BSc Eng Thesis
Bachelor of Science Engineering

DTU Electrical Engineering
Department of Electrical Engineering

Tether Control for Unmanned Aerial Vehicle

Creating a Platform for Tether Control of UAV

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Kongens Lyngby 2015

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Tether Control of Unmanned Aerial Vehicle
Tøjr-styring til ubemandet luftfartøj

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Project period:	1 September 2014 - 23 January 2015
ECTS:	15
Education:	Bachelor of Science Engineering
Field:	Electrical Engineering
Class:	Public
Remarks:	This report is submitted as partial fulfilment of the requirements for graduation in above education at the Technical University of Denmark.
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Abstract

Unmanned Aerial Vehicles or UAVs is getting more common in everyday life, both as hobby projects and in industrial applications. The aim of this project is to propose a solution to extend flight time for UAVs in industrial application using a tether cable connection. Develop a platform, which handles the mechanical part of winching and storing the cable, the electrical part of powering the UAV, using the cable as position reference for the UAV, and using the cable for communication with the UAV is desired. Using a hexacopter(a 6 rotor UAV) with lifting capabilities of about 3kg and a 50m lightweight cable ensures the UAV to be able to lift the cable. Two methods of winching and storing the cable is analysed, and one method selected for prototyping. Developing two electrical measurement devices to measure the position references for position control of UAV. This work does not deal with the position controller for the UAV. An Ethernet link from the Ground Control Station to the UAV system is established through a regular Ethernet over power line adapter. Designing both Ground Control Station and the UAV to run on Beaglebone Black, the actual flight controller is a PixHawk. The system design and prototype is analysed, and discussed for further development on this project.

Resume

Ubemandet luftfartøjer eller i daglig tale UAV'er bliver et mere almindeligt syn i hverdagen, både som hobby projekter og i industrielle applikationer. Formålet med dette projekt er at forslå en løsning til at forlænge flyvetiden for UAV'er ved hjælp af en kabel forbindelse til UAV'en. Det er ønsket at udvikle en platform, der håndtere den mekaniske del af ind og ud rulning af kablet, samt opkvejling[1], den elektriske del ved at benytte kablet som positions reference for UAV'en, og at kommunikere med UAV'en via kabel forbindelsen. Til formålet benyttes en 6 rotor, Hexacopter, som UAV med en løfte kapacitet på omkring 3kg og et 50m letvægts kabel. To metoder til at rulle kablet ind og ud, samt opbevaring analyseres, hvoraf en metode udvælges til at blive prototype fremstillet. To elektriske måleapparater designes til at måle positions referencerne for positions regulering af UAV'en. Dette projekt omhandler ikke selve positions regulatoren til UAV'en. En netværksforbindelse etableres fra jordstationen til UAV'en via et "Ethernet-over-power-line" system. Både jordstationen og UAV'ens flyve computer designes til at køre på en Beaglebone Black, UAV'en er dog udstyret med en PixHawk microcontroller. Det samlede system design og prototype analyseres og diskuteres til fremtidigt videre arbejde med systemet.

[1]At kvejle er en Maritim terminologi for at opsamlet et torværk flot, således det ikke er tvunden og uden knuder.

Preface

This bachelor thesis was written at the department of Automation and Control at the Technical University of Denmark in fulfilment of the requirements for acquiring a bachelor degree in Electrical Engineering.

This project is an innovation project, which pushes the boundaries of the relative low cost technology. There is an Old Danish saying that "Deep fall, high flying". Innovation project is about being willing to take a high risk, of falling deep, to achieve results no one thought was possible. If every innovation project succeeded, it is not innovation - but only a further development of existing technology. To achieve an innovative goal, you have to set a goal 110 per cent higher of what you expect to achieve and afterwards be fair in sentencing if missing the target.

The target audience for this thesis is students/staff with an electrical engineering background who are interested in this project and the focus is on how they can benefit from this work using the method and results.

Kongens Lyngby, January 20, 2015

Peter Juhl Savnik (s113556)

Acknowledgements

A special thanks to my two academic advisers, for always seeing the possibilities rather than the impossibilities in this project. Thanks to Søren Hansen for introducing me to ”a real world problem” that is very relevant today. Thanks to Christian Andersen for always having time to help me problem solving or introduce me to programming concepts, even when it got late in the evening. It has been supportive to see and feel you both share a huge personal interest in this project.

Thanks to all friends and family who has supported me though this project and helped me having time for this project to become a success. A special thanks to Nicholas Swiatecki who helped me making this thesis readable and detect misspellings.

Thanks to Martin Meister from DTU Skylab team for helping out with the mechanical work and supplying materials for this project. Whenever the mechanic from the institute only saw problems, Martin Meister always saw possibilities and guided me towards a mechanical solution. It has been a long battle for me, without any mechanical experience, to master such an underestimated expertise, both the design process, manufacturing parts and documentation.

Thanks to RS Components for sponsoring electrical and mechanical components for this project.

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CHAPTER 1

Introduction

Unmanned Aerial Vehicles, also commonly known as UAVs or drones, have for long time only been used for military, research and hobby purposes - recently a wide range of industrial applications has seen the potential in using UAVs for industrial purposes. A variety of applications such as monitoring, photography/filming, surveying the landscape and much more have implemented flying UAVs [Dan15].

At present, most UAVs have a flight time of 20-30 minutes on their on-board battery. In some applications, such as power line inspections, the system must be capable of operating for a long period. In these cases, there is a need for a constant power supply via a cable. This project aim to develop a platform for tether control of UAV with a cable. A solution must not be limited to solving a single problem, but as a general platform for the implementation of tethered UAVs in a wide range of applications.

1.1 Previous work

Several attempts to build a tethered UAV have been seen before, several design concepts have been panted across the world [Pev13] - yet there is no commonly known commercial system available for sale. It is a great curiosity because most UAV systems have started to be tethered in some degree.

For this project a 6 rotor UAV from Mikrocopter[1] with a PixHawk[2] is provided. The UAV and the PixHawk has in previous work been set up and are working.
Mikkel Wahlgreen has designed a power supply system [Wah14], which attempts to meet the requirements described in this design requirement specification and Claudia G. Walls is working on a position controller for the UAV while this thesis is written.

1.2 Problem formulation

The objective for this project is to analyse and propose mechanical and electrical design for a platform for tether control of UAV. The UAV must be able to stay airborne for

[1]German company specialised in building UAV systems. http://www.mikrokopter.de/en/home
[2]The PixHawk is a microcontroller especially developed to work as a flight controller. https://pixhawk.org/

significantly longer time than a battery powered alternative. The designs have to be analysed and through the analysis one design chosen to be prototyped and tested.

1.3 Problem limitation

- It is assumed the anchor point of the UAV has significantly greater mass than the UAV lifting capabilities.

- The power supply may be optimized by using both a cable and a battery. The UAV do not use 100 per cent of its power at all time, but cable and power converters is dimensioned to deliver 100 per cent power when needed. Therefore, it is imagined the UAV is capable to take off and land on the battery, and the battery is recharged in air by the cable. This thesis only investigates the case without battery.

- This project will not cover the position control in the PixHawk.

- Due to the price range of UAV systems today, the system must keep a relative lost cost.

- The UAV used in this project will be a Hexacopter from Mikrocopter.

1.4 Example of use case

In Denmark agriculture grain production constitutes 35 per cent of the total area, or $1,495,000$ hectares with a value of 29.4 billion. kr. Producing increasingly more with less resources, the Agriculture puts a strong focus on optimizing production through research and innovation[Fø13].

A well-known problem in cereal production is when the farmer harvests near the forest, there is often young wild deer hiding in the grain. Their natural instinct of danger is to hide or pretend to be dead. This means when the farmer harvests his field, the animal is not moving away from the machinery. This results in a large number of young deer who are hit by farmer's machinery. It have economic consequences for the farmer, hence the harvested grain is destroyed, materiel damage can happen to the equipment resulting in down-time, and not least it is an unpleasant experience for the farmer.

A research group at the department of Automation and Control at DTU have proposed a solution with a tether UAV flying in front of the vehicle and with a vision system that is capable of detecting obstacles such as animals or stones in front of the harvester.

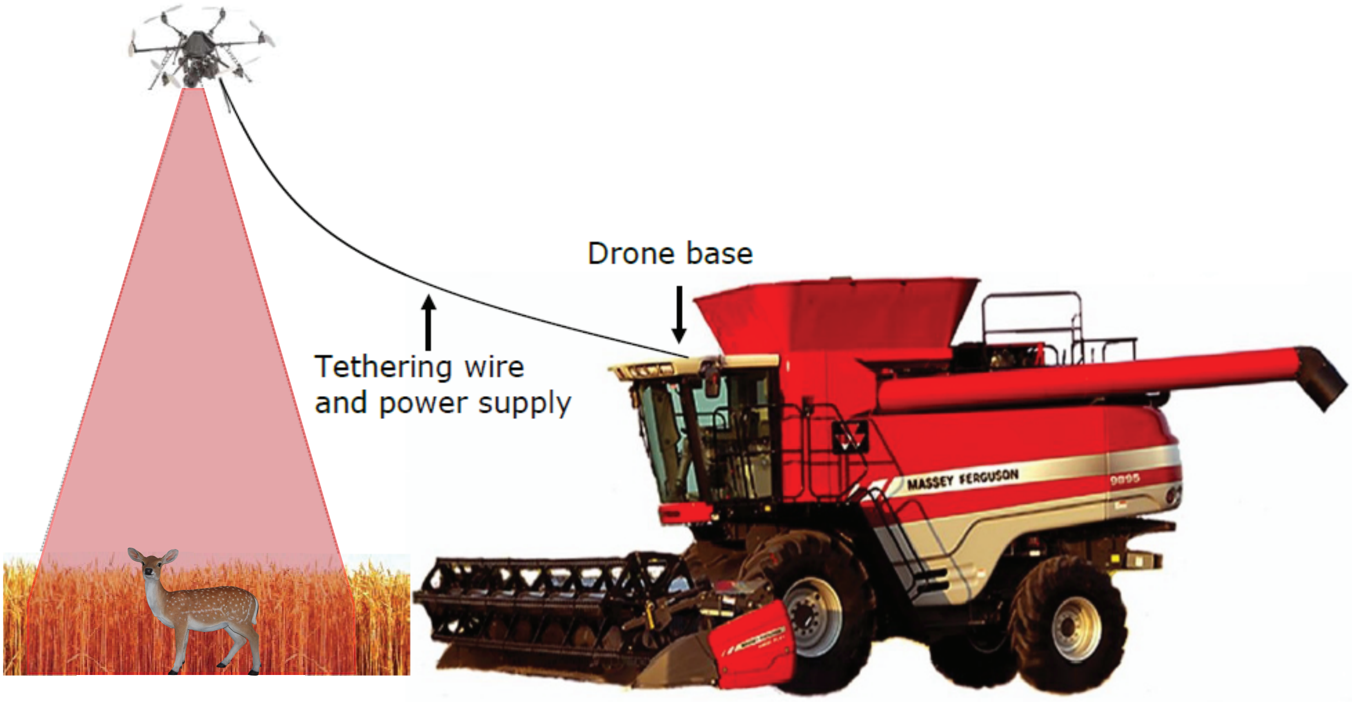


Figure 1.1: A UAV using a vision system is scanning the field in front of the Harvester.

1.5 Outline of this thesis

This thesis is divided into two main chapters, excluding the introduction. Chapter 2 investigate the presented problem through deeper analysis - resulting in a design requirement specification. Chapter 3, Prototyping, using the design requirement specification from the analysis chapter to develop both mechanical and electrical components. All practical information and configuration for replicating this work is located in the appendix. Chapter 4 is all about testing and discussing the results.

CHAPTER 2

Analysis

2.1 Background

It is desired to develop a platform for tether control of UAV. Such a platform can have many applications in the industrial world - which also raises a number of requirements for reliability and robust design.

The project has several issues, which needs to be addressed in the analysis in order to make a design requirement specification. This analysis will cover the issues, and the solutions will be addressed in the prototype chapter.

2.2 Platform for Tether UAV

A platform for tether control of UAV must have tree basic elements; the UAV, a power line and a Ground Station. The Ground Station supplies the power line with power and keeps track of the cable. The UAV must be able to land and take-off from the Ground Station. The power line must be light enough for the UAV to lift it. The Ground Station must assure that the power line is not touching the ground by releasing or pulling cable.

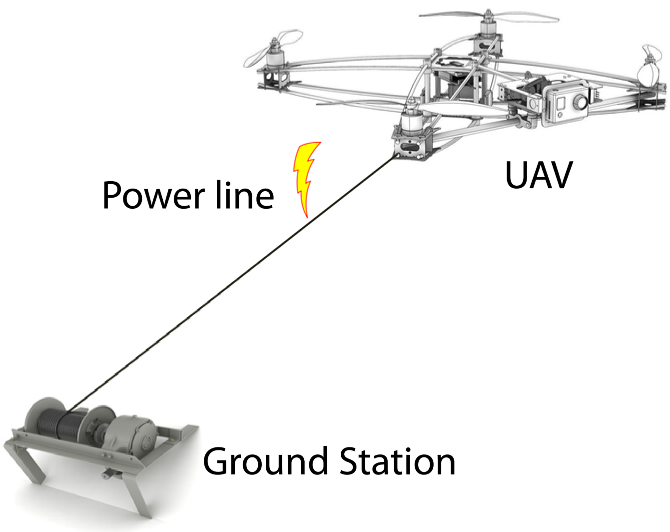


Figure 2.1: Illustration of key elements for a platform for tether UAV

2.3 Power line

Every cable has an electrical loss, and this factor contributes significantly when the cable is long and have a low cross-sectional area. Wanting to have a cable, which is as long as possible, but the UAV can only lift a limited amount of payload. The cross-sectional area and the length has a big impact on the weight. Investigating the electrical loss in the cable results in the cable specification requirements.
It is assumed the UAV requires 500 watt at 12 volt when using maximal thrust[Wah14]. To be on the safe side adding a tolerance of 10 per cent, ending up with supplying the UAV with 550 watt. Calculating the cable loss as following. P is the power in Watt, U is the voltage in Volt, l is the cable length in meter, ρ is the electrical resistivity in $\Omega \cdot m$ and A is the cross sectional area in m^2. The current I, in ampere, through the wires is given by the power divided with the voltage.

$$I = P/U \quad [\mathrm{A}] \tag{2.1}$$

The resistance R, in ohm, per unit length is to be determined by the electrical resistivity $\rho[\Omega \cdot m]$ divided by the conductors cross sectional area, A.

$$R = \frac{\rho}{A} \quad [\Omega] \tag{2.2}$$

The voltage drop U_{drop} per unit length is to be determined by the current times the resistance.

$$U_{drop} = I \cdot R \quad [V] \tag{2.3}$$

The voltage drop depends on the current going through the wire and the resistance. It is favourably to have a high voltage and low current to minimize the voltage drop; hence, the voltage drop is independent of the voltage. It is a commonly known method used in power supply systems all over the world. For a low voltage, the per cent of voltage drop is very high, as illustrated on figure 2.2.
In order to avoid the Low Voltage Directive [PCTU06] the DC voltage must be less or equal to 75 volt. 75 volt DC is easily achieved with standard components and therefore set as the power transmission voltage.

The cable loss P_{loss}, in Watt, per unit length is now given by

$$P_{loss} = I^2 \cdot R \quad [\mathrm{W}] \tag{2.4}$$

The loss in the cable needs to be minimal. A known method to minimize the loss on the cable is to step up the voltage. This is because of the fact the loss depends on the current squared times resistivity and independent of the voltage.
From figure 2.3 it is seen the electrical loss is the conductor also depends on length and cross-sectional area of the conductor. The electrical loss is converted into heat in the cable.

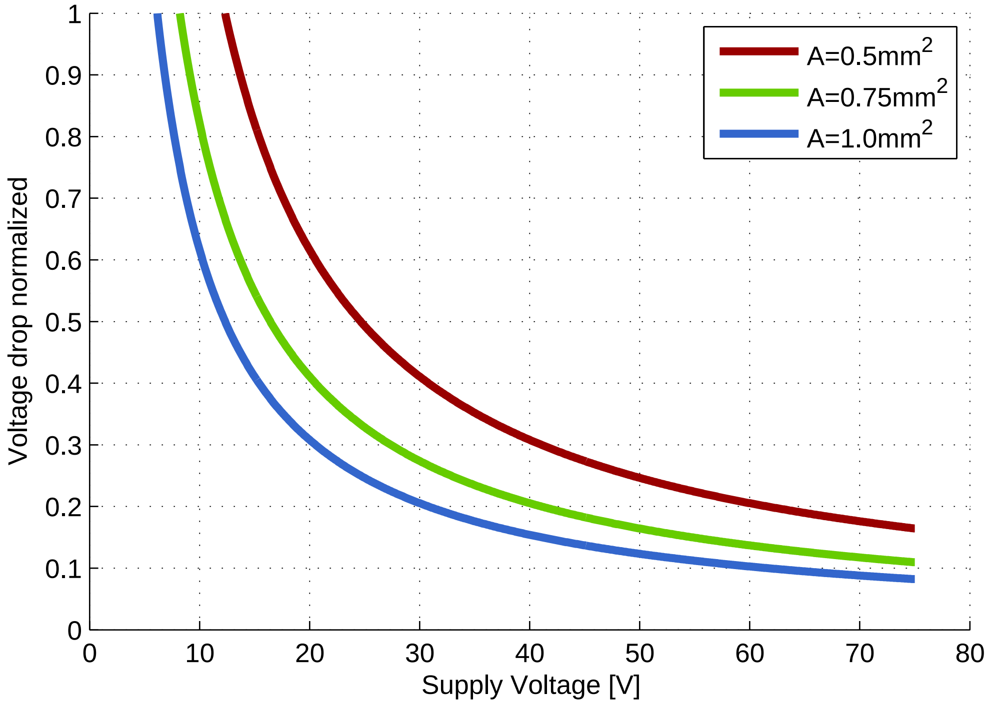


Figure 2.2: Relationship between voltage drop and cable length per ampere over a 50m cable. A is the cross-sectional area of the conductor.

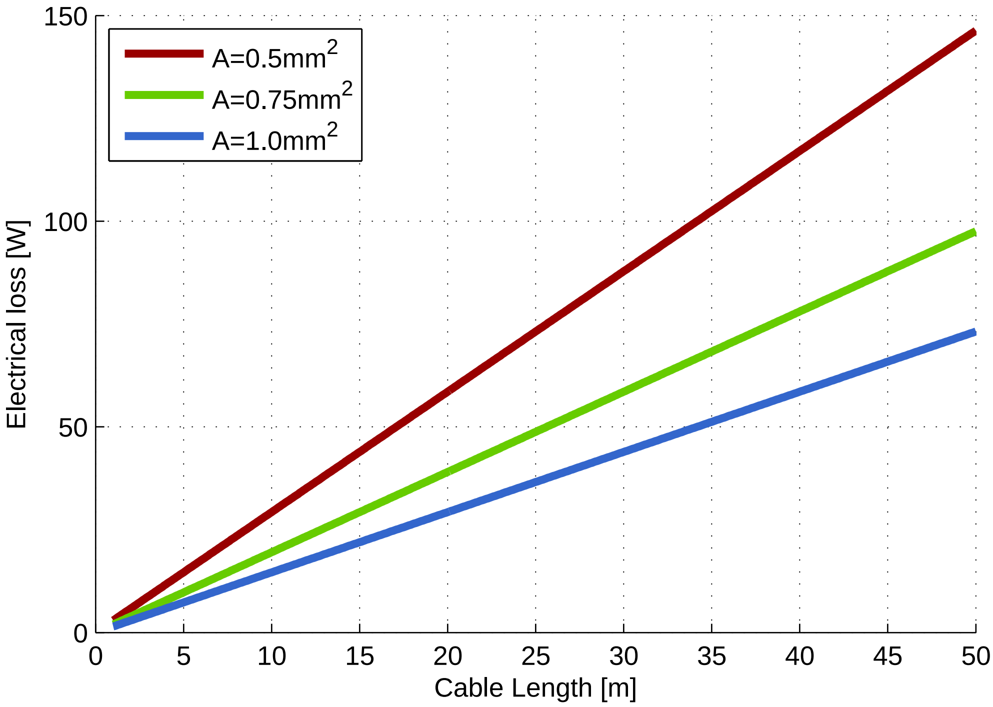


Figure 2.3: Relationship between cable length, cross-sectional area, and loss.

2.4 Tension force in the Cable

In a simplified model, the weight of the cable will only drag the UAV on one axis, towards the Ground Station. On the UAV there is one load cell mounted, measuring the force in the direction of the tension. The output of the load cell will enable the Ground Station to decide if it should roll cable out or in. However, this simplified model assumes the UAV perpendicular to the cable at all times. In the real world, this is only true when it hovers directly over the Ground Station. As the UAV goes to one of the sides, it will try to maintain horizontal pitch/tilt. On figure **??** the definition of roll, pitch and yaw are shown. The cable will try to drag the UAV in the direction of the Ground Station, cause at steady force the UAV have to work against. Because of aerodynamics the UAV will tilt in some extend to work against the tension. If this tilt get to large, the UAV will lose its lifting capability, therefore stall, and crash towards the ground.

Modelling the Tension in the Free Hanging Cable

Modelling the cable in the real world has a great complexity and in order to make a robust design we must assume the surrounds are not ideal. The ideal case is the cable is hanging in a direct line, as seen on figure 2.4. Only at the anchor point, the cable touches the ground. Worst-case seanario is all cable is lying on the ground, except what is directly underneath the UAV. Assuming the cable will be in between the direct line and worst case. The maximal position error will be the difference between the direct line and worst-case line, calculated to approximately 14.65 meters or 29.3 per cent.

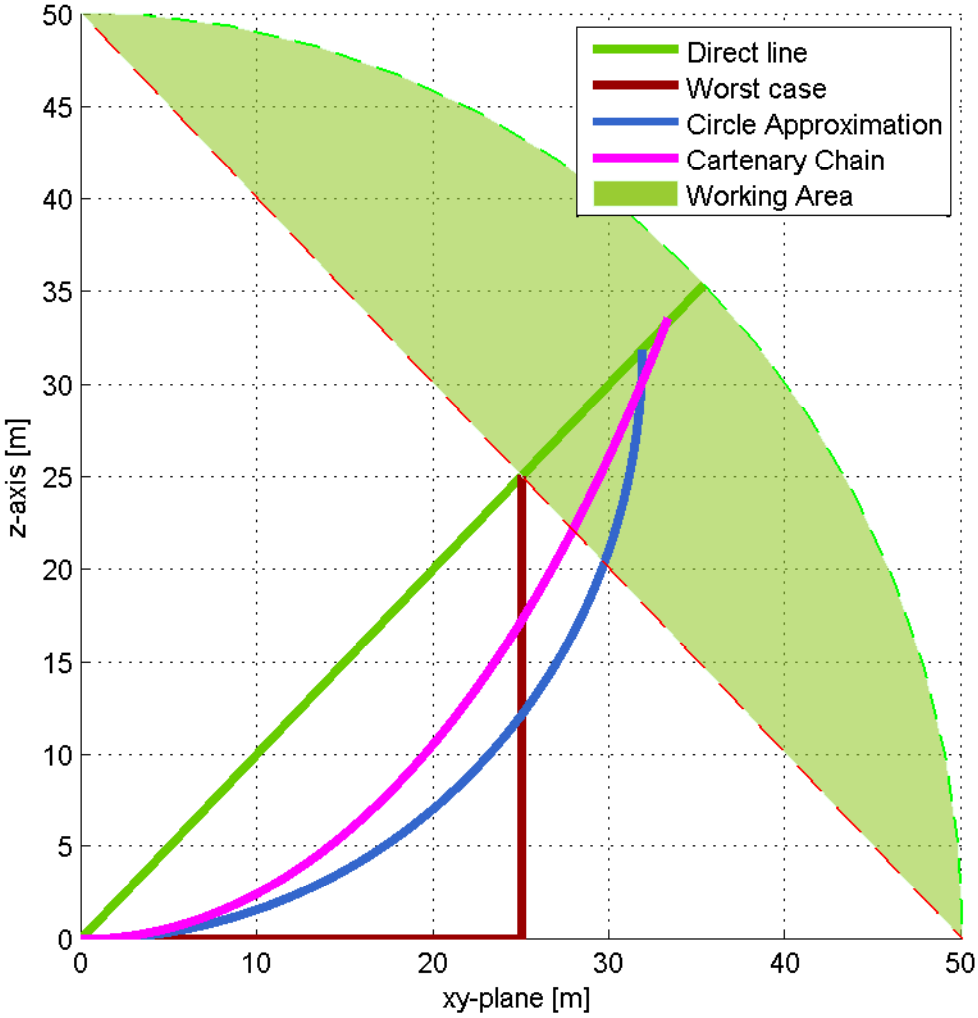


Figure 2.4: Diagram showing four ways of approximate the cables position. The direct line the ideal case. The area between the ideal and worst case is the actual working area where it has assumed the position of the UAV to be. Position estimation using a circular shape and catenary chain to approximate the position.

Both the direct line and worst case is possible, but highly unlikely in the real world. A cable hanging between two points will have a curved shape from the sag and the cable flexibility. Assuming the curve from the sag is described as a circle, the cable will curve uniformly over the entire length. This assumes the cable has no mass, but in the real world, it has. The catenary chain is close to a parabolic shape but describes the curve of a freely hanging chain with the mass uniformly distributed[Whe33]. The catenary equation have the form:

$$y = a \cdot \cosh\left(\frac{x}{a}\right) \tag{2.5}$$

The catenary chain assumes the cable is so flexible that any force exerted by the chain is parallel to the chain. This set a requirement for the bending radius for the cable to be much less than the length of the cable. The weight of the cable pulls the UAV down and towards the anchor point. Let the point c be the anchor point to the ground and r be a force vector at the anchor point on the UAV. r must be at a higher point than c. The force T_0 at point c is tangential to the curvature thus only has a x component. The force T at point r is tangential to the curvature at point r and can be described as

$$T = T\cos(\phi) + T\sin(\phi) \tag{2.6}$$

ϕ is the angle between the x axis and the force vector and T is the magnitude of the force. The cable weight is represented as λ per unit length. g is the gravitational force and s is the length of the cable. The downward force is therefore $-\lambda gs$.

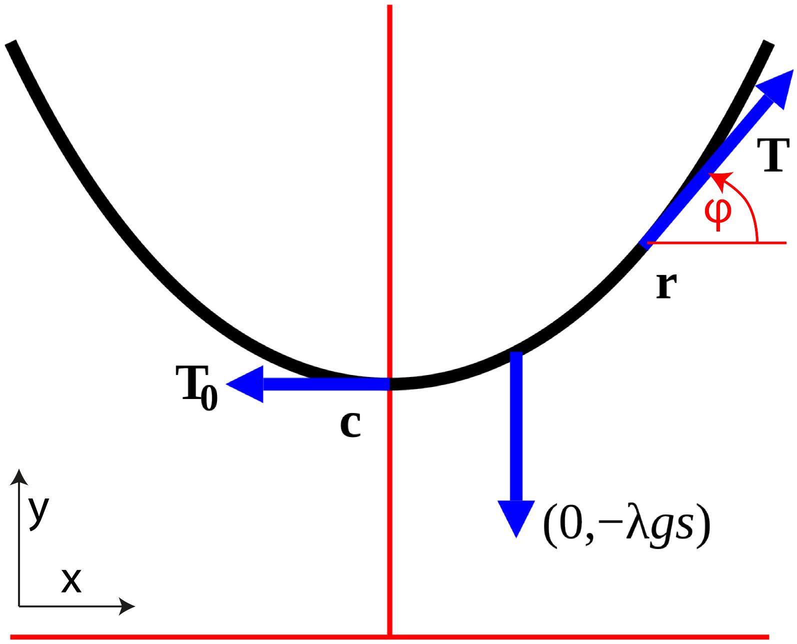


Figure 2.5: Catenary Chain Force diagram displaying forces acting from anchor point c to point r. T_0 is the tension at anchor point c and T is the tension at point r. Note the y axis in this diagram will correspond to the height later denoted as z in a tree dimensional coordinate system.

In this analysis the cable is in equilibrium thus the sum of the tree forces is zero.

$$\sum T_0 + T - \lambda gs = 0 \tag{2.7}$$

Splitting up the sum in x and y components gives:

$$T\cos(\phi) = T_0 \quad (2.8)$$
$$T\sin(\phi) = \lambda g s \quad (2.9)$$

Resulting in the expected force at T as a function of either the force at the anchor point or the cable length, and ϕ.

$$T = \frac{T_0}{\cos(\phi)} = \frac{\lambda g s}{\sin(\phi)} \quad (2.10)$$

To be able to model the cable using the catenary chain four parameters must be available; the tension at anchor point T_0, the angle at the UAV ϕ, the total force at the UAV, and the length of the cable.

This model excludes all cases where either the UAV is below the anchor point or the cable fully or partially is below the anchor point.

Horizontal Angular Force Measurement

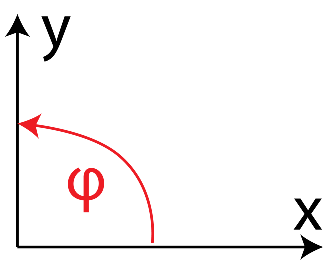


Figure 2.6: Coordinate system for horizontal measurement device.

Measuring the horizontal angle, ϕ, relative to the Ground Control Station and the UAV; a 2-axes measuring device is needed. The two axes must be perpendicular to each other. In that way a scalar of two unit vectors $\hat{x}$ and $\hat{y}$ can represent the tension from the cable in a combination of each direction. From the length of the scaled vectors $\overline{X}$ and $\overline{Y}$ the angle ϕ can be found.

$$\phi = \operatorname{atan2}(Y, X) = 2 \cdot \arctan\frac{\sqrt{X^2+Y^2}-X}{Y} \quad (2.11)$$

ϕ is the angle from the positive $\hat{x}$-direction and increases counter clockwise.
The length of $\overline{XY}$ is given by:

$$\overline{XY} = \sqrt{X^2+Y^2} \quad (2.12)$$

The length og $\overline{XY}$ corresponds to the T_0 tension in the cable in ϕ direction.

Tree Dimensional Force Measurement at the UAV

The UAV has tree degrees of freedom in space, thus a tree axes measurement devices is needed in order to measure the total force T. The measurement device must measure the force relative to the UAV, thus if the UAV tilted to one side, by roll or pitch, it will not be adjusted in the angular calculation of θ.

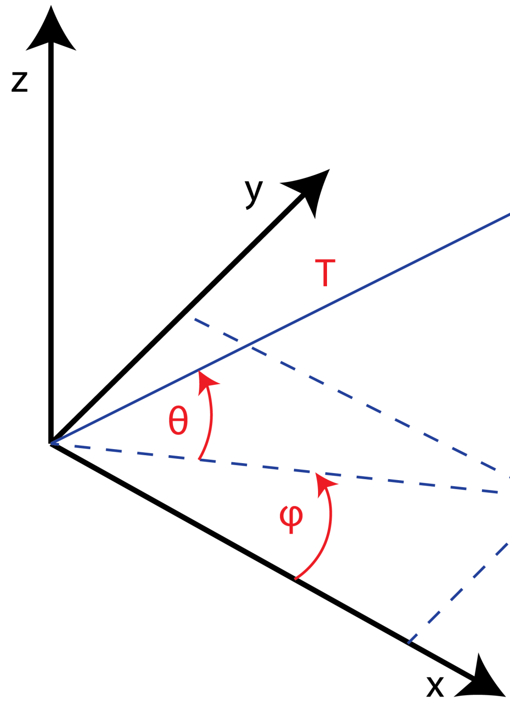


Figure 2.7: Diagram showing the force T the UAV have to withstand from the cable.

Calculating the total force from the tree axes using the same method as in the Horizontal Measurement Device.

$$T = \sqrt{x^2 + y^2 + z^2} \tag{2.13}$$

To determine the direction of the total force the angle between x- and y-axes is denoted as ϕ and the angle between the xy-plane and z-axis is denoted as θ. ϕ is derived as in the horizontal force measurement device.

$$\phi = \text{atan2}(y, x) \tag{2.14}$$

θ is derived as the inverse cosine to the force in the z-direction over the total force.

$$\theta = \text{acos}\left(\frac{z}{T}\right) \tag{2.15}$$

Load cell

The load cells used in this project is a single-point load cell. Determining the type and brand of load cells based on the availability/flexibility to create multidimensional measurements and the cost. A load cell is a strain gauge (flexibly resistor pattern) that will change resistance when bended, mounted on a flexible material. In this case, a block is cut out of Aluminium and a strain gauge is mounted on one surface. When the aluminium is exerted with a force or weight, it will bend slightly, causing a small change of resistance in the strain gauge. The change of resistance can be measured by a Wheatstone bridge, as the one on the Phidget bridge[1].
The calibration of the load cell is very important to obtain a useful reading. The calibration converts the measured value to the measured force.

$$F = K_f \cdot (V_{in} - b) \tag{2.16}$$

$$W = K_w \cdot (V_{in} - b) \tag{2.17}$$

F and W is the expected force and weight. K is a gain value depending on weather the output unit is force or weight. The offset b will vary between individual load cell, even from the same batch. V_{in} is the value reading from the Phidget bridge. The size V_{in} depends on the gain set in the Phidget configuration.
When dealing with multiple load cells there are two ways of configuring them electrical wise. First is to measure each load cell individual and second to measure all together. The first one has the advantage of being able to measure each load cell individually, but the disadvantage of using many inputs and each load cell needs to be calibrated individually. Second, one has the advantage of only using one input on the bridge and all cells can be calibrated together, but the disadvantage of all load cells need to be of same type and size and not being able to measure each load cell individually. In this project, the information of direction of the tension is important and because of that measuring each load cell individually is the best solution[Phi12].

Data Connection

The measurements from both the Ground Station and the UAV is used as position references in the position controller on the UAV. Thus, the data sent to the PixHawk flight controller must have as little delay as possible.

[1] Phidget bridge 1046, http://www.phidgets.com/products.php?product_id=1046

2.5 Design Requirement Specification

- The UAV must be capable to stay airborne significantly longer time than a battery powered alternative.
- Supply the UAV with 12 volt DC and 500 watt.
- The weight of the cable must not be greater than the lifting capability of approximately 3kg [Sid13].
- The system must not be subject to the Electrical Safety: Low Voltage Directive, and therefore keep any voltage under 75 volt DC [PCTU06].
- Given the cheap cost of UAVs today, the solution must keep a low material cost.
- Measuring the total horizontal force at the anchor point.
- Measuring the total force and direction at the UAV.
- Measuring the length of the free hanging cable.
- The Ground Station is supplied with 12 volt.

CHAPTER 3

Prototype

The Ground Control Platform must have some physical dimension due to the size of the UAV used in this project. The dimension of the UAV used will affect the dimension and choice of construction of the ground station. In dimensioning and designing the ground station the primary focus is on making an industrial and robust prototype.

3.1 Landing platform / Helipad

The landing platform or helipad is a 60cm x 60cm wide plate with a hole in the middle. Dimensioning of the size mainly relies on tolerance on the precision of landing the UAV. The UAV only needs 30cm x 30cm space for the landing gear, but in case a big wind gust comes in just before landing/take-off, the UAV can slide off the platform if the platform is too small. On figure 3.1 the helipad is seen from the top.

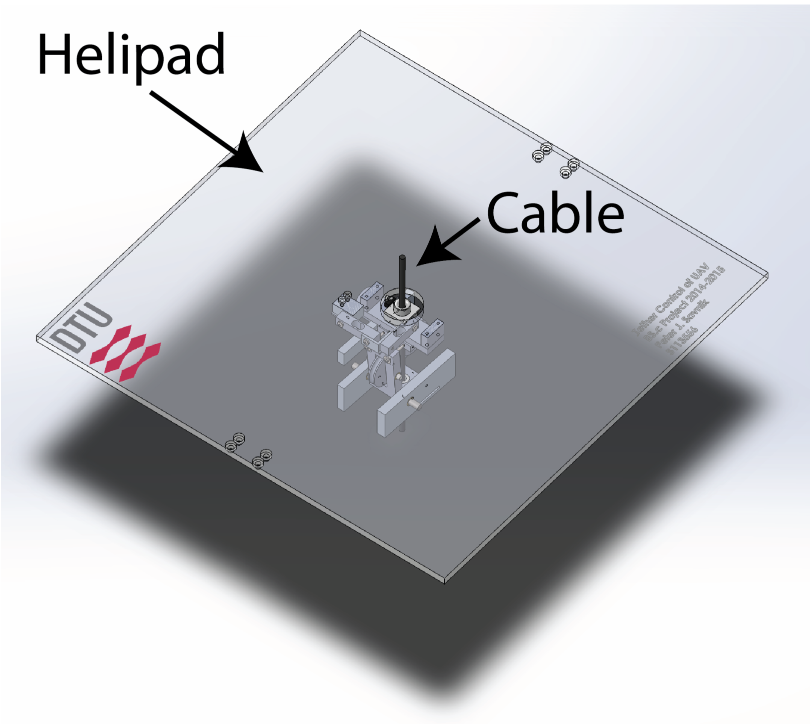


Figure 3.1: Illustration of Helipad with a hole in the middle for the cable.

3.2 Messuring the horisontal angle

In order to precisely determinate where the UAV is positioned relative to the helipad on a horizontal plane a coordinate system on figure 3.2 is introduced. x and y are Cartesian coordinates corresponding to the measurements of load cell 1 and load cell 2 from figure 3.3. ϕ is the angle, starting at the positive x direction and increases in positive direction of rotation.

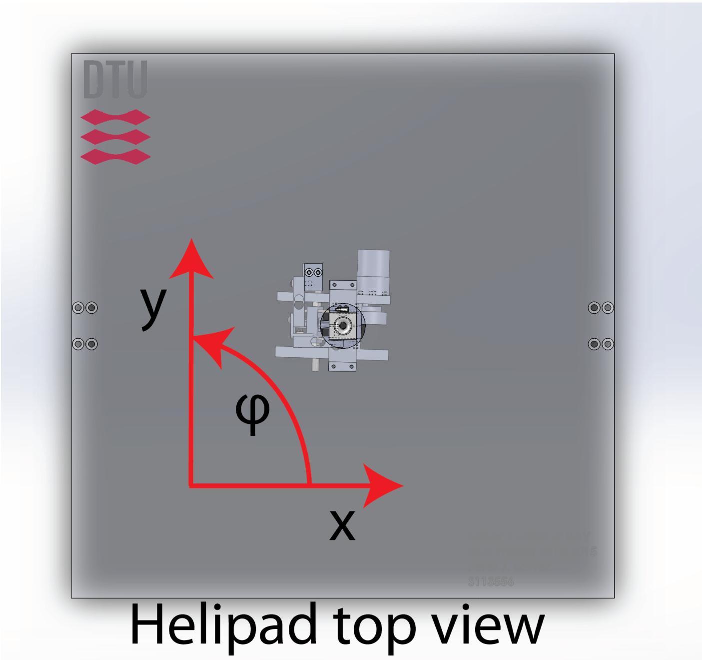


Figure 3.2: Helipad seen from top view with coordinate system.

To measure the horizontal angle between the Ground Station and the UAV to load cells are used, perpendicular to each other. One end attached to the Ground Station and the other end attached to a cable though hole made in Teflon. Then the UAV is exactly direct over the centre, no force will be measured, but then the UAV moves to one of the sides it will create a cable tension that results in a force in x- and y-direction. Combining the x and y force can be translated to an angle.

The UAV can lift about 3kg payload and therefore exert 3kg thrust to the cable and the measuring device must be able to withstand such a force without permanently bending. Two 5kg load cells from Phidget Inc is assessed to be the best match for the job with regard to what is available in the projects price range.

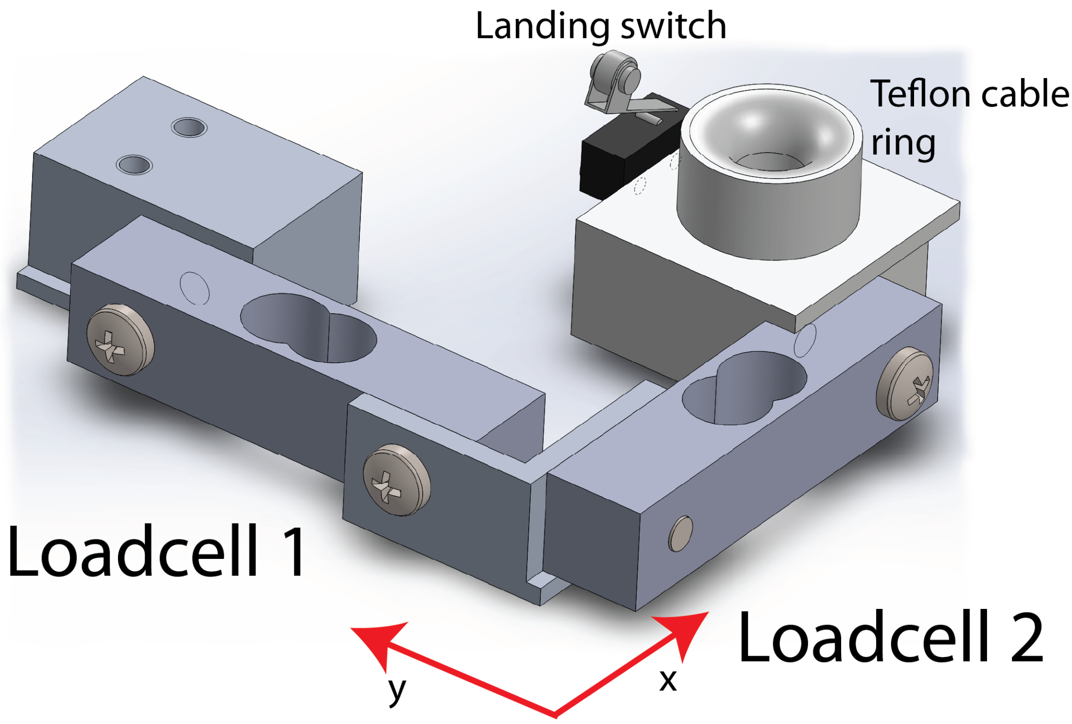


Figure 3.3: Configuration of two load cells, for measuring the cable drag in x and y direction. Load cell 1 measures in x-direction and load cell 2 in y-direction.

3.3 Winching and storing the cable

There are several ways to keep the cable when it's not rolled out, two commonly used methods are on a cable drum or in a winded pile. The critical parameters here is the flexibility of the cable, diameter of the cable and heat tolerances. Because the cable is stored tightly together, heating from the cable resistance has to be given a thought in the cable storing design.

Storing cable on a drum

Storing cable on a drum is a very practical and commonly known method to store cables in a organised way. The benefits of this design is that the drum it self can be used as a winch to winch in the cable. But the minimum diameter of the drum is given by the cable minimum bending radius for flexible installation and that sets a physical minimum for the drums outer diameter. The larger the diameter the greater the force needed for rotating the drum. To assure smooth windings the drum can move from side to side. In theory the rotation of the drum can be used as a feedback for how much cable is rolled out, but in practice this will be a source to a large margin of error. Further more this design is very dependent on the cable always have tension on. If there is no or too little tension on the cable it will loosen from the drum resulting is bad windings and the possibility for jams.

On figure 3.4 a cable drum is put under the helipad and the horizontal measurement device.

