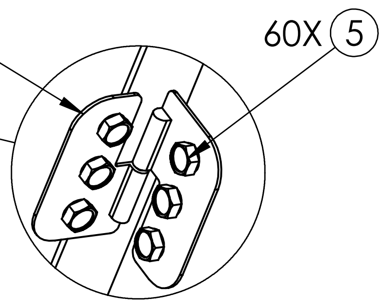


DESIGNER: Kari Wilhelmsen Johansen	DWG NO. FRAME		A4
	SCALE: 1:20	SHEET 1 OF 9	

Appendix B

ITEM NO.	PART NUMBER	Material	Weight [g]	QTY.
1	FRAME long side	Plywood	5473.94	1
2	FRAME Hengsel	Aluminium Al 6061	3.71	18
3	FRAME short side	Plywood	2951.44	2
4	FRAME short long side	Plywood	2744.92	2
5	formed hex screw_am	Aluminium Al 6061	0.9105	60
6	AM A M2X25-N	Aluminium Al 6061	0.24	8
7	FRAME lås	Aluminium Al 6061	3.91	2





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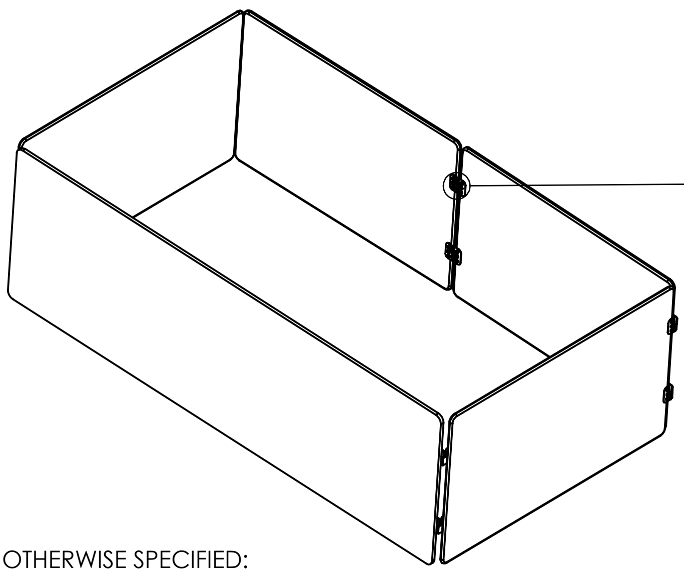

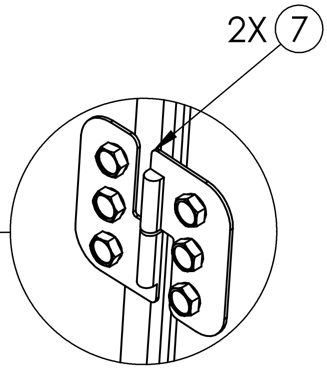

DETAIL B
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

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APPV'D — NAME: Kari Wilhelmsen Johansen — DATE: 6.6.2017

TITLE: Detachable Frame

WEIGHT: 16997.82

DWG NO. FRAME

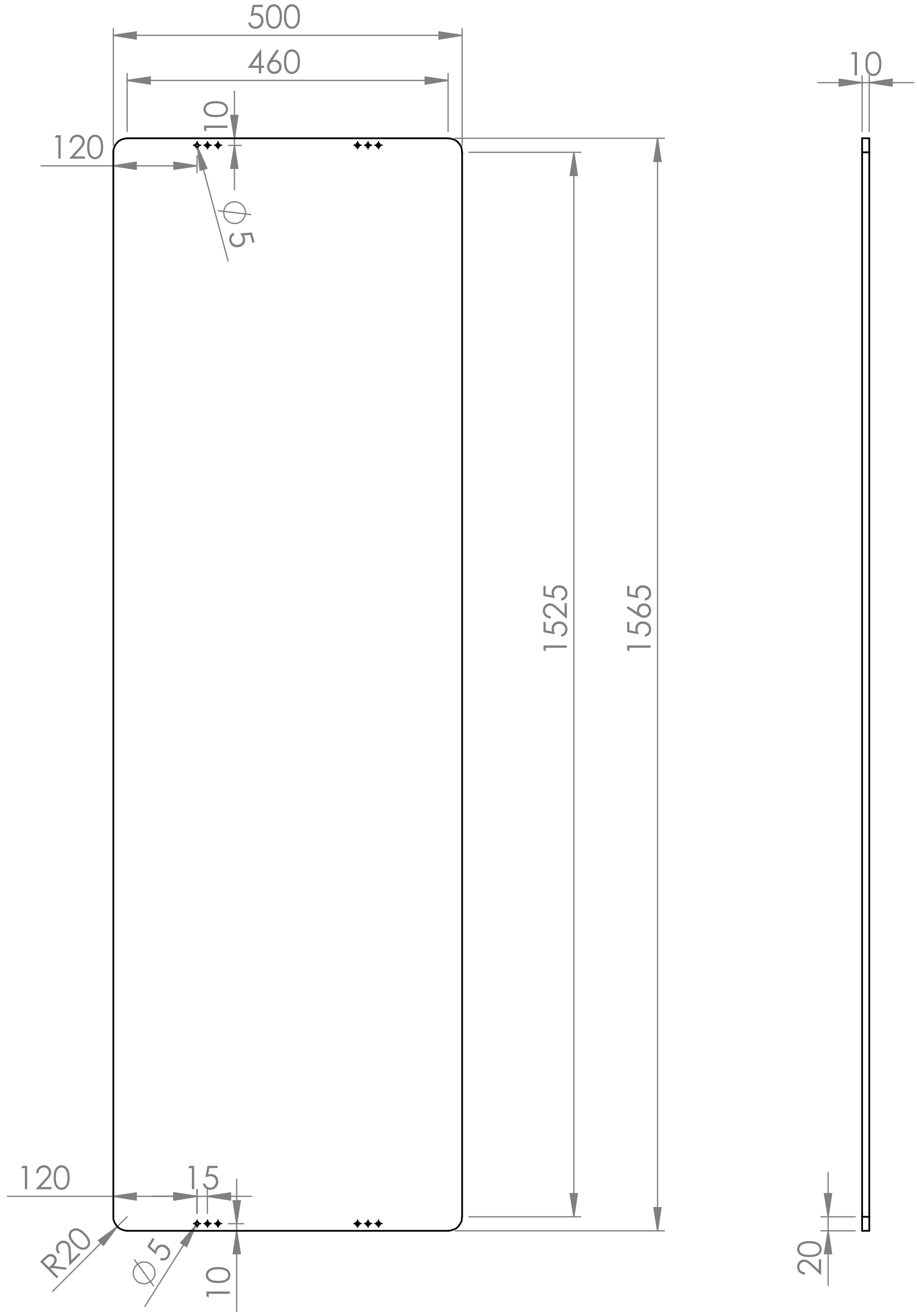
A4

MATERIAL: N/A

SCALE:1:100

SHEET 2 OF 9

Appendix B



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DIMENSIONS ARE IN MILLIMETERS

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APPV'D	NAME: Kari Wilhelmsen Johansen	DATE: 6.6.2017	
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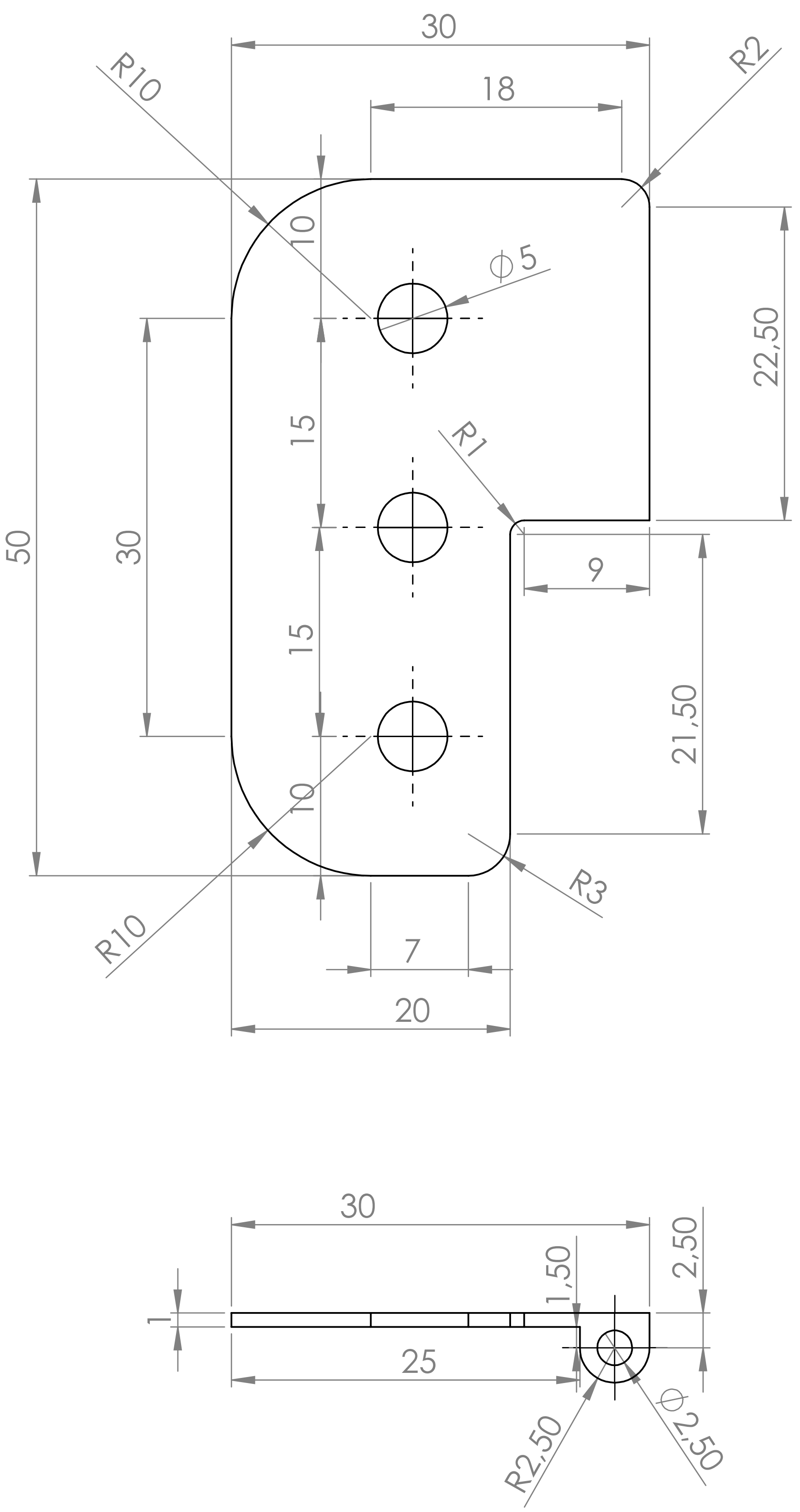
		MATERIAL: Plywood	SCALE: 1:10 — SHEET 3 OF 9



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APPV'D	NAME: Kari Wilhelmsen Johansen	DATE: 6.6.2017	
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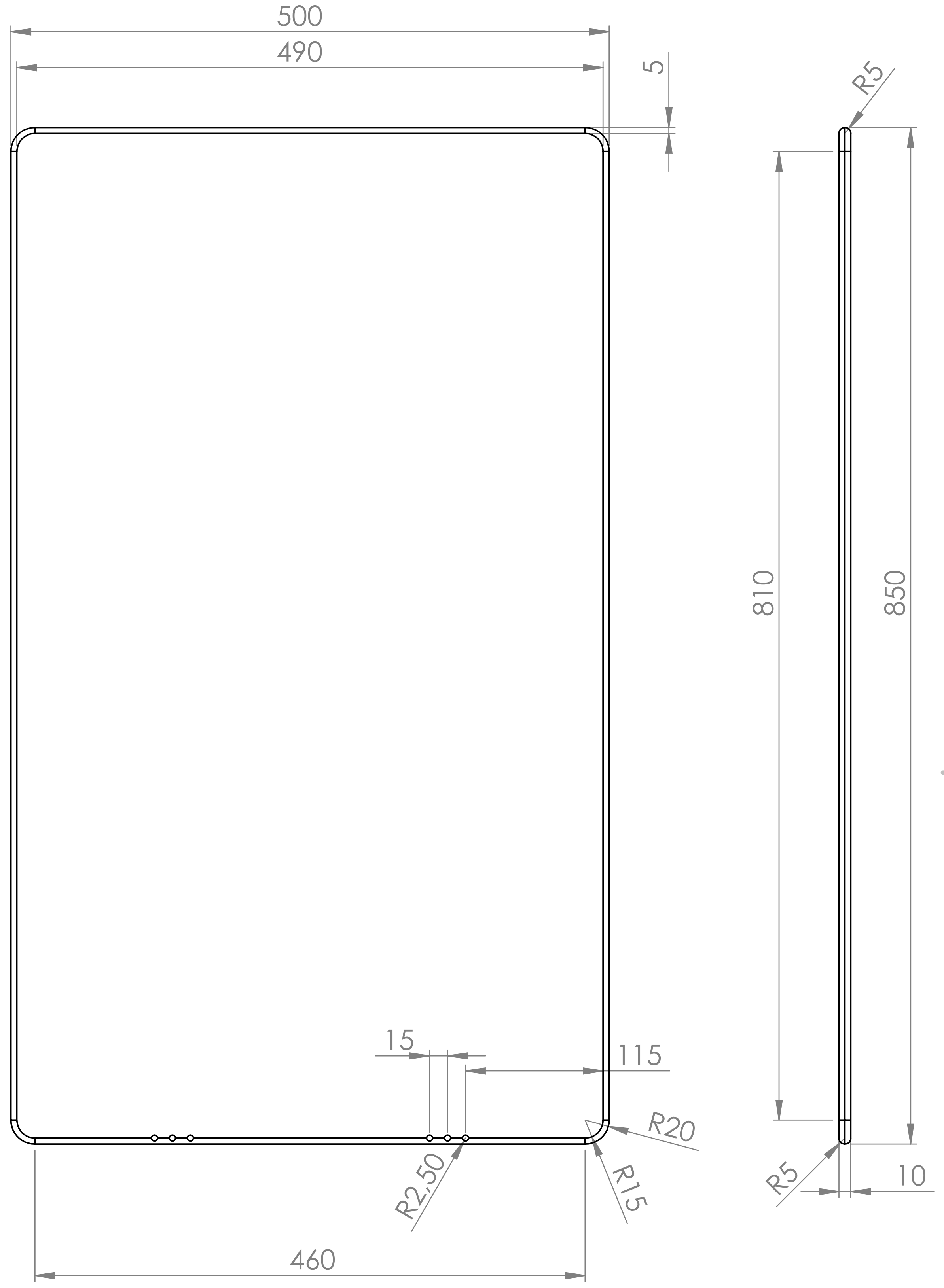
Appendix B



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DRAWN — NAME: Kari Wilhelmsen Johansen — DATE: 30.3.2017

APPV'D — NAME: Kari Wilhelmsen Johansen — DATE: 6.6.2017

TITLE: 3: Short side

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WEIGHT: 2951.44 g

DWG NO. FRAME

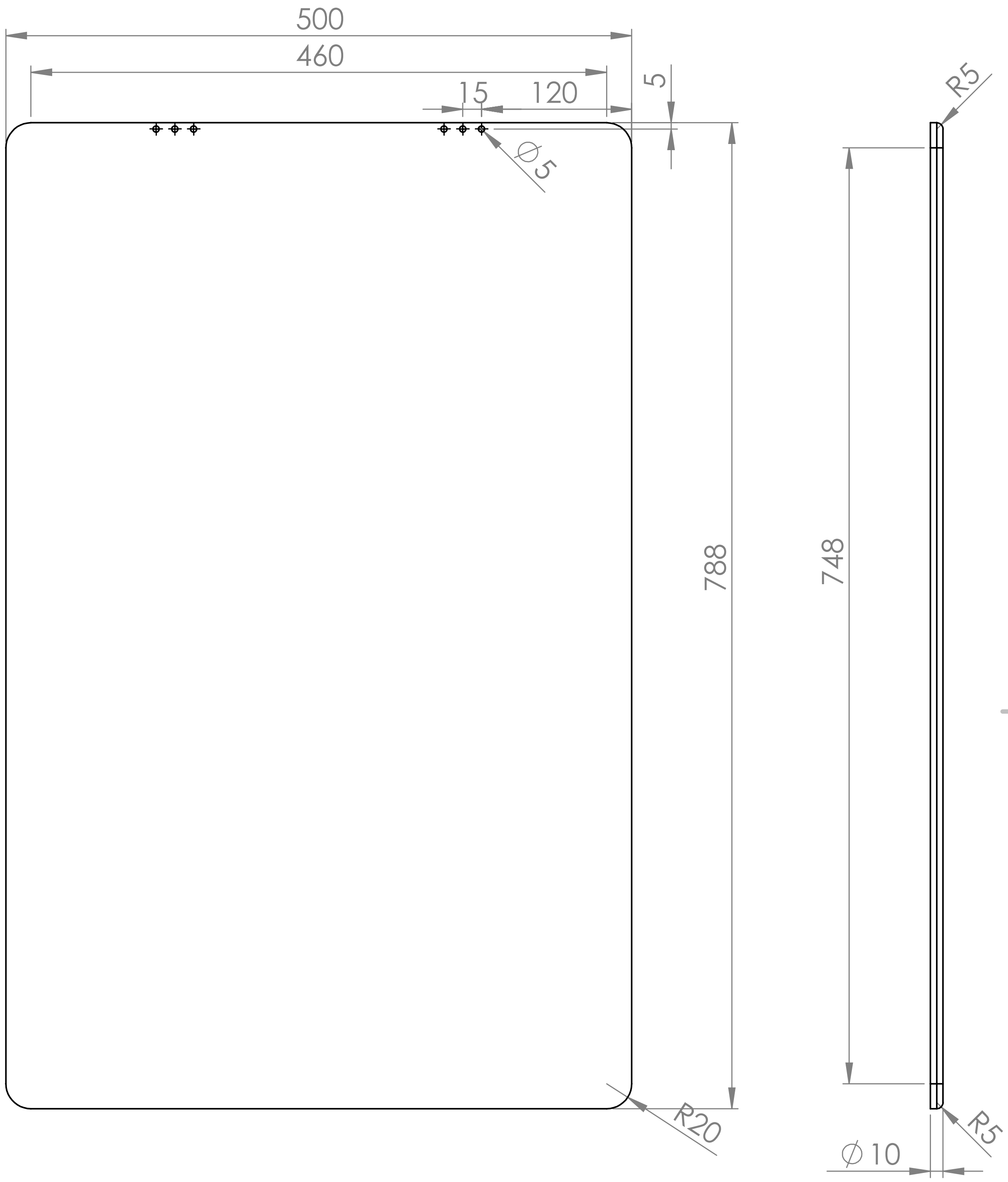
A4

MATERIAL: Plywood

SCALE:1:5

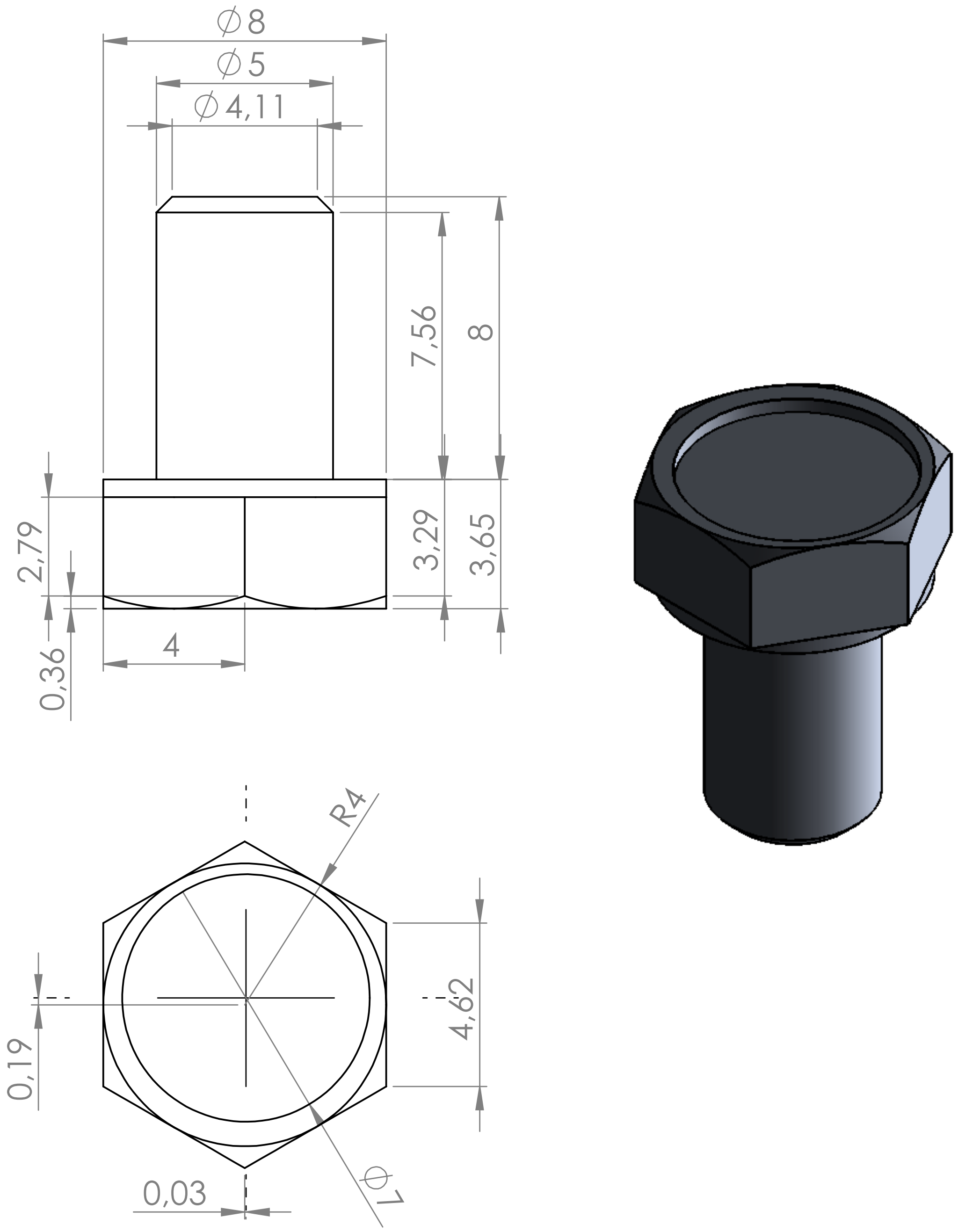
SHEET 5 OF 9

Appendix B



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: Kari Wilhelmsen Johansen	DATE: 30.3.2017	TITLE: 4: Short longitudinal side
APPV'D	NAME: Kari Wilhelmsen Johansen	DATE: 6.6.2017	
	SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 2744.92	DWG NO. FRAME — A4
		MATERIAL: Plywood	SCALE:1:10 — SHEET 6 OF 9



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN — NAME: SolidWorks Design Library Toolbox ANSI Metric — DATE:

APPV'D — NAME: Kari Wilhelmsen Johansen — DATE: 6.6.2017

TITLE: **5: Formed Hexscrew**

SOLIDWORKS Student Edition.
For Academic Use Only.

