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Mechanical Landmine Clearing Tool for NMBU`s Agricultural Robot

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Preface

When I first heard that the Norwegian Defence Research Establishment (Forsvarets forskningsinstitutt – FFI) where interested in using NMBU`s agricultural robot as a way of clearing landmines, I knew that I had found the subject for my master thesis. I knew that it was going to be challenging, and as I learned more and more about landmines, the task proved to be even more challenging. However, I was determined to develop a product that might save lives one day.

I would like to thank the people at the FFI for discussions and sharing knowledge. Especially Jan Arild Teland for taking the time to run simulations for me, and Ove Dullum for sharing his knowledge and experience and for taking me to FAES (Norwegian defence`s school for ammunition and EOD) at Sessvollmoen. I would like to thank Ivar Foss and Magnus Strømsvåg, at FAES for sharing their knowledge about landmines and showing me their stock of landmines. I would like to thank my contact person at FFI, Kim Mathiassen, and the man in charge, Lorns Harald Bakstad. Ph.D. candidate, Lars Grimstad, has contributed with knowledge and discussion and I would therefore thank him as well. I would also like to thank my advisor and teacher, Pål Johan From, for guidance.

I hope that someone will continue working on this project, and take the idea of an autonomous landmine clearing robot further. This thesis has been an honour, fun, and a challenge to work on.

Ås /05-2016

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Espen Noreng Ovik

Sammendrag

Denne oppgaven omhandler fremstillingen av et modulært og mekanisk mineryddings verktøy for NMBU sin landbruksrobot, Thorvald 2. Oppgaven består av bakgrunnsinformasjon om problemet med landminer i verden i dag og hvordan landminer opererer, samt hele utviklingsfasen til produktet, inklusivt konsept drøfting, beregninger og simuleringer.

Konseptet innebærer at en last slippes ned på bakken der en landmine befinner seg. Lasten skaper en bakketrykk som vil detonere landminene. Lasten er en sekk med sand på 25 kilogram som slippes fra 1 meters høyde. En vinsj løfter lasten opp fra bakken og holder den oppe. En clutch frigjør trommelen fra resten av vinsjen slik at sandsekken faller ned på bakken. Et stilas monteres på roboten med en trinse på toppen. Stillaset og trinsen er konstruert og plassert slik at trinsen er direkte over landminen, som er plassert i midten og bak roboten. Et ståltau forbinder lasten og vinsjen via trinsen. Clutchen er konstruert fra bunnen av og tilpasset systemet. Den bruker en lineær aktuator for av og på kobling. Vinsjen drives av en børsteløs likestrøms motor, sammen med et gir.

Simuleringer gjort av FFI gir optimisme med tanke på videre testing. En prototype er ikke ferdigstilt.

Abstract

This thesis contain the process of creating a modular and mechanical landmine clearing tool for NMBU`s agricultural robot, Thorvald 2. In this thesis, there will be information about the problem with landmines today and how a landmine work, along with the development process for the product, including concept evaluation, calculations and simulations.

The basic idea of the concept is that a load is to be dropped at the landmines location. The load will create a ground pressure that will trigger any pressure sensitive landmines. The load is a 25 kg heavy bag of sand and it will be dropped from a height of 1 meter. A winch lifts the load up and keeps it in the air. A clutch disconnects the drum from the rest of the winch system and the load drops to the ground. A scaffold is placed on the robot, with a pulley wheel at the top. The scaffold and the pulley wheel are designed and placed so that the pulley wheel is directly above the landmines, which are located in the middle and at the rear of the robot. A steel wire connects the load and the winch via the pulley wheel. The clutch is custom designed from scratch to fit the winch system. A linear actuator connects and disconnects the clutch. The winch is driven by a brushless direct current motor, along with a gearbox.

Simulations done by FFI gives reason for optimism for the continuation of the project. A prototype is yet to be completed.

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Abbreviations

ICBL – International Campaign to Ban Landmines

AP – Anti personnel

AT – Antitank

FFI – Forsvarets forskningsinstitutt (Norwegian Defence Research Establishment)

UN – United Nations

ERW **-** Explosive residue of war

NMBU – Norwegian University of Life Sciences

WW1 – World War One

EOD – Explosive Ordinance Disposal

FAES – Forsvarets ammunisjons og EOD-skole (Norwegian defence`s school for ammunition and EOD)

ERW – Explosive remnants of war

UXO – Unexploded ordnance

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1 Introduction

The objective of this project is to create a modular, mechanical and autonomous landmine clearing robot, using NMBU`s agricultural robot. The robot has to be able to locate and detonate landmines in a cheap and safe manner, completely autonomous and with minimal supervision. The robot must also be modular and easy to repair.

1.1 Motivation

Thousands of people are killed each year, and many more injured, by the millions of landmines that lies beneath the surface around the world. The problem with landmines is not going away any time soon and will continue to kill civilians if they are not removed. The methods for removing landmines today are either life threatening or soil damaging, as well as expensive. An autonomous landmine clearing vehicle can possibly save lives and money.

1.2 Landmines today

Landmines are explosive devices, buried underground near the surface, with a detonating system [1]. There are several different triggering systems. Direct pressure from above, pressure put on a wire attached to a pull switch, radio signal or other remote firing method, and simply proximity from an object, are examples of detonation methods. Landmines are designed to injure or kill people and they can lie still for decades before they are triggered [2].

Landmines are classified as victim activated weapons, since they could be triggered by anyone and anything. All from civilians, children, soldiers and animals to vehicles [2].

Landmines are divided into two main groups, antipersonnel landmines (AP) and antitank landmines (AT). There are more than 600 different types of AP landmines, and they can be divided into three groups, explosive blast effect, fragmentation and bounding. The most common landmines are the one that uses explosive blast effect. These are designed to injure the lower half of the leg, causing blood loss and infection that leads to amputation. These mines are sold for as little as $3. One type of mine that uses this principle is the “Butterfly”. A landmine that has an odd shape and bright colour, making it interesting for children, who mistake these landmines for toys.

Fragmentation mines are either stuffed with metal fragments or designed so that the metal casing becomes fragments when the landmine explode. The explosion turn the fragments into lethal projectiles and can cause damage and even kill up to a hundred meters away.

Bounding fragmentation mines is the most deadly type. Referred to as “Bouncing betties”, these mines are thrown up in the air by a primary charge. Around waist height, a secondary charge explodes and shoot fragments in a 360-degree horizontal arc. These mines can kill up to 35 meters away and can injure even up to 100 meters away [1].

When the explosives in a landmine are detonated the blast will either kill the victim or cause injury, such as blindness, burns, damaged limbs and shrapnel wounds. If the victim survives the blast, they will still be at risk dying of blood loss or infections [2].

AT mines are made to destroy or damage vehicles. They are much larger than AP mines and carries a whole lot more explosives. They are used to prevent the use of certain roads and in general prevent the use of vehicles in certain locations. An unarmoured vehicle is usually totally destroyed and in the case of detonation by a person, it would be fatal [1].

Landmines are now classified as either first, second or third generation. The difference between them are the intelligence within the fuze, and how they react to different threats. First generation mines have simple mechanical activation that require a physical force to detonate them. Second generation mines operate with electronical fuzes with an intelligent chip, able to detect the target. Some of them can calculate speeds and use a time delay to detonate at the best time. Third generation mines have advanced fuze systems, that can tell friend from foe, detect targets from a certain distance, calculate speed, communicate with other mines, report to control centres and are able to attack targets from several to over a hundred meters away [3].

1.2.1 Victims

There are estimated to be around 110 million landmines in the ground today, and another 100 million are stockpiled around the world. Over 70 people are killed or injured every day by AP mines [1]. In addition, around 60 countries are estimated to be affected by landmines [4].

In 2014, according to the landmine monitor 2015, 3768 people lost their lives due to a landmine or other explosive leftovers from war (ERW). This was a 12 % increase from 2013, although the pattern is a decrease of casualties over the years. In total, since 1999, almost a hundred thousand people have lost their lives due to a landmine or ERW. Afghanistan is the country with the most deaths caused by landmines in 2014, with 1296 fatalities [4].

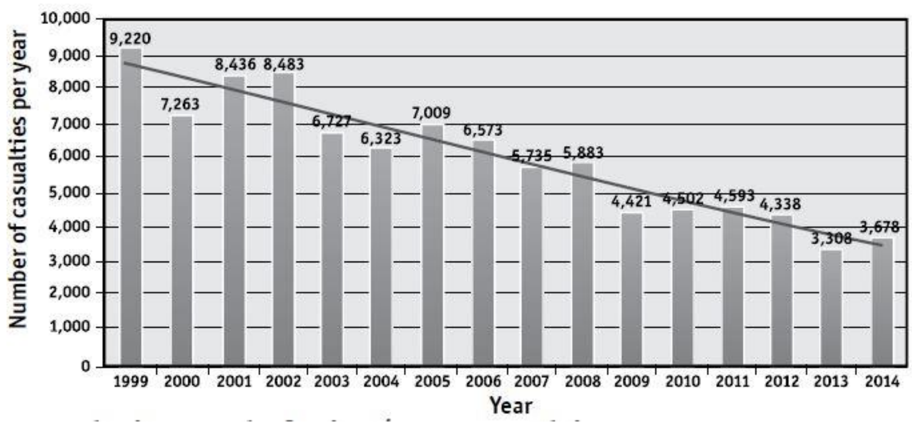


Figure 1: A bar chart of number of casualties per year from 1999 to 2014, due to landmines or ERW [4].

Of the lives lost in 2014, 39 % of them where children and 12 % where women. 2 % of the casualties where deminers, 18 % where military and 80 % where civilians [4]. This statistics validates the statement that landmines are victim activated weapons and that the majority of victims is not military.

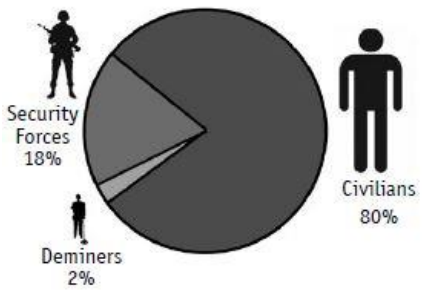


Figure 2: A pie chart of the fraction of civilians, deminers and security forces, killed by landmines or ERW [4].

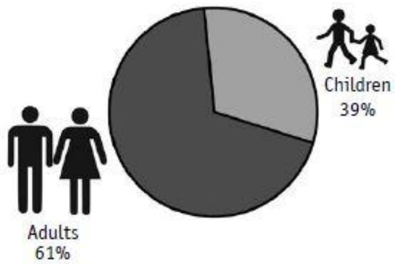


Figure 3: A pie chart of the fraction of adults and children, killed by landmines or ERW [4].

1.2.2 Landmine clearing and demining

We separate between military and humanitarian clearing of mines. Mine clearance is the military form, meant to break through a minefield or clear a road, while demining is the humanitarian form of clearing mines. The purpose of demining is to clear areas for landmines preventing innocent lives from being lost.

In 2014 a total of 201 square kilometres where cleared of landmines and 231.809 AP mines where destroyed. Afghanistan is the country that cleared the most square kilometres, while Mozambique cleared the most AP mines. Since 2010, a total of 976 square kilometres has been cleared, and 1.479.708 AP mines and 82.200 AT mines have been destroyed [4].

State	Mined area cleared (km^2)	Antipersonnel mines destroyed	Notes
Afghanistan	62.87	12,517	Major discrepancies between the Article 7 report and data-from the mine action center
Cambodia	54.38	20,479	Substantial inconsistencies in data, and discrepancies between the Article 7 report and data from the mine action center
Croatia	37.75	1,842	
Algeria	6.4	42,428	
Iraq	5.58	16,734	Major discrepancies between data provided by mine action centers and operators
Azerbaijan	4.76	42	
Sri Lanka	3.75	32,223	
Mozambique	3.07	45,681	
South Sudan	2.62	880	
Angola	2.6	2,676	
Sub-totals	**183.78**	**175,502**	
Other programs combined	17.19	56,307	
Total global clearance	**200.97**	**231,809**	

Figure 4: A chart showing the number of cleared AP landmines and square kilometres in different countries [4].

The international mine clearing standards and the definition of clearance set by the United Nations are as follows:

"*An area is cleared when all mines and munitions have been removed and/or destroyed. All debris from mines and explosives such as fuzing systems, percussion caps and other items that constitute an explosive hazard, is to be removed.*

The area should be cleared of mines to a standard and depth which is agreed to be appropriate to the residual/planned use of the land, and which is achievable in terms of the resources and time available. The contractor must achieve at least 99.6% of the agreed standard of mine clearance. The target for all UN sponsored clearance programmes is the removal of all mines and UXO to a depth of 200mm." [5]

1.3 Existing methods

There are many methods for clearing landmines. Some of them require precision and training, and others require heavy machinery. The following are a selection of methods used in demining and mine clearance.

1.3.1 Locating

These next methods are only for landmine detection. They do not detonate, disarm or engage the landmine in any way.

Metal detectors

Metal detectors where first used to find landmines and other explosive residue after WW1. However, the detectors where big and unpractical [6]. After the invention of the portable metal detector, further refinements and adaptation for detecting landmines, metal detectors where commonly used during and after WW2 [7]. Metal detectors today can typically detect objects within a foot under the surface. Normal maximum depth for metal detectors are somewhere between 20 and 30 cm [8].

Figure 5: A Vallon VMH3 metal detector [11].

There are three different technologies used in metal detectors. Very low frequency (VLF), Pulse induction (PI) and Beat-frequency oscillation (BFO) [8].

VFL, also known as induction balance, is the most used in metal detectors today. A VFL metal detector has two coils. One outer transmitter coil and one inner receiver coil. Electrical current is sent through the transmitter coil back and forth thousands of times a second creating a magnetic field that pulses back and forth into the ground. This field interacts with objects in the ground causing them to generate weak magnetic fields of their own. The magnetic field of the object is directly opposite to the field from the coil. The receiver coil is completely protected and untouched by the field coming from the transmitter coil, but it is not shielded from the fields coming from the objects in the ground. When the receiver coil passes over an object that generate a magnetic field, electrical current is created in the coil and the detector lets the user know that it has found an object. By using phase shifting, a VLF metal detector can distinguish between different types of metals. Basically it means that different metals reacts differently to the magnetic fields, something a VLF metal detector with a pair of electronic circuits, called phase demodulators, use to tell the type of metal [8].

Both PI detectors and BFO detectors work a little bit different from the VFL, and from each other, but the principle is about the same. They all use electric current to make magnetic fields that cause a reaction in a metal object in the ground. However, the way they detect the magnetic field generated by an object is a bit different. PI uses a technique that reminds of an echo while BFO uses radio waves [8] [9].

GPR

Ground penetrating radar or GPR is a device that transmits high frequency radio signals into the ground and picks up the reflected signals from objects beneath the surface. The reflected signals are stored on digital media and the computer uses the measured time taken for a signal to travel to and from an object and the strength of the signal to calculate the depth and the location of the object [10] .A GPR system can map and create a picture of the subsurface.

While GPR technology has come a long way, it is not yet been widely developed for mine detection. Today it is mainly used for looking through pipes and concrete in the industry, though the military do use it to find tunnels and hidden rooms in the ground. GPR results vary on the type of soil and the type of objects, and so far, the understanding of how different environmental factors and characteristics of a landmine affect its performance is far from complete [9].

Figure 6: A person using a Vallon Minehound VMR3 [11].

Since GPR is yet to be fully developed in order to locate landmines, and metal detectors lack the capability to detect landmines containing little or no metal, equipment using both GPR and metal detecting, have been developed. One of the companies that has developed such a system is Vallon, a company that manufacture metal detectors and UXO locators. They have developed a hand held detector, called Minehound, using both GPR and metal detector [11].

Dogs

Dogs have an incredible sense of smell and they can be trained to sniff out the explosives in the landmines. Since they smell the actual explosive and not the metal, they can locate both metal and plastic landmines. Dogs are much more time effective than metal detectors if the conditions are right [12]. If there is a lot of distracting surroundings, excessively warm or cold, heavy rain, thick vegetation or areas with barbed wires, the dogs will not be very successful. Dogs require a lot of training and a lot of motivation and encouragement [3].

Figure 7: A mine detection dog, searching for landmines [33].

Rats

Like dogs, rats also have an exceptional sense of smell and they are intelligent and trainable. But unlike dogs, they are too light to set off any landmines. With weights of under a kilogram, they cannot set of landmines that require a pressure of five or more kilograms. The rats are trained to scratch on the surface where they have found a landmine [13]. Rats also require a lot of training.

Figure 8: A rat, trying to locate a landmine at a training facility [32].

Bees

In recent years, scientists have developed a method for using honeybees to detect explosives. Bees are capable to detect pollen with their sense of smell and could sniff out explosives when trained to do so. They are trained in the same way as dogs and rats, by associating the desired smell with a reward [14] [15] .

1.3.2 Clearing

Once the location of landmine is known, there are several methods for removing them. The following are a selection of methods for removing, disarming and detonating landmines.

Probing

Figure 9: Mine Prodder ABL700 [28].

Though this might go under the detection category, probing the ground with a prodder is the method used after locating a possible landmine with a metal detector, a dog, or another detection method. Since these detection methods only detect that there is a mine under the surface, they do not always detect what kind of mine it is or how deep under the surface it is located. After marking the suspected area deminers will have to identify the landmine and disarm it or just try to detonate it. The most common method is to probe with a prodder. There are several different tools for this, but the basic principle is the same. A person probes the ground and excavates the ground until the landmine can be identified. Manual demining is the most commonly used method in humanitarian demining. It is also, so far, the only method that can achieve UN standards of a 99,6 % clearing rate. However, it is also the most costly and timely method. It requires a lot of human effort and training [9].

Figure 10: Manual demining method using metal detector and prodder [16].

Armoured vehicles

The military might not have the time needed for mine detection and probing. Big, heavy and armoured vehicles are used to quickly clear an area. The vehicles drive over a surface equipped with certain tool systems and mechanically detonate the landmines [17].

Flail system

A flail is the most commonly used type of mechanical system. Several lengths of chain-links are attached to a fast rotating axle, shaft or drum, violently smashing the ground. This results in the landmines either being damaged, detonated or thrown aside [17]. The rotating drum is kept in a constant height above the ground using a flail depth-control system. The flail system can clear a path up to 4,6 meters wide and up to a depth of 0,9 meters [3].

Figure 11: M1271 Mine Clearing Vehicle [18].

Tiller system

The second most commonly used mechanical system is the tiller. A rotating drum is fitted with overlapping rows of steel teeth, sharp blades or bits, which grind and rip up the ground as the drum is lowered to a selected depth. The depth varies from 0 to 40 cm and the impact from the teeth and blades are called a bite. A tiller bite can result in a landmine being damaged, detonated or thrown aside, just like the flail system [17].

Figure 12: Digger D-3 with a tiller system [19].

Mine roller

The principle of a mine roller is to roll over an area with pressure on the ground and detonate operational landmines. They cannot influence mines that, from some reason, are inactive. These rollers are often mounted on the front of an armoured vehicle. The purpose of mine rollers is to get to a desired area quickly and create a safe path for people and other vehicles [17]. Rollers are normally used in sets of 3 to 6 with a gap between the sets. To also catch mines that could be set of by trip wire or tilt rods between the sets, there are often a chain or another linkage between them [3].

Figure 13: MMPV Type II (RG-31) with EHP Roller [20].

Mine Plough

The mine plough system is based on farming science. A wide plough is attached to a tank and can clear a safe lane up to 4 meters wide by digging up the top layer of the ground.. The modern plough is lowered and raised by an electro-hydraulic system. The ploughing depth can be controlled by use of skids that are constantly in contact with the ground [3].

Figure 14: Full Width Mine Plough from Pearson Engineering [21].

1.4 Limitations and flaws in existing methods

Searching for landmines with a metal detector is a very time consuming operation. Very carefully, the detector must be moved back and forth over the entire area, and even though it can locate landmines containing metal, it will not detect the landmines that contain no or very little metal. This makes searching for landmines with a metal detector very dangerous. Though the detectors with both GPR and metal detectors might reduce this danger, it is still a very slow process.

The use of animals is a quicker way of locating landmines. Although it is not safe for the animals, persons are away from harm's way. Rats are not likely to be heavy enough to detonate a pressure sensitive landmine, but a landmine that has lied in the ground for several decades might be unpredictable. Bees will most definitely not detonate any landmine, but they might be hard to spot when flying around. Dogs are heavy enough to detonate landmines. Therefore, the loss of some dogs are expected. What these animals have in common is that it takes a lot of training to make these methods successful.

The methods, of removing or neutralizing a landmine, as mentioned earlier, have their flaws. The flair, tiller, mine roller and mine plough are all big and heavy machines that damages the soil. Apart from the mine roller, they more or less rip the ground up. Most places, this will not be a problem, but if the soil is in use in any way, these machines will ruin it. In addition, these machines are very expensive. Not only expensive to buy, but maintenance, crew and gas are also high cost.

The probing method, on the other hand, is not soil damaging. The probing does involve digging out a crater around the located landmine, but compared to the damage caused by the heavy machines, it is not an issue. However, probing is very time consuming. Digging up a single landmine takes time and it takes a lot of training. Put those two together and it becomes expensive as well. However, the biggest flaw is that it is dangerous. Mistakes may cause serious injuries or even fatalities.

1.5 Scope and limitations of this thesis

Since GPR is so expensive and not yet fully developed for landmine location, and metal detectors have its flaws, this thesis will not contain landmine location. This decision was made along with the people at FFI. This thesis will focus on the mechanical detonation of landmines, which location is already known.

The thesis will contain the development of a modular and mechanical detonation system that would fit on NMBU`s agricultural robot. The system must be low cost, environmentally friendly and non-life threatening. It is important that the system is simple and modular, so that damaged parts can be easily replaced or repaired on site. The system must also be able to withstand several explosions from an AP landmine without being damaged. In that way the robot could detonate several landmines and work for longer periods of time without the need for service. Once given the location of a landmine, the system must be able to detonate the landmine autonomously and minimal supervision required.

The system will only consider AP landmines. AT landmines are developed to damage armoured vehicles and would destroy the robot when detonated at close range. The people at FFI suggested that the system should detonate every landmine located, and if the detonated landmine happens to be a AT landmine, the destruction of the robot is acceptable. The mechanical detonation system will only consider landmines that are triggered by pressure.

A system like this, as far as I know, does not exist. The reason probably being that autonomous robots are just now been developed to a point where such applications are feasible. In addition, there are many factors to consider when developing such a system.

The development process include problem analysis and concept and design evaluation, as well as calculations and simulations. Equipment, such as motors, gearboxes, actuators, wires, etc. will be existing products on the marked.

1.6 Thorvald

Thorvald is NMBU´s agricultural mobile robotic platform made in the first half of 2014. This small, lightweight and modular robot is fully autonomous and was intended as the next step in farming. Thorvald was not made as a product to be sold, but as a science platform. It has four wheel drive and four wheel steering and could work up to speeds of 3,5 km/h. The idea was that Thorvald could work 24 hour a day, 7 days a week with minimal supervision.

Five master students wrote their master thesis on Thorvald in 2014. Now, in 2016, two master students and one PhD candidate are working on the second version of Thorvald, called Thorvald 2.

As the first Thorvald, Thorvald 2 will also be lightweight and small as well as modular and autonomous.

Figure 15: Thorvald 2 in three different models. From the left: One wheel drive and one wheel steering, two wheel drive (front) and two wheel steering (front), four wheel drive and four wheel steering. Curtesy of Lars Grimstad.

1.7 Methods

The method for this development process is similar to other product development methods. First, the problem at hand is analysed, before different concepts are suggested. Careful evaluation of each concept leads to one chosen concept. The same procedure is repeated for the design of the concept. After a concept and design has been chosen, calculations and simulations will determine the equipment and material needed.

2 Technical walkthrough

This part of the thesis contains the technical aspects of different types of landmines and how big the shockwave pressure, from an exploding landmine, is. By studying how these landmines operate and what kind of forces they create when they are detonated, the development of the concept and design is more efficient. The technical walkthrough will only consist of AP landmines, since AT landmines are not taken into consideration.

2.1 AP mine specifications

Pressure activated landmines are the most commonly found landmine. A pressure-activated landmine usually requires an activation pressure between 5 and 20 kilograms. However, some of the landmines equipped with pressure sensitive fuzes, require the pressure to be held for a while. Usually this takes from a fraction of a second to several seconds. There are several hundred different types of landmines, but to understand how they work a small selection of them are studied below [3] [22].

M14

The M14 is a United States military AP landmine that is a pressure operated blast mine. It is made of a plastic body with a height of just 40 mm and a 56 mm diameter, making it very small. When armed, a pressure between 9-16 kg, or more, can detonate the mine. The M14 carries 28 grams of the explosive compound, Tetryl [3].

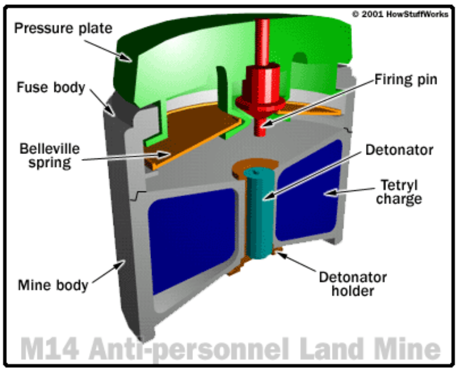


Figure 16: Illustrated cross-section of a M14 AP Landmine [30].

The M14 has a cylindrical shape, consisting of an all-plastic body with a minimal of steel parts in the detonating mechanism. It has six vertical ribs on the outside, for easy identification [3].

Figure 17: A M14 AP Landmine held in a hand [31].

Once armed, and the necessary pressure is put on the pressure plate, the Belleville spring depresses and snaps into reverse and drives the firing pin into the detonator, activating the main charge. This landmine is very difficult to detect because of the few metal parts. Only a very strong and precise metal detector can detect it. However, once the location of the M14 is known, it is an easy mine to handle [3].

PMN-1

The PMN-1 AP blast mine is one of the most commonly used mines in the world. Mostly found in the Middle East and the Far East. This mine was primarily developed as protection for the AT mines, but is also used in protective minefields and ambush. With a diameter of 112 mm and a height of 56 mm, the PMN-1 is a large cylindrical landmine.

Figure 18: PMN-1 AP Landmine [3].

The PMN-1 contains a main charge of 240 grams of TNT and a booster charge of 9 grams. In addition, any direct pressure above 5-8 kg will detonate the charge.

This large landmine is designed to kill and can cause casualties some distance away. It might also damage wheeled vehicles, making this a threat to the robot.

The PMN-1 has enough metal in it to be easily detected by a standard metal detector [3].

PMR-2A

The PMR-2A is an anti-personnel fragmentation stake mine. Based on the original design of the USSR POMZ stake mine, it is a mine that uses trip wire as a detonating mechanism. It has a height of 132 mm, diameter of 66 mm, explosive weight of 100 grams of TNT and it takes a pressure of 3 kg on the trip wire to detonate. The PMR-2A has nine fragmentation rows of cast iron [3].

Figure 19: A PMR-2A AP fragmentation stake mine.

This mine is normally laid above the ground and is therefore visible to the naked eye. However, the mine might be covered by vegetation or sand and therefore might not be detected before the trip wire fuze is activated. The trip wires might go as far as 10 meters away, and because this is a fragmentation mine, it can cause damage at up to a hundred meters away [22].

Valmara 69

Figure 20: A Valmara 69 bounding AP landmine.

The Valmara 69 is an Italian bounding AP landmine. The plastic bodied and cylindrical landmine has a diameter of 130 mm and a height of 205 mm, making it a large AP mine. The Valmara 69 uses both pressure and trip wire activation to detonate the 420 grams of explosives. The internal body consist of the main charge, surrounded by more than 1000 steel splinters. The pressure required for the trip wire is 6 kg and 10,8 kg for the pressure mechanism [3].

When buried, the visible part of the mine resembles the top of a carrot. Hence the nickname “carrot head”. The Valmara 69 consist of metal and is very easy to detect with a metal detector. However, since it also uses trip wire, using a metal detector is not without risk [3].

2.2 Explosion specifications

To calculate the magnitude of the pressure exerted on the robot, the scaled distance must be found. This can be done by using the equation 2.1. This equation is retrieved from a handbook at FFI, which is kept from the public.

$$Z = \frac{R}{Q^{\frac{1}{3}}} \tag{2.1}$$

Where:

Z = The scaled distance (m/kg$^{1/3}$).

R = Distance from the origin of the blast (m).

Q = Mass of the explosive (kg).

When the scaled distance is found, the pressure of the shock wave from the explosions can be calculated by equation 2.2. This equation is retrieved by a document marked with the security classification, NATO Unclassified. This mark is applied to official information owned by NATO and though it is not classified information, it is somewhat held from the public [23]. The equation uses TNT as the explosive compound. If the explosive is something other than TNT, the weight of the explosive must be given a TNT weight equivalency. The equation also does not take into account that the explosion happens a little below the surface.

$$P_i = e^{(A+B(\ln(Z))+C(\ln(Z))^2+D(\ln(Z))^3+E(\ln(Z))^4+F(\ln(Z))^5+G(\ln(Z))^6} \tag{2.2}$$

Where:

P_i = Incident pressure (kPa).

Z = Scaled distance (m)

The remaining values A to G are found in table 2.1.

Table 1: Table from a NATO unclassified document, containing values for calculation of incident pressure.

Structure	Incident pressure, Pi (kPa)							
	A	B	C	D	E	F	G	Range (m/kg$^{1/3}$)
Spherical free air burst	6,86944	-2,32414	-0,19443	0,32038	-0,08784	0,00841	0	0,5<Z<100
Hemispherical surface burst	7,2106	-2,1069	-0,3229	0,1117	0,0685	0	0	0,2<Z<2,9
	7,5938	-3,0523	0,40977	0,0261	-0,01267	0	0	2,9<Z<23,8
	6,0536	-1,4066	0	0	0	0	0	23,8<Z<198,5

3 Concepts

The following are the possible concepts, briefly explained and evaluated until a concept is chosen.

3.1 Concept suggestions

All concepts use the assumption that the robot is equipped with sensors that can detect possible landmines in the ground. Therefore, the concepts are only focused on the detonating mechanism.

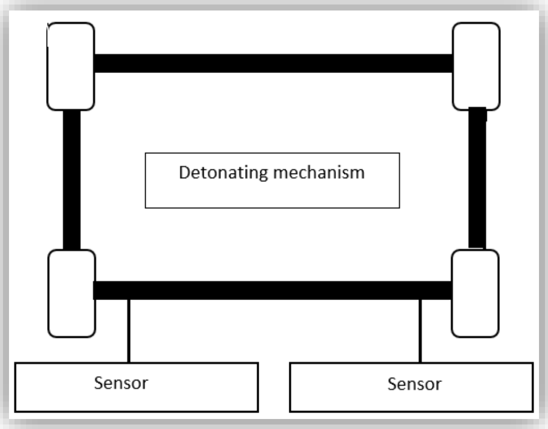


Figure 21: Simple overview sketch of the concept. The robot, with a detonating mechanism in the middle and sensors in front.

Dropping a load

After finding a possible landmine, the robot will simply drop a load, of some kind, on the ground. This will simulate the weight of a person stepping on the mine. The robot will position itself so that the load is directly above the target. The load that is being dropped will have the weight and the height enough to create a force on the ground, matching the force exerted by a person. A winch, or another lift mechanism, will be mounted so that the load could be raised up again after being dropped.

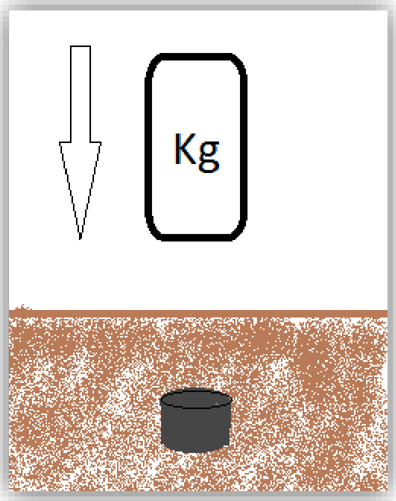


Figure 22: Simple drawing of the dropping load concept.

Placing explosives and detonate remotely

Instead of dropping a load on the target area to simulate a person, a small explosive charge would be placed. The robot will then drive away before detonating the charge. The pressure from the explosion of the charge would be sufficient for detonating or destroying the landmine.

Shooting at the landmine

On top of the robot, there will be placed an automatic rifle. When the robot have found a possible landmine, it will drive a certain distance away before firing a bullet at the target area, destroying or damaging the landmine.

Dragging a roller

A roller of some kind is attached on the back of the robot, hanging a certain distance behind. The robot will drag the roller over an area, detonating landmines with the ground pressure created by the roller. This concept does not necessarily require sensors to detect landmines. The robot could simply drive in a pattern until an entire area is cleared.

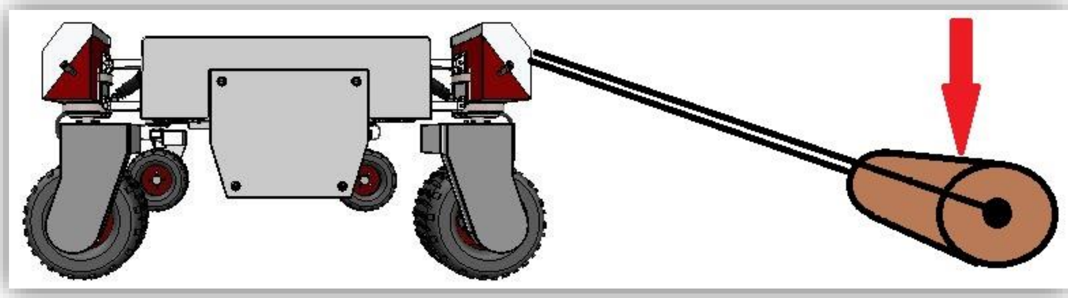


Figure 23: Illustration of the robot dragging a roller.

3.2 Concept discussion

This subchapter contains the positive and negative sides of each concept. In addition, it contains the challenges each concept face.

Dropping a load

Table 2: Positives, negatives and challenges for the dropping load concept.

Positives	If the object the sensors have found turn out not to be a landmine, the winch will lift the load up again. In that way, no material is wasted. In case the object is an armed and functional landmine, the impact force will detonate it. In the case of a landmine that requires pressure over time, the load will remain on the ground for enough time for them to be triggered as well. Parts for a system like this will be cheap and easily replaced and there is no need for heavy programming.
Challenges	Since the explosion will happen near the robot, there will be some forces acting on it. Therefore, the robot should have protection and a design that minimise the damage. The robot must position itself roughly close to the target, and compensate for any angle.
Negatives	Since there will be forces acting on the robot, it will be more exposed for damages and might require more maintenance.

Placing explosives and detonate remotely

Table 3: Positives, negatives and challenges for the concept of placing small charges.

Positives	The explosion from the landmine will not harm the robot and the pressure form the detonated explosives will be enough to trigger pressure sensitive landmines.
Challenges	Finding a way to place the explosive charge and detonate it. There should be a magazine of charges, otherwise it will require refill every time it has placed a charge. To keep the costs down, the detonation should be with a wire fuse. There will be challenging to find a way to get a fuse in every charge in the magazine.
Negatives	If the sensors gave a false lead, then a charge would be used in vain. Since there probably is going to be many false detections there will be a lot of wasting of explosive charges and since there will be small blast craters every time a charge goes off, there will be some damage done to the soil. Although the pressure from the explosives will detonate some landmines, they might not detonate the kind that requires pressure over time.

