Bachelor project: **I**ce **S**ampling for **A**nalysing **S**ediment - Drone (ISAS)

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M7BAC - Bachelor thesis

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Ice Sampling for Analysing Sediment - Drone

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Executive summary

This thesis describes the challenges of collecting data from icebergs and delivers a solution on how to solve the task, with the primary focus being on icebergs in the fjords of Greenland. The project was giving by Daniel Frazier Carlson from Arctic Research Centre at Aarhus University, who has also been responsible for specifying the wanted data sets, which the device should collect.

The data sets was prioritized in a Specification of Requirements, and the main focuses ended up being GPS tracking and ice sampling. The problem was solved by building a drone which has a GPS delivering mechanism and a developed ice drill. It was decided to limit the thesis to using an existing flying platform (drone), in order to have more time for developing the attachments needed. The developed drill is capable of cutting a 500 g and 200 mm ice core from a solid block of ice, which will be further tested in Greenland, January 2019. The drill has a modular construction with a 3D printed cutting head and sleeve, and a drill top and center tube in aluminium. It is fitted with three cutter heads/teeth made from hardened knife steel which has been PVD coated to seal the iron from contaminating the ice sample. Along with the drill a new landing gear for the drone has been developed, which is capable of raising and lowering the drone when drilling. All of the sample taking equipment along with the needed electronics and software has been created/selected by the authors of this thesis.

The project has in general been a success with the equipment thoroughly tested in Denmark, where it lived up to the requirements set for the project. As mentioned above a field test will be made in Greenland, January 2019.

Preface

This thesis has been developed by two Mechanical Engineering students at Aarhus School of Engineering (ASE) in the period from August 2018 - December 2018. The thesis has been made for the course: M7BAC Bachelor-project, with the purpose of documenting the development of a data collecting drone made for Daniel Frazier Carlson from Arctic Research Centre at Aarhus University.

The drone was specified to collect the following data: GPS-tracking of icebergs and Ice core samples. Also a reflection camera has been added, to collect reflection data from the surface. The equipment made for the drone will be described throughout this report, and is divided into Mechanical design, Electronics and Software development. All this was created in a concurrent development process.

The group would like to thank the following people for their help and contributions to the project:

Our Academic supervisor **Claus Melvad** and the Project holder **Daniel Frazier Carlson**, for their engagement in the project.

Beside the academic help received, the Mechanical development was only made possible with the help from the workshop located at ASE along with its competent and capable employees: Birger Fiksach Jensen, David Graadal, Henrik Roed Jensen, Jeppe Seeberg, Jesper Jensen and Jim Ottosen.

Reading guide

The project is divided in a Main report (Thesis) and an Appendix. The Main report contains the most important and relevant information, decisions and conclusions. The Appendices contain the underlying calculations, Experimental reports, diagrams and descriptions used as documentation for the thesis.

When a reference is made to the Appendix, it will be done as follows: *See Appendix "A.X"*. The appendices will be listed in chronological order, according to when the reference is made in the thesis. The only exceptions being: the Parts list, the Technical drawings, the Time schedule and the User manual, which are presented as the last four appendices.

Tables and Figures are labelled with the Section number they are in and a Table/Figure number. Furthermore appropriate Table/Figure-texts are added. When a reference is made it will be done as follows: *See Figure "X.X"* or *See Table "X.X"*.

When a reference to a source is made, it will be done by adding a footnote[x] on the relevant page. A bibliography is added at the end of the Main report containing a complete list of sources, divided into "Web pages" and "Articles".

The thesis is a technical report, which requires the reader to have a general knowledge of the following subjects: Mechanics, Electrical theory & Programming.