WEIGHT: 0.9105

DWG NO. FRAME

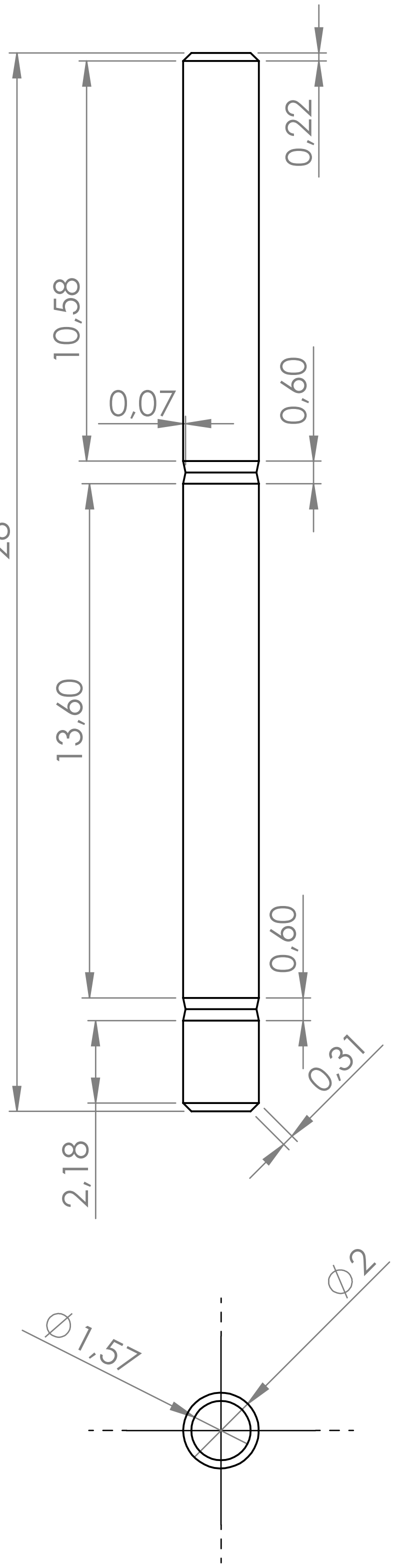
A4

MATERIAL: Aluminium Al 6061

SCALE:5:1

SHEET 7 OF 9

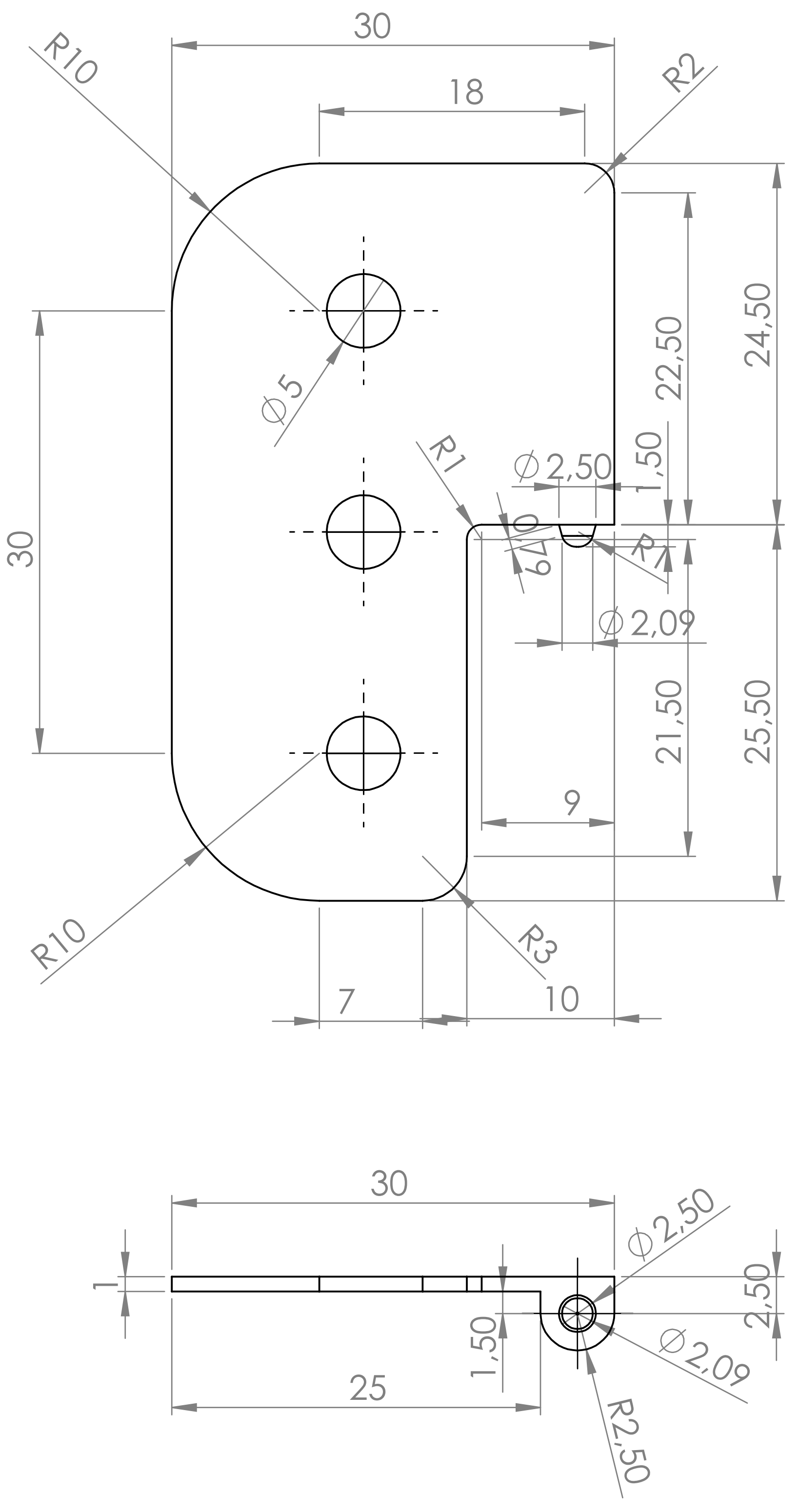
Appendix B



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME SolidWorks Design Library Toolbox ANSI Metric	DATE	TITLE: 6: AM A M2X25-N Pin
APPV'D	NAME Kari Wilhelmsen Johansen	DATE 6.6.2017	
		WEIGHT: 0.24 g	DWG NO. FRAME — A4
		MATERIAL: Aluminium Al 6061	SCALE:5:1 — SHEET 8 OF 9

Appendix B



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

	NAME	DATE	TITLE:
CHK'D	Kari Wilhelmsen Johansen	30.3.2017	7: Click lock
APPV'D	Kari Wilhelmsen Johansen	6.6.2017	
	WEIGHT: 3.91 g		DWG NO. FRAME	A4
	MATERIAL: Aluminium Al 6061		SCALE:2:1	SHEET 9 OF 9

Age-hardening wrought Al-alloys

Description

Figure 1: 1. A close-up of building cladding made from wrought aluminum alloy . © John Fernandez 2. Chassis of a personal computer. © Chris Lefteri 3. The 2000 and 7000 series age-hardening aluminum alloys are the backbone of the aerospace industry.

The material

The high-strength aluminum alloys rely on age-hardening: a sequence of heat treatment steps that causes the precipitation of a nano-scale dispersion of intermetallics that impede dislocation motion and impart strength. This can be as high as 700 MPa giving them a strength-to-weight ratio exceeding even that of the strongest steels. This record describes for the series of wrought Al alloys that rely on age-hardening requiring a solution heat treatment followed by quenching and ageing. This is recorded by adding TX to the series number, where X is a number between 0 and 8 that records the state of heat treatment. They are listed below using the IADS designations (see Technical notes for details).2000 series: Al with 2 to 6% Cu -- the oldest and most widely used aerospace series.6000 series: Al with up to 1.2% Mg and 1.3% Si -- medium strength extrusions and forgings.7000 series: Al with up to 8% Zn and 3% Mg -- the Hercules of aluminum alloys, used for high strength aircraft structures, forgings and sheet. Certain special alloys also contain silver. So this record, like that for the non-age hardening alloys, is broad, encompassing all of these.

Compositional summary

2000 series: Al + 2 to 6% Cu + Fe, Mn, Zn and sometimes Zr

6000 series: Al + up to 1.2%Mg + 0.25% Zn + Si, Fe and Mn

7000 series: Al + 4 to 9 % Zn + 1 to 3% Mg + Si, Fe, Cu and occasionally Zr and Ag

General properties

Density		2,5e3	-	2,9e3	kg/m^3
Price	*	19,6	-	22,4	NOK/kg
Date first used		1916			

Mechanical properties

Young's modulus	68	-	80	GPa
Shear modulus	25	-	28	GPa
Bulk modulus	64	-	70	GPa

Poisson's ratio	0,32	-	0,36	
Yield strength (elastic limit)	95	-	610	MPa
Tensile strength	180	-	620	MPa
Compressive strength	95	-	610	MPa
Elongation	1	-	20	% strain
Hardness - Vickers	60	-	160	HV
Fatigue strength at 10^7 cycles	57	-	210	MPa
Fracture toughness	21	-	35	MPa.m^0.5
Mechanical loss coefficient (tan delta)	1e-4	-	0,001	

Thermal properties

Melting point	495	-	640	°C
Maximum service temperature	120	-	200	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	118	-	174	W/m.°C
Specific heat capacity	890	-	1,02e3	J/kg.°C
Thermal expansion coefficient	22	-	24	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	3,8	-	6	µohm.cm

Optical properties

Transparency	Opaque

Processability

Castability	4	-	5
Formability	3	-	4
Machinability	4	-	5
Weldability	3	-	4
Solder/brazability	2	-	3

Eco properties

Embodied energy, primary production	*	198	-	219	MJ/kg
CO2 footprint, primary production	*	12,2	-	13,4	kg/kg
Recycle		False			

Supporting information

Design guidelines

The age-hardening alloys have exceptional strength at low weight, but the origin of the strength -- age hardening -- imposes certain design constraints. At its simplest, age-hardening involves a three step heat treatment.

Step 1: the wrought alloy, as sheet, extrusion or forging, is solution heat treated -- held for about 2 hours at around 550 C (it depends on the alloys) to make the alloying elements (Cu, Zn, Mg, Si etc) dissolve.

Step 2: the material is quenched from the solution-treatment temperature, typically by dunking or spraying it with cold water. This traps the alloying elements in solution. Quenching is a savage treatment that can cause distortion and create internal stresses that may require correction, usually by rolling.

Step 3: the material is aged, meaning that it is heated to between 120 and 190 C for about 8 hours during which the alloying elements condense into nano-scale dispersions of intermetallics (CuAl, CuAl2, Mg2Si and the like). It is this dispersion that gives the strength.

The result is a material that, for its weight, has remarkably high strength and corrosion resistance. But if it is heated above the solution treatment temperature -- by welding, for example -- the strength is lost. This means that assembly requires fasteners such as rivets, usual in airframe construction, or adhesives. Some 6000 series alloys can be welded, but they are of medium rather than high strength.

Technical notes

Until 1970, designations of wrought aluminum alloys were a mess; in many countries, they were simply numbered in the order of their development. The International Alloy Designation System (IADS), now widely accepted, gives each wrought alloy a 4-digit number. The first digit indicates the major alloying element or elements. Thus the series 1xxx describe unalloyed aluminum; the 2xxx series contain copper as the major alloying element, and so forth. The third and fourth digits are significant in the 1xxx series but not in the others; in 1xxx series they describe the minimum purity of the aluminum; thus 1145 has a minimum purity of 99.45%; 1200 has a minimum purity of 99.00%. In all other series, the third and fourth digits are simply serial numbers; thus 5082 and 5083 are two distinct aluminum-magnesium alloys. The second digit has a curious function: it indicates a close relationship: thus 5352 is closely related to 5052 and 5252; and 7075 and 7475 differ only slightly in composition. To these serial numbers are added a suffix indicating the state of hardening or heat treatment. The suffix F means 'as fabricated'. Suffix O means 'annealed wrought products'. The suffix H means that the material is 'cold worked'. The suffix T means that it has been 'heat treated'. More information on designations and equivalent grades can be found on the Granta Design website at www.grantadesign.com/designations

Phase diagram

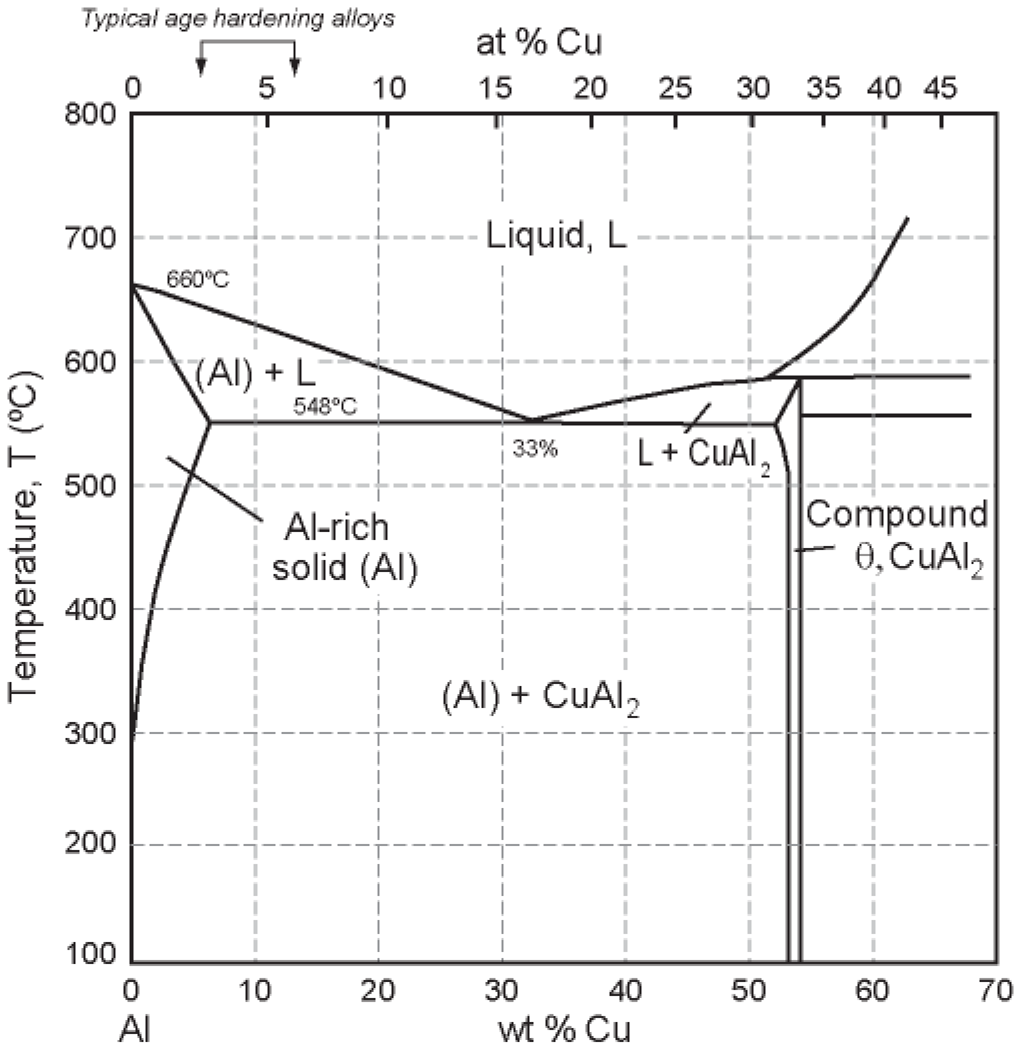


Figure 2: The 2000 series of wrought aluminum alloys are based on aluminum (Al) with 2.5 - 6% copper (Cu). This is the relevant part of the phase diagram.

Typical uses

2000 and 7000 series: aerospace structures, pressure vessels, ultralight land-based transport systems; sports equipment such as golf clubs and bicycles.

6000 series: cladding and roofing; medium strength extrusions, forgings and welded structures for general engineering and automotive such as connecting rods.

Values marked * are estimates.

No warranty is given for the accuracy of this data

Reference

CES EduPack 2016, datasheet Age-hardening wrought Al-alloys

Towbar rod

Force (F)	18518,51852	N
Length (L)	0,9	m
Density (ρ)	2900	kg/m^3
Youngs (E	68000000000	Mpa

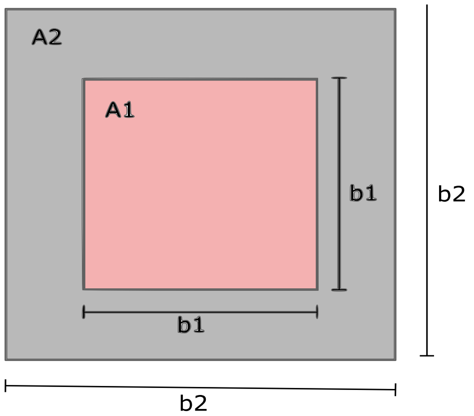
$$m = (12F)^{\frac{1}{2}}\left(\frac{L^2}{\pi}\right)\left(\frac{\rho}{E^{\frac{1}{2}}}\right)$$

Mass	1,351675465	kg

$$b^2 = \left(\frac{12FL^2}{\pi^2 E}\right)^{\frac{1}{2}}$$

width	0,02275705	m
	22,7570499	mm
Area	0,000517883	m^2

Force = ma		
Acceleration	18,51852	m/s^2
Mass (Sled + Cargo)	1000	kg
Acceleration		
Speed	100	km/h
	27,77778	m/s
Time	1,5	s



First iteration after material selection; Setting b1, finding b2

b1	0,015	m
A1	0,000225	m^2
b2	0,027255886	m
A2	0,000742883	m^2

After FEA analysis; setting b2, finding b1, different sidelengths in y and x directions

b2x	0,04	m		
b2y	0,035	m		
a2	0,0014	m^2	relationsship y and x	0,875
a1	0,000882117	m^2		
b1	0,029700449	m		
b1x	0,03394337	m		
b1y	0,025987893	m		

Plywood

Description

Figure 1: 1. Close-up of the material. © Chris Lefteri 2. Skateboard made with plywood. © Chris Lefteri 3. Plywood used in the construction area.

The material

Plywood is laminated wood, the layers glued together such that the grain in successive layers are at right angles, giving stiffness and strength in both directions. The number of layers varies, but is always odd (3, 5, 7…) to give symmetry about the core ply - if it is asymmetric it warps when wet or hot. Those with few plies (3,5) are significantly stronger and stiffer in the direction of the outermost layers; with increasing number of plies the properties become more uniform. High quality plywood is bonded with synthetic resin. The data listed below describe the in-plane properties of a typical 5-ply.

Compositional summary

Cellulose/Hemicellulose/Lignin/12%H2O/Adhesive

General properties

Density		700	-	800	kg/m^3
Price	*	4,87	-	5,4	NOK/kg
Date first used		1907			

Mechanical properties

Young's modulus		6,9	-	13	GPa
Shear modulus	*	0,5	-	2	GPa
Bulk modulus	*	1,6	-	2,5	GPa
Poisson's ratio		0,22	-	0,3	
Yield strength (elastic limit)	*	9	-	30	MPa
Tensile strength		10	-	44	MPa
Compressive strength		8	-	25	MPa
Elongation		2,4	-	3	% strain
Hardness - Vickers		3	-	9	HV
Fatigue strength at 10^7 cycles	*	7	-	16	MPa
Fracture toughness	*	1	-	1,8	MPa.m^0.5
Mechanical loss coefficient (tan delta)	*	0,008	-	0,11	

Thermal properties

Glass temperature		120	-	140	°C
Maximum service temperature	*	100	-	130	°C
Minimum service temperature	*	-100	-	-70	°C
Thermal conductor or insulator?		Good insulator			
Thermal conductivity		0,3	-	0,5	W/m.°C
Specific heat capacity		1,66e3	-	1,71e3	J/kg.°C
Thermal expansion coefficient		6	-	8	µstrain/°C

Electrical properties

Electrical conductor or insulator?		Poor insulator			
Electrical resistivity		6e13	-	2e14	µohm.cm
Dielectric constant (relative permittivity)		6	-	8	
Dissipation factor (dielectric loss tangent)	*	0,05	-	0,09	
Dielectric strength (dielectric breakdown)	*	0,4	-	0,6	1000000 V/m

Optical properties

Transparency		Opaque			

Processability

Moldability		3	-	4	
Machinability		5			

Eco properties

Embodied energy, primary production	*	13,8	-	15,2	MJ/kg
CO_2 footprint, primary production	*	0,786	-	0,869	kg/kg
Recycle		Recycle			

Supporting information

Design guidelines

Plywoods offers high strength at low weight. Those for general construction are made from softwood plys, but the way in which plywood is made allows for great flexibility. For aesthetic purposes, hardwoods can be used for the outermost plys, giving "paneling plywoods" faced with walnut, mahogany or other expensive woods on a core of softwood. Those for ultra-light design have hardwood outer plys on a core of balsa. Metal-faced plywoods can be riveted. Curved moldings for furniture such as chairs are made by laying-up the unbonded plys in a shaped mold and curing the adhesive under pressure using an airbag or matching mold. Singly curved shapes are straightforward; double curvatures should be minimized or avoided.

Technical notes

Low cost plywoods are bonded with starch or animal glues and are not water resistant -- they are used for boxes and internal construction. Waterproof and marine plywoods are bonded with synthetic resin -- they are used for external paneling and general construction.

Typical uses

Furniture, building and construction, marine and boat building, packaging, transport and vehicles, musical instruments, aircraft, modeling.