Shooting at the landmine

Table 4: Positives, negatives and challenges for the concept of shooting at the landmines.

Positives	The explosion from the landmine will not harm the robot.
Challenges	For this to work, the gun must be very accurate. If the robot is to drive a distance away, the gun must be able to hit exactly right at the mine. There will have to be some very high-resolution cameras and a program that can process the images to ensure that the gun hits the target.
Negatives	Though not very expensive, bullets are not free. And like the explosive charges there will be many false detections, which will lead to a lot of bullets being wasted. In addition, the bullets might not trigger all of the landmines, especially the ones that require pressure over time. Part for this kind of system, like the gun and cameras, are not cheap and would be a little difficult to replace or repair. If there is a manual demining afterwards to verify that the area is cleared, there will be a lot of metal bullets in the ground that will set off metal detectors.

Dragging a roller

Table 5: Positives, negatives and challenges for the concept of dragging a roller.

Positives	No precision system is needed. The robot would simply plan a route, and drag the roller over the whole area. Any pressure sensitive landmines would detonate. If driven slowly, the landmines that require pressure over time would be activated as well.
Challenges	It will be very heavy and create a lot of drag for the robot. The robot will require motors with high torque and tyres with good grip. The wheels of the robot must evade the landmines. Otherwise the wheels of the robot might be damaged or destroyed. The roller must be able to be dragged a lot of places, and will need to overcome rocks and tree stumps.
Negatives	This might damage the soil a bit more than wanted.

3.3 Chosen concept

The chosen concept is the dropping load concept. Mainly because the amount of false detections, might lead to a lot of wasted material and high cost. In addition, since the robot will not be influenced in another way then some weight of the detonating system, it might be a better option than dragging a roller. A load dropping system does not require extreme precision since there, in case of a miss, is just to lift the load up and try again.

4 Design

This chapter is about the design of the chosen concept. As before, different designs are briefly explained and then evaluated.

4.1 Design suggestions

The following are a selection of different design that follow the load dropping principle.

Hammer design

A robotic arm will be attached to the robot and work as a hammer. The arm will be raised up and dropped to the ground creating a large force on the ground, which will detonate pressure sensitive landmines.

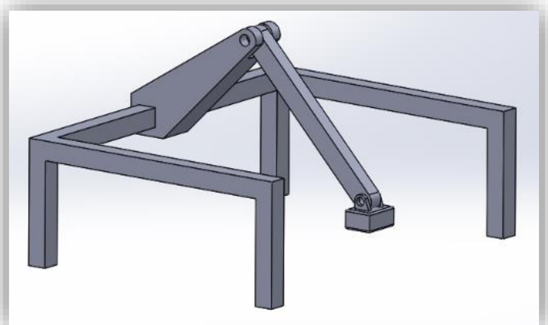


Figure 24: Simple illustration of the hammer design.

Load dropper with winch

A scaffolding will be attached to the robot, along with a winch and a pulley wheel. A steel wire will connect the winch and the load via the pulley wheel. The winch will lift the load up, and drop it down on the target area. This will create a large force of impact on the ground. The load could be different shapes and materials.

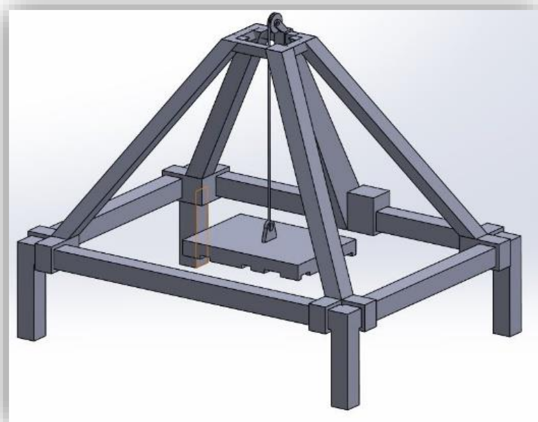


Figure 25: Simple illustration of the load dropper with winch design.

Load dropper with tracks

Instead of a winch, this system will have a massive load that will run up and down along a track, driven by a motor and gears.

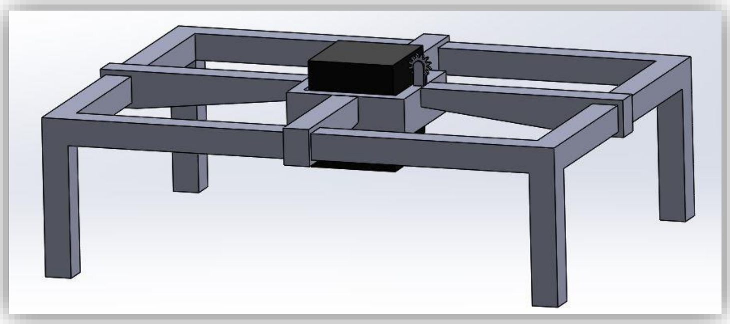


Figure 26: Simple illustration of the load dropper with tracks design.

4.2 Design evaluation

In this subchapter, just like in the concept chapter, each of the design suggestions gets their positive and negative sides, as well as their challenges, explained.

Hammer design

Table 6: The positive and negative sides, along with the challenges for the hammer design.

Positives	If there is a false detection, the robot arm will simply retract and be ready for the next one.
Challenges	The arm will sustain a massive force when detonating a mine, and will be pushed back with a massive acceleration. Getting the arm to rotate freely when pushed back, to avoid breaking anything would be challenging. In addition, the arm must break before it hits something else.
Negatives	A lot of programming is needed for a system like this, and the motors required might be hard to find. As mentioned, the motors must be able to accelerate incredibly fast and must be able to brake without being damaged. Such motors, if they exist, would probably be expensive.

Load dropper with winch

Table 7: The positive and negative sides, along with the challenges for the load dropper with winch design.

Positives	Little programming is needed for this system. The winch will get a signal from the robot, when it is positioned correctly, and start the procedure. Minimal material close to the explosion and the system that has the fewest parts exposed for damage. Probably the cheapest solution.
Challenges	To ensure high enough velocity, the load must be able to fall close to freely, otherwise the load must fall further, which means the structure must be larger. When the height increases, the accuracy decreases. The load will experience, like the hammer, a massive force. The load will then have the potential to be a dangerous projectile and might damage the robot. The load will drop in the same direction as the gravitational pull. If the robot is standing at an angle, the robot must adjust its position so that the load will hit the target.
Negatives	The load might be dangerous if it is a solid. If the load dissolves when detonating a mine, the robot will require service for every detonation.

Load dropper with tracks

Table 8: The positive and negative sides, along with the challenges for the load dropper with tracks design.

Positives	This will ensure high pressure on the ground, and unlike the load dropper with a winch, it will not dangle around and it will fall parallel to the robot.
Challenges	As the winch system, getting the load to fall close to freely is a challenge. Getting the load to fall freely on a track is even more difficult, than with a winch.
Negatives	A lot of material is close to the explosion, which makes it very exposed to damaging forces.

4.3 Chosen design

The design chosen is the load dropper with winch. This design is probably the cheapest, easiest and the most practical. It is the design with the least parts close to the explosion and the system that has the most chance of surviving a detonation of a landmine.

4.4 Design improvements

First of all, the type of load is to be determined. The original thought was to use a steel ball. In that way the load will have a small volume and a shape that is suitable for all terrain.
Another suggestion was a steel plate, as illustrated on figure 25. With a shape like that, a larger area can be hit, assuring that the target object is affected. However, this will only be successful if the ground is level. If there is small holes, trenches or rocks, the plate might not hit the target. Therefore, the load must have another shape.

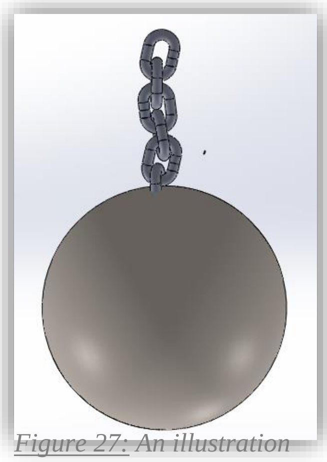


Figure 27: An illustration of the load as a steel ball.

An issue, explained by Ove Dullum at FFI, is that the blast from a detonated mine will exert a big force on the load and cause extreme acceleration. A steel ball will then become a projectile that could potentially be very dangerous. In addition, if the ball is attached to the robot, the ball will probably rip the robot apart when flying away. To fix this problem, the load must dissolve when exposed to an explosion and the remaining bits must be either small enough or light enough to ensure that they do not become smaller projectiles. This would result in the robot needing service every time it detonates a landmine. Although not completely ideal, the people at FFI and I agreed that it was a necessary compromise.

If the material is to be solid and lightweight, the load will have too big of a volume. The best solution is to have a material, which in small amount is so small that it lose speed quickly, but in a large amount, will be heavy enough.

Since the load is to be dissolved every time a landmine detonates, the material will be scattered over the location of operation. To prevent littering, the materials must be natural. Also, to make it easier to replace the load, the material can be something that can be found everywhere. That leads to the possible materials to be either water or sand. Some places in the world, water is in short supply and it would be wasteful to use water for this purpose. That leaves sand as the logical solution. Sand can be found virtually anywhere in the world.

Dry sand has a density of around 1600 kg/m^3 [24]. A bag of sand will not have too much of a volume, and it could be shaped as desired. When the landmine detonates the bag of sand will dissolve and it will not become a threat to the robot or surrounding area. A replacement bag is filled with sand found on site and the robot will be good to go again.

4.5 Load

The weight of the load and the height, from which it is dropped, must be great enough to trigger the landmines. A landmine can go off by a pressure of as little as 5 kilograms, but some require more. The landmines can also be buried a little deeper than when first planted, by sand or vegetation. To ensure that the landmine will detonate, the impact force on the ground should be greater than the force exerted by a 100 kilograms heavy man. Newton's first law (4.1) can calculate the force acting on the ground from a man, standing on it.

$$F = ma \tag{4.1}$$

Where:

F = Force (N)
m = Mass (kg)
a = Acceleration (m/s^2)

To calculate the impact force acting on the ground from a falling object, the impact speed must be found. By equation 4.2 the impact speed of an object, falling from a certain height, can be calculated.

$$v = \sqrt{2gh} \tag{4.1}$$

Where:

v = Velocity (m/s)
g = Gravitation (m/s^2)
h = Height (m)

The equation for the energy of an object with speed and the equation for work done by a force are put together to create an equation (4.3) for the impact force exerted from the falling object onto the ground.

$$F = \frac{mv^2}{2s} \tag{4.2}$$

Where:

F = Force (N)
m = Mass (kg)
v = Velocity (m/s)
s = Stopping distance (m)

The stopping distance is the distance the load travel after hitting the ground. The stopping distance is dependent on the ground. What the material is and the state of the material affect the stopping distance. Longer stopping distance means less impact force. Since the ground is different from one minefield to another, it is hard to determine the stopping distance.

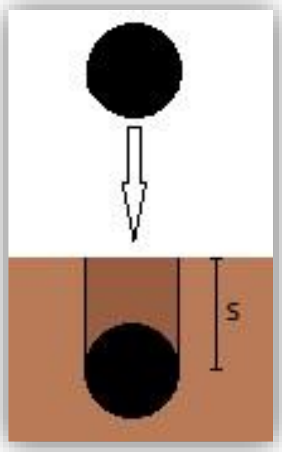


Figure 28: Illustration of the stopping distance, s.

After choosing the mass of the load, the dimensions of the load need to be worked out. The volume of the load is dependent on the density of the material, as shown in equation 4.4.

$$V = \frac{m}{\rho} \tag{4.3}$$

Where:

V = Volume (m^3)
m = Mass (kg)
ρ = Density (kg/m^3)

Volume is also given by equation 4.5, which can be used to determine the dimensions.

$$V = Al \tag{4.4}$$

Where:

V = Volume (m^3)
A = Area (m^2)
l = Length (m)

The size of the impact area and the actual shape of the load, also must be determined. To calculate this there are some equations that are useful. Equation 4.6 gives the area.

$$A = \pi r^2 \tag{4.6}$$

Where:

A = Area (m^2)

r = Radius (m)

An equation (6.7) for calculating the pressure on an area could also be helpful.

$$p = \frac{F}{A} \tag{4.7}$$

Where:

P = Pressure (N/m^2)

F = Force (N)

A = Area (m^2)

In chapter 5, during the calculation, it is decided that the shape of the load will be a cone. The volume of the bottom half of a cone is given by equation 4.8 [25].

$$V = \frac{\pi h}{12} (d^2 + db + b^2) \tag{4.8}$$

Where:

V = Volume (m^3)

d = The smaller diameter (m)

b = The larger diameter (m)

h = Height (m)

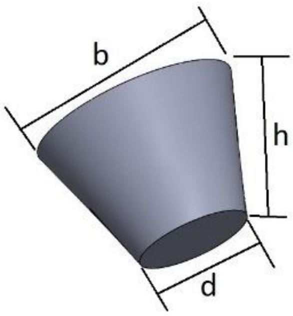


Figure 29: Illustration of the dimensions of the half cone shape.

The quadratic equation (4.9) might be useful as well.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{4.9}$$

4.6 Winch

The winch must be able to lift the load up, hold it there, and then release it. When released, the load must fall with as little resistance as possible to ensure high acceleration. To achieve this, either a clutch system can be used or the motor must be able to reverse at high speed.

Many winches on the market contains both motor and gear. Most of them are mainly built for other purposes, like dragging cars up from a trench, and they lack the ability to release quickly. The solution is to build a custom-made winch.

An electrical motor with the capacity to turn with enough torque one way, and release quickly the other way, is a challenge to find. In addition, they are often more costly and over dimensioned for this type of use. Therefore, it might be best to use a clutch.

An electric motor along with a gear will drive the winch, and a clutch will separate the motor and gear from the drum when the load is to be released.

The winch does not have to be fast. Therefore, the required rpm is low. The torque required is dependent on the weight of the load and the radius of the drum.

Equation 4.6 gives the torque induced by the load on the axle of the winch.

$$M = Fr \tag{4.9}$$

Where:

M = Torque (Nm)

F = Force (N)

r = Distance from the force to the centre of the axle (m)

The circumference of the cross section of the drum can be calculated with equation 4.7.

$$O = 2\pi r \tag{4.10}$$

Where:

O = Circumference (m)

r = Radius (m)

The motor effect required can be calculated with equation 4.8, after calculating the required work done with equation 4.9.

$$P = \frac{W}{t} \tag{4.11}$$

Where:

P = Power (W)
W = Work (J)
t = time (s)

$$W = Fs \tag{4.12}$$

Where:

W = Work (J)
F = Force (N)
s = Distance (m)

4.7 Final design

This subchapter contains the final solutions for the design.

4.7.1 Load

The load will be a cone shaped bag of sand. It will be 25 kg heavy, with a volume of 0,015625 m^3 and a height of 0,25 m. These values are determined in chapter 5. The load will be dropped from a height of approximately 1 meter above ground. The weight and the height will ensure high enough impact force to detonate AP landmines.

Since the load is a bag of sand, it will dissolve when exposed to an explosion. Therefore, the load will not become a dangerous projectile when detonating a landmine.

Figure 30: A rendered picture illustrating the shape of the load.

4.7.2 Winch

The Winch is custom made to suit the required specifications and needs. An electric motor, along with a gearbox will power the winch. A linear actuator will connect and disconnect the custom made clutch, which connects the drum to the axle. A motor controller will control the actions of the motor and the actuator, and a power converter provides the electrical power needed. The axles, shafts and mountings are crafted in steel. Though most of these parts could just as well be aluminium, they should all be steel in case of they are exposed to the explosions. Figure 31, illustrates the winch assembly with explanation of each component.

The electric motor, actuator, gearbox, motor controller, power converter, ball bearings and retaining rings are existing parts on the market. The remaining parts are built.

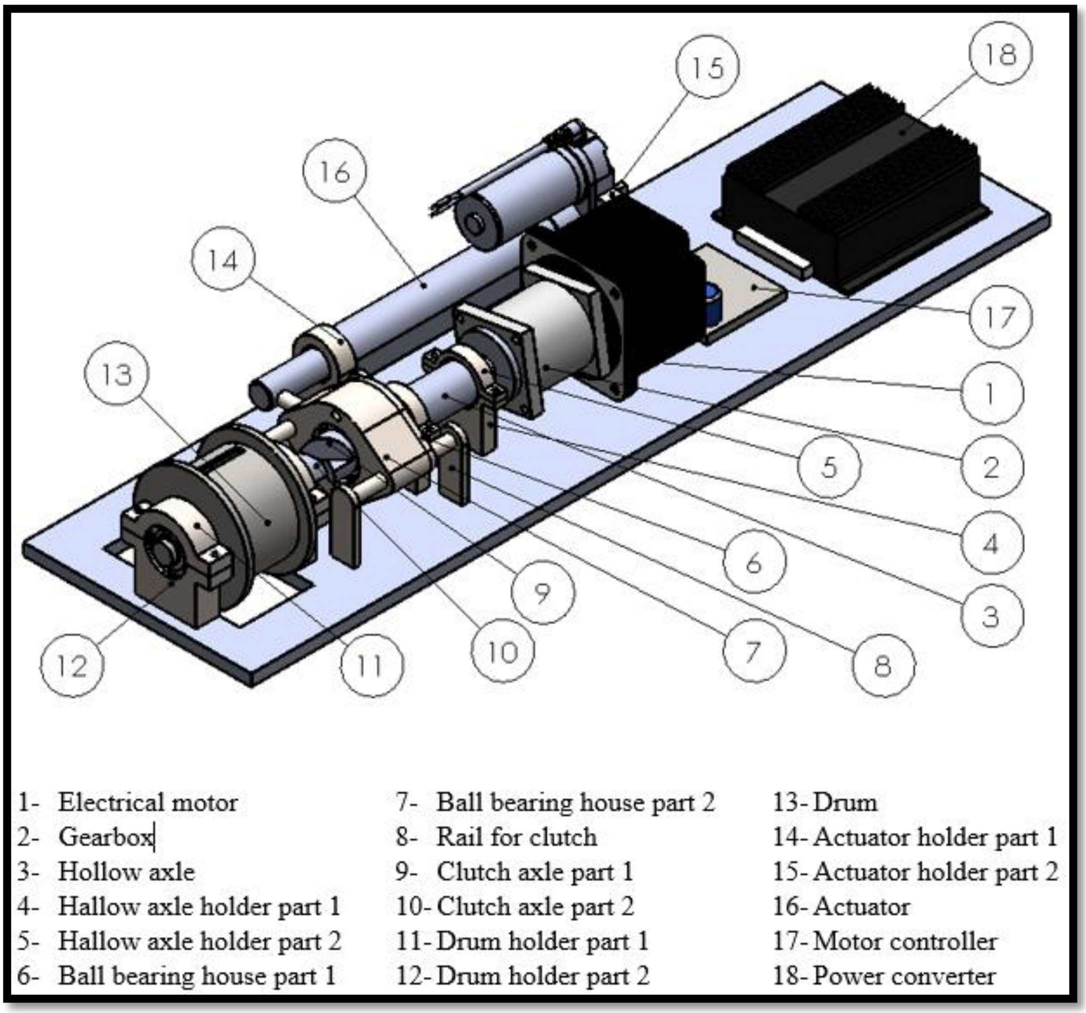


Figure 31: Assembly of the winch system, with numbered components.

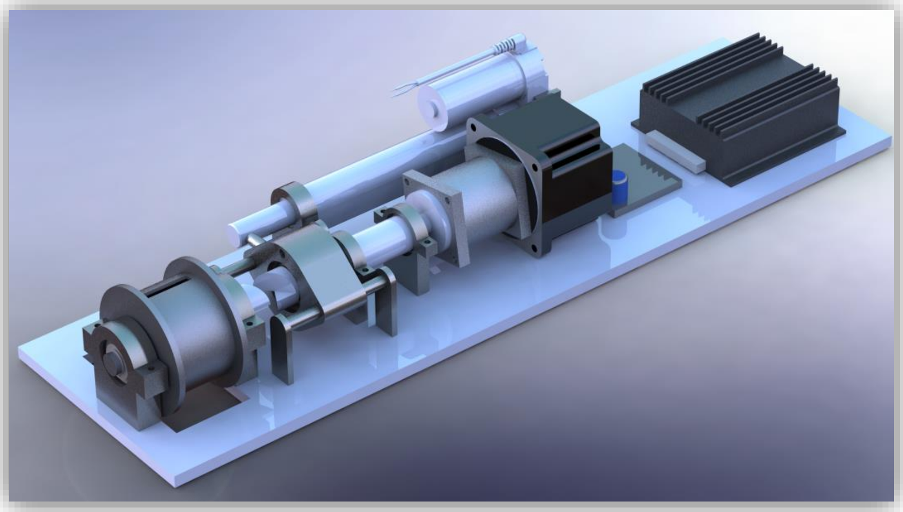


Figure 32: Rendered picture of the winch system.

4.7.3 Scaffold

Thorvald 2 has an aluminium frame, but the scaffold will consist of steel.

Simulations, from chapter 7, revealed that rods, even in steel, becomes deformed when in the range of approximately 1 meter form the explosion. The final design makes sure that the closest rod to the explosion is at a distance of 1,3 meters, as illustrated by figure 33.

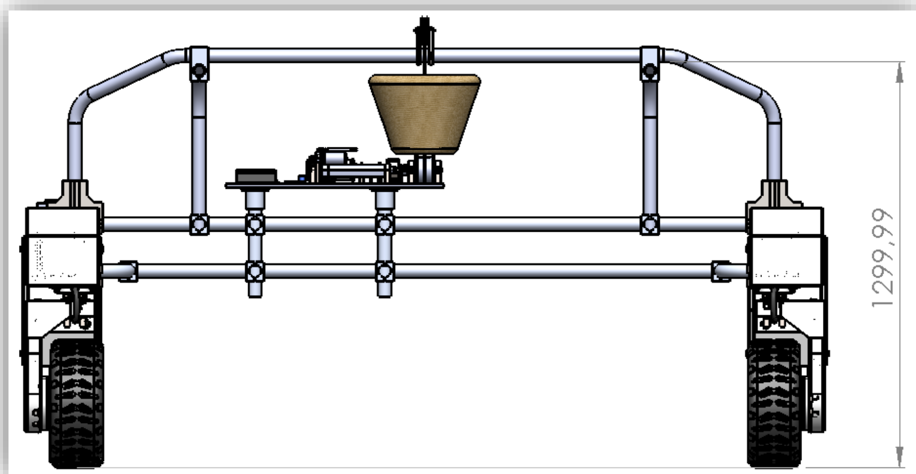


Figure 33: Thorvald 2, with the scaffold, winch and load attached, viewed from the side.

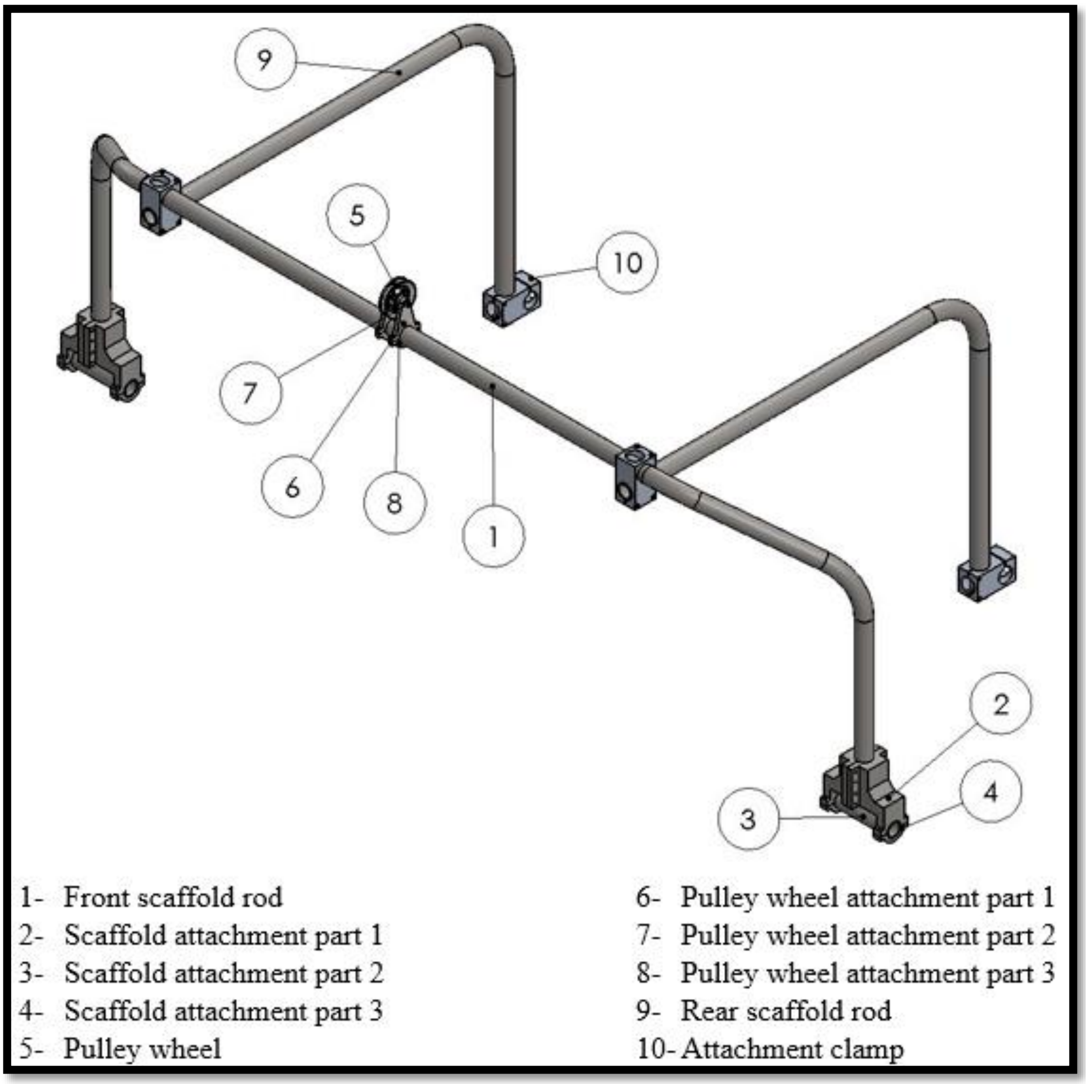


Figure 34: Assembly of the scaffold, with numbered components.

Figure 35: Rendered picture of the scaffold.

5 Calculations

This chapter contains the necessary calculations for the design.

5.1 Explosions

The most common amount of explosives in a landmine is between 40-100 grams. However, there are some landmines containing more than that [22]. To compare the effect different amount of explosives have on an object, equation 2.1 and 2.2 are used, and the values are plotted in a diagram.

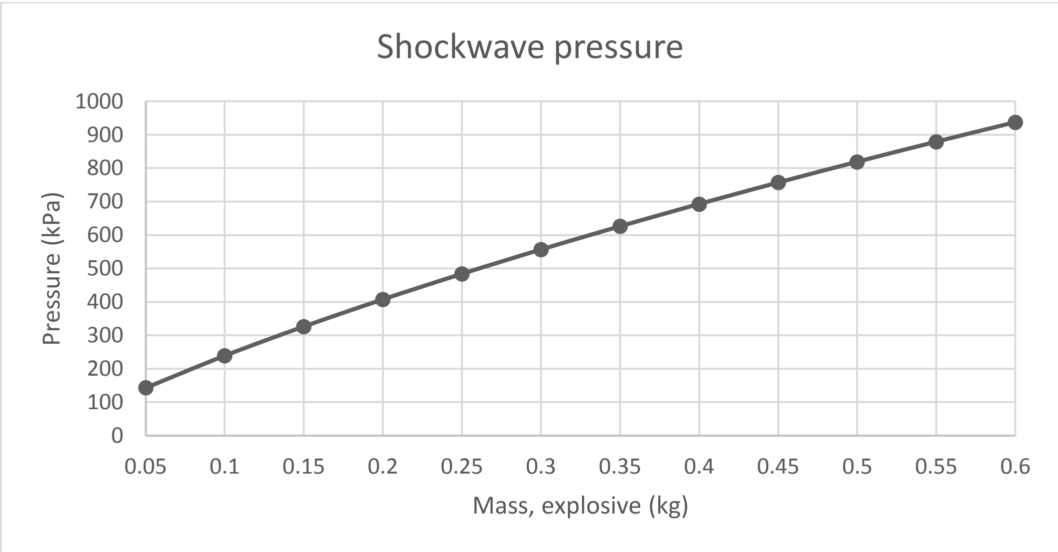


Figure 36: Shockwave pressure with different amount of explosives and with a distance of 1 meter.

As illustrated by figure 36, the relation between shockwave pressure and the amount of explosives, is almost linear. Since it is possible to encounter big landmines such as the PMN-1, the following calculations are made with 0,25 kg as the amount of explosives. Again, equations 2.1 and 2.2 are used, and the results are plotted in a diagram.

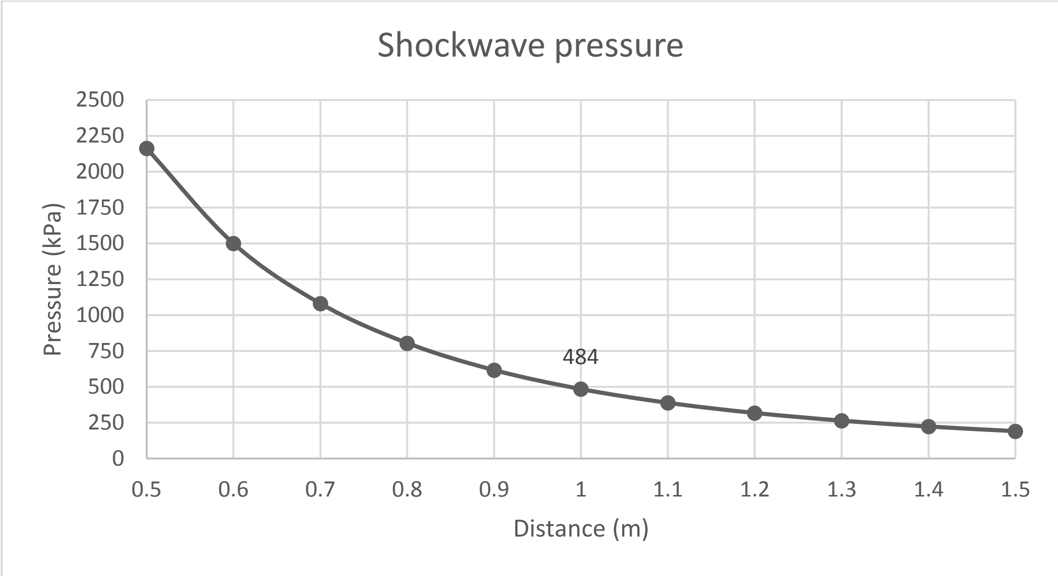


Figure 37: Shockwave pressure at different distances, with 0,25 kg of explosives.

Figure 37 illustrates the effect the distance away from the blast has on the shockwave pressure.

5.2 Impact force

The object is to create enough pressure on the ground to detonate active landmines. As mentioned earlier, the pressure should simulate a 100 kg heavy man, to be sure that the pressure mechanism activates. A 100 kg man creates a force on the ground equal to 981 N, calculated by equation 4.1.

Using a drop height of 1 meter the impact velocity is calculated with equation 4.2.

$$v = \sqrt{2 * 9{,}81 * 1} = 4{,}23$$

The stopping distance, as mentioned, is hard to predict. To see what effect the stopping distance has on the impact force, equation 4.3 can be used. Below is a couple of diagrams, illustrating how the weight of the load and the stopping distance affect the impact force.

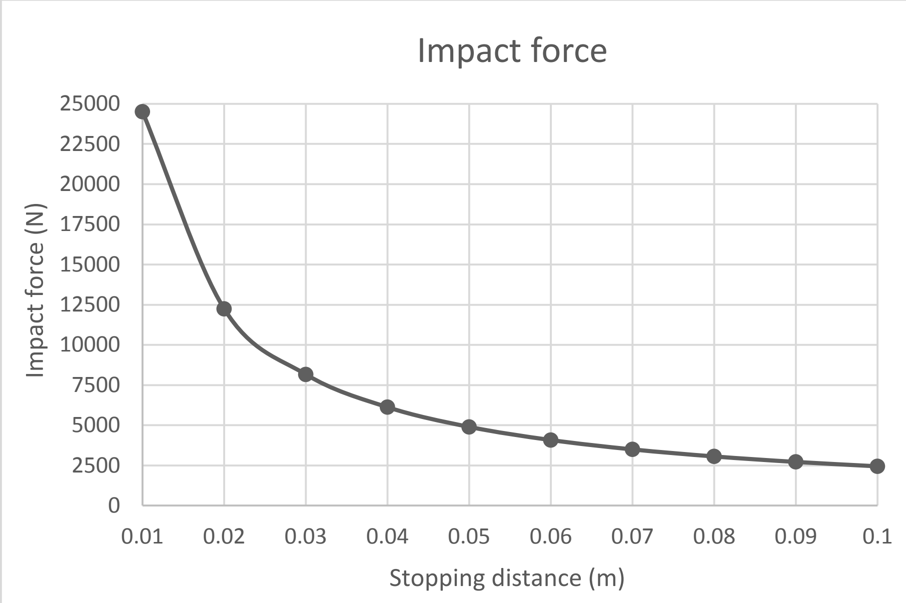


Figure 38: Impact force for a 25 kg load, dropped from a height of 1 meter, with different stopping distances.

The figure above, illustrates what effect the stopping distance has on the impact force of an object falling from 1 meter, with a mass of 25 kg. With a stopping distance of 1 cm, the impact force is nearly 25000 N, while with a stopping distance of 10 cm the impact force is down at 2500 N. The figure illustrates that as the stopping distance increases, the difference in impact force decreases.

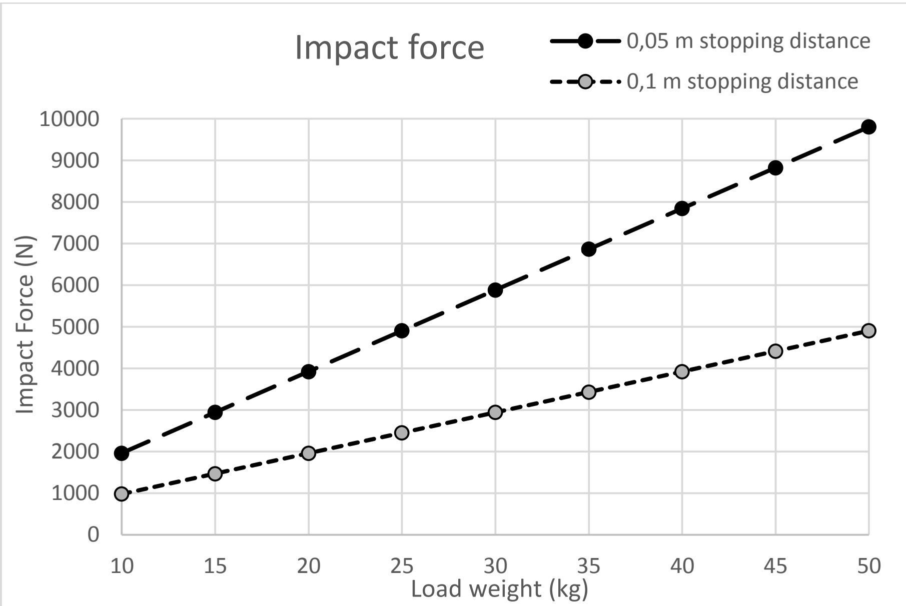


Figure 39: Impact force of a load, dropped at a height of 1 meter, for different load weight. One line for 0,05 m stopping distance and one for 0,1 m stopping distance.