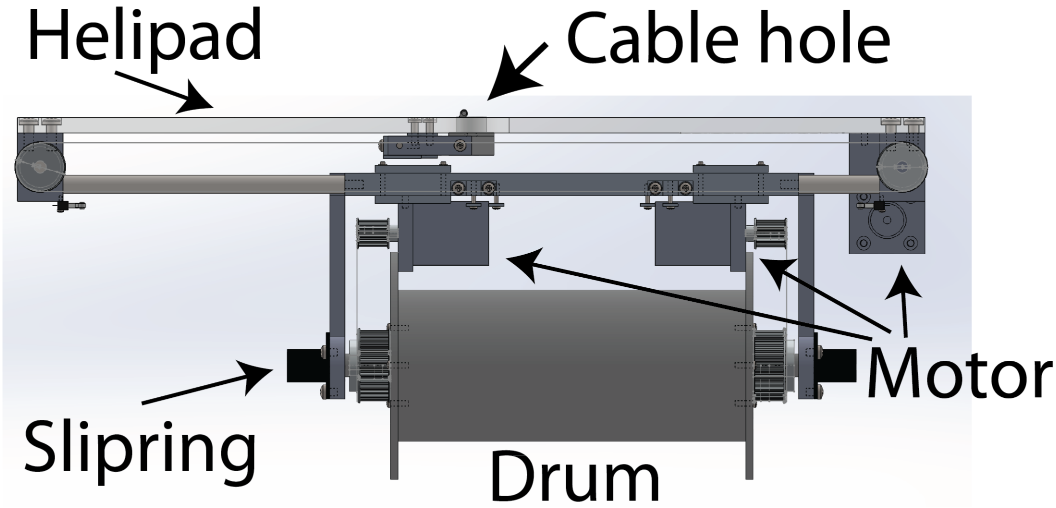


Figure 3.4: Cable drum design. The drum can rotate to winch in/out the cable, and also move from side-to-side to assure smooth windings.

With all wire winded in and the UAV on maximum throttle there is assumed to be 500W running through the cable with a electrical loss at around 120 Watt, which is transformed into heat. 120 Watt of heat will give rise to heating up the cable drum. This is a known cause of electrical fire, when a cable drum gets too hot and melts. Therefore a series of pretests where performed to address how big a problem this would be, and to incorporate the result in the design of the system. The test and results are described in next chapter.

The Simple Winch

Sometimes simple is better. The simple design have a motorized toothed wheel and an encoder wheel pushing the cable against the wheels. The encoder wheel turns only when the cable is moving, and the slip is minimal making it a very robust feedback for the motor controller. The encoder wheel is pushing the cable toward the motor wheel with a spring, that assures small imperfections in the cable does not make it slip. two simple screws adjust the spring tension. For storing the cable a box underneath collects the cable.

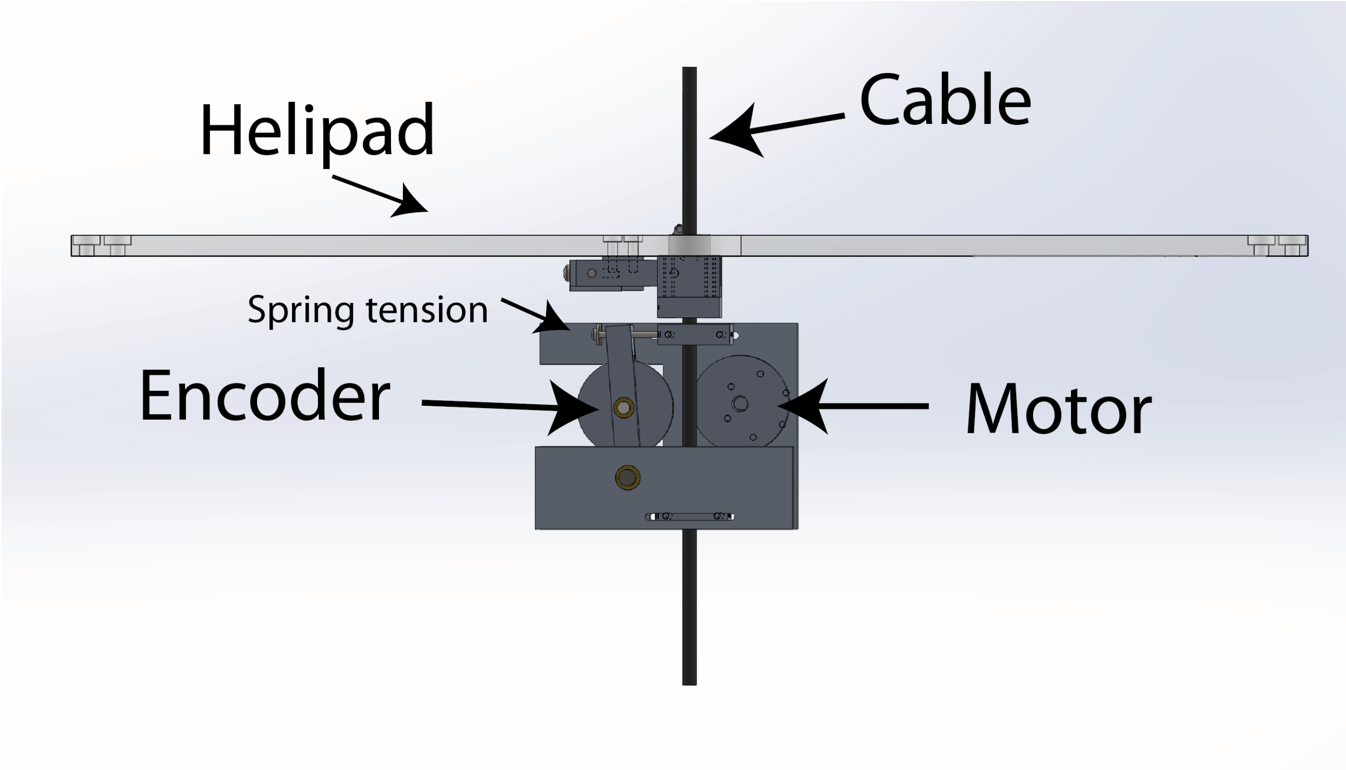


Figure 3.5: The Simple Winch only has one motor and an encoder wheel pushing the cable towards the motor wheel. Two springs adjust the tension.

Summary

Both concepts are mature enough to be prototyped and tested, but due to the time frame of this work there is only time for manufacturing and testing one design. Based on the lower mechanical complexity of the simple winch, the simple winch is the chosen design.

3.4 Cable Connection point on the UAV

Connecting the cable to the UAV have several issues to address. First a 3-axes measurement device is needed to measure how much the cable tension is and in tree directions - x, y, and z directions. The load cells used is of same type as in measuring the horizontal angle in section 3.2 on page 16. In z-direction the maximal force applied to the load cell is the UAVs lifting capability on approximately 3kg[Sid13]. Hence the choice of load cell is a 5kg load cell.
In x- and y-direction the force applied by the cable or the UAV is not expected to exceed 0.5kg, thus two smaller 0.78kg load cell is used to measure the x- and y-directional force.

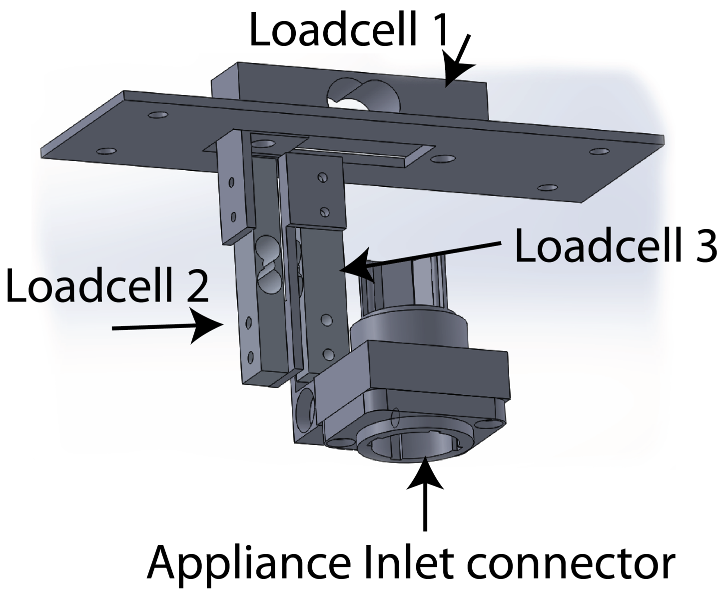


Figure 3.6: 3-axes measuring device for the UAV with appliance inlet connector.

Second an appliance inlet connector for easy plug-in and unplug is wanted. The connector must be capable to withstand the weight of the cable and the force applied of the UAV.

Figure 3.7: Neutrix True One appliance connector system.

3.5 The Cable

The cable connection is the UAVs lifeline; if it breaks, the UAV will immediately crash towards the ground. Thus, the cable must be robust and resistant to the surrounding conditions, such as UV-light, heat and mechanical wear and tear. Given the UAVs limited lifting capabilities, the cable must be lightweight. The choice of cable ended on the Ölflex Classic Flexible Mains range, hence great performance on flexibility, heat

resistance and low weight. Furthermore, the sheath material is made of silicone resulting in a better grip on the winch. The cable has two conductors of $0.75mm^2$ and the total length is 50m[1]. The detailed specifications are found in the appendix.
The cable weight is 54kg/km giving a total cable weight of 2.7kg, for 50 meter cable.

3.6 Electrical Design

From an electrical view there are two separate systems, Flight Control System on the UAV and Ground Control Station. The system reading the sensor data on the Ground Control Station has to feed the UAV with the measured data hence the UAVs position controller is running on the UAV. The UAV needs a 12 volt DC power supply and the Ground station will be supplied with 12 volt DC. The power supply unit (PSU), Mikkel Wahlgreen developed, takes a 12 volt input and convert it to 75 volt DC output for the power line, and at the UAV the reverse process of converting it back to 12 volt.

Ground Station

The ground station sends data to the UAV system and decides weather to roll cable in or out based on the wanted position and cable tension. The control of feeding the cable is done by comparing the load on the UAV system to what is expected by the weight of the rolled out amount of cable. If the load is higher then expected more cable are rolled out and vice versa. The Ground Station have both an encoder on the motor, and one on the encoder wheel. The encoder signal is red from the GPIO pins on the Beaglebone, detailed described in the appendix.

UAV System

The system on the UAV measures a 3-axes load cell connected to a Phigets Bridge. The Phidget Bridge are interfaced via a Beaglebone Black.

[1]ÖLFLEX HEAT 180 Deg H05SS-F 2 x 0.75mm

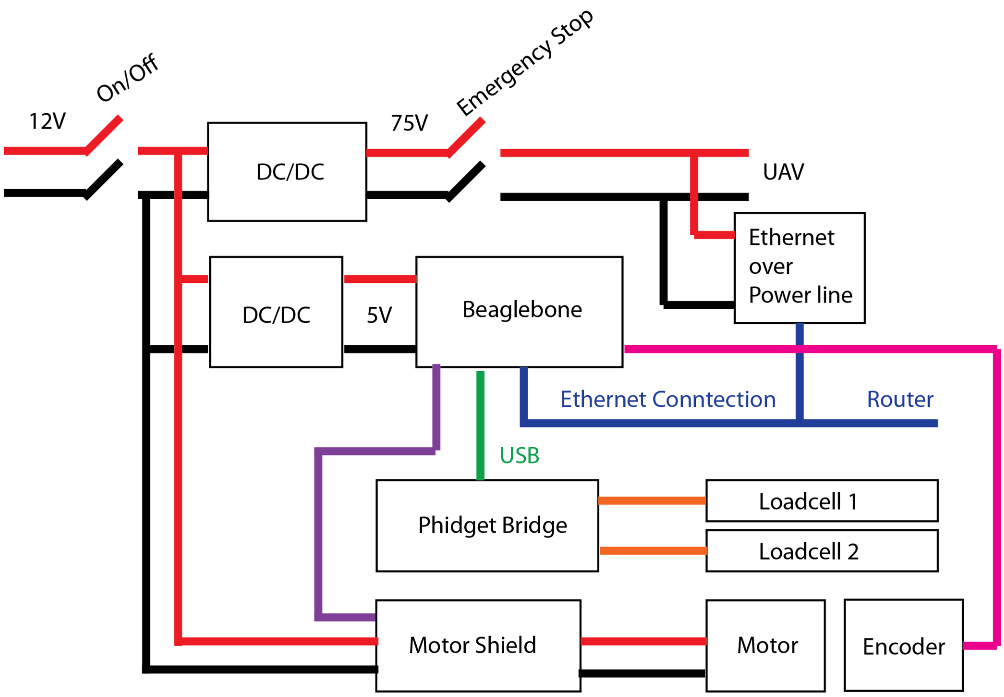


Figure 3.8: Ground Station electrical overview.

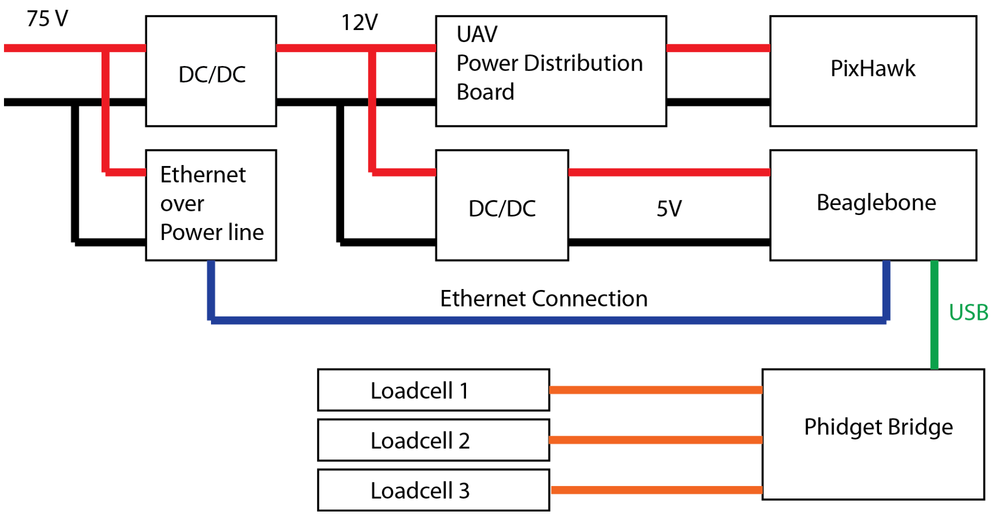


Figure 3.9: UAV electrical overview.

Data Connection using Ethernet over Power line

To connect the UAV to the Ground Station an Ethernet over power line system is used. Ethernet over power line operate by adding a modulated carrier to the wiring system, intended to work on 110-230 volt AC with frequencies in 50-60 Hertz. The AV500 Nano[2] system from TP-Link supports speeds up to 500Mbps and works without any configuration needed. Stripping the housing from the electronic and soldering two wires on to parallel connect the component to the 75 volt system. All detailed setup and configurations are descried in the appendix.

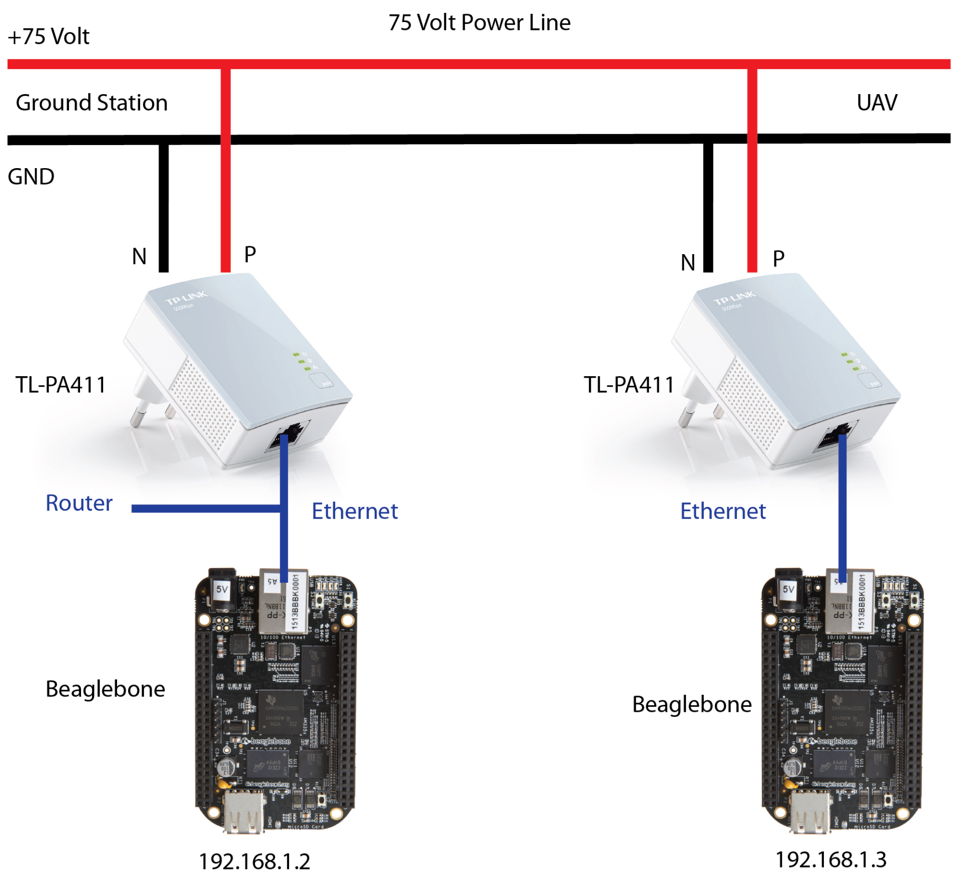


Figure 3.10: Ethernet over power line setup. Two TL-PA411 is connected to the 75 volt powerline creating an Ethernet over power line connection to the UAV.

[2]Model number: TL-PA411KIT.

3.7 Software Design

All software for measuring and controlling is implemented in the real-time software framework Robot Hardware Daemon, RHD. RHD is the real-time hardware abstraction layer for the Mobotware platform, developed at the department of Automation and Control at DTU. RHD is a plugin-based platform that allows easy integration with sensors and actuators. RHD creates a synchronized database with read/write variables that can be shared between plugins and/or accessed by other software applications. On figure 3.11 a block diagram is showing a overview of key software components and their structural relations to other components.

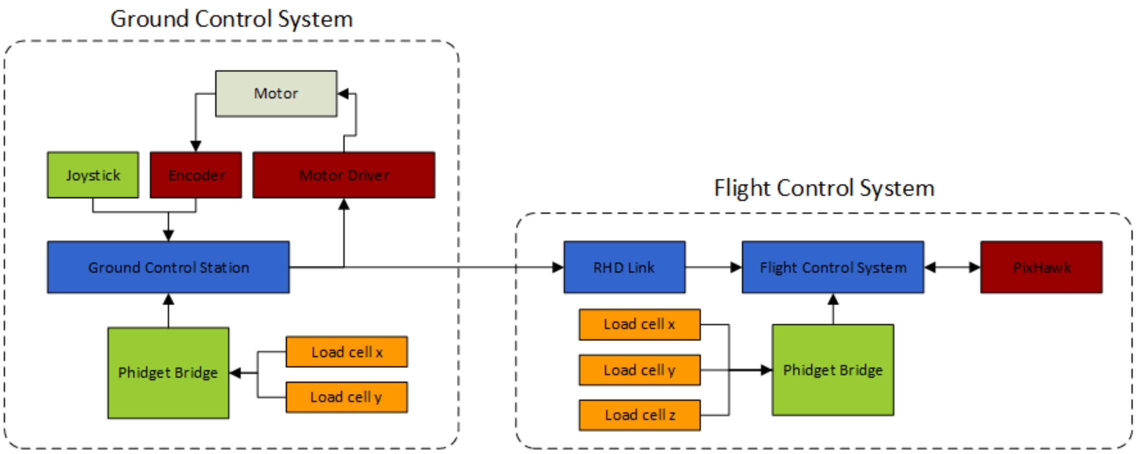


Figure 3.11: Software Block Diagram.

Ground Control Station

The objective of the Ground Control station software is to measure the horizontal force, fetch steering reference signals from joystick or other controller, control the cable winch, and make the calculated control signals available in the variable database. On figure 3.12 a graphical overview of the plugin structure shows the periodic run sequence and plugin variable dependency relationship. The speed variables are created in the plugin tcuav, and not the joycontrol hence the joycontrol module estimates the steering method by variables available. This also mean the initialization of joystick must be performed after initialization of tcuav.
The Ground Control Station interfaces the hardware component through the on-board GPIO pins allowing the Beaglebone to send a Pulse Width Modulation signal to the motor driver and reading the encoders, either as a SPI signal or by counting rising and falling edges.

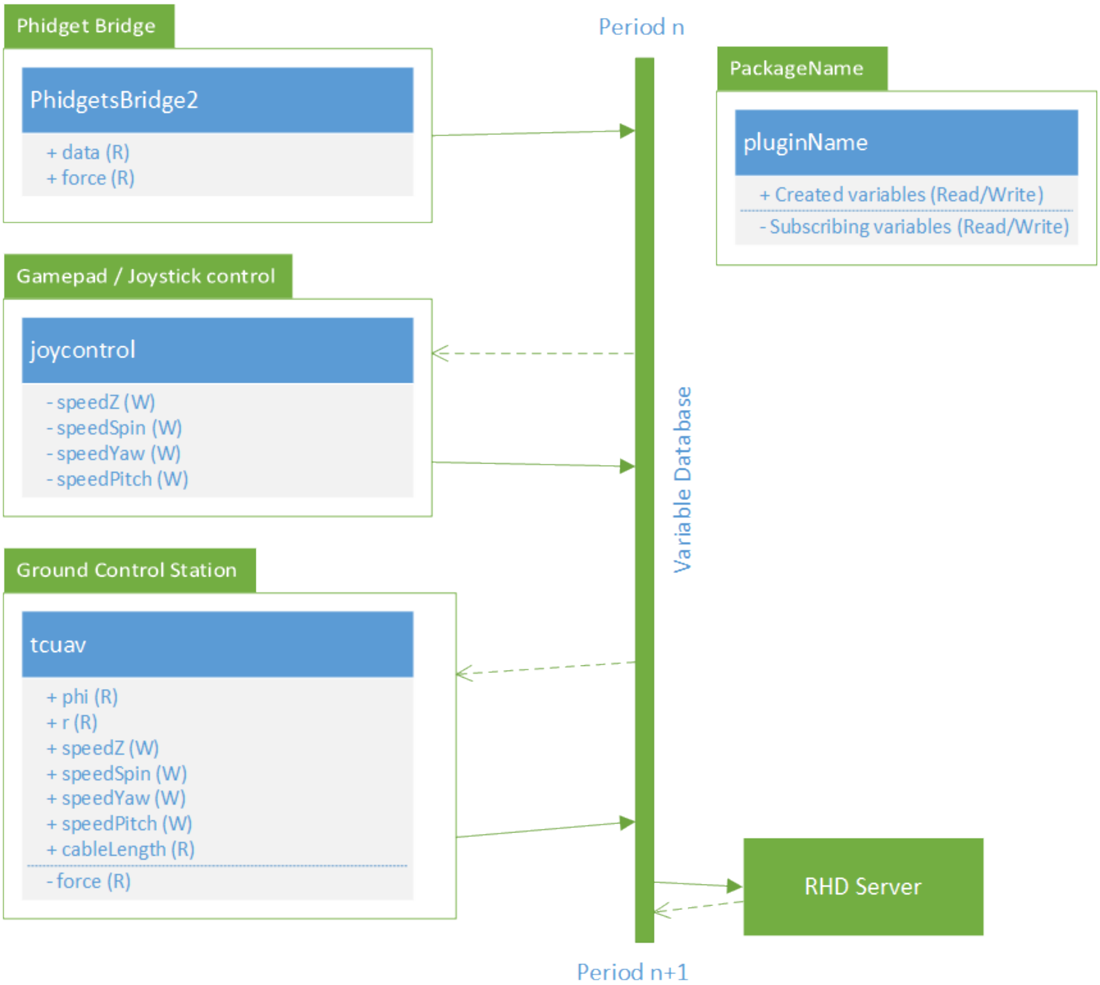


Figure 3.12: Ground Control Station software overview based on the RHD plugin structure showing plugin sequence for one sample period.

Flight Control System

The objective of the Flight Control System is to measure the force from the 3-axes load cell system, establish a link connection to Ground Control Station and fetch control variables, and make control variables available to the PixHawk(UAV Flight Controller) through a serial connection, hence the USB plug is already occupied.

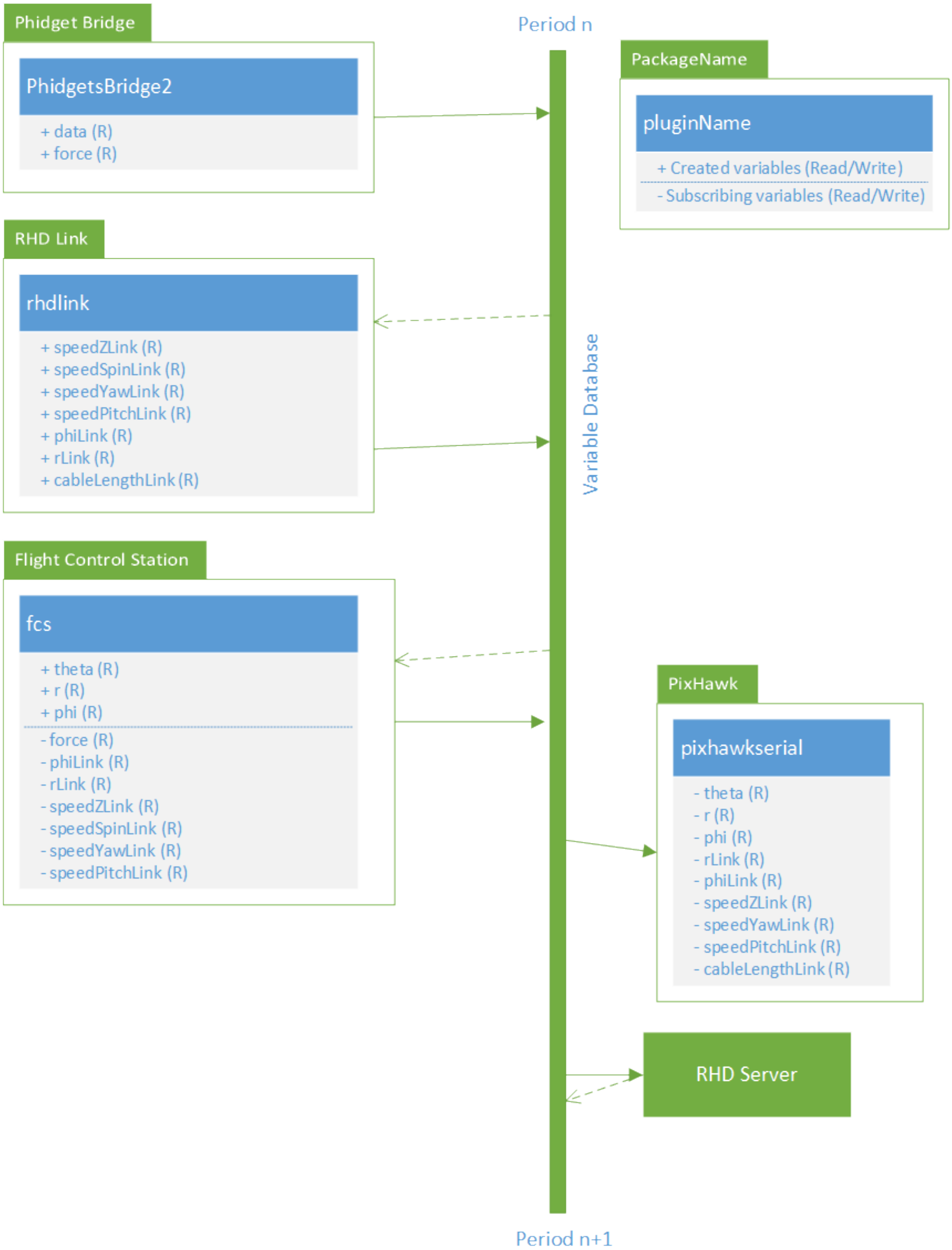


Figure 3.13: Flight Control System software overview based on RHD plugin structure showing plugin sequence for one sample period.

CHAPTER 4

Test and Results

This chapter deals with testing of the prototype, discussion of the results achieved and how to improve the results in case the data achieved is not satisfying.

4.1 The test setup

Given to the short time frame for this project and unexpected long time sick leave foreman in the mechanical workshop some short cuts was performed in order to get a working prototype. The mechanical and electrical parts are fitted into a rack cabinet.

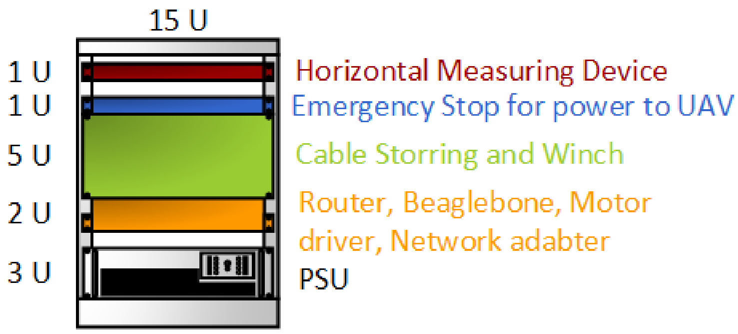


Figure 4.1: Rack cabinet overview.

From top the Horizontal Measurement Device is mounted underneath the helipad. On the front a emergency switch is mounted to disconnect the 75 volt supply to the UAV. In the middle there is room for cable storing and winching mechanism. The position of the winch can easily be adjusted through aluminium bars milled track. Underneath that a shelf is mounted with the Beaglebone, motor driver, Network adapter and router. At the bottom, the DC/DC power converters are mounted and a on/off switch is surface mounted to the entire system.

4.1 (1) sæt billede

4.2 Cable Drum

To address the heating issue in the cable drum a test was performed to evaluate the heating's influence, in order to incorporate the results in the design process.

Test - Worst-case heating in the cable coil

The worst-case test with full load over long time was performed at indoor environment with room temperature on 24 degree Celsius. The coil was excited with 75V DC and 360W just over an hour. This is not 100 per cent of the UAVs power consumption, but the testing equipments upper limit. The inner diameter of the coil is 10cm and is made of 2mm thick PVC pipe.

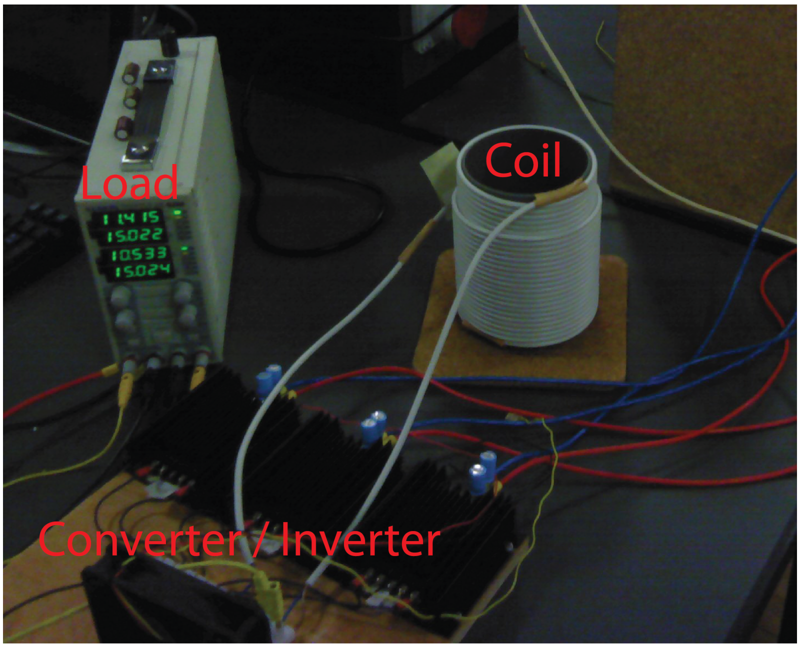


Figure 4.2: Heat test setup showing the coil, the test load and DC/DC power converters.

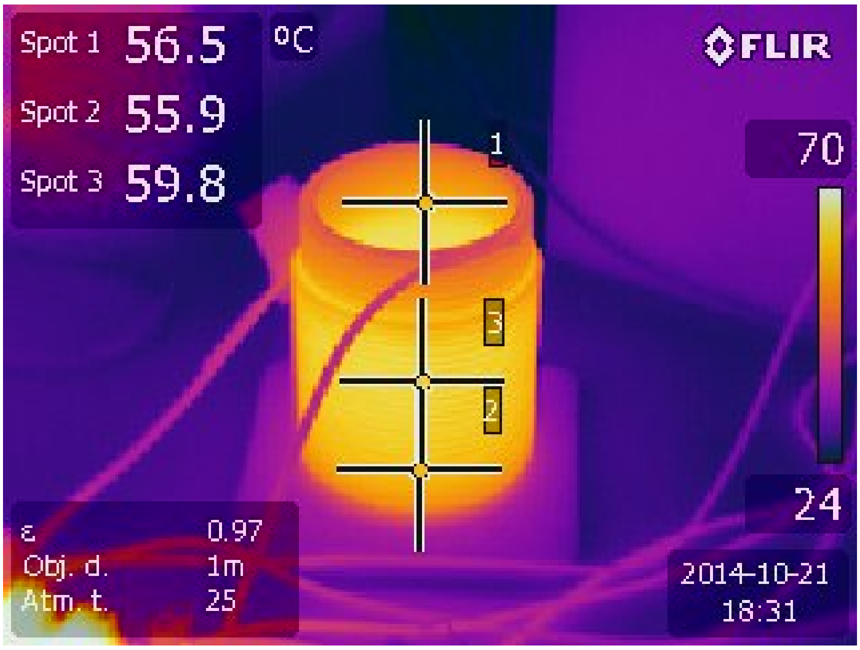


Figure 4.3: Heat test of 20m standard household cable[1]winded in two layers with 75V DC and 360W. Spot 1 is inside the coil, spot 2 is the lower side of the outer coil and spot 3 i at center of the outer coil. On the lower left corner thermometer calibration constants is displayed.

Summary

Even through the cable is not excited with 100 per cent of the UAV power consumption; the test puts the heating issue in perspective. The heating is not critical high, but must be considered in the cable requirement specification; hence, CE certification only requires the cable to withstand up to 80 degrees[PCTU06].

4.3 Horizontal Measuring Device

This measurement devices is tested with regards to stability and the results of the calculated position references. Hence this is relative cheap load cells, the precision is expected to be within an acceptable region.

Calibration

First off is calibrating the load cells. First measurement is without any forces acting in x and y direction in order to determine the offset of each load cell. The offset for x is

[1]House hold cable with unknown origin, cross-sectional area 0.75mm2, Max voltage 230 AC, Max current 10A

found to -455.9787 and the y offset to -511.2618, as seen on figure 4.4.

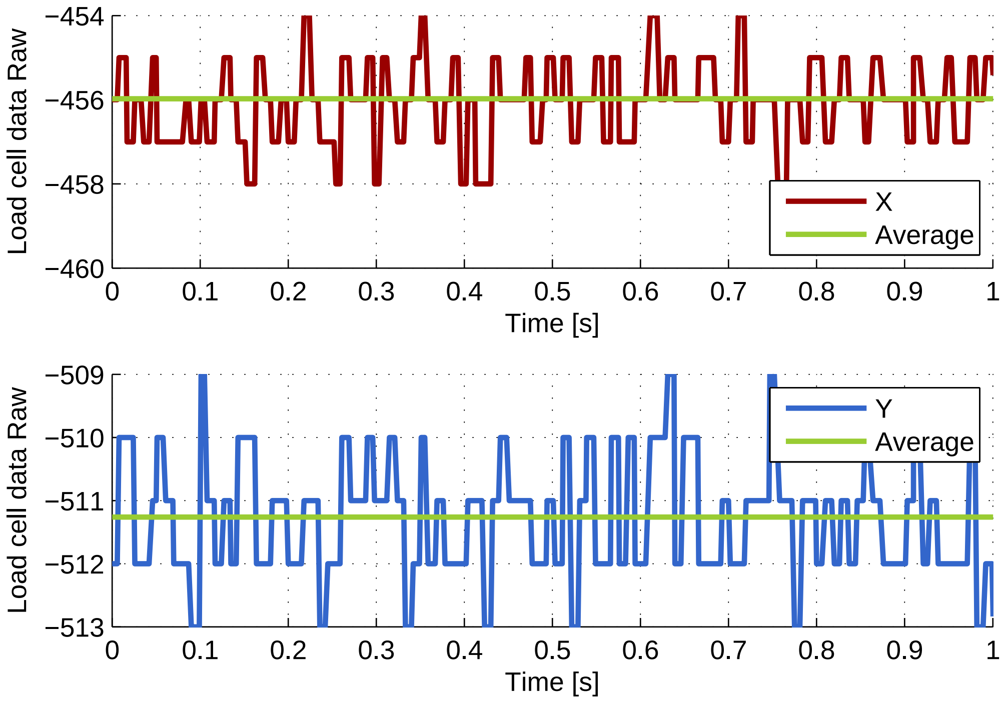


Figure 4.4: Raw input data from load cell x and y. The average line is the calculated offset used for calibration. Measured without load in any directions.

Next 1000g of load is put on the load cell with a rope through the Teflon ring first purely in positive x direction and next in purely y direction, in order to determine the gain factor Kx and Ky. Kx is found to 0.4786 and Ky to -0.5134. Afterwards the calibration is tested by applying 600g of force in x-direction and then checking the result.

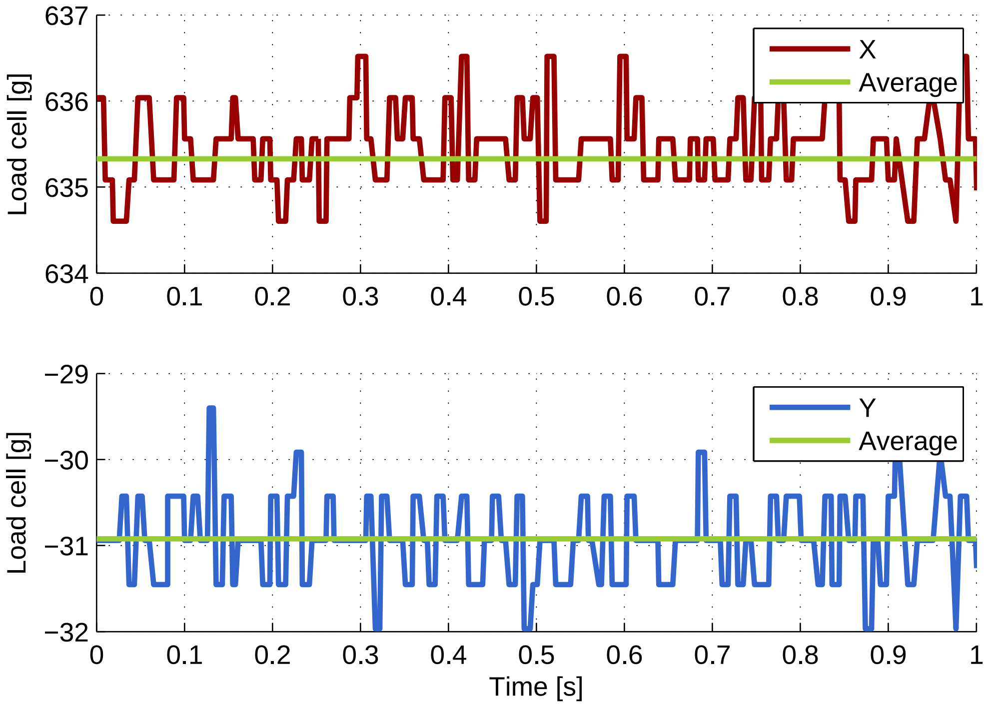


Figure 4.5: The result of calibration. The x-calibrated values are between 633g and 636g, then the force applied was 600g. The $33-36$g difference is most likely caused by the limitations of precision from calibrating with the spring load. The y-calibrated data is ranging from -29g to -32g. It is expected the precision will vary ± 75g around the zero balance.

Test of angular calculations

After the calibration process, a test of the calibration shows the quality of the calibration. This test is performed by applying a known force in a combination of x and y direction. For this test ϕ is set to 45 degrees and the total force is 1kg. On figure 4.6 it is seen that the data slightly decreases over time. This is probably due to tolerances in the manufacturing process of the mount enabling the load cell to move slightly over time or the elasticity of the connecting rope between the spring load and the load cell.

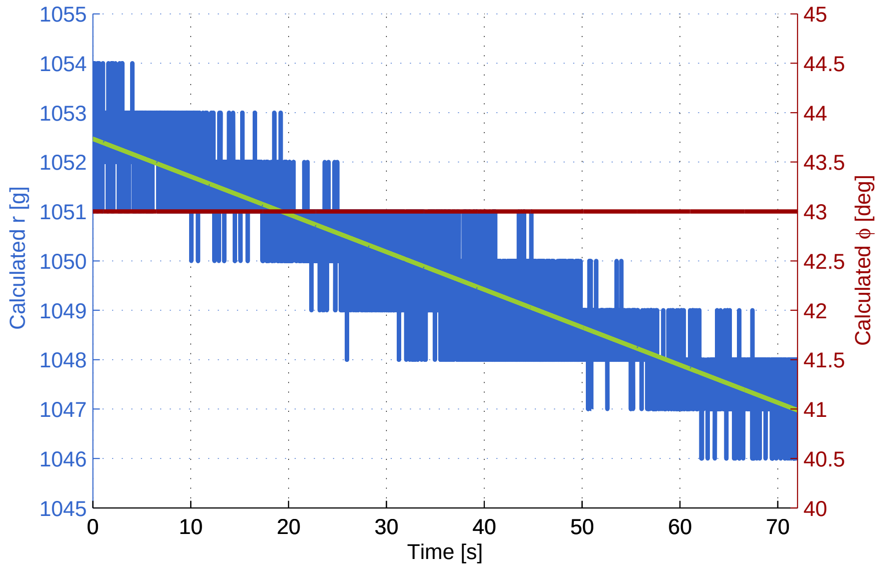


Figure 4.6: This test combines both x and y direction by setting $\phi = 45$ degrees and 1kg of load, therefore the total force is calculated into the variable r, equivalent to T_0 from the analysis chapter. Notating the data drift slightly decreasing, but the calculated angle is steady.

On figure 4.6 it is seen that the data slightly decreases overtime. This is probably due to the spring load is permanently bending, not excluding the elasticity of the rope and tolerances in the manufacturing process enabling the load cell to move slightly over time. Taking a closer look at the data on figure 4.7 showing this phenomena applies to both x and y load cell. Because it applies to both load cells the calculated angle ϕ is constant, thus the drift the data is still valid and results in an accurate angle. The two degrees error in the angle is likely due to the precision of the load angle.

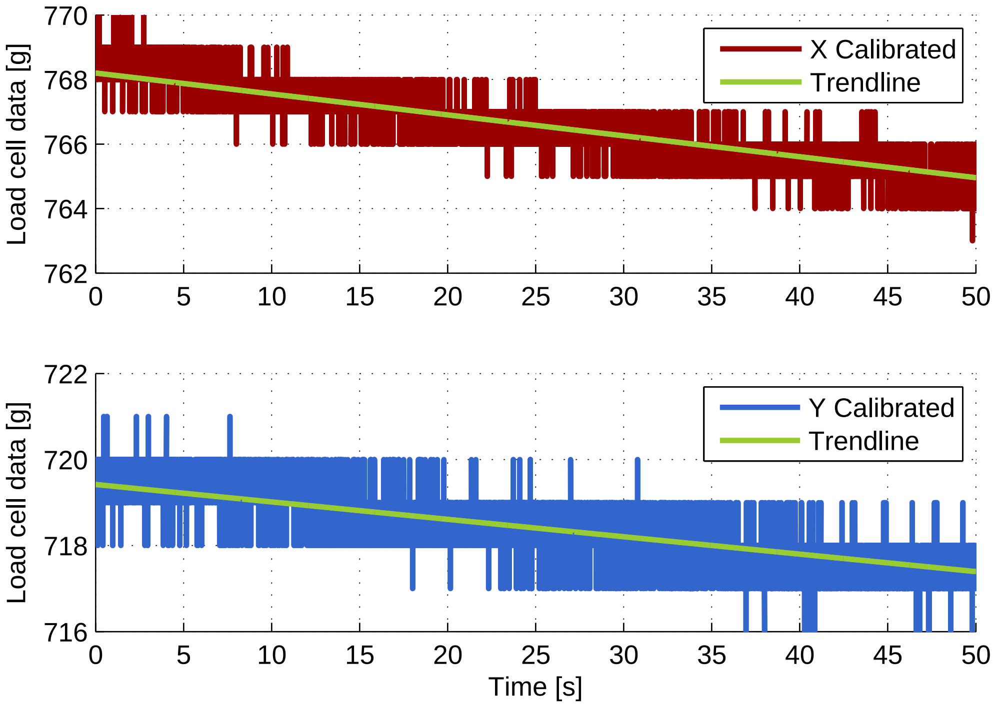


Figure 4.7: Showing the calibrated data from x and y load cell then 1kg of load is applied with $\phi = 45$ degrees. The trend lines decays with a equal factor.