Values marked * are estimates.
No warranty is given for the accuracy of this data

Reference

CES EduPack 2016 Datasheet Plywood

Investment casting

Description

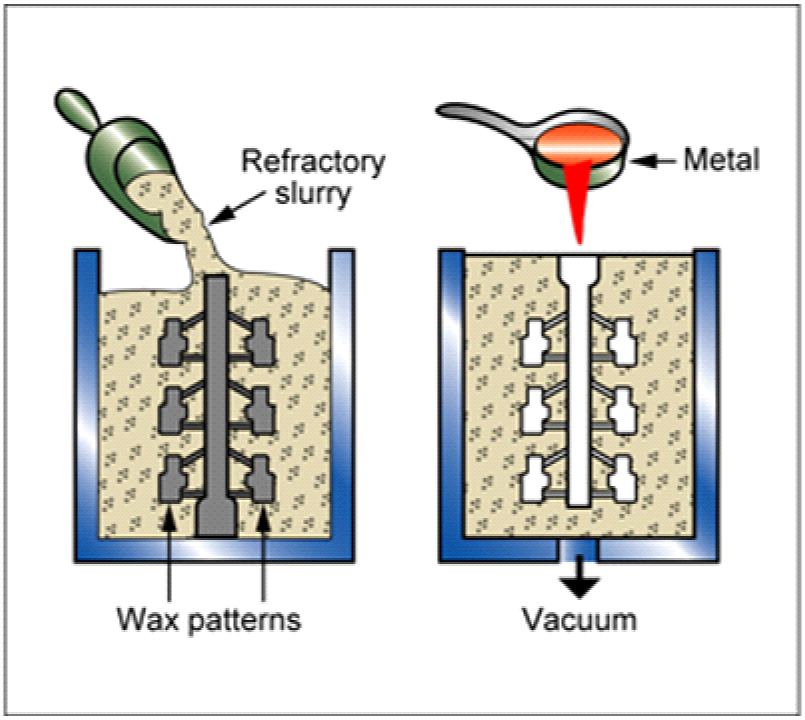


Figure 1: Process schematic

The process

If you have gold fillings (or more elaborate metal work) in your mouth, be thankful for this process - it was used to make them. The lost wax process - the old name for INVESTMENT CASTING - has been practiced for at least three thousand years; sophisticated jewelry, ornaments and icon were being made in Egypt and Greece well before 1500BC. In investment casting, wax patterns are made and assembled (if small) into a tree with feeding and gating systems. The assembled pattern is dipped into refractory slurry, then covered in refractory stucco and allowed to dry. The procedure is repeated a number of times until about 8 layers have built up, creating a ceramic investment shell. The wax is then melted out and the ceramic shell fired before the molten metal is cast. Gravity die casting is adequate for simple shapes, but air pressure, vacuum or centrifugal pressure is needed to give complete filling of the mold when complex, thin sections are involved. The mold is broken up to remove the castings. The process is suitable for most metals of melting temperatures below 2200 C. Because the wax pattern is melted out, the shape can be very complex, with contours, undercuts, bosses, and recesses. For making hollow shapes, this process is very sophisticated: all large bronze statues are hollow, and they are made by an elaboration of this process.

Tradenames

Lost wax casting

Material compatibility

Metals - ferrous	False
Metals - non-ferrous	False

Shape

Circular prismatic	False			
Non-circular prismatic	False			
Solid 3-D	False			
Hollow 3-D	False			

Economic compatibility

Relative tooling cost	low			
Relative equipment cost	medium			
Labor intensity	high			
Economic batch size (units)	1	-	1e4	

Physical and quality attributes

Mass range	0,01	-	20	kg
Range of section thickness	1	-	75	mm
Tolerance	0,05	-	0,25	mm
Roughness	0,5	-	3,2	µm
Surface roughness (A=v. smooth)	A			

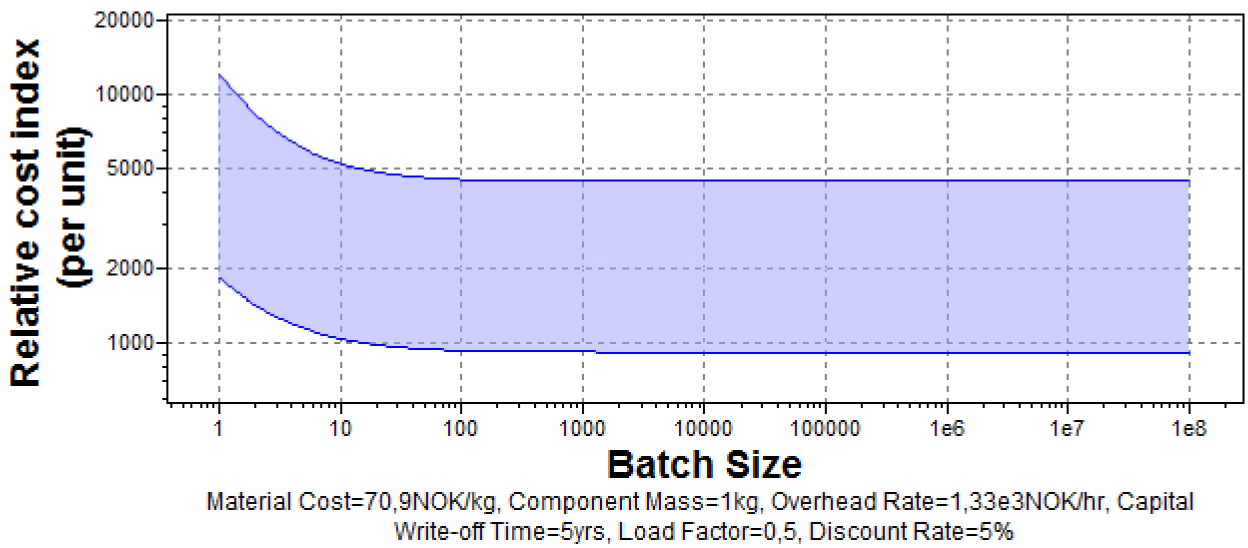
Process characteristics

Primary shaping processes	False			
Discrete	False			
Prototyping	False			

Cost model and defaults

Relative cost index (per unit)	* 922	-	4,48e3	

Parameters: Material Cost = 70,9NOK/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 1,33e3NOK/hr, Discount Rate = 5%, Capital Write-off Time = 5yrs, Load Factor = 0,5



Capital cost	* 2,91e3	-	1,45e4	NOK
Material utilization fraction	* 0,8	-	0,85	
Production rate (units)	* 1	-	200	/hr

Tooling cost	* 726	-	7,26e3	NOK
Tool life (units)	* 1	-	5	

Supporting information

Design guidelines
The process is extremely versatile, allowing great freedom of form. It offers excellent reproduction of detail in small 3D components.

Technical notes
Investment casting is one of the few processes that can be used to cast metals with high melting temperatures to give complex shapes; it can also be used for low melting metals. The traditional uses of investment casting where for the shaping of silver, copper, gold, bronze, pewter and lead. Today the most significant engineering applications are those for nickel, cobalt and iron-based alloys.

Typical uses
Jewelry, dental implants, statuary, metal sculpture and decorative objects, blades for high temperature gas turbines and similar equipment.

The economics
Investment casting lends itself both to small and large batch sizes. For small batch sizes the process is manual, with low capital and tooling costs, but significant labor costs. When automated, the capital costs are high, but quality control and speed are greater. The production rate is increased by the use of multiple molds.

The environment
There are the usual hazards associated with casting molten metal, but procedures for dealing with these are routine. The mold materials cannot, at present, be recycled.

Values marked * are estimates.
No warranty is given for the accuracy of this data

Reference
CES EduPack Datasheet Investment Casting

UiT- University of Tromsø
www.uit.no

Appendix G: Simulation of TOWBAR

Date: 29. may 2017
Designer: Kari Wilhelmsen Johansen
Study name: Towbar Static
Analysis type: Static

Table of Contents

Description ... 1
Design improvements ... 2
Model Information ... 3
Study Properties ... 6
Units ... 6
Material Properties ... 7
Loads and Fixtures ... 8
Contact Information ... 9
Mesh information ... 9
Resultant Forces ... 11
Study Results ... 11
Conclusion ... 14
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Description

Static analysis of the towbar with applied forces from the sled itself and the snowmobile accelerating and turning simultaneously. The analysis is performed in the simulation tool in SolidWorks Educational edition for the academic year 2015- 2016.

Changes done in the design after the first analysis: Profile of the attachmentring increased by 5 mm and the design is fitted to welding. The material of the ring changed to titanium alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si (SS), and the profile of the rods are increased from 35x35 mm to 35x40 mm solid profiles.

These changes resulted in large improvement of von Mises stress, displacement and strain.

Design improvements

After the first analysis, it became clear that the profiles of the towbar and the design of the ring needed some alterations. The following changes were done in the design:

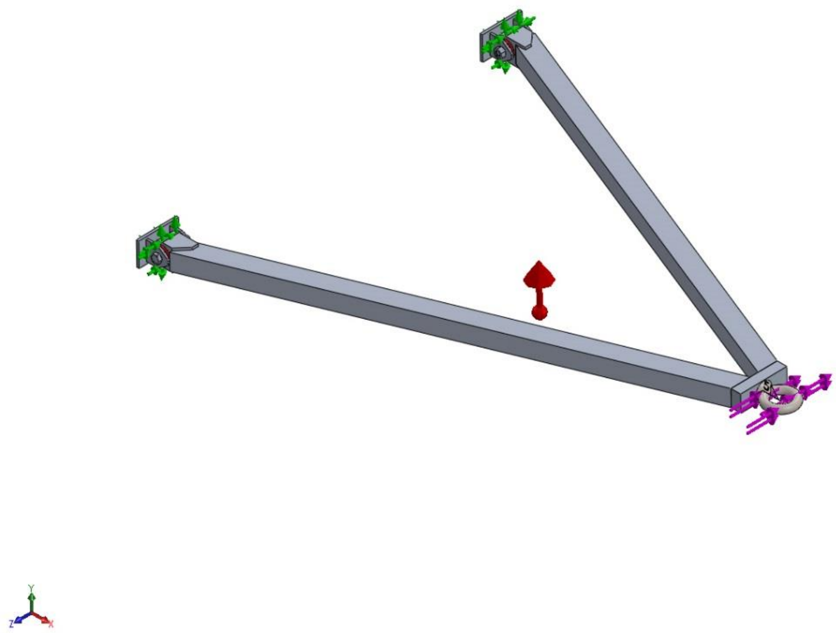
- The profile of the attachmentring were increased by 5 mm, the design were changed from a simple ring with a rod to a weldable fit to the towbar. The material of the ring were changed from 6061 Aluminium alloy to 201 Annealed stainless steal, which gave a increase in Young's modulus of 33,33%.
- The rod that attaches the ring to the rest of the structure were at first shortened so that the length fits the rest of the structure, but ultimately had to be deleted from the design in order to attempt to reduce the Von Mises stress.
- Profile of the towbar rods were increased from 35x35 mm to 35x40 mm with inner side lengths 25x33 mm.

Regarding the applied forces, the calculated forces acting on the system in both directions were somewhat altered as well:

- In the first analysis, a small force of 500 N were applied on the hingejoints. Further studies of the situation showed this was unnecessary. The force were too small to have a large impact on the results and the result is therefor included.
- The force acting on the attachment ring, acting as the snowmobile accelerating and turning simultaneously, where decreased by 5500 N due to calculation errors.

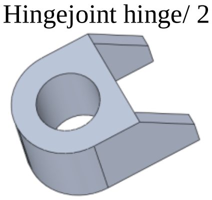
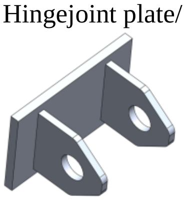
Additionally, the meshing of the towbar have been refined.

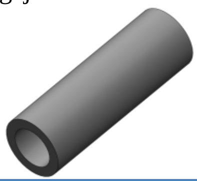
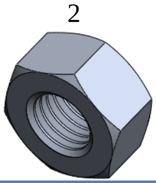
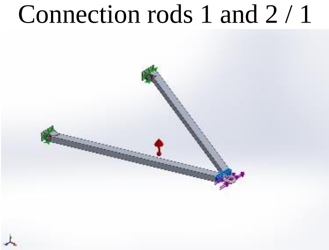
Model Information

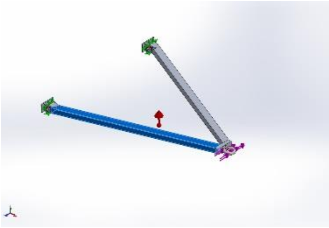
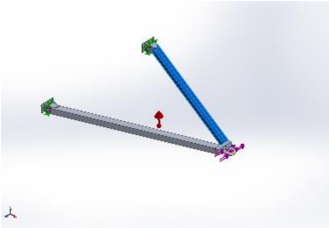


Model name: TOWBAR
Current Configuration: Default

Solid Bodies

Document Name/ number of components in model	Treated As	Volumetric Properties	Date Modified
Hingejoint hinge/ 2 	Solid Body	**Mass:0.125547 kg** **Volume:4.64987e-005 m^3** **Density:2700 kg/m^3** **Weight:1.23036 N**	May 16 15:36:49 2017
Hingejoint plate/ 2 	Solid Body	**Mass:0.0845562 kg** **Volume:3.13171e-005 m^3** **Density:2700 kg/m^3** **Weight:0.828651 N**	May 16 15:39:03 2017

Hingejoint Rubber tube/ 2 	Solid Body	**Mass:0.00424115 kg Volume:4.41786e-006 m^3 Density:960 kg/m^3 Weight:0.0415633 N**	May 16 15:40:02 2017
Hingejoint side/ 4 	Solid Body	**Mass:0.0100374 kg Volume:7.06858e-006 m^3 Density:1420 kg/m^3 Weight:0.0983664 N**	May 16 15:43:53 2017
Attachment ring / 1 	Solid Body	**Mass:0.17751 kg Volume:3.81742e-005 m^3 Density:4650 kg/m^3 Weight:1.7396 N**	May 29 11:07:07 2017
Hingejoint Hex Screw / 2 	Solid Body	**Mass:0.0155823 kg Volume:5.77122e-006 m^3 Density:2700 kg/m^3 Weight:0.152707 N**	May 29 11:40:48 2017
Hingejoint Hex Nut Style 11 / 2 	Solid Body	**Mass:0.00353385 kg Volume:1.30883e-006 m^3 Density:2700 kg/m^3 Weight:0.0346317 N**	May 29 11:41:18 2017
Connection rods 1 and 2 / 1 	Solid Body	**Mass:0.155311 kg Volume:5.75225e-005 m^3 Density:2700 kg/m^3 Weight:1.52205 N**	May 28 17:20:14 2017

Rod 1 / 2 	Solid Body	**Mass:0.836496 kg** **Volume:0.000309813 m^3** **Density:2700 kg/m^3** **Weight:8.19766 N**	May 29 10:19:53 2017
Rod 2 / 1 	Solid Body	**Mass:0.836496 kg** **Volume:0.000309813 m^3** **Density:2700 kg/m^3** **Weight:8.19766 N**	May 29 10:19:53 2017

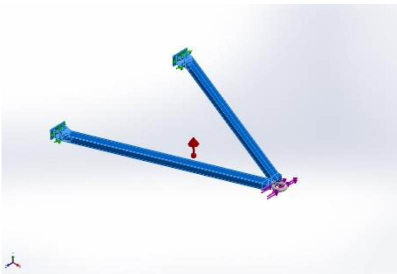
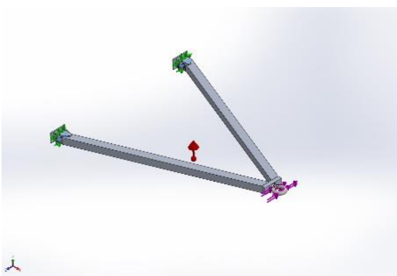
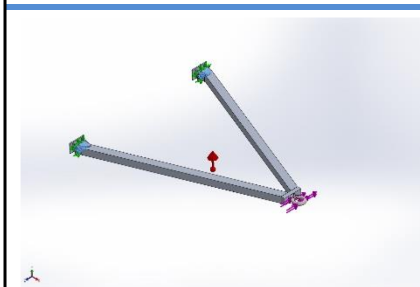
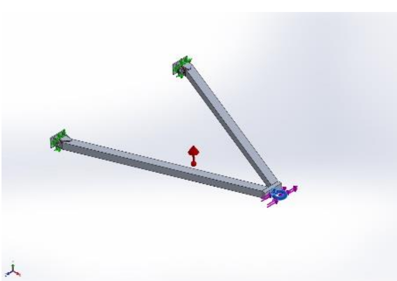
Study Properties

Study name	Towbar Static
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off

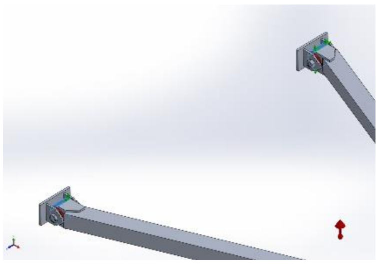
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

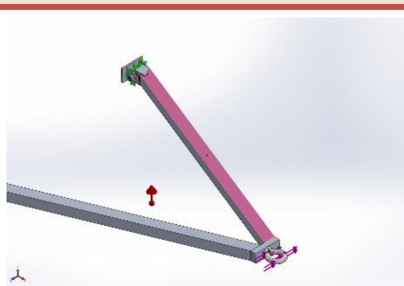
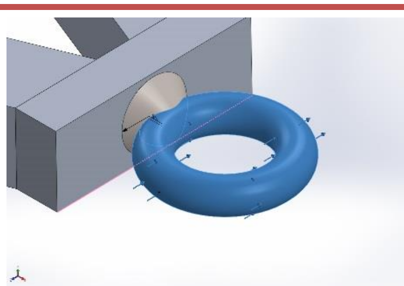
Model Reference	Properties	Components
	**Name:** 6061 Alloy **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 5.51485e+007 N/m^2 **Tensile strength:** 1.24084e+008 N/m^2 **Elastic modulus:** 6.9e+010 N/m^2 **Poisson's ratio:** 0.33 **Mass density:** 2700 kg/m^3 **Shear modulus:** 2.6e+010 N/m^2 **Thermal expansion coefficient:** 2.4e-005 /Kelvin	HINGEJOINT-1 hengsel-1, HINGEJOINT-1 plate-1, HINGEJOINT-2 hengsel-1, HINGEJOINT-2 plate-1, TOWBAR connection rods 1 and 2-1, TOWBAR rod-1, TOWBAR rod-2, formed hex screw_am2-1, formed hex screw_am2-2, hex nut style 11_am-1, hex nut style 11_am-2
	**Name:** Natural Rubber **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Tensile strength:** 2e+007 N/m^2 **Elastic modulus:** 10000 N/m^2 **Poisson's ratio:** 0.45 **Mass density:** 960 kg/m^3	HINGEJOINT-1 rubber tube-1, HINGEJOINT-2 rubber tube-1
	**Name:** PET **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Tensile strength:** 5.73e+007 N/m^2 **Compressive strength:** 9.29e+007 N/m^2 **Elastic modulus:** 2.96e+009 N/m^2 **Poisson's ratio:** 0.37 **Mass density:** 1420 kg/m^3	HINGEJOINT-1 sides-1, HINGEJOINT-1 sides-2, HINGEJOINT-2 sides-1, HINGEJOINT-2 sides-2
	**Name:** Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si (SS) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 1.07e+009 N/m^2 **Tensile strength:** 1.16e+009 N/m^2 **Compressive strength:** 1.17e+009 N/m^2 **Elastic modulus:** 1.23e+011 N/m^2 **Poisson's ratio:** 0.33 **Mass density:** 4650 kg/m^3 **Shear modulus:** 4.6e+010 N/m^2 **Thermal expansion coefficient:** 9e-006 /Kelvin	TOWBAR attachment ring-1

Loads and Fixtures

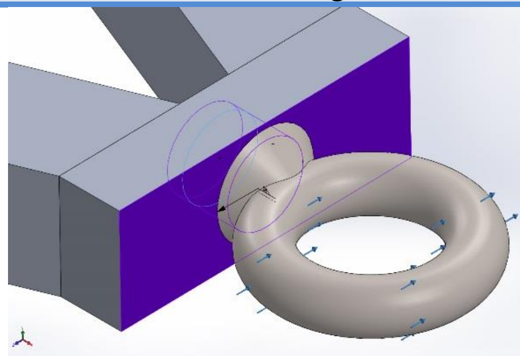
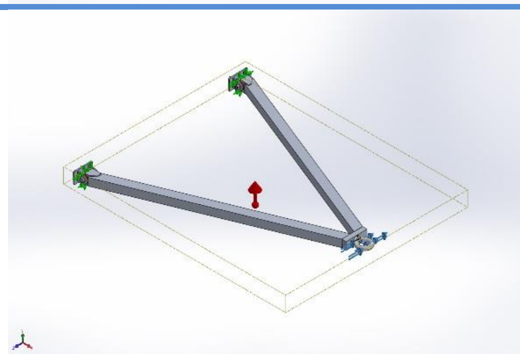
Fixture name	Fixture Image	Fixture Details
Fixed Hinge-1		**Entities:** 4 face(s) **Type:** Fixed Hinge

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.000610352	-420.555	19995.6	20000
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Gravity-1		**Reference:** Face< 1 > **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 1 face(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---, ---, 20000 N

Contact Information

Contact	Contact Image	Contact Properties
Contact Set-53		**Type:** No Penetration contact pair **Entites:** 3 face(s) **Advanced:** Node to surface
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	7.70942 mm
Tolerance	0.385471 mm
Mesh Quality	Draft Quality Mesh
Remesh failed parts with incompatible mesh	On

Mesh information - Details

Total Nodes	13126
Total Elements	40031
Maximum Aspect Ratio	81.555
% of elements with Aspect Ratio < 3	68.4
% of elements with Aspect Ratio > 10	0.102
Time to complete mesh(hh;mm;ss):	00:00:16
Computer name:	NAR-E1570-08

Figure 1: Model of the towbar, drawn in SolidWorks with applied meshing.