Figure 39 illustrates the difference the weight of the load has on the impact force with stopping distances of 0,05 m and 0,1 m. The difference in impact force increases as the load increases.

From studying figures 38 and 39, the chosen weight of the load is 25 kg, the chosen height is 1 m, and the chosen stopping distance is 0,05 m. From equation 4.2 and 4.3, the impact force is calculated.

$$v = \sqrt{2 * 9{,}81 * 1} = 4{,}43$$

$$F = \frac{25 * 4{,}43^2}{2 * 0{,}05} = 4906\ N$$

The impact force of 4906 N is considerable more than the 981 N. 25 kg should therefore be more than enough to trigger any pressure sensitive landmines.

5.3 Load dimensions

The density of sand varies according to what state it is. Wet sand has a higher density than dry sand, but since the desired feature of the material is that it dissolves easy, the sand should be dry. Dry sand has an approximately density of 1600 kg/m^3. Using equation 4.4 the volume of the load is calculated.

$$V = \frac{25}{1600} = 0{,}015625\ m^3$$

To figure out the best size of the impact area, the specifications for the M14 AP landmine are used, because it is a small landmine that requires a relatively high activation pressure. With a diameter of 56 mm, the area is given by equation 4.6. For this to make sense, the assumption that the pressure has to be placed directly on top of the landmine is made.

$$A = \pi(\frac{56}{2})^2 = 2463\ mm^2$$

The M14 landmine detonates when a pressure of 9-16 kg is present. To find the minimum pressure needed to detonate this landmine, equation 4.1 and 4.7 is used.

$$p = \frac{16 * 9{,}81}{2463} = 0{,}064\ N/mm^2$$

As established earlier, a load with a weight of 25 kg, will have an impact force of 4900 N. By reversing equation 4.6 and 4.7, the smallest required impact area is found.

$$A = \frac{4900}{0{,}064} = 76563\ mm^2$$

$$r = \sqrt{\frac{76563}{\pi}} = 156\ mm$$

This means that if the impact area is 76563 square millimetres, which equals to a 312 mm diameter, the pressure would be enough to detonate the landmine. However, only if the load falls onto the entire area of the mine.

To reduce the risk of not hitting the landmines, when small holes and trenches appear, the impact area should be small. A diameter of 200 mm is selected, which will give an impact area, calculated by equation 4.6, and a pressure, calculated by equation 4.7.

$$A = \pi(\frac{200}{2})^2 = 31416\ mm^2$$

$$p = \frac{4900}{31416} = 0{,}156\ N/mm^2$$

This means that the load will only have to hit an area of about 1000 square millimetres to detonate the landmine.

Now that the impact diameter is selected, the rest of the load must be determined. If the shape is to be a cylinder, the length of the cylinder is given by merging equation 4.5 and 4.6.

$$l = \frac{0{,}015625}{\pi * 0{,}100^2} = 0{,}5\ m$$

A height of 0,5 m is a bit much. Therefore, the shape cannot be a cylinder. Maybe a cone shape would be a better option.

Equation 4.8 has three variables. Four, if you count the volume. We have already determined the smaller diameter at 0,2 m and we have the required volume of 0,015625 m^3. There are still two variables left, which means that one of them has to be determined first. Since the height was a problem of a cylinder, the height can be set as 0,25 m. Any higher, and the load will be too tall, any lower, the load will get very wide.

First, equation 4.8 and 4.9 are mixed to give an expression for the larger diameter.

$$x = \frac{-d \pm \sqrt{d^2 - 4b(\frac{d^2V12}{\pi h})}}{2b}$$

Now, the variables are placed.

$$x = \frac{-0,2 \pm \sqrt{0,2^2 - 4(0,2^2 - \frac{0,015625 * 12}{\pi * 0,25})}}{2} = 0,36\ m\ or - 0,55\ m$$

Of course the larger diameter cannot be negative, therefore the negative value is discarded. To verify the volume, the newly found diameter, along with the other known variables, are placed in equation 4.8.

$$V = \frac{\pi * 0,25}{12}(0,2^2 + 0,2 * 0,36 + 0,36^2) = 0,015813\ m^3 \tag{4.8}$$

The volume adds up to be a tiny bit bigger than the required volume. To compensate for any rounded off edges, the larger diameter is selected as 0,37 m.

5.4 Winch

Now that the weight of the load is determined, the power requirements for the motor, gear and actuator can be calculated.

First, equation 4.1 calculates the force of the load.

$$F = 25 * 9{,}81 = 245{,}25\ N$$

The diameter of the drum is selected as 0,08 m, which means the radius is 4 cm. This diameter is selected on the base of not creating too much torque, but still require few rotations. The torque acting on the drum is found by equation 4.9.

$$M = 245{,}25 * 0{,}04 = 9{,}81\ Nm$$

The required torque from the motor and gear is 9,81 Nm.

$$O = 2 * \pi * 0{,}04 = 0{,}25\ m$$

Equation 4.10, calculates the circumference of the drum to be 25 cm. Which means that the drum will only have to rotate a minimum of four times to lift the load up from the ground, depending how deep the load sinks into the ground or how much it bounces away.

To calculate the amount of power the motor must produce, equation 4.11 and 4.12 are used. First, the amount of time lifting the load would take must be determined. Since there is no requirements regarding time consumption, the lift time is set to 10 seconds.

$$W = 245{,}25 * 1 = 245{,}25\ J$$

$$P = \frac{245{,}25}{10} = 24{,}5\ W$$

Since four rotations are required and the time is 10 seconds, the required rpm is 24.

6 Equipment

This chapter contains the different equipment, the mechanical detonation system needs, that exist on the market. To ensure that none of the equipment fails and that they could still work if the design is altered, like the weight of the load being changed, they are somewhat over dimensioned.

6.1 Motor

The batteries already fitted on Thorvald 2 are 48V DC batteries. So to avoid the use of a converter, a 48V DC motor should be selected. If a suitable motor is not 48 VDC it is possible to equip a battery just for the winch or use an electric power converter.

The motor will have to produce a minimum of 25 W to be able to lift the load.

6.2 Gearbox

To get the right rotational speed and the desired torque, a gearbox needs to be attached to the motor. The motor, along with the gearbox, will have to put out a minimum of 24 rpm and a torque of a minimum of 10 Nm.

6.3 Clutch

For this thesis, a decision to build a custom made clutch was made. However, it is possible to use existing clutches for the same job. Although clutches on the market normally are made for purposes of connecting rotating axles at high speeds, some clutches fit the required specifications. However, after searching the internet and contacting several manufacturers, they turn out to be heavy and expensive. Both mechanical and electromagnetically clutches are possible options.

6.4 Actuator

The custom made clutch use an actuator. A linear actuator connects and disconnects the drum from the drive shaft. There are no requirements for the speed of the actuator, and the stroke length does not have to be big.

6.5 Converter

If the chosen motor and actuator require something other than 48V DC, an electrical power converter is required.

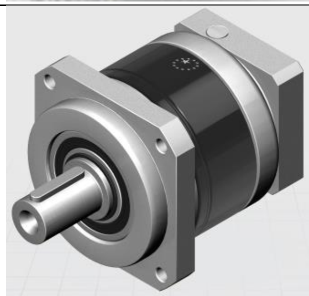
6.6 Motor controller

The motor and the actuator need to be controlled. They need to know when to do what, and when to stop. This is done by using a motor controller.

6.7 Chosen components

Table 9 contains the chosen equipment found on the market for the prototype. Equipment, such as the pulley wheel, micro switches, steel wire with hook and ball bearings are not listed, since they are cheap components and their specifications does not have to be precise.

Table 9: Chosen components for the prototype, with their specifications and price.

Component	Specifications	Price	Picture
Motor: BL910-A03 Provided by Electro Drives AS.	Voltage: 24 VDC Rated power: 250 W Rated torque: 0,75 Nm Rated speed: 3250 rpm Rated current: 12,5 A	Free	
Gearbox: PAII60-50 Bought from Electro Drives AS.	Exchange: 50:1 Torque: 35 Nm Max rpm: 65	2300 NOK	
Actuator: CAHB-10 Bought from Betamo AS.	Stroke length: 150 mm Strength: 1000 N Voltage: 24 VDC Motion: Linear	1000 NOK	
Converter: Mascot 8862 DC/DC Bought from Elfa Distrelec	Input voltage: 48 VDC Output voltage: 24 VDC Output Current: 3 A Power: 81 W	951 NOK	
Motor controller: SBL1360 Bought from Roboteq	Motor type: Brushless Max voltage: 60 Number of channels: 1 Max Amp per channel: 30 Direction: Forward/reverse	1852 NOK	

7 Simulations

Although no physical tests have been done, there have been computer simulations in ANSYS and IMPETUS. In ANSYS the scaffold structure have been tested for deformation and stress caused by the load, while in IMPETUS, the explosion of a landmine, and the effects the explosion has on the robot, have been tested.

7.1 ANSYS Workbench

ANSYS is an engineering simulation program able to simulate structures, fluids, electronics and more. The ANSYS Workbench is a platform where different simulation can be done in a user friendly fashion [26].

For this study, static structural where chosen as the type of simulation, and structural steel where chosen as the material. Structural steel, in ANSYS, has a density of 7850 kg/m3 and a yield strength of 250 MPa.

The geometry were imported from Solidworks CAD design.

Instead of a wire attached to the load, a force where placed on the surface of the pulley wheel. The force from the load where rounded up to 250 N. After calculating the forces in z and y direction, a force of 390 N where set for the y direction in negative direction, and the force in z direction where set to 207 N in negative direction.

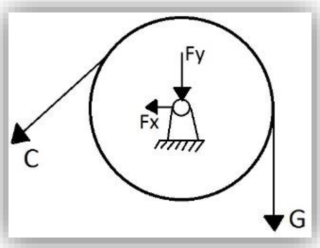


Figure 40: Illustration of the forces acting on the pulley wheel. The G stands for the weight of the load and the C stands from the tension force of the cable.

The cylinder mountings were set as compressive support and the meshing size set to default.

Figure 41 and 42, illustrates where the force and supports where placed.

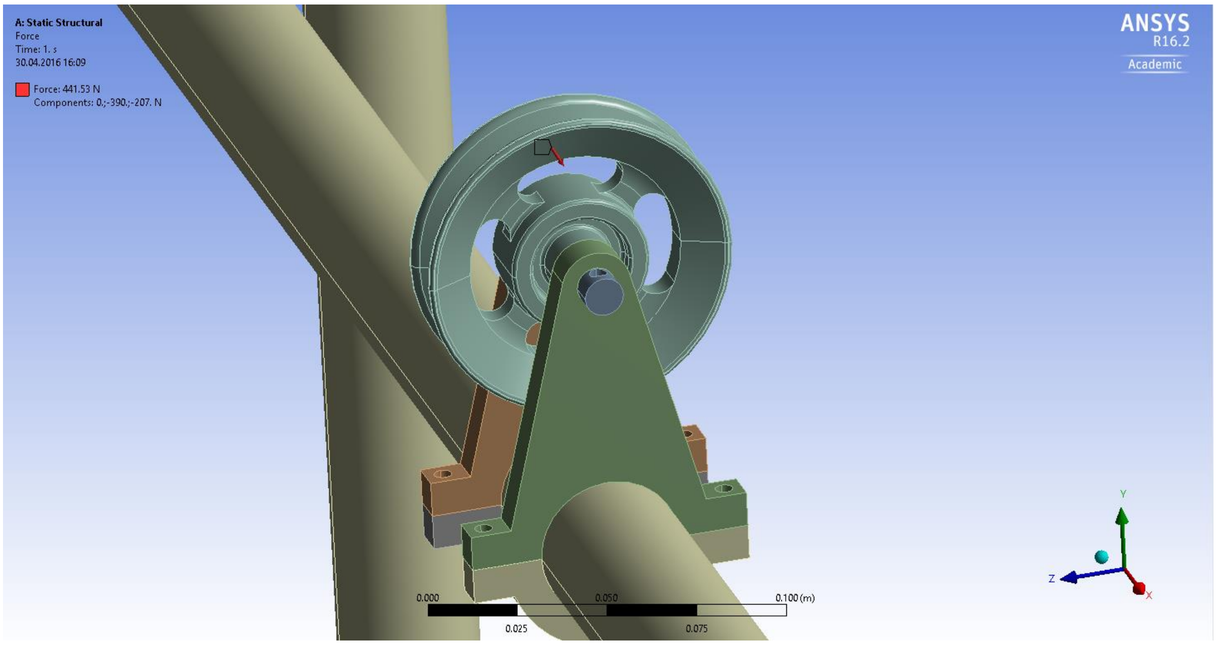


Figure 41: Illustration of the force added on the pulley wheel.

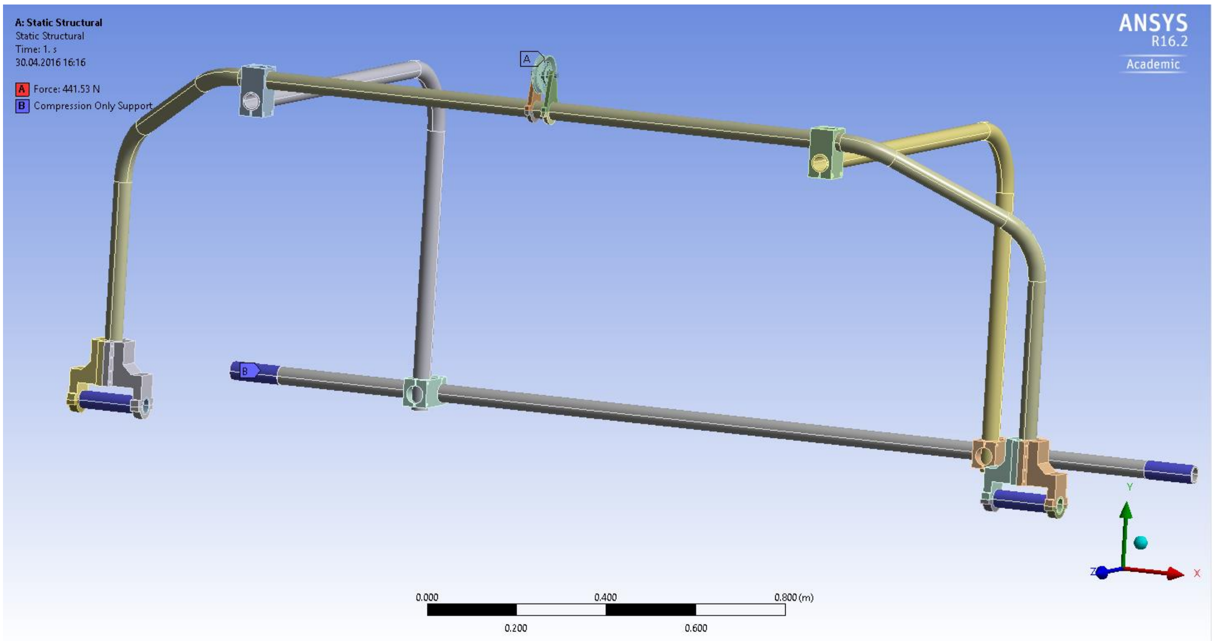


Figure 42: Illustration of where the compressive supports are placed.

The goals for the simulations are to see where the stress occurs, the magnitude of the stress, the magnitude of the deformation, and where it occurs.

First the original design, with the pipes having a 3,5 mm wall thickness, where simulated. Figure 43 illustrates the mesh on the original design.

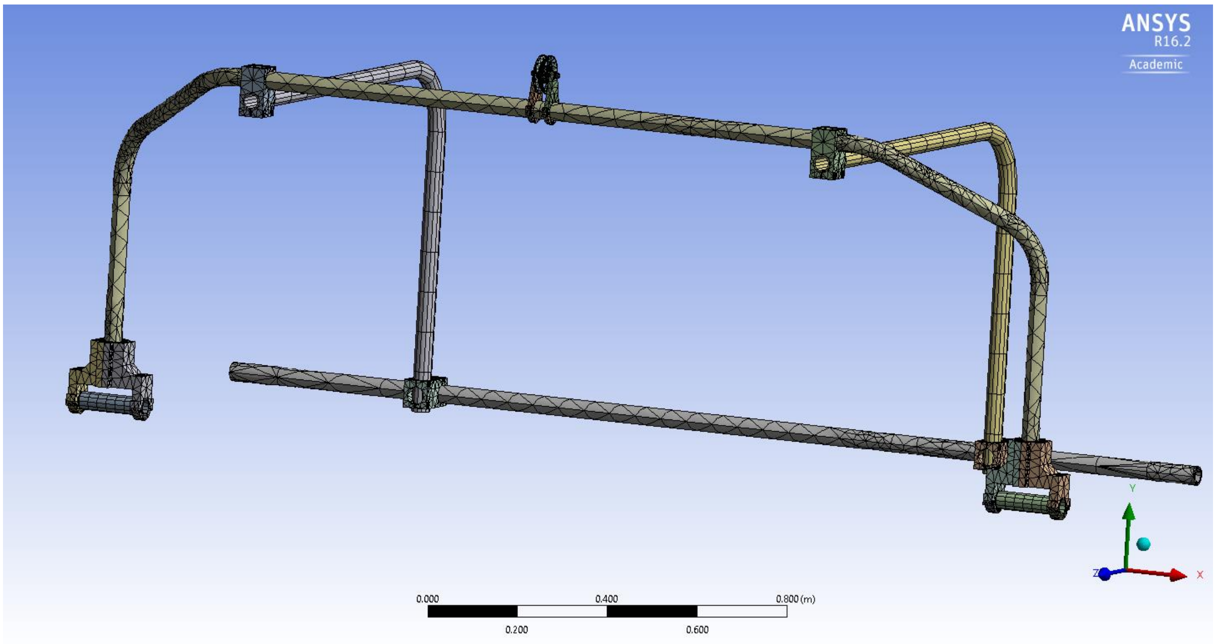


Figure 43: Shows the meshing of the design with the rods having a 3,5 mm thickness

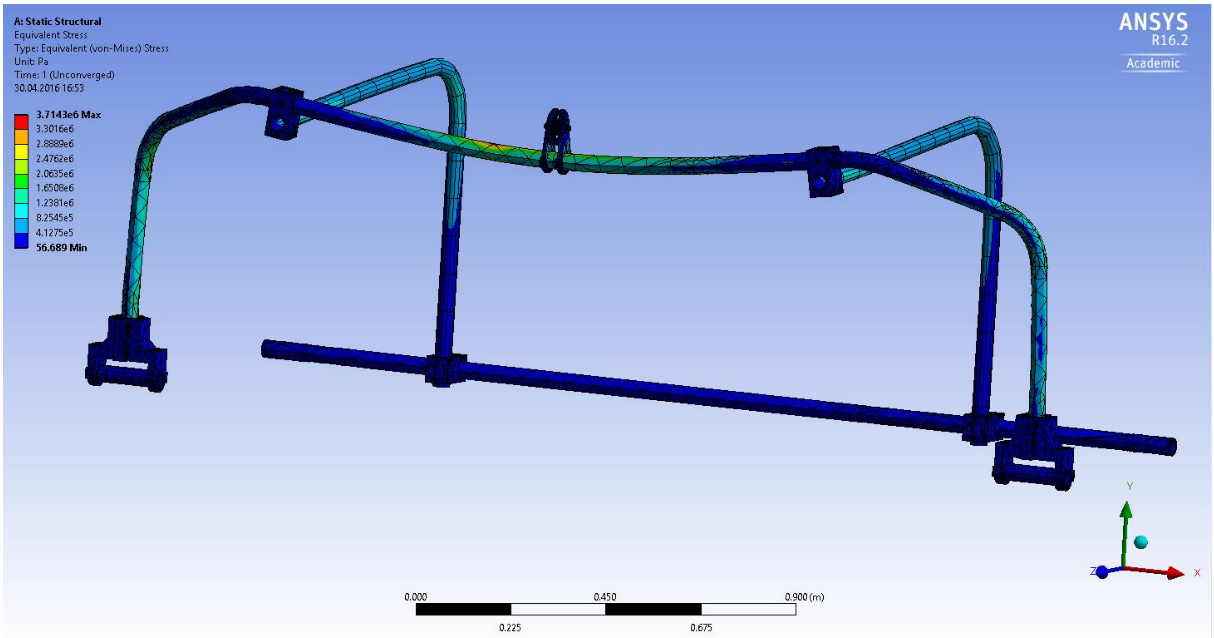


Figure 44: The stress results of the design with the rods having a thickness of 3,5 mm.

The results, as figure 44 illustrates, reveals that the place where the most stress occurs is right next to the pulley wheel. The maximum stress that occurs at this point is 3,7 MPa. With a yield strength of 250 MPa, the stress that occurs will not lead to permanent deformation.

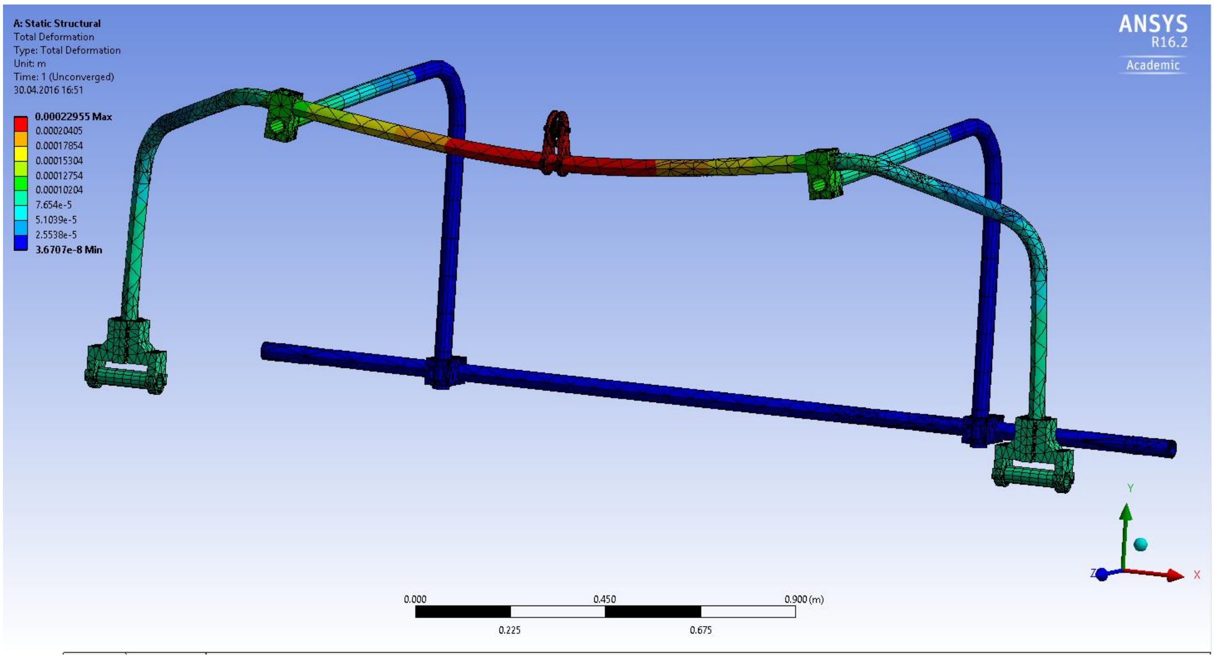


Figure 45: The deformation results for the design, with the rods having a thickness of 3,5 mm.

The deformation results revealed that the maximum deformation is 0,22955 mm. That kind of deformation is negligible and is consistent with the stress results.

After simulating with a 3,5 mm wall thickness, a simulation where done with a wall thickness of 2 mm. A simulation with 2 mm where done, since the available material for the prototype has a thickness of 2 mm. Figure 46 displays the mesh for this simulation.

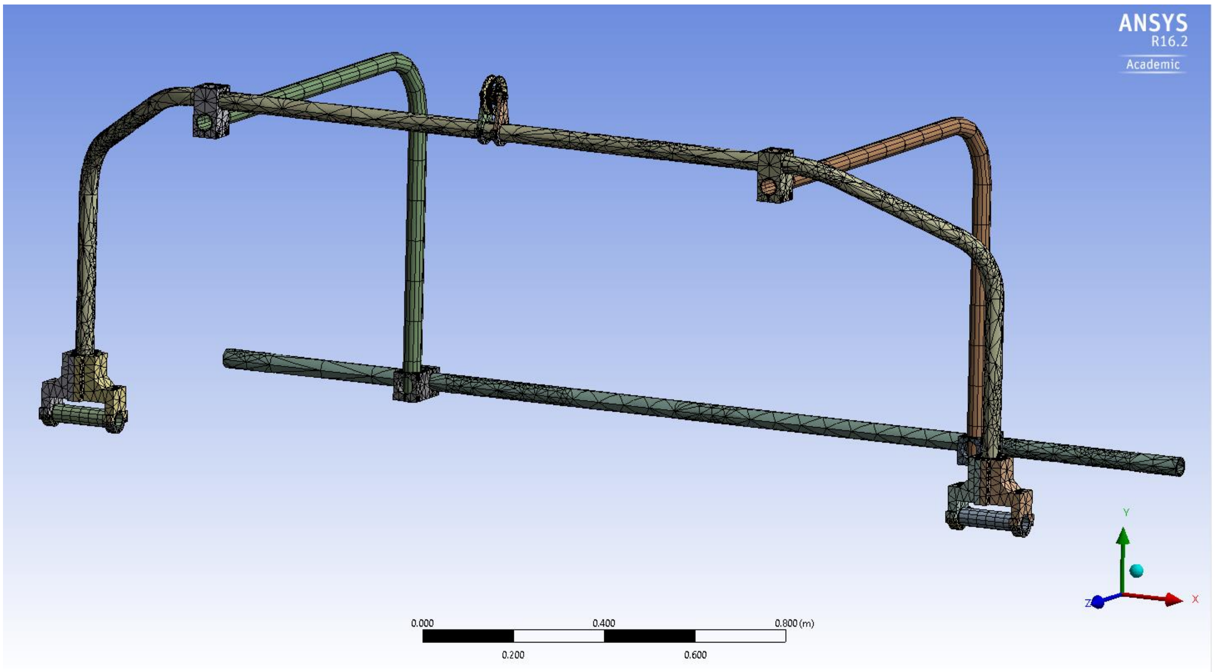


Figure 46: Illustration of the meshing for the design with a 2 mm thickness.

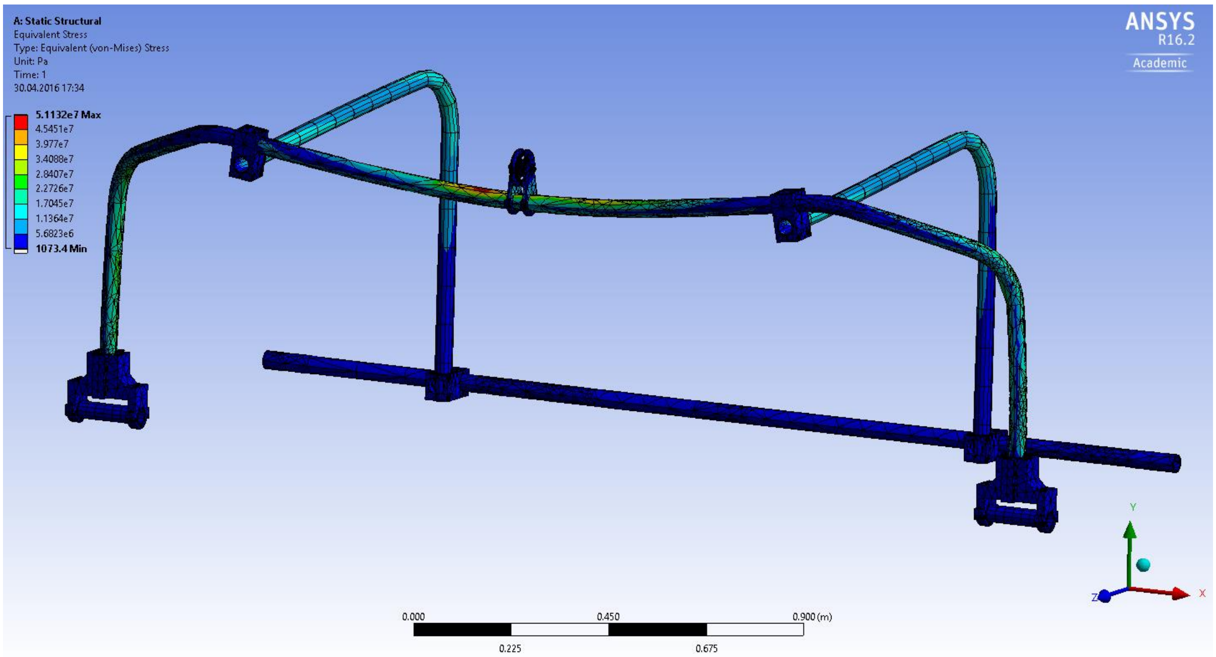


Figure 47: The stress results of the design with the rods having a thickness of 2 mm.

The results from the second simulation gave much higher values than the first one. The maximum stress occurs on the same place as before, but it is now a lot higher. The maximum stress is now at 51,1 MPa, which is more than 10 times as much.

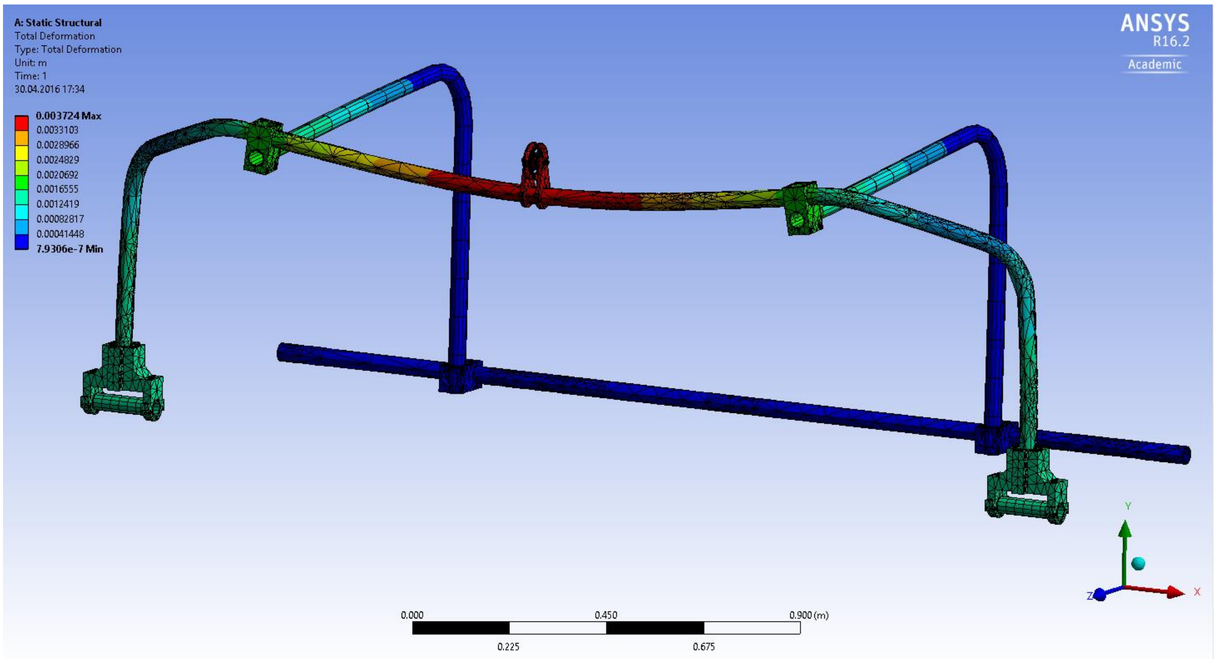


Figure 48: The deformation results for the design, with the rods having a thickness of 2 mm.

The deformation results for the second simulation shows a total deformation of 3,724 mm. This deformation happens in the middle of the front scaffold.

Though these results show that the deformation and stress would not be leading to permanent damage, the simulation was a static simulation. In real life, the load would swing and the forces will vary. Additional test are required, but for the 2 mm thickness, some alterations is required.

7.2 IMPETUS

Jan Arild Teland at FFI ran a simple simulation of how the robot will be affected by the blast of a landmine. The program used for this simulation was IMPETUS, a system for non-linear explicit finite element simulations. The programs is primarily used to predict deformation of structure and components exposed to extreme loading conditions [27].

A full simulation with the CAD design of Thorvald 2 would take too much time. Therefore the model was very simplified. Two hallow boxes and two hallow rods represented Thorvald 2. The boxes where given the dimensions 500 mm x 240 mm x 400 mm with a wall thickness of 1,5 mm. The material of the boxes where set as plastic without further specification. The boxes where connected with the two rods, which was given a outer diameter of 20 mm and inner diameter of 16,5 mm. The length of the rods where set as 2000 mm. The type of material was set as steel, without further specification.

The landmine used in the simulation was a PMN AP mine, which contains 240 g of TNT, and it where placed below and in the middle of the boxes. Therefore the ground where set as a cylinder with depth 0,5 m and a radius of 2 m. The bottom of the boxes where placed 0,1 m above the ground and the bottom of the explosives placed 0,1 m under the ground. The particle count selected for the simulation was 1 million particles.

The final numerical setup, along with element, node and particle count are shown in figure 49.

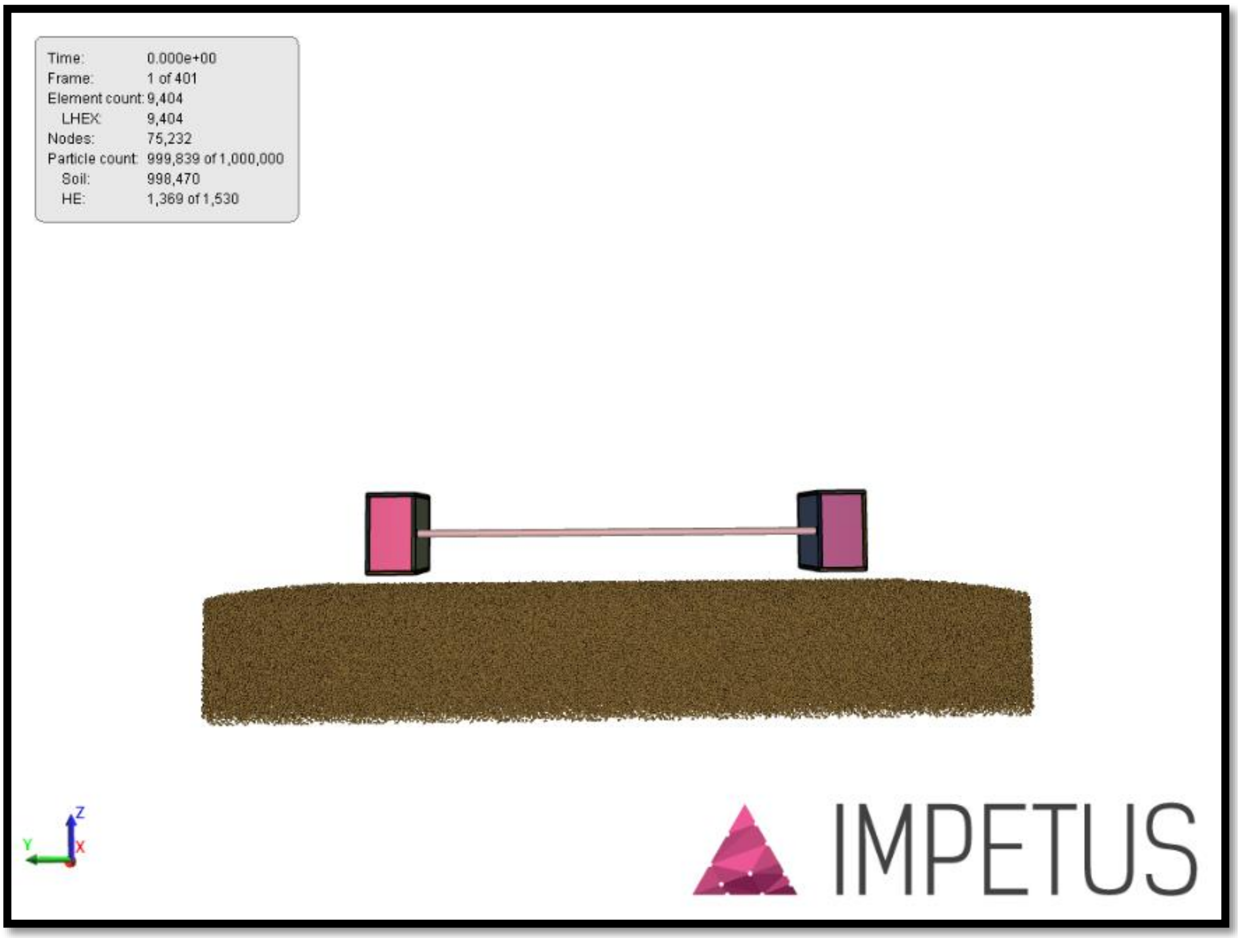


Figure 49: The set up in IMPETUS.