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1 Introduction

This project was build around a problem given by Daniel Frazier Carlson from the Institute of Bioscience, Arctic Research Centre (ARC) at Aarhus University (AU). Dan Carlson is an oceanographer and specializes in ice/ocean interactions in Greenland. The knowledge of understanding how icebergs melt and how much freshwater they release into the sea is of great importance to the climate. But these studies are made difficult because of the nature of icebergs; the arctic environment, hard to reach places and dangerous conditions when working on or close to the icebergs. In other words, it is hard to collect the important data needed for the studies. The studies include melt speed, drift speed, the amount of freshwater produced, what materials the melt contains and where these icebergs come from.

The data can be used to understand the ice-conditions in the fjords, but also in advanced models of the sea, since a lot of the icebergs continue out of the fjords and into the Atlantic ocean to melt. Therefore, the melt plays a significant role in the amount of freshwater and the temperature of the Atlantic ocean, which has a huge impact on the global climate conditions.

As these data are important to his studies, Dan Carlson contacted Claus Melvad at Aarhus School of Engineering (ASE), with a project suggestion of making a data collecting device. Dan proposed the 5 most relevant data sets to collect, which will be described in greater details in the following sections.

1.1 Ice sampling

As an iceberg melts it leaves sediment in its wake. By researching what types of particles the melt contains and by which icebergs it comes from, it might be possible to find a correlation between iceberg drift and the local biology as well as the environment.

1.1.1 Sediment

The sediment on an iceberg is made up of sand, pebbles, rocks and micro particles and it might even contain trace amounts of iron, from the bedrock underneath the glaciers. Sediment in icebergs can speed up the melting process, because of an increased absorption rate of radiation from the sun, see Figure 1.1[1].

Figure 1.1: Ice with sediment

[1] http://www.nordiclandscapes.com/Glaciers-Icebergs/index.html

If the sediment of a melting iceberg can be analysed and scientists are able find the amount, the composition and the size distribution of the sediment, it will be possible to understand how the sediment dissipates in the water, see Appendix A.1. This will benefit many areas of research such as geology, biology and arctic research. Another interesting part of the sediment is the micro particles. These particles can affect the water clarity, especially in the areas where the iceberg has drifted in circles. The sediment in the melt can change the turbidity of the water, and as a result affect the biology in the area. The increased turbidity will change the amount of sunlight that travels through the water, and since phytoplankton need light for photosynthesis they will decrease in numbers. Another important part of the sediment is to figure out if it contains iron, as iron is a fertilizer for phytoplankton, which has an effect on the CO_2 absorption. Because of the above mentioned reasons it is important to understand what types of sediment and minerals are present in the ice. So far there have been little to no research done in this field, and the melt from these icebergs are Daniel Carlson's current main research area.

1.1.2 Ice samples

Dan Carlson is interested in ice samples from icebergs, such as the one in Figure 1.2[2]. This would give him a chance to analyse the content. But as Dan Carlson is interested in the contents in the ice and not in the individual layers the ice sample can take any shape or form.

Figure 1.2: Ice sample

Normally the extraction of an ice sample from an iceberg is done by sailing up next to it and using a pickaxe to collect a piece of ice. This type of extraction is not exactly safe, as there is a risk of the iceberg rolling over and creating a wave which could possibly sink the boat. Furthermore a sample from the top is wanted as this is in direct sunlight. These are the reasons why Dan Carlson is asking for an ice sampling device that can be used remotely.

[2]How do icebergs affect the Greenland ice sheet under pre-industrial conditions? – a model study with a fully coupled ice-sheet–climate model

1.2 GPS Tracking

Another important information to know about the icebergs is how they travel once they are released from the glaciers into the fjords. As mentioned in Section 1.1, the sediments from the iceberg is transported via the melt into the water. Where this sediment ends up, can be analysed by tracking the icebergs position with a GPS beacon. This will help to understand if the icebergs moves slowly, drifts in circles or if they move with high speed out of the fjords. When an icebergs moves slow or spirals, the concentration of the sediment release will be high in these areas, whereas if they move fast, the sediment will be distributed evenly over longer distances. Through GPS data analysis it is possible to the determine how the majority of the icebergs moves, and how the distribution of sediment is expected to be.