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.000610352	-420.555	19995.6	20000

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Study Results

Von Mises stress

Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.40517 N/m^2 Node: 1553	3.7023e+008 N/m^2 Node: 1801

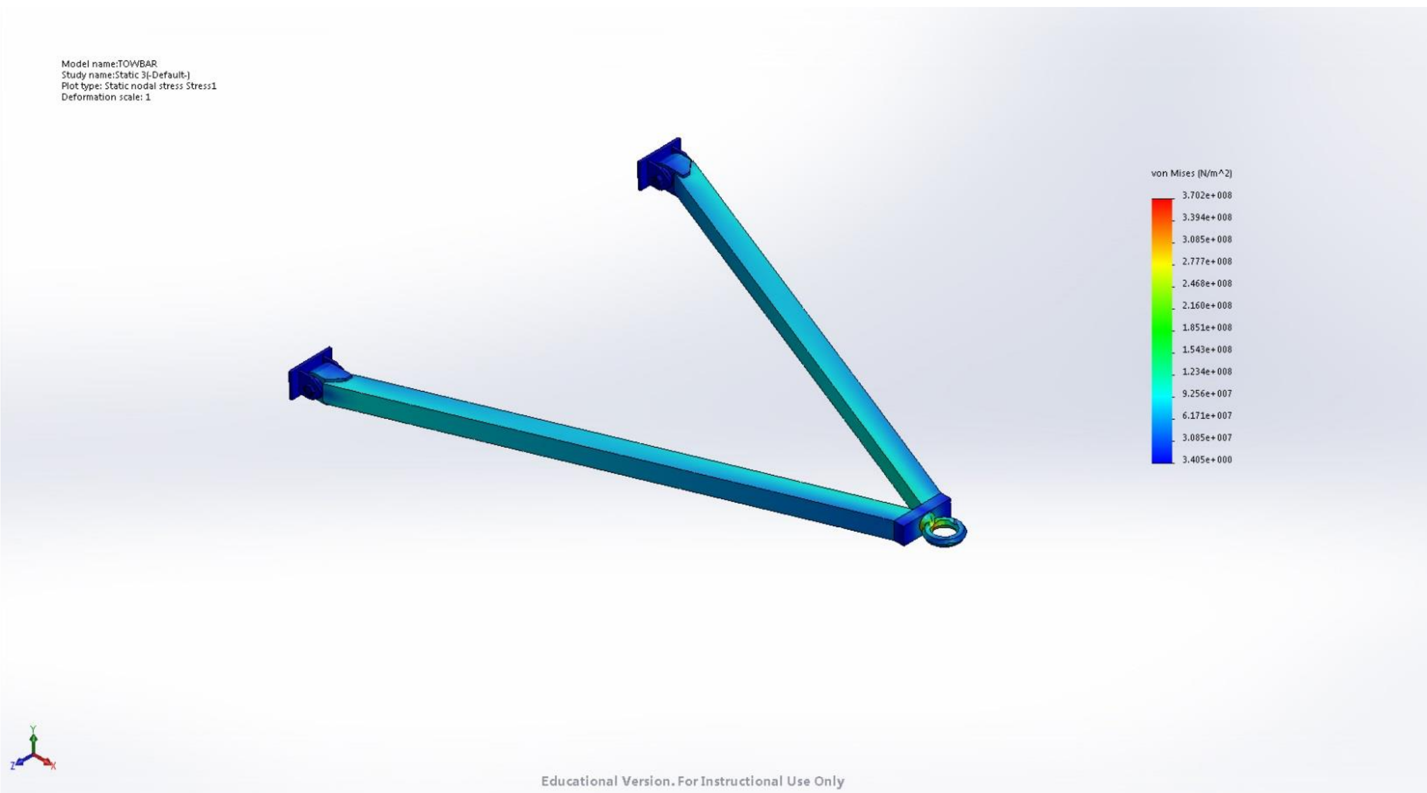


Figure 2: Improved model of the towbar, drawn in SolidWorks with resulting von Mises stresses

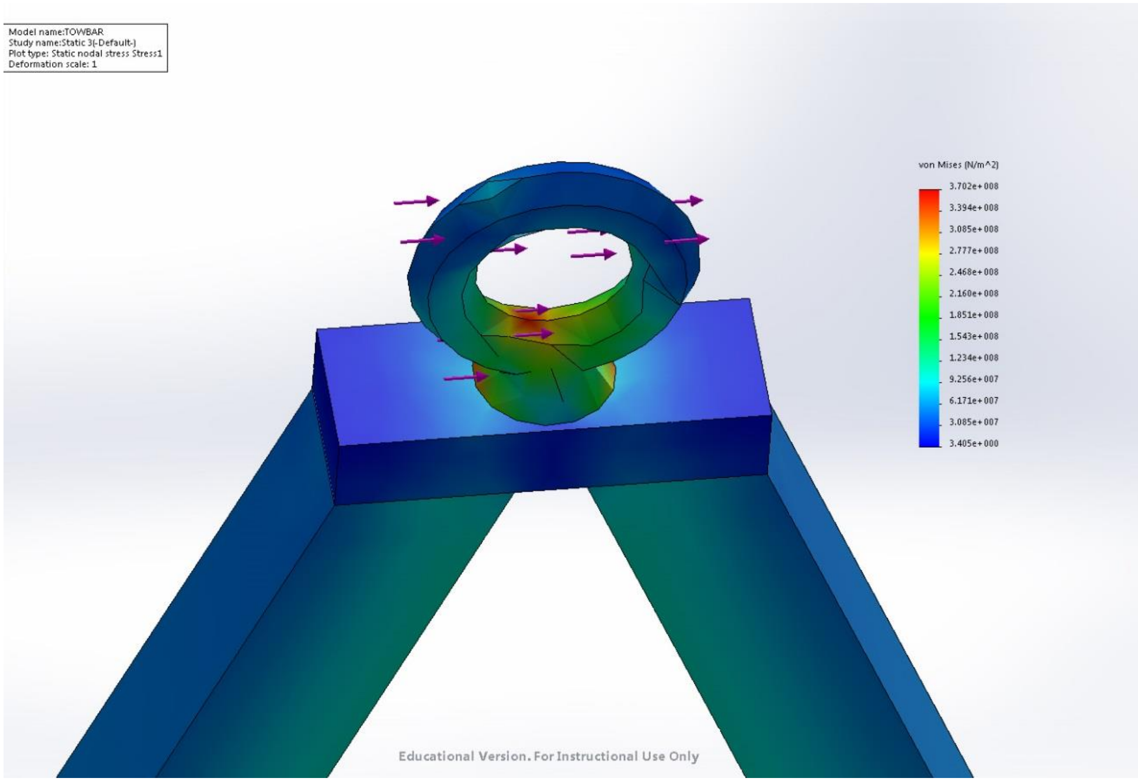


Figure 3: Close-up on towbar with maximum Von Mises stress

Displacement

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000269449 mm Node: 69	3.44939 mm Node: 1874

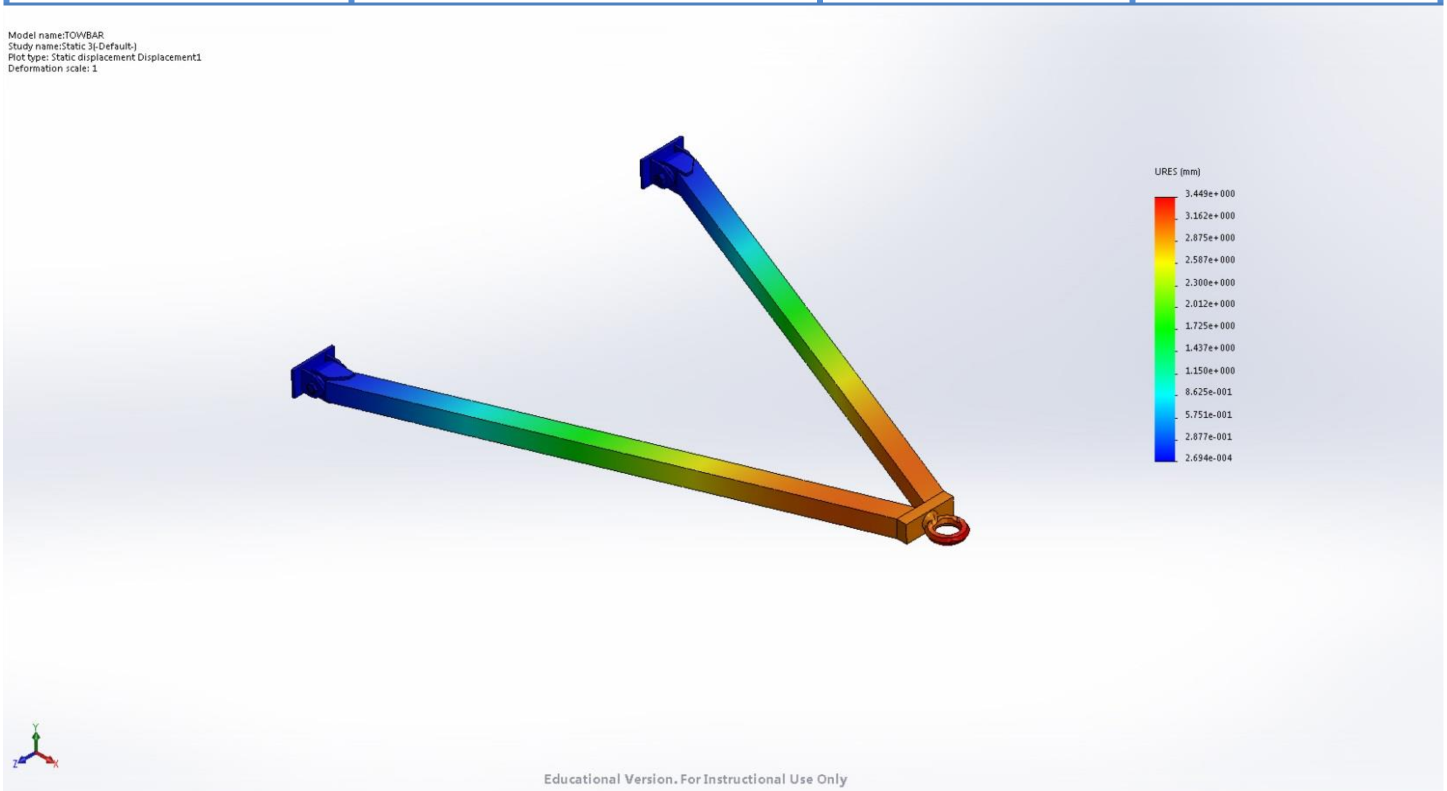


Figure 4: Improved model of the towbar, drawn in SolidWorks with resulting deformation

Strain

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.65926e-010 Element: 33445	0.00503221 Element: 4173

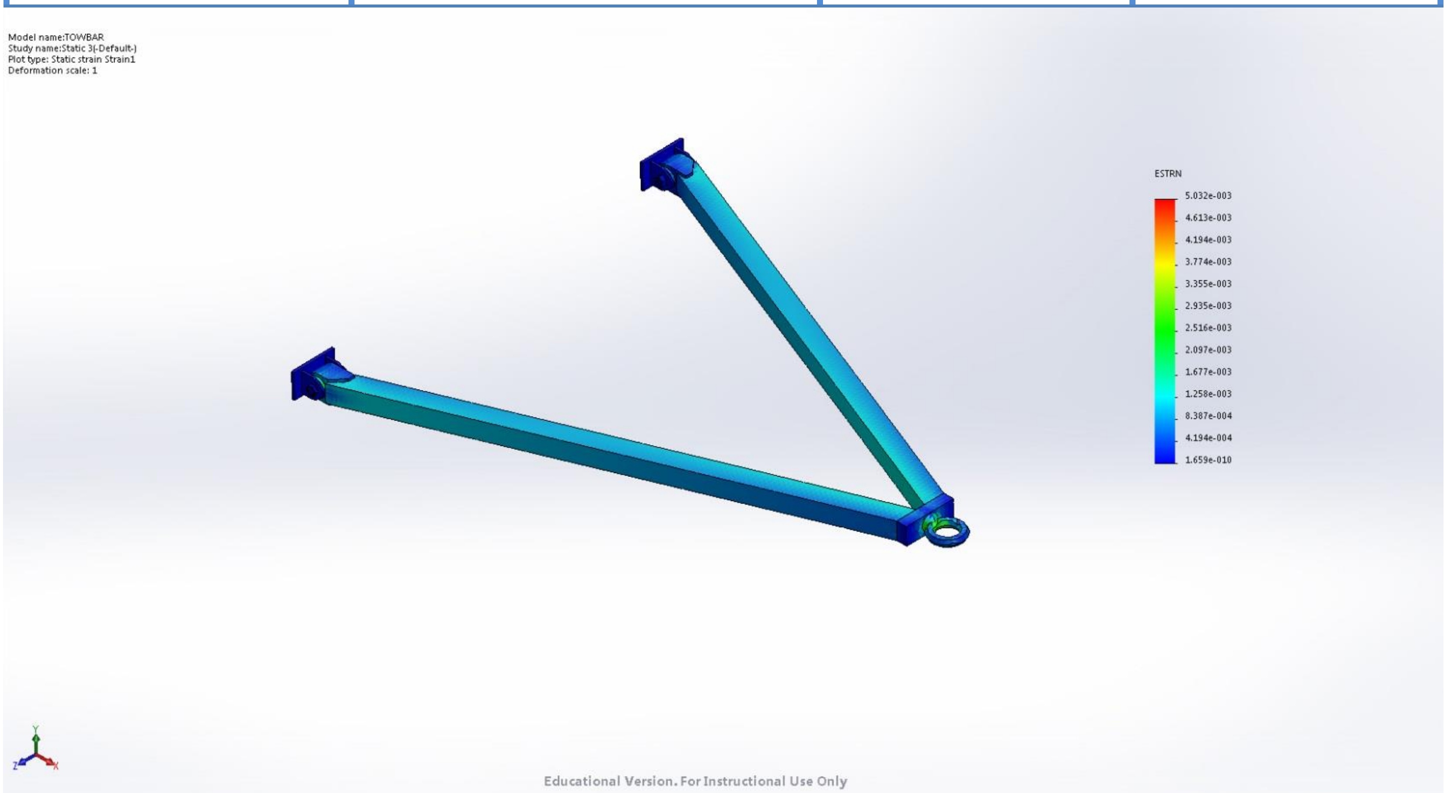


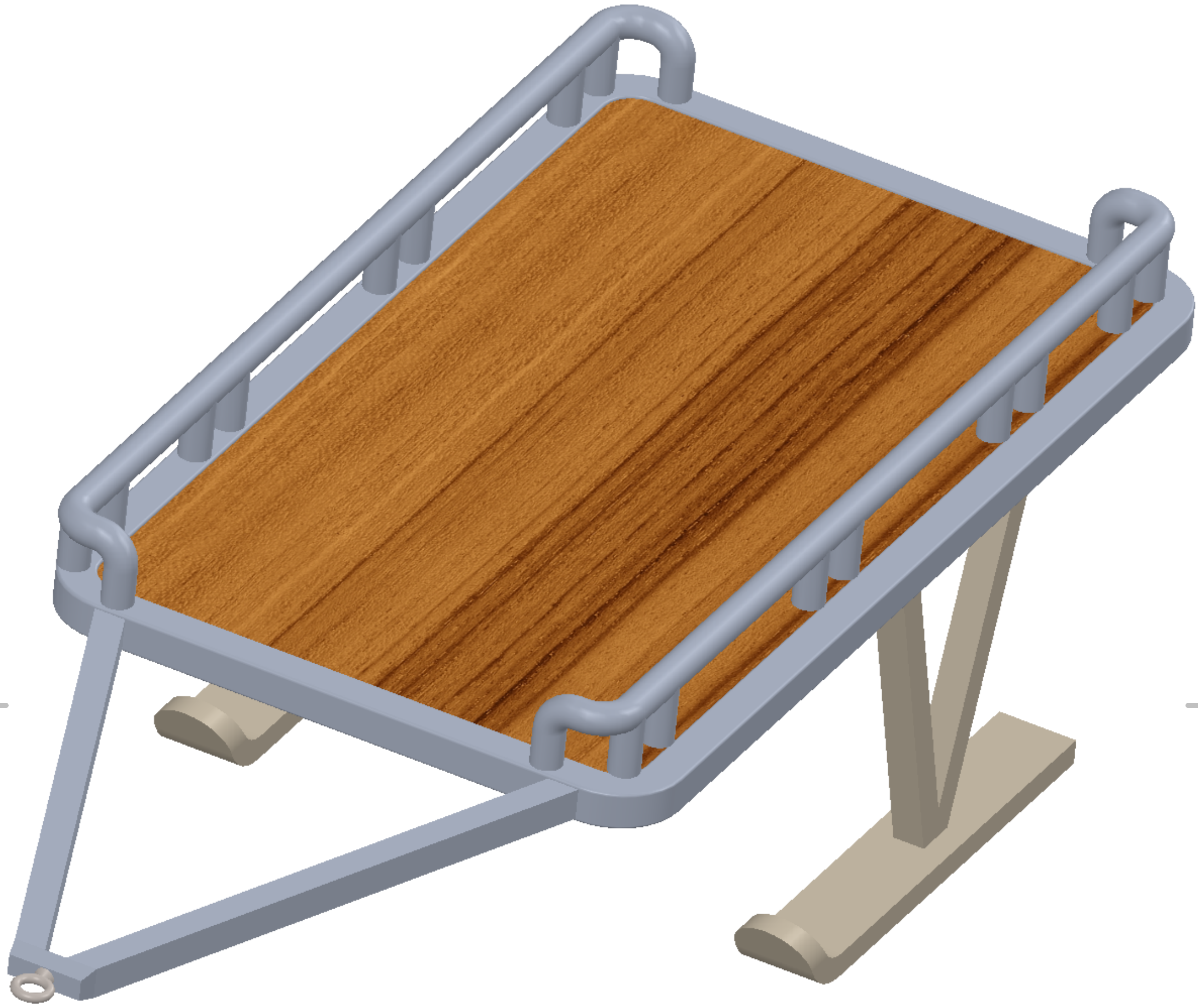
Figure 5: Model of the towbar, drawn in SolidWorks with resulting strain and deformation

Conclusion

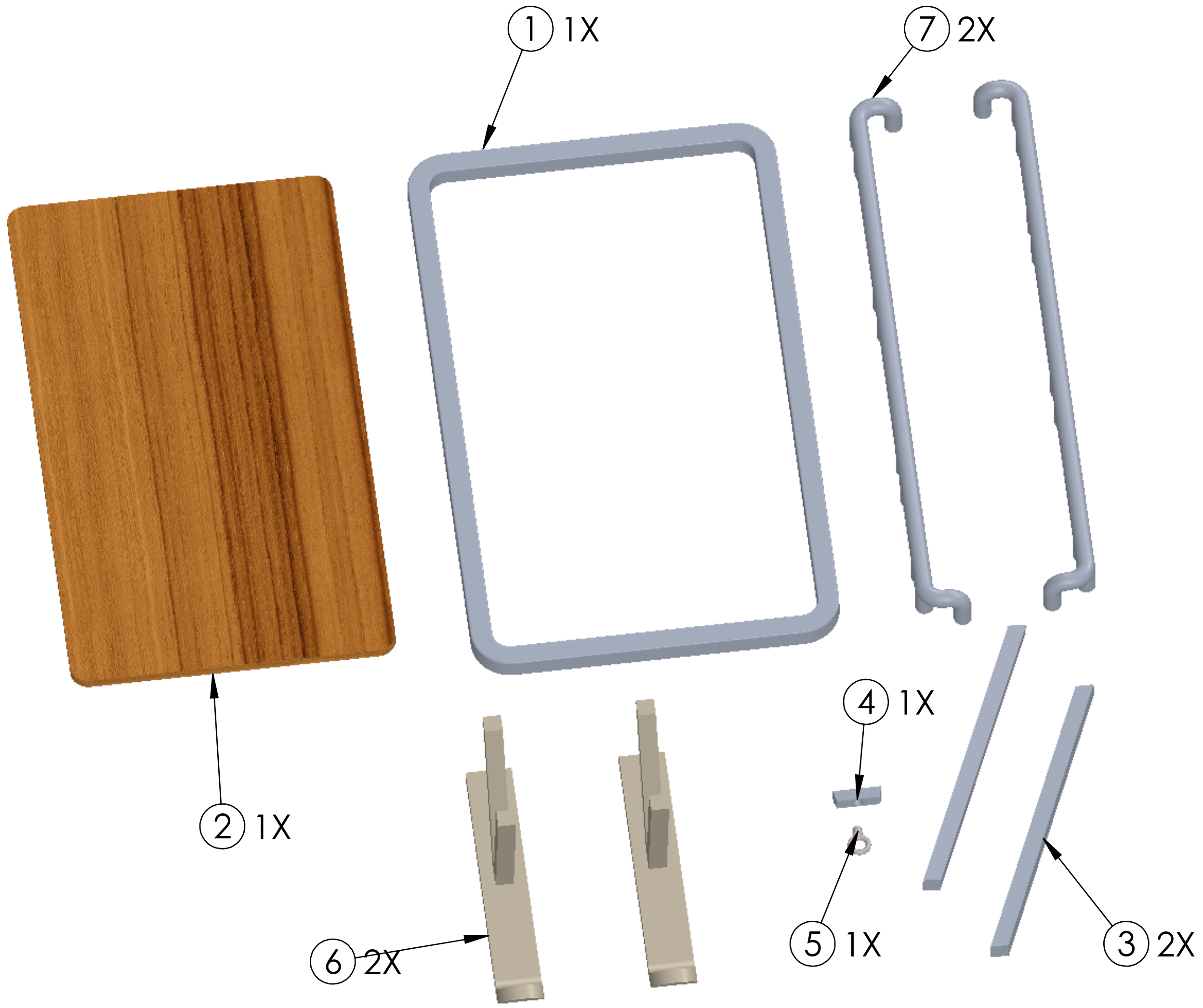
The Von Mises stress, deformation and the strain are all within acceptable limits and the design are satisfying.

Table of figures

Figure 1: Model of the towbar, drawn in SolidWorks with applied meshing. 10
Figure 2: Improved model of the towbar, drawn in SolidWorks with resulting von Mises stresses 11
Figure 3: Close-up on towbar with maximum Von Mises stress 12
Figure 4: Improved model of the towbar, drawn in SolidWorks with resulting deformation 13
Figure 5: Model of the towbar, drawn in SolidWorks with resulting strain and deformation 14



DWG NO.		
3D print SLED		A4
SCALE:1:50	SHEET 1 OF 9	



ITEM NO.	PART NUMBER	QTY.
1	3D print BODY STRUCTURE frame	1
2	3D print Top plate	1
3	3D print TOWBAR rod 2	2
4	3D print TOWBAR connection rods 1 and 2	1
5	TOWBAR attachment ring	1
6	3D print SKI	2
7	3D print Railing handtakssøyle2	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

	NAME	DATE	TITLE:
DRAWN	Kari Wilhelmsen Johansen	30.5.2017	3D print Sled
APPV'D	Kari Wilhelmsen Johansen	30.5.2017	