The following pictures shows the simulations after 20 and 40 ms.

Figure 50: The simulation results after 20 ms.

Figure 51: The simulation results after 40 ms.

As the images show, there is a noticeable deformation on the rods. One of them even break off the boxes. Teland explains this by referring to the settings and that there were not set a strength for the connection between the boxes and the rods.

The velocity and the acceleration of the bottom of one of the boxes are illustrated by figure 52 and 53.

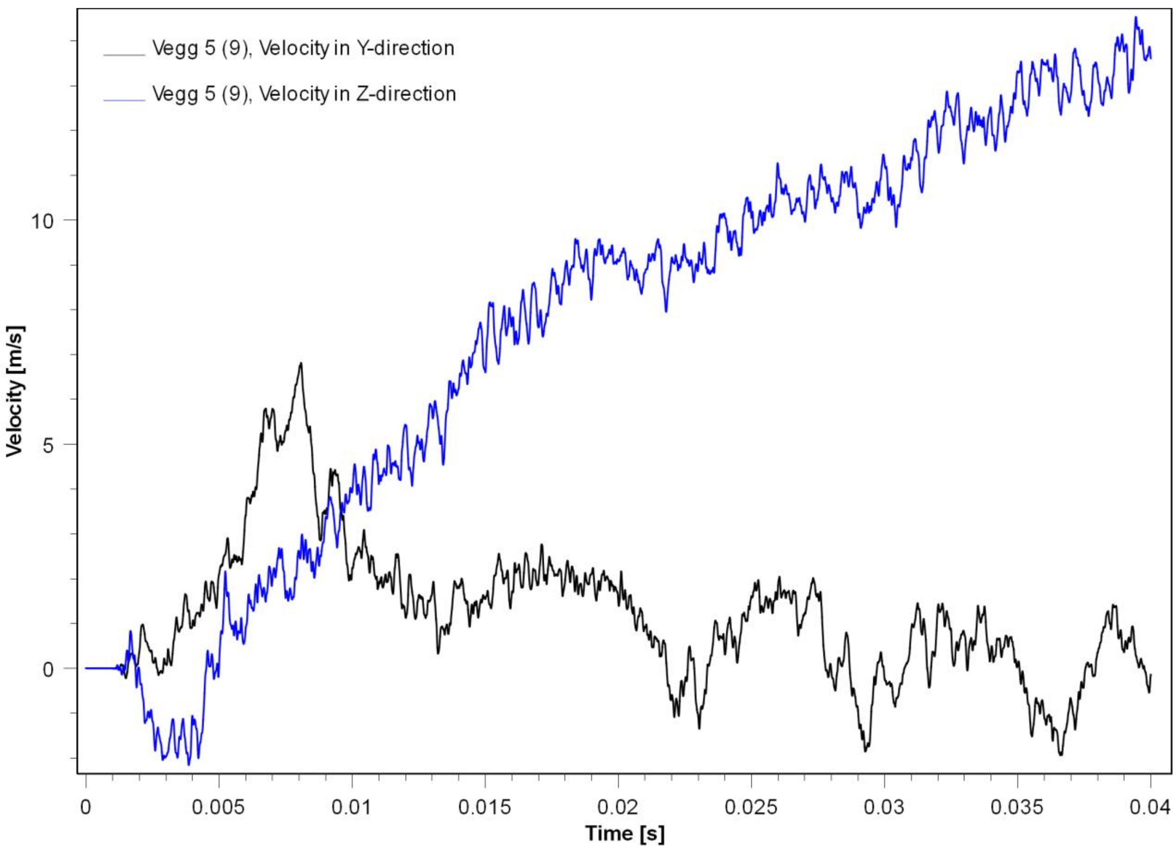


Figure 52: The velocity results in horizontal (z) and vertical (y) direction, illustrated by a graph.

As illustrated, the velocity of the box almost reaches 15 m/s in the z-direction within 4 ms, while the velocity in the y-direction peaks at 7 m/s after 0,8 ms.

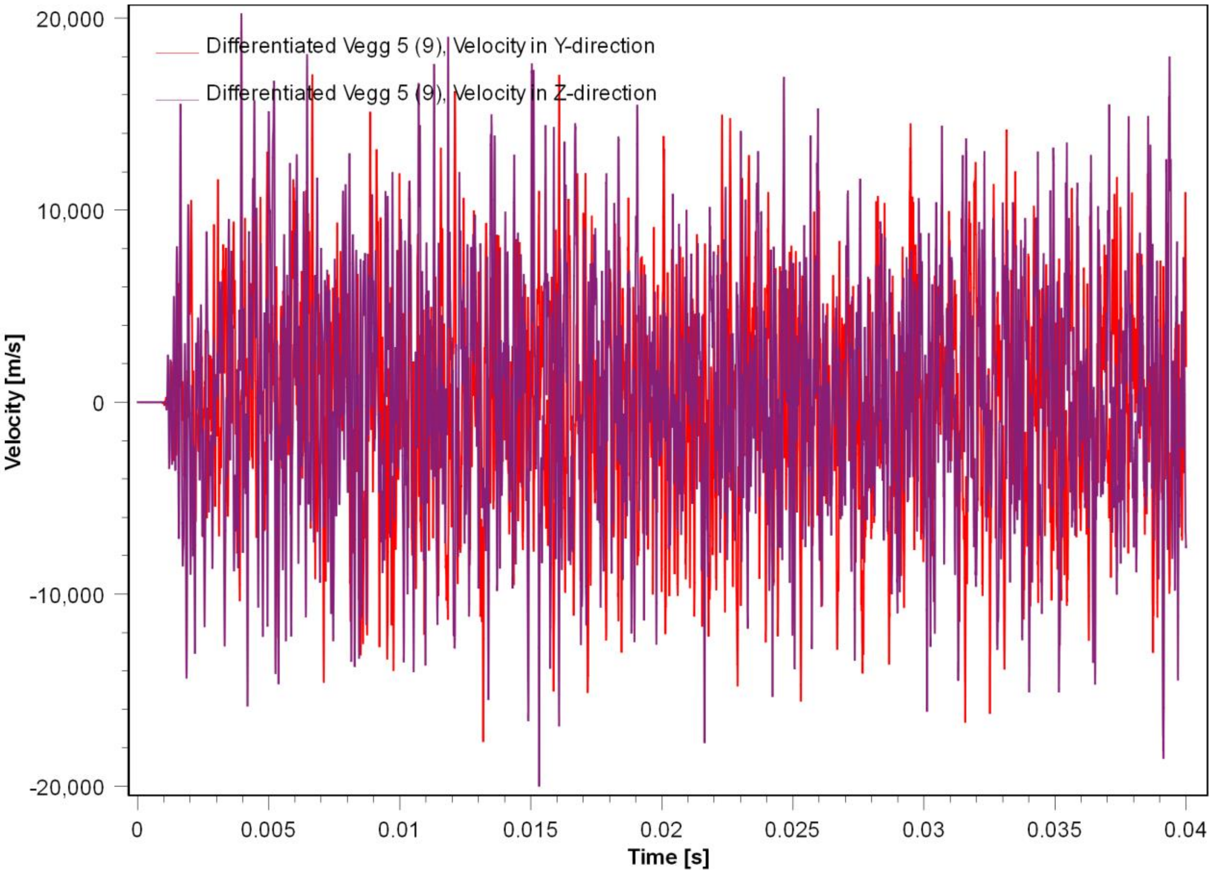


Figure 53: The acceleration results in z and y direction, illustrated by a graph.

The acceleration curves are the derivative from the velocity curves. The acceleration in z-direction peaks at 20000 m/s^2 but is typically around 10000 m/s^2.

The velocity and acceleration will, in reality, be lower since the mass on the actual robot is larger. Also in reality, the ground is normally not just sand. In addition, the geometry is different from the final design and the simulated model.

However, the results from simulation gives reason to be concerned.

Despite the magnitude of the velocity and acceleration in the simulation, there are no sign of permanent deformation on the boxes.

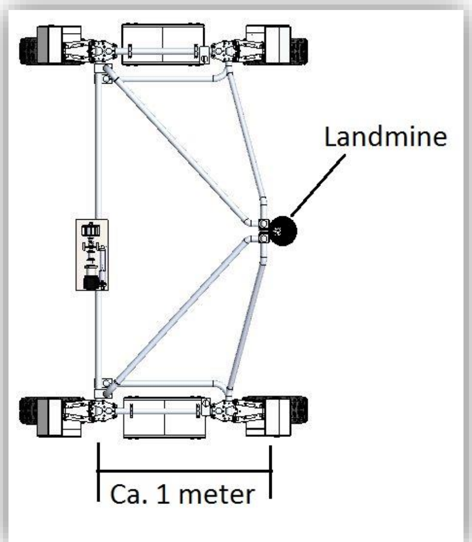


Figure 54: Overview of a design where the detonation of the landmine is placed further away from the robot.

Teland was given figures 54 and 55 and ran a new simulation with the new information. The new results revealed an improvement in the results and that the rods closest to the explosion where the ones that got deformed.

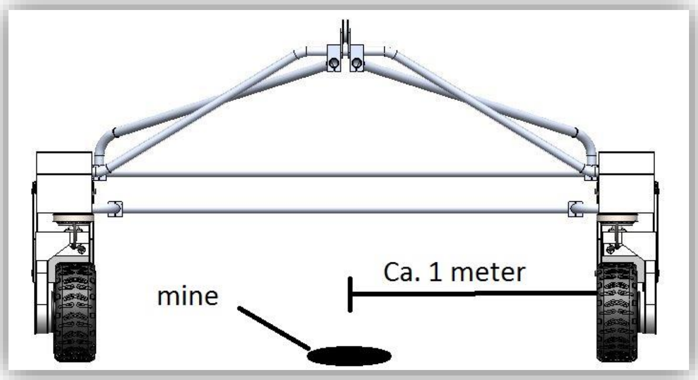


Figure 55: The same design as figure 54, displayed from the side.

After this simulation, the design has again been altered, but it has not been simulated. The scaffold rods are further away from the explosion and the explosion origins a little further away from the robot.

8 Evaluation

8.1 Evaluation of the product

It is unclear how an actual explosion will affect the robot and the equipment. The simulations are ran with a relatively big landmine, which might not be encountered very often. The simulations gives reason to believe that the robot will be unharmed by smaller landmines, but might be damaged from larger landmines. In the case of detonation of an AT landmine, the robot would be destroyed. This was a fact known before the project began and is acceptable.

The load of 25 kilograms, when dropped from a height of 1 meter, seems to be enough to create a ground pressure big enough to set off landmines that are pressure activated. The load will probably not be able to detonate every UXO´s and ERW`s, but might affect some of them.

The product is only capable of detonating landmines that react to pressure. Third generation landmines have more advanced detonating system, making it very difficult to find a system able to deal with them. The product is also weak against landmines triggered by trip wires.

The objective was to develop a mechanical detonation mechanism with the focus on pressure activated landmines. In that regard, the product is successful. If the location of a landmine is known, the system is able to detonate the landmine. However, the system must undergo a test to verify this statement. Another part of the objective was that the product had to withstand several explosions before the need of service and repairs. As mentioned, the simulations gives reason to believe that the robot may survive an explosion. However, the load dissolves when detonating a landmine, and therefore the product need service for every detonation.

The idea of Thorvald 2, equipped with a landmine clearing tool, is that it would be cheaper than the methods, for clearing landmines, used today. Although I do not have exact figures, I strongly believe that this system is a lot cheaper than existing methods.

8.1.2 Other solutions

The Thorvald 2 platform might be used for other purposes than a mechanical detonation system. If the desired action is to just locate landmines and plot them in to a map, Thorvald 2 might be fitted with only sensors.

Figure 56: A possible solution for the robot, where only sensors are fitted to the robot.

Should the future tests reveal that the robot does get damaged by the detonation of a landmine, a possible solution would be to use two robots with a scaffold between them. In that way, the robot would be much further away from the explosion and the scaffolds rods might be placed higher up from the ground. If so, the rods might not be harmed and the load could be smaller or shaped differently.

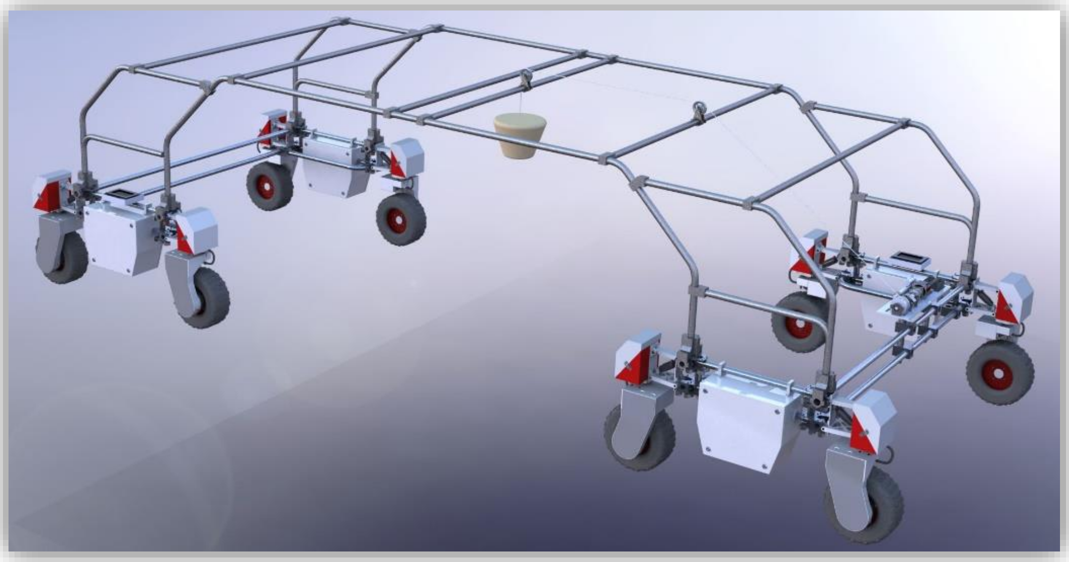


Figure 57: A possible solution, if the detonation needs to be further away from the robot. Two robots are connected with a common scaffold, with the load in the middle of them.

8.1.3 Is it revolutionary?

This product is not capable of clearing a minefield by itself. This product is simply a tool for clearing landmines, which location is already known. In that way, the product is not world changing. However, by using this product, no lives are endangered. If this product can remove, let us say, 20 % of the landmines in a minefield, there will be less danger for the rest of the demining process and maybe some lives could be spared. Since manual demining is so expensive, the product will also remove some of the costs of demining.

Even though it is not revolutionary by itself, the product is the start of a project that might lead to a revolution in the world of demining. The project contains a lot of potential and could possibly clear the world of landmines in the future.

8.1.4 What would it take to become word changing

First of all, the GPR, or another radar system, will have to be developed to the point where they can detect every landmine and detect the size and depth of it. If such a system is developed, then the product, along with sensors and Thorvald 2, can potentially clear a minefield by itself. At least it can map out every detection on GPS, so the rest of the demining process goes much quicker. If the robot, along with the equipment, becomes able to deal with all kinds of landmines and UXO`s, and not just the pressure activated landmines, I am confident that it will be world changing.

8.2 Future work

As mentioned in the introduction, the project is to develop an autonomous robot that can clear landmines. For this project to be completed, there is a lot more work to be done.

Prototype

The first thing that needs to be done is to build a prototype of the mechanical detonation system. The prototype might not contain equipment and solutions that are optimal, but will contain available parts. However, the prototype might shed light on possible issues and improvement areas. The prototype will then be tested to see if the system is able to detonate a buried landmine. The system will be attached to a custom made platform and sensors will measure the forces that will act on the robot.

After gathering test results and noticed issues and improvement areas, the design will be altered and either a new prototype is built or alterations on the existing prototype is made. The process is then repeated until a satisfying product is developed.

Programming

If the mechanical detonation system is to be fully autonomous, a program must be written for the motor controller. The program will only control the actions of the electric motor and the actuator. The actions of the motor is simply on and off, and the action of the actuator is forward, stop and reverse.

First of all, when turned on, the capacitors on the motor controller needs to be charged. Once the robot is in place, it will send a signal to the motor controller, letting it know that the robot is in position. The motor controller will then check if the kill switches are on and operational. If the kill switches are on, the actuator will be signalled to reverse, thus disconnecting the clutch. The actuator will continue to reverse until the first kill switch is triggered. It will then stop.

After the clutch has been disconnected for a few seconds, the actuator is told to move forward and connect the clutch. As before, it will continue to go forward until the second kill switch is triggered. Once the clutch is connected, the motor controller signals the motor to start. The load will then be lifted. The motor will continue to run and stop when the third kill switch is triggered. Then the motor controller awaits for a new start signal from the robot.

Image processing

It is very important that the robot position itself correctly when attempting a detonation of a landmine. If it positions itself incorrectly, after the sensors have located a target, the system will miss and the landmine may not go off. To ensure that the robot is standing where it should be, it could be fitted with cameras and equipped with an image-processing program.

One idea is that one camera take a picture of the area in front of the robot, and marks the point where the sensors have located a target. The second camera is aimed at the ground under the robot and will tell the robot whether it is positioned correctly or not by recognizing the image from the first camera.

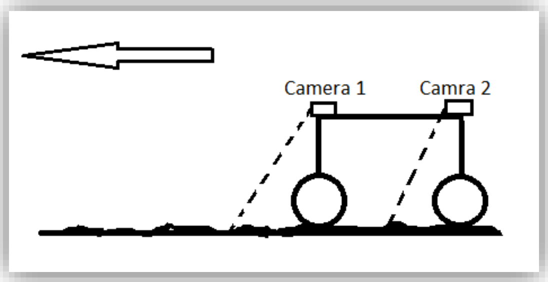


Figure 58: A simple drawing of a possible solution for the image processing system.

Another idea is to have a mechanism on the radars that spray or put down a mark. The camera at the back will recognize the mark and coordinate with robot, making sure that it is positioned correctly and that the target is hit.

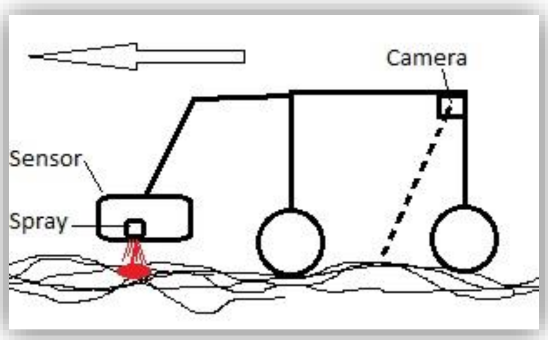


Figure 59: A possible solution for the image processing program with spray marking.

UXO and trip wire

The issues regarding trip wire and other detonating mechanisms must be addressed. Droplets and other explosive residues, as well as landmines that do not detonate by pressure, might not be triggered when the load is dropped on them. In addition, landmines might be located close to a wall, a large rock, or anything else that makes it impossible for the robot to position itself above it. Solutions for these issues will have to be developed.

Then there are the landmines that uses trip wire. These mines often have a part of themselves above the ground. They might be visible to the naked eye or they might be covered by vegetation or sand. A high resolution camera and a camera that recognizes thermal signatures, along with a image processing program, might be able to detect these landmines, like the PMR-2A, at a distance. After detecting an object that possibly is a landmine with a trip wire, the cameras would search for the trip wire. When the trip wire landmine is detected, a possible solution is to use the concept of placing a gun on the robot, and shoot at the mine from a distance.

Protection

The robot does need protection. The simulations indicates that the boxes does not sustain permanent deformation, but there is a lot of pressure coming from the explosion. To prevent the robot from being ripped apart, some protection that leads the shockwaves away from the robot is necessary. In addition, fragments, rocks and gravel will head for the robot in extreme speeds. The protection must keep these flying object from damaging the robot.

Sensors

When the mechanical detonation system is completed, the future work will be focused on the landmine locating system. A possible solution is to use the detectors with both GPR and metal detectors, and in some way adapt them to the robot. Another solution is to attempt to invent a new sensor or a system with sensors, that could do the job. Otherwise, wait for GPR systems to be further developed and to become cheaper.

When a sensor is selected or developed, a program must be written for the robot to cooperate with the sensors.

9 Conclusion

In theory, the mechanical detonation system is able to detonate pressure sensitive landmines. Although, the system must undergo an actual detonation test to be sure. Once a landmine is located the system will be able to detonate the landmine by itself, but after detonation, service is required since the load will dissolve and needs to be replaced. If there is no explosion, the winch will lift the load up, and will be ready to go again.

The product is, so far, not equipped with a solution for the landmines and UXO`s that does not detonate, neither for landmines activated by trip wire. It also lacks the protection necessary to withstand an explosion. Therefore, the product is not ready for testing with the actual robot. However, the product is ready for prototype stage, and will then be ready for testing.

The product is not revolutionary by itself, but it is the start of a project that could be world changing, if further developed.

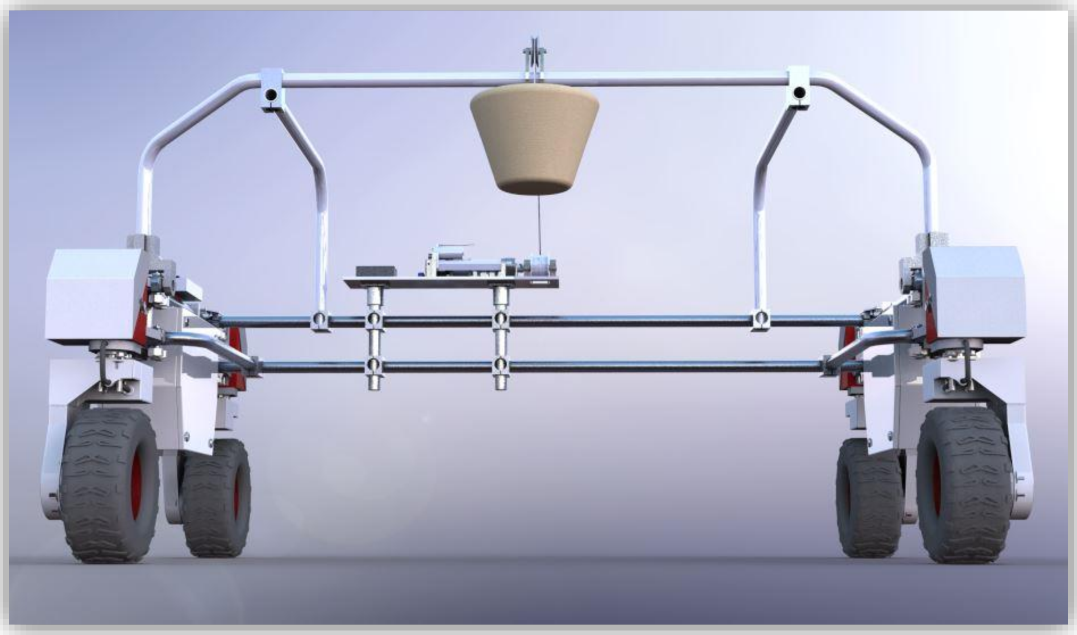


Figure 60: A rendered image of the finished product, on Thorvald 2, viewed from the rear.

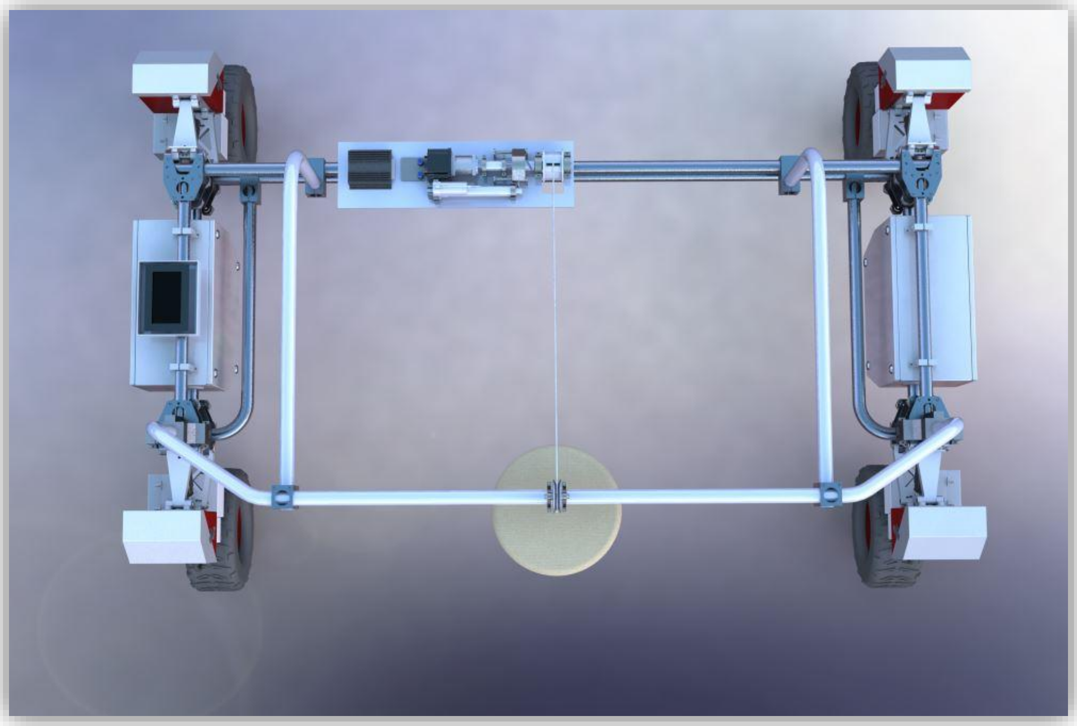


Figure 61: A rendered image of the finished product, on Thorvald 2, viewed from above.

Figure 62: A rendered image of the finished product, on Thorvald 2, viewed from the side.

References

[1] "Care.org," [Online]. Available: http://www.care.org/emergencies/facts-about-landmines. [Accessed 21 March 2016].

[2] "the-monitor.org," [Online]. Available: http://www.the-monitor.org/en-gb/the-issues/landmines.aspx. [Accessed 21 March 2016].

[3] E. Banks, Anti-Personnel Landmines, Recognising & Disarming, Brassey´s, 1997.

[4] "Landmine Monitor 2015," ICBL, 2015.

[5] IMAS, "International Mine Action Standards," [Online]. Available: http://www.mineactionstandards.org/. [Accessed 19 April 2016].

[6] "metaldetector.com," [Online]. Available: http://www.metaldetector.com/learn/metal-detector-history/history-of-the-metal-detector. [Accessed 15 April 2016].

[7] "Whites Metal detectors," [Online]. Available: http://www.whiteselectronics.com/the-hobby/knowledge-base/history. [Accessed 15 April 2016].

[8] J. Tyson, "How stuff works," [Online]. Available: http://electronics.howstuffworks.com/gadgets/other-gadgets/metal-detector.htm. [Accessed 09 May 2016].

[9] J. R. L. Jacqueline MacDonald, Alternatives for Landmine Detection, RAND Corporation, 2003.

[10] "Global GPR Services," [Online]. Available: http://www.global-gpr.com/gpr-technology/how-gpr-works.html. [Accessed 15 April 2016].

[11] Vallon, [Online]. Available: http://www.vallon.de/products.lasso?a=mine-detection. [Accessed 07 May 2016].

[12] "The Marshall Legacy Institute," [Online]. Available: http://marshall-legacy.org/programs-2/mine-detection-dogs/. [Accessed 15 April 2016].

[13] "apopo," [Online]. Available: https://www.apopo.org/en/about/our-work/why-rats. [Accessed 15 April 2016].

[14] "Science Daily," [Online]. Available: https://www.sciencedaily.com/releases/2006/11/061128140820.htm. [Accessed 18 April 2016].

[15] "How Stuff Works Science," [Online]. Available: http://science.howstuffworks.com/bomb-sniffing-bees.htm. [Accessed 18 April 2016].

[16] Digger Foundation, “Digger Foundation,” [Online]. Available: http://foundation.digger.ch/mine-clearance/. [Accessed 18 April 2016].

[17] Geneva International Centre for Humanitarian Demining, “A Study of Mechanical Application in Demining,” Geneva International Centre for Humanitarian Demining, Geneva, 2004.

[18] U.S. Army, “The Official Homepage of The United States Army,” [Online]. Available: http://www.army.mil/article/137372/Army_Reserve_lays_down_the_hammer__striking_through_mine_fields_with_a_force/. [Accessed 18 April 2016].

[19] IRIN, “IRINThe inside story on emergencies,” [Online]. Available: http://www.irinnews.org/report/93932/senegal-demining-machine-clears-path-better-future. [Accessed 19 April 2016].

[20] U.S. Army, “Unites Sates Army Acqusition Support Centre,” [Online]. Available: http://asc.army.mil/web/portfolio-item/cs-css-mine-protection-vehicle-family-mpvf/. [Accessed 19 April 2016].

[21] Pearson Engineering, “Pearson Engineering,” [Online]. Available: http://www.pearson-eng.com/products/full-width-mine-plough/. [Accessed 19 April 2016].

[22] M. S. -. F. N. A. F. -. S. Ivar Foss, Interviewee, [Interview]. 20 April 2016.

[23] US Navy, “Secretary of the Navy,” [Online]. Available: http://www.secnav.navy.mil/dusnp/Security/Information/Documents/intro-natosecuritybrief.pdf. [Accessed 07 May 2016].

[24] “The Engineering ToolBox,” [Online]. Available: http://www.engineeringtoolbox.com/density-materials-d_1652.html. [Accessed 22 April 2016].

[25] NASA, “National Aeronautics and Space Administration,” [Online]. Available: https://www.grc.nasa.gov/www/k-12/airplane/volume.html. [Accessed 28 April 2016].

[26] ANSYS, [Online]. Available: http://www.ansys.com/. [Accessed 30 April 2016].

[27] IMPETUS Afea AS, [Online]. Available: http://www.impetus-afea.com/products/features/. [Accessed 22 April 2016].

[28] ABP, “ABP Explosive Ordanance Disposal,” [Online]. Available: http://www.abprecision.co.uk/EOD/EOD_mine_prodder.htm. [Accessed 18 April 2016].

[29] G. W. H. L. B. S. C. W. Tan Chun, “Introduction to Mine Clearing Technology,” DSTA.

[30] "How Stuff works Science," [Online]. Available: http://science.howstuffworks.com/landmine3.htm. [Accessed 24 April 2016].

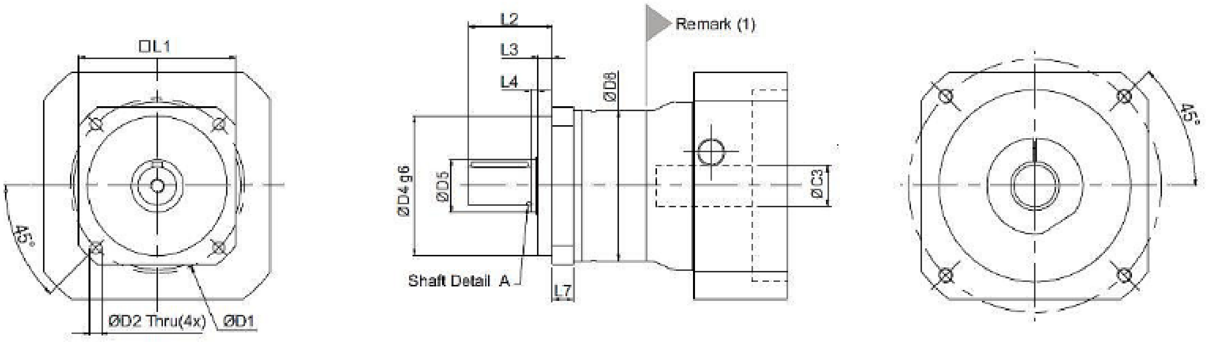
[31] AVS Mine Action Consultants, "Landmines and Humanitarian Mine Action," [Online]. Available: http://www.nolandmines.com/minesM14.htm. [Accessed 24 April 2016].

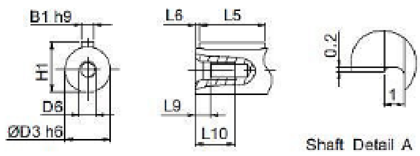
[32] D. Carrington, "CNN," CNN, 26 September 2014. [Online]. Available: http://edition.cnn.com/2014/09/26/world/africa/hero-rats-sniff-out-landmines-and-tb/. [Accessed 07 May 2016].

[33] The Marshall Legacy Institute, "The Marshall Legacy Institute," [Online]. Available: http://marshall-legacy.org/programs-2/mine-detection-dogs/. [Accessed 07 May 2016].

Appendix

<u>Gearbox dimensions</u>



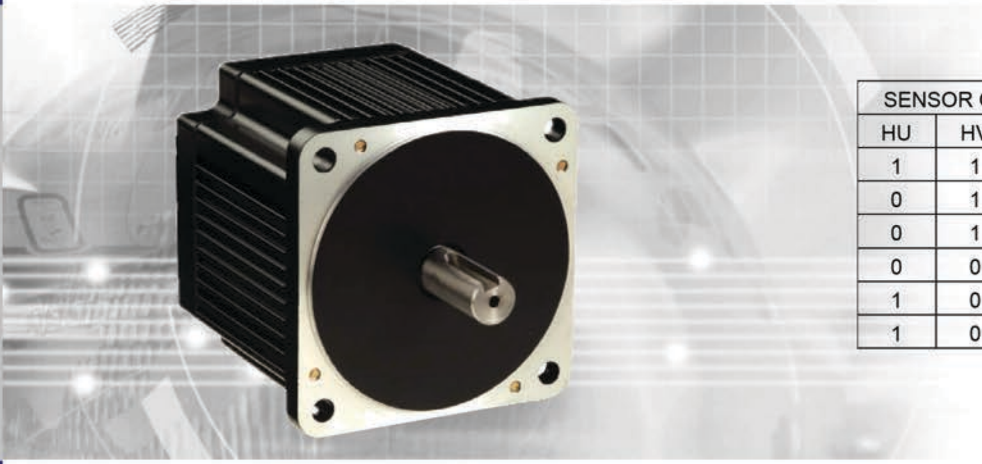


Dimension		PAII 042		PAII 060		PAII 090		PAII 115		PAII 142	
		1-stage	2-stage	1-stage	2-stage	1-stage	2-stage	1-stage	2-stage	1-stage	2-stage
D1		50		70		100		130		165	
D2		3.4		5.5		6.6		9		11	
D3	h6	13		16		22		32		40	
D4	g6	35		50		80		110		130	
D5		17		22		30		40		55	
D6		M4X0.7P		M5X0.8P		M8X1.25P		M12X1.75P		M16X2P	
D8		44		60		86		114		140	
L1		42		60		90		115		142	
L2		26		37		48.5		65		97	
L3		5.5		5.5		8.5		10		12.5	
L4		2.5		3.5		4		5		5.5	
L5		14		25		32		40		63	
L6		2		2		2		5		5	
L7		6.5		10		12		16		20	
L9		4.5		4.8		7.2		10		12	
L10		10		12.5		19		28		36	
B1	h9	5		5		6		10		12	
H1		15		18		24.5		35		43	

(1) Dimensions are related to motor interface. Please contact APEX for details.