In 2017 Dan Carlson did a research on tracking icebergs in Godthåbsfjord (SW Greenland) with an self-invented device called Expendable Ice Tracker (EXITE)[3]. This research ended up with a paper in "Frontier in Marine Science", which describes the project and how the icebergs moved over time. In Figure 1.3, an iceberg is tracked for 27 days, before the GPS signal was lost.

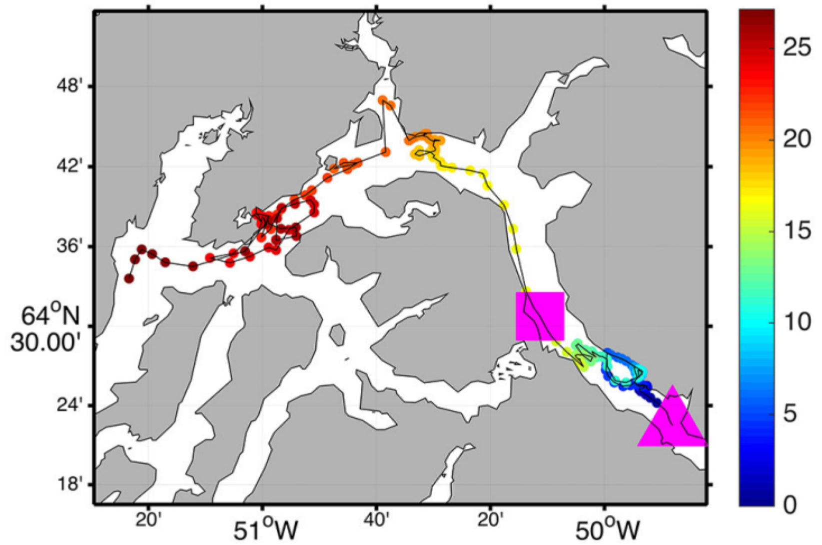

FIGURE 9 | A trajectory of an EXITE beacon initially deployed at the large pink triangle. Locations are color-coded according to time, in days, since deployment. Every 4th measurement is shown for clarity. The location where the critical acceleration was exceeded is indicated by the large pink square.

Figure 1.3: GPS tracking of iceberg done by EXITE

By using the data from Figure 1.3 it is possible to determine how the velocity and movement changed over the course of tracking and gives an indication of areas where the iceberg spiralled in the water. These areas could have a higher concentration of sediment material which can, as mentioned earlier, change the biology in the water. The speed of the iceberg is also a factor when it comes to the freshwater flux, as higher speed yields faster melting.

The article describes how the flux of freshwater emitted to the fjord is a relevant factor when doing numerical models of the oceans, which can help to describe the current but also

[3]Bergy bits and Melt Water Trajectories in Godthåbsfjord (SW Greenland) Observed by the Expendable Ice Tracker

future climate conditions. This is backed up by the article: "How do icebergs affect the Greenland ice sheet under pre-industrial conditions? – a model study with a fully coupled icesheet–climate mode"[4], which states that the icebergs contribute with lowering the salt concentration and temperature of the water. This strengthens, according to the article, the sea-ice along the coasts of Greenland as well as lowering the atmosphere temperature, which are huge environmental impacts.

1.3 3D scan

To determine how big the icebergs are it is possible to compile a series of pictures into a 3D scan of the surface. This 3D scan be used to find the volume of the iceberg over water, and from there calculate the size of the iceberg according to the buoyancy of ice, se Figure 1.4. In the article: "Subsurface iceberg melt key to Greenland fjord freshwater budget"[5], it is stated that most of the melt happens underneath the water surface, which makes it important to give an estimate on the shape and determine the size. The shape of the iceberg can have a big impact on the melt rate as grooves and recesses increases the surface area. In the past these volume and shape calculations were only based on rough estimates, whereas 3D scans are much more exact.