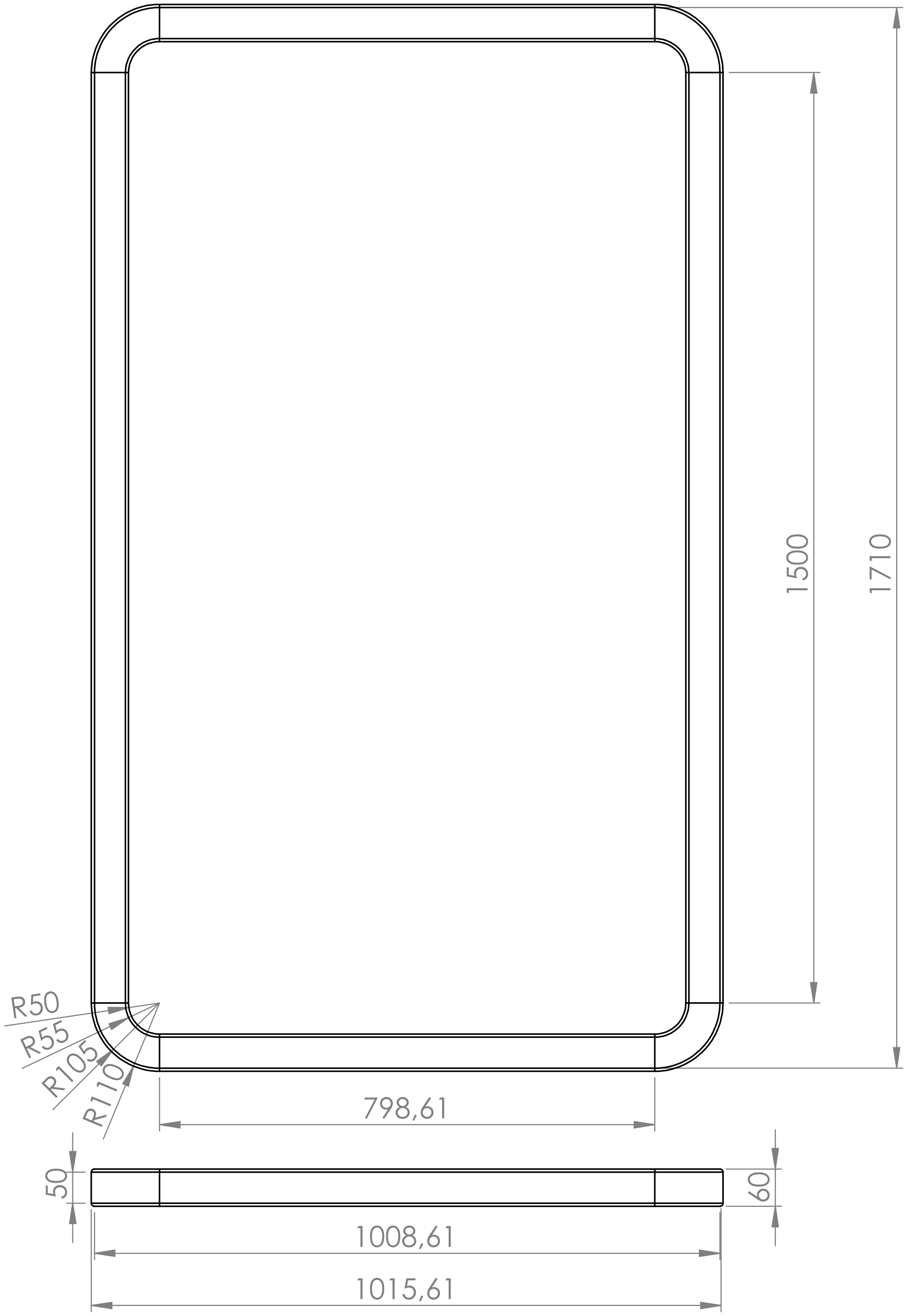
WEIGHT: 85963.93 g

DWG NO. 3D print SLED

A4

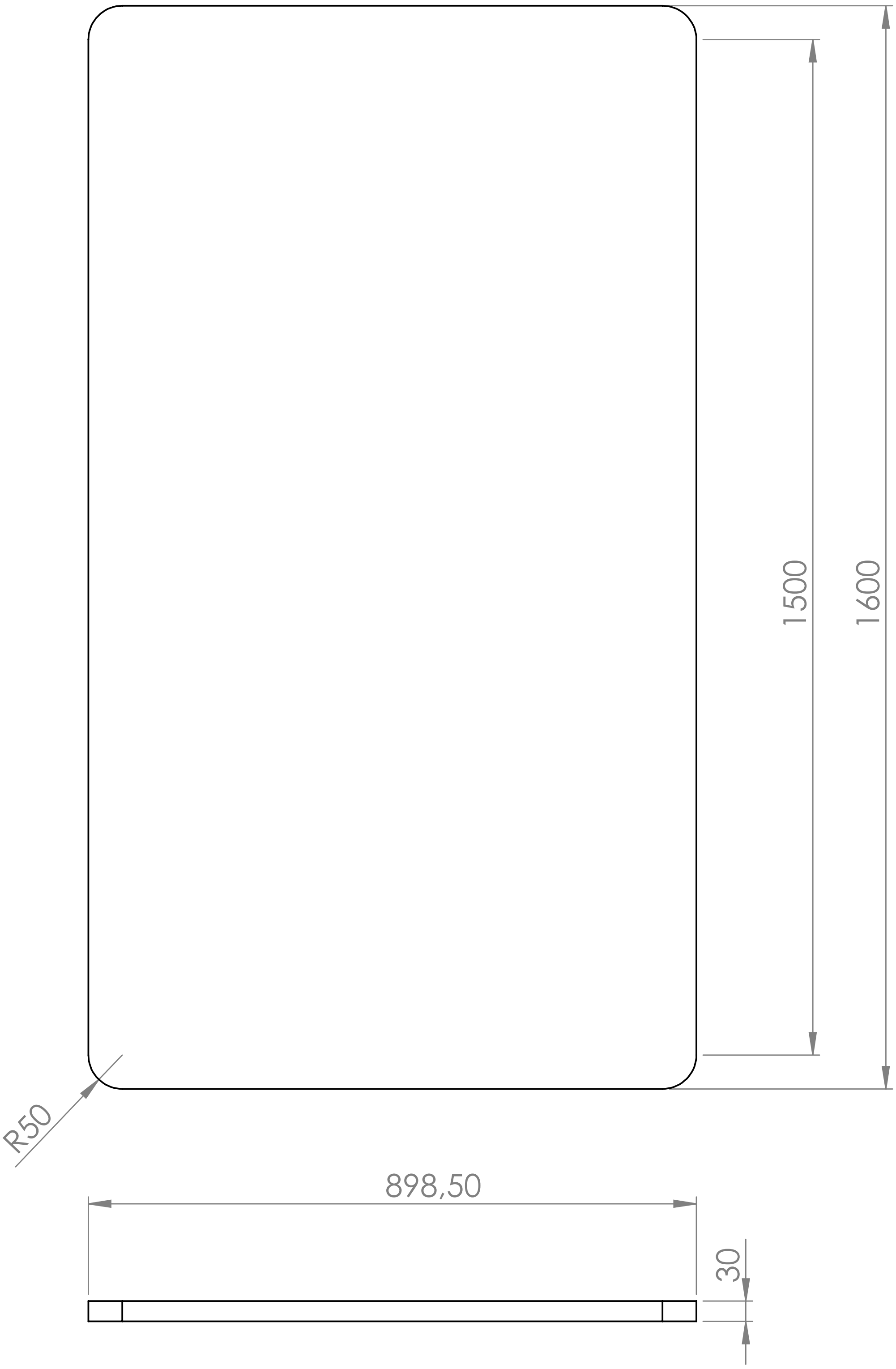
SCALE: 1:20

SHEET 2 OF 9



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

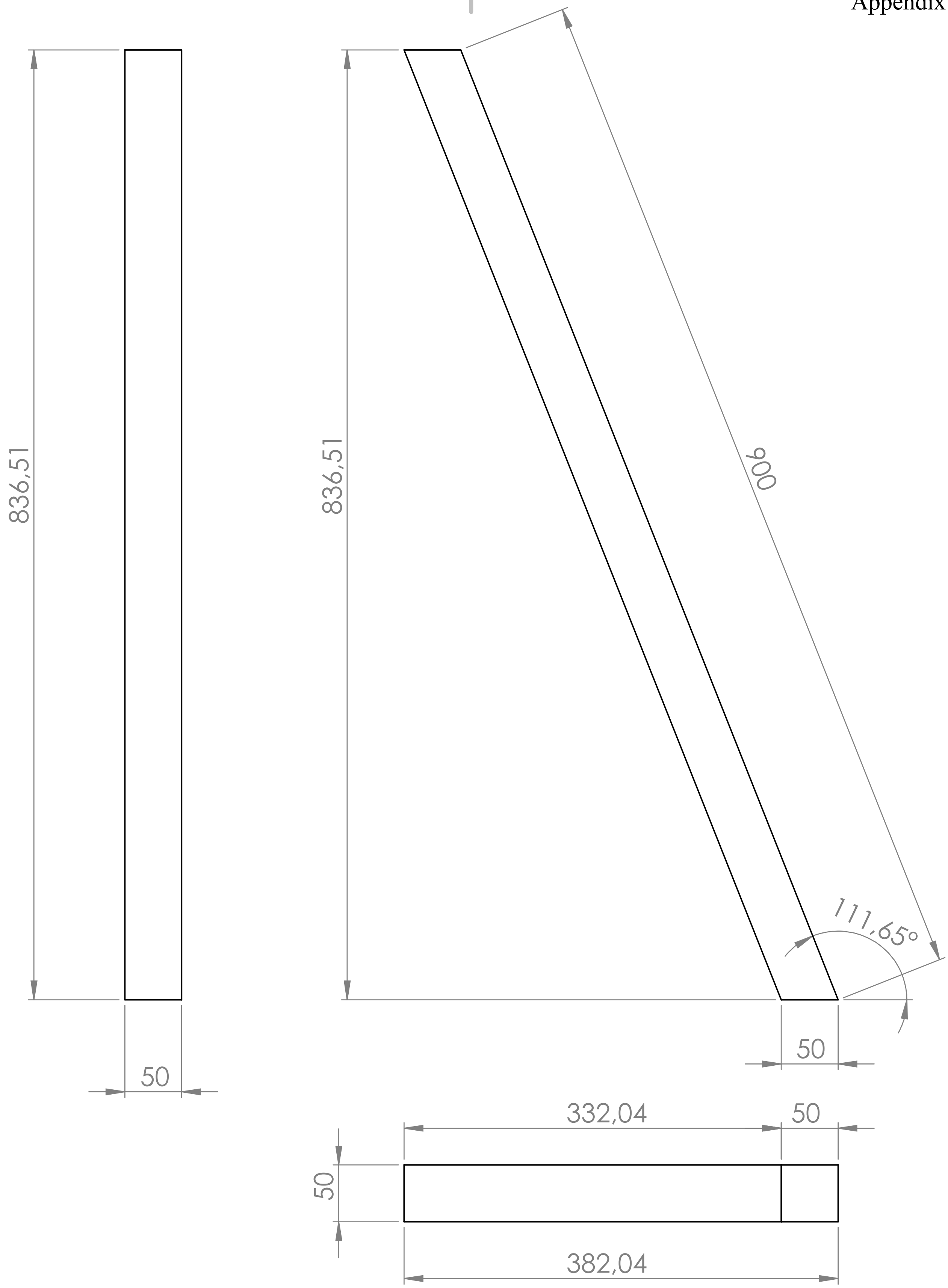
DRAWN	NAME: Kari Wilhelmsen Johansen	DATE: 30.5.2017	TITLE: 1: Bodystructure frame
APPV'D	NAME: Kari Wilhelmsen Johansen	DATE: 30.5.2017	
	SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 9229.28 g	DWG NO. 3D print SLED — A4
		MATERIAL: Aluminuim Al6061	SCALE 1:10 — SHEET 3 OF 9



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME Kari Wilhelmsen Johansen	DATE 30.5.2017	TITLE: 2: Top plate
APPV'D	NAME Kari Wilhelmsen Johansen	DATE 30.5.2017	
	WEIGHT: 27130.08 g		DWG NO. 3D print SLED — A4
	MATERIAL: Plywood		SCALE: 1:10 — SHEET 4 OF 9

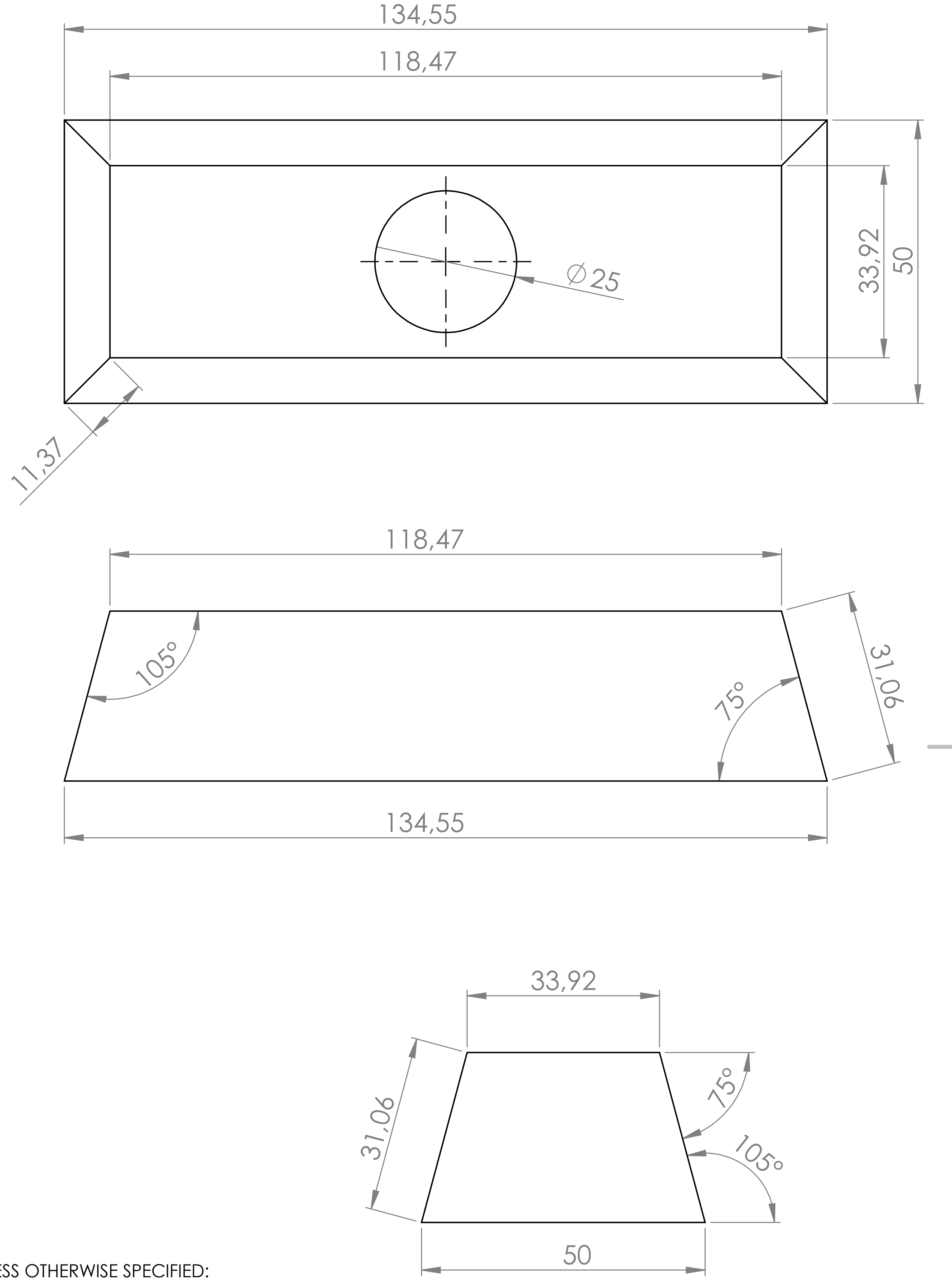
Appendix H



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

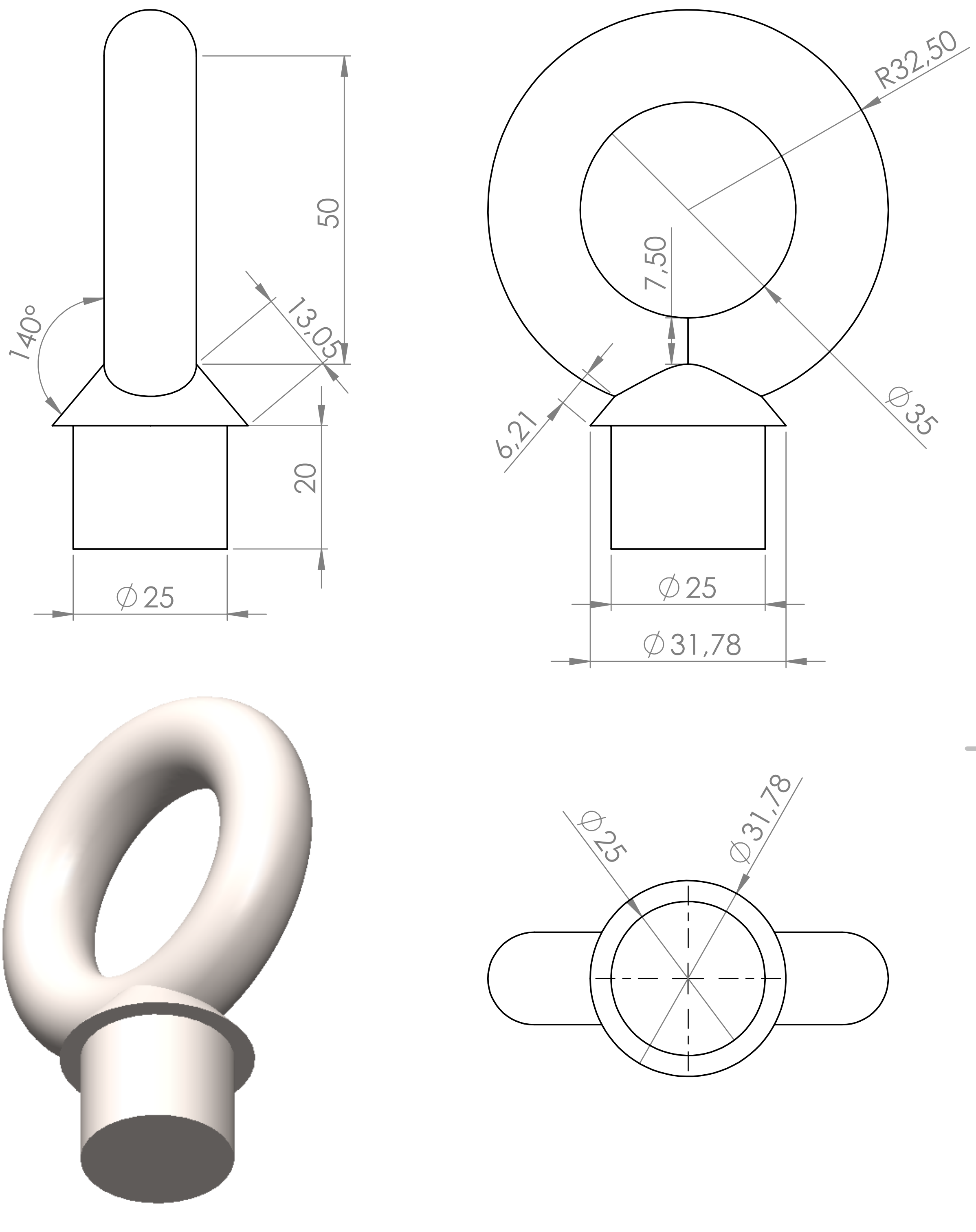
DRAWN	NAME Kari W. Johansen	DATE 30.5.2017	TITLE: 3: Towbar rod
APPV'D	NAME Kari W. Johansen	DATE 30.5.2017	
SOLIDWORKS Student Edition. For Academic Use Only.		WEIGHT: 5646.44 g	DWG NO. 3D print SLED — A4
		MATERIAL: Aluminium Al 6061	SCALE: 1:5 — SHEET 5 OF 9

Appendix H



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

	NAME	DATE	TITLE:
DRAWN	Kari Wilhelmsen Johansen	30.5.2017	4: Towbar connection rods 1 and 2
APPV'D	Kari Wilhelmsen Johansen	30.5.2017	
	WEIGHT: 391.98 g		DWG NO. 3D print SLED — A4
	MATERIAL: Aluminium Al 6061		SCALE: 1:1 — SHEET 6 OF 9



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN NAME Kari Wilhelmsen Johansen DATE 30.5.2017

APPV'D NAME Kari Wilhelmsen Johansen DATE 30.5.2017

TITLE: 5: Towbar attachment ring

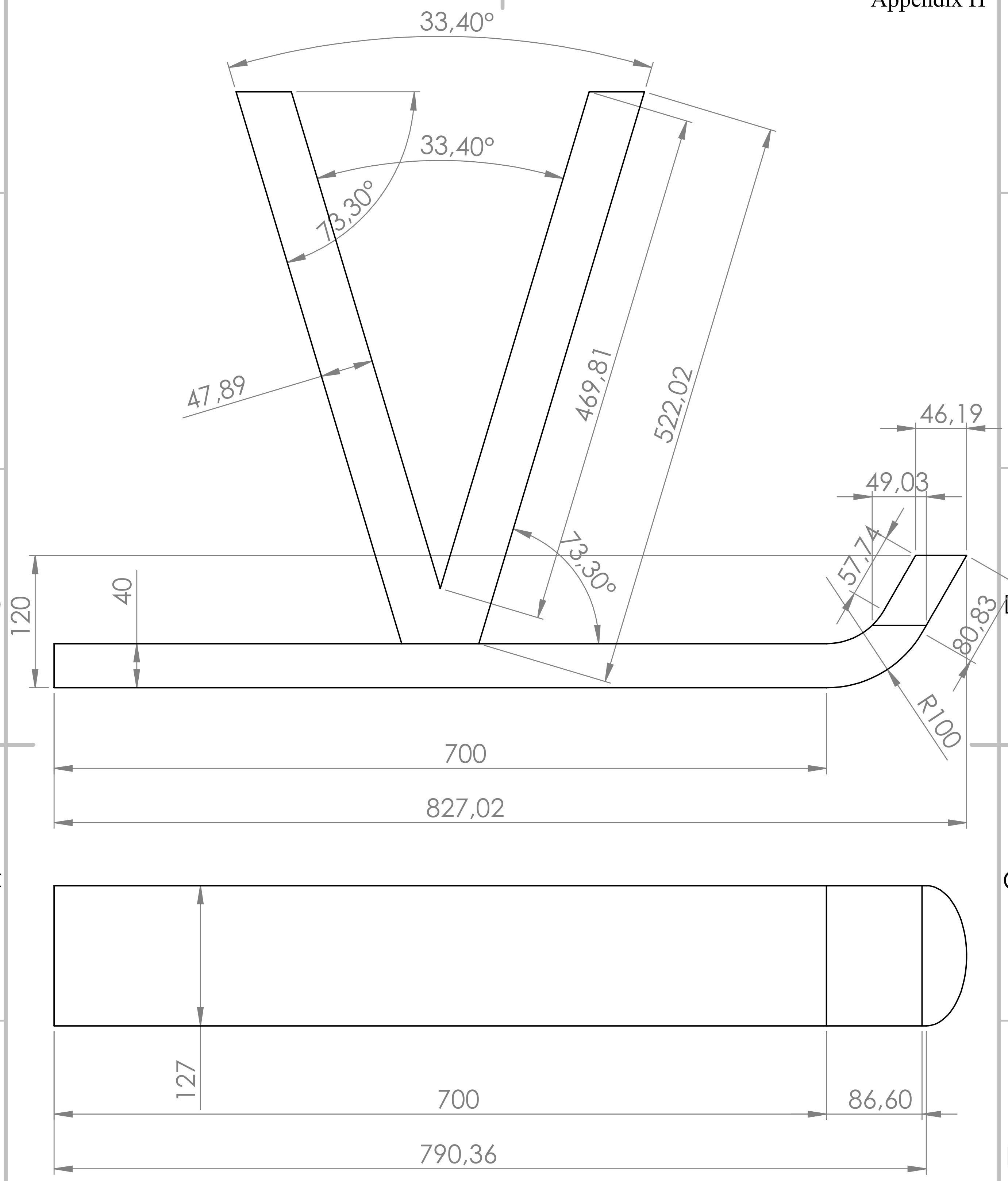
WEIGHT: 188.92 g

DWG NO. 3D print SLED

A4

MATERIAL: Ti- 6Al-2Sn-2Zr-2Mo-2Cr

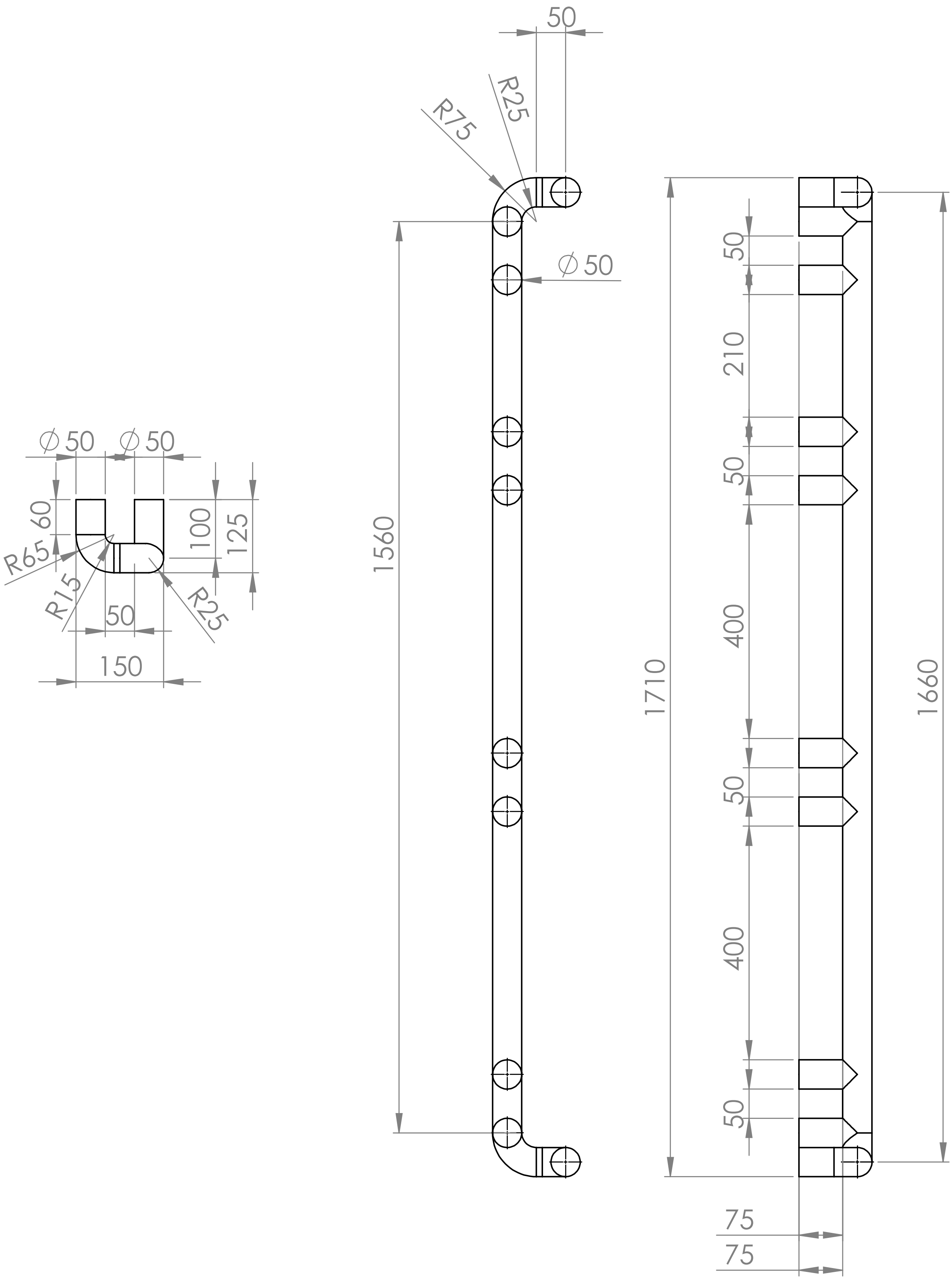
SCALE: 1:5



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

Only for illustrative purposes

DRAWN	NAME Kari Wilhelmsen Johansen	DATE 30.5.2017	TITLE: 6: Ski
APPV'D	NAME Kari Wilhelmsen Johansen	DATE 30.5.2017	
	WEIGHT: 5000 g	DWG NO. 3D print SLED	A4
	MATERIAL: N/A	SCALE: 1:10	SHEET 8 OF 9