Brushless DC Motor
BL9 Series

Frame Size: 90mm
Power O/P: 150~750W
Torque (Cont.): 5.5~21Kg-cm

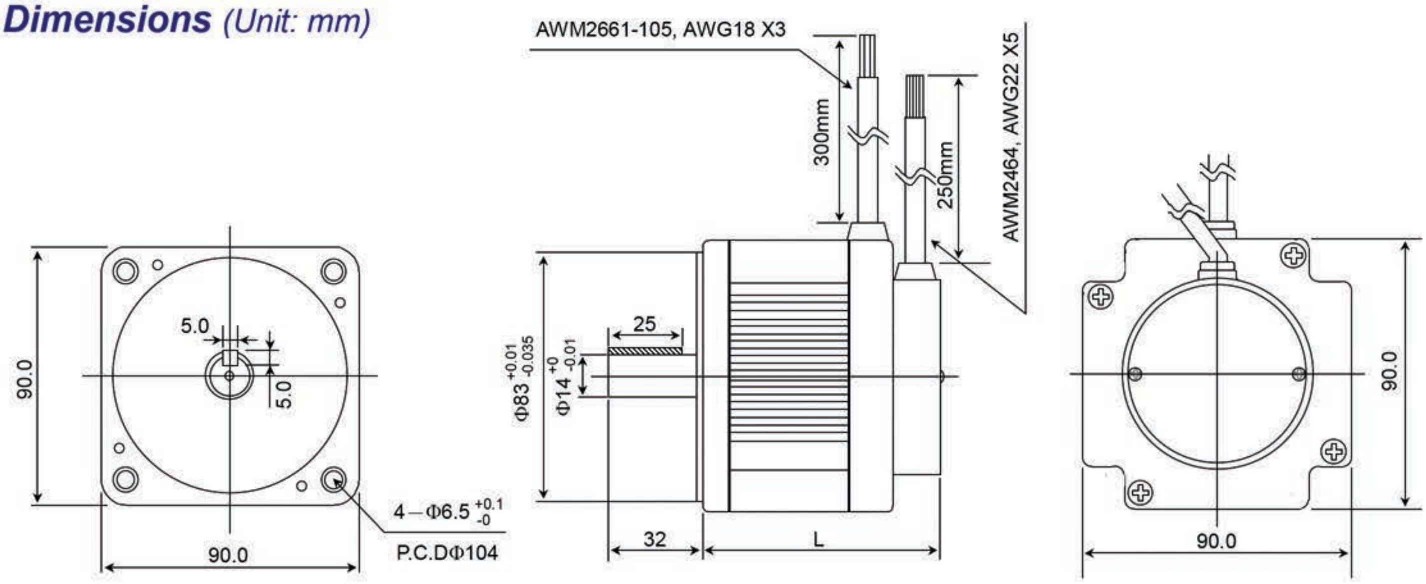


SENSOR OUTPUT			DRIVER OUTPUT			
HU	HV	HW	U	V	W	CW ↓ / ↑ CCW
1	1	0	X	HI	LO	
0	1	0	LO	HI	X	
0	1	1	LO	X	HI	
0	0	1	X	LO	HI	
1	0	1	HI	LO	X	
1	0	0	HI	X	LO	

Specifications

	Unit	Model Name			
		BL900-A03	BL910-A03	BL923-A03	BL933-A03
Voltage	volts	24	24	48	48
No Load Speed	RPM	4000	4000	4000	4000
Rated O/P Power	watt	150	250	500	750
Rated Torque	N-m	0.55	0.75	1.45	2.10
Rated Current	amper	9.5	12.5	12.0	18.0
Rated Speed	RPM	2700	3250	3400	3500
Back EMF (at 1000rpm)	volts	6.0	6.0	12.0	12.0
Insulation Class	---	Class F	Class F	Class F	Class F
Resistance	Ohms	0.200	0.118	0.177	0.096
Inductance	mH	0.50	0.20	0.32	0.20
Motor Length (L)	mm	70.0	80.0	100.0	120.0
Weight	Kg	1.40	1.56	2.23	3.00

Dimensions (Unit: mm)



Linear Actuator
CAHB 10

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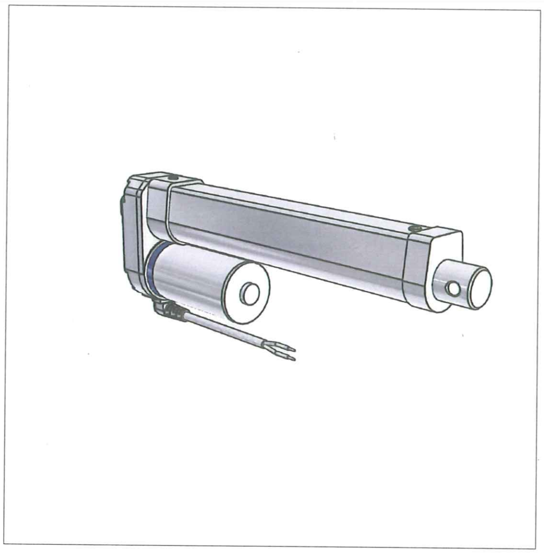
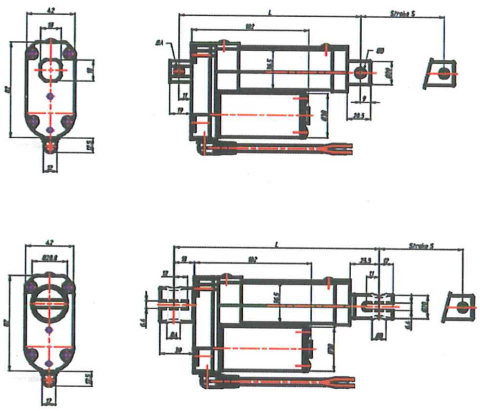
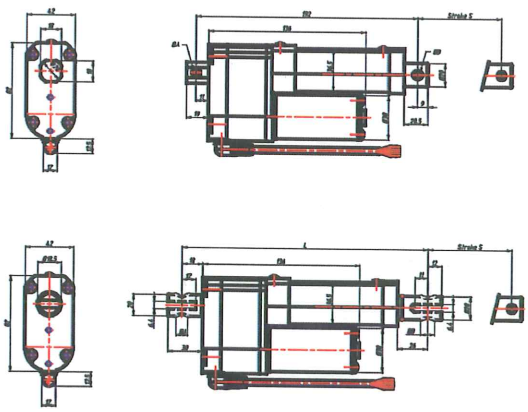




Basic Configuration and optional 2-Hall encoder



Optional Potentiometer

SKF

Linear Actuator
CAHB 10

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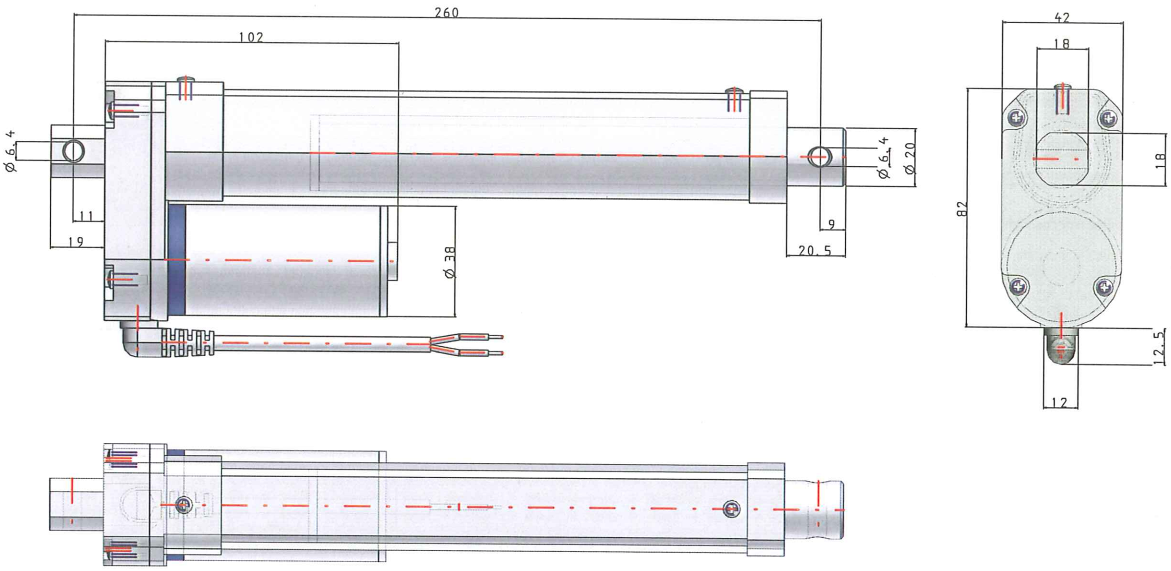

SKF

Linear Actuator
CAHB 10

PDF DATASHEET

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V (Voltage / V)	24 V DC
LO (Load / N)	1000
SCR (Screw)	TR12 Screw
S (Stroke (S) / mm)	150
L (Retracted length (L) / mm)	260
IP (IP)	Standard (IP 66)
FA (Front attachment)	Rod with Hole Dia. = 6.4 mm
RA (Rear attachment)	Rod with Hole Dia. = 6.4 mm
HD (Hole Direction of the Attachments / °)	0
OP1 (Position feedback option)	None
CL (Cable Length (without Connector) / mm)	600
AC (Auxiliary Code)	000
PN (Ordering key)	CAHB-10-B5A-150-AAAA0A-000
P (CAD model position)	Retracted
NOTE (Note)	Cable 3D Model is just a Segment of the Actual Model

Linear Actuator
CAHB 10

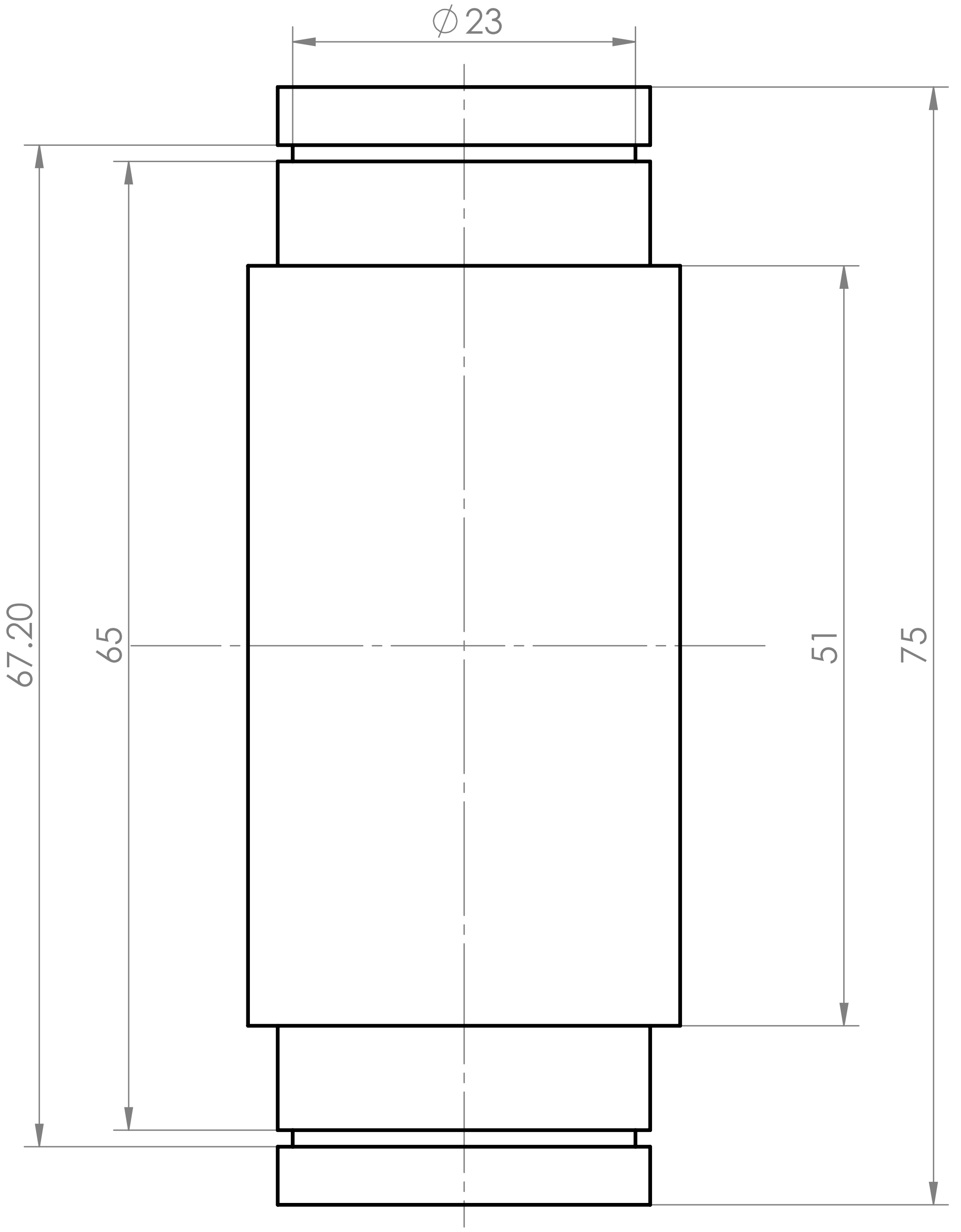
PDF DATASHEET

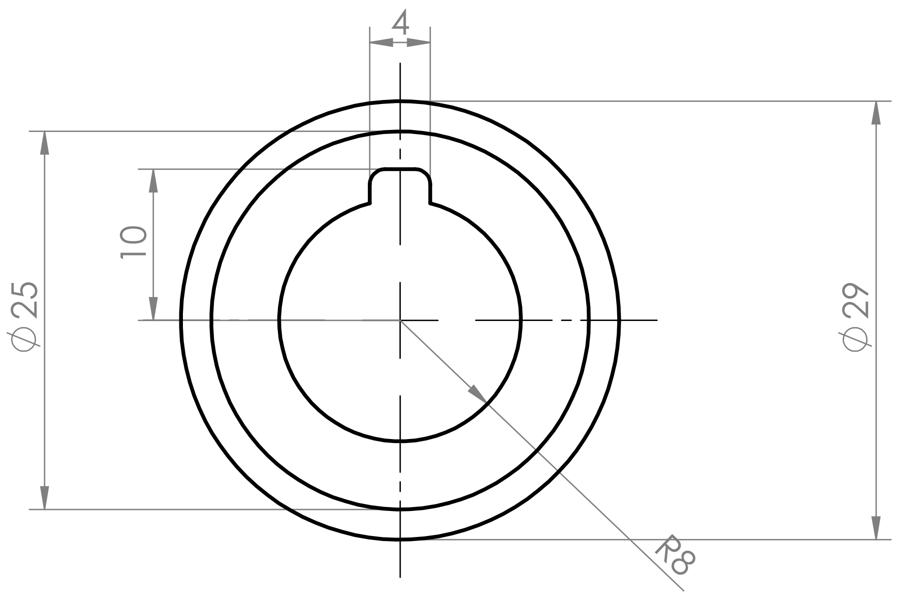
Last Modification (geometry): 09/07/2015 09:25

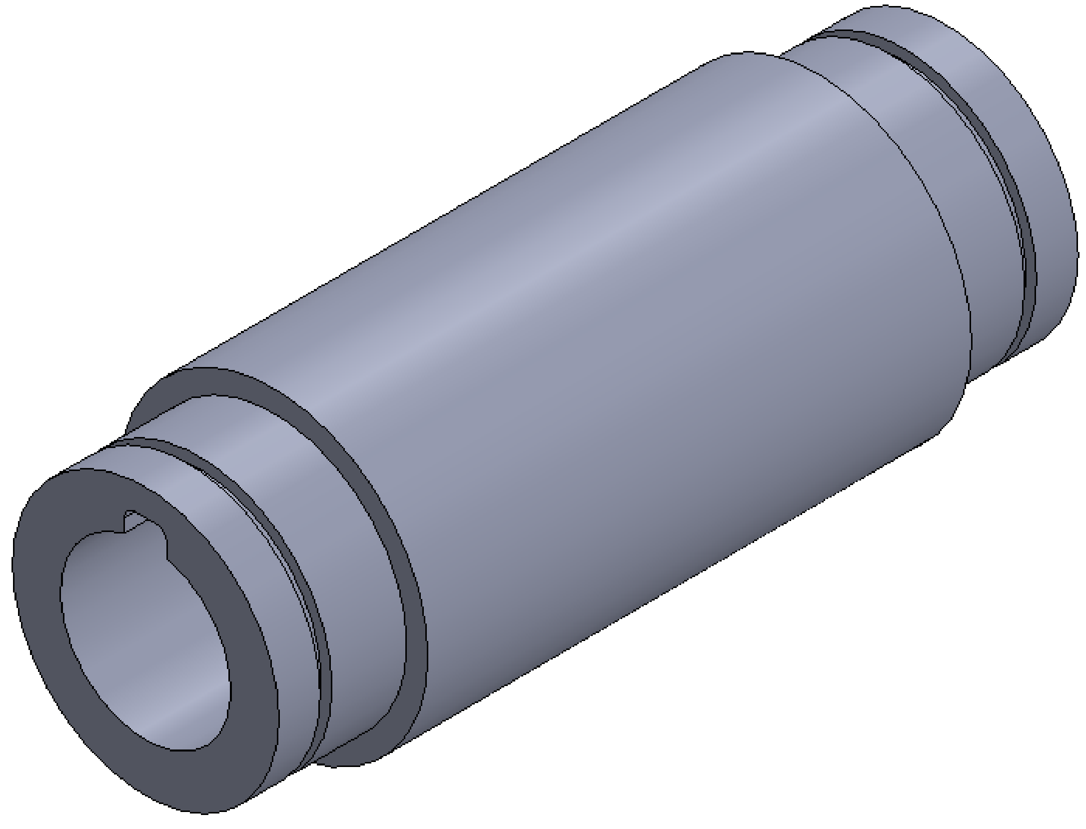
Datasheet creation date: 18/03/2016 16:03

Bill of material

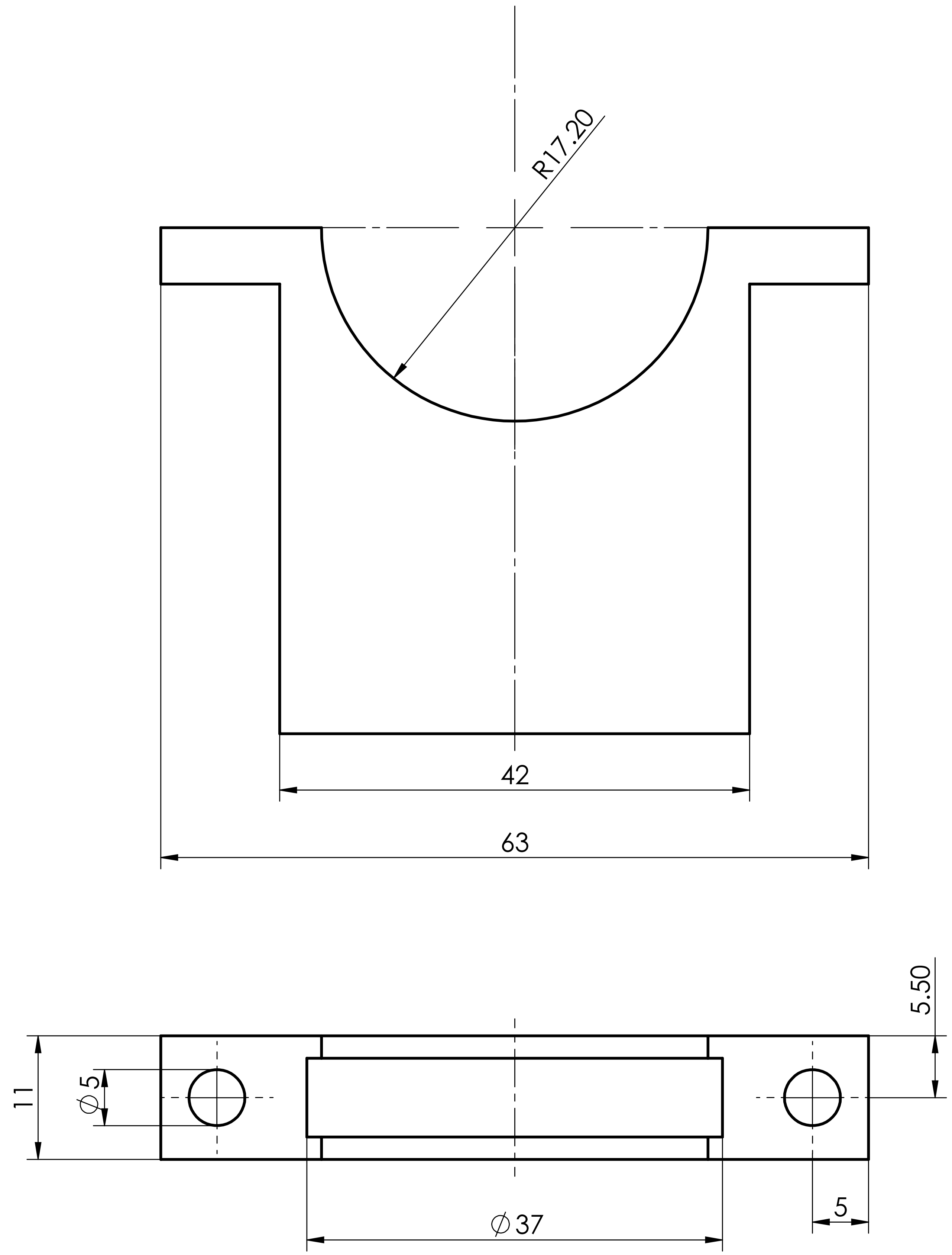
N°	Description	Amount
1	CAHB-10-B5A-150-AAAA0A-000	1

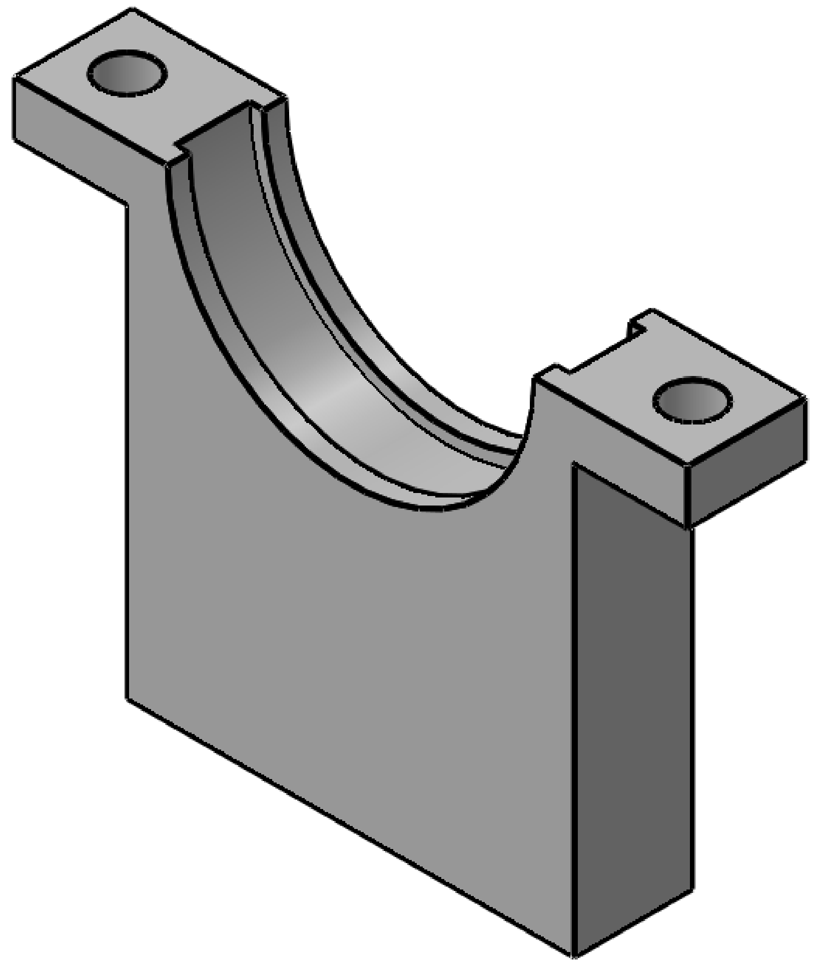




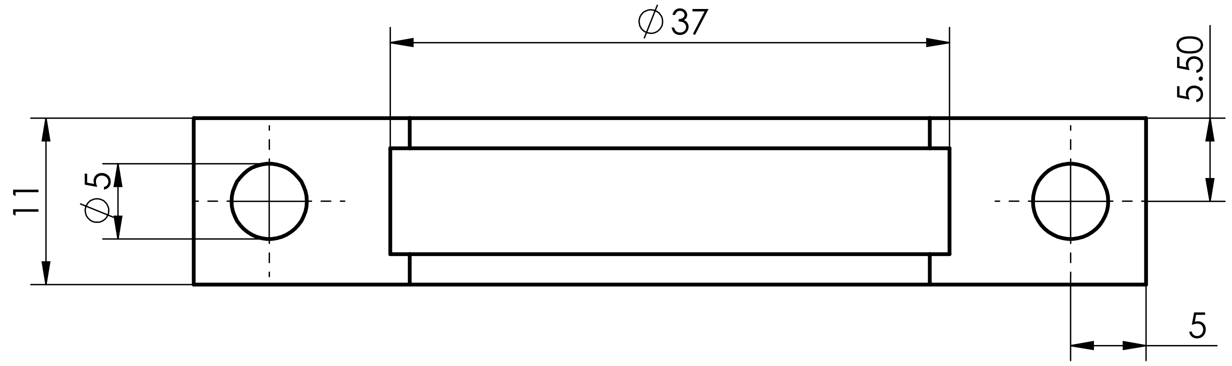


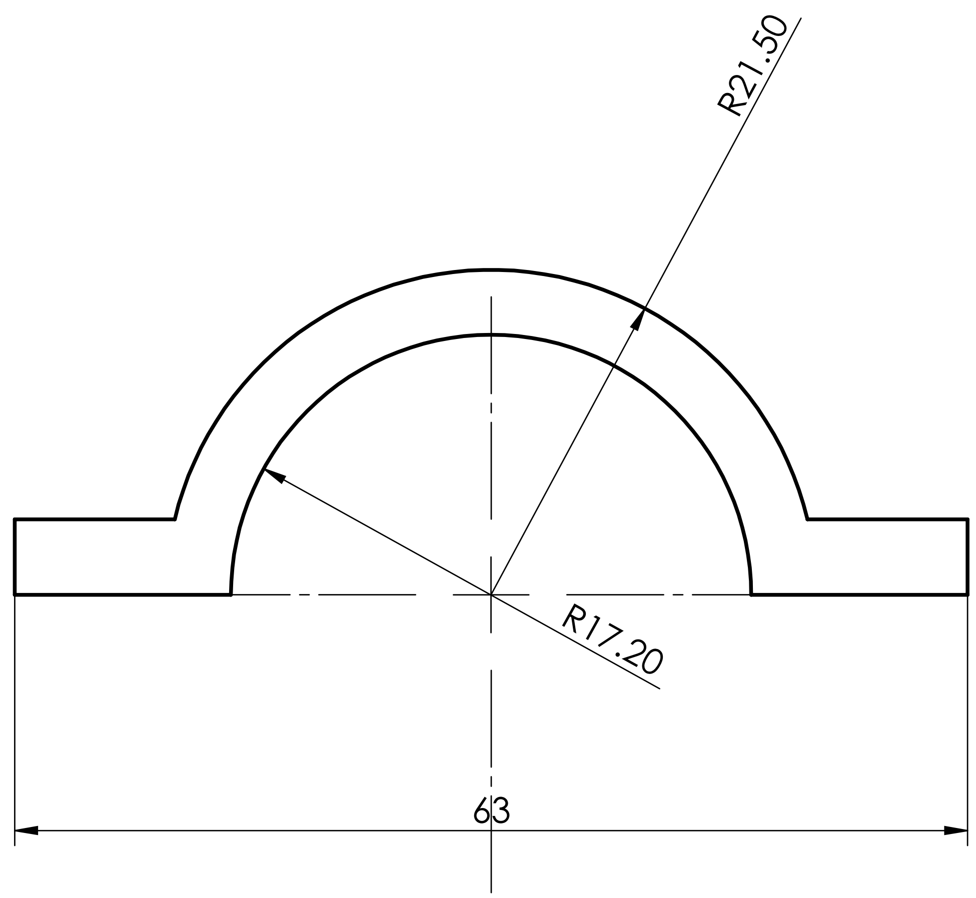
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 2:1	
Title: Hallow axle			Drawing nr: 1 of 21

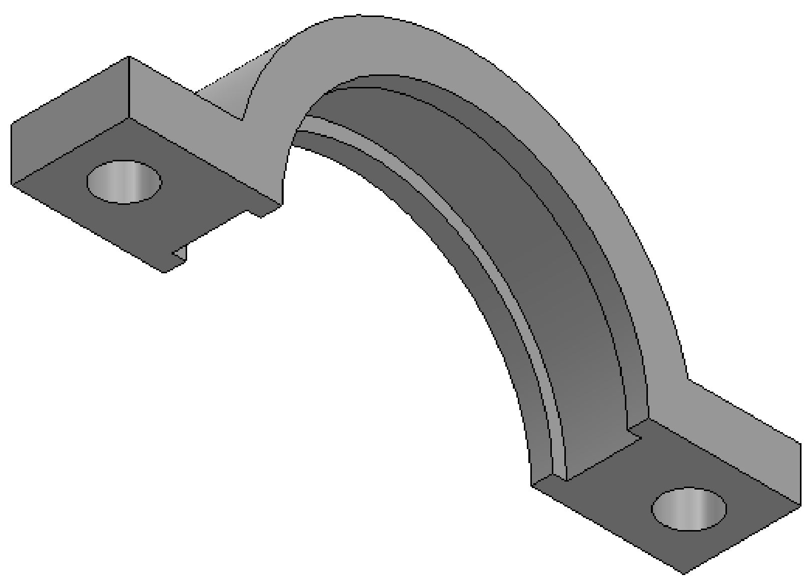




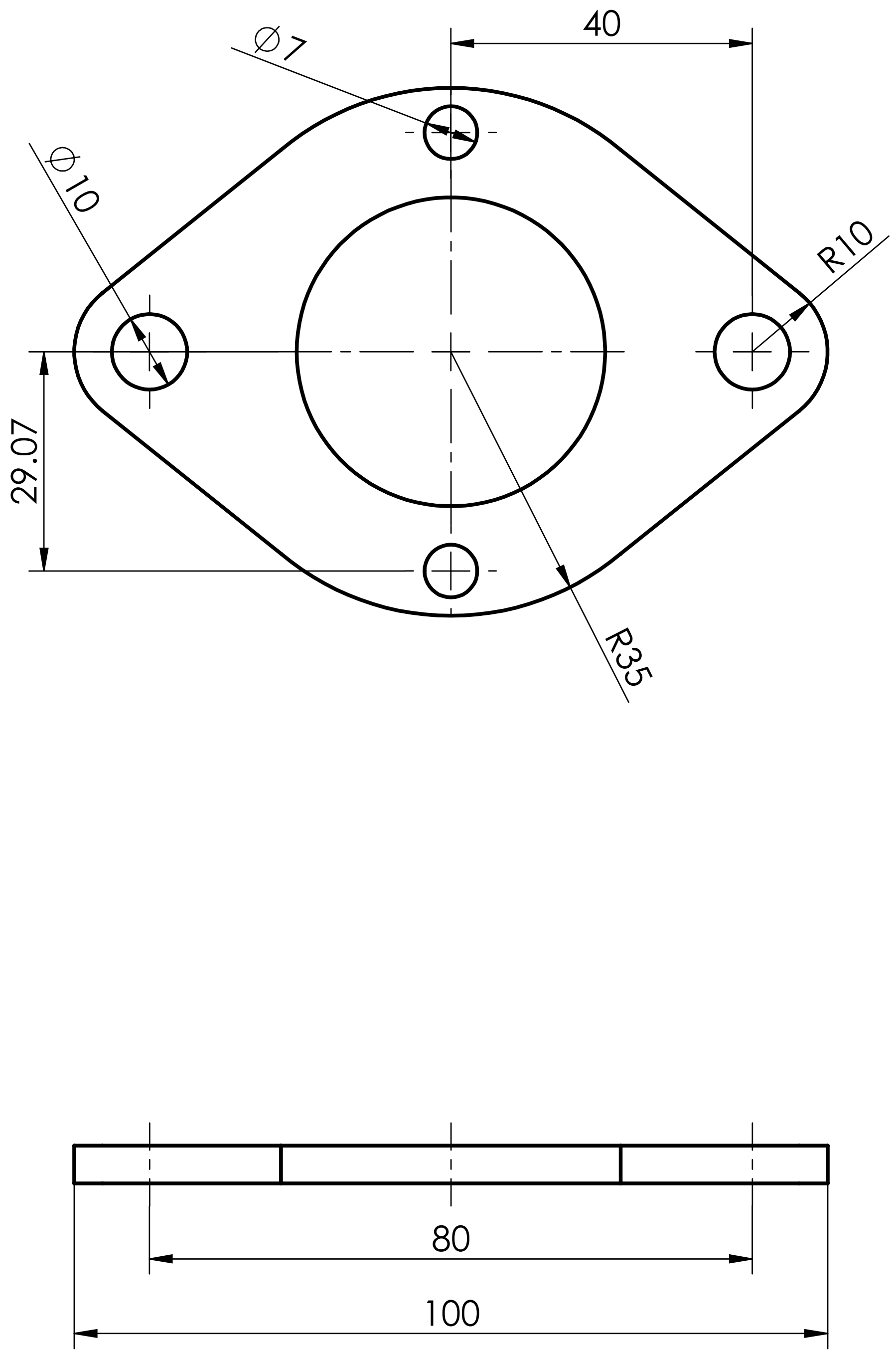
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 2:1	
Title: Hallow axle holder part 1			Drawing nr: 2 of 21