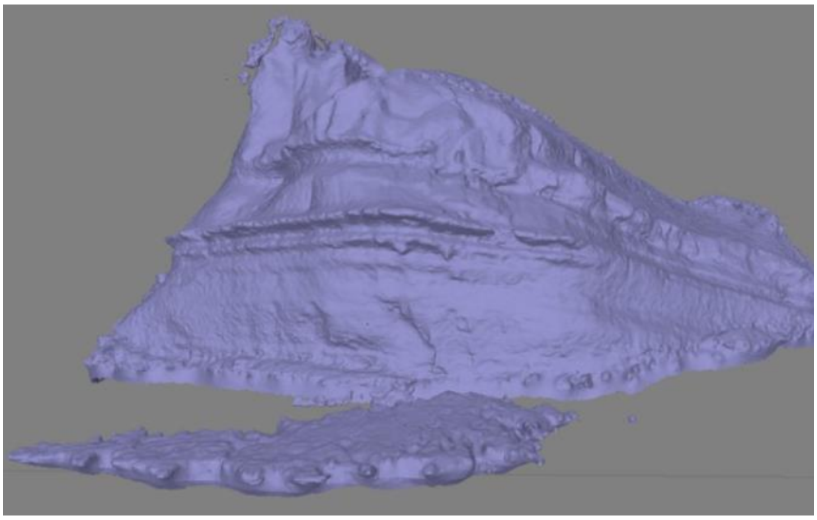

Figure 1.4: 3D scan of iceberg surface

Other than tracking the iceberg via GPS the shape and size can also be important to predict the movement of the iceberg, as a deeper keel (bottom of the iceberg) can result in different currents in the fjord.

1.4 Reflection from the surface

Another important part of determining how fast an iceberg is melting is to analyse the reflection from the surface of the iceberg. Because of the different types of surfaces such as the ones seen in Figure 1.1, the icebergs absorb different amounts of sunlight and are therefore melting at different rates. By understanding the different kinds of reflection on the iceberg surface it might be possible to make more accurate melting prediction models than those used today.

[4] How do icebergs affect the Greenland ice sheet under pre-industrial conditions? – a model study with a fully coupled icesheet–climate mode

[5] Subsurface iceberg melt key to Greenland fjord freshwater budget

1.5 Core Temperature measurement

Another factor when determining the melting rate of the icebergs is to know the core temperature of the icebergs. The core temperature is important as it defines the temperature difference between the water, the air and the iceberg itself. Therefore this information can be used in models of the icebergs and how fast they melt. In order to find the core temperature it is only necessary to measure 100 mm to 150 mm underneath the surface, according to Dan Carlson, as the temperature from this point on is almost constant.

1.6 Environmental impact of the research

Since there is such a large lag of research on icebergs and their melt rate, and because they are expected to have a high influence on the water composition in the fjords and in the northern part of the Atlantic Ocean, it can have a huge impact to understand the icebergs behaviour. As described in both Section 1.1 and 1.2, the melt water from the icebergs deliver a lot of sediment to the water which influences the biology in the local environment, see Appendix A.1. To understand what type of sediment, how much and where it is being released into the water, is therefore very important to the arctic research.

1.6.1 Relevant research locations

Arctic Research Centre at AU has interest in all types of arctic research, but Dan Carlson's primary focus lies on icebergs in Greenland. But this is not the only place where this type of data is relevant. Another focus could also be the glaciers of Antarctica which also delivers icebergs to the Atlantic Ocean.

Furthermore the sampling technique from this project can also be used elsewhere. For example when collecting data from sea ice in the winter time in Norway, Canada, Greenland or other arctic areas. Data from sea ice is also very important as it traps sediment from the air, but this research is also made difficult because of the environment and the areas with thin ice. The same thing applies when it comes to collecting data from glaciers in Greenland, Iceland, Norway or other regions with glaciers. All this data is of interest for different researcher, and therefore the impact of such a data collecting device, can be very high.

2 Problem description

The significance of this Mechatronic project is indicated clearly in Section 1 where the different research areas were covered. From here a full description of the problem can be compiled.