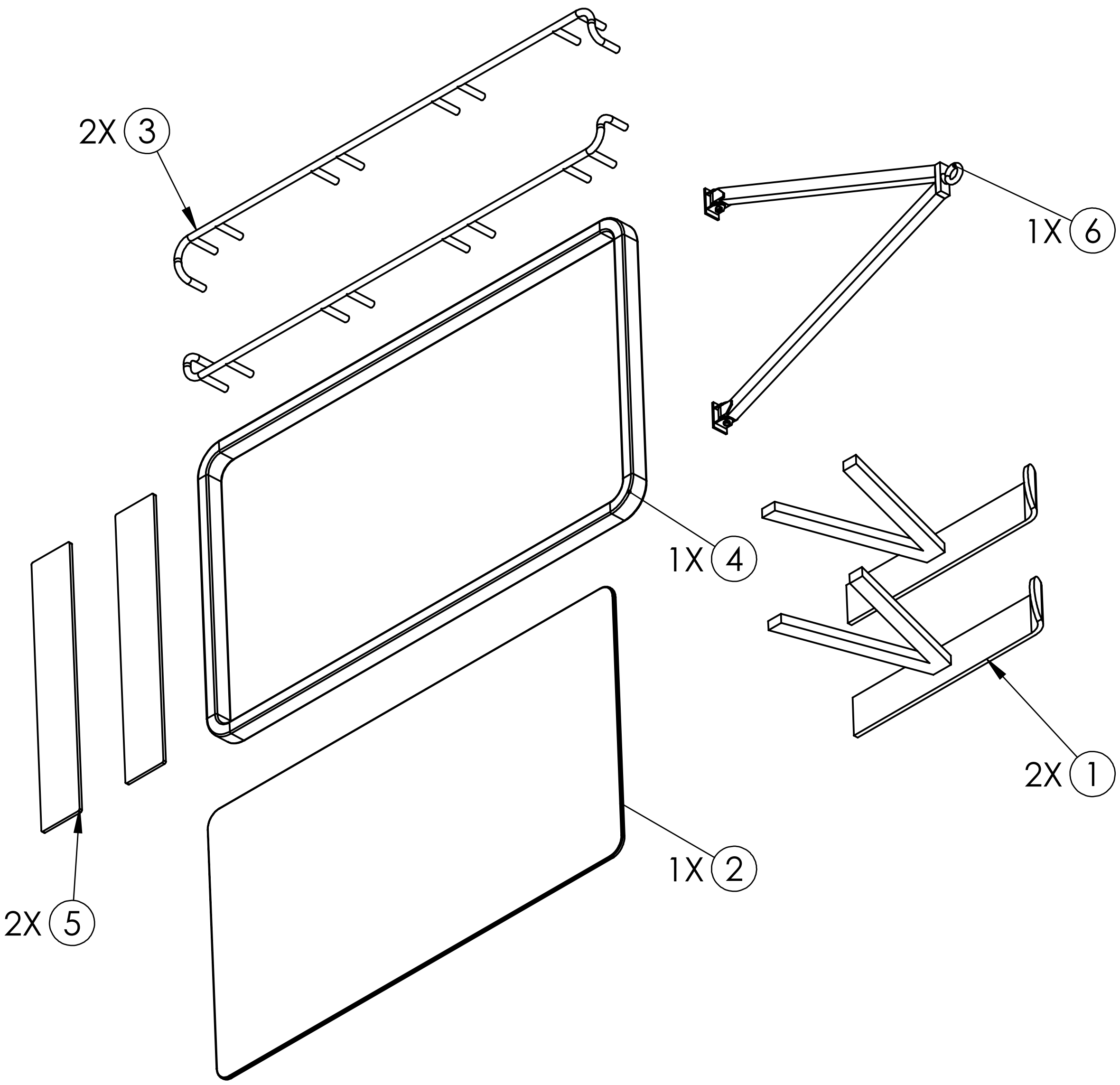


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME Kari Wilhelmsen Johansen	DATE 30.5.2017	TITLE: 7: Railing
APPV'D	NAME Kari Wilhelmsen Johansen	DATE 30.5.2017	
	WEIGHT: 13851.9 g		DWG NO. 3D print SLED — A4
	MATERIAL: Aluminium Al 6061		SCALE: 1:10 — SHEET 9 OF 9

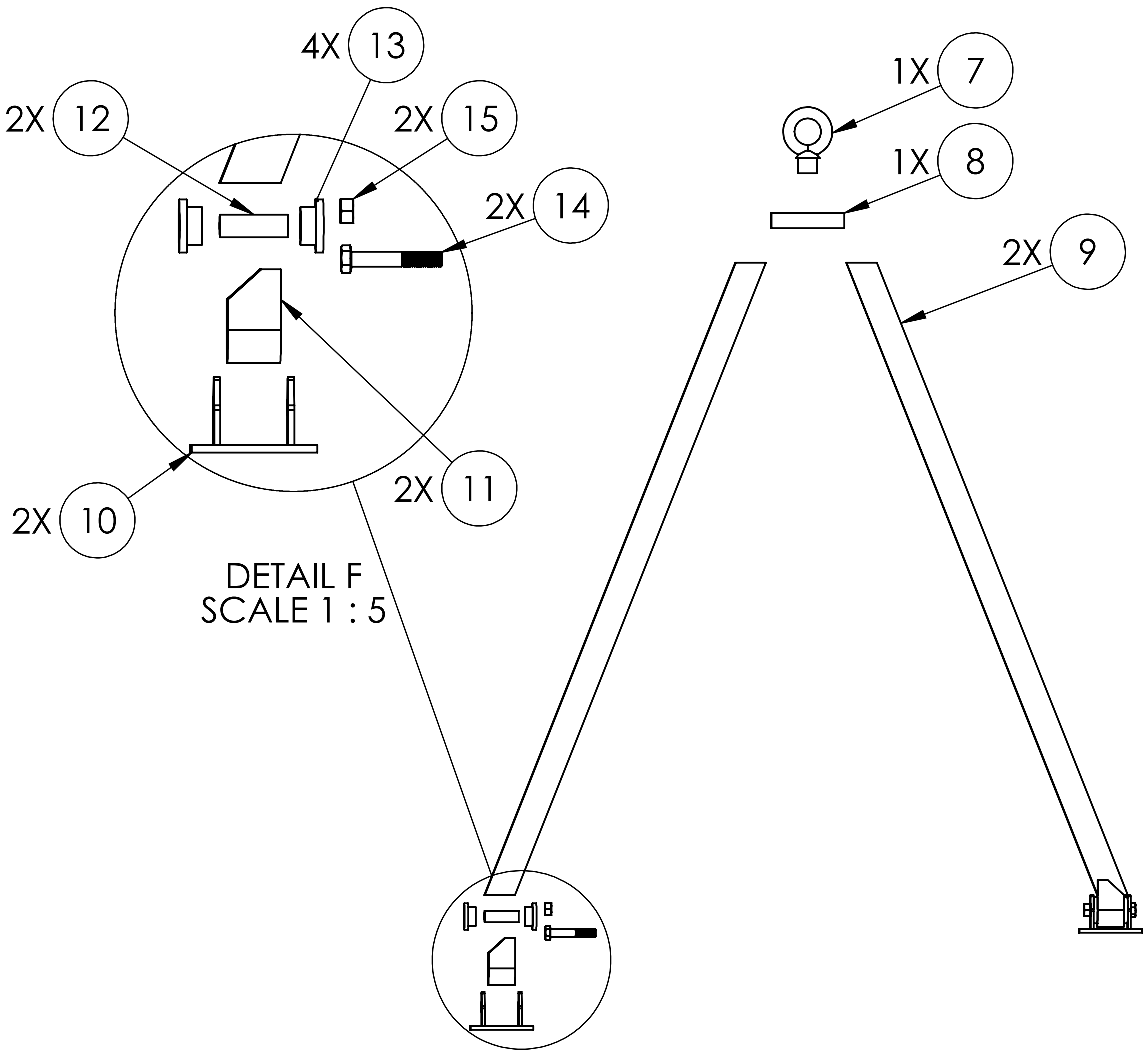
DESIGNER Kari Wilhelmsen Johansen	DATE 31.5.2017
TITLE: Snowmobile Sled	
DWG NO. SLED 2D drawings	A4
SCALE: 1:10	SHEET 1 OF 17

ITEM NO.	PART NUMBER	MATERIAL	WEIGHT [g]	QTY.
1	Ski	For illustrative purposes only	5000	2
2	Top plate	Plywood	10048.18	1
3	Railing	Aluminium AL6061 alloy	2277.01	2
4	Body structure frame	Aluminium AL6061 alloy	7483.58	1
5	Body structure supportbeam	Aluminium AL6061 alloy	3638.35	2
6	Towbar	Specified in sheet 2	2524.29	1

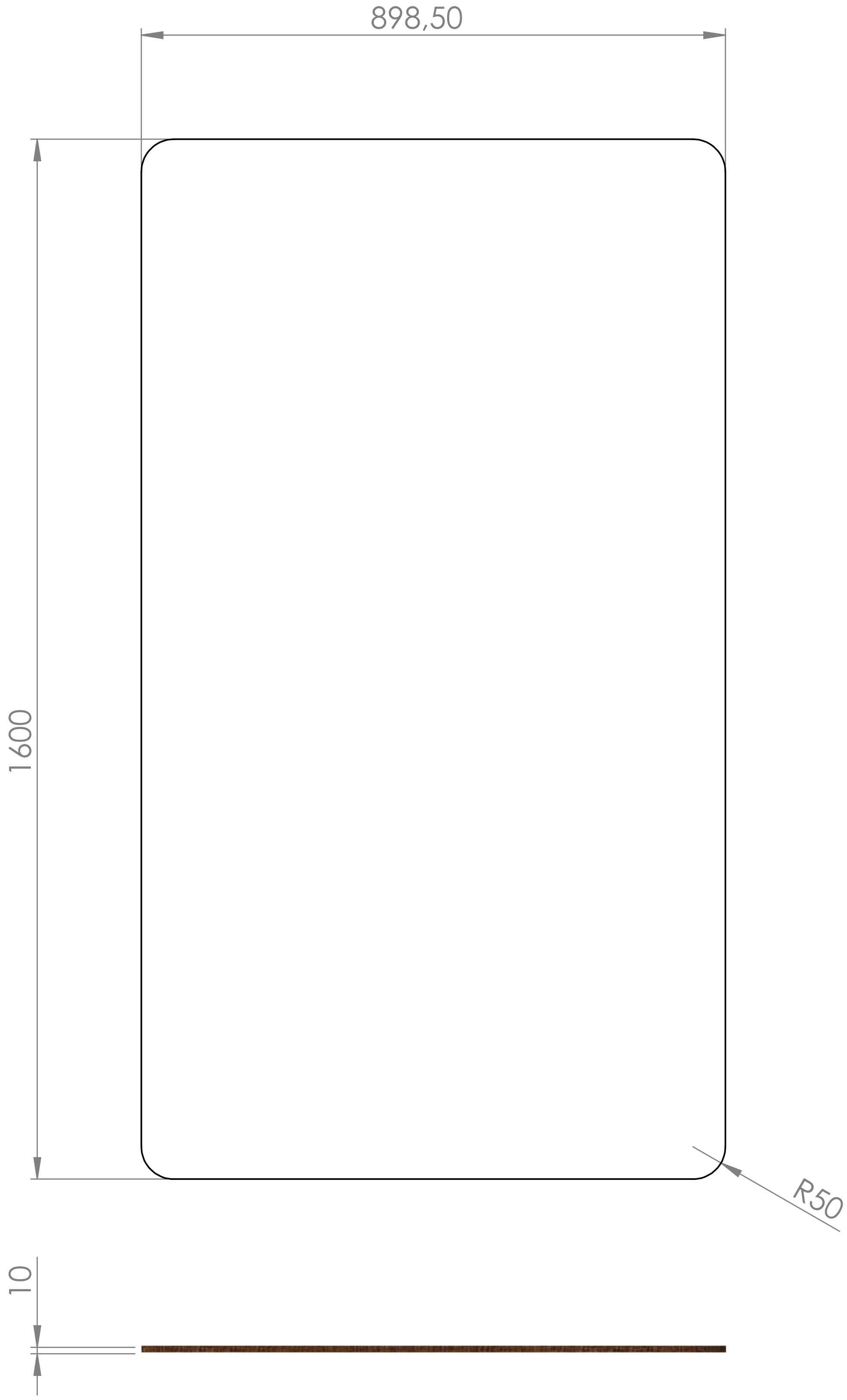


DRAWN	NAME Kari wilhelmsen Johansen	DATE 29.5.2017	TITLE: Snowmobile sled
APPV'D	NAME Kari Wilhelmsen Johansen	DATE 31.5.2017	
	SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 41856.66 g	DWG NO. SLED 2D drawings — A4
			SCALE: 1:20 — SHEET 2 OF 17

ITEM NO.	PART NUMBER	MATERIAL	WEIGHT [g]	QTY.
7	Attachment ring	Titanium alloy (SS)	188.92	1
8	Connection rods 1 and 2	Aluminium AL6061 alloy	155.31	1
9	Rod	Aluminium AL6061 alloy	836.5	2
10	HINGEJOINT plate	Aluminium AL6061 alloy	84.56	2
11	HINGEJOINT hengsel	Aluminium AL6061 alloy	125.55	2
12	HINGEJOINT rubber tube	Natural rubber	4.24	2
13	HINGEJOINT sides	PET	10.04	4
14	formed hex screw_am	Aluminium AL6061 alloy	15.58	2
15	hex nut style_am	Aluminium AL6061 alloy	3.53	2

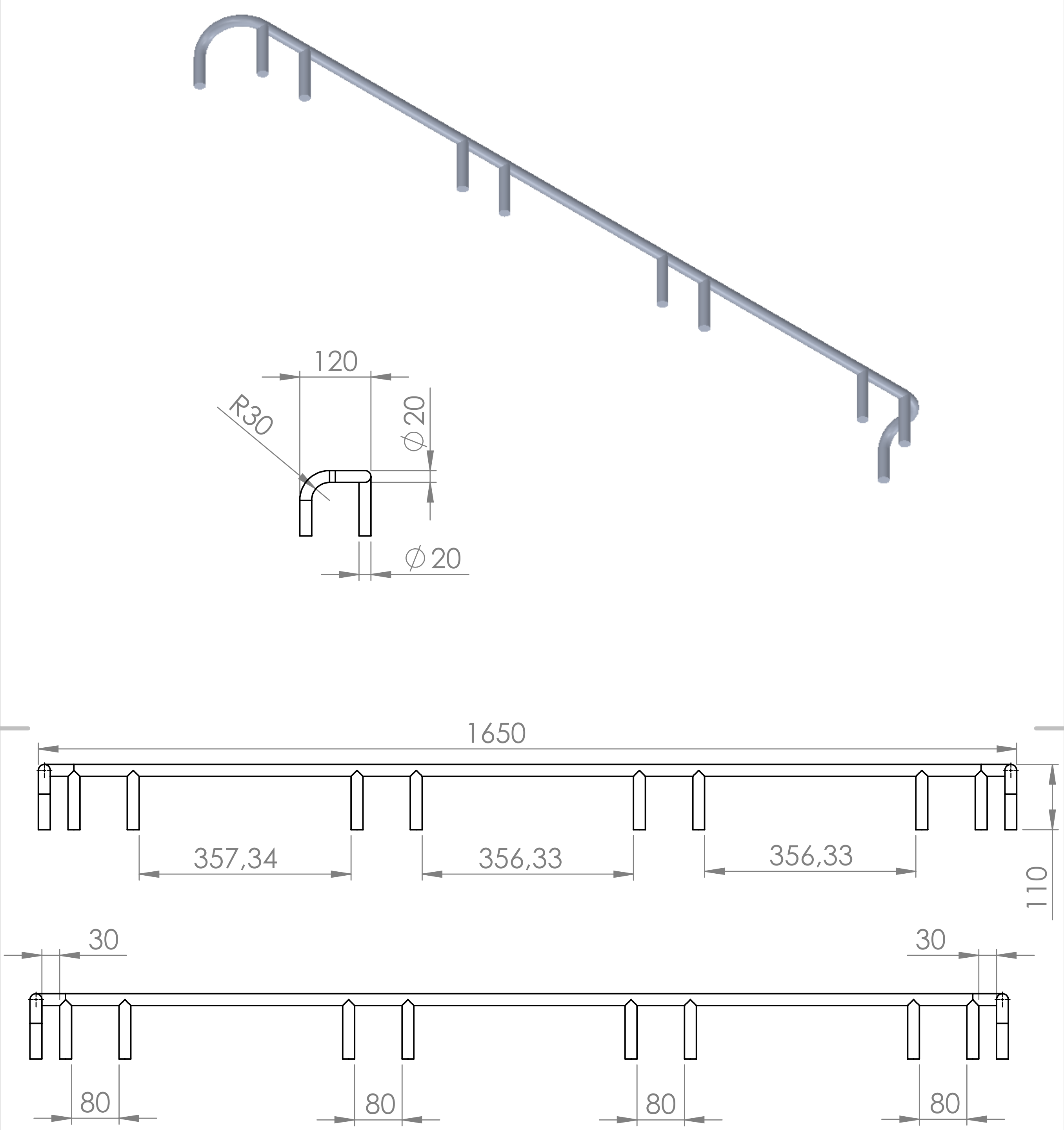


DRAWN: Kari Wilhelmsen Johansen	DATE: 29.5.2017	TITLE: TOWBAR	
APPV'D: Kari Wilhelmsen Johansen	DATE: 31.5.2017		
WEIGHT: 2524.29		DWG NO.: SLED 2D drawings	A4
		SCALE: 1:10	SHEET 3 OF 17



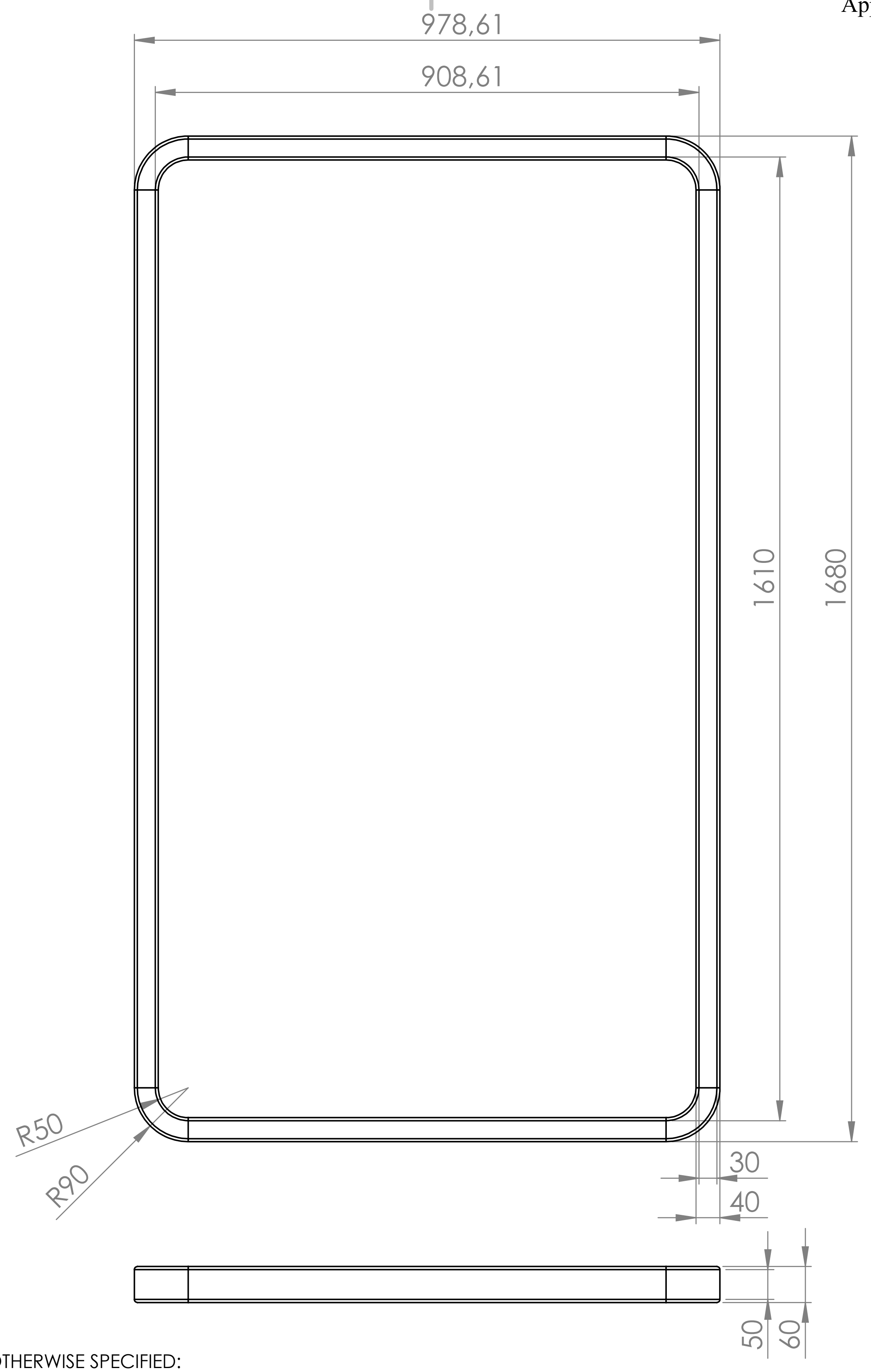
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME Kari Wilhelmsen Johansen	DATE 15.4.2017	TITLE: 2: Top-plate
APPV'D	NAME Kari Wilhelmsen Johansen	DATE 31.5.2017	
		WEIGHT: 10048.18 g	DWG NO. SLED 2D drawings — A4
		MATERIAL: Plywood	SCALE: 1:10 — SHEET 4 OF 17