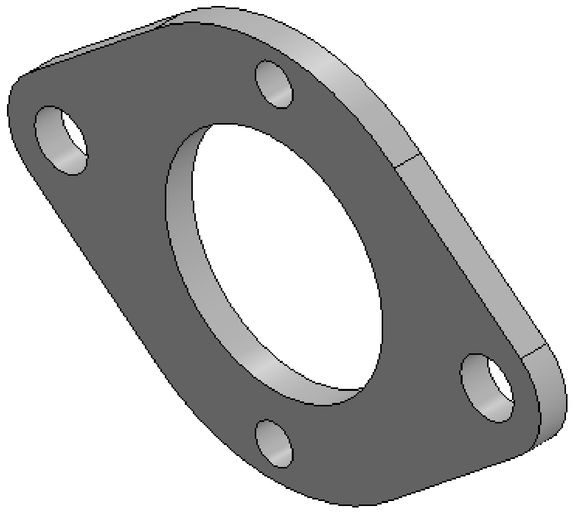




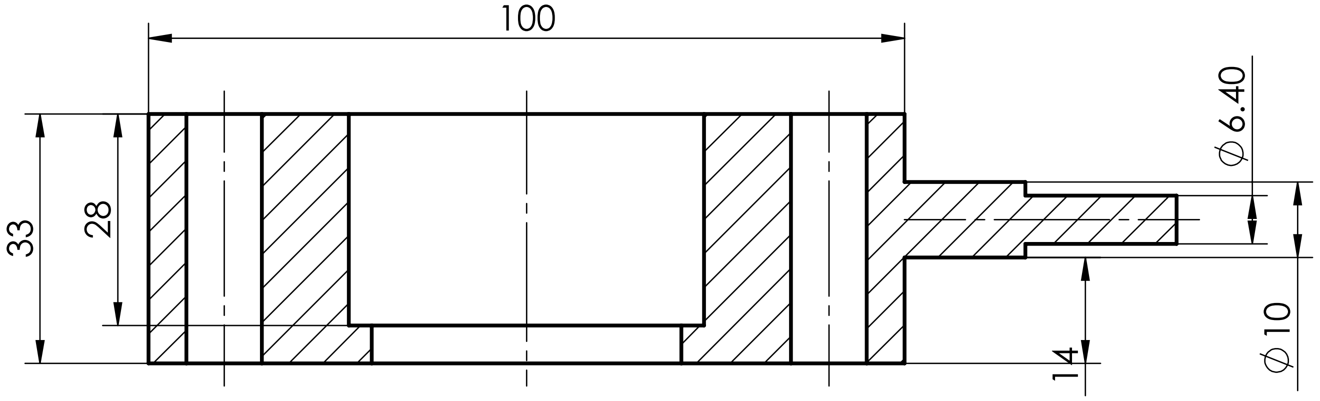


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 2:1	
Title: Hallow axle holder part 2			Drawing nr: 3 of 21

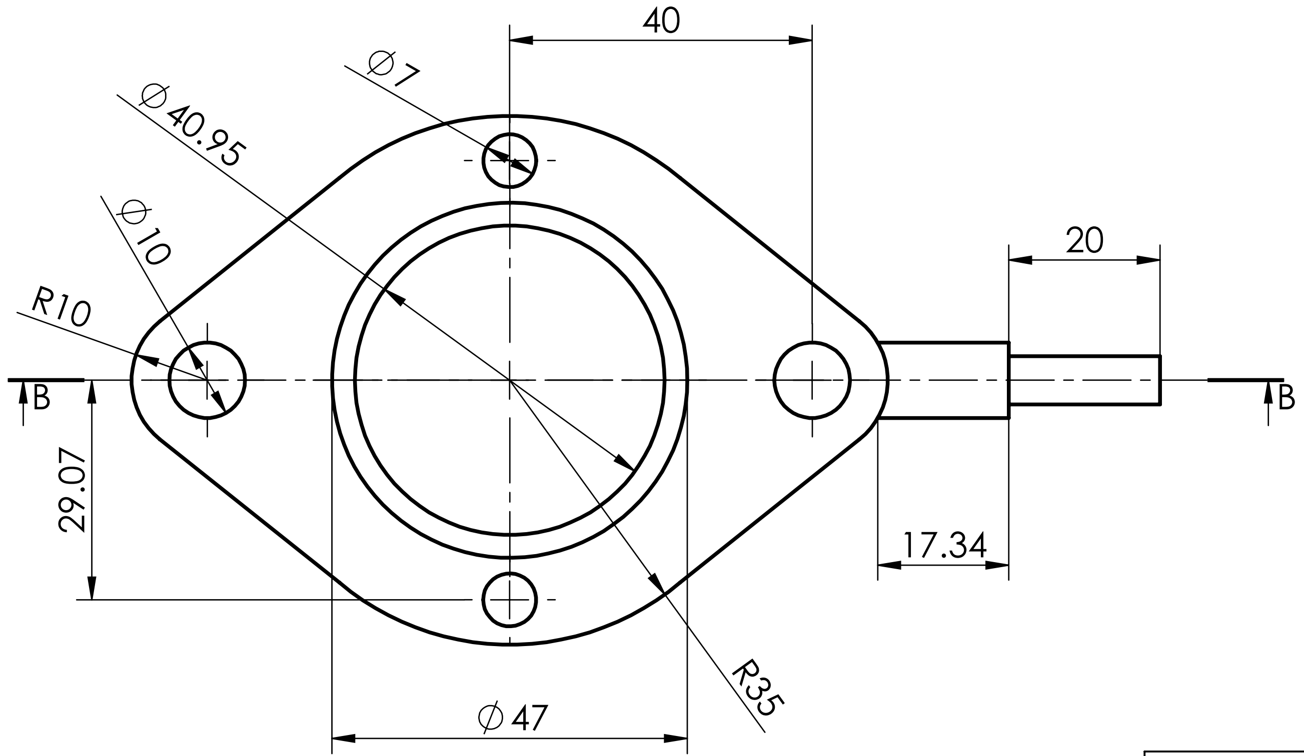


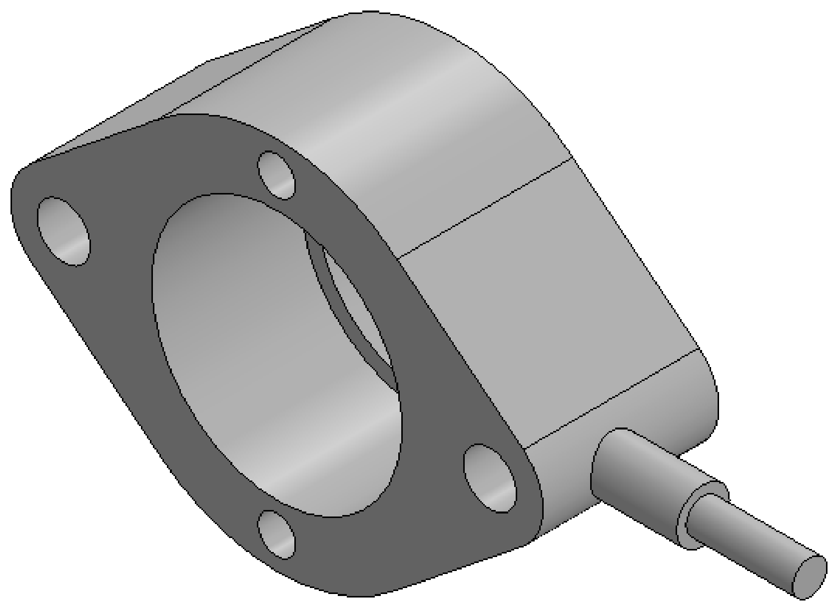


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 1:1	
Title: Ball bearing house part 1			Drawing nr: 4 of 21

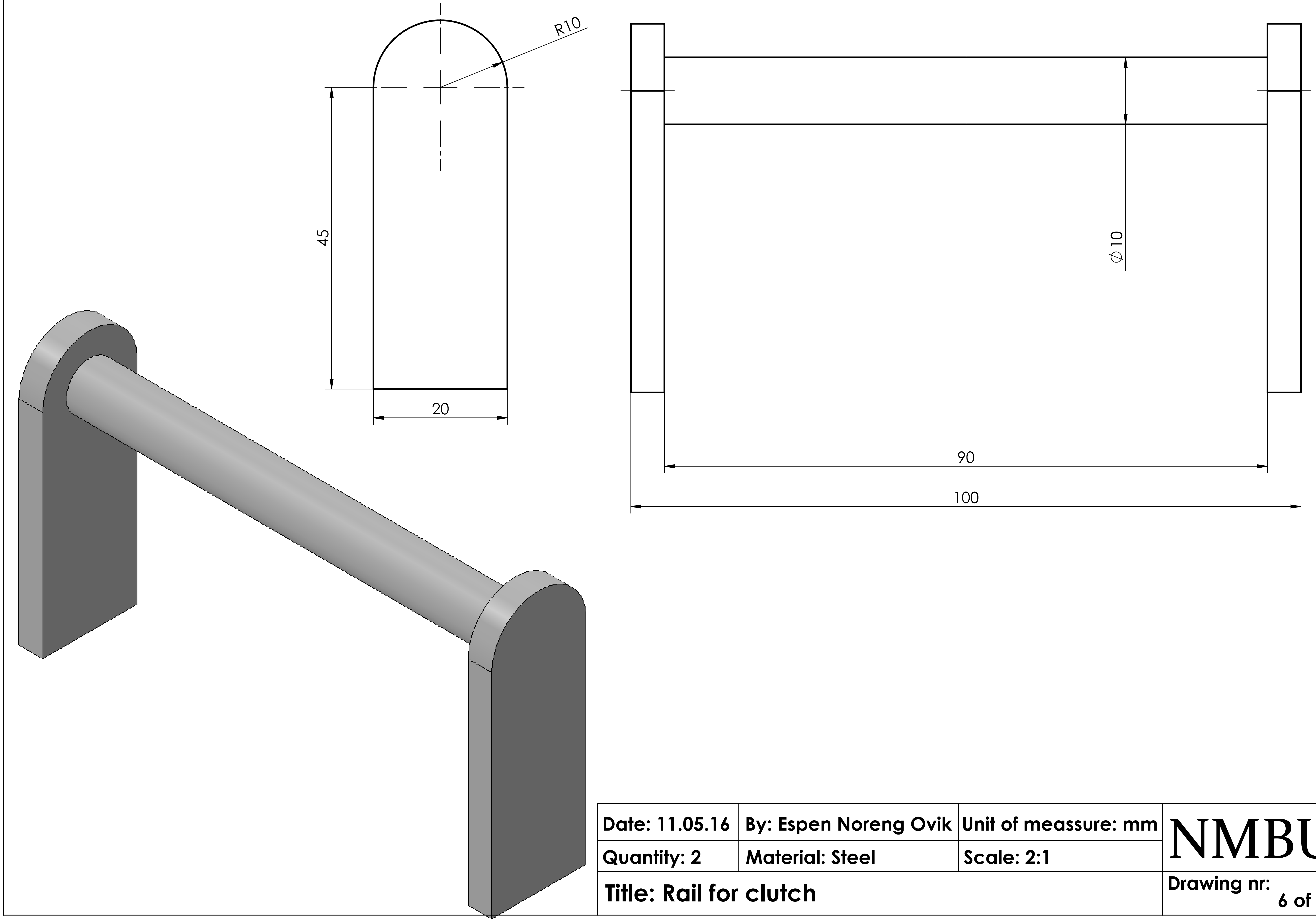


SECTION B-B

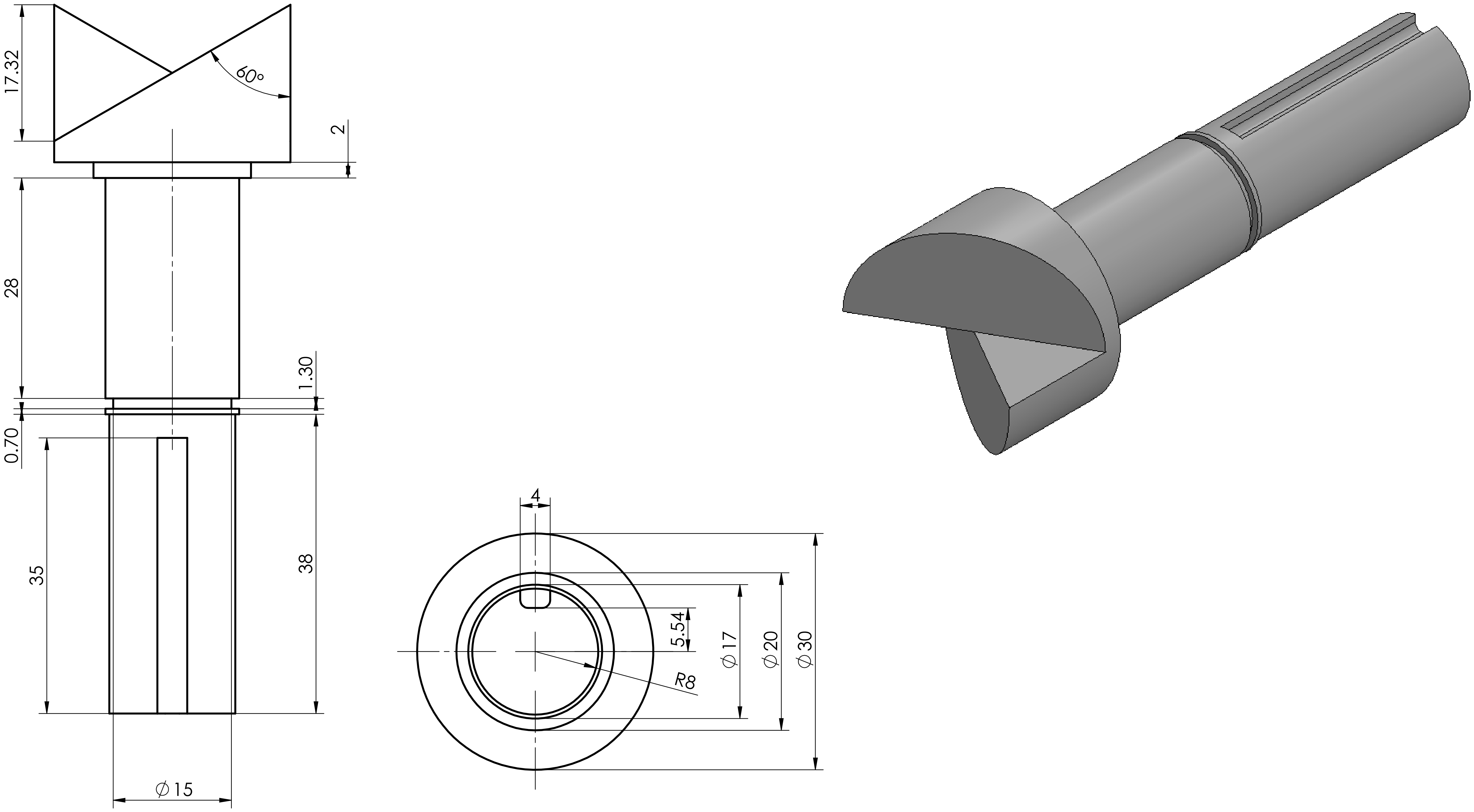




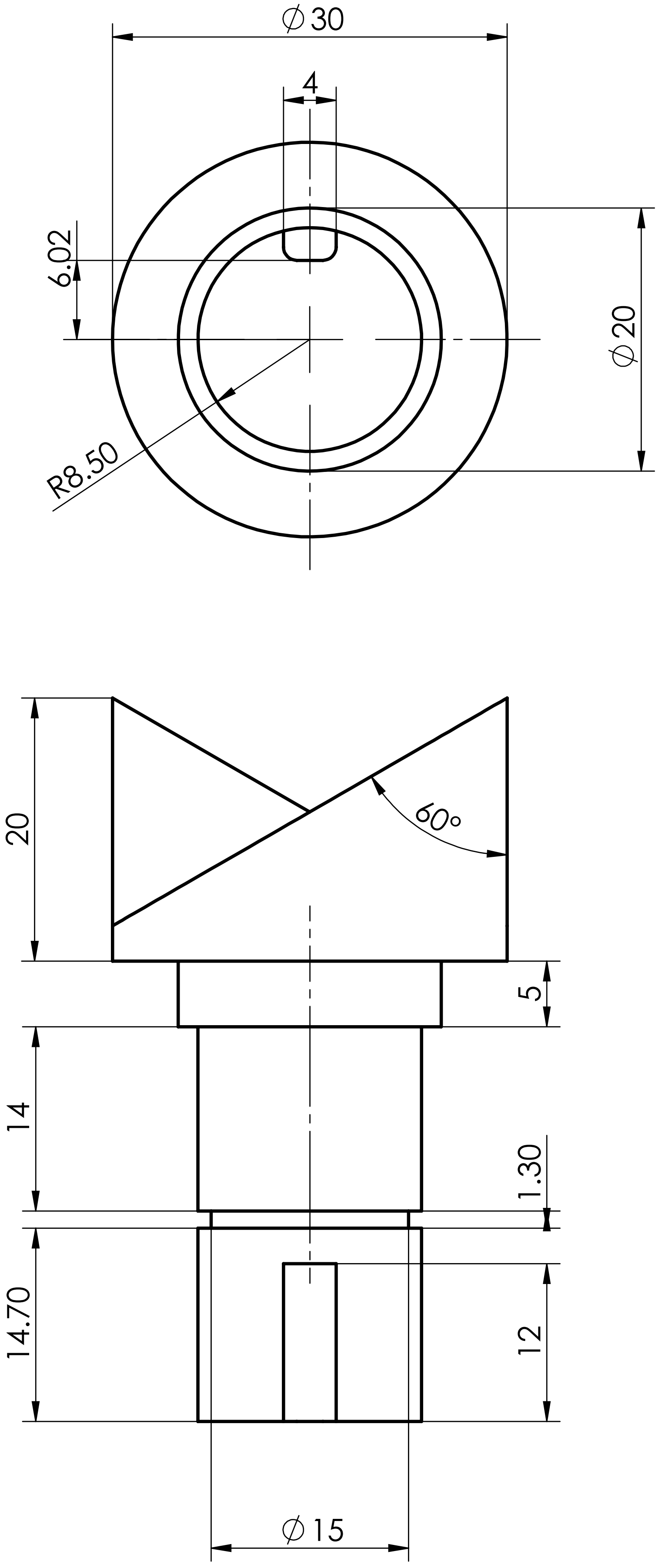
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 1:1	
Title: Ball bearing house part 2			Drawing nr: 5 of 21

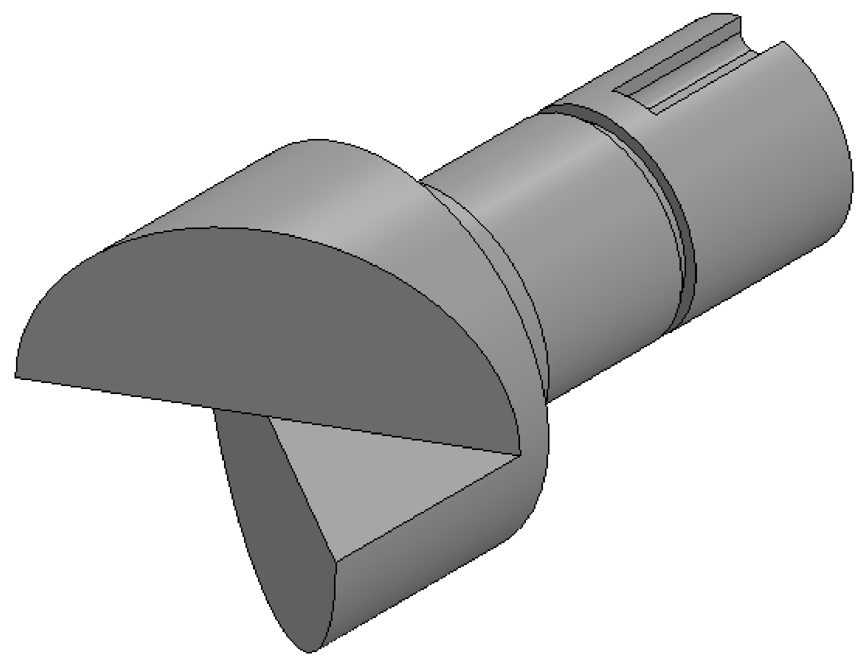


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 2:1	
Title: Rail for clutch			Drawing nr: 6 of 21

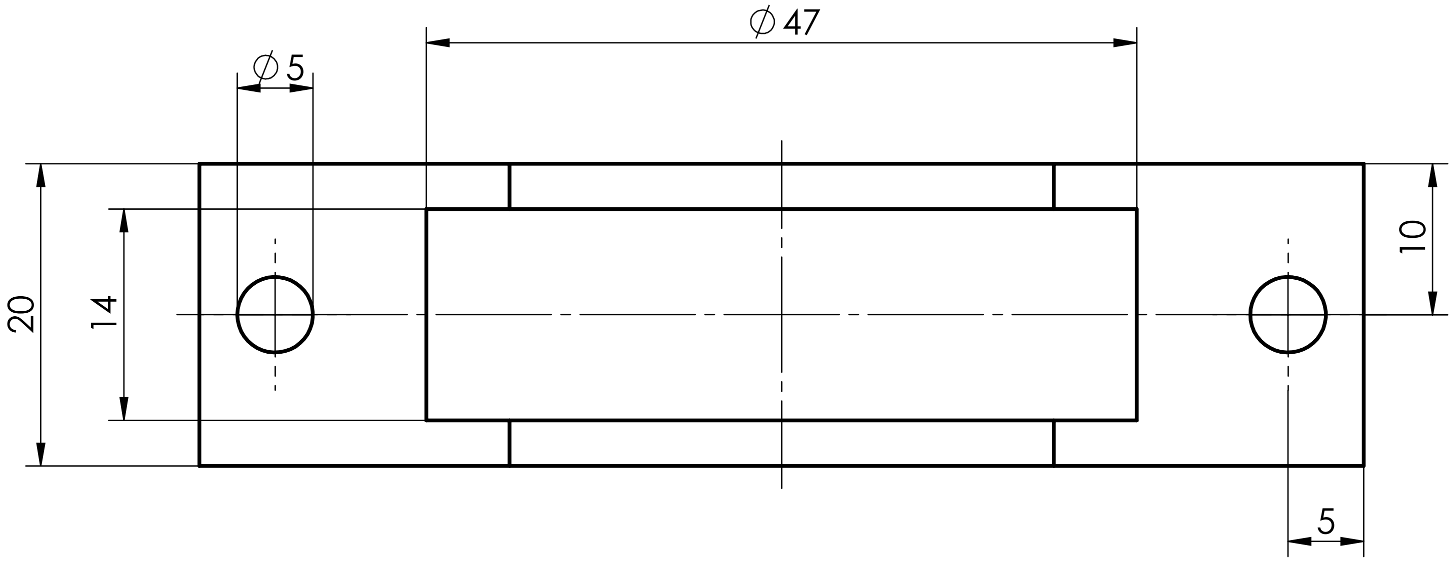


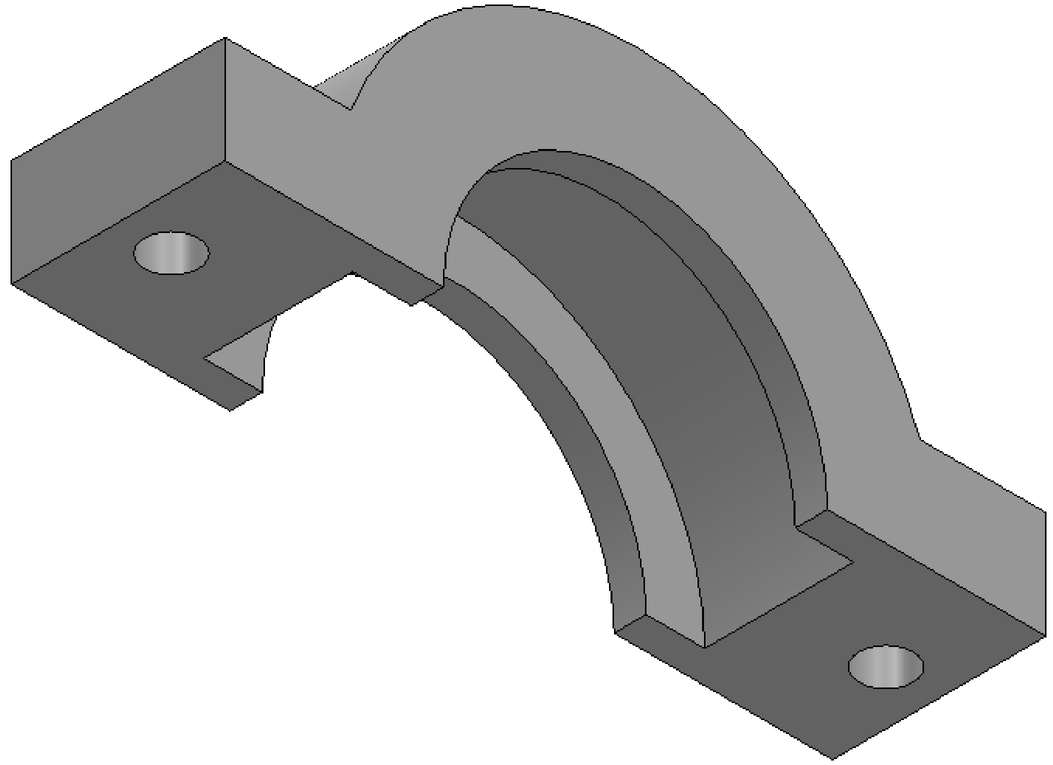
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale:	
Title: Clutch axle part 1			Drawing nr: 7 of 21

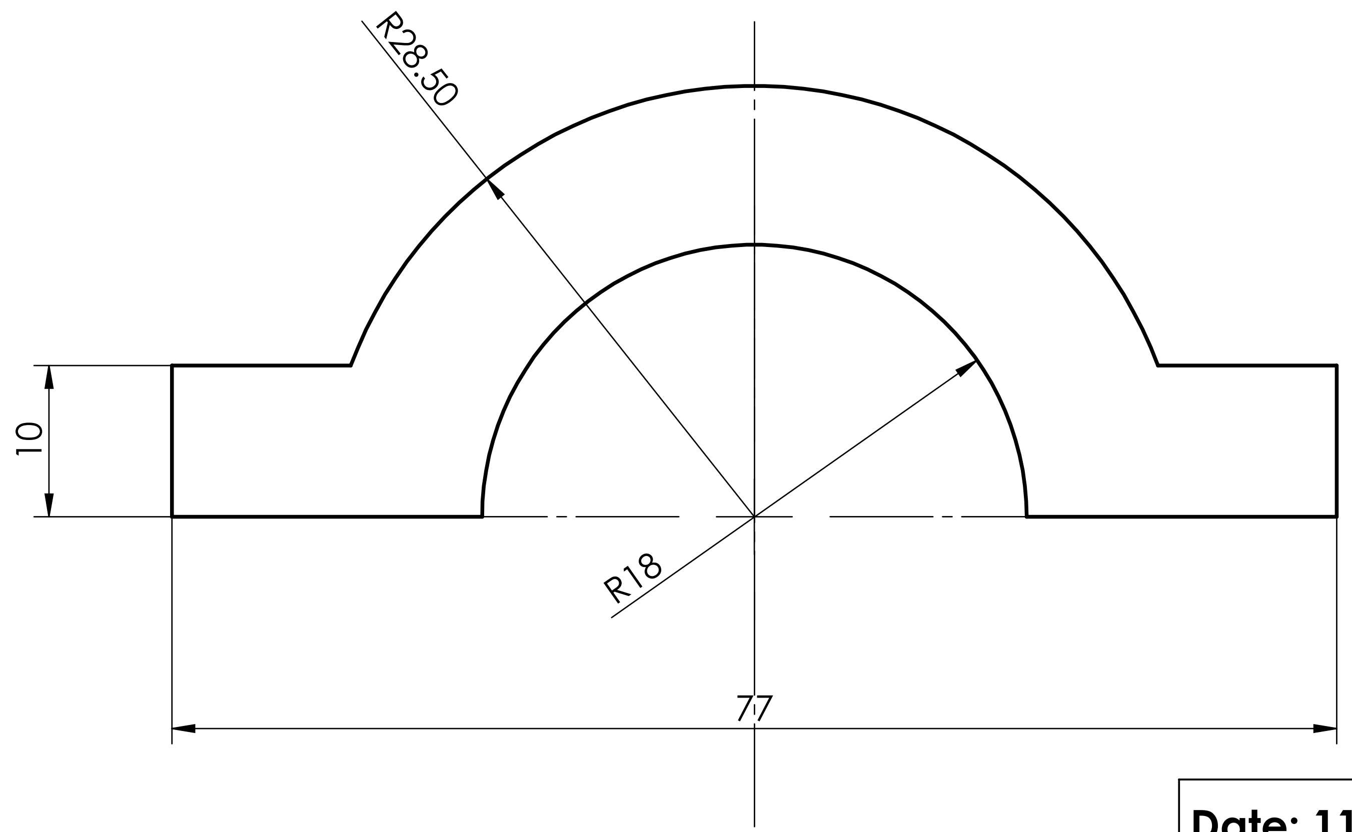




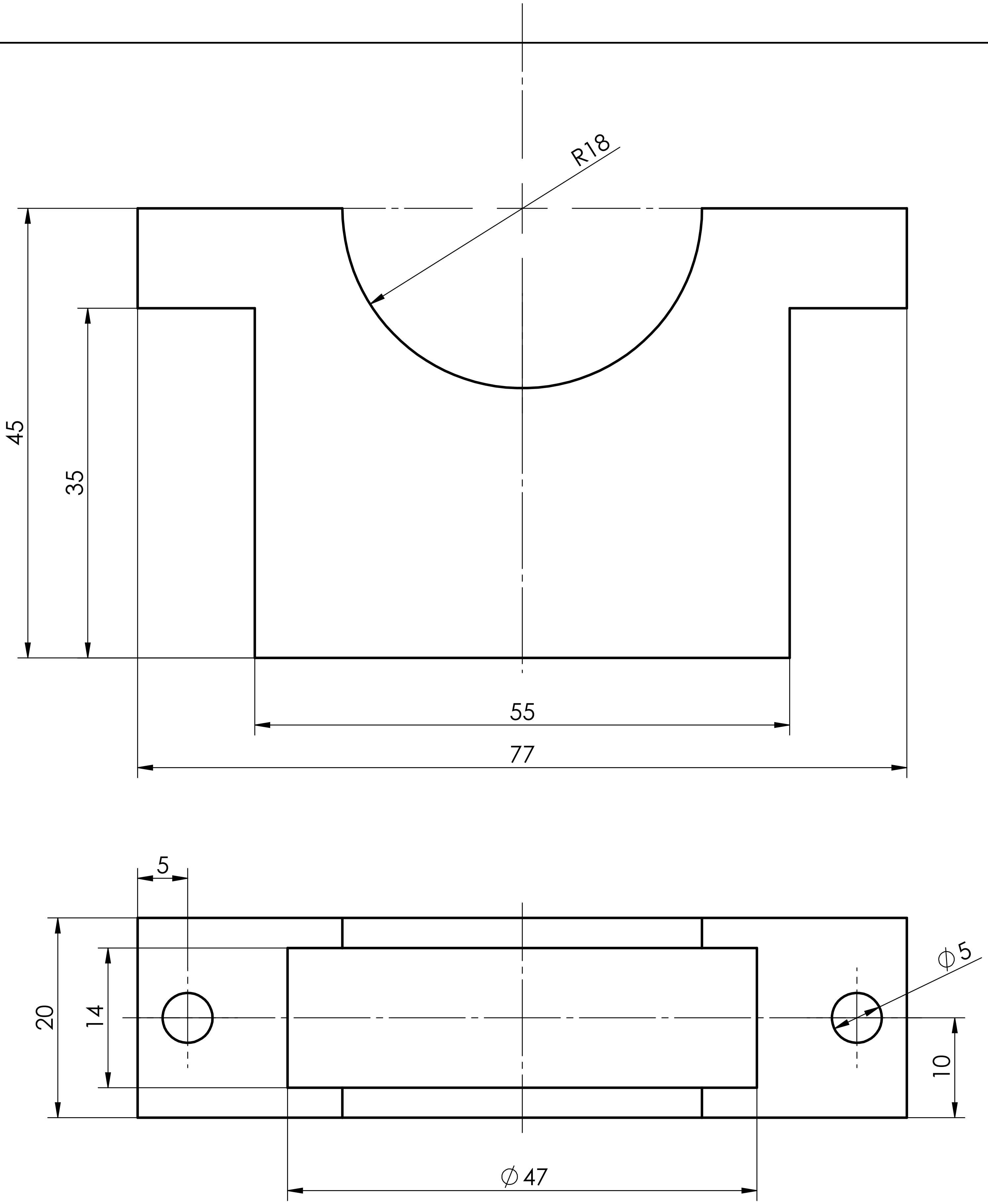
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 2:1	
Title: Clutch axle part 2			Drawing nr: 8 of 21