Testing with $\theta > 0$

Next test is performed by keeping the ϕ angle and the tension constant and varying the θ angle. Is is expected as θ approach 90 degrees the measured force will be approaching 0.

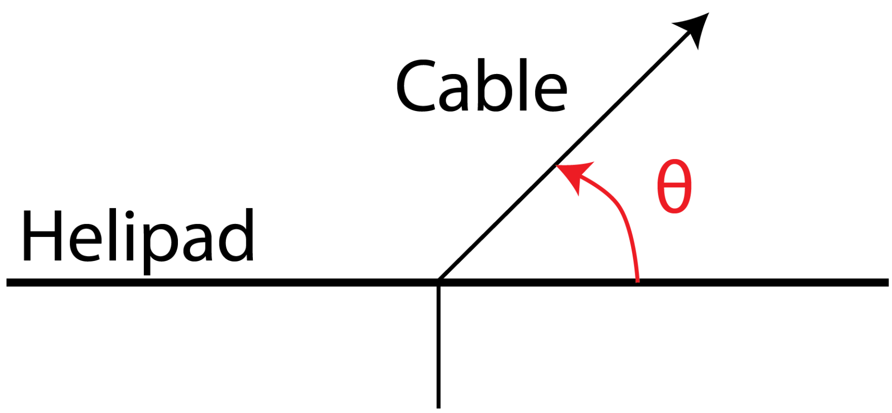


Figure 4.8: Testing the horizontal measuring device by keeping ϕ constant and varying θ.

At $\theta = 45$ degrees and 1kg of load the measured result is very close to the expected result.

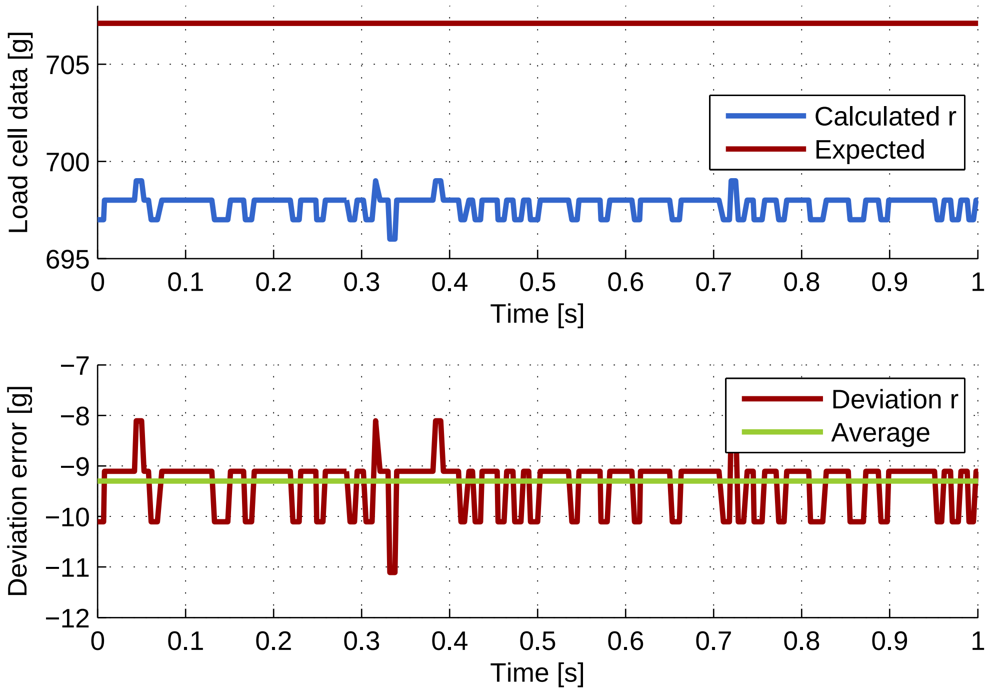


Figure 4.9: Comparing the measured load to the theoretical expected values with a load of 1kg when setting $\phi = 45$ degrees. The result is showing slightly less than expected.

At all previous tests the load has only been anchored in the Teflon ring, but in the real setup the cable are anchored in the winch instead. This mean the measured force is now only a component of the total force. From figure 2.5 T_0 only has an x-component, but when the cable now is anchored in the winch the total force equation change to:

$$\sum T - \lambda g s + (T_{0,x} + T_{whinch,y}) = 0 \tag{4.1}$$

Hence the measurement device only measures $T_{0,x}$, $T_{whinch,y}$ is unknown. This test will show how much $T_{winch,y}$ influences. On figure 4.10 the measured values are slightly higher than expected. At $\theta = 0$ the overshoot is $13 - 17$g and at $\theta = 45$ the overshoot is $28 - 32$g, which is within what's in the first test was discussed as due to limitation in precision of the calibration.

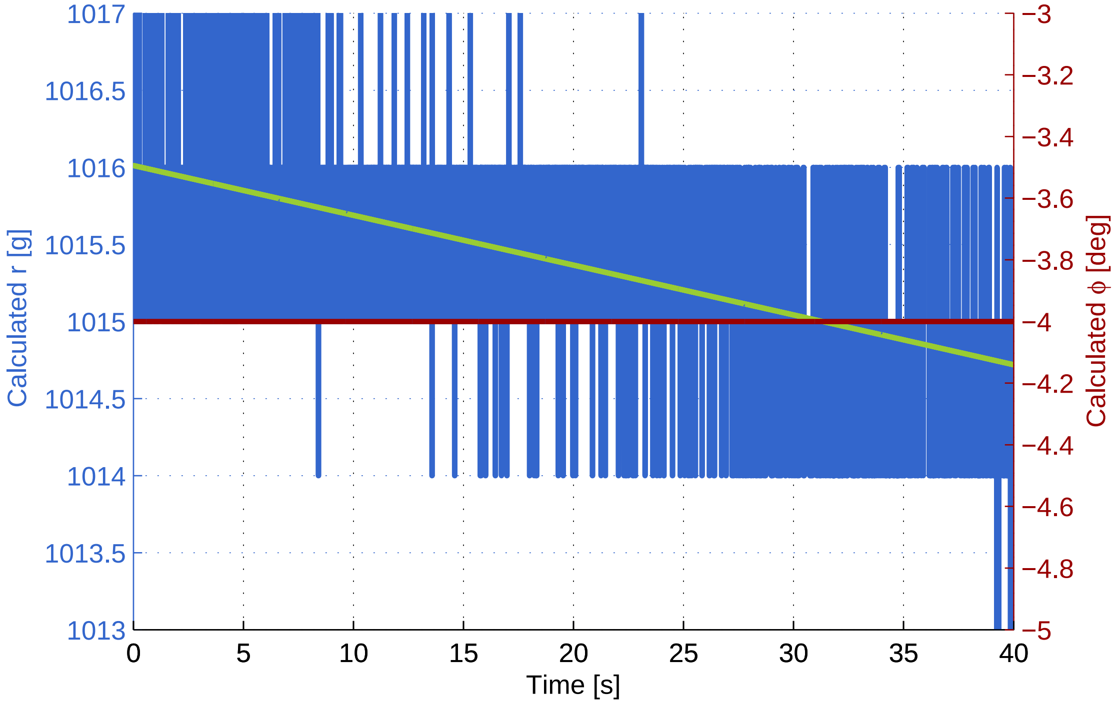


Figure 4.10: Calculated total force and angle when 1kg load, $\phi = 0$ and $\theta = 0$. The green trend line shows the data is drifting slightly.

Repeating the above test with $\theta = 45$ degrees on figure 4.11. Again a slightly decreasing total force but stable angle calculation, hence x and y load cell is decreasing in the same rate. The expected total force is 707g and the measured is around 23g higher, might because the angle have been a little less than 45 degrees or the tension has been a little higher. This is given to et limited precision in the test setup.

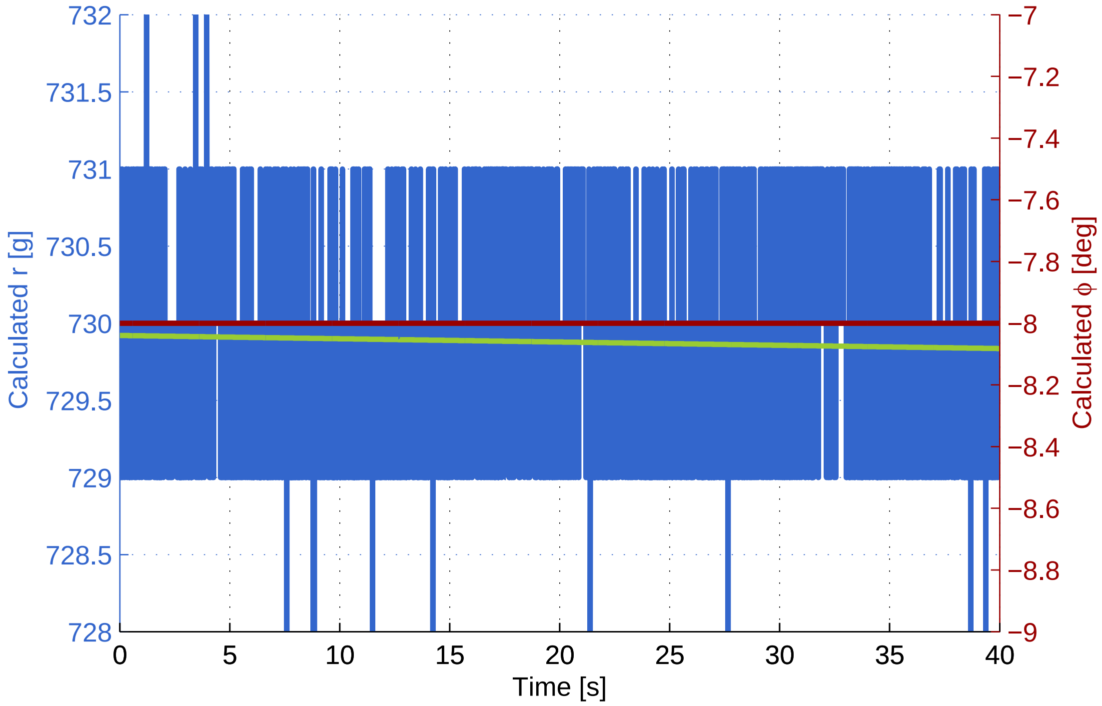


Figure 4.11: Calculated total force and angle then pulling the cable with 1kg load when $\phi = 0$, and $\theta = 45$ degrees.

Summary

The prototype is able to measure the force in x- and y-direction, ϕ and r can be calculated with good results. Higher precision might be possible with more precise testing equipment. The 5kg load cell has a zero balance at $\pm 75g$. Any values close to this range must be considered as very unreliable. When calibrating the 5kg load cell, the calibration gives better results using a calibration load greater than 0.5kg. The force in $T_{winch,y}$ is quite small and can therefore be ignored.
All plots have a zoom time axis, thus resulting in more readable and intuitive graphics.
All test where measured in 60-120 seconds to ensure the data is stable over time.
It is very important to keep +50mm distance between the winch and the load cell, if they are too close the measured force is rapidly decreasing.

4.4 Tree Dimensional Force Measurement Device

This measurement devices consist of tree load cells, all perpendicular to each other. The load cells are of different working range, but after calibration their scale is close to equal. However they have different precision, creep and non-linearity region, which might cause unexpected results.

Calibration

As in the Horizontal Measuring Device, first thing is to perform a calibration, now in tree axes, but with same method. The x offset is -5992.5241, y offset 464.4041, and z offset 104.0533, as seen on figure 4.12.

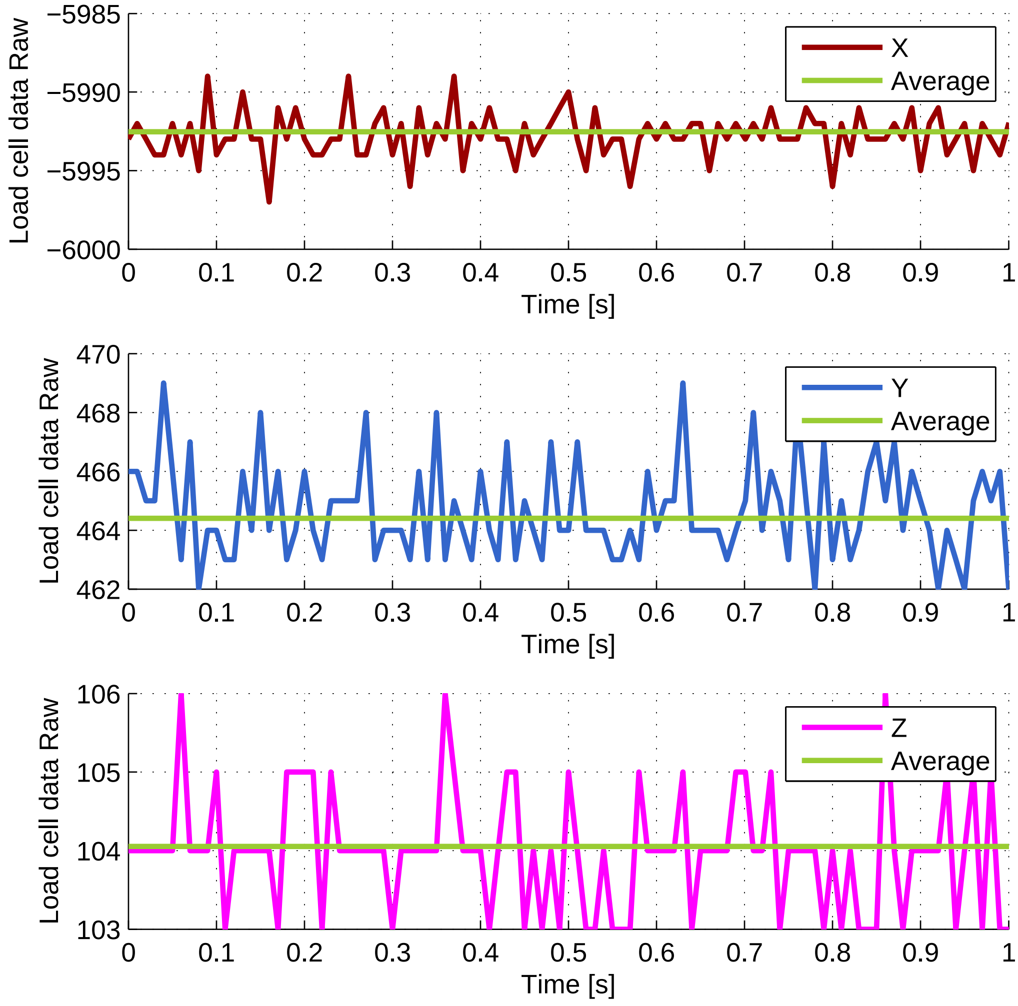


Figure 4.12: Raw input data from load cell x, y, and z. The average line is the calculated offset used for calibration. Measured without any load.

The z-axis is calibrated with 1000g load, hence it is a 5kg load cell. The x- and y-axes is calibrated with 500g load, hence their measuring range limit is 0.78kg. The gain is calculated to: $Kx = 0.0868$, $Ky = -0.0851$, and $Kz = 0.4277$.

Test of Calibration

Testing the calibration with 600g of load at $\phi = 0$ degrees and $\theta = 45$ degrees. The results are shown on figure 4.13. The results seams to have unexpected results in the first 10 seconds and the last 20 seconds. This might be due to vibrations in the test setup, when people are walking by, touching the table, or the spring is not in equilibrium, because the distortion is seen on all tree axes. From approximate 15 seconds in to 50 seconds, the reading is quite stable, thus it has a slight drift. This drift is, as describes in testing of the Horizontal Measurement Device, presumably given due to elasticity in the rope, the spring is permanently bending or tolerances in the manufacturing process gives rise to small displacements of mechanical components.

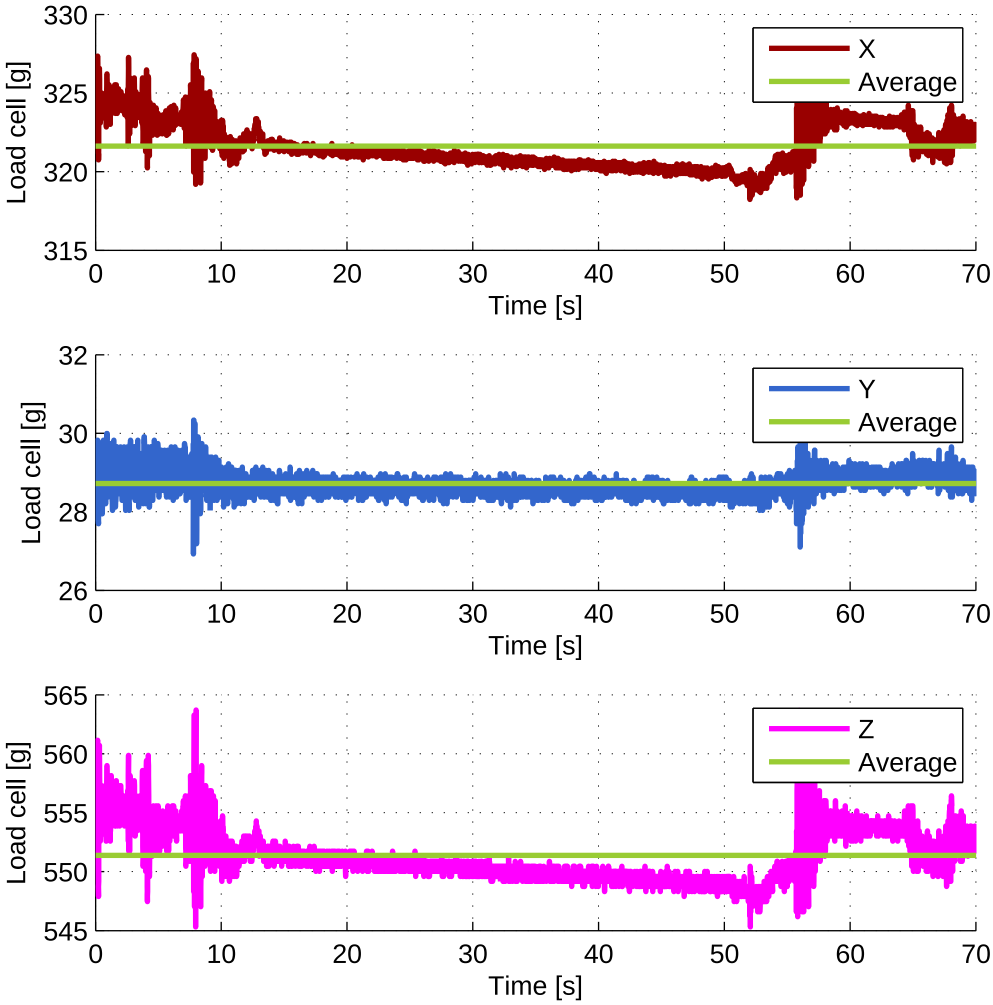


Figure 4.13: Calibrated load cell input data with $\phi = 0$ degrees, $\theta = 45$ degrees, and 600g load.

Taking a look at the calculated values for r, ϕ, and θ reflects the distortion from the calibrated tension, but it is not a significant distortion and can be smooth out with a lowpass filter. Filtering the data must be done very cautious since it might interfere with the position controller in a negative way.

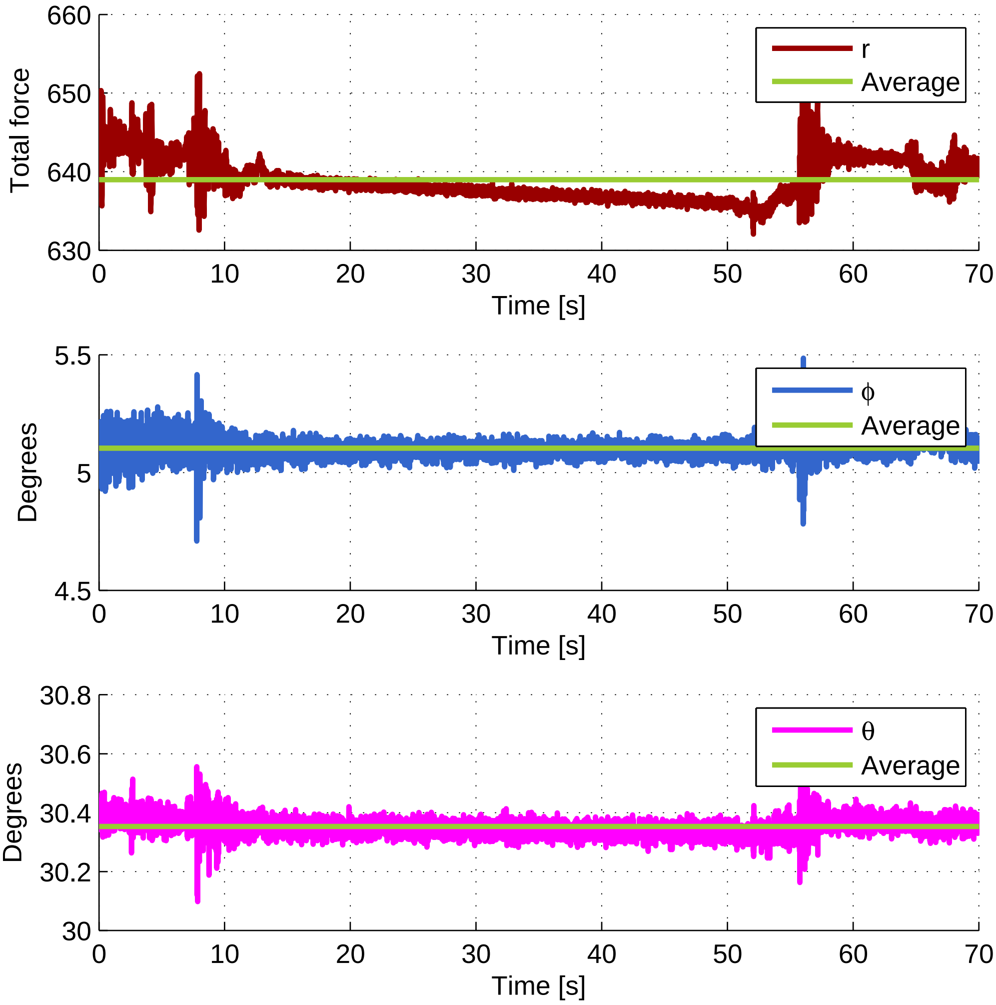


Figure 4.14: The calculated variables after calibration; $\phi = 0$ degrees, $\theta = 45$ degrees, and 600g load.

Summary

The measurement device can measure all tree axis independently with acceptable results. The drift in the data, of same type as in the Horizontal Measurement Device, are very likely of same causes. The x-axis load cell has a very large offset compared to the others. This might be caused by a damage or over load resulting in permanent bending of the Aluminium block. Thus the data from it is still acceptable.

4.5 Data connection test

The data connection is tested by performing a ping test from Ground Control Station to the Flight Control System and measuring the response time. The ping test is started and then the throttle for the UAV is moved slowly up to a point where the UAV is close to take off.

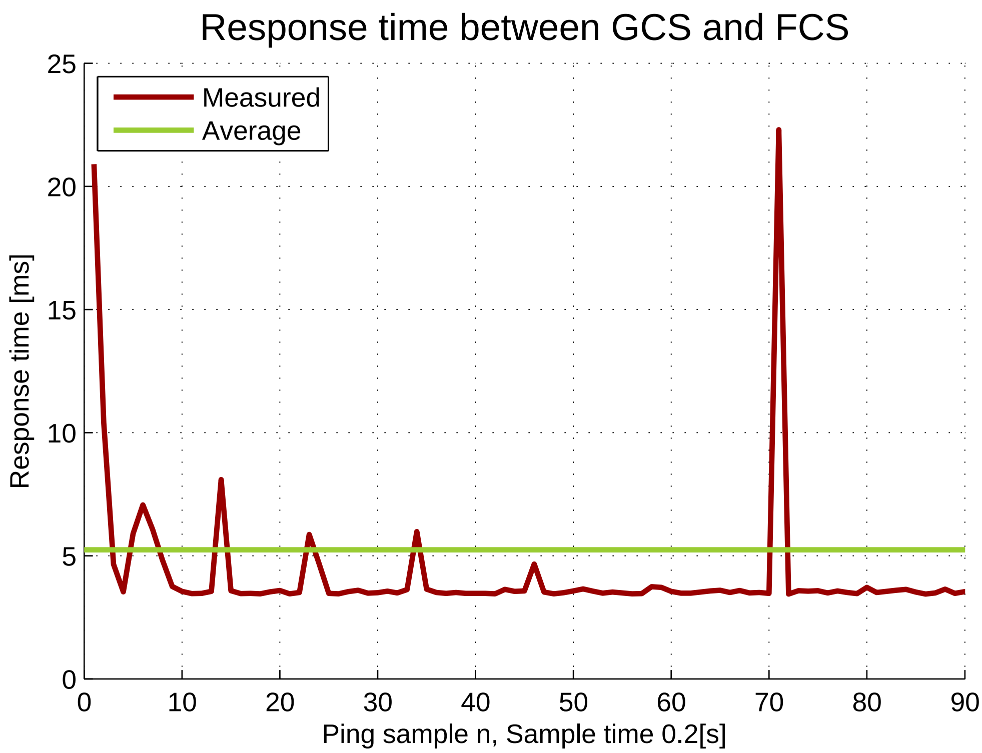


Figure 4.15: Ping test from Ground Station to Flight Control System, while throttle is on.

From figure 4.15 the average response time is 5.16ms which is a robust result. Unfortunately is have not been possible to test the data connection when the UAV is on full throttle, which also is the worst-case conditions for the network connection. The test where performed with 50m of cable, and the supply volte in the power line never went under 69 volt. Taking this in consideration further testing must be performed to finally conclude if this concept works.

CHAPTER 5

Conclusion

The problem formulation was analysed resulting in a design requirement specification. The design requirement specification have been used to analytically design a prototype and discussing several methods. For this project the simple solution was prototyped. The prototype have been tested and the results clearly indicates the measuring devises works as intended with an acceptable precision. The data connection turn out to be stable under the testing conditions. Unfortunately problems with the power supply system obstructed testing the system with the UAV airborne. Several elements are subject to further development.

5.1 Further Work

Every project can always be improved and further developed. This is my opinion on some subjects which are obvious to follow up on.

Rearrange load cells on UAV

The load cells on the UAV can be rearranged to ensure the center of gravity and the cable connection coming closer to each other, and thus improves the UAV's stability.

Power system

At the moment the power supply system are only able to deliver 400W instead of 500W over only 20m of cable. The limiting factor is in the converters/inverters system developed by Mikkel Wahlgreen. A way of solving this problem is to combine the power supply from the cable with a on board battery. When the UAV not are using all the power it can recharge the battery and when extra power is need is can be delivered in combination with the battery.

RHD Link

The link between the Ground Control Station and Flight Control Station is using the RHD server connection. However the RHD software is not intended to be used at two different computers and then merge the variable database. Many programming issues turned out on the way and the time was not to finish implementing this plugin.

Joystick

The Joystick control is a nice feature while developing and testing the setup. Unfortunately the Joystick linux driver Xpad is not compiled with the distributed debian build for Beaglebone. This issue is discussed in the General Notes for Beaglebone setup in the Appendix.

Network connection

The network connection has to be tested under the worst-case conditions, in order to safely determine the stability of the connection when the voltage drop.

Serial connection to PixHawk

This project relies on the Beaglebone at the UAV can communicate with the PixHawk, in order to feed the position controller with the measured positions references. Hence the USB connection on the Beaglebone is already used to the Phidget bridge, a serial communication to the PixHawk is preferred.

APPENDIX A

Symbols and Acronyms

A.1 Acronyms

BBB	Beaglebone Black
CAD	Computer Aided Design
DTU	Danish Technical University
FCS	Flight Control System
GCS	Ground Control Station
GPIO	General Purpose Input and Output
PSU	Power Supply Unit
RHD	Robot Hardware Daemon
UAV	Unmanned Aeriel Vehcile
XML	Extensible Markup Language

A.2 Symbols

Units are as following, unless otherwise stated.

U	Voltage
I	Current
R	Resistance
ρ	Electrical resistivity
A	Surface area
P	Power
W	Watt
F	Force
K	Constant
b	Offset
T	Tension force
λ	Cable Weight per unit length
g	Gravitational constant
ϕ	The angle from x axis in positive rotational direction.

APPENDIX B
Beagle Bone Setup

This project used a BeagleBone Black edition revision C with Debian distribution from 2014-05-14 running.
Setting up is done by cloning the git repository at https://github.com/savnik/rhd that contains all code needed[1].

```
git clone https://github.com/savnik/rhd
```

Inside the folder rhd/ a setup file found basic containing all setup that is needed. The setup is explained in parts below.

```
cd rhd/
./setup
```

B.1 usblib

For communication with the Phidget bridge the usblib are needed and in this project version 1.0.9 is used. The library can be downloaded from http://www.libusb.org/.

B.2 libphidget

The Phidget bridge comes with a library for interfacing the Phidget bridge easy. For this project version 2.1.8.2014 is used. The library can be downloaded from Phidgets website http://www.phidget.com/.
It is very important to setup the rules using the 99-phidgets.rules file, otherwise the RHD plugins can't connect.

B.3 Networking

Connecting the Beaglebone to the Ethernet is straight forward using the RJ45 plug, but in this setup the RJ45 plug is already used in connection to the UAV. There fore it is needed to bridge the network connection via USB. Beaglebone natively support a network connection through USB, but needs some configuration to connect to the internet through the USB cable[2].

[1]In order to bridge the usb network connection see Networking below.
[2]https://github.com/anujdeshpande/BBB-workshop

On the Beaglebone run following command:

```
/sbin/route add default gw 192.168.7.1
echo "nameserver 8.8.8.8" >> /etc/resolv.conf
```

First line tells the Beaglebone to go through 192.168.7.1 when trying to connect to the internet and second line tell the Beaglebone to use google name-server.
On the host computer (Ubuntu):

```
sudo iptables -A POSTROUTING -t nat -j MASQUERADE
sudo echo 1 | sudo tee /proc/sys/net/ipv4/ip_forward > /dev/null
```

B.4 GPIO

Setting up the GPIO is done through the device tree source file. This file shows an example on 4 GPIO pins that is setup to Output or Input, and the internal pullup/pulldown settings.

```
/dts-v1/;
/plugin/;

/{
       compatible = "ti,beaglebone", "ti,beaglebone-black";
       part-number = "DM-GPIO-Test";
       version = "00A0";

       fragment@0 {
             target = <&am33xx_pinmux>;

             __overlay__ {
                  pinctrl_test: DM_GPIO_Test_Pins {
      pinctrl-single,pins = <

        0x070 0x07  /* P9_11 OUTPUT MODE7 - M1EN */
        0x078 0x07  /* P9_12 OUTPUT MODE7 - M1NA */
        0x031 0x07  /* P9_13 OUTPUT MODE7 - M1NB */
              /* No PWM */
        0x040 0x27  /* P9_15 INPUT MODE7 - M1CS */

                           /* OUTPUT  GPIO(mode7) 0x07 pulldown, 0x17
                              pullup, 0x?f no pullup/down */
             /* INPUT   GPIO(mode7) 0x27 pulldown, 0x37 pullup, 0x?f no
                pullup/down */

      >;
      };
             };
       };

       fragment@1 {
```

```
    target = <&ocp>;
    __overlay__ {
      test_helper: helper {
        compatible = "bone-pinmux-helper";
        pinctrl-names = "default";
        pinctrl-0 = <&pinctrl_test>;
        status = "okay";
      };
    };
  };
};
```

Compiling a Device Tree Source file (.dts files) can be done like this:

```
dtc -O dtb -o DM-GPIO-Test-00A0.dtbo -b 0 -@ DM-GPIO-Test.dts
```

It is a little tricky because "-O" is for output format, dtb is for Blob format, "-o" is output file DM-GPIO-Test–VERSION.dtbo, "-b" physical boot cpu 0 and the input file DM-GPIO-Test.dts[3].
The device tree blob object can be loaded on boot or by

```
echo DM-GPIO-Test > /sys/devices/bone_capemgr.9/slots
```

A list over active device tree blob object is obtained by

```
cat /sys/devices/bone_capemgr.9/slots
```

Writing, reading and some level of configuration is done by normal unix input/output method, writing/reading to/from a virtual file located at /sys/devices/gpio/.

```
gpioXX
├── active_low
├── direction
└── value
```

B.5 PWM

Using the PWM output from the Beaglebone is not "out-of-the-box". In order to enable the PWM module a Device Tree Blob Object (.dtbo file) needs to be loaded is the cape slots. Beaglebone comes with a default Device Tree Blob Object file that supports the PWM module. The Device Tree Blob Object files can be found in /lib/firmware/. For this project the default Device Tree Blob Object file for pin 14 was used[4].
Accessing the PWM module is like normal unix input/output method, writing to a virtual file. The PWM modules virtual files is at /sys/devices/ocp.3/

```
pwm_p9_14
```

[3] http://web.mit.edu/freebsd/head/contrib/dtc/Documentation/manual.txt
[4] /lib/firmware/bone_pwm_P9_14-00A0.dtbo

```
├── duty
├── period
├── polarity
└── run
```

B.6 SPI

To enable the SPI interface on the beaglebone follow instructions from http://elinux.org/BeagleBone_Black_Enable_SPIDEV. Using the SPI interface can only be done be disabling the HDMI interface because they use the same pins. Because of the long cable connection (over about 10cm) the communication speed needs to be slowed down.

B.7 Wire connections

Encoder wiring:

Encoder Cable Pin	AMS AS5045B Pin	Beaglebone Pin
1	16 VDD 5V	5/6 P9
2	7 VSS	1/2 P9
3	12 PWM	
4	11 CSN (Chip Select)	
5	6 Index	
6	10 CLK	31 P9
7		
8	9 DO (data out)	29 P9
9	8 PDIO	
10	1 MagIn	
11	2 MagDec	

Motor Driver wiring:

Cable pin	Motor Driver Pin	Beaglebone pin
Blue	Green GND	P8 1 GND
Green	Blue VSS 5V	SYS 5V
Yellow	Yellow Encoder Channel A	P8 7
Orange	Orange Encoder Channel B	P8 8
Red	Red Motor 12V	Motor Driver M1+
Black	Black GND	Motor Driver M1-

B.8 General notes

The Device tree blob object can be loaded at boot in the uEnc file, but it seems to be root of many booting problems loading the Device tree blob object at boot, therefore it is a better solution to run a shell script after bootup that loads the device tree blob objects. This way the Beaglebone is always able to boot, and in case of bad device tree blob object files it does not prevent the system from booting.

The Beaglebone Debian distribution does unfortunately not include a compiled version of xpad. Xpad is the driver for the joystick and is needed for using the gamepad plugin. The raw files for the xpad driver is available several places on the internet and even through available at the Beaglebone Debian Distribution, but is somehow not included in the latest build from 2014-15-14. In order to compile xpad the header files placed in /usr/src is needed but in they does not come with the distribution. So to use xpad a new debian image is needed to be compiled. The distribution image size is 2Gb and the Beaglebone Back memory size is only 4Gb. The distribution image must be compiled on same type of processor in order to work properly or compiled using a cross compiler. Thus the joystick plugin will be disabled by default in the setup, but can be activated in rhdconfig.xml.

The Beaglebone community is rather small compared to the Arduino or Raspberry Pi community, therefore searching for patches or solutions is generally extensive work and requires a high level of unix skills.

APPENDIX C
Robot Hardware Daemon

RHD (Robot Hardware Daemon) is the real-time hardware abstraction layer for the Mobotware platform, developed at DTU. RHD is a plugin-based platform that allows easy integration with sensors and actuators. RHD creates a synchronized database with read/write variables that can be shared between plugins and/or accessed by other software applications. RHD uses a real-time scheduler to ensure a fixed sample rate.
All setup of RHD is done based on a XML configuration file, containing all parameters and plugins specific to the robot. Plugins are intended to be general and works across robots, and all ”magic” variables are placed in the configuration file.

This project has been implemented as a configuration in RHD and plugins for hardware has been developed. To run the program type in:

```
rhd trunk/plugins/tcuav/rhdconfig.xml
```

This runs the RHD program and loads the configuration for the Ground Control Station.

C.1 Plugins

PhidgetsBridge2

PhidgetBridge2 is build on the initial Phidgets Bridge plugin, only made more flexible by allowing the configuration file to contaion all of Phidgets Bridge configuration settings. The Phidget Bridge is a 4 channel amplifier, and is intended for measuring small voltages for example in loadcells.

Configuring the bridge is done by first enabling the wanted channels. The default amplifier gain is 128V/V. The minimum sample time is 10 milliseconds. Calibration constant offset and gain is found by $F_{Exspected} = K * (Messured - Offset)$.

```
<!-- Phidget Bridge -->
    <phidgetsbridge2
      enable = "true"
      lib="phidgetsbridge2.so.1"
      debug = "1"
      interval = "0"
      updateTimeMs = "10"
      gain = "128 128 128 0"
      enableCh = "1 1 1 0"
      offset = "-290 6050 -90 0"
      k = "876 870 360 1"
      >
```

```
  </phidgetsbridge2>

  <!-- Flight Control System - Tether Control of UAV -->
  <fcs
    enable= "true"
    lib="fcs.so.1"
    debug = "true"
    >
  </fcs>
```

This plugin depends on Phidgets Linux Library. Special installation notes are found in the readme file.

Files:

```
plugins
└─phidgetsbridge2
   ├─99-phidgets.rules
   ├─Makefile
   ├─README
   ├─libphidget_2.1.8.20140319.tar.gz
   ├─phidgetsbridge2.c
   ├─phidgetsbridge2.h
   └─rhdconfig.xml
```

TCUAV

TCUAV or Tether Control of UAV is the Ground Station plugin. This plugin handles the steering input references, the horizontal measurement, and winching control. TCUAV relies on the Phidget Bridge plugin to determine the horizontal angle, and the Joycontrol plugin to switch between steering references. Hence this plugin uses the GPIO on the Beaglebone a special installation procedure is found in the readme file.

```
<?xml version="1.0" ?>
<!--
    Configuration file for
    Robot Hardware Daemon
    This configuration is for the Ground Control Station

-->
<!-- Starting RHD Configuration -->
<rhd>
  <!-- *** Core Components Configuration *** -->
  <!-- Sheduler configuration -->
  <sheduler>
    <period value="1000"/>
    <type value="itimer"/><!--"usleep","itimer","LXRT" -->
  </sheduler>
  <!-- Server configuration -->
  <server>
```

```
    <port value="24902"/>
    <clients number="10" allwriters="1"/>
  </server>

  <!-- *** Plugins Configuration *** -->
  <plugins basepath="/home/debian/rhd/trunk/build/lib/rhdplugin/">
    <!-- Joystick Control
          Updated!! Observe the max speed setting, deadband and the "safety" parameter -->


    <!-- Phidget Bridge -->
    <phidgetsbridge2
      enable = "true"
      lib="phidgetsbridge2.so.1"
      debug = "1"
      interval = "0"
      updateTimeMs = "10"
      gain = "128 128 0 0"
      enableCh = "1 1 0 0"
      offset = "-456 -511"
      k = "4786 -5134 0 0"
      >
    </phidgetsbridge2>

    <!-- tcuav - Ground Station System - Tether Control of UAV -->
    <tcuav
      enable= "true"
      lib="tcuav.so.1"
      debug = "true"
      critical = "true"
      >
    </tcuav>


    <!-- Joystick Control Not critical plugin for Guidebot -->
   <joycontrol enable="true" lib="libjoycontrol.so.1" critical="false" safety="1">
    <joystick port="/dev/input/js0"/>
  <speed maxlr="5000" maxfwd="5000" maxspin="5000" maxupdown="5000" />
  <deadband max="767" min="-767"/>
  <control enable="true"/>
  <scale right="1.000" left="1.000"/>
    </joycontrol>


    <rhdlog enable = "true"
            lib="rhdlog.so.1"
            debug="true"
            interval="0"
           >
    </rhdlog>
```

```
  </plugins>
</rhd>
```

Files:

```
plugins
└─tcuav
   ├─Makefile
   ├─README
   ├─gpio.c .3 gpio.h .3 pwm.c .3 pwm.h .3 rhdconfig.xml
   ├─tcuav.c
   └─tcuav.h
```

FCS

FCS or Flight Control System is a part of the Tether Control of UAV project. This plugin establish contact to Ground Station via a Socket connection, and exchange information(references) from the ground stations measurements and control parameters, and then sends control parameters in to a PixHawk. It also reads 3 load cell from a Phidget Bridge to determine the yaw and the force from the cable in x,y and z direction.
It is intended the PixHawk runs it's own position estimator in hard real time, and the control parameters from this plugin in soft real time, because of the variable delay in the feedback from the Ground Station.

Setting up this plugin requires the PhidgetBridge2 to be configured first.

```
<!-- Phidget Bridge -->
    <phidgetsbridge2
      enable = "true"
      lib="phidgetsbridge2.so.1"
      debug = "1"
      interval = "0"
      updateTimeMs = "10"
      gain = "128 128 128 0"
      enableCh = "1 1 1 0"
      offset = "-290 6050 -90 0"
      k = "876 870 360 1"
      >
    </phidgetsbridge2>

    <!-- Flight Control System - Tether Control of UAV -->
    <fcs
      enable= "true"
      lib="fcs.so.1"
      debug = "true"
      >
    </fcs>
```

This plugin depends on the phidgetsbridge2 plugin.

Files:

```
plugins
└─fcs
  ├─Makefile
  ├─fcs.c
  └─fcs.h
```

RHDLink

This plugin creates a socket connection to another RHD server(Server) and makes a copy of the variable database on the local machine(Client). The client with this plugin installed can access read and write variables on the other RHD server it is connected to, but the server can not read or write in the clients variable database. The Plugin is based on a copy of librhd.c, with a few alternations in the function and variable names to avoid name conflict. Only one RHD link per RHD server can run without conflicts.

The configuration of the plugin is done in the XML file "rhdconfig.xml" and adding following to the plugin configuration. Substitutting host and port to the corresponding RHD server will access another server weather it's on the local machine or on the network. The access rights can be set as read(r) or write(w), if write both read and write are possible.

```
<!-- *** RHD Link - creates a link to another RHD server *** -->
<rhdlink enable="true"
    lib="rhdlink.so.1"
      host="192.168.7.2"
      port="24902"
      access="w"
      debug="true">
</rhdlink>
```

This plugin requires the RHD component of Mobotware version 3.583.

Files:

```
plugins
└─rhdlink
  ├─Makefile
  ├─librhdlink.c
  ├─librhdlink.h
  ├─rhdconfig.xml
  ├─rhdlink.c
  └─rhdlink.h
```

Joycontrol

This plugin provides remote override control possibilities using a standard HID Joystick. The plugin is developed by Anders Billso Beck and automatic detect the vehicle steering configuration for wheel based robots. For this project the plugin was modified to be able to detect UAV steering parameters. The plugin detect the steering configuration on which unique control variables it can find in the variable database. UAV steering has unique control variables like yaw, pitch, roll and height.

Figure C.1: Implementation of joystick control for UAV control.