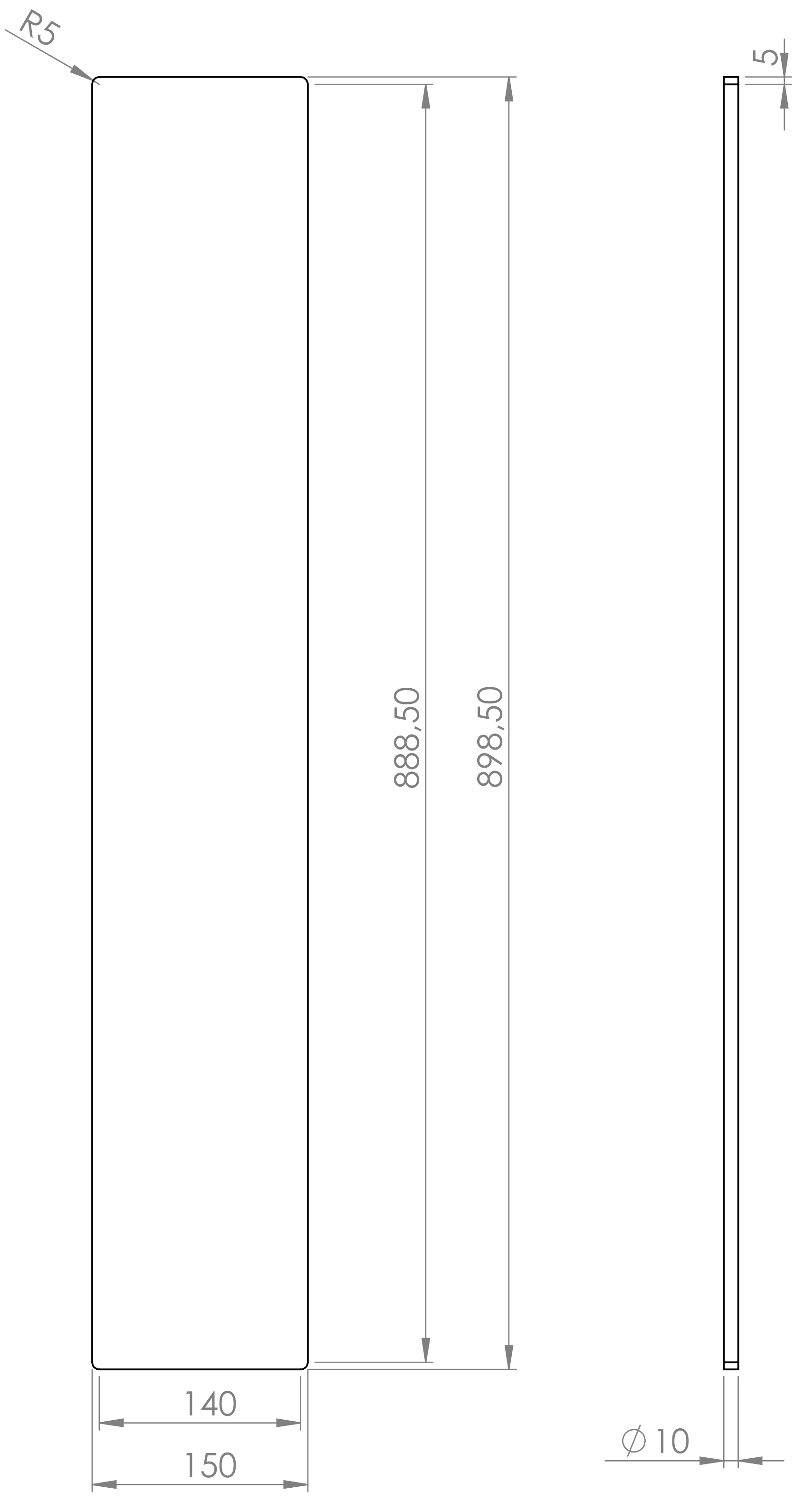
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

	NAME	DATE	TITLE:
DRAWN	Kari wilhelmsen Johansen	15.4.2017	3: Railing 2
APPV'D	Kari wilhelmsen Johansen	31.5.2017	
	SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 2277.01 g	DWG NO. SLED 2D drawings — A4
		MATERIAL: Aluminium AL6061 alloy	SCALE: 1:10 — SHEET 5 OF 17



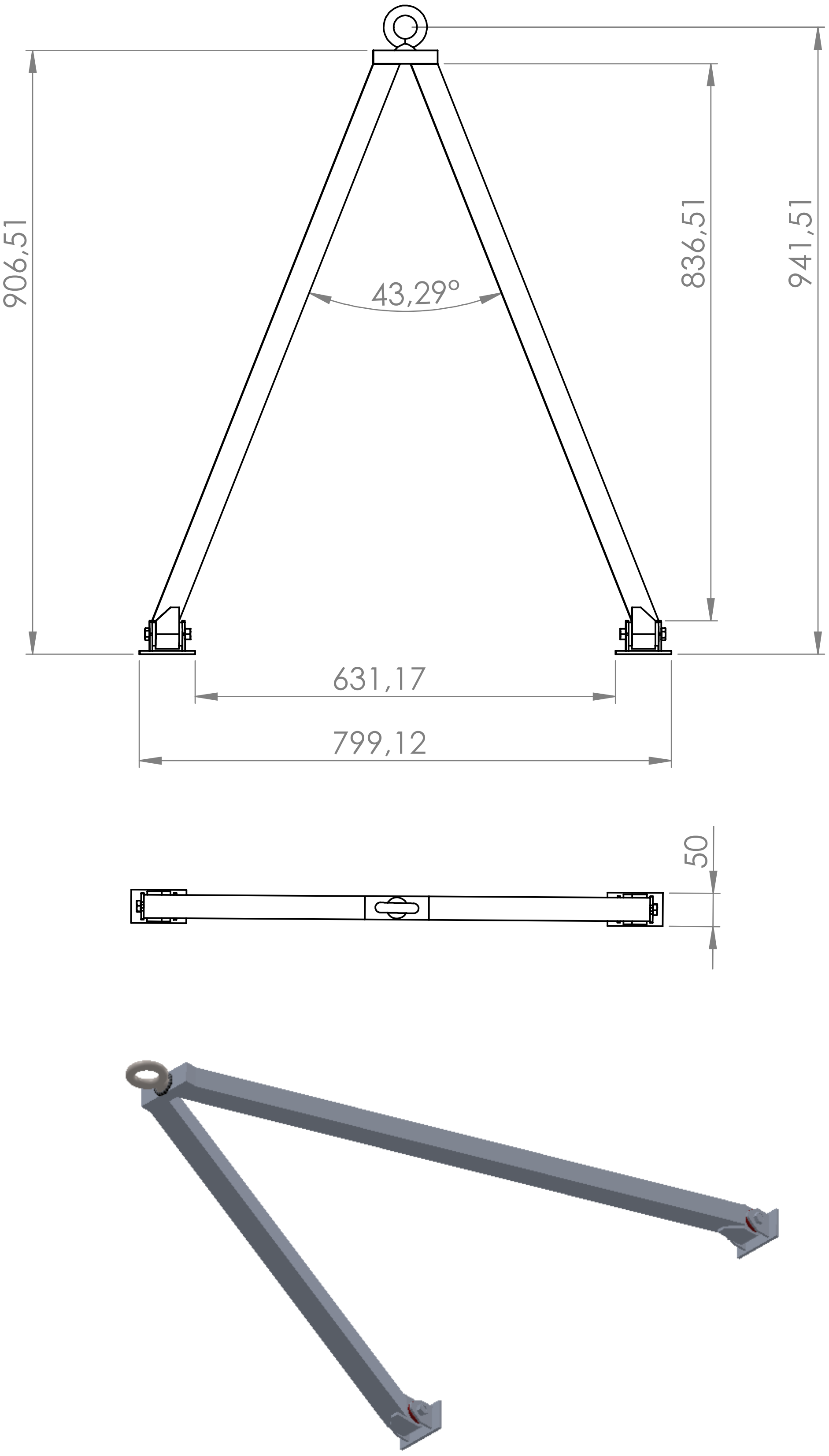
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: Kari wilhelmsen Johansen	DATE: 29.5.2017	TITLE: 4: Body structure frame	
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 29.5.2017		
SOLIDWORKS Student Edition. For Academic Use Only.		WEIGHT: 7483.58 g	DWG NO. SLED 2D drawings	A4
		MATERIAL: Aluminium AL6061 alloy	SCALE: 1:10	SHEET 6 OF 17



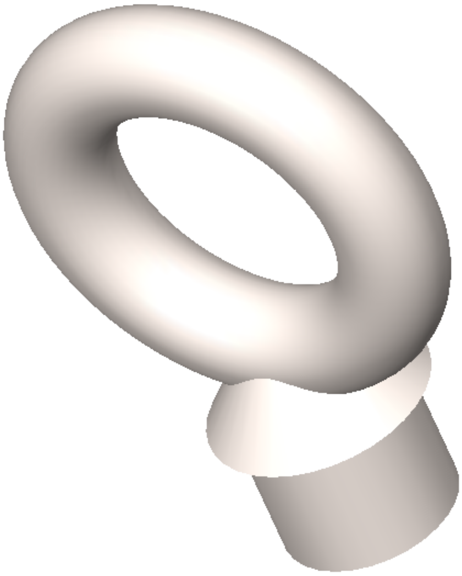
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

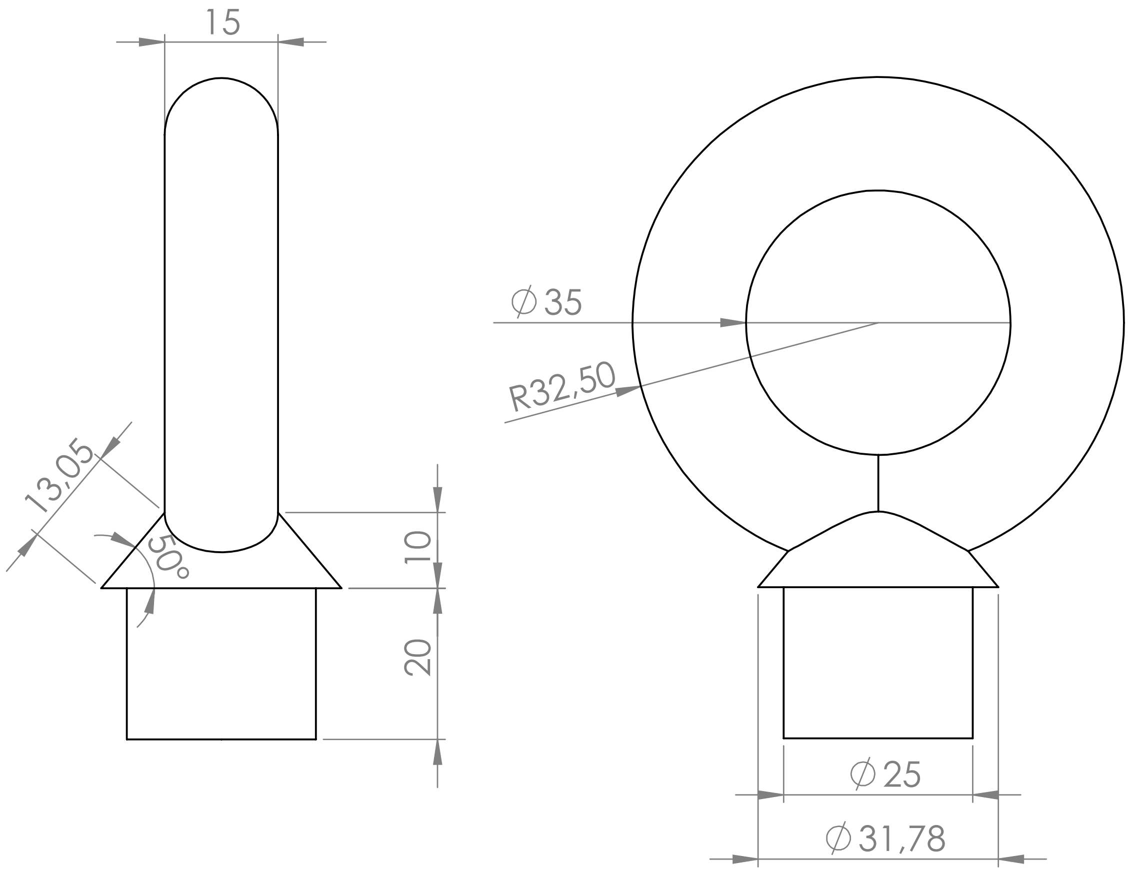
	NAME	DATE	TITLE:
DRAWN	Kari wilhelmsen Johansen	29.5.2017	5: Body structure support beam
APPV'D	Kari wilhelmsen Johansen	29.5.2017	
	WEIGHT: 3638.35 g		DWG NO. SLED 2D drawings A4
	MATERIAL: Aluminium AL6061 alloy		SCALE: 1:5 SHEET 7 OF 17



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

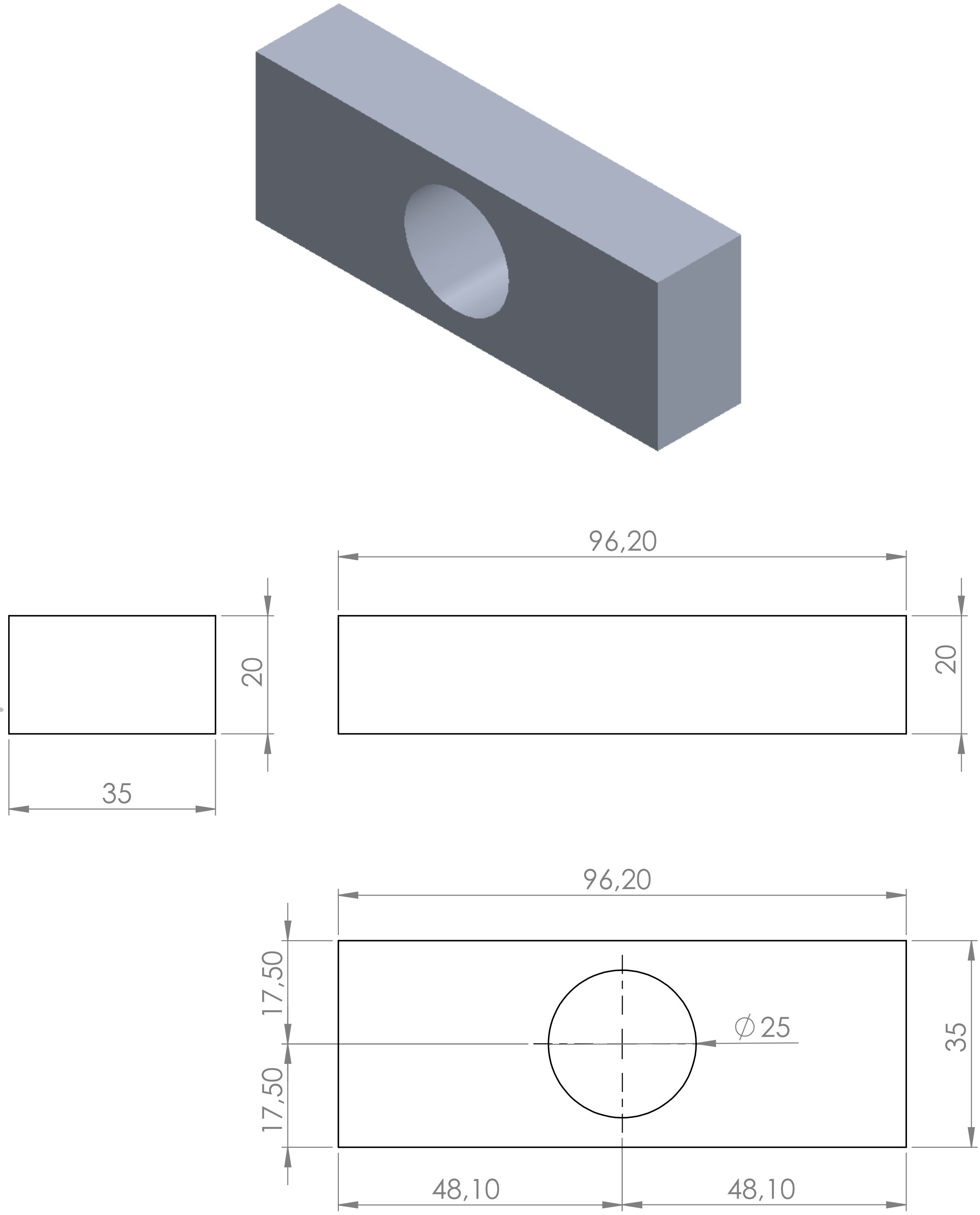
DRAWN	NAME: Kari wilhelmsen Johansen	DATE: 29.5.2017	TITLE: 6: Towbar
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	
	SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 2524.29 g	DWG NO. SLED 2D drawings — A4
		MATERIAL: N/A	SCALE: 1:10 — SHEET 8 OF 17





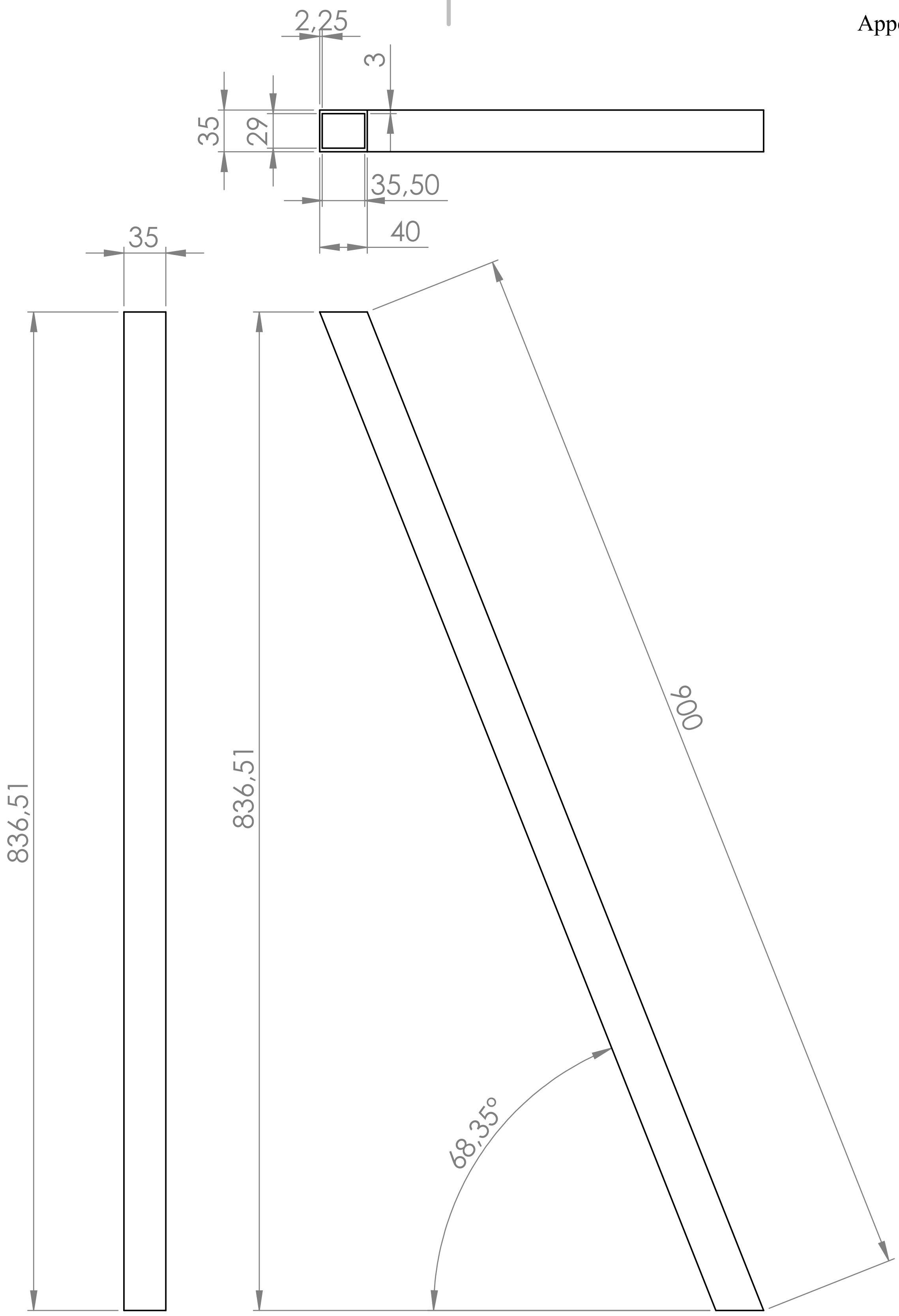
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	TITLE: 7: Attachment ring
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	
	WEIGHT: 188.92 g	DWG NO.: SLED 2D drawings	A4
	MATERIAL: Titanium alloy (SS)	SCALE: 1:1	SHEET 9 OF 17



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	TITLE: 8: Connection rods 1 and 2
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	
	WEIGHT: 155.31 g		DWG NO. SLED 2D drawings — A4
	MATERIAL: Aluminium AL6061 alloy	SCALE: 1:1	SHEET 10 OF 17