Before going into the Problem statement, it is necessary to make a Market analysis and a section which sets the boundaries for the project. The Market analysis is important as it can help the group make the right choices when setting up the Project limitations, as relevant information or existing products can save the group a lot of time later on. If an existing product can complete a certain task already and with the necessary precision and/or speed, it will be logical to include this in the Project Limitations, so the focus can lay on other tasks.

2.1 Market analysis

This section is meant to describe some of the products on the market that could solve parts of the problem or serve as inspiration for the development process. Unfortunately an ice sampling drone is a rather understudied area and therefore there are not any products on the market. But by separating the drone and the ice sampling device into two separate systems it is possible to find some relevant sources of inspiration on the current market.

2.1.1 Drones

The market for drones is getting rather big and there are a lot of solutions for making drone assisted sampling. By looking at existing products it might be possible to get some inspiration for attaching the sampling device to the drone. Generally the drones used for data sampling are from DJI, one of the top brands. The drones typically used are DJI Matrice and DJI S-series which both have mounting possibilities underneath as seen in Figure 2.1[6].

Figure 2.1: Drone fitted with sample device

[6] www.kortlink.dk/com/w9mc

Ussually drones are not used over water, but since the mission is carried out over open water in the arctic, it will be a good idea to look into waterproofing the drone and emergency water landings.

Figure 2.2: Drones for water landing

As seen on Figure 2.2[7] [8] two reasonable ideas could be pontoons or foam on the landing gear.

2.1.2 Ice sampling

Ice sampling is usually done by drilling out an ice core and it is commonly done in two ways, see Figure 2.3[9]. The first type is called thermal drilling and as the name suggest it uses heat to cut through the ice. Once the ice has been cut it uses a small spring loaded pick to snap the sample and hold it in place so it can be removed. The other type is called mechanical core drilling and it involves a rotating drill head which cut away the ice surrounding the sample. It usually uses the same breaking mechanism as the thermal drill.

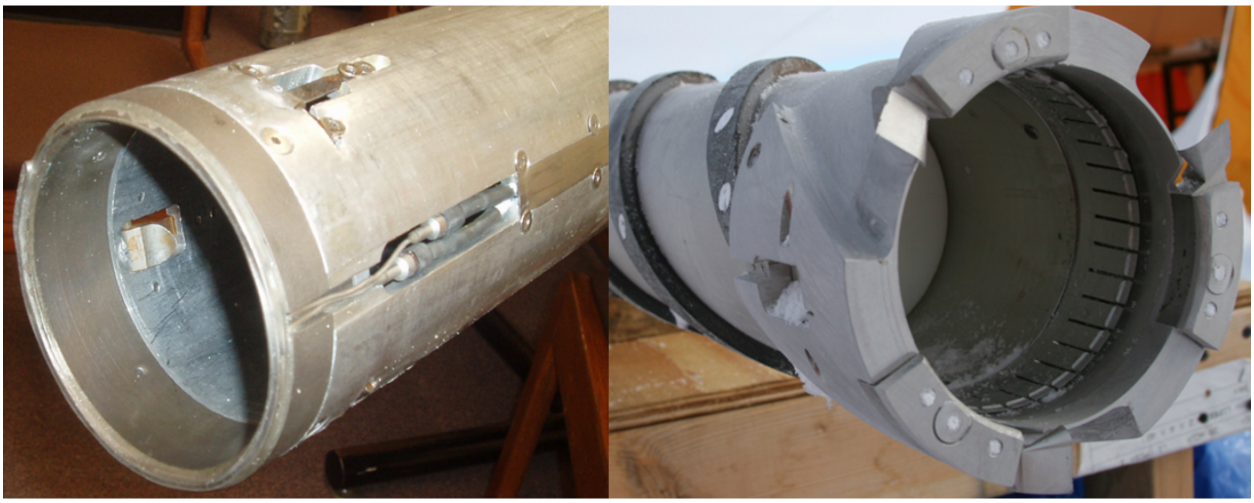

Figure 2.3: Thermal(Left) and Core(right) drill

Both methods have their drawbacks, the thermal drill has high power consumption, leaves melt water, and might degrade the sample, whereas the mechanical core drill can get stuck because of the cold shavings of ice. Generally both methods are used on solid ice such as glaciers and sheet ice. Both drill types will be evaluated in Section 4.2.1.5.