Files:

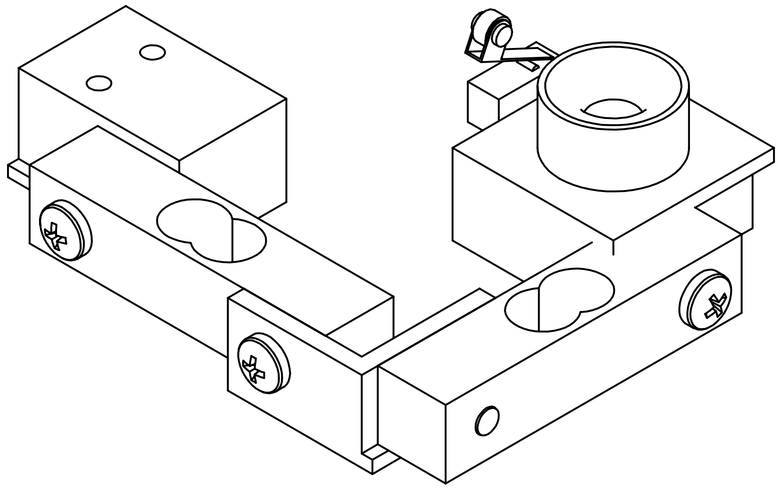
```
plugins
└─joycontrol
   ├─Makefile
   ├─joycontrol.c
   └─joycontrol.h
```

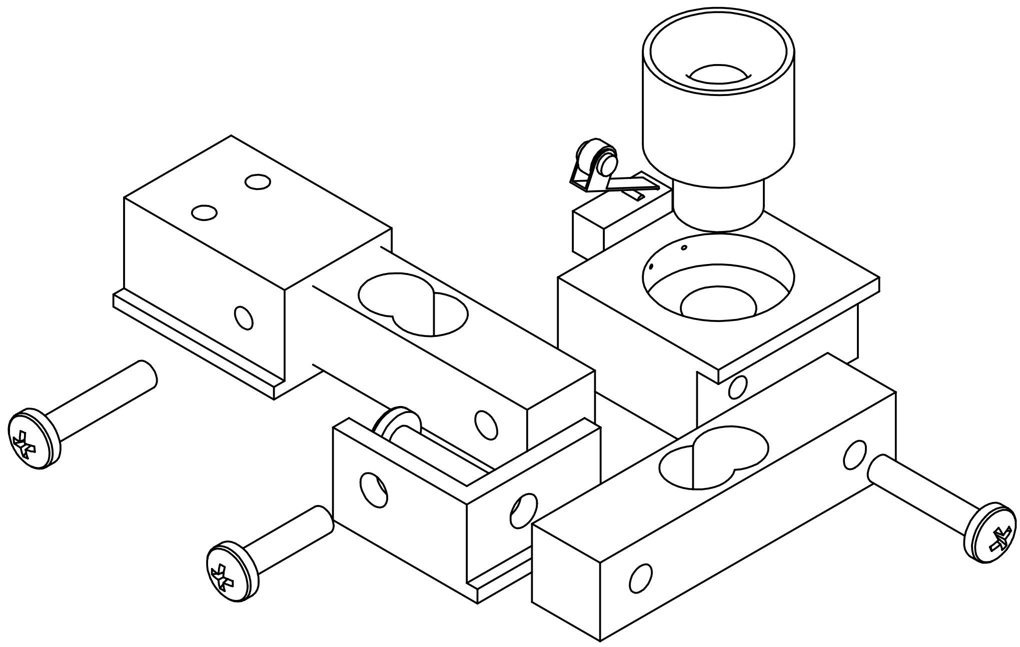
APPENDIX D

CAD Design

All tolerances are 1/100mm, screws and blots are in metric units, dimensions are in mm, and the material is aluminium unless other is stated.

Horizontal angle messurement device





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 4.2

Peter J. Savnik

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

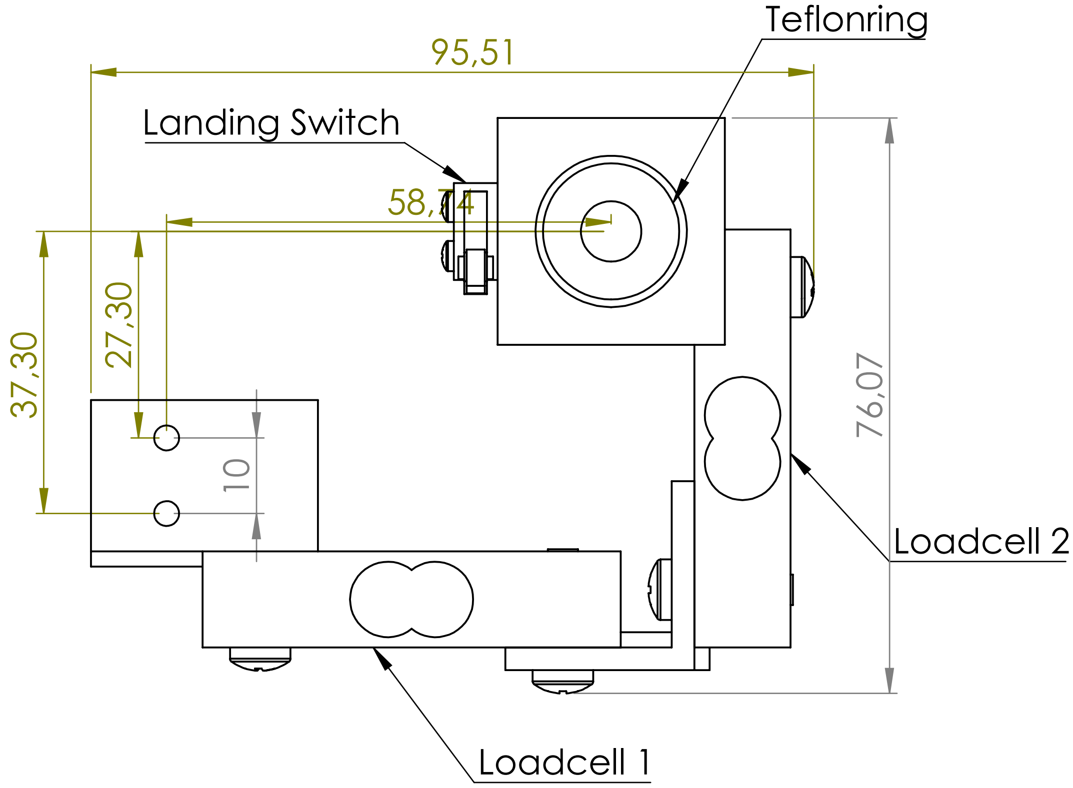
WEIGHT:

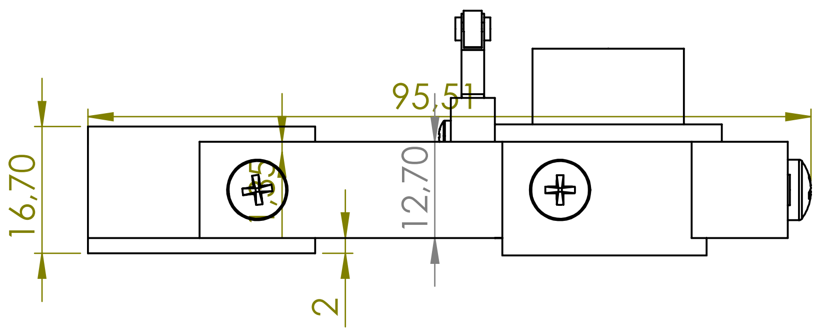
TITLE:

TCUAV

DWG NO. loadcell-assembly A4

SCALE:1:2 SHEET 1 OF 3





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REVISION 4.2

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

DWG NO. loadcell-assembly

A4

SCALE:1:2

SHEET 2 OF 3

Material List

ITEM NO.	PART NUMBER	DESCRIPTION	exploded/QTY.
1	cable_hole		1
2	loadcell-vinkel-fitting		1
3	loadcell-to-toplevel-fitting_V2		1
4	loadcell-5kg		2
5	B18.6.7M - M4 x 0.7 x 20 Type I Cross Recessed PHMS --20N		2
6	B18.6.7M - M4 x 0.7 x 16 Type I Cross Recessed PHMS --16N		2
7	teflon-ring-insert		1
8	switch		1
9	B18.6.7M - M2 x 0.4 x 10 Type I Cross Recessed PHMS --10N		2

UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

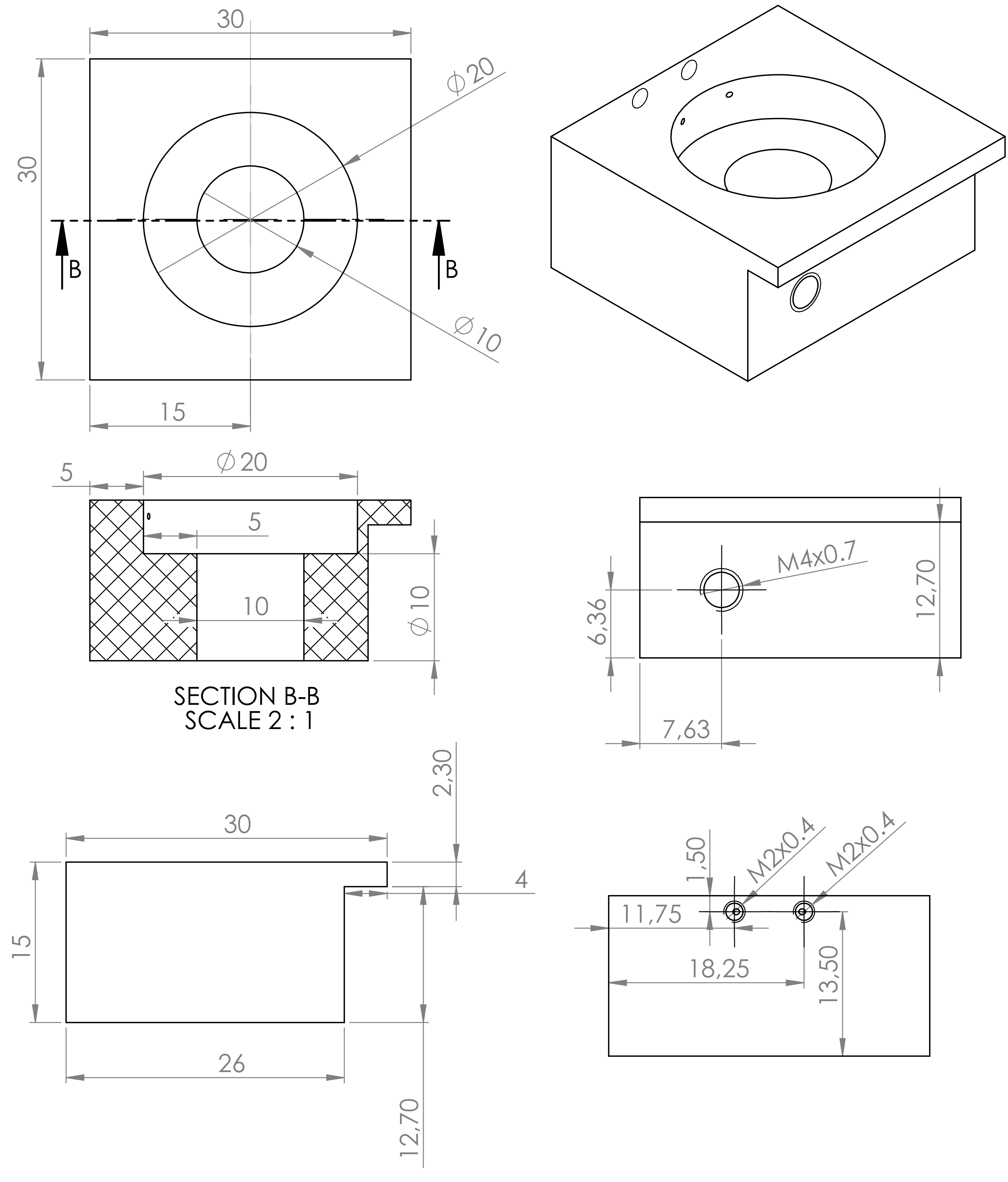
MATERIAL:

DWG NO. loadcell-assembly A4

WEIGHT:

SCALE:1:2

SHEET 3 OF 3



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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 4.2

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

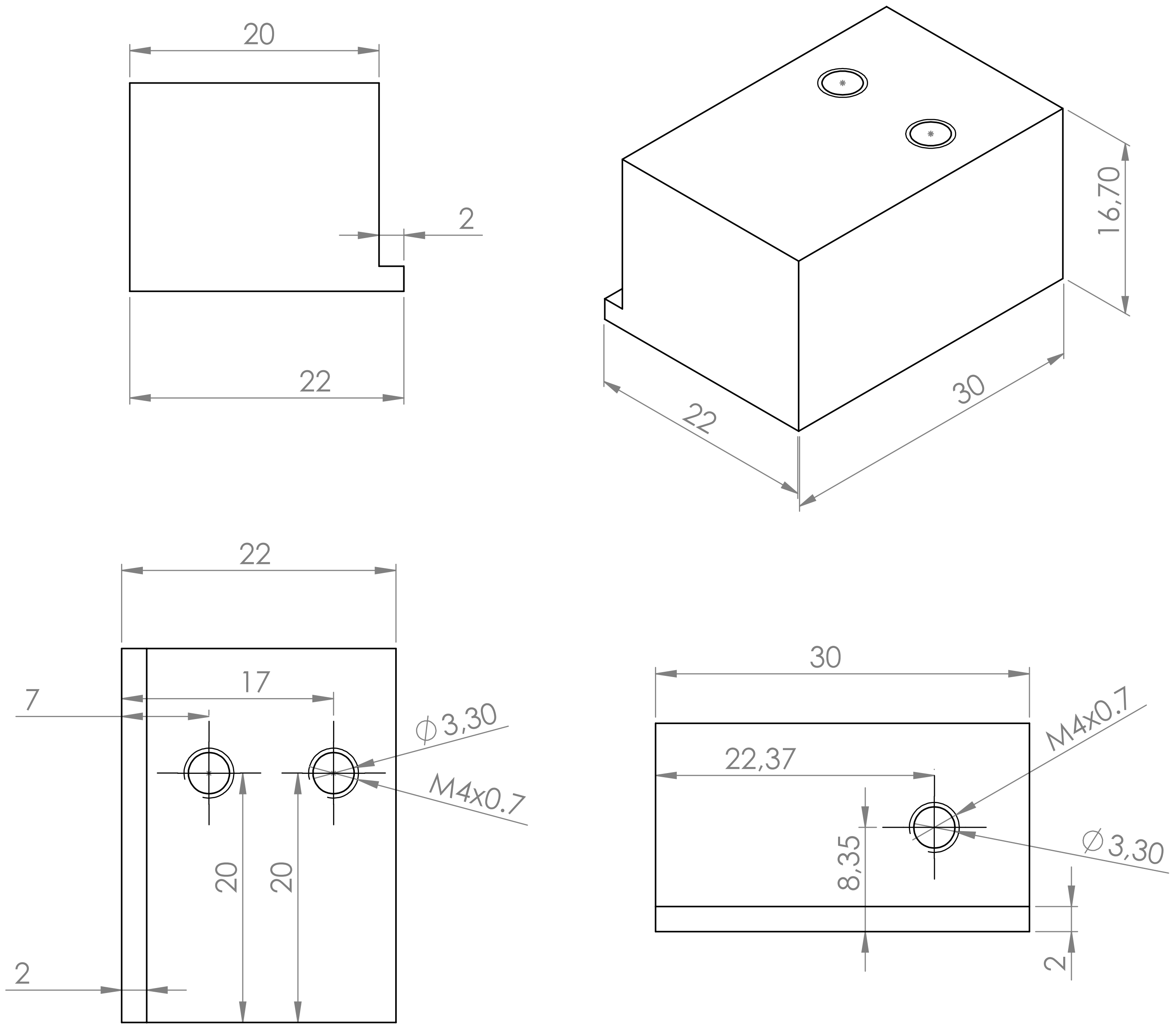
TITLE:

DWG NO. cable_hole

A4

SCALE:1:1

SHEET 1 OF 1



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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 3

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

TITLE:

MATERIAL: Alu

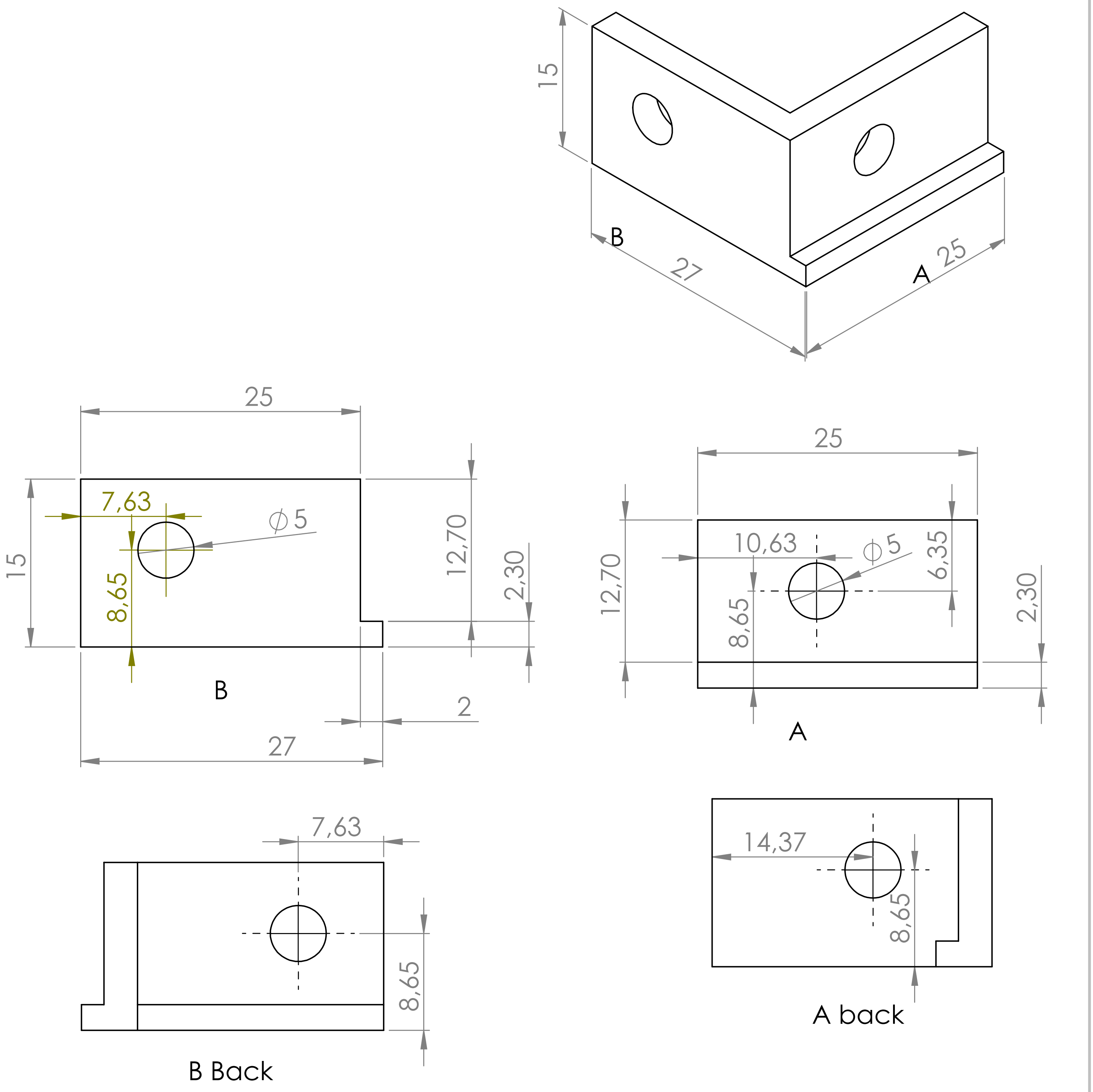
DWG NO. loadcell-to-toplevel-fitting

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 3

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

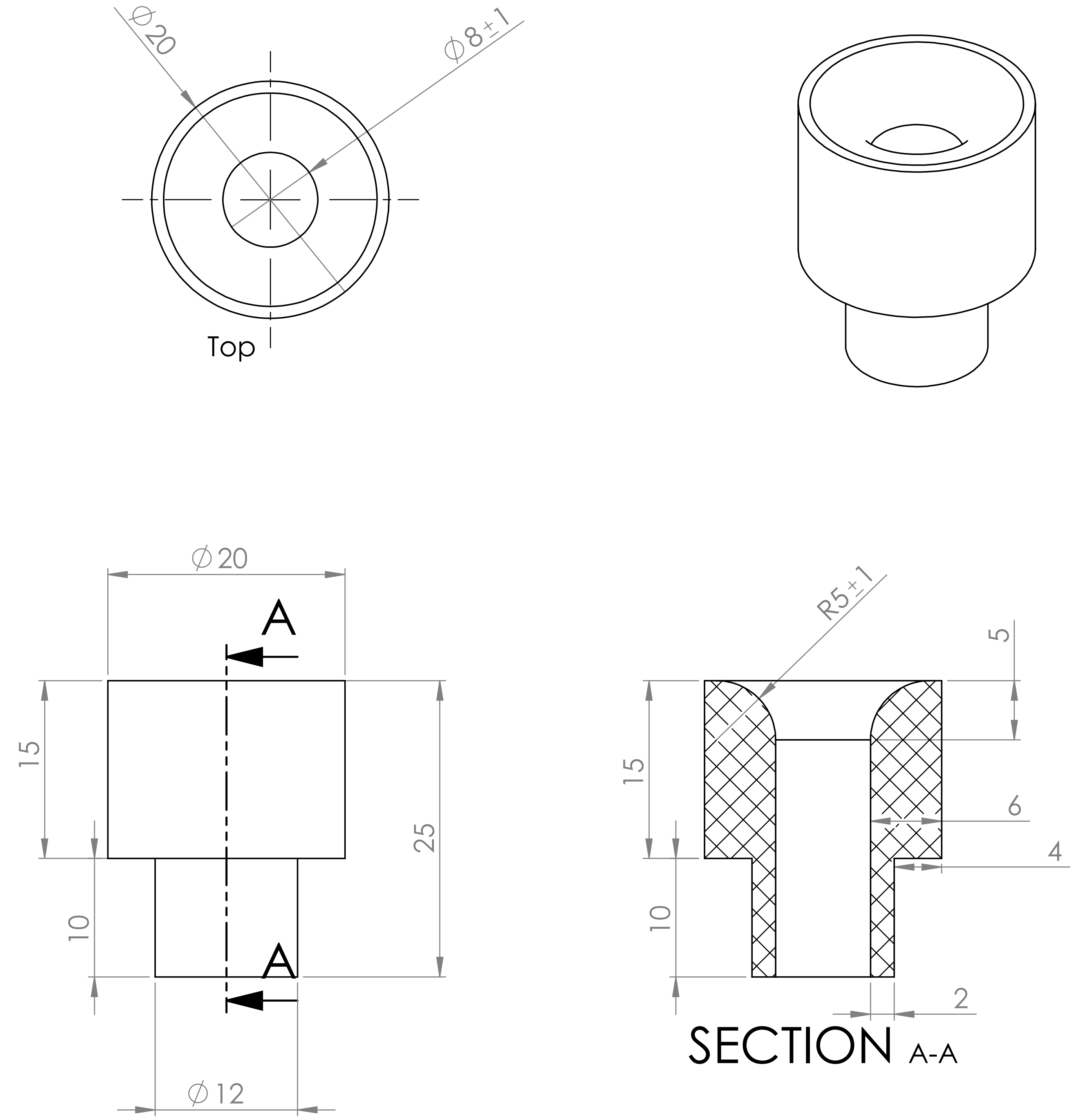
MATERIAL: Alu

DWG NO. loadcell-vinkel-fitting A4

WEIGHT:

SCALE:2:1

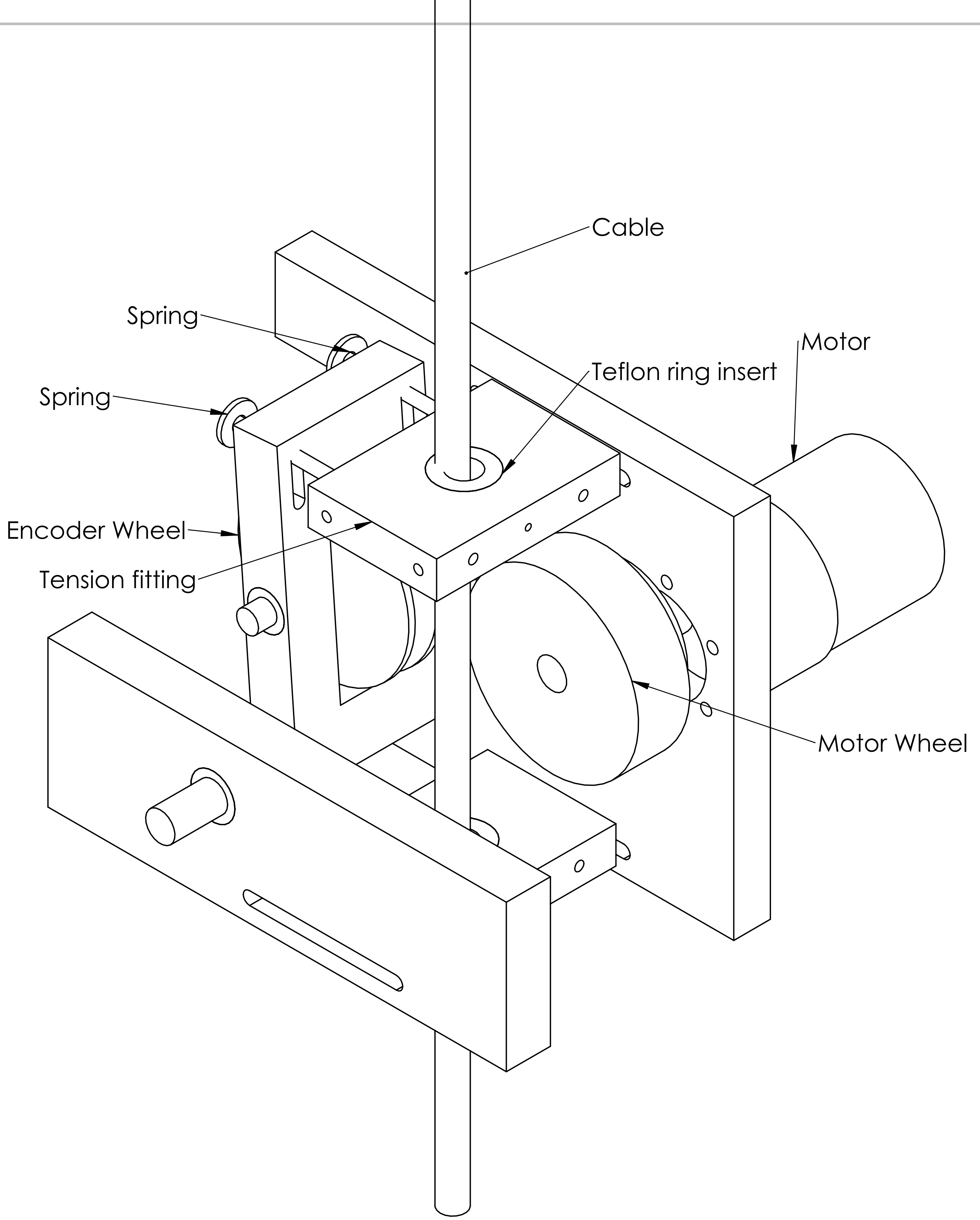
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL:	DWG NO.	teflon-ring-insert	A4
			WEIGHT:	SCALE:2:1	SHEET 1 OF 1	

The Simple Winch

The simple winch is inspired from 3D printer extruder mechanism. The is pushed between two wheels. One wheel is motorized and fixed in position and second is pushing towards the motor wheel with a spring tension. The spring assures the second wheel always have contact with the cable, even if there is small variations in cable thickness. Second wheel also includes an encoder. Having the encoder on the second wheel, instead of the motor wheel, assures the rotation is actually from the cable and not because the motor wheel slips on the cable. The springs in this prototype is normal ballpoint pen springs taken from two arbitrary ballpoint pens.
The encoder is a magnetic encoder with a magnet attached at the end of the shaft. The shaft is made of steel, so the magnet will stick.



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 4.2

Peter J. Savnik

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

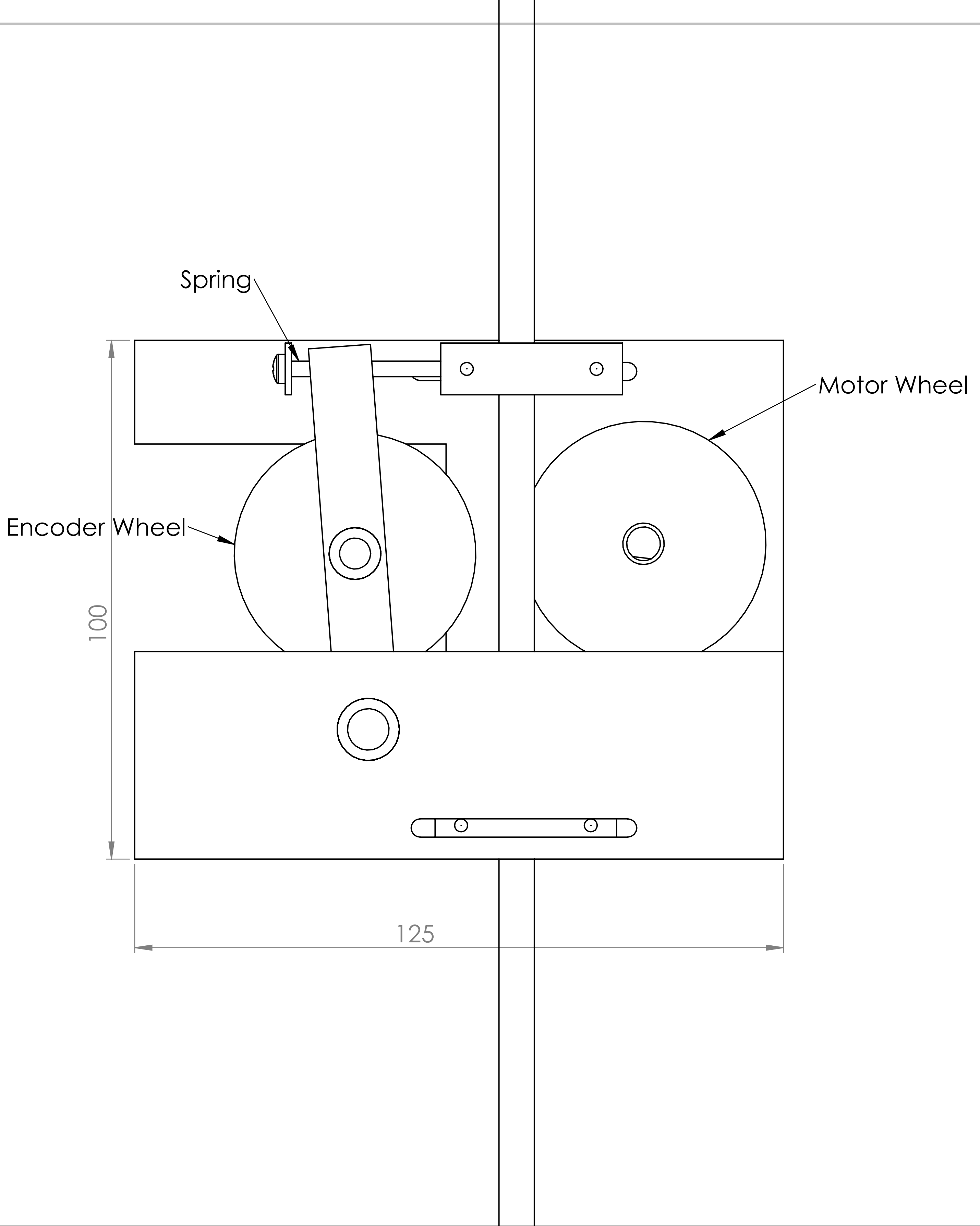
TCUAV

DWG NO. winch-assembly

A4

SCALE:1:5

SHEET 1 OF 4



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

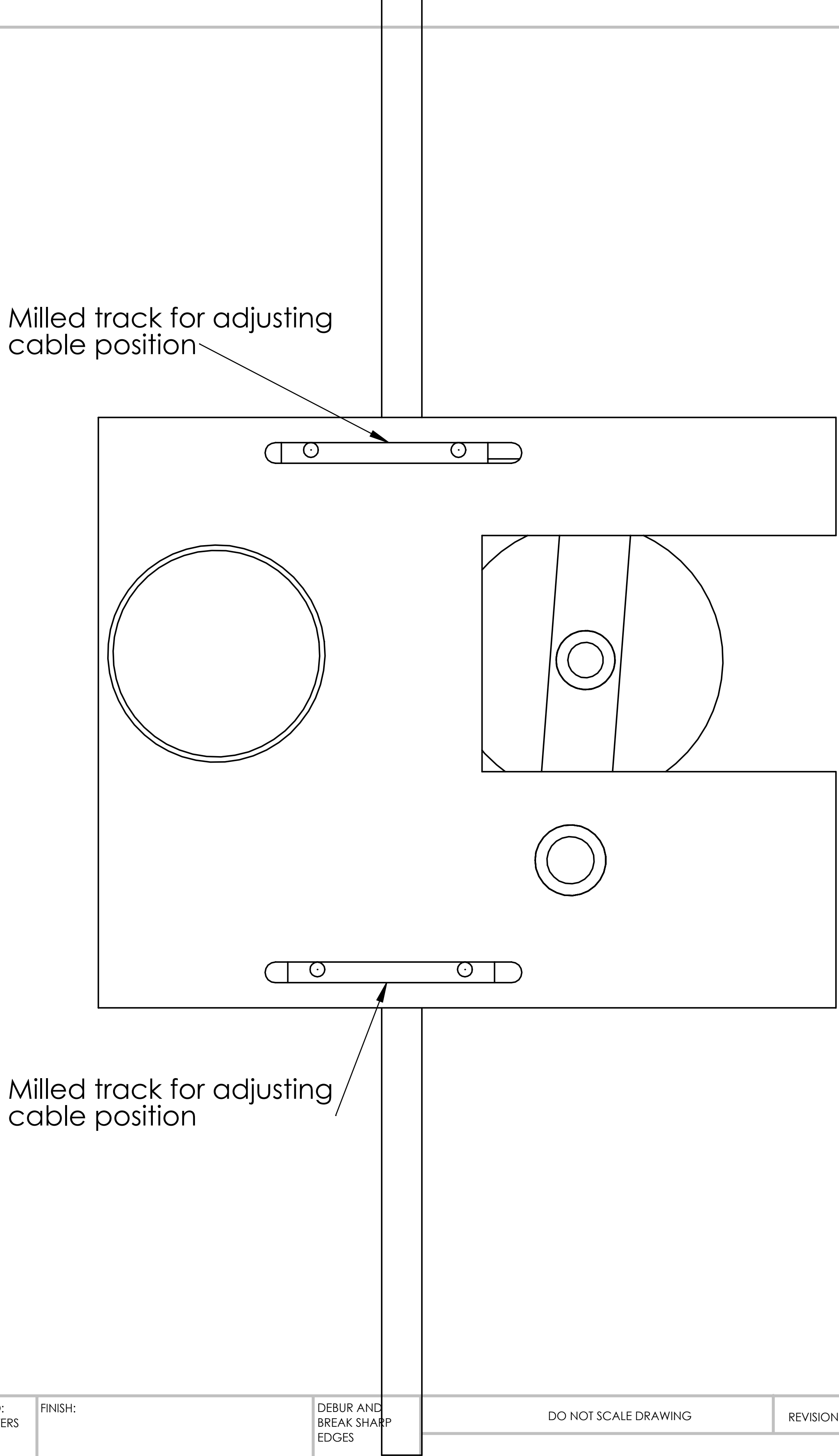
DWG NO. winch-assembly

A4

WEIGHT:

SCALE:1:5

SHEET 2 OF 4



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

DWG NO.

winch-assembly

A4

SCALE:1:5

SHEET 3 OF 4

ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	winch-side-plate-motor		1
2	cable		1
3	winch-side-plate		1
4	wheal-1		1
5	T2-5-60		1
6	tension-fitting		2
7	B18.6.7M - M3 x 0.5 x 30 Type I Cross Recessed PHMS --30N		2
8	axis-holder		1
9	brass-bearing		2
10	smooth-rod-6mm		1
11	smooth-rod-8mm-winch		1
12	brass-bearing-8-12		2
13	B18.22M - Plain washer, 3 mm, regular		2
14	teflon-ring		2
15	Pololu motor		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

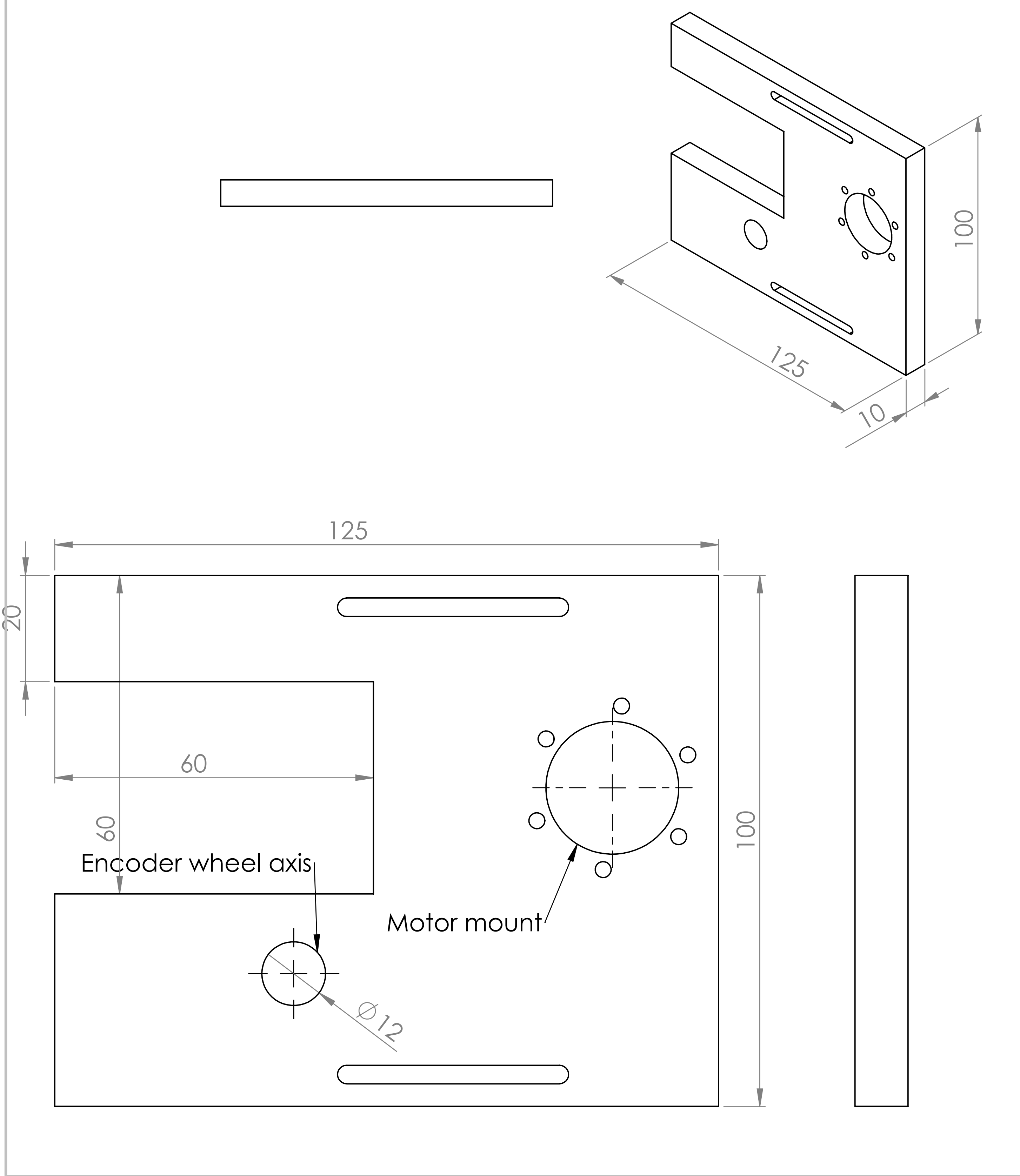
DWG NO. winch-assembly

A4

WEIGHT:

SCALE:1:5

SHEET 4 OF 4



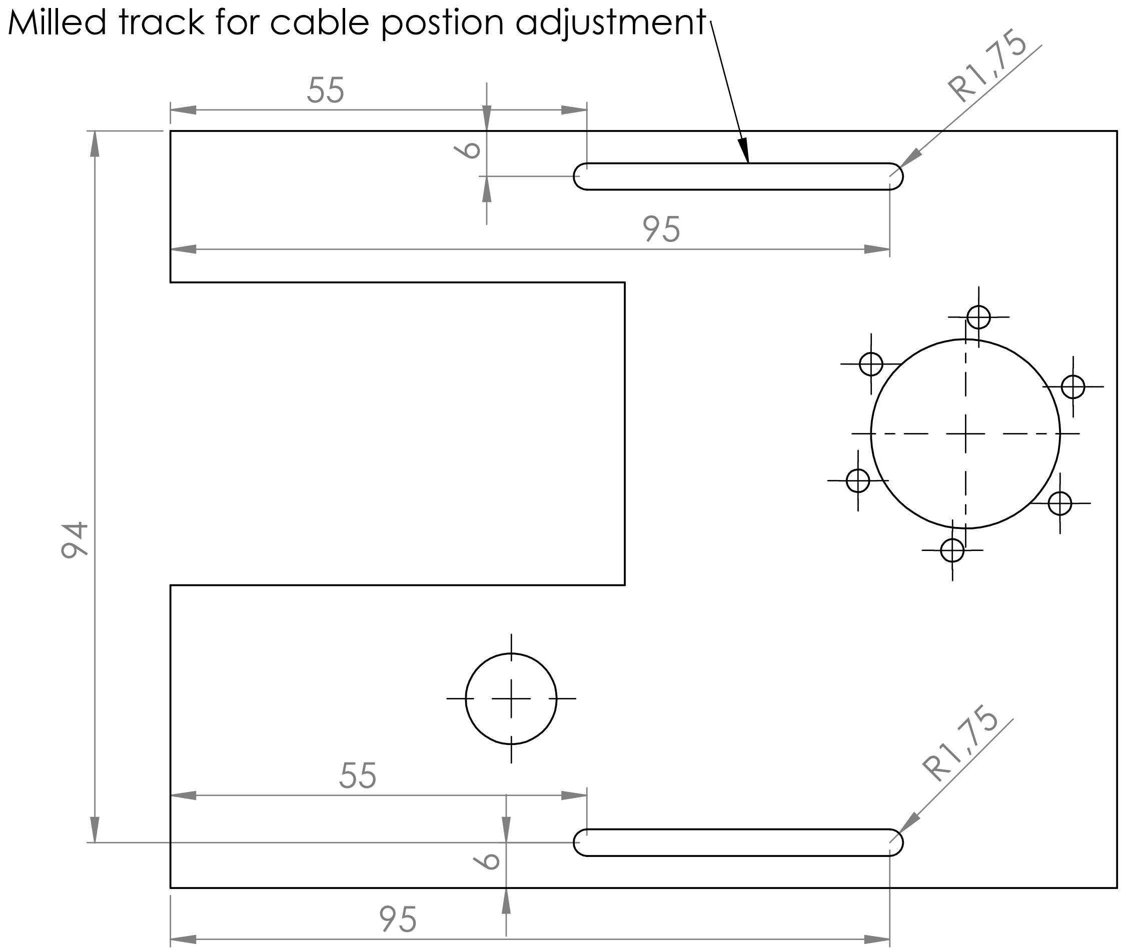
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	
				WEIGHT:	

TITLE:

DWG NO. winch-side-plate-motor A4

SCALE:1:2 SHEET 1 OF 4



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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

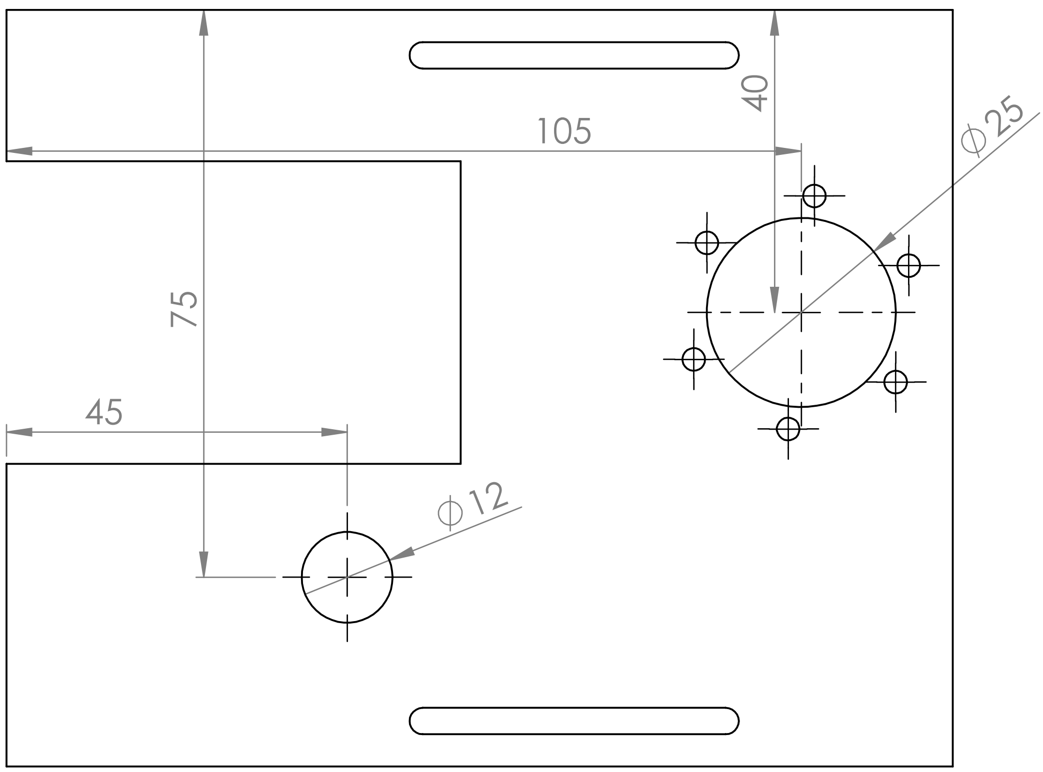
DWG NO. winch-side-plate-motor

A4

WEIGHT:

SCALE:1:2

SHEET 2 OF 4



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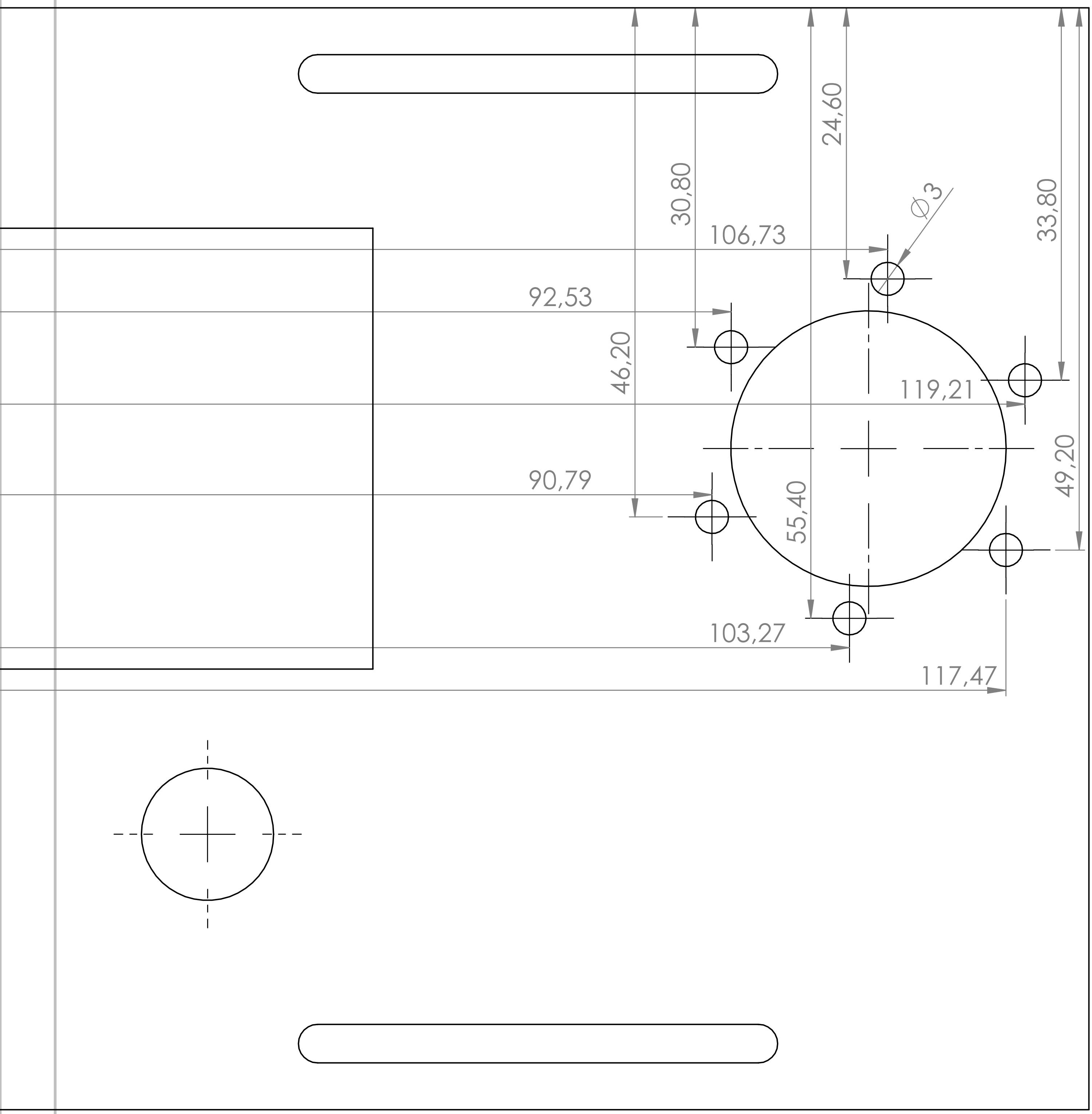
	NAME	SIGNATURE	DATE			TITLE:
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:		DWG NO. winch-side-plate-motor A4
				WEIGHT:		SCALE:1:2 SHEET 3 OF 4



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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

TITLE:

MATERIAL:

SolidWorks Student Edition.
For Academic Use Only.