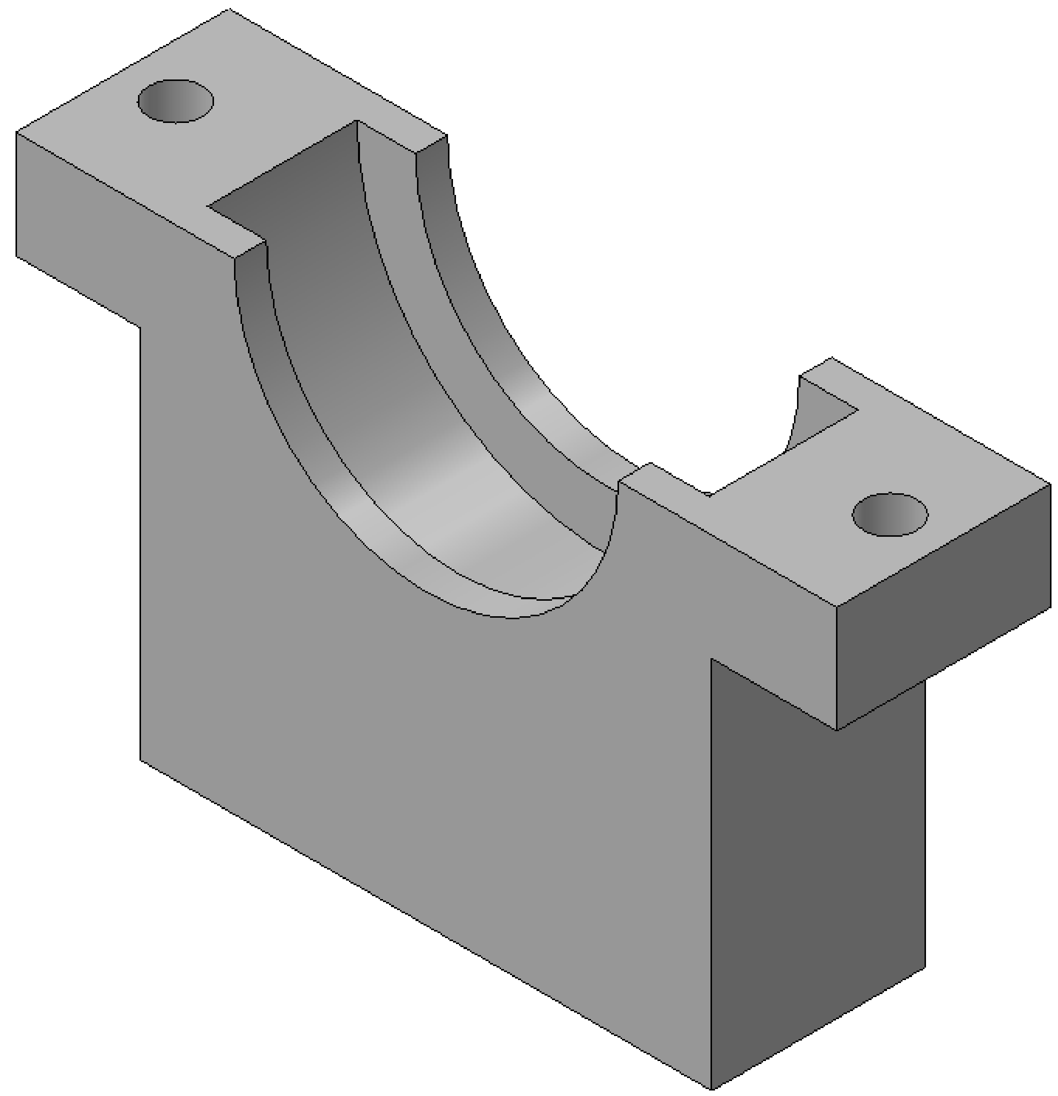




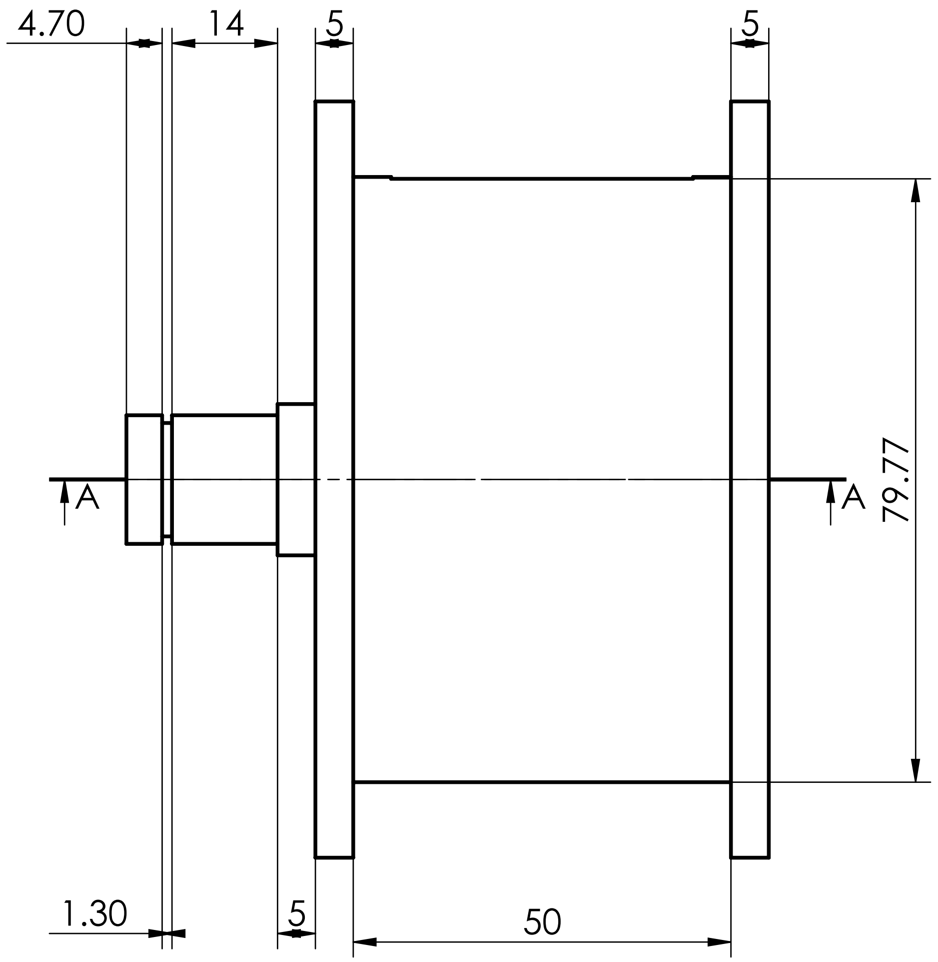


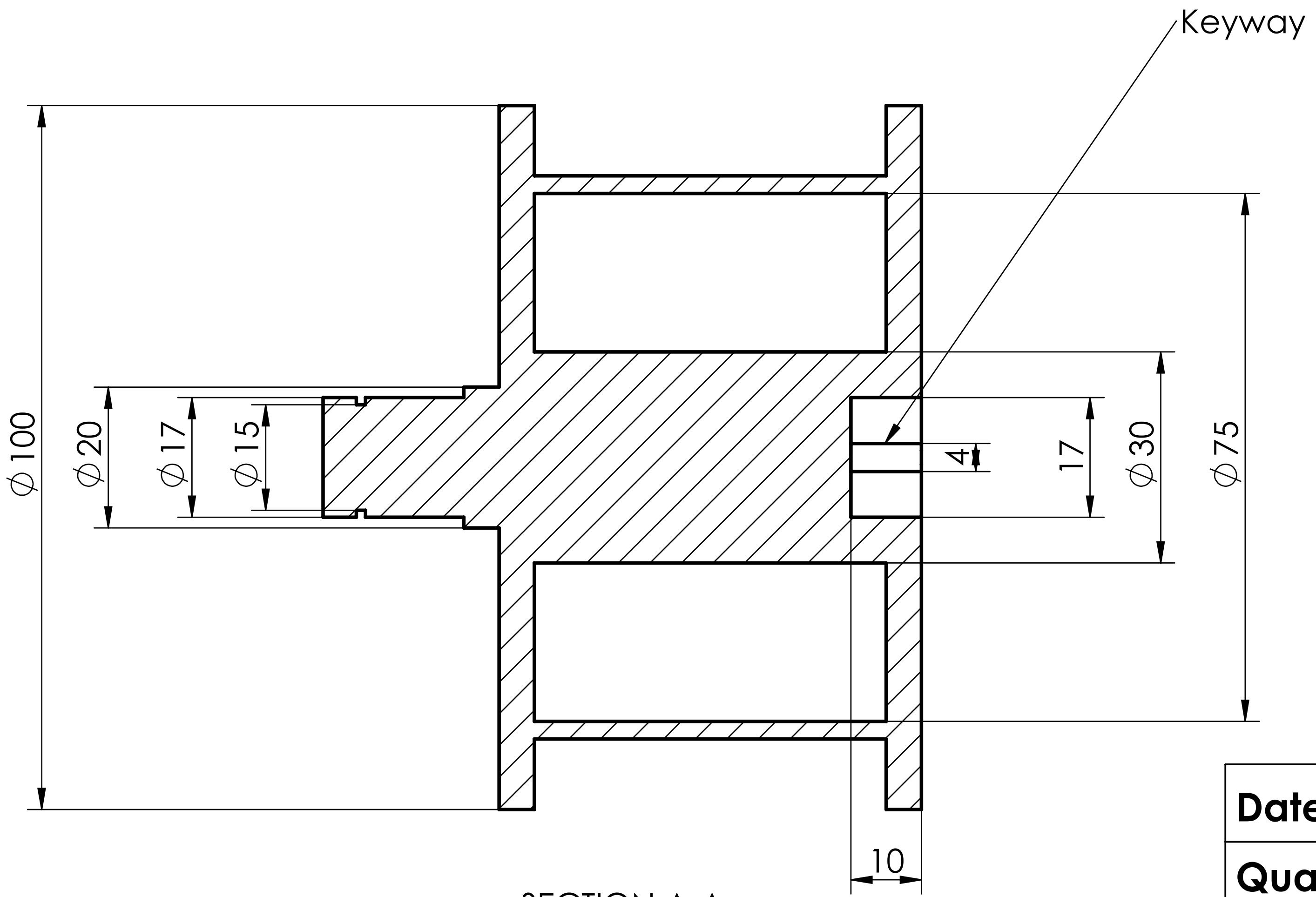
Date: 11.05.16	**By: Espen Noreng Ovik**	**Unit of meassure: mm**	NMBU
Quantity: 2	**Material: Steel**	**Scale: 2:1**	
Title: Drum holder part 1			**Drawing nr:** 9 of 21



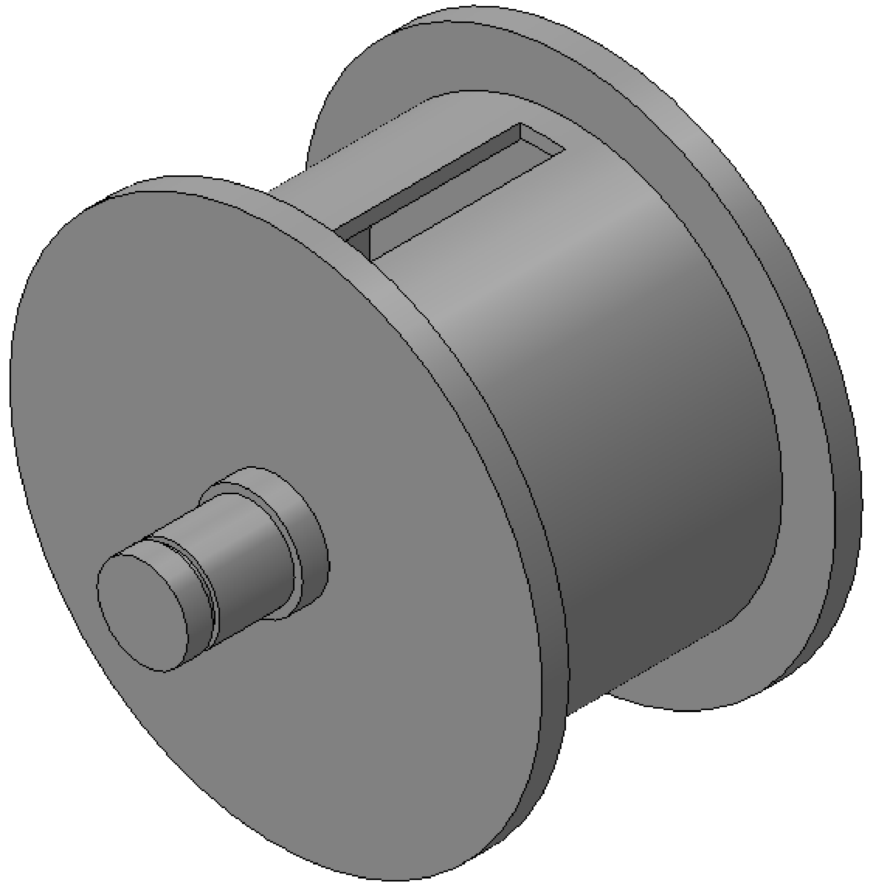


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 2:1	
Title: Drum holder part 2			Drawing nr: 10 of 21

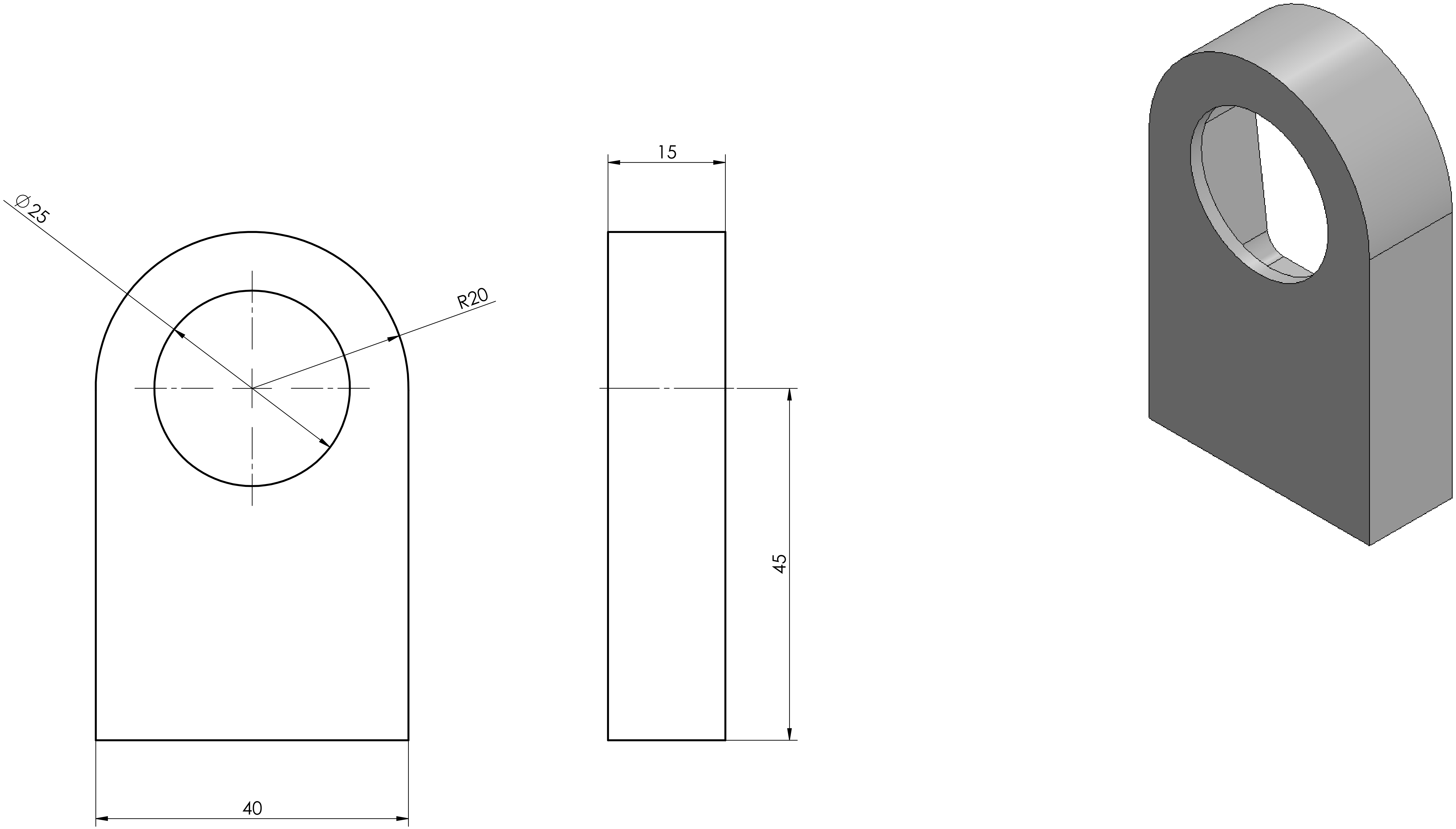




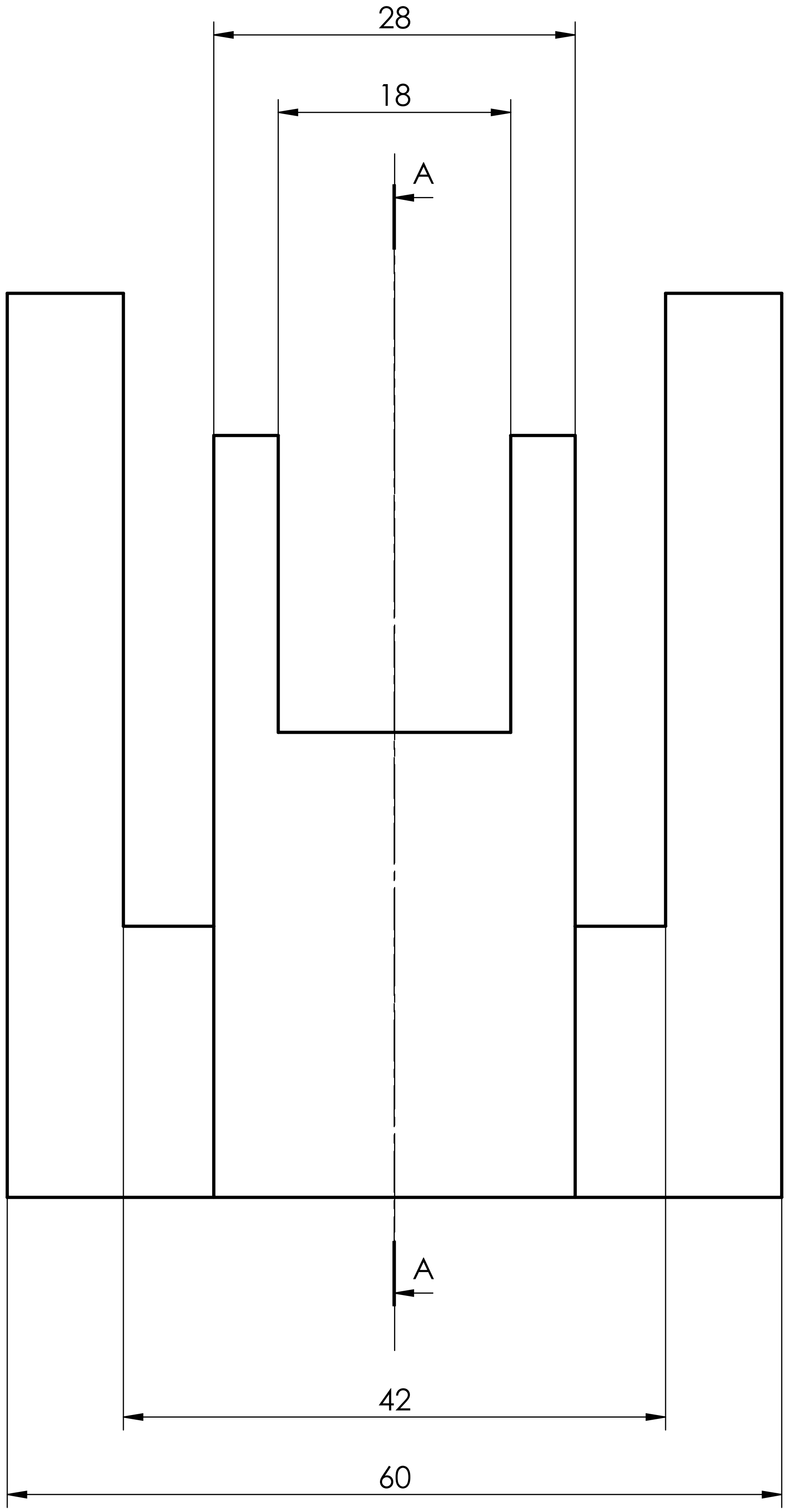
SECTION A-A
SCALE 1 : 1

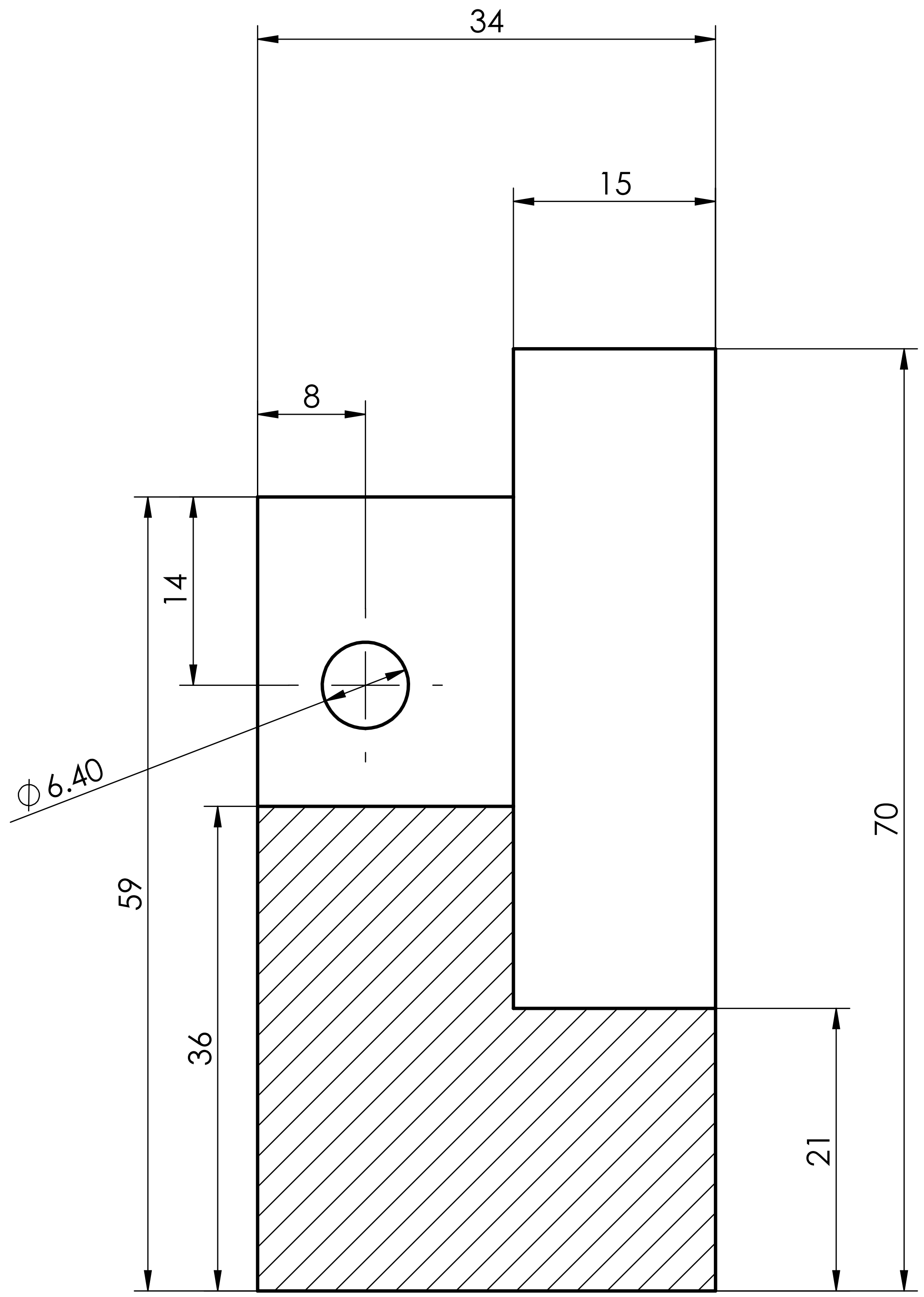


Date: 11.05.16	**By: Espen Noreng Ovik**	**Unit of meassure: mm**	NMBU
Quantity: 1	**Material: Steel**	**Scale: 1:1**	
Title: Drum			**Drawing nr: 11 of 21**

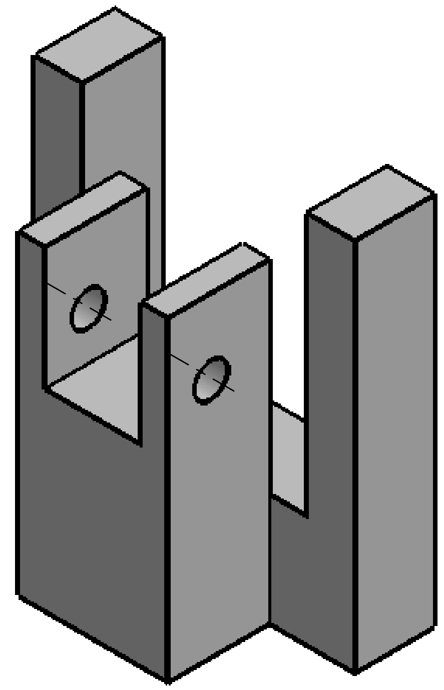


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity:1	Material: Steel	Scale: 2:1	
Title: Actuator holder part 1			Drawing nr: 12 of 21



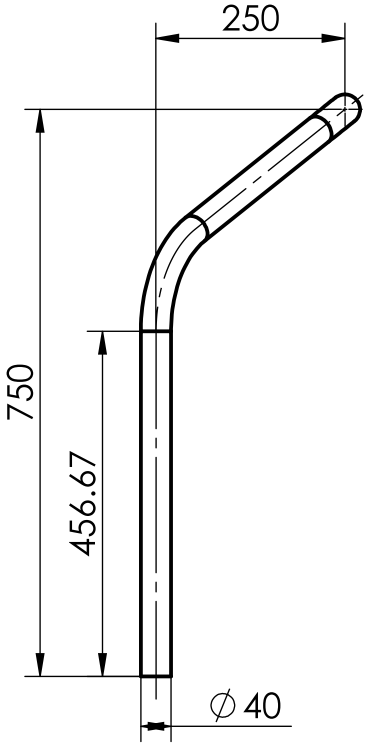


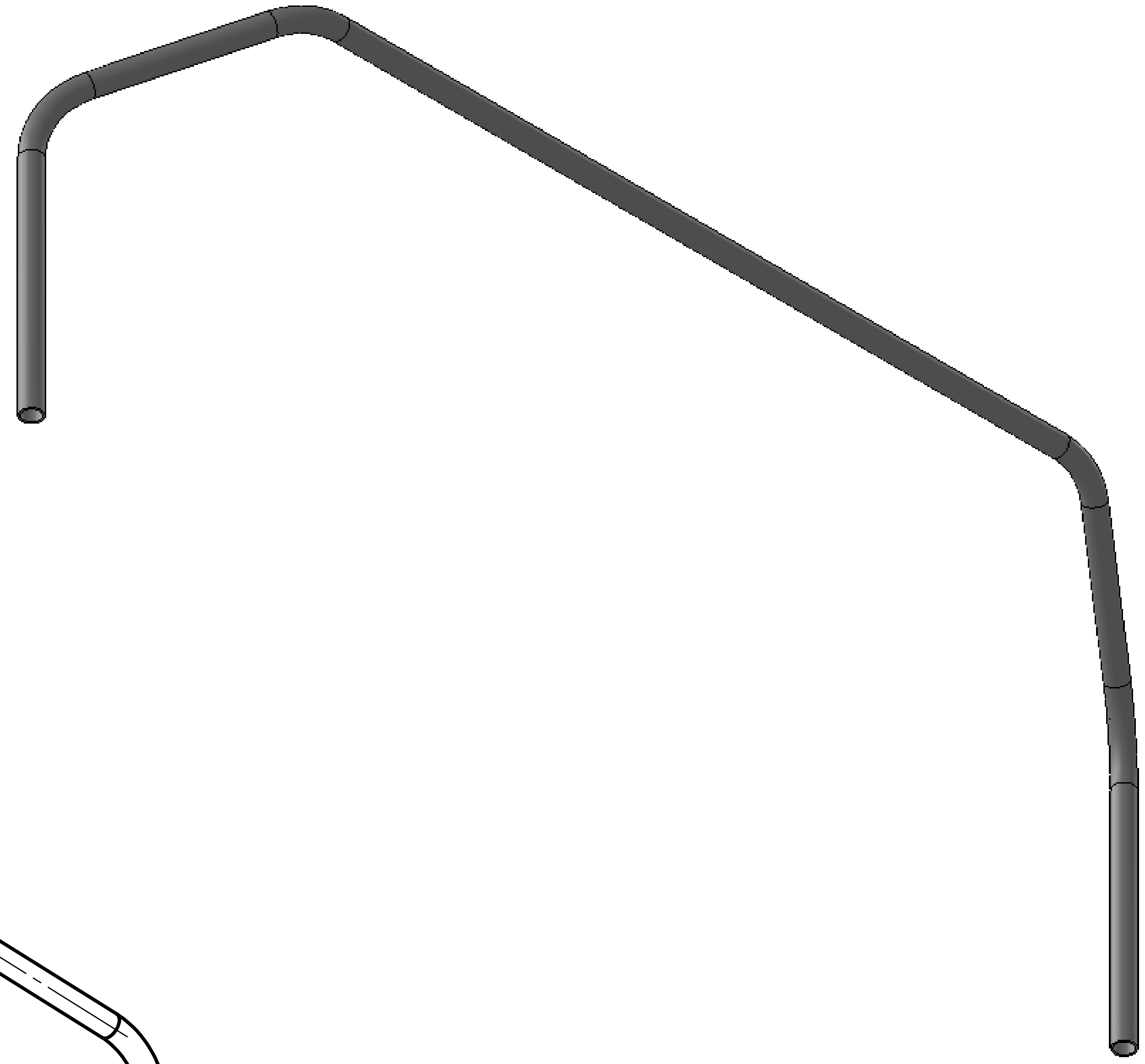
SECTION A-A
SCALE 2 : 1

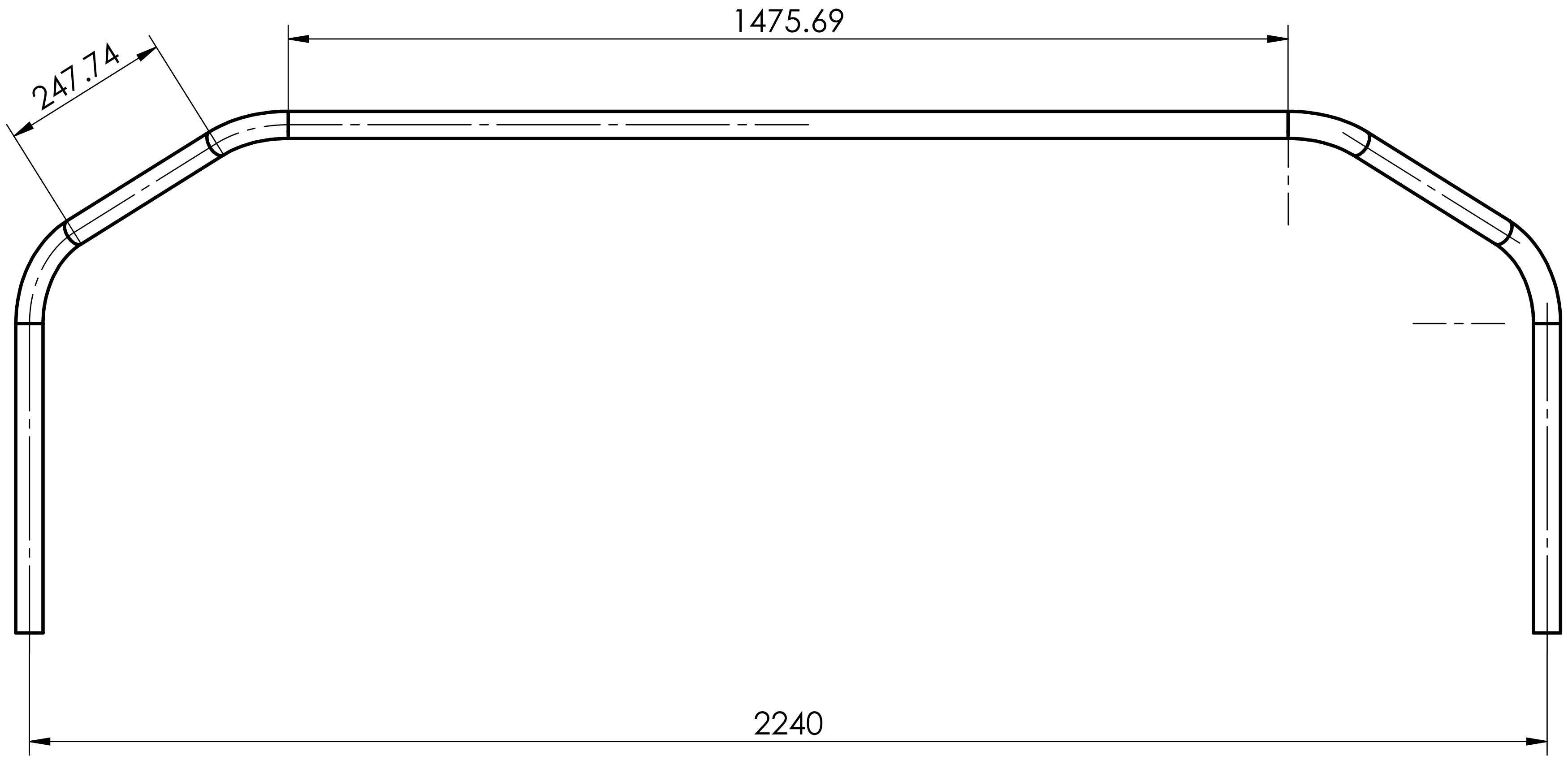


Scale: 1:1

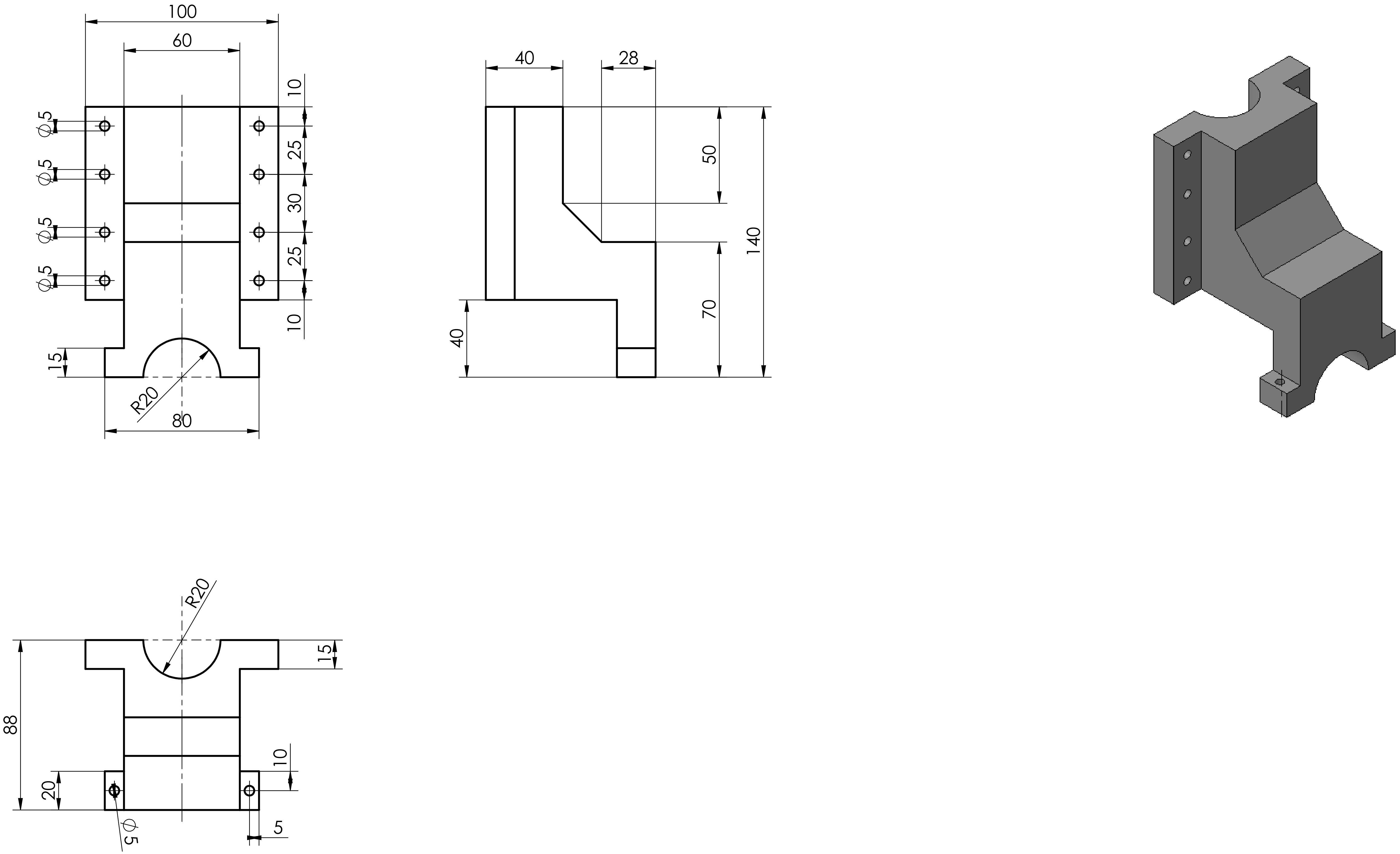
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 2:1	
Title: Actuator holder part part 2			Drawing nr: 13 of 21