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN — NAME: Kari wilhelmsen Johansen — DATE: 31.5.2017

APPV'D — NAME: Kari wilhelmsen Johansen — DATE: 31.5.2017

TITLE: 9: Towbar rod

SOLIDWORKS Student Edition.
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WEIGHT: 836.5 g

DWG NO. SLED 2D drawings

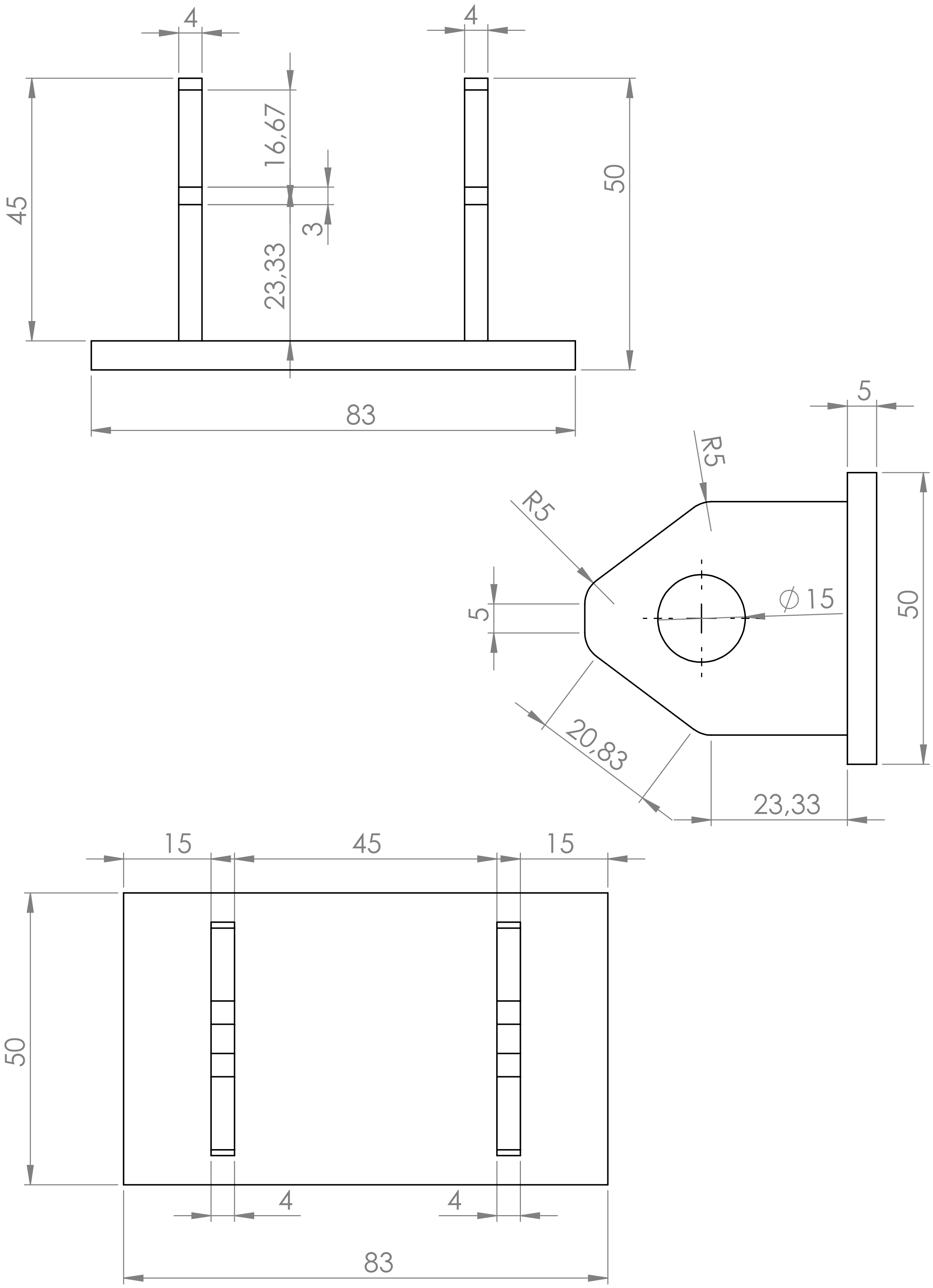
A4

MATERIAL: Aluminium AL6061 alloy

SCALE: 1:5

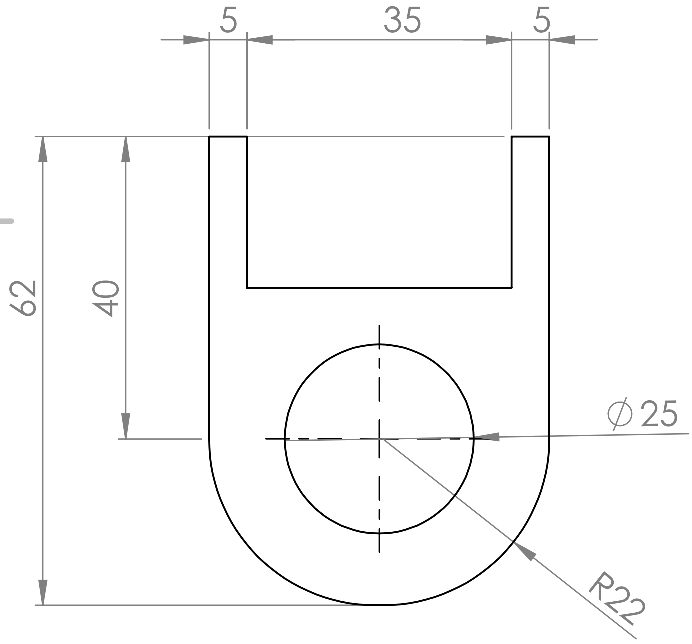
SHEET 11 OF 17

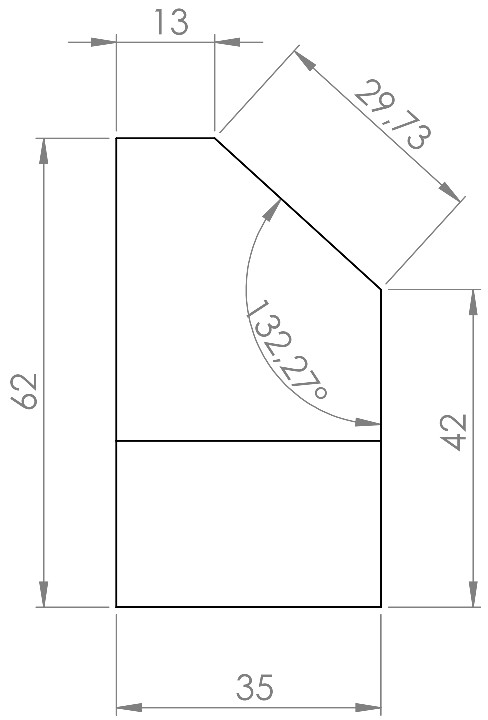
Appendix I



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

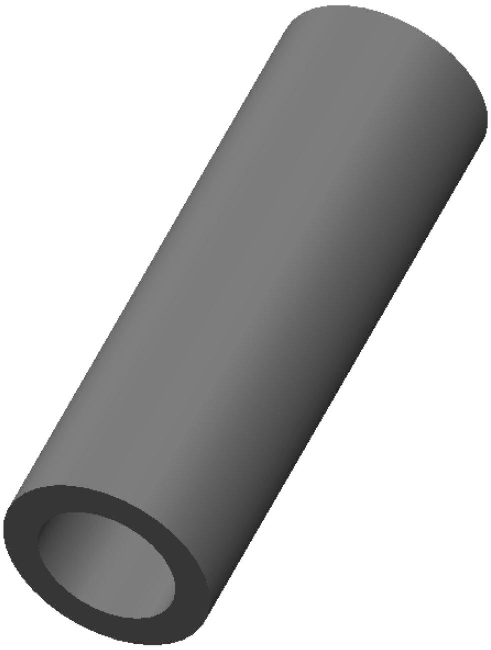
	NAME	DATE	TITLE:
DRAWN	Kari wilhelmsen Johansen	31.5.2017	10: Hingejoint plate
APPV'D	Kari wilhelmsen Johansen	31.5.2017	
	WEIGHT: 84.56 g	DWG NO. SLED 2D drawings	A4
	MATERIAL: Aluminium AL6061 alloy	SCALE: 1:1	SHEET 12 OF 17

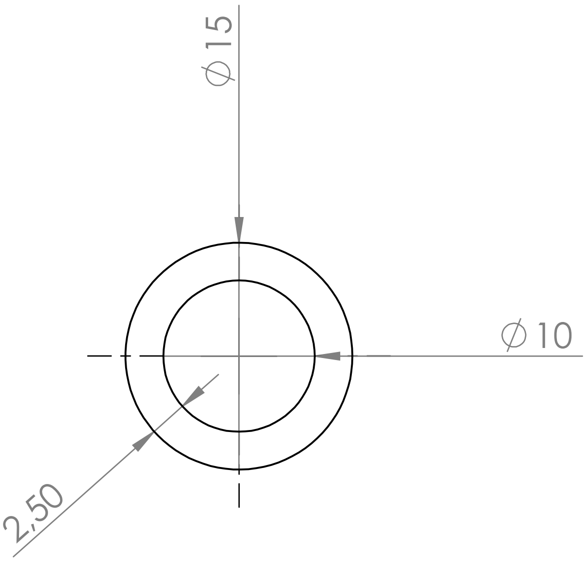


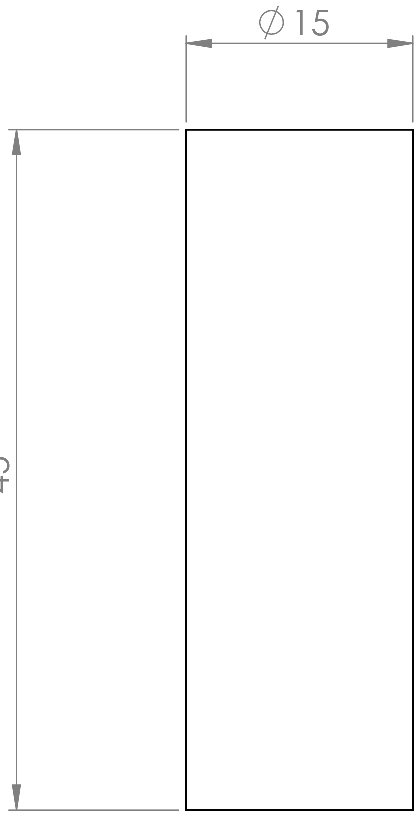


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	TITLE: 11: Hingejoint hinge
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	
SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 125.55 g	DWG NO. SLED 2D drawings	A4
	MATERIAL: Aluminium AL6061 alloy	SCALE: 1:1	SHEET 13 OF 17



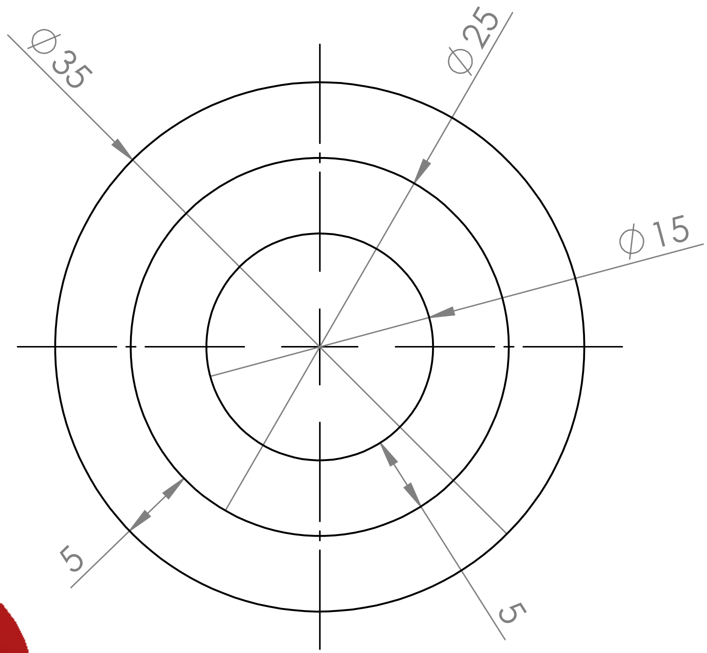


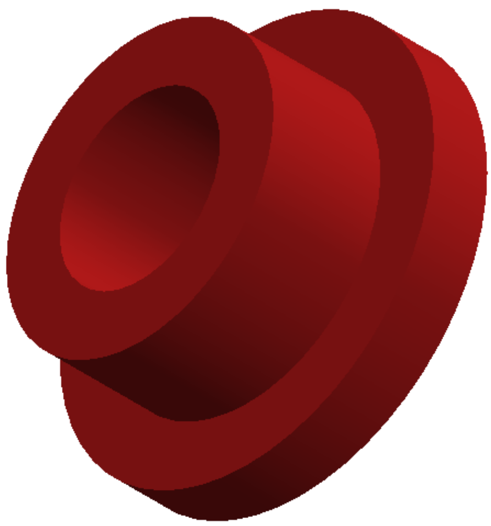


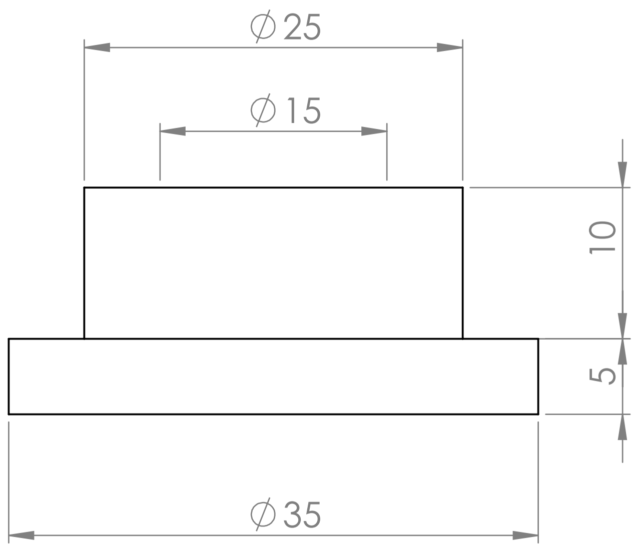
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	TITLE: 12: Hingejoint rubber tube
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	
	WEIGHT: 4.24 g		DWG NO.: SLED 2D drawings — A4
	MATERIAL: Natural rubber		SCALE: 2:1 — SHEET 14 OF 17

Appendix I

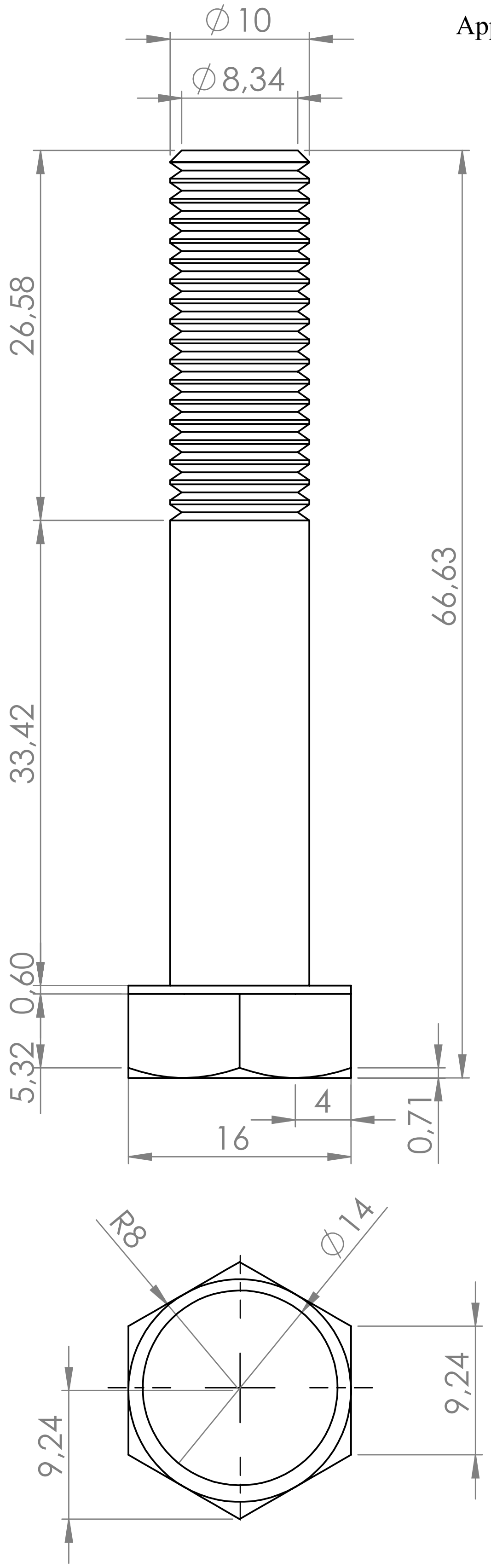






UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME Kari wilhelmsen Johansen	DATE 31.5.2017	TITLE: 13: Hingejoint sides
APPV'D	NAME Kari wilhelmsen Johansen	DATE 31.5.2017	
	WEIGHT: 10.04 g		DWG NO. SLED 2D drawings — A4
	MATERIAL: PET		SCALE: 2:1 — SHEET 15 OF 17



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN — NAME: SolidWorks Design Library Toolbox ANSI Metric — DATE:

APPV'D — NAME: Kari wilhelmsen Johansen — DATE: 31.5.2017

TITLE: 14: Hingejoint Formed Hex Screw

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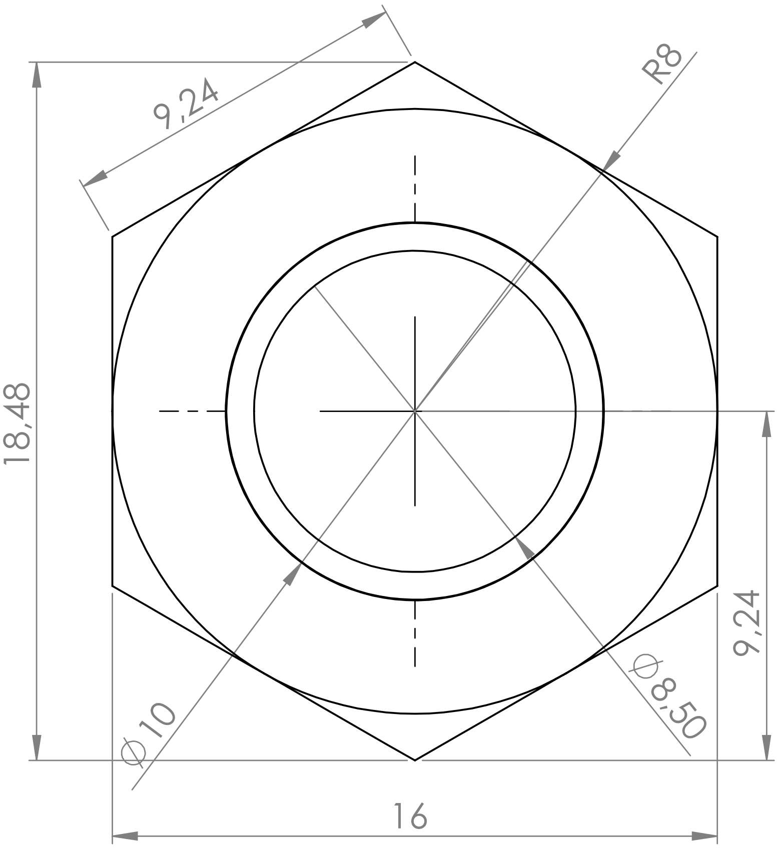
WEIGHT: 15.58 g

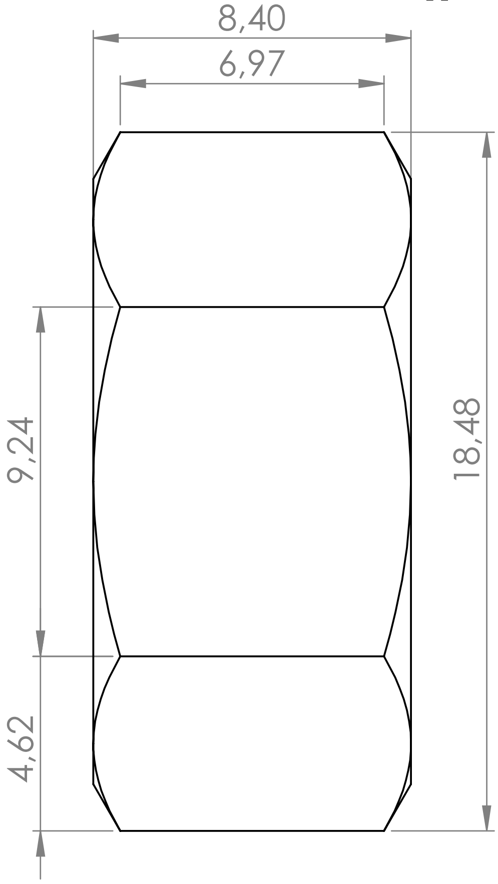
DWG NO. SLED 2D drawings — A4

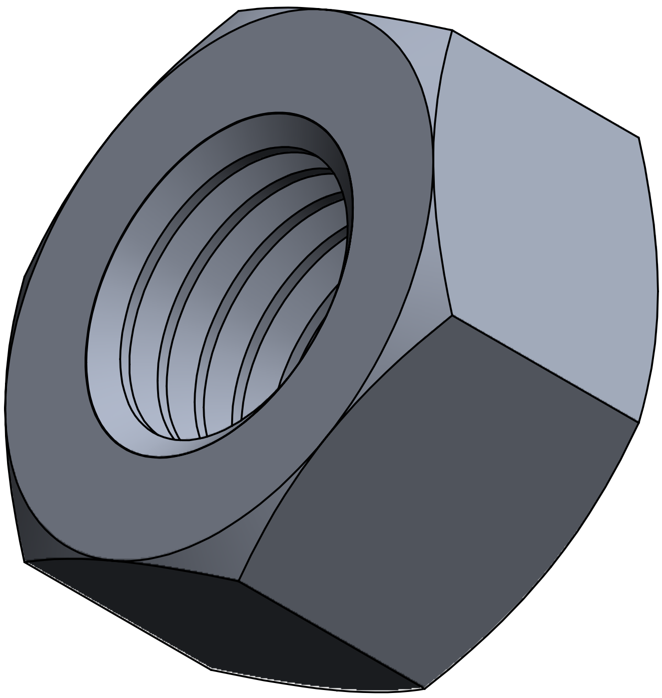
MATERIAL: Aluminium AL6061 alloy

SCALE: 2:1

SHEET 16 OF 17







UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

DRAWN	NAME: SolidWorks Design Library Toolbox ANSI Metric	DATE	TITLE: 15: Hingejoint Hex Nut
APPV'D	NAME: Kari wilhelmsen Johansen	DATE: 31.5.2017	
	SOLIDWORKS Student Edition. For Academic Use Only.	WEIGHT: 3.53 g	DWG NO. SLED 2D drawings — A4
		MATERIAL: Aluminium AL6061 alloy	SCALE: 5:1 — SHEET 17 OF 17