DWG NO.

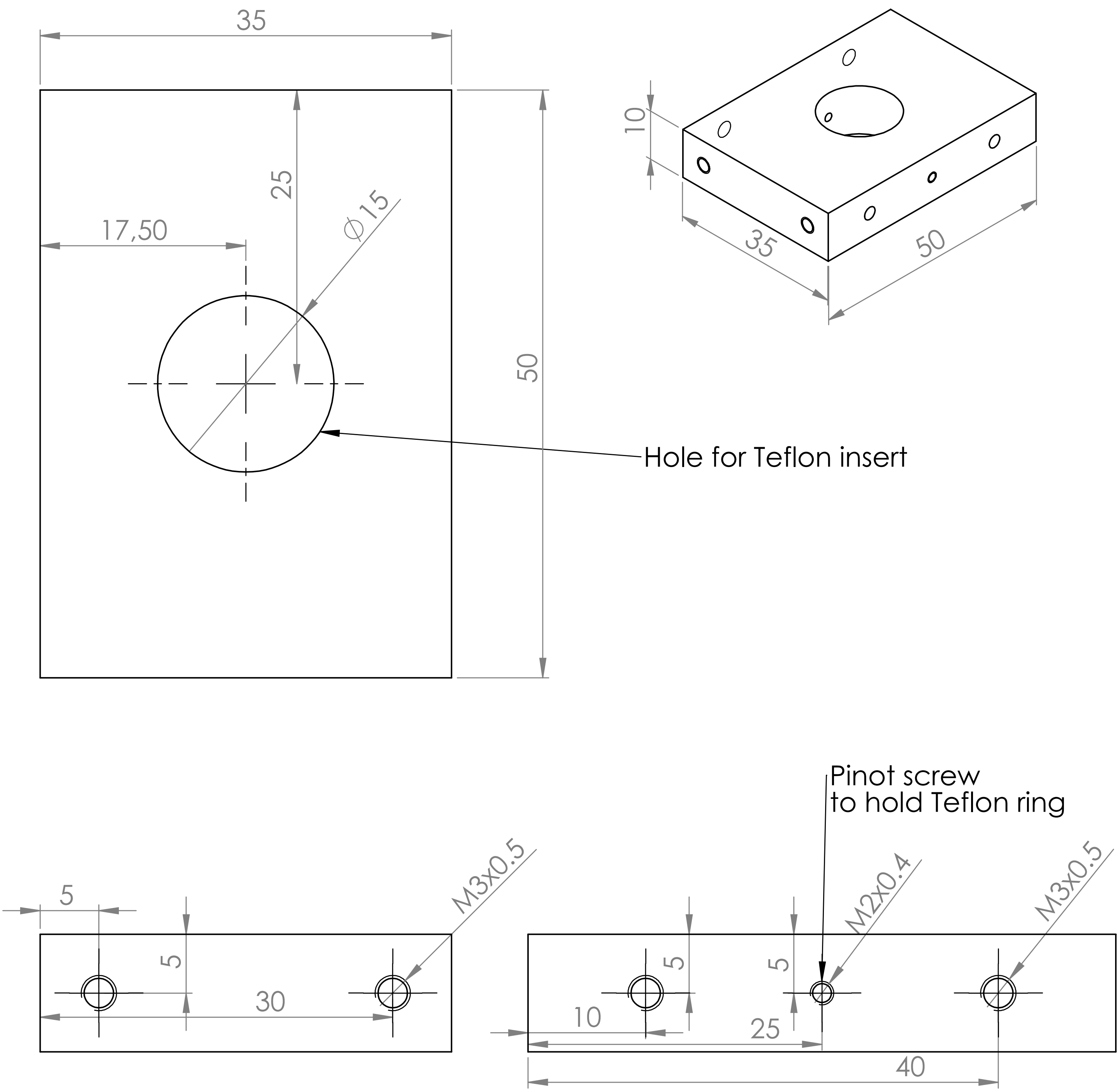
winch-side-plate-motor

A4

WEIGHT:

SCALE:1:2

SHEET 4 OF 4



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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

MATERIAL:

WEIGHT:

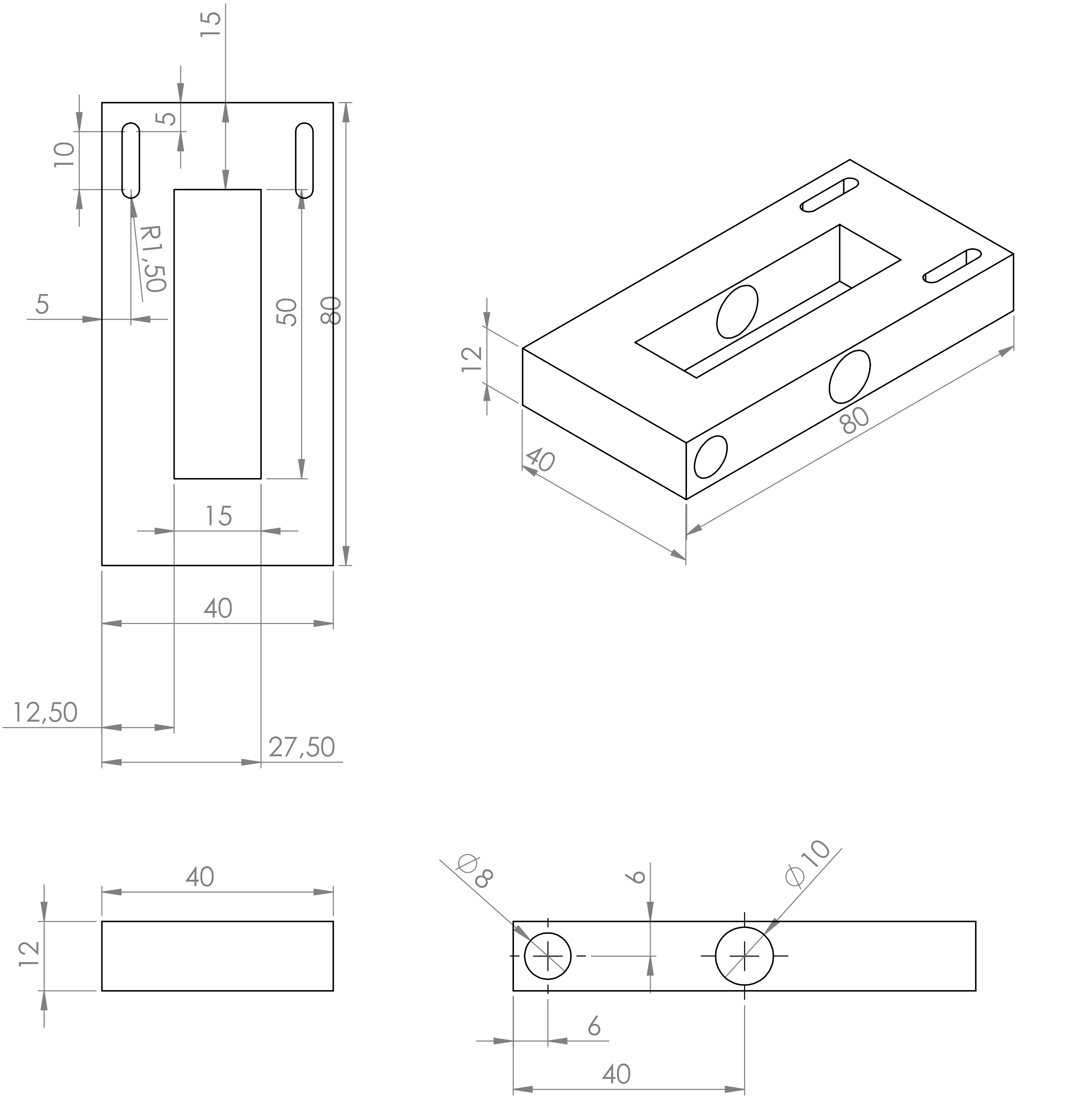
TITLE:

DWG NO. tension-fitting

A4

SCALE:1:1

SHEET 1 OF 1



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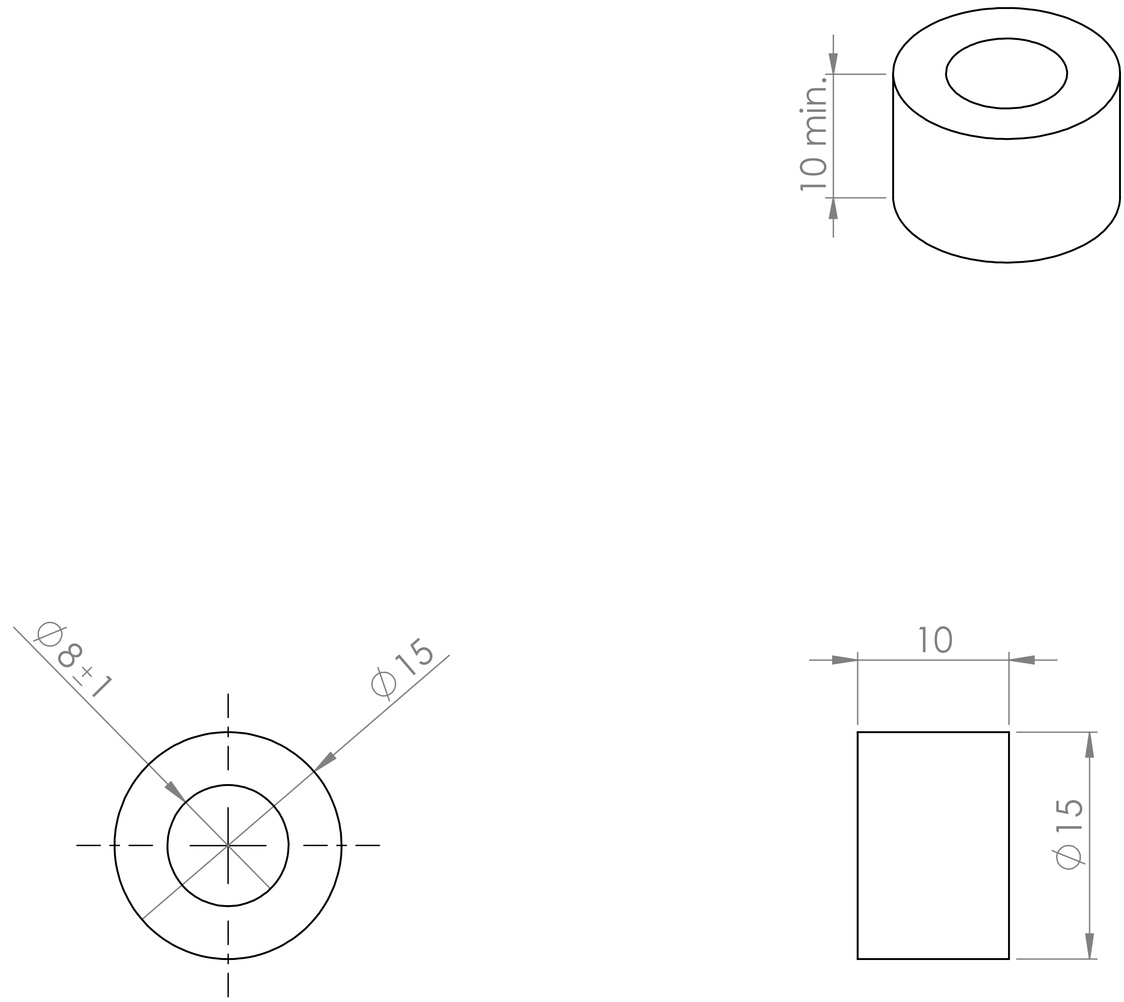
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL:	DWG NO. axis-holder	A4
			WEIGHT:	SCALE:1:2	SHEET 1 OF 1



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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

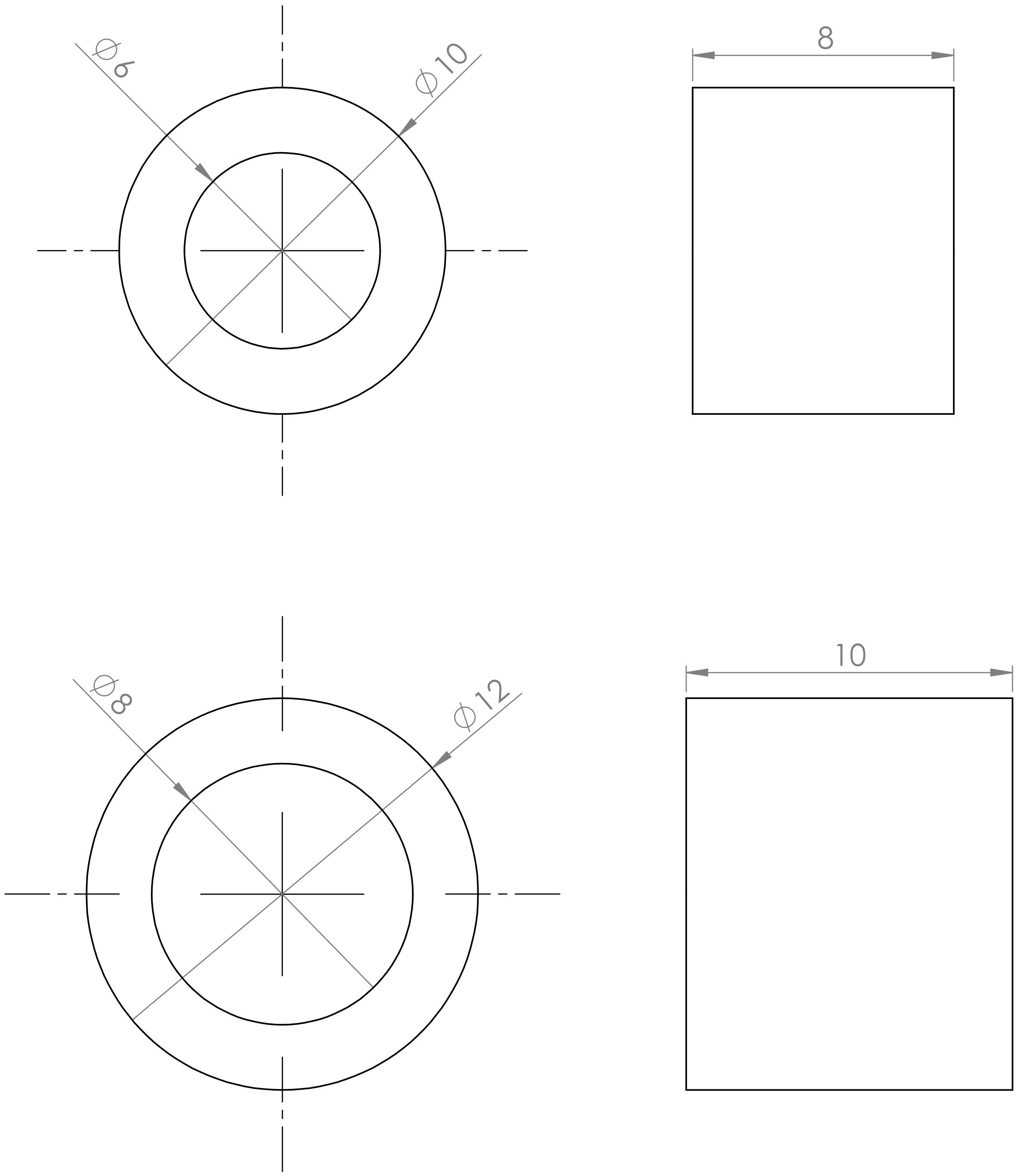
TITLE:

DWG NO. teflon-ring

A4

SCALE:2:1

SHEET 1 OF 1



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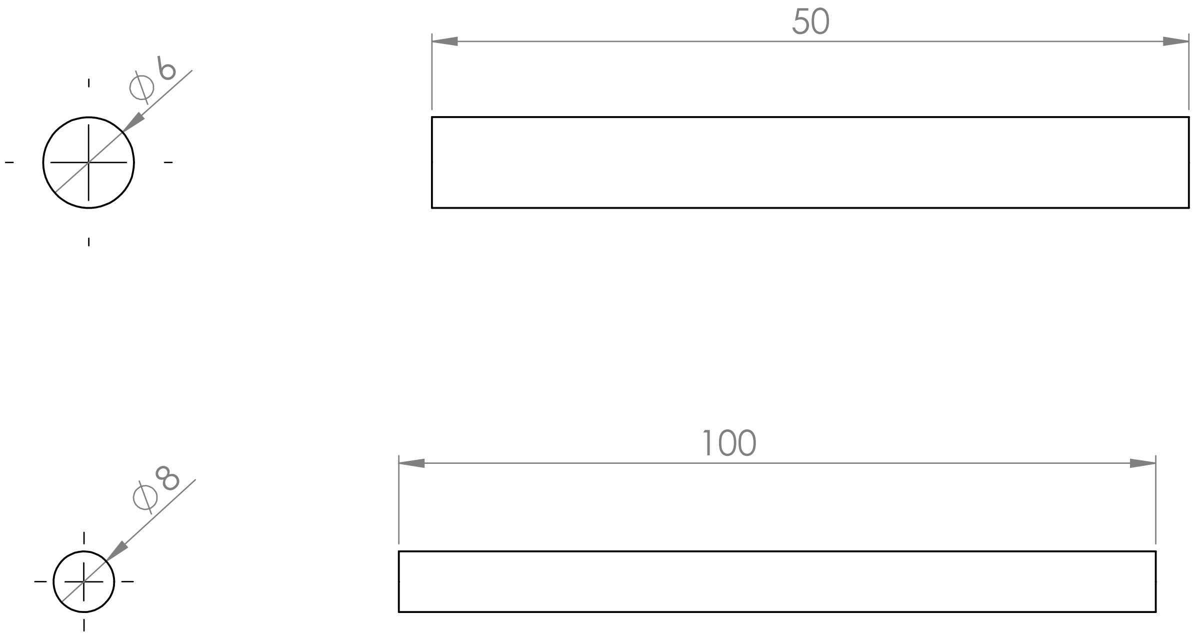
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Brass	DWG NO. brass-bearings	A4
			WEIGHT:	SCALE:5:1	SHEET 1 OF 1

Smooth rods



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH: Polished

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

TITLE:

MATERIAL: Carbon Steel

WEIGHT:

DWG NO. smooth-rods

A4

SCALE:2:1

SHEET 1 OF 1

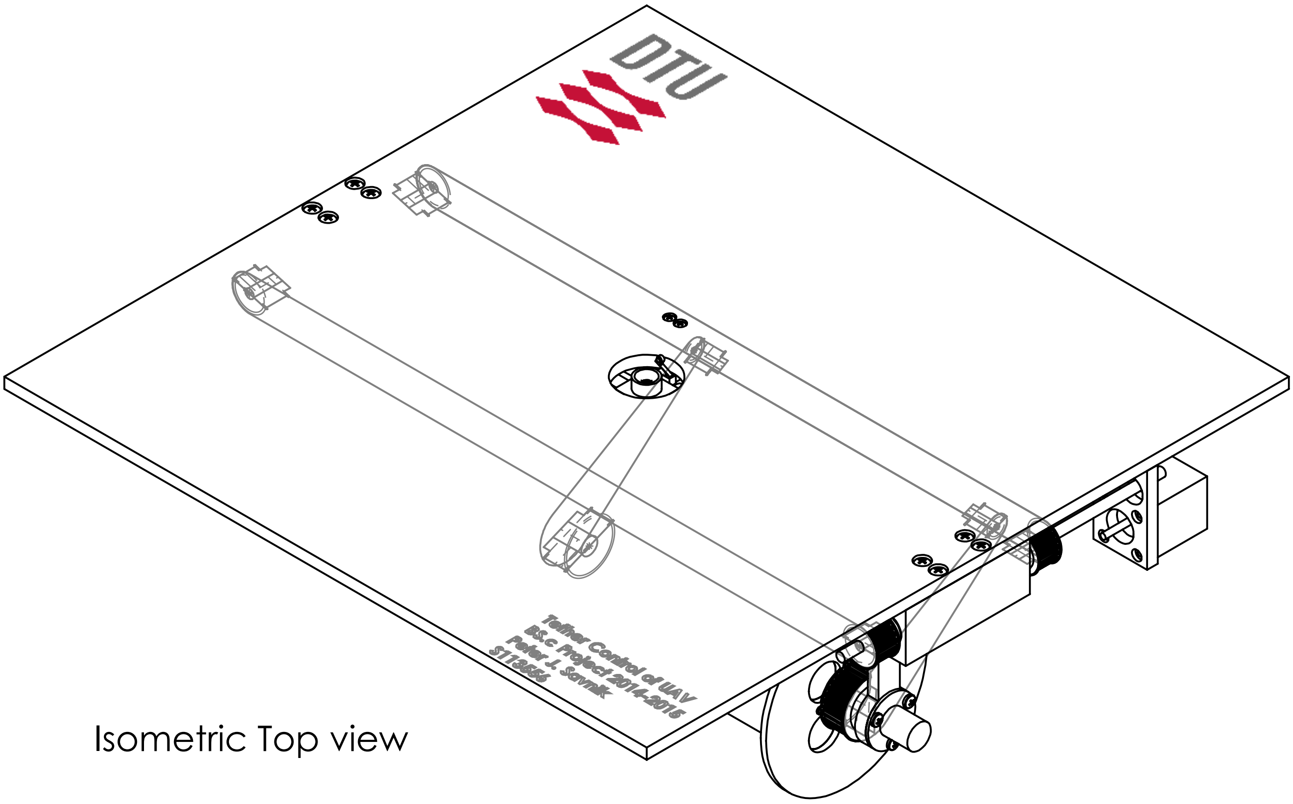
The Cable Drum

The Cable Drum is the most developed and complex prototype of the two winching methods. It has 3 motors, 2 to turn the drum around and 1 to move the carrier from side to side. Again it is very much inspired of open source 3d printers[1]. Every thing can be mounted to the bottom of the helipad.

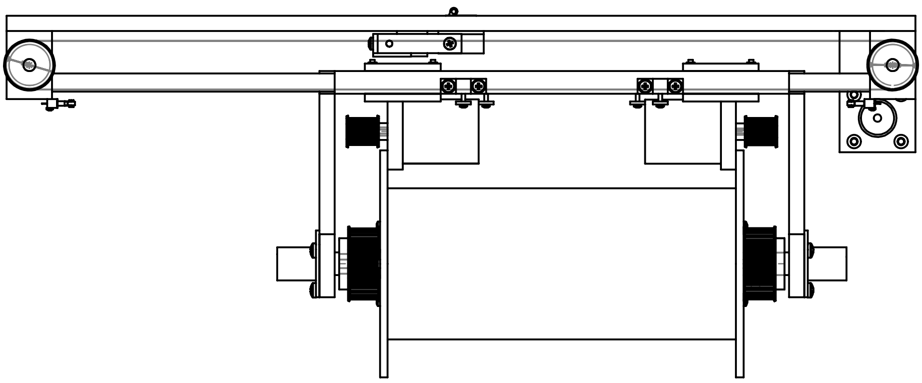
The power is connected to the drum through 2 slips rings. The slip rings can't carry any payload since they are made of thin plastic.

The drum has 4 big holes in the vertical direction to help passive heat dissipation from the cable.

[1]Reprep open source 3d printers, www.reprap.org.

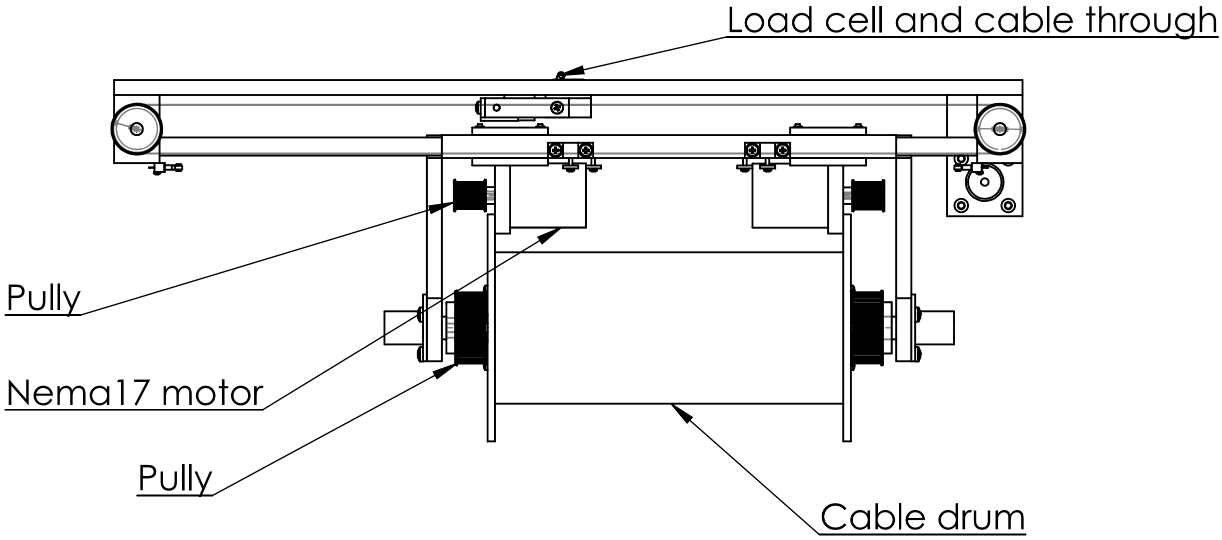


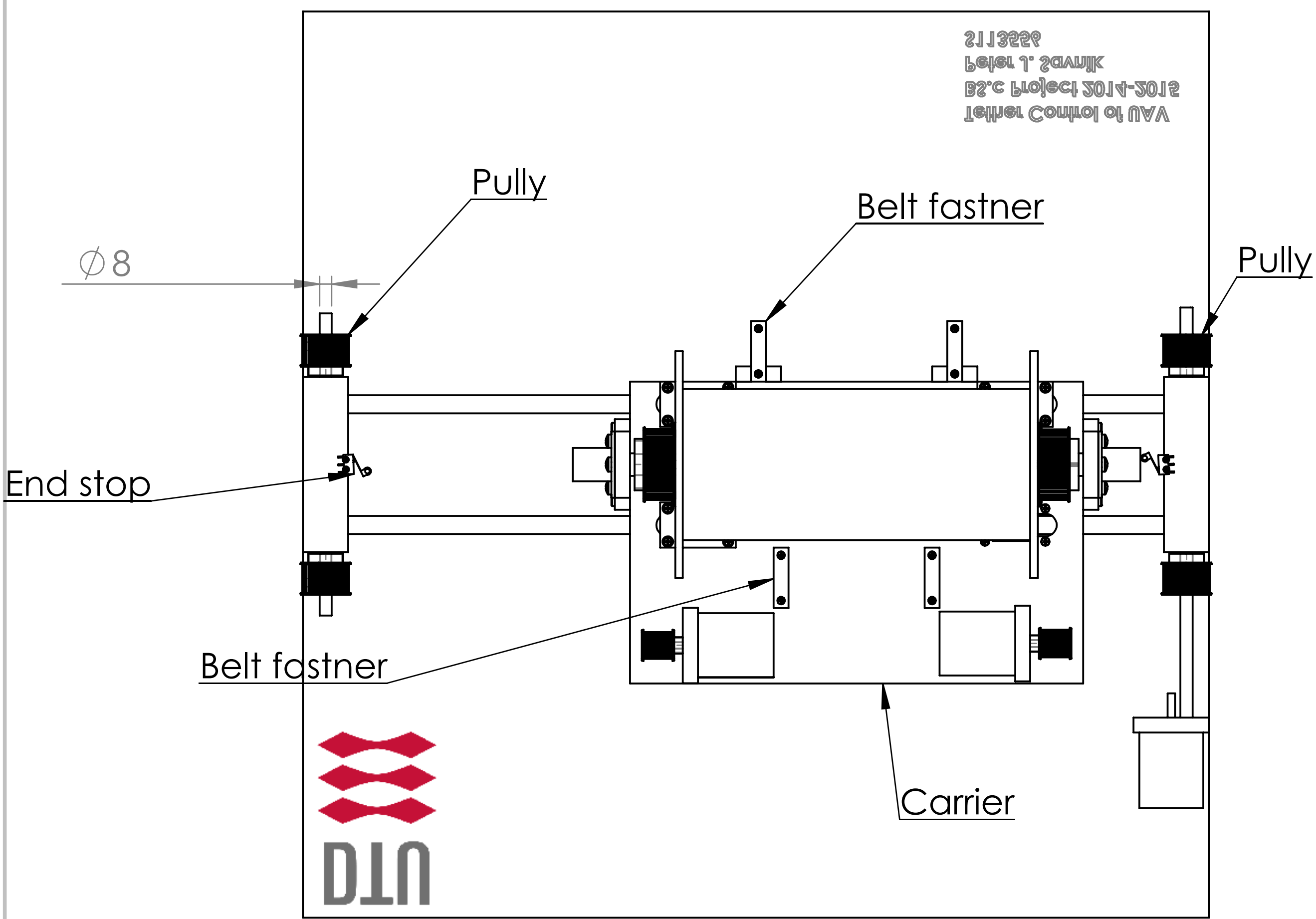
Isometric Top view



Front view

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:				DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO. main_assembly	A4
				WEIGHT:		SCALE:1:20	SHEET 1 OF 4





Bottom view

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

TITLE:

DWG NO.

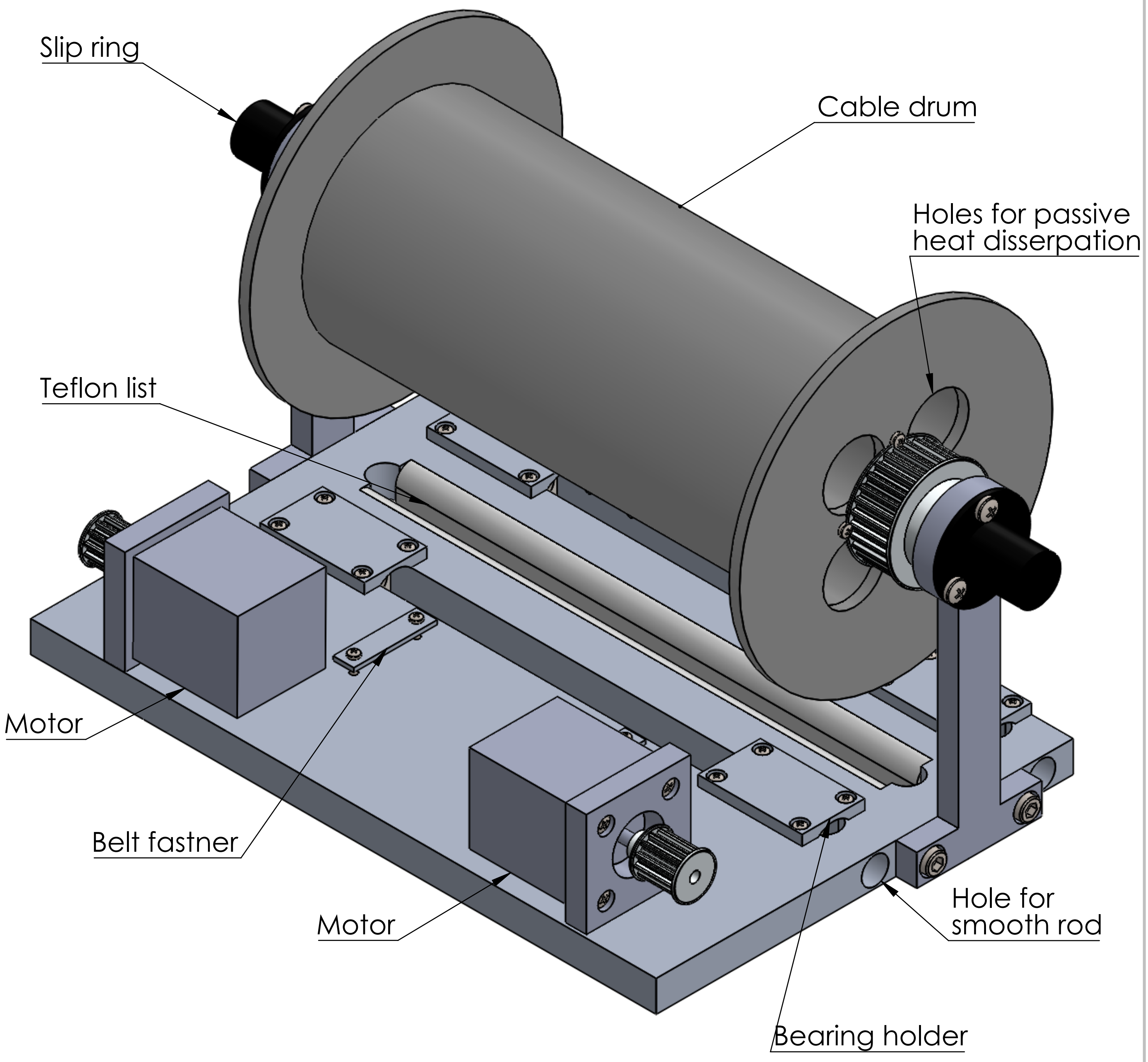
main_assembly

A4

WEIGHT:

SCALE:1:20

SHEET 2 OF 4



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 3

Peter J. Savnik

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

TITLE:

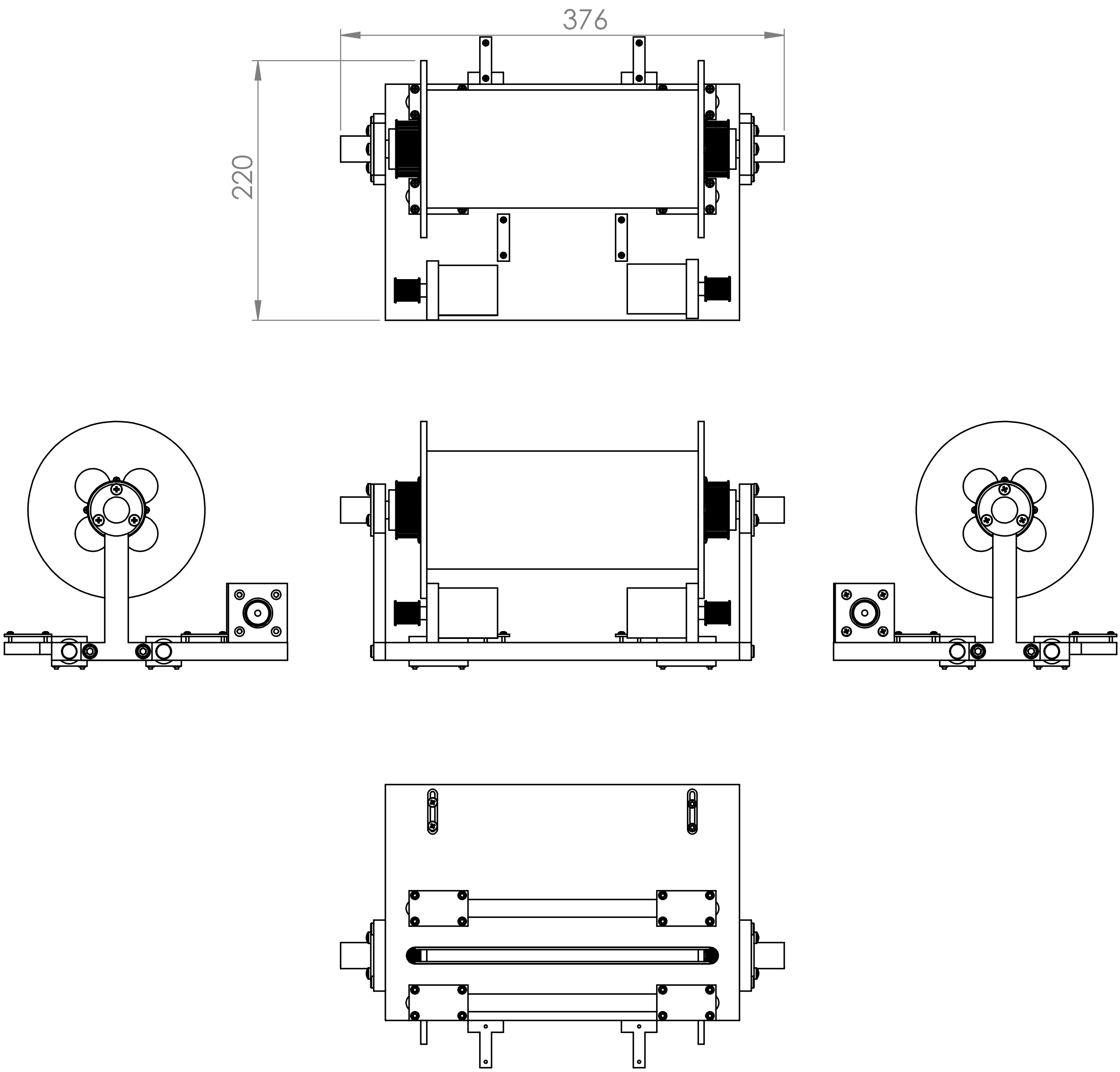
DWG NO. drum-carrier-assembly

A4

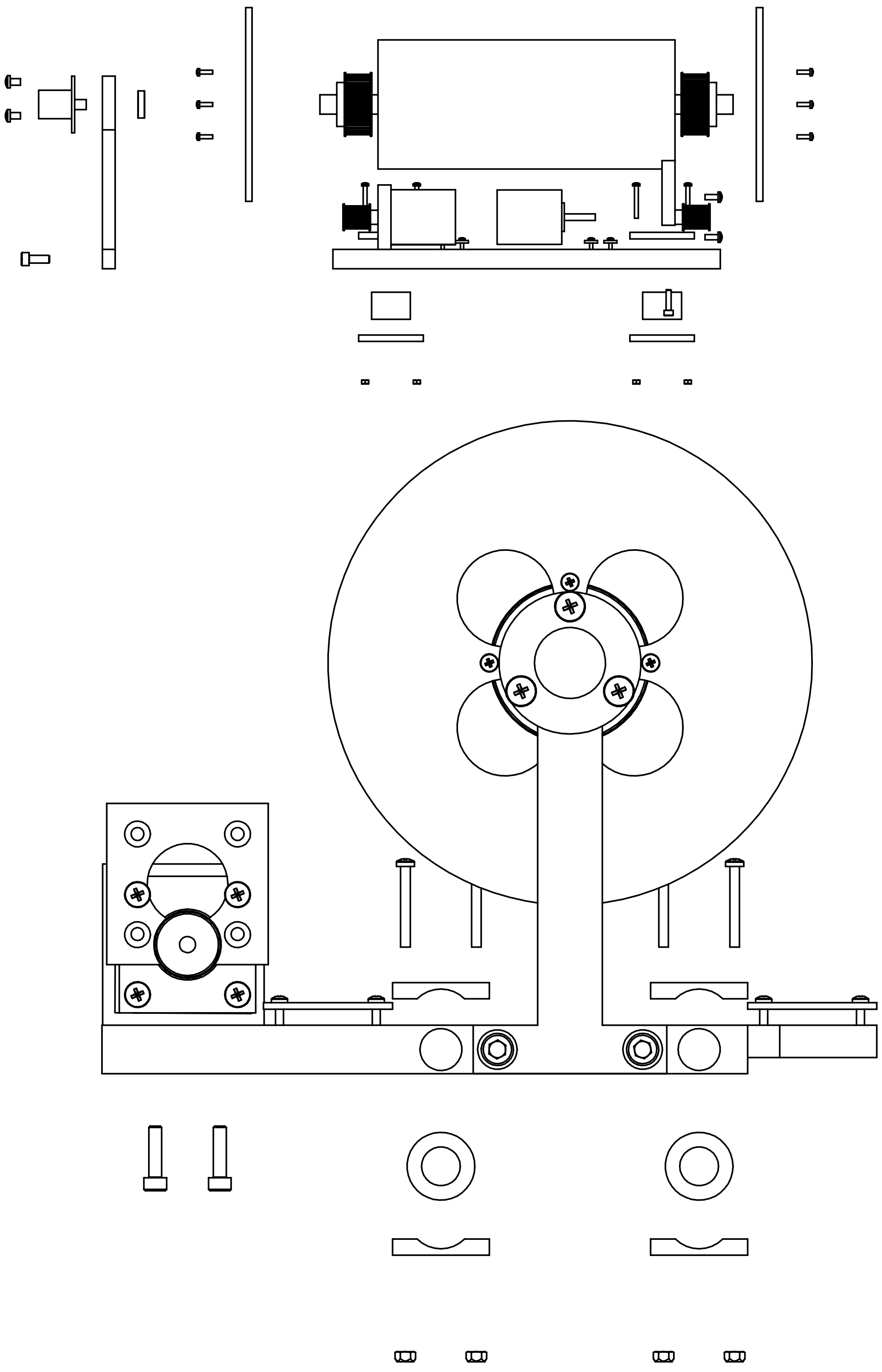
WEIGHT:

SCALE:1:10

SHEET 1 OF 10

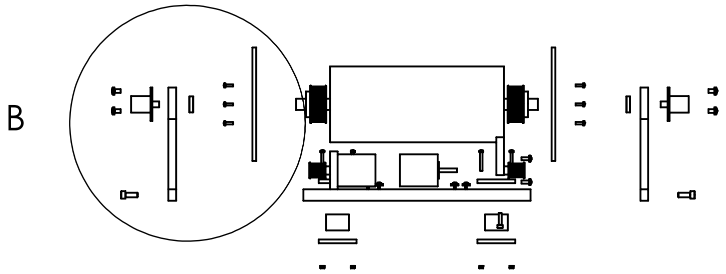


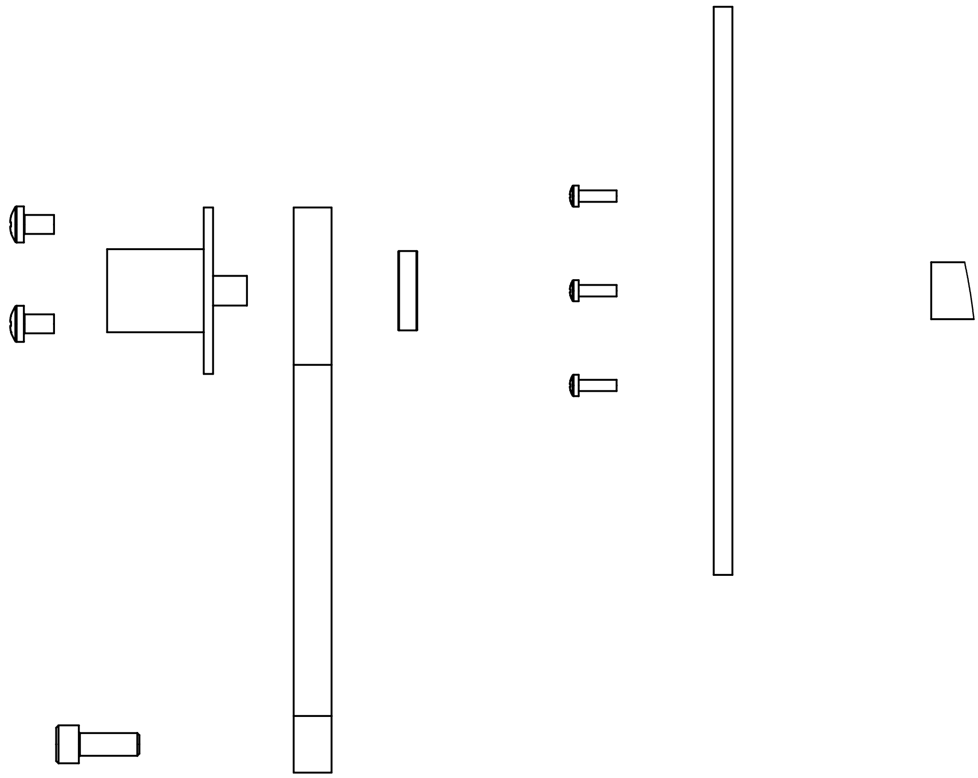
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	Peter J. Savnik					
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL:		DWG NO. drum-carrier-assembly	A4
			WEIGHT:		SCALE:1:10	SHEET 2 OF 10



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE		TITLE:
DRAWN	Peter J. Savnik				
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	DWG NO. drum-carrier-assembly
					A4
				WEIGHT:	SCALE:1:10
					SHEET 3 OF 10





DETAIL B
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

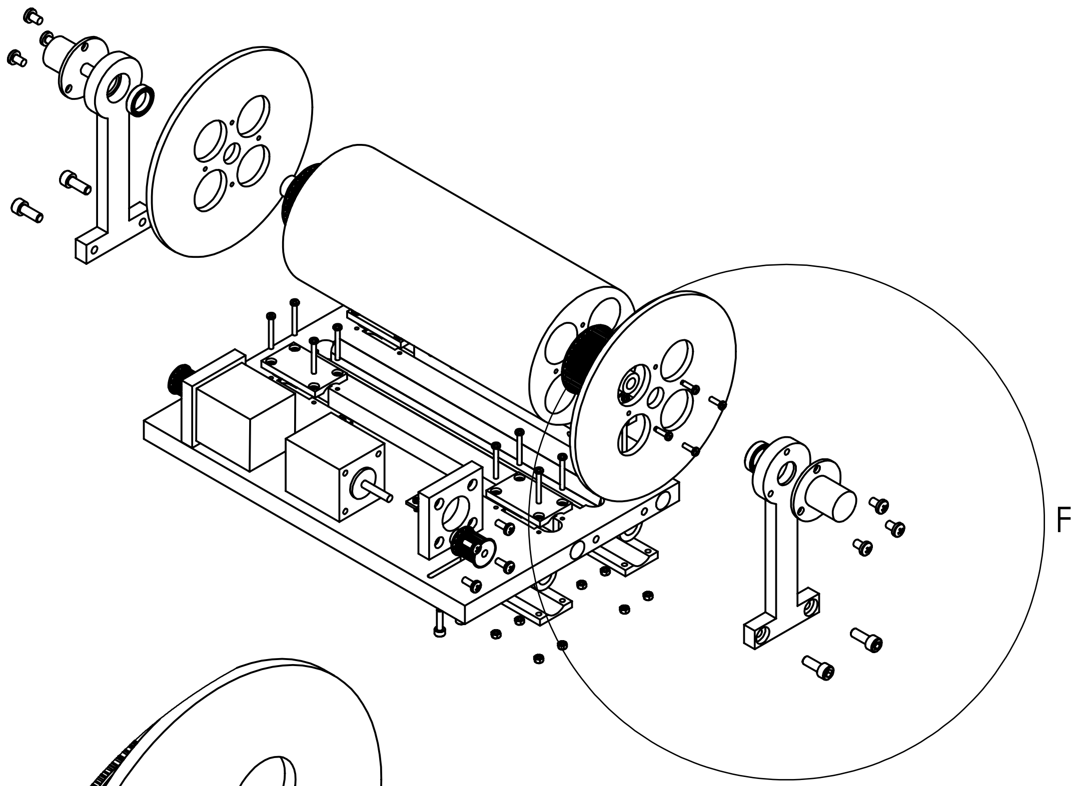
DWG NO.
drum-carrier-assembly

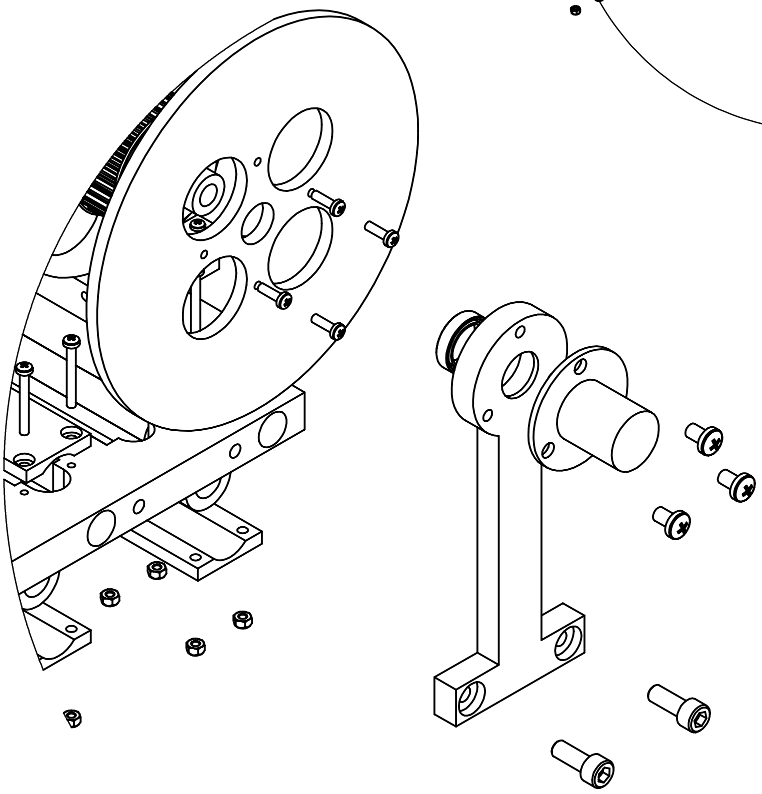
A4

WEIGHT:

SCALE:1:10

SHEET 4 OF 10

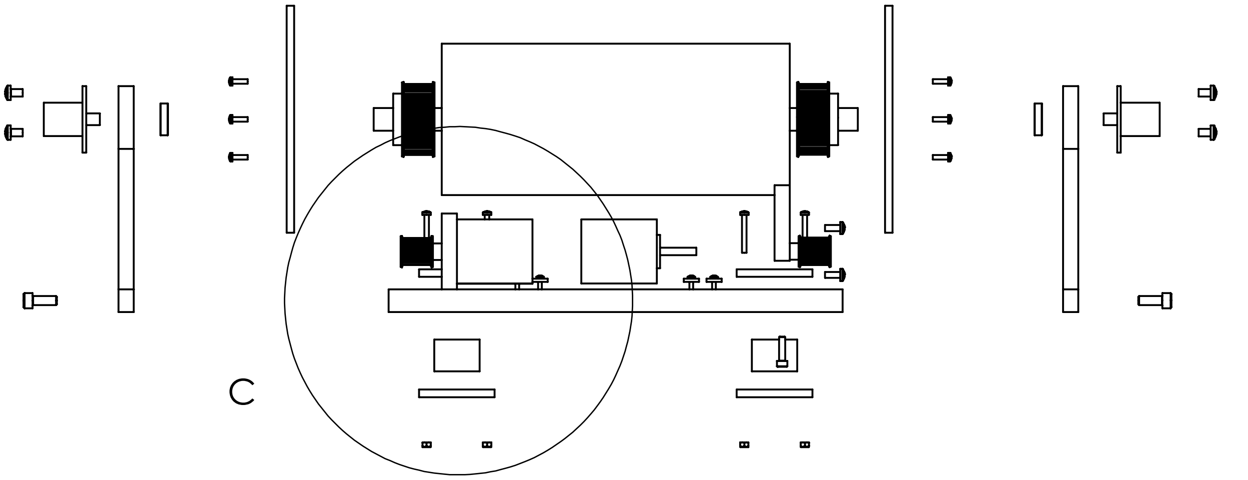


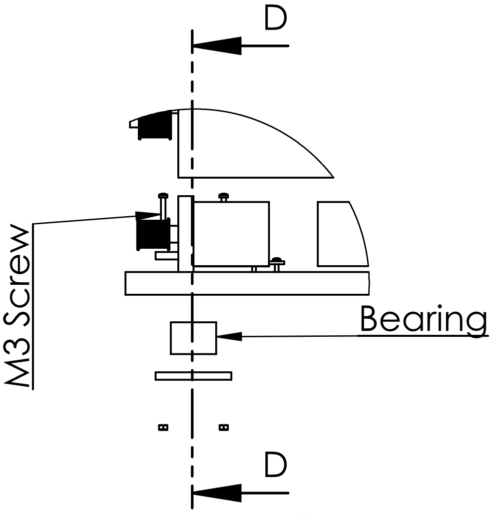


DETAIL F
SCALE 2 : 5

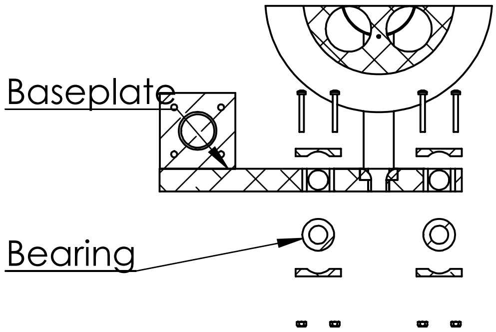
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE		TITLE:
DRAWN	Peter J. Savnik				
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	DWG NO. drum-carrier-assembly A4
				WEIGHT:	SCALE:1:10 SHEET 5 OF 10





DETAIL C
SCALE 1 : 5



SECTION D-D

SCALE 1 : 5

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

Bearing assembly

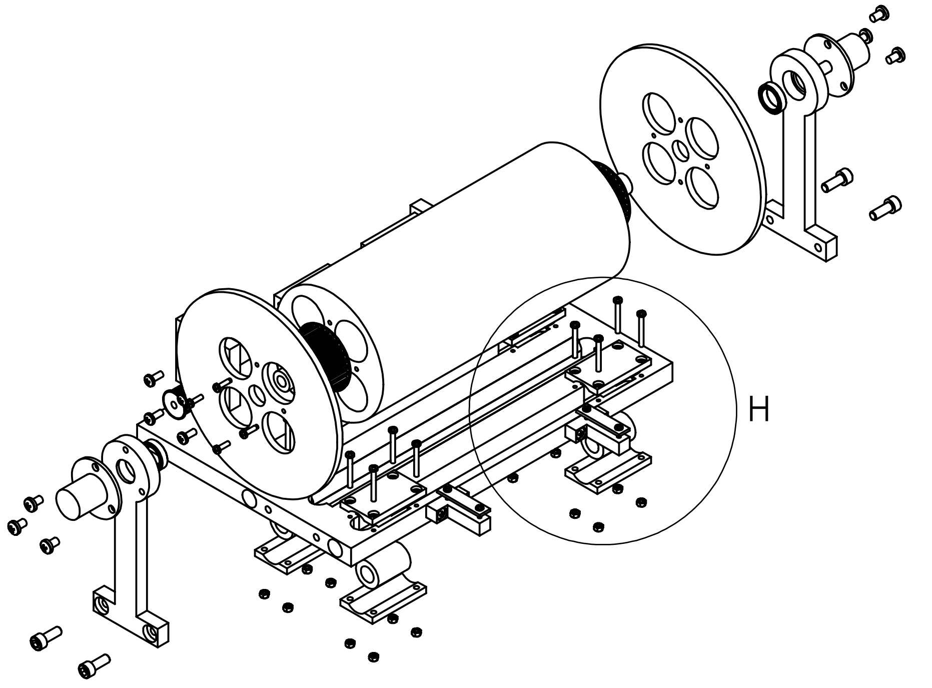
DWG NO.

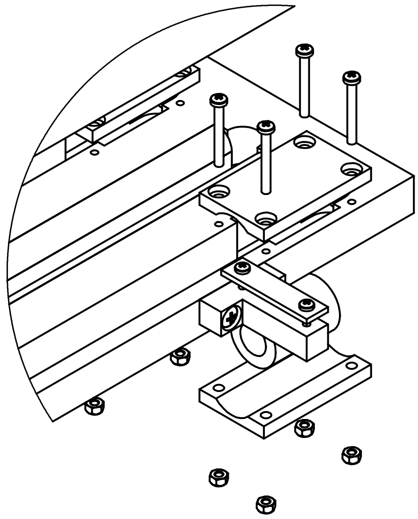
drum-carrier-assembly

A4

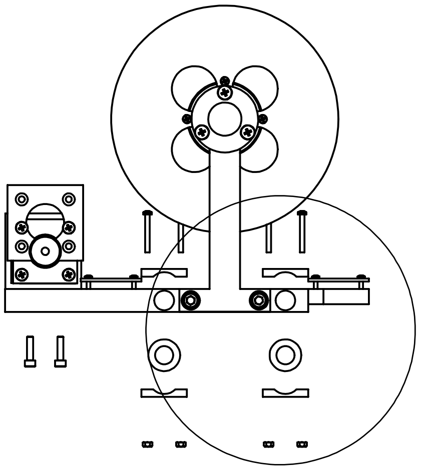
SCALE:1:10

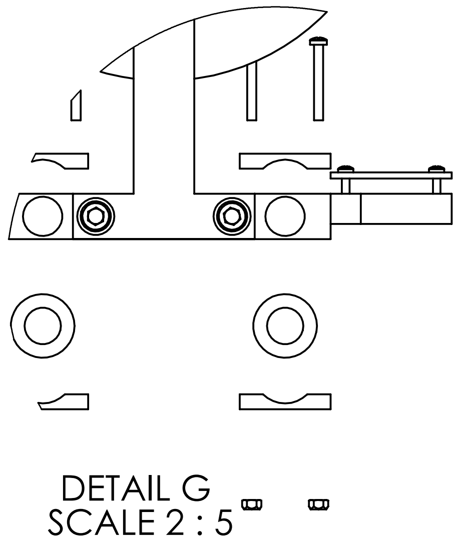
SHEET 6 OF 10





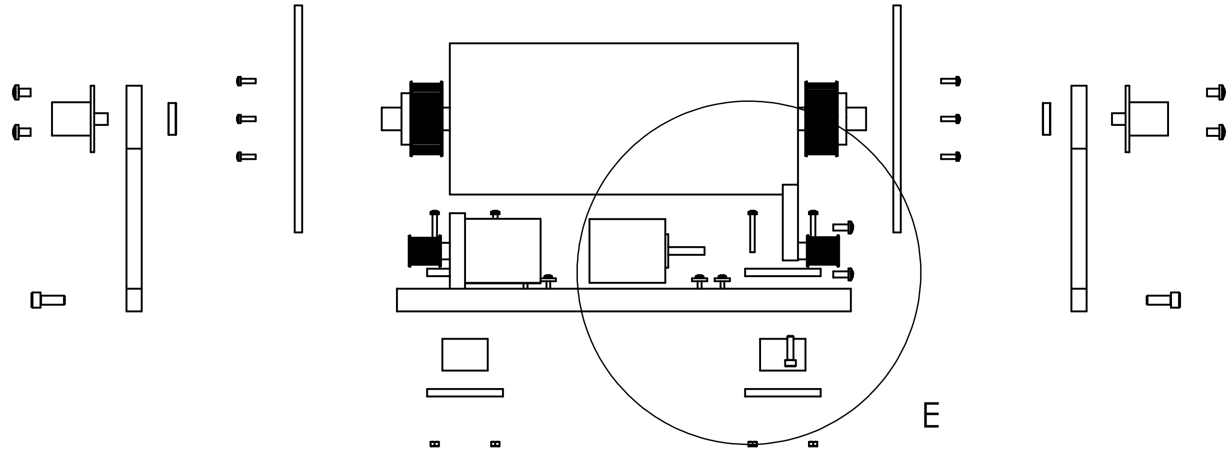
DETAIL H
SCALE 2 : 5

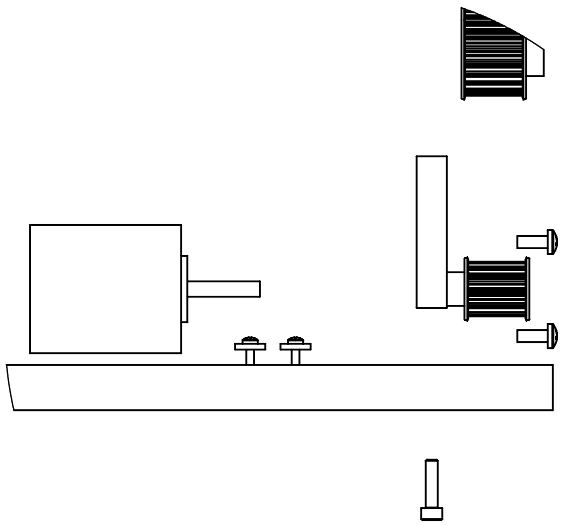




DETAIL G
SCALE 2 : 5

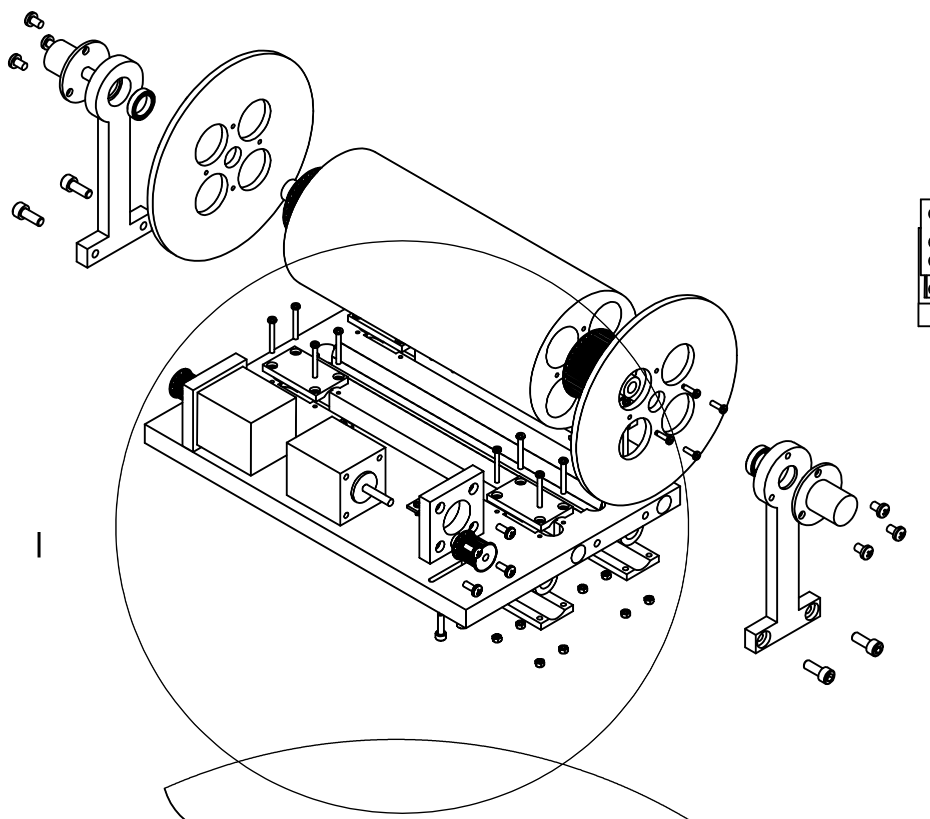
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	Peter J. Savnik					
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL:		DWG NO. drum-carrier-assembly	A4
			WEIGHT:		SCALE:1:10	SHEET 7 OF 10

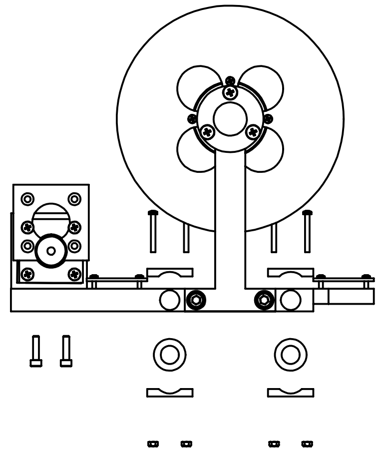


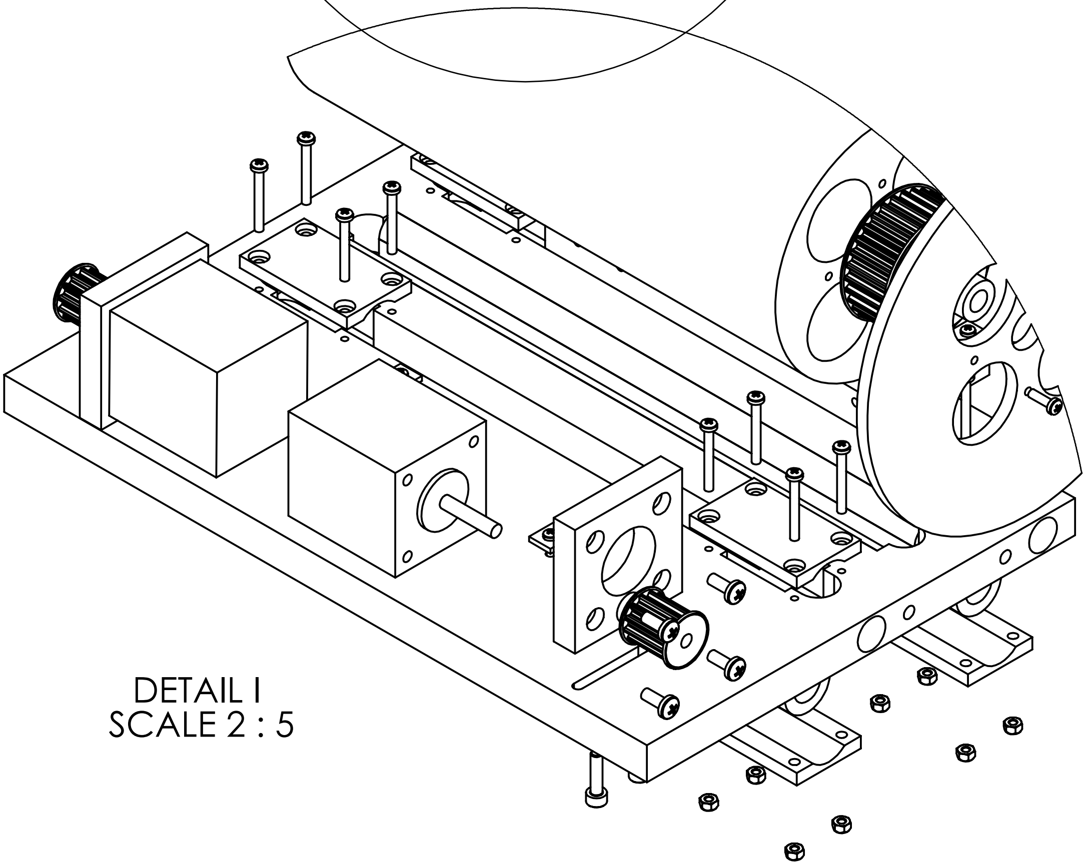


DETAIL E
SCALE 2 : 5

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:				DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION
	NAME	SIGNATURE	DATE			TITLE:
DRAWN	Peter J. Savnik					Motor assembly
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:		DWG NO. drum-carrier-assembly A4
				WEIGHT:		SCALE:1:10 / SHEET 8 OF 10







DETAIL I
SCALE 2 : 5

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

DWG NO.
drum-carrier-assembly

A4

SCALE:1:10

SHEET 9 OF 10

ITEM NO.	PART NUMBER	Default/ QTY.
1	baseplate	1
2	teflon-insert-2	2
3	end	2
4	B18.3.1M - 6 x 1.0 x 16 Hex SHCS -- 16NHX	4
5	B18.3.1M - 4 x 0.7 x 16 Hex SHCS -- 16NHX	2
6	AFBMA 12.1.4.1 - 0150-21 - Full,DE,NC,Full_68	2
7	rod	1
8	side	2
9	B18.6.7M - M3 x 0.5 x 10 Type I Cross Recessed PHMS --10N	8
10	B18.6.7M - M5 x 0.8 x 8 Type I Cross Recessed PHMS --8N	3
11	B18.6.7M - M4 x 0.7 x 10 Type I Cross Recessed PHMS --10N	4
12	B18.6.7M - M3 x 0.5 x 25 Type I Cross Recessed PHMS --25N	16
13	slip_ring_with_flange	2
14	ISO 7045 - M5 x 8 - Z --- 8N	3
15	motor-holder	2
16	Nema17motor	2
17	LM12UU	4
18	LM12UU-holder	8
19	AM-M3-N	16
20	teflon-insert	2
21	Pulley-27T5_30-2-Aratron	2
22	Pulley-27T5_12-2-Aratron	2
23	B18.6.7M - M4 x 0.7 x 25 Type I Cross Recessed PHMS --25N	2
24	belt-fastner-bracket	2
25	B18.6.7M - M4 x 0.7 x 13 Type I Cross Recessed PHMS --13N	4
26	belt-fastner-plate	4
27	B18.6.7M - M2.5 x 0.45 x 16 Type I Cross Recessed PHMS --16N	8

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

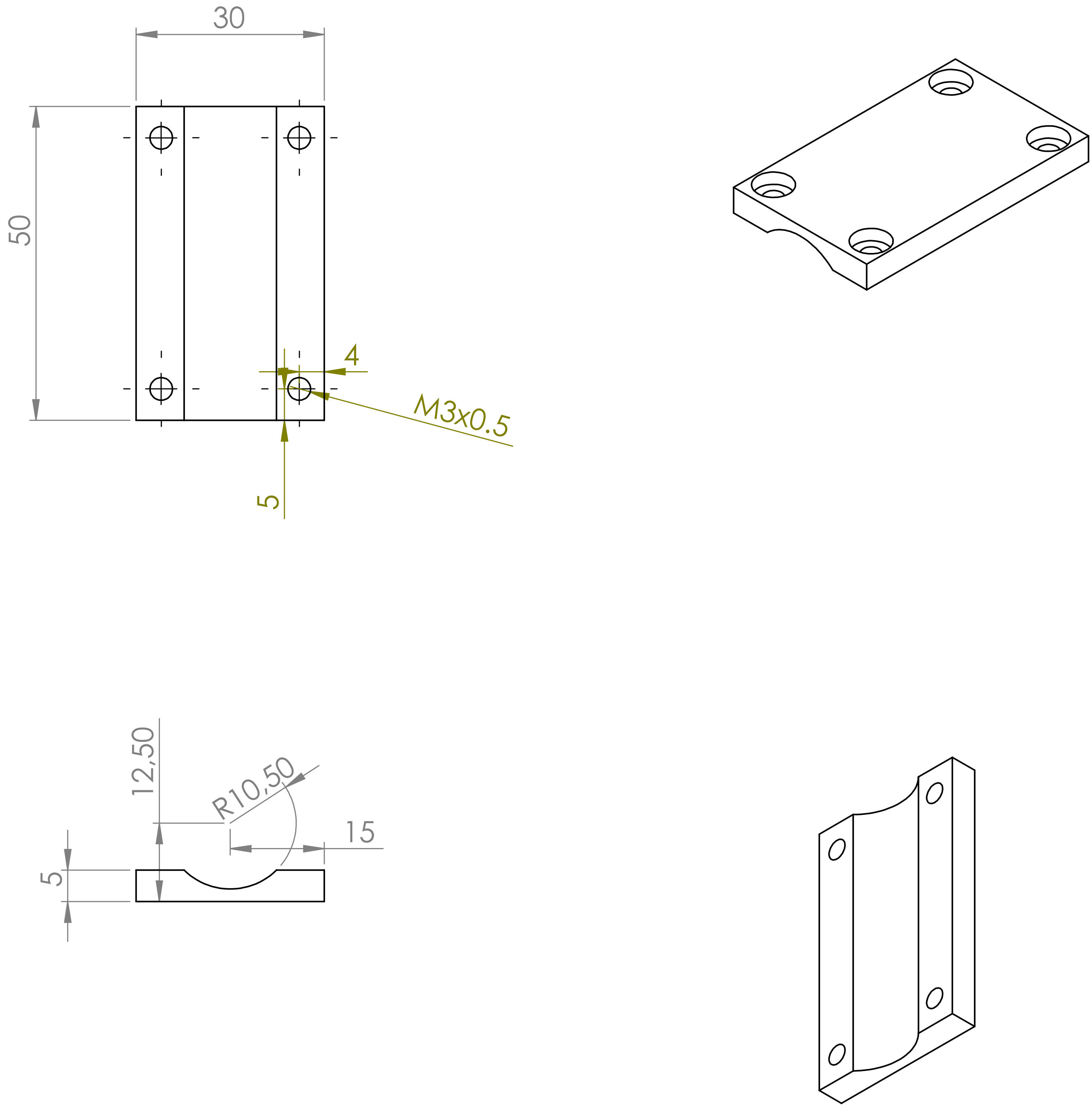
DWG NO. drum-carrier-assembly

A4

WEIGHT:

SCALE:1:10

SHEET 10 OF 10



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION 3

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Alu

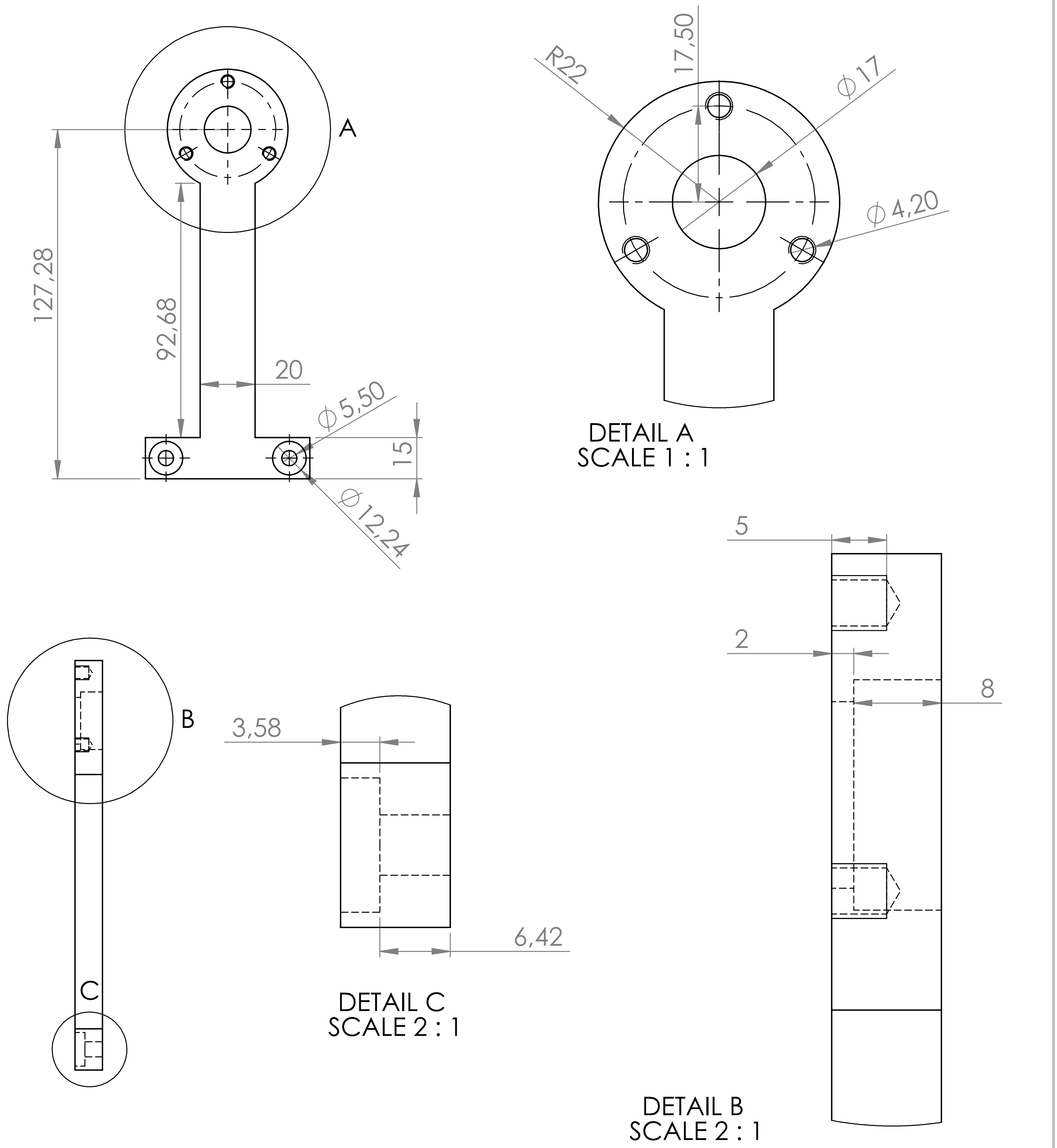
WEIGHT:

DWG NO.
LM12UU-holder

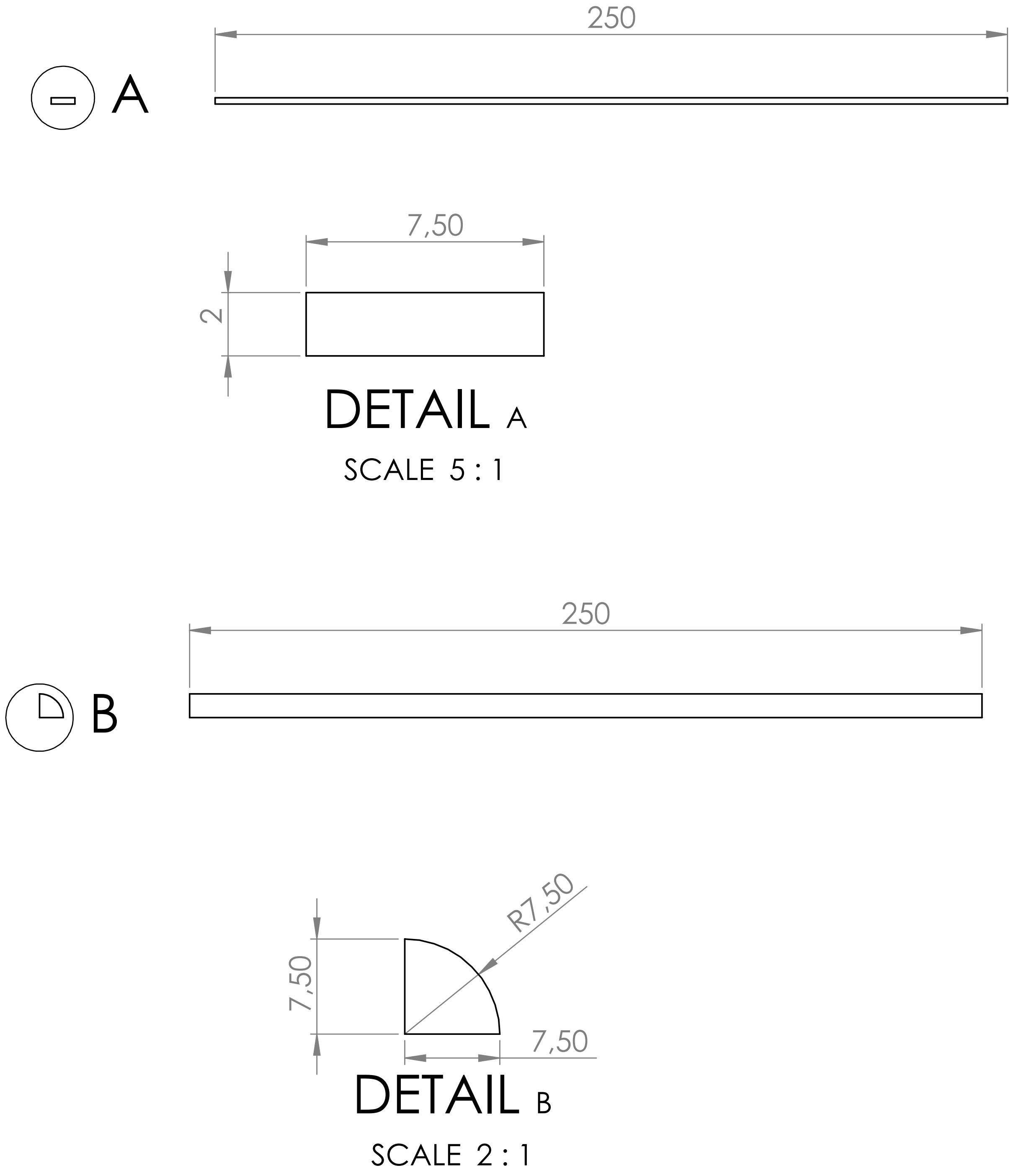
A4

SCALE:1:1

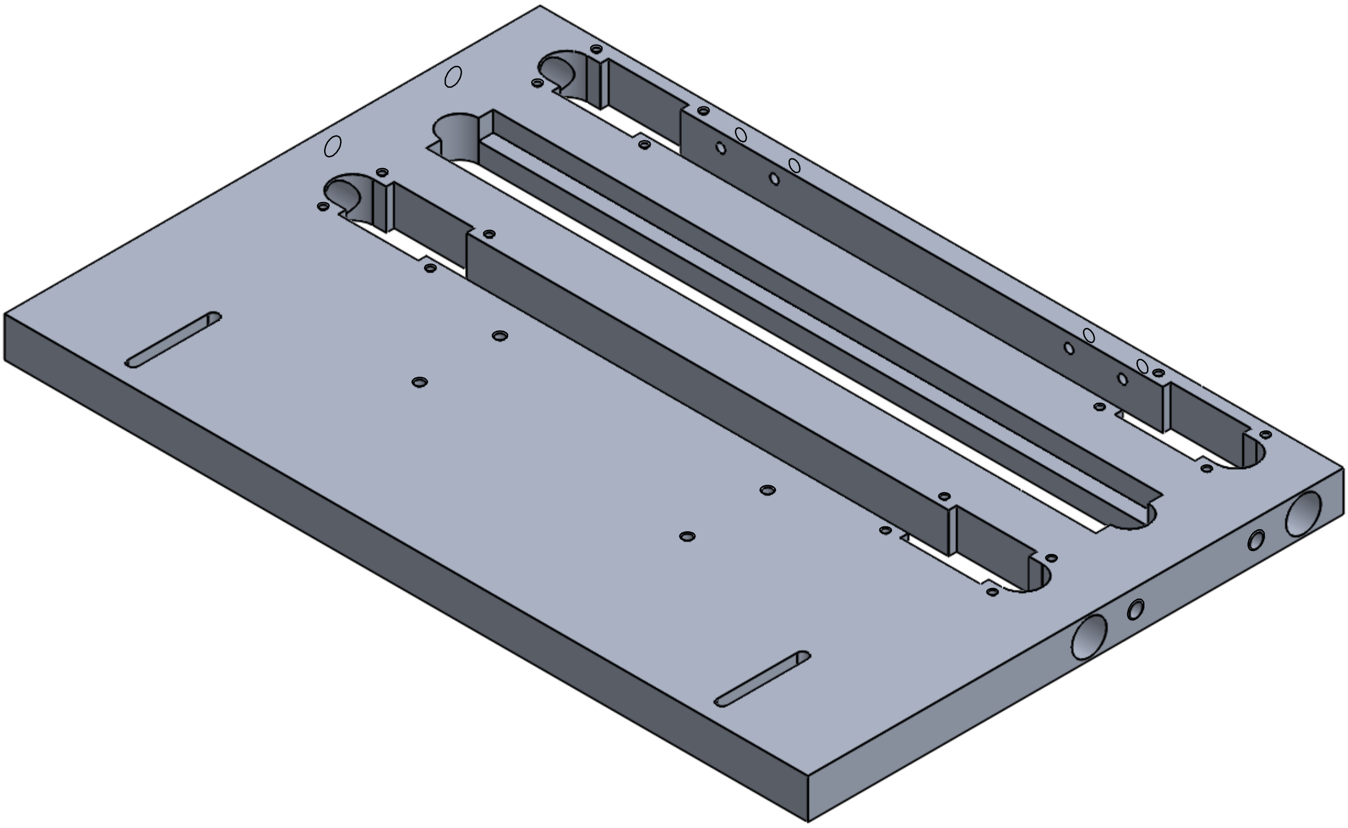
SHEET 1 OF 1

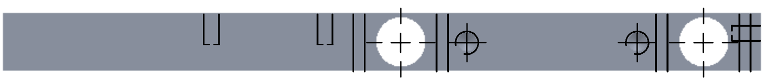


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3
	NAME	SIGNATURE	DATE	TITLE:
DRAWN	Peter J. Savnik			Carrier End, hold drumroll
CHK'D				
APPV'D				
MFG				
Q.A			MATERIAL: Alu	DWG NO. end A4
			WEIGHT:	SCALE:1:2 SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION		
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Teflon	DWG NO. teflon-inserts	A4
				WEIGHT:	SCALE:1:5	SHEET 1 OF 1