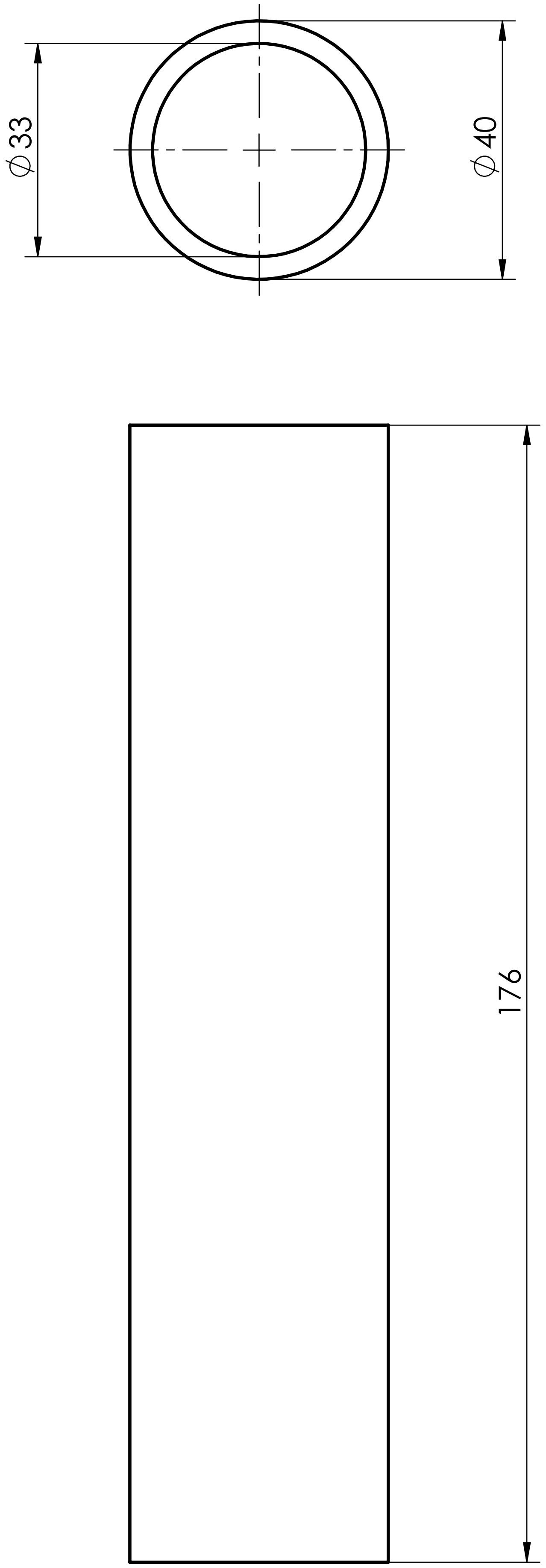


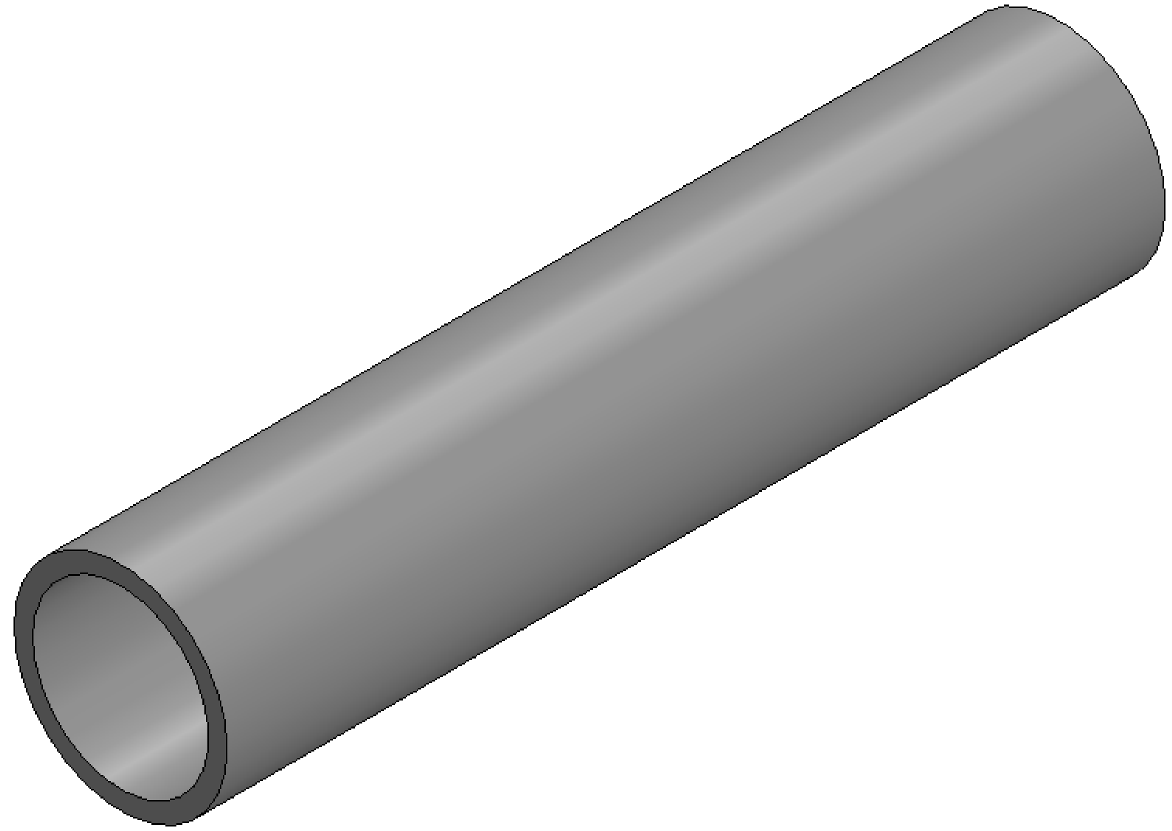


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 1:10	
Title: Front scaffold rod			Drawing nr: 14 of 21

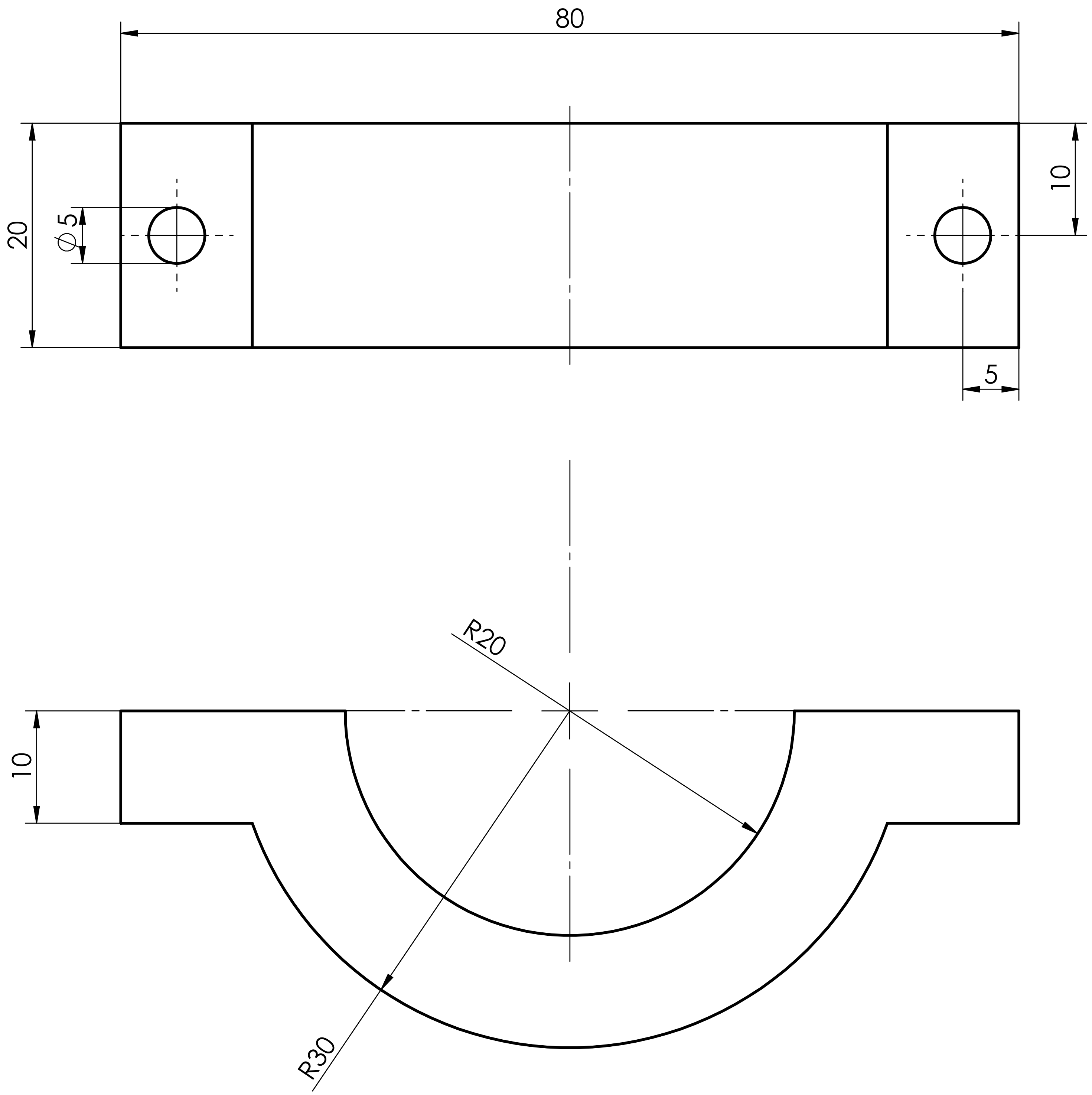


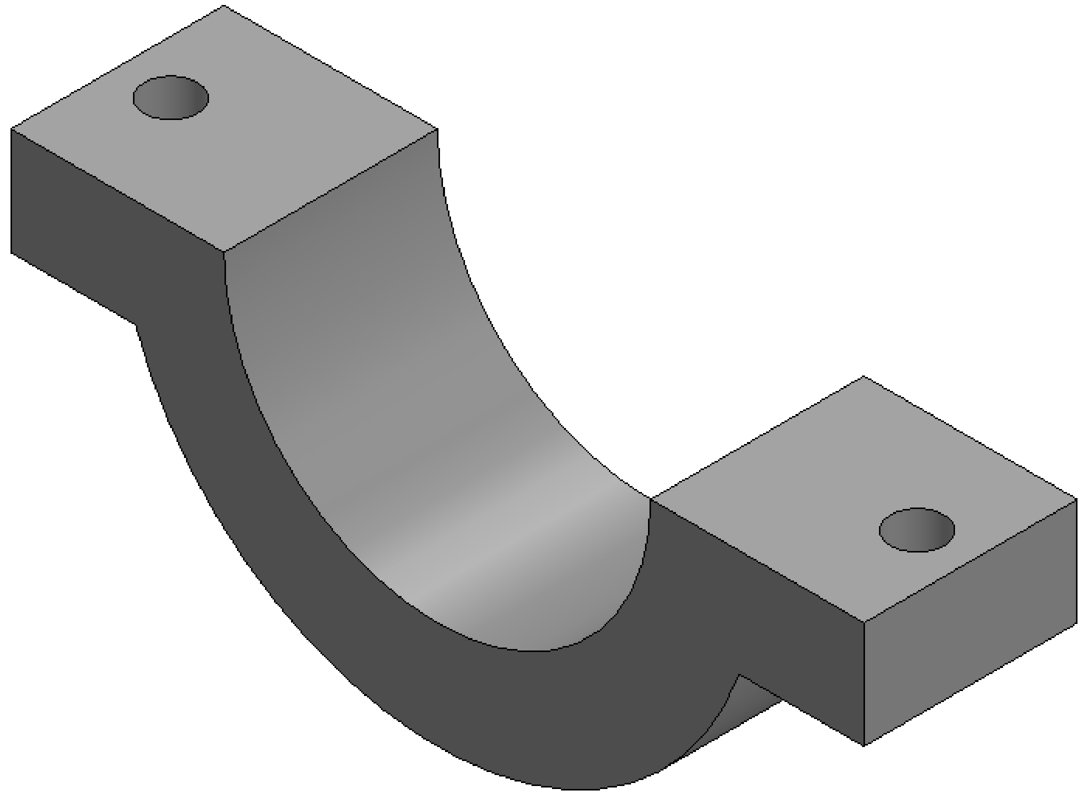
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 4	Material: Steel	Scale: 1:2	
Title: Scaffold attachment part 1			Drawing nr: 15 of 21



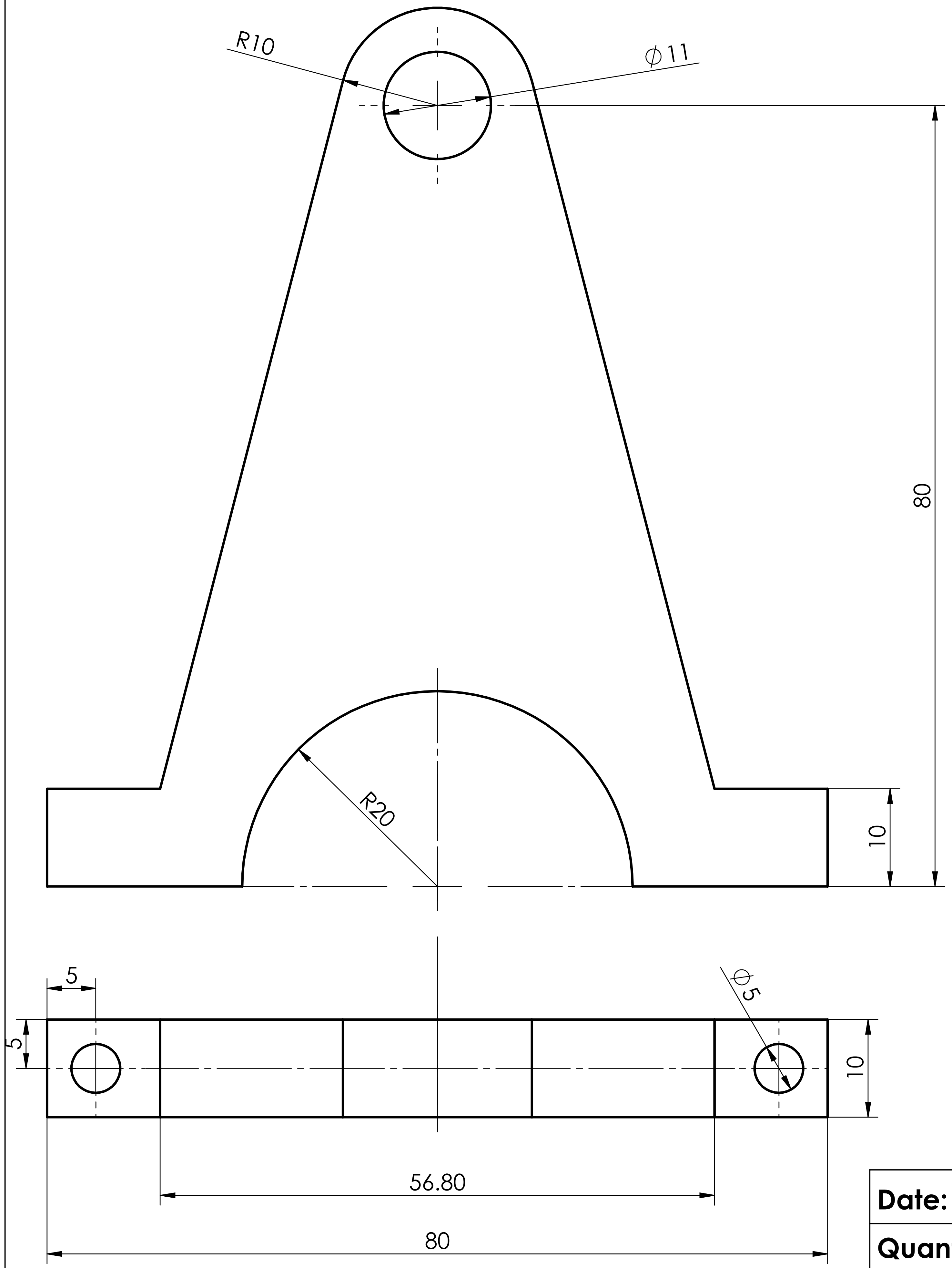


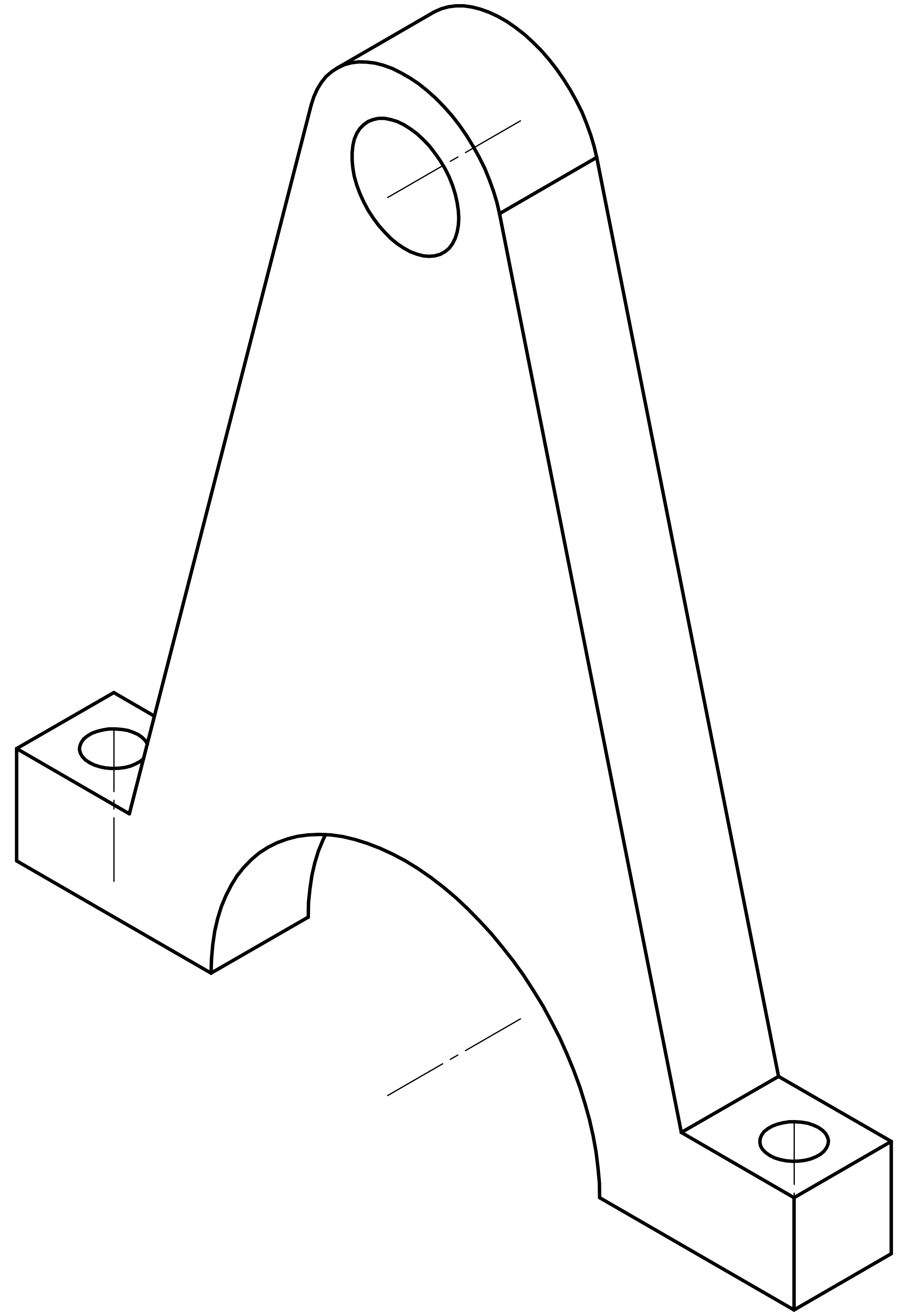
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 1:1	
Title: Scaffold attachment part 2			Drawing nr: 16 of 21



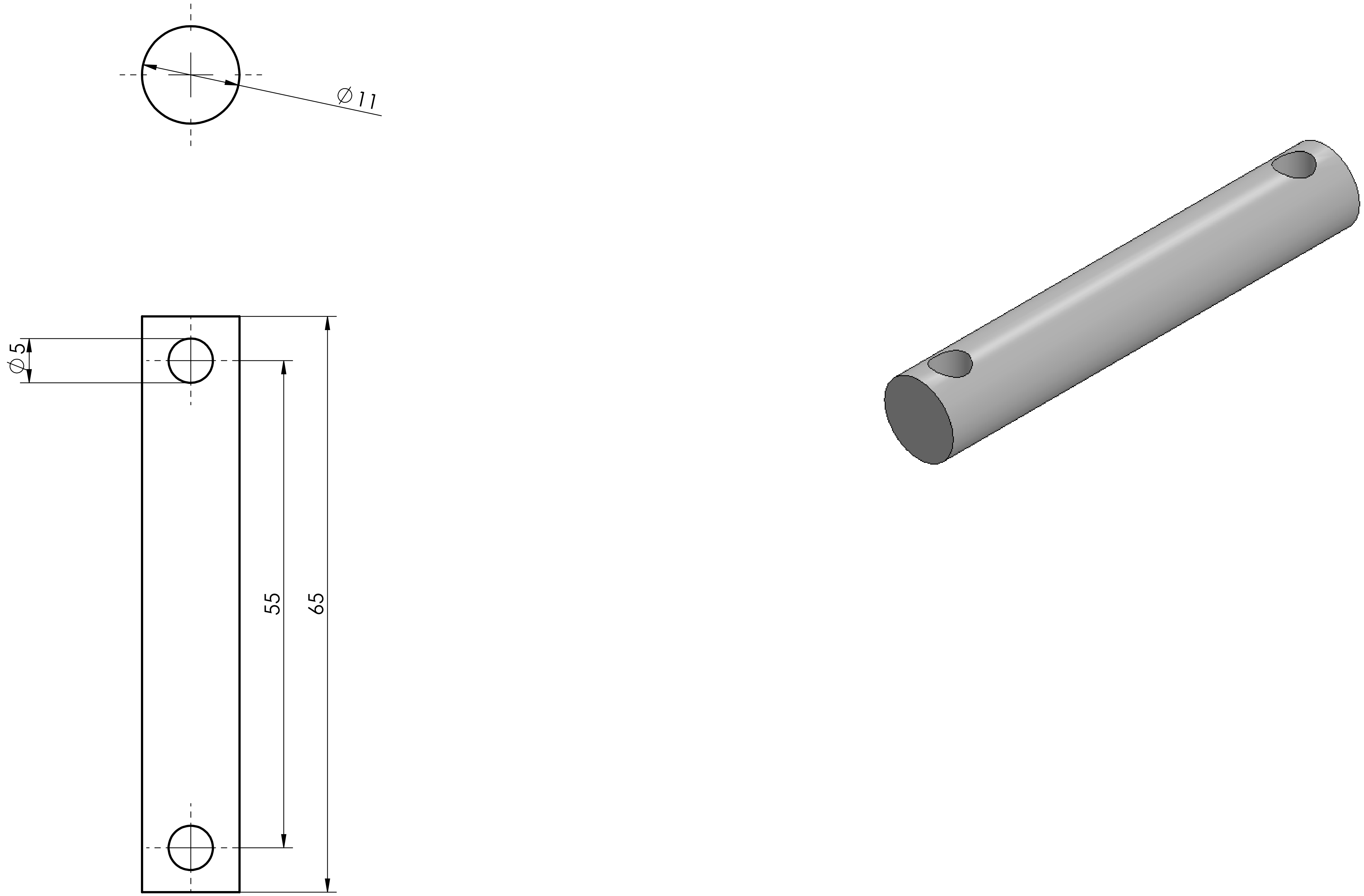


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 4	Material: Steel	Scale: 2:1	
Title: Scaffold attachment part 3			Drawing nr: 17 of 21

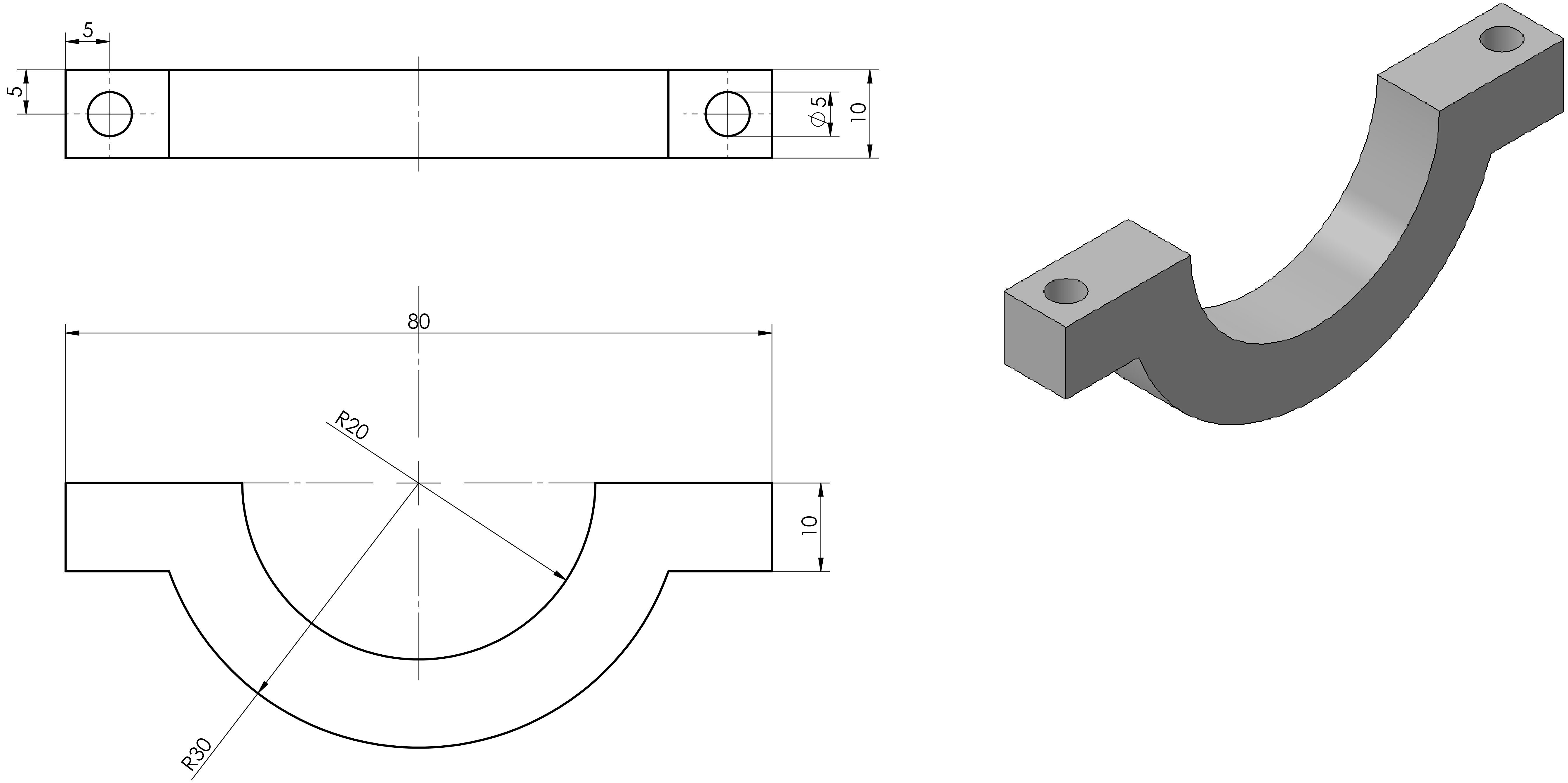




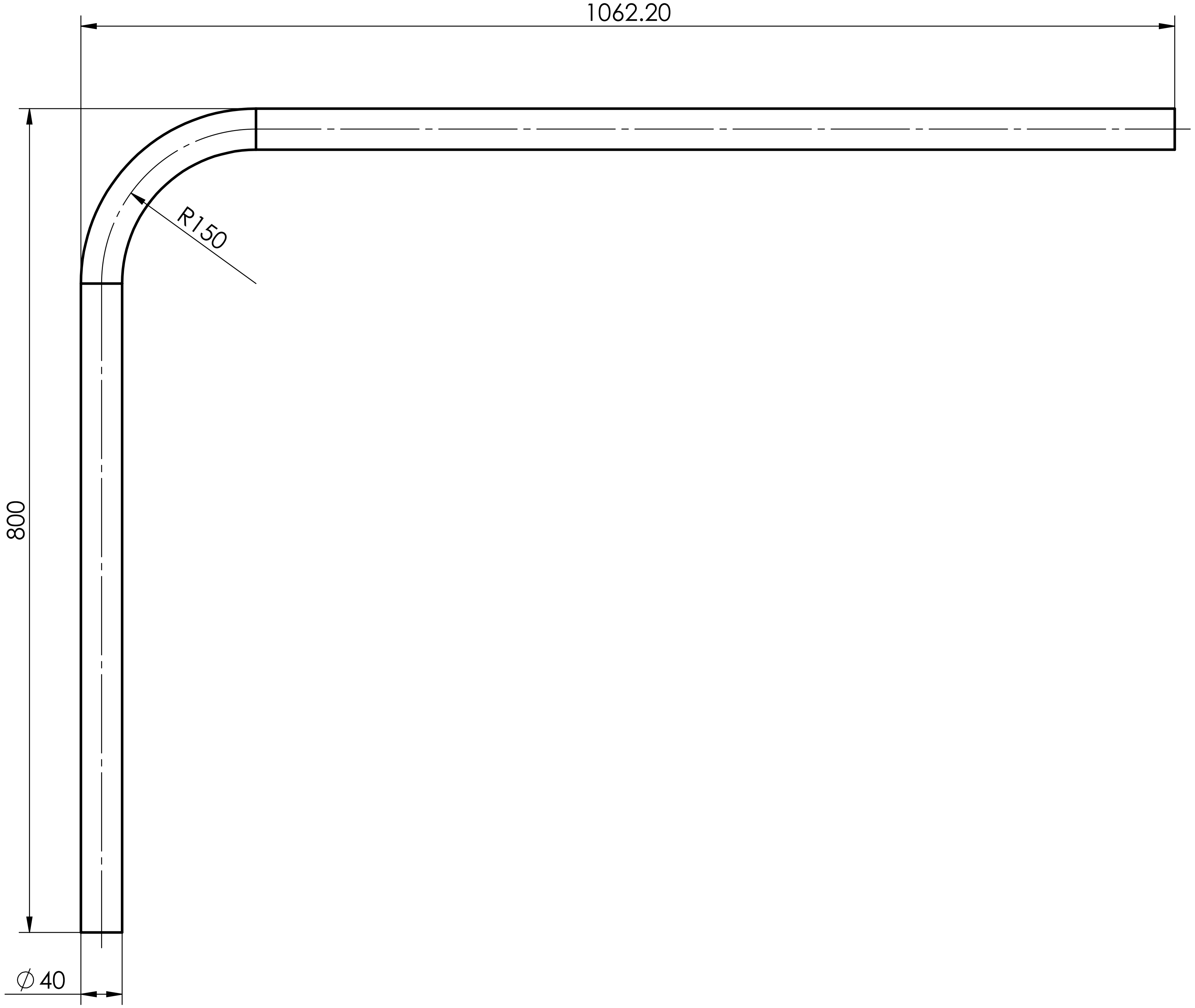
Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 2:1	
Title: Pulley wheel attachment part 1			Drawing nr: 18 of 21

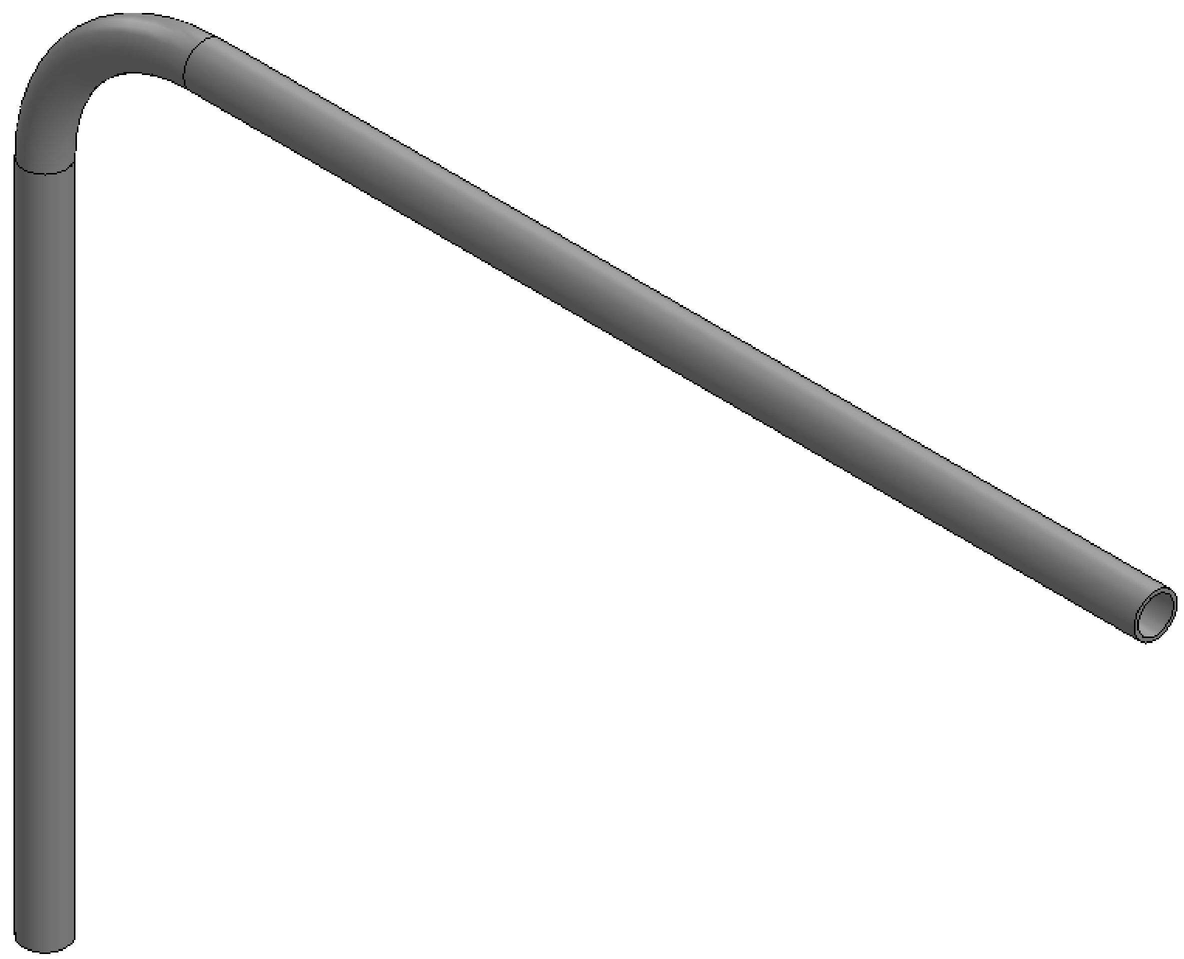


Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 1	Material: Steel	Scale: 2:1	
Title: Pulley wheel attachment part 2			Drawing nr: 19 of 21



Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 2:1	
Title: Pulley wheel attachment part 3			Drawing nr: 20 of 21





Date: 11.05.16	By: Espen Noreng Ovik	Unit of meassure: mm	NMBU
Quantity: 2	Material: Steel	Scale: 1:5	
Title: Rear scaffold rod			Drawing nr: 21 of 21

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