[7]www.kortlink.dk/kickstarter/w9md
[8]https://www.youtube.com/watch?v=14iKxSUET2M
[9]https://icecores.org/icecores/drilling.shtml

2.2 Project limitations

It was, in collaboration with the groups supervisor Claus Melvad and Dan Carlson, decided that the project should be limited to focus on flying to and from the icebergs as sailing or diving to the icebergs is slow, inconvenient and comes with unwanted challenges. Underwater ice samples are not of interest to this exact project, and taking samples from the side of the icebergs is made unnecessarily difficult because of the shape of the icebergs.

The Project is limited to using an existing flying platform (quadcopters, hexacopters or octacopters), where a lot of companies already have good and stable products, which can be used directly in collaboration with other parts of the project.

Also, the project is limited to primarily being used from a boat, which means that the device should be able to land and take off from a boat. Although the versatility of flying also allows it to be operated from land.

Furthermore, the project is limited to not operate in bad weather conditions with heavy rain, high wind speeds and poor visibility, which can occur in the fjords. To sum this up, the project is limited to the following list:

Project limitations:

- Flying to and from the iceberg
- Using an existing flying platform/drone
- Doing missions from a boat
- Only flying in good weather conditions

All this leads to the Problem statement which is the backbone of the project.

2.3 Problem Statement

Research on icebergs is limited as it is hard to collect data in the harsh environment where icebergs are formed. It is expected that the icebergs can be of great importance to the climate's behaviour, and therefore time and effort is put into expanding the knowledge of the phenomenon, called icebergs. Dan Carlson from the Arctic Research Center at Aarhus University is determined to explore this field, and therefore the group from ASE has accepted to help him gather these important data sets. Taking the Project limitations in Section 2.2 into consideration, it is possible to establish a Problem statement:

Problem statement:
Is it possible by the group from Aarhus School of Engineering to make a flying device, which can be operated from a boat, and which can collect the data needed for Dan Carlson to complete his research?

From this Problem statement a Specification of Requirements will be made. This will help to determine where the main focus of the project should be (Must have requirements), and which elements are of less importance (Should have and Could have requirements). If there is time to implement functions from the "Should have and Could have"-lists, it will be done in prioritized order, according to Dan Carlson. The Project limitations, the Problem statement and the Specification of Requirements were accepted by Dan Carlson, the group and the groups supervisor on ASE Claus Melvad at the start of the project.

2.4 Specification of Requirements

In order to establish the requirements for the project as a whole, a Specification of Requirements has been made. It consists of a list with Functional requirements and from here a set of Product requirements which has been spawned from the Functional requirements. The tables are divided into 7 columns;"Description of Requirement", "Must have", "Should have", "Could have", "Won't have", "Verification of Requirement" and the "Source of Requirement". This type of list is called **MoSCoW**. The MoSCoW list divides the Requirements into 4 categories, which makes it easier to prioritize the project requirements, and which things "won't" be implemented. The last two coloumns describes how the requirement can be verified and who is the source for making the requirement. The weight estimations can be seen in Appendix A.2.

Functional requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The drone should be able to be operated from a boat	Operation from a modified boat	-	Operation from a boat with no modifications	-	Site Assembly test (SAT)	Dan Carlson
The drone should be able to operate in the arctic environment	Operate in good weather conditions, with moderate wind speeds	Operate in light rain and mist, with slightly higher windspeeds	-	Flight in snowy weather, heavy fog and heavy wind	Expert knowledge from DroneVolt.dk	