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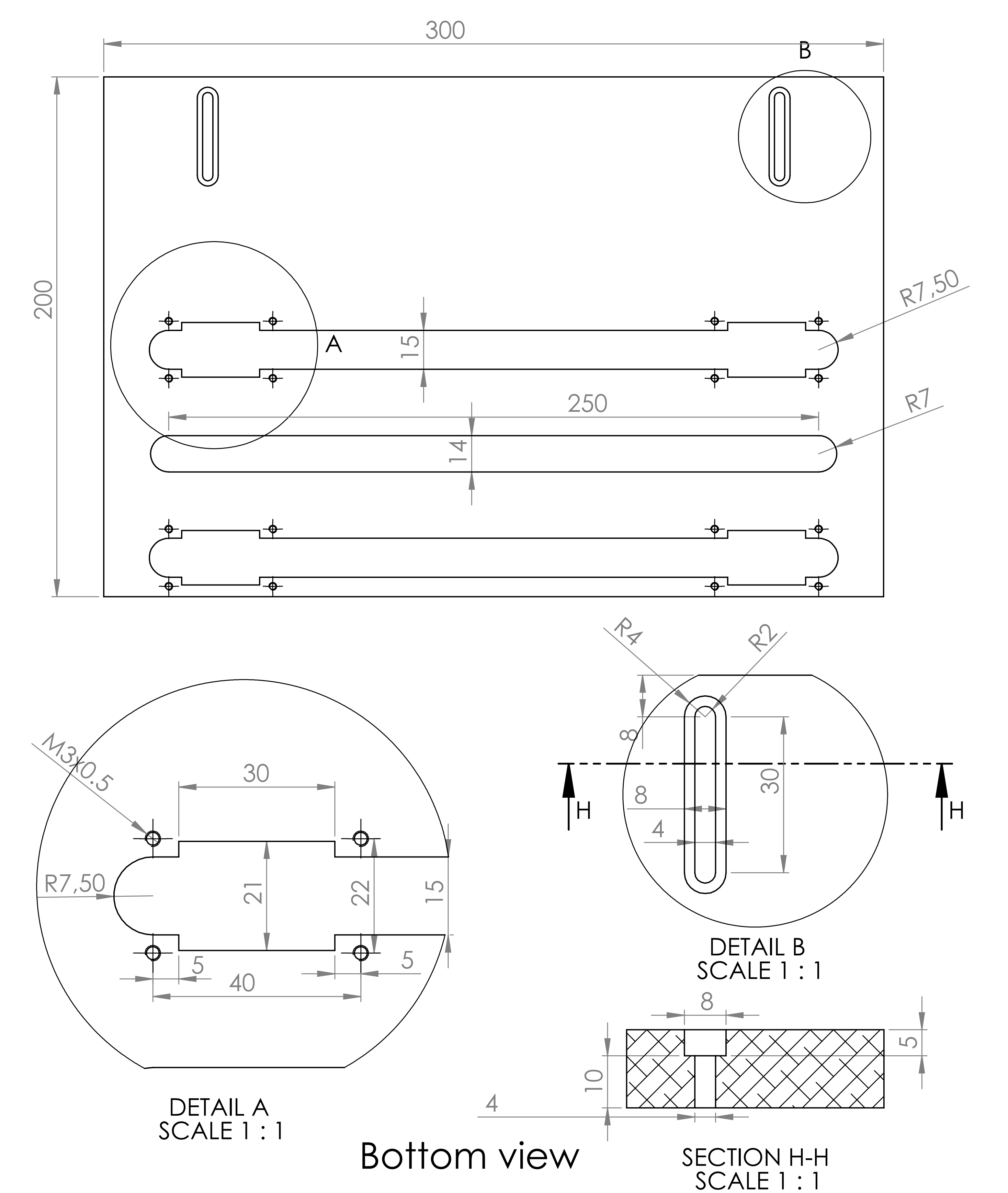
	NAME	SIGNATURE	DATE		TITLE: Baseplate for carrier	
DRAWN	Peter J. Savnik					
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Alu	DWG NO. baseplate	A4
				WEIGHT:	SCALE:1:5	SHEET 1 OF 5



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

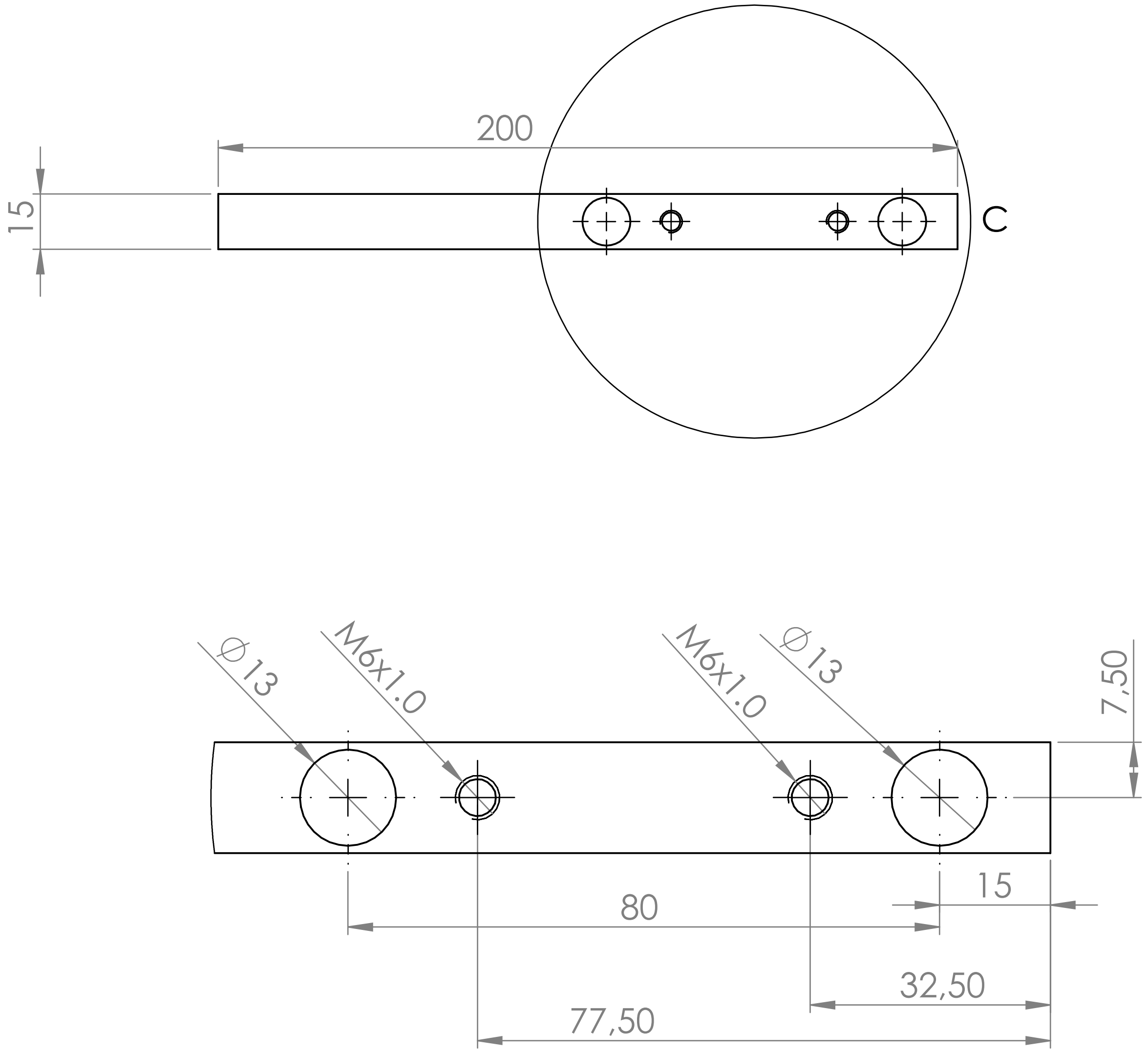
WEIGHT:

DWG NO. baseplate

A4

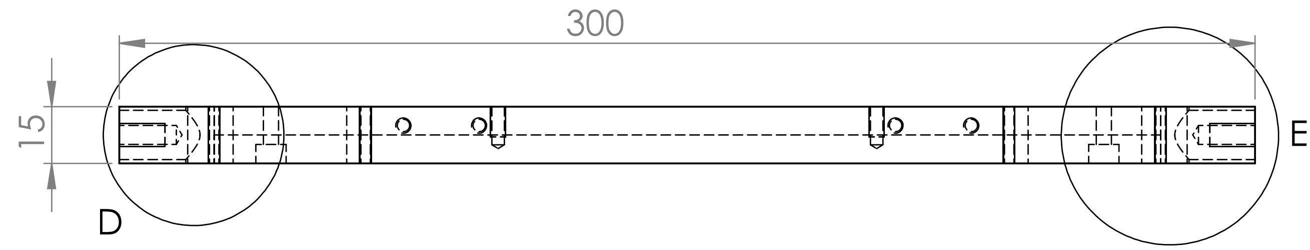
SCALE:1:5

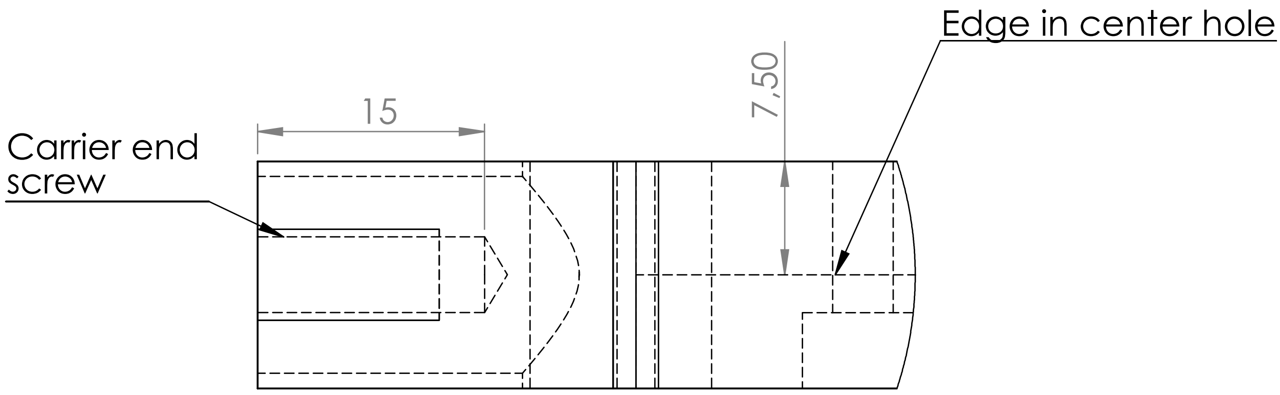
SHEET 2 OF 5



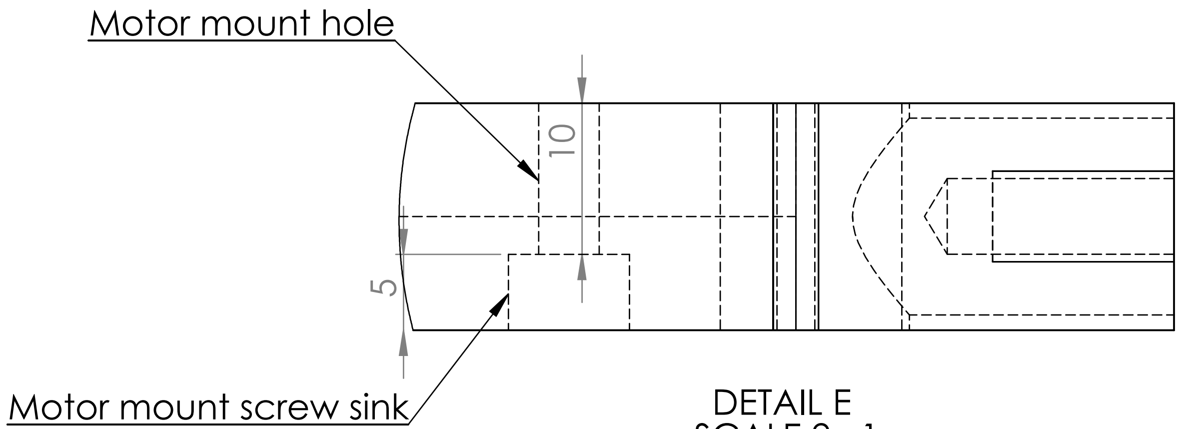
DETAIL C
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3			
	NAME	SIGNATURE	DATE				TITLE:
DRAWN	Peter J. Savnik						
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:			DWG NO. baseplate A4
				WEIGHT:			SCALE:1:5 SHEET 3 OF 5



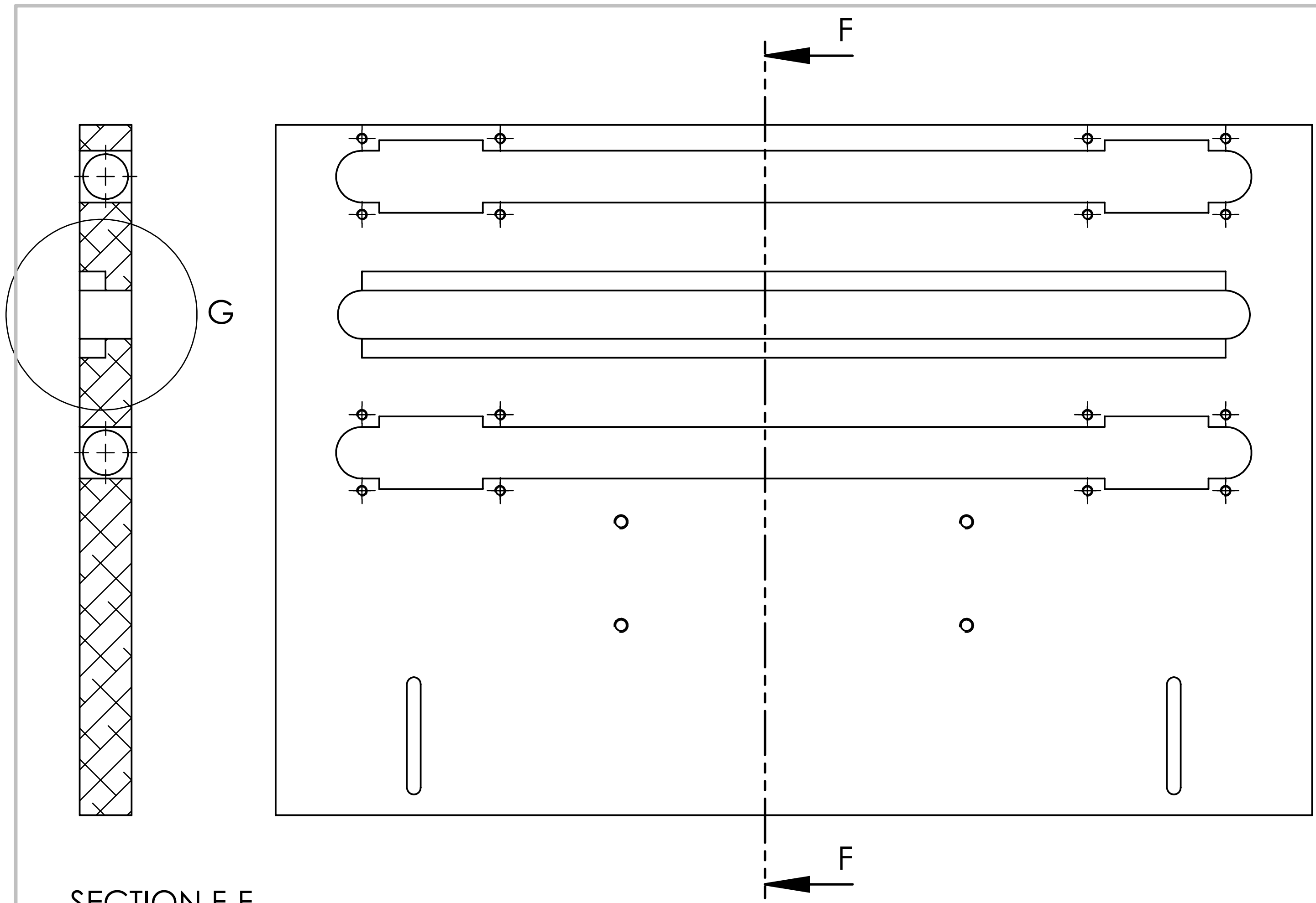


DETAIL D
SCALE 2 : 1

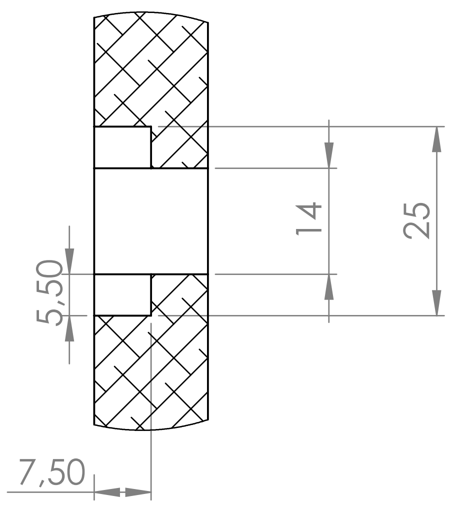


DETAIL E
SCALE 2 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3
	NAME	SIGNATURE	DATE	TITLE:
DRAWN	Peter J. Savnik			
CHK'D				
APPV'D				
MFG				
Q.A			MATERIAL:	DWG NO. baseplate A4
			WEIGHT:	SCALE:1:5 SHEET 4 OF 5



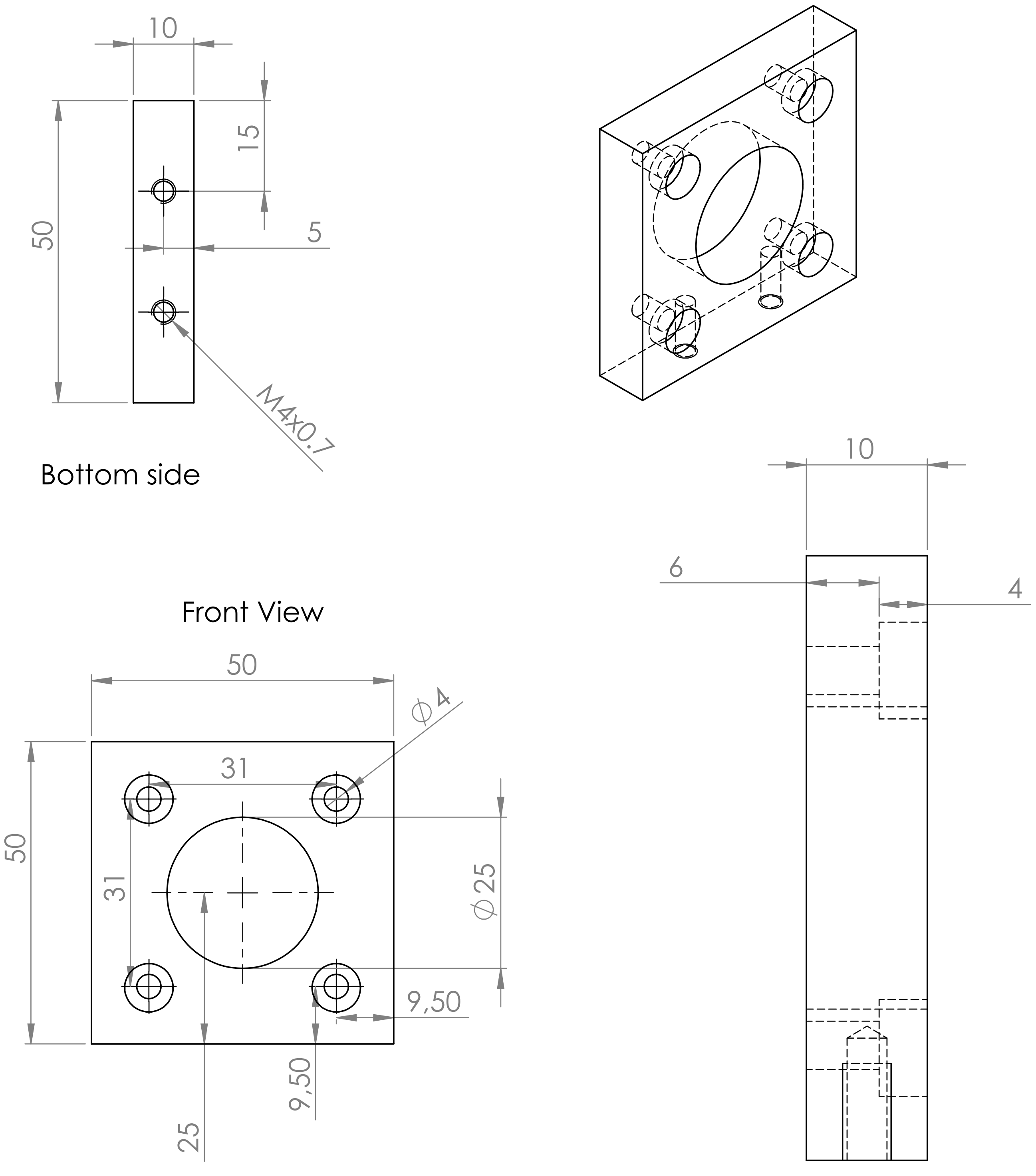
SECTION F-F
SCALE 1 : 2



DETAIL G
SCALE 1 : 1

Center hole

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3			
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Peter J. Savnik						
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO. baseplate	A4
				WEIGHT:		SCALE:1:5	SHEET 5 OF 5



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3.1			
	NAME	SIGNATURE	DATE				
DRAWN	Peter J. Savnik						
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: Alu			
				WEIGHT:			

Motor holder for Nema 17 stepmotor

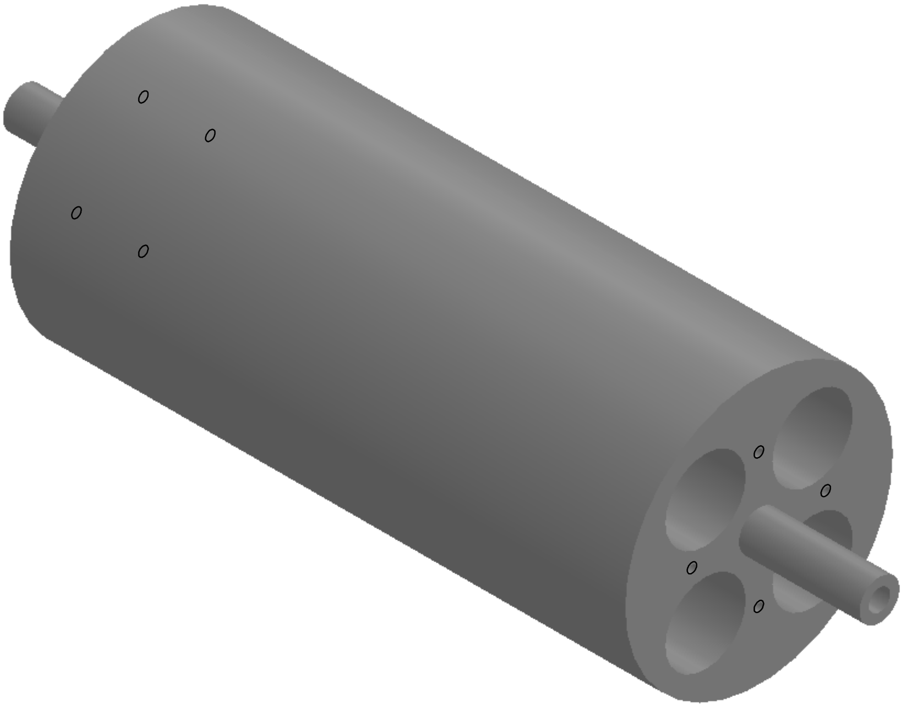
TITLE:

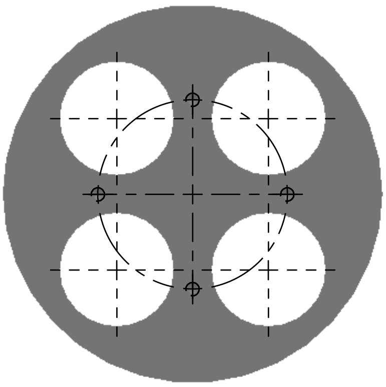
DWG NO. motor-holder

A4

SCALE:1:1

SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 3

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: POM

WEIGHT:

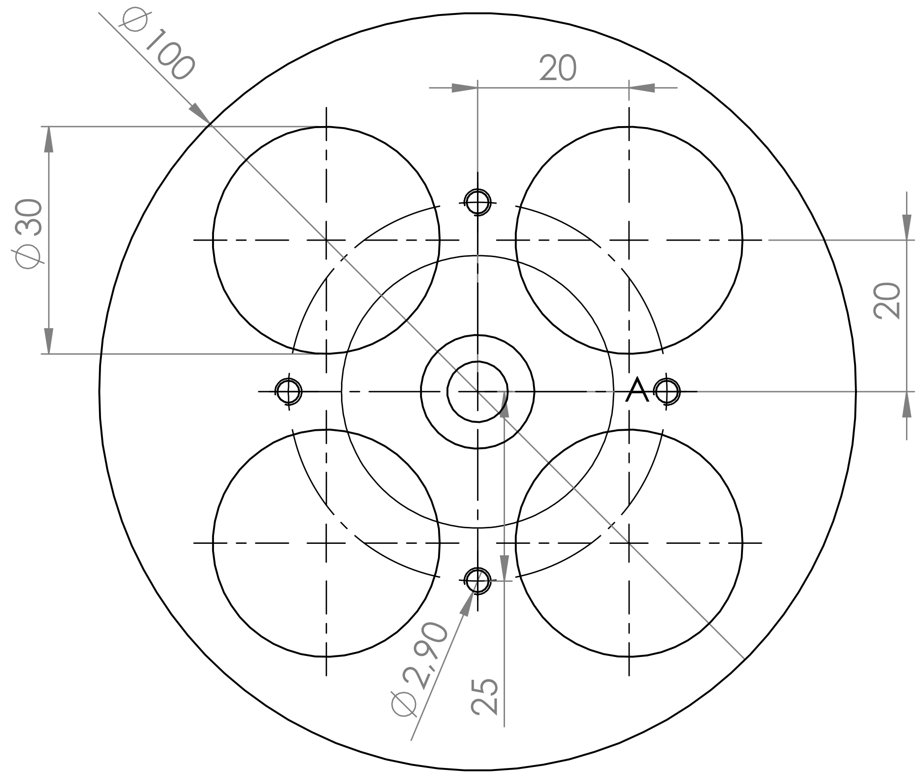
TITLE: Drumroll rod

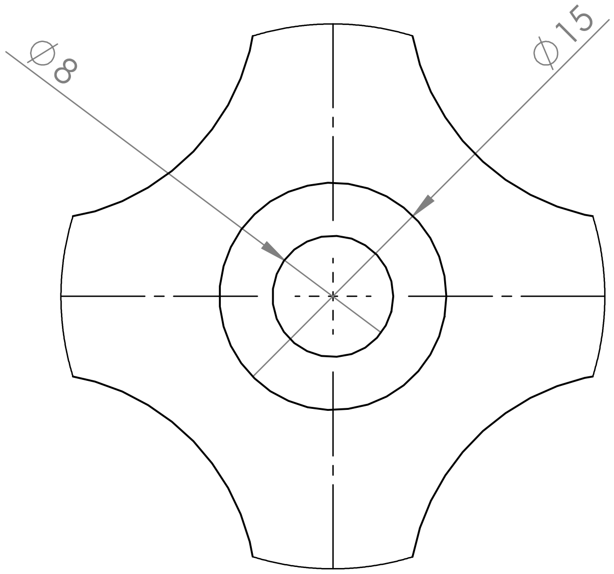
DWG NO. rod

A4

SCALE:1:5

SHEET 1 OF 3





DETAIL A
SCALE 2 : 1

Side view

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 3

	NAME	SIGNATURE	DATE
DRAWN	Peter J. Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

DWG NO.

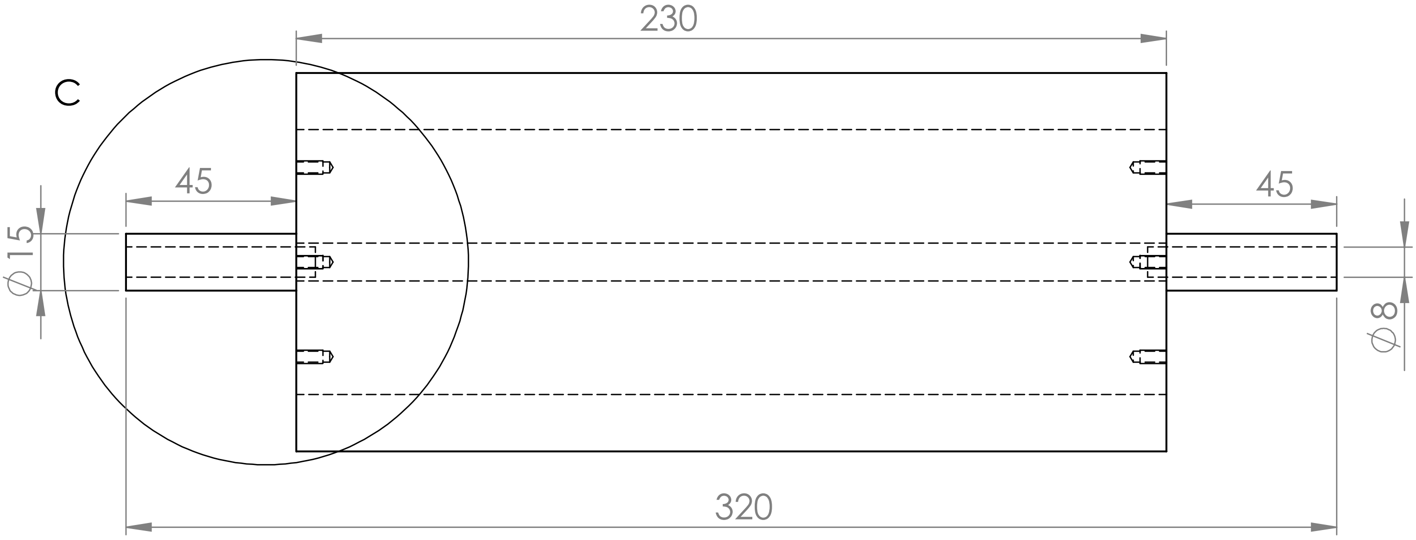
rod

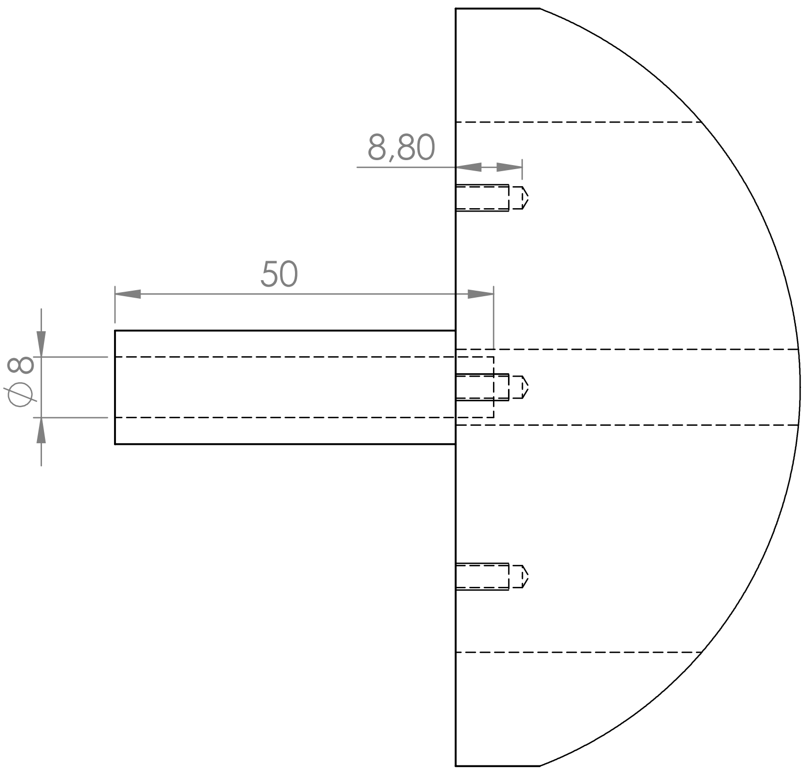
A4

WEIGHT:

SCALE:1:5

SHEET 2 OF 3

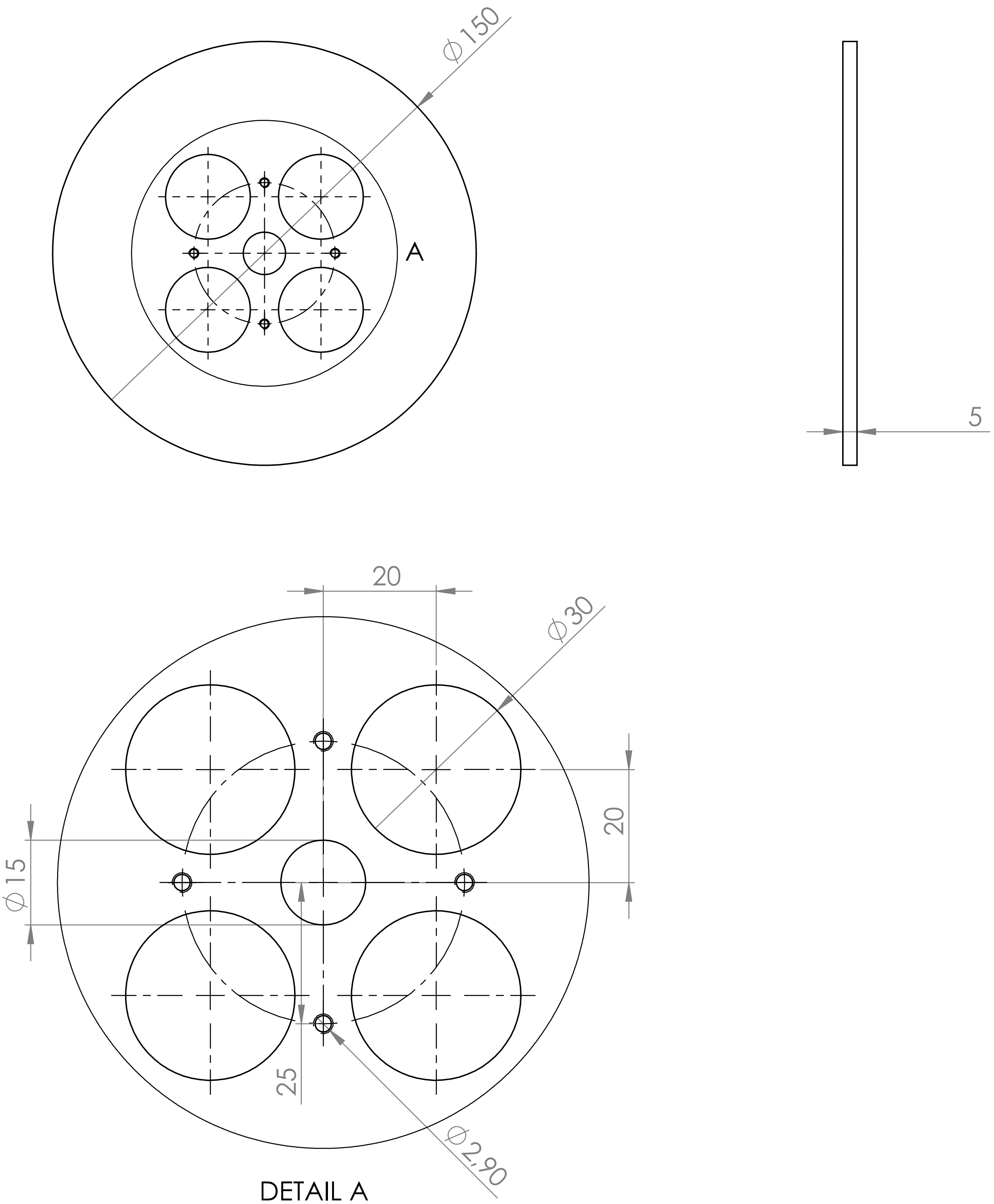




DETAIL C
SCALE 1 : 1

Front view

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 3
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Peter J. Savnik						
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: POM		DWG NO. rod	A4
				WEIGHT:		SCALE:1:5	SHEET 3 OF 3



DETAIL A
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 3

	NAME	SIGNATURE	DATE
DRAWN	Peter Savnik		
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: Acryl

WEIGHT:

TITLE:

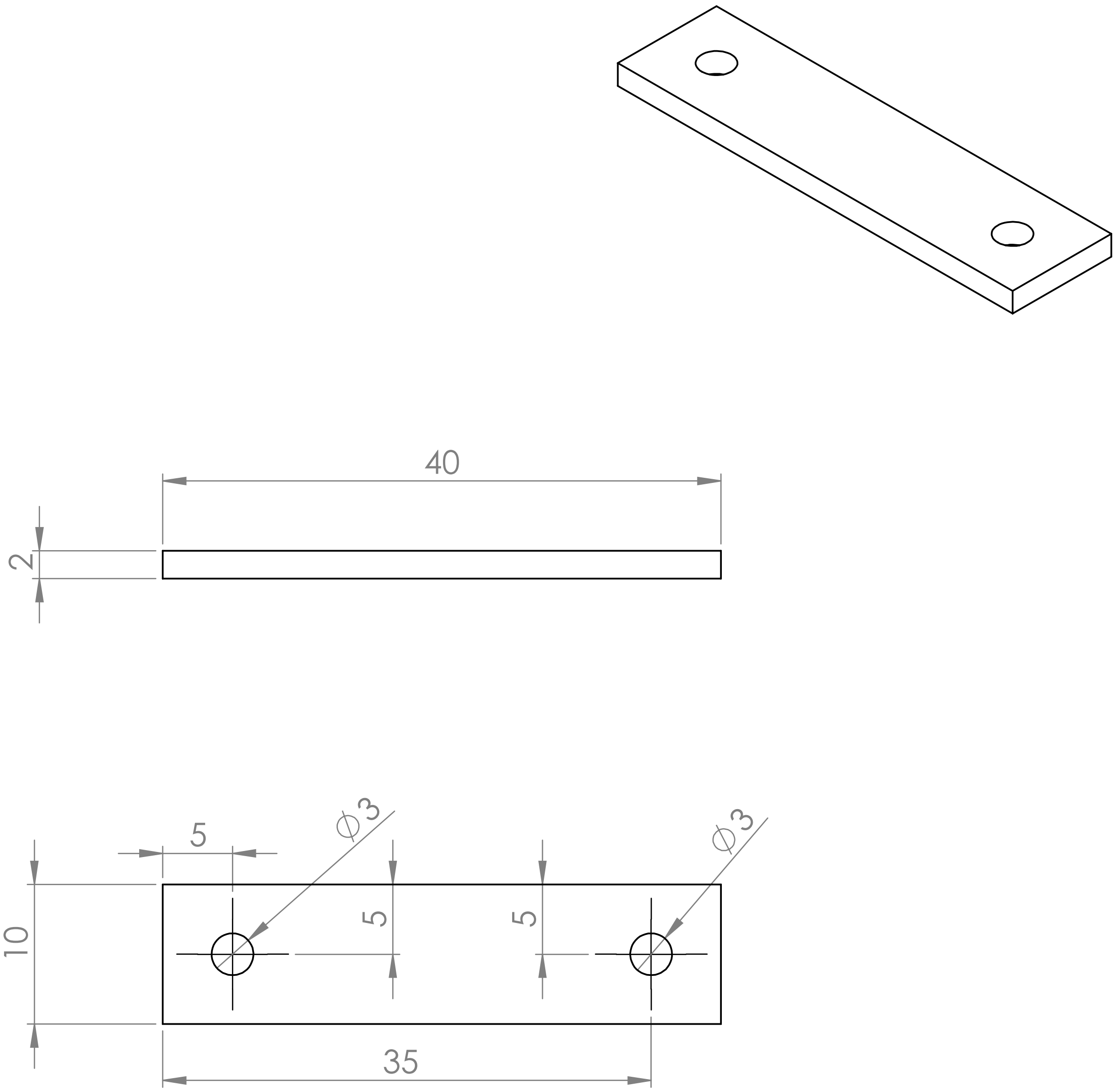
Side Dish for drumroll

DWG NO. side

A4

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Alu

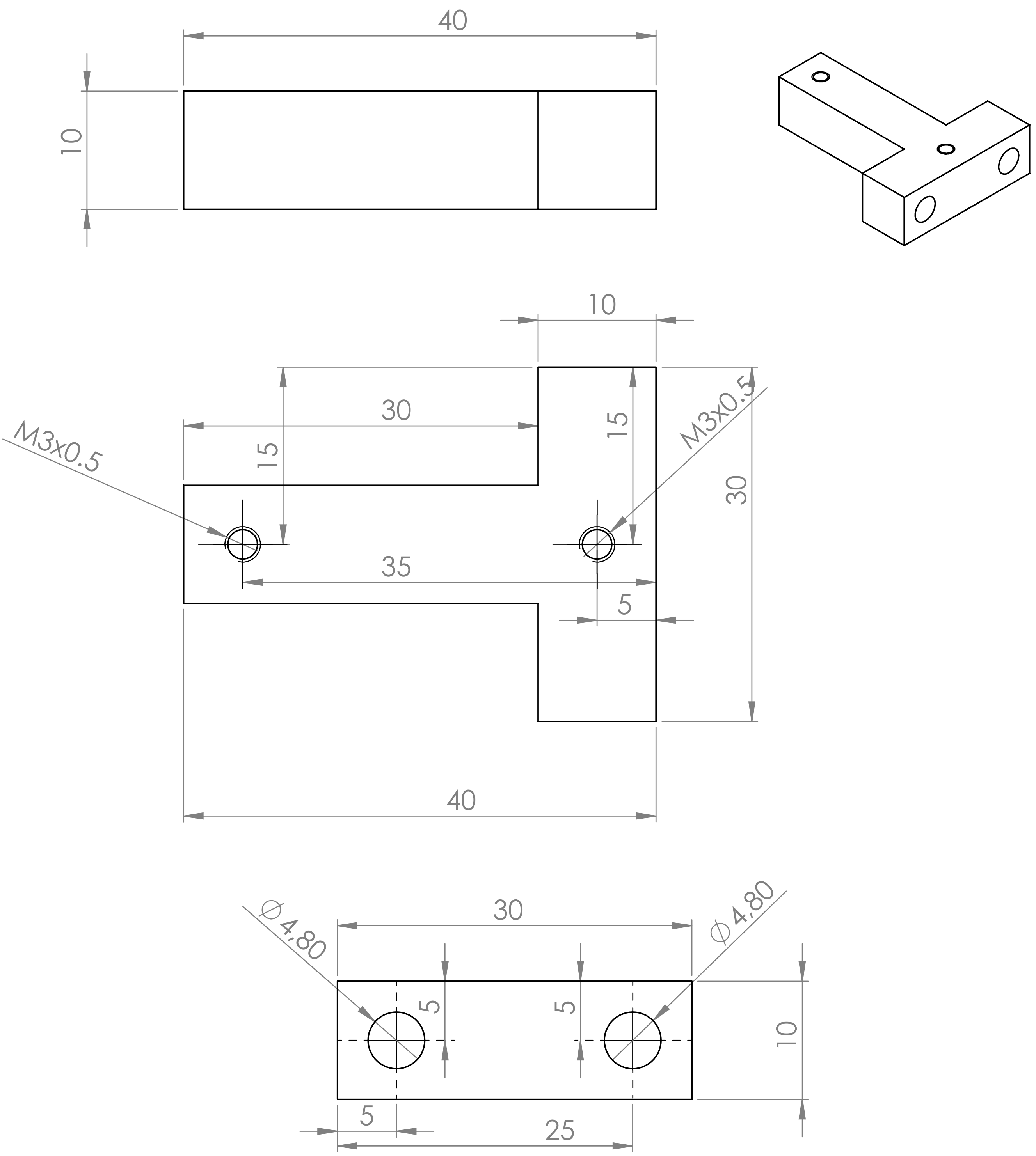
DWG NO.
belt-fastner-plate

A4

WEIGHT:

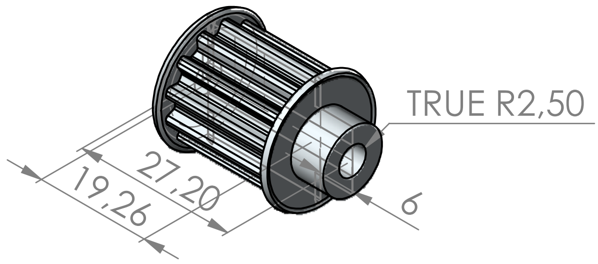
SCALE:2:1

SHEET 1 OF 1

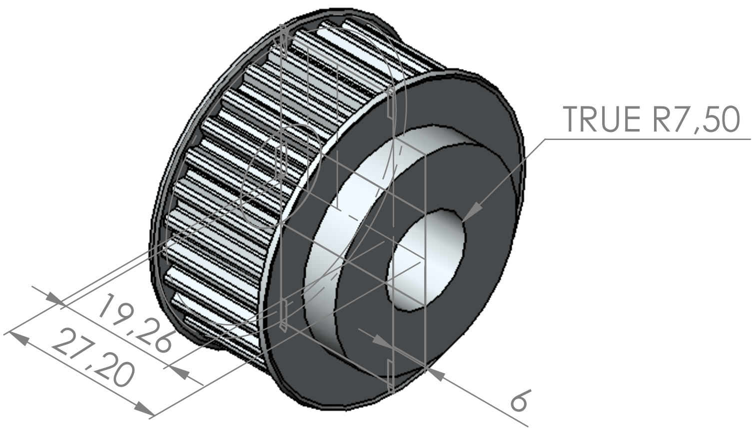


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION		
	NAME	SIGNATURE	DATE			TITLE:
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:		DWG NO. belt-fastner-bracket A4
				WEIGHT:		SCALE:1:1 SHEET 1 OF 1

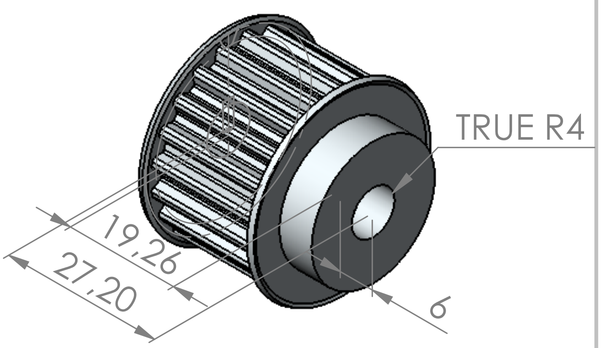
27T5 12-2



27T5 30-2



27T5 20-2



UNLESS OTHERWISE SPECIFIED:
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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

DWG NO.

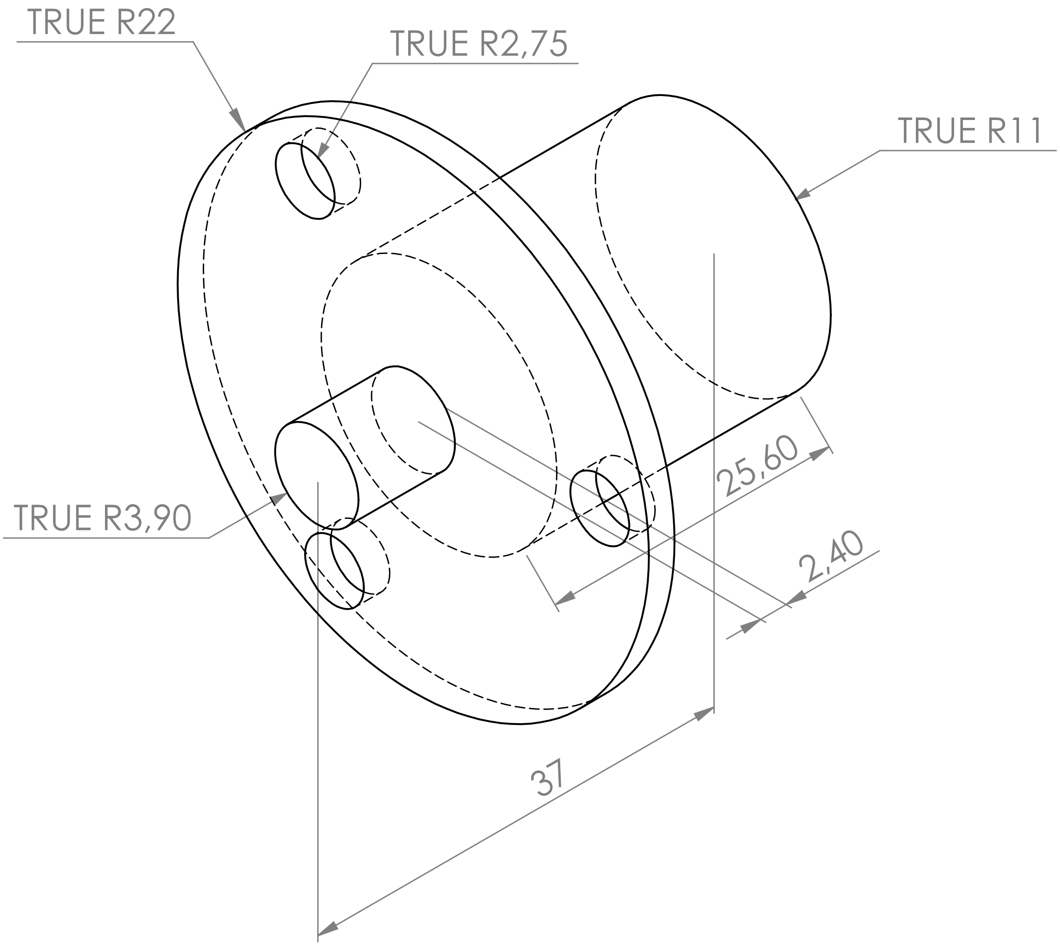
pullys

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1

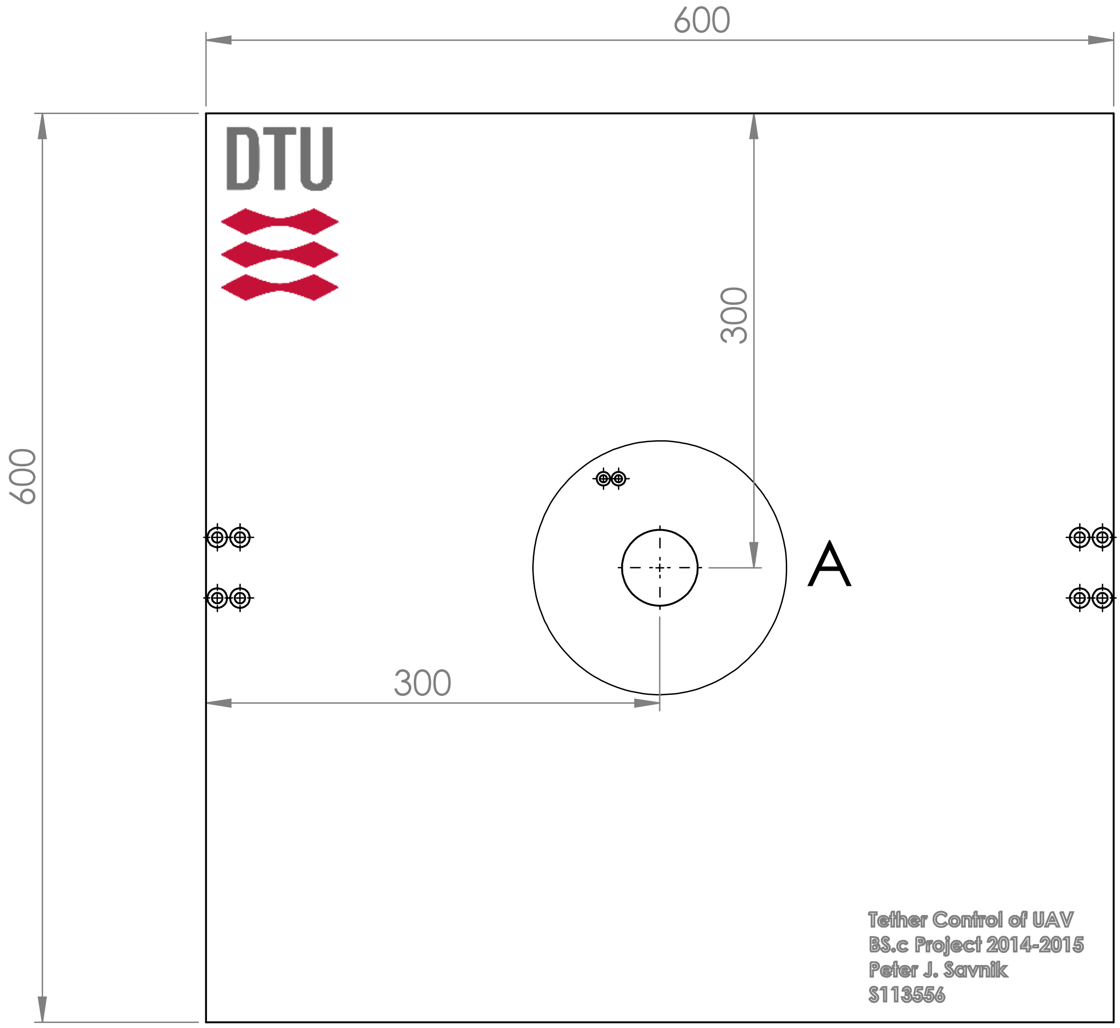


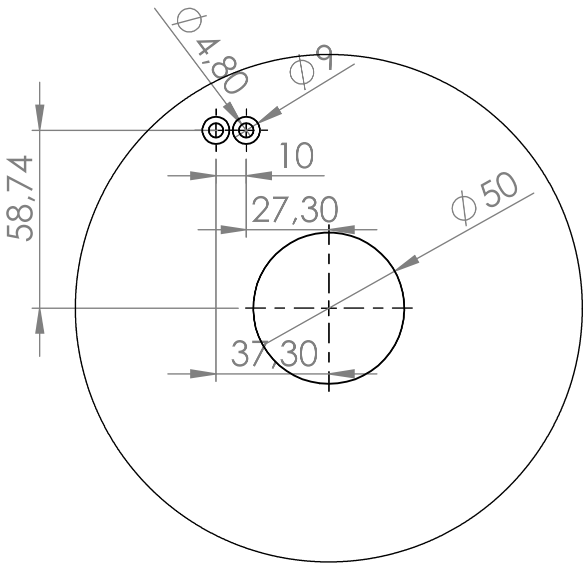
Slipring with flange from Adafruit

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME / SIGNATURE / DATE		TITLE:	
DRAWN				
CHK'D				
APPV'D				
MFG				
Q.A	MATERIAL:		DWG NO. slip_ring_with_flange	A4
	WEIGHT:		SCALE:1:1	SHEET 1 OF 1

Helipad

The Helipad is the platform where the UAV land and take off. In the middle of the platform a hole for the cable is made. Next to this hole two counterbore holes fits to mount the horizontal measurement device underneath.





DETAIL A
SCALE 2 : 5

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

DWG NO. toplevel

A4

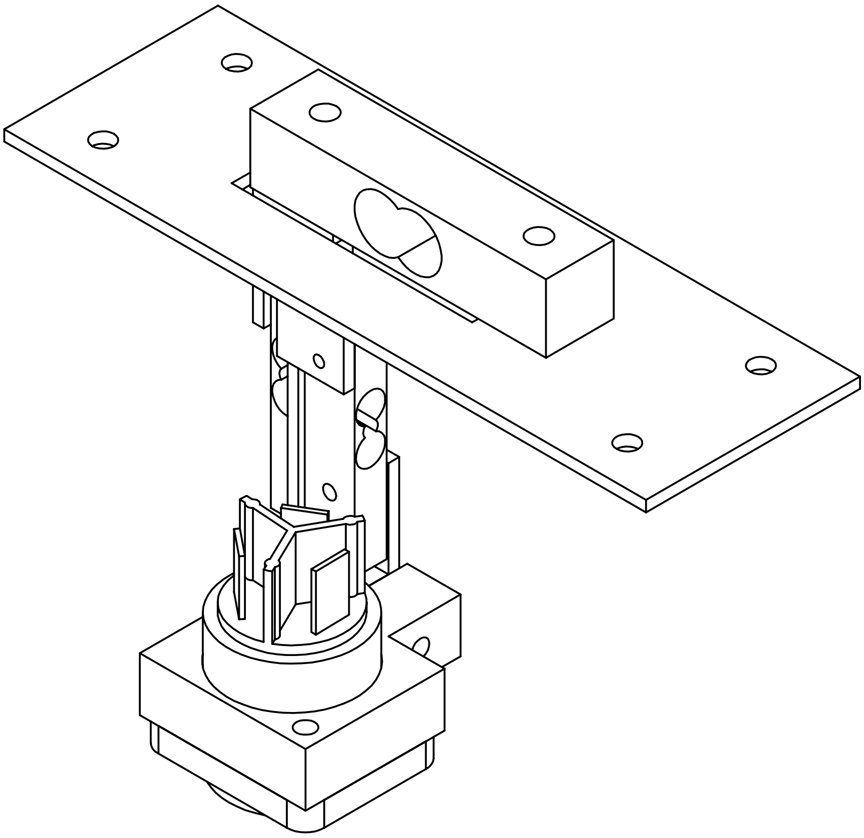
WEIGHT:

SCALE:1:20

SHEET 1 OF 1

D.1 UAV

The mechanical configuration on the UAV was partially made from a previous project, but was rebuild to fit a Neutrix powercon true connector and slightly adjusted in the configuration height.



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			Peter J. Savnik	

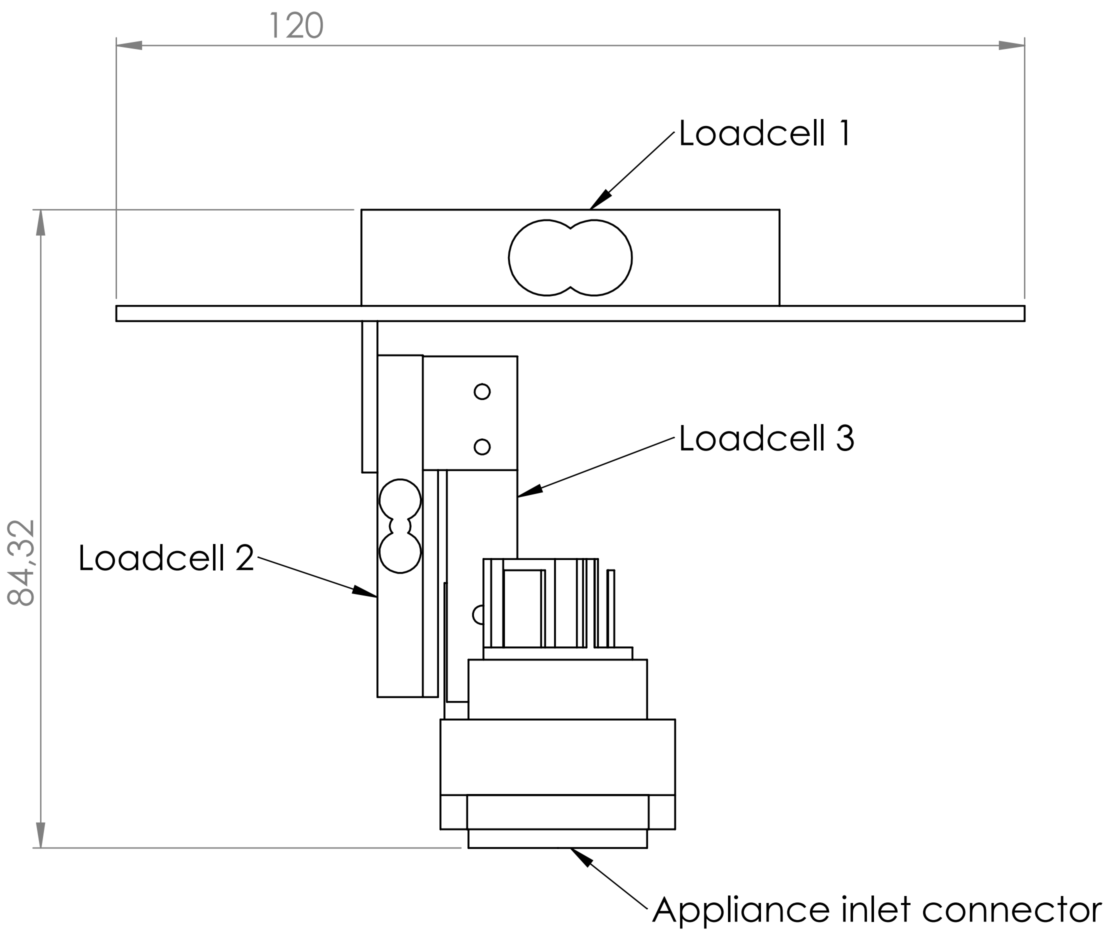
	NAME	SIGNATURE	DATE			
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:		
				WEIGHT:		

TITLE:

TCUAV

DWG NO. hexa-assembly A4

SCALE:1:2 SHEET 1 OF 4



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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

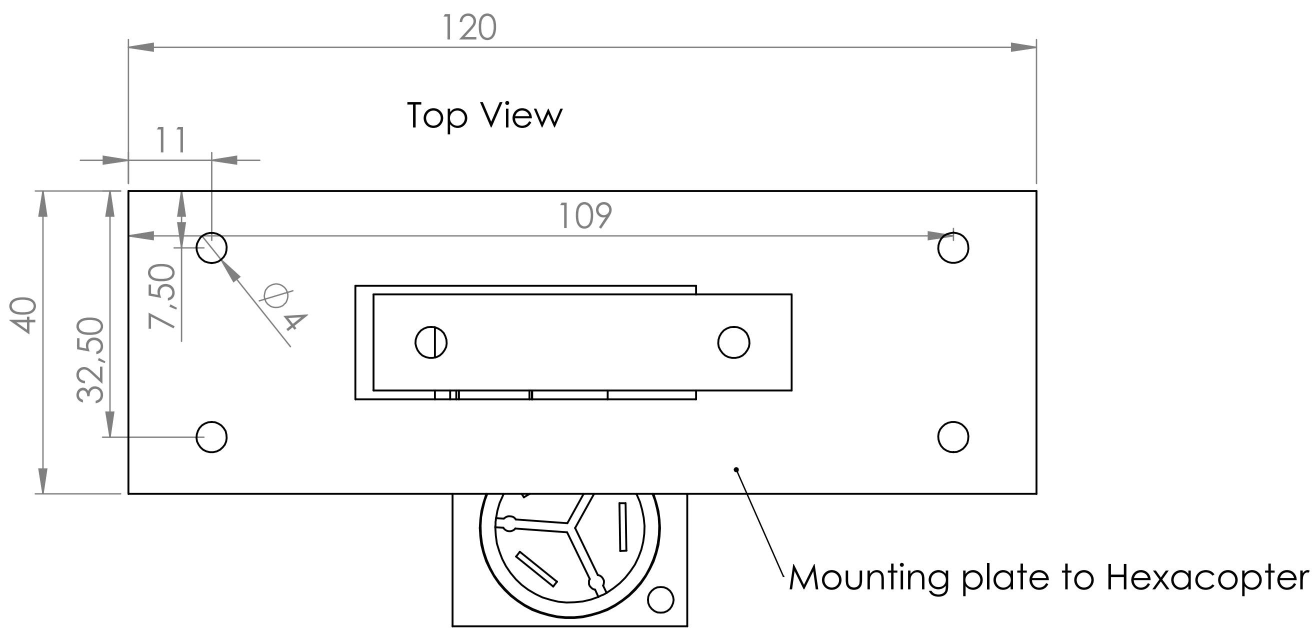
WEIGHT:

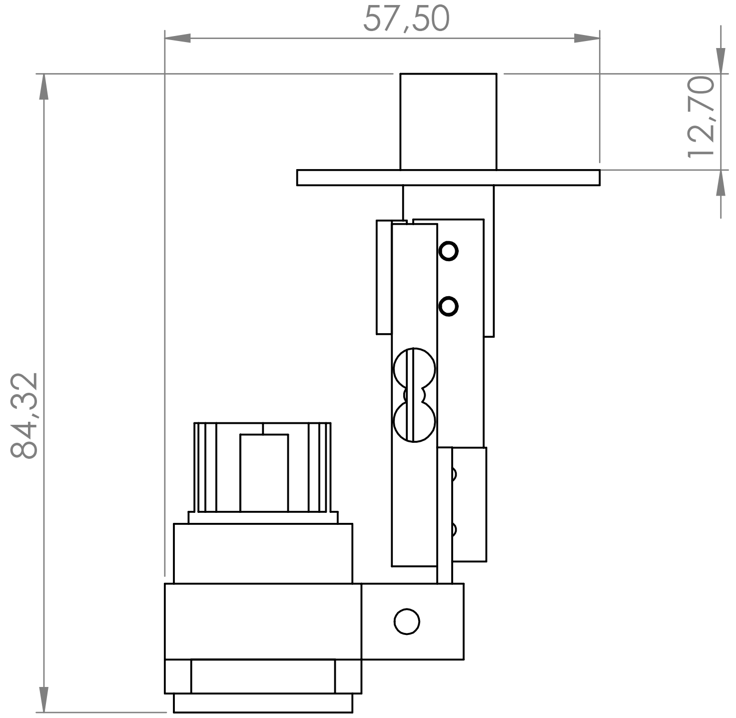
DWG NO. hexa-assembly

A4

SCALE:1:2

SHEET 2 OF 4





UNLESS OTHERWISE SPECIFIED:
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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

TITLE:

MATERIAL:

DWG NO.

hexa-assembly

A4

WEIGHT:

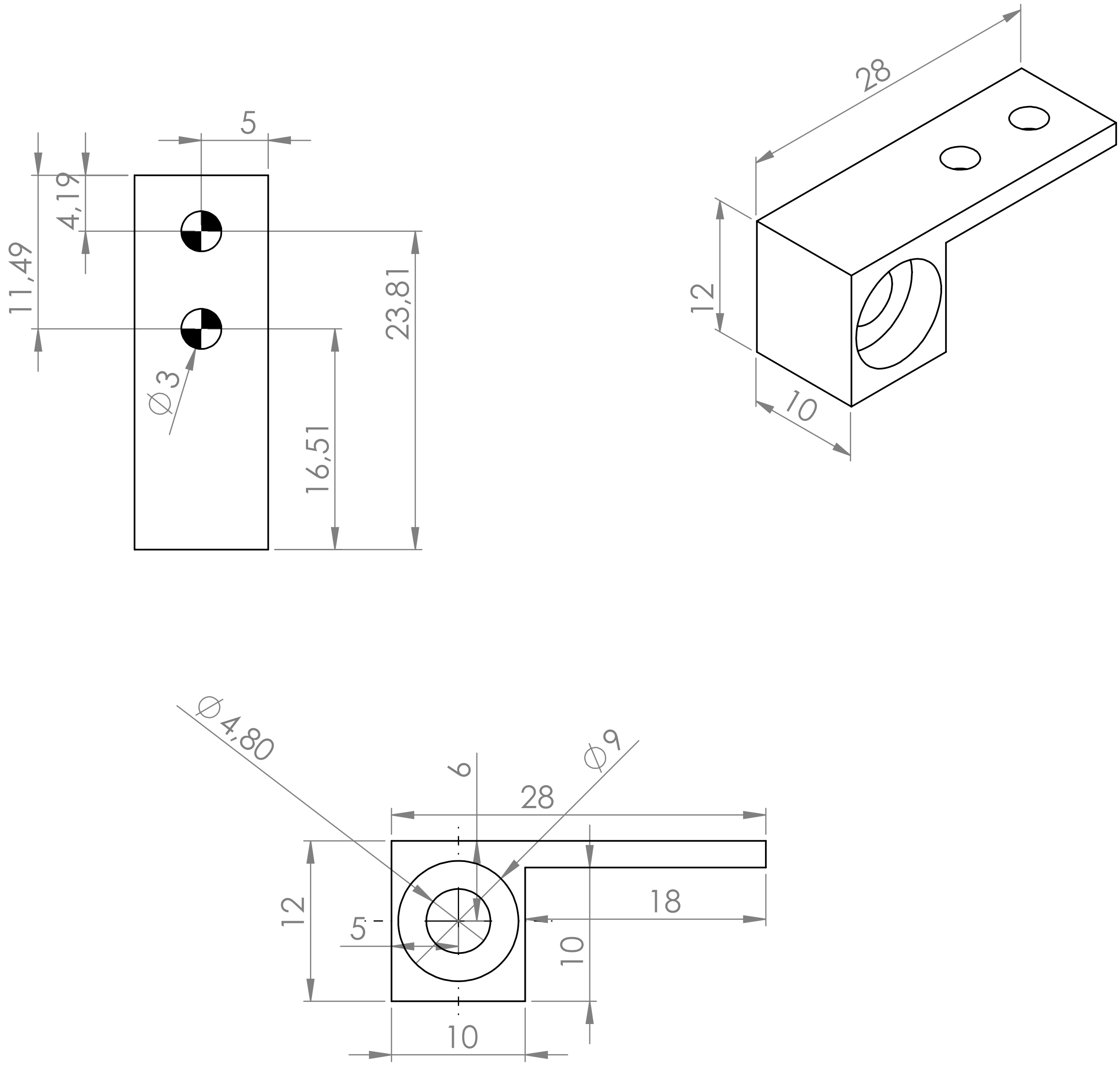
SCALE:1:2

SHEET 3 OF 4

Bill of Materilas

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	mount-plate		1
2	loadcell-5kg		1
3	fitting-5kg-to-075kg		1
4	loadcell		2
5	fitting-075-to-075		1
6	Neutrix-powercon-true		1
7	powercon-fitting		1
8	powercon-to-loadcell		1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE		TITLE:		
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:	DWG NO.	hexa-assembly	A4
				WEIGHT:	SCALE:1:2	SHEET 4 OF 4	



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND
BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	

TITLE:

DWG NO.

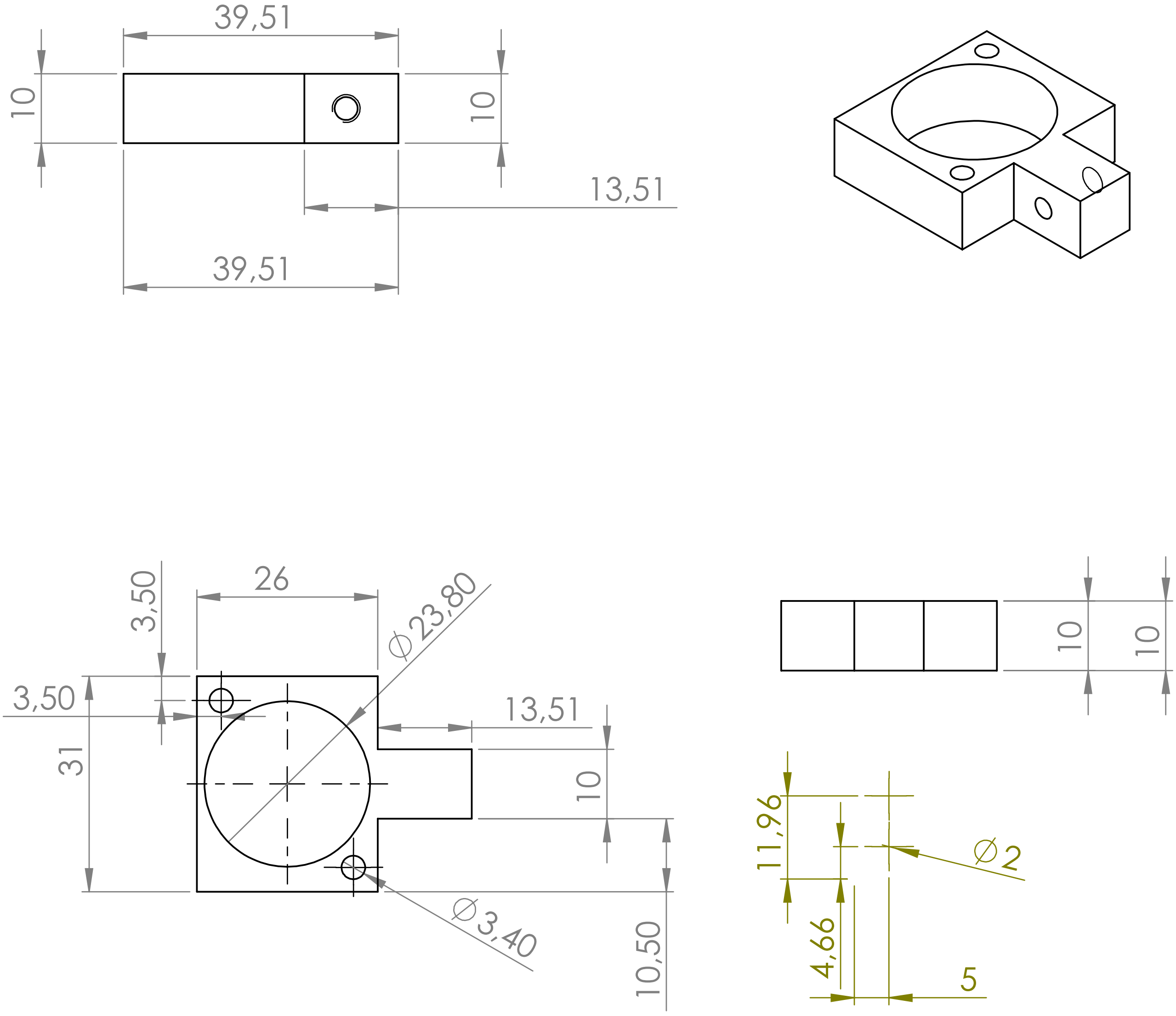
powercon-to-loadcell

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

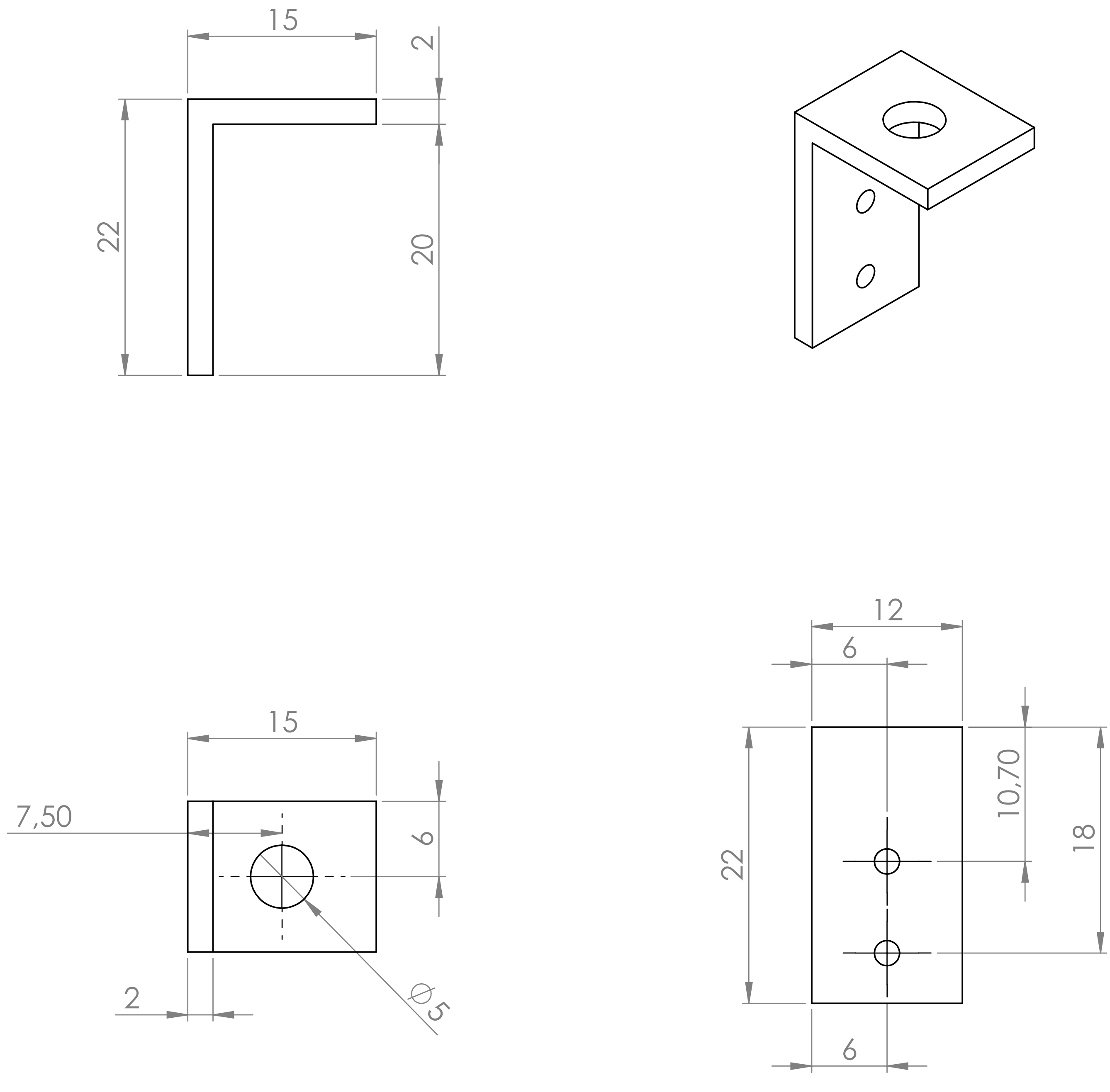
DWG NO.

powercon-fitting

A4

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

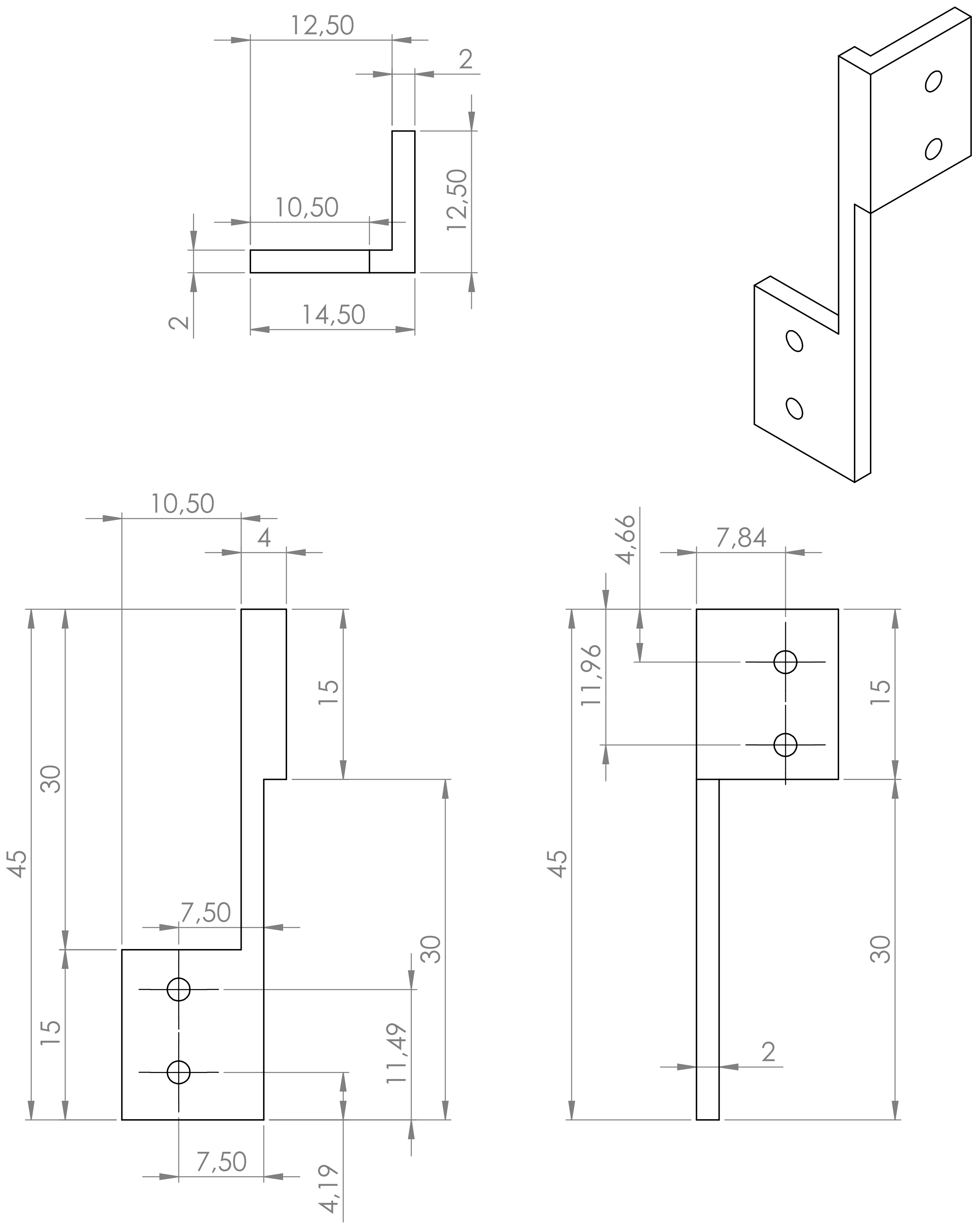
TITLE:

DWG NO. fitting-5kg-to-075kg

A4

SCALE:2:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	

TITLE:

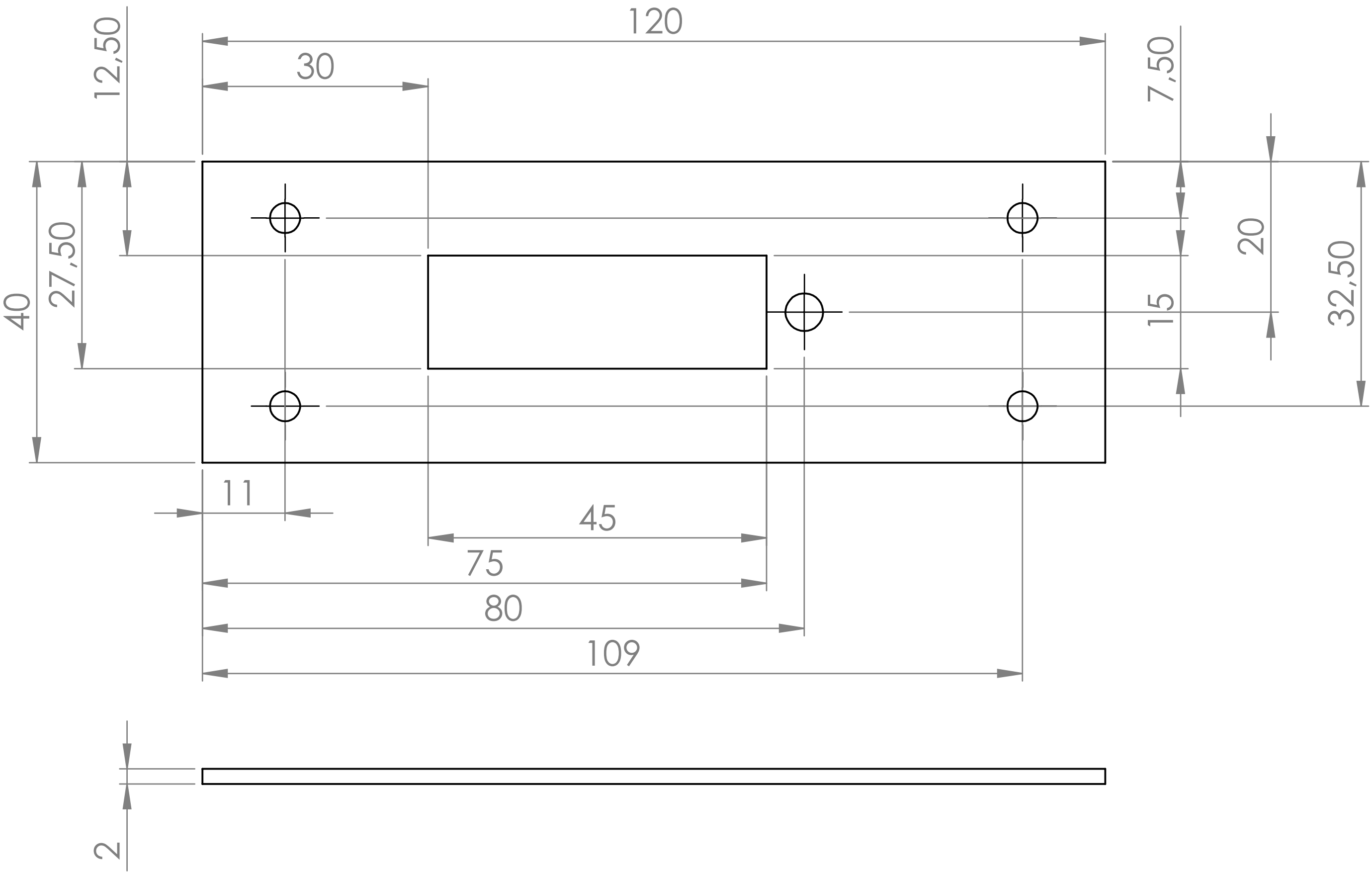
DWG NO. fitting-075-to-075

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

DWG NO.

mount-plate

A4

SCALE:1:1

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APPENDIX E Component Specifications

E.1 ÖLFLEX HEAT 180 Deg H05SS-F 2 x 0.75mm

RS part number: 807-9259
RS Description:
Europe-wide standardised silicone connection cables with increased mechanical performance Halogen-free and flame-retardant (IEC 60332-1-2) Good hydrolysis and UV-resistance Resistant to a multitude of oils, alcohols, vegetable and animal fats and chemical substances EWKF: Initial tear propagation and notch resistance More durable than conventional H05SS-F standardised cables Flexibility simplifies installation where space is limited Possesses insulatin Polytetrafluoroethylene cables for most extreme loads Space-saving installation due to small cable diameters Ideal for harsh environments Stress crack resistant to frequent ambient temperature fluctuations Resistant to contact with mostly all highly aggressive chemical media Low outgassing behaviour Temperature and UV resistant For use in areas with high ambient temperatures and occasionally mechanical stress Typical fields of application include steel, ceramic and iron works; bakery equipment and industrial furnaces; electric motor industry; sauna/solarium construction; thermal and heating elements; lighting technology; ventilator engineering; air-conditioning technology; galvanisation technology.

Bedding Material	Tinned Copper
Cable Shape	Twisted Pair
Conductor Material	Copper
Cross Sectional Area	0.75 mm^2
Insulation Material	Silicone
Length	50m
Maximum Operating Temperature	+180°C
Minimum Bend Radius	15x6.4mm(Occasional Flexing), 4x6.4mm(Fixed Installation)
Minimum Operating Temperature	-50°C
Number of Cores	2
Outer Diameter	6.4mm
Screen Type	Tinned Copper Braid
Screened/Unscreened	Unscreened
Sheath Colour	Black
Sheath Material	Silicone
Voltage Rating	300 V, 500 V
Weight (kg/km)	54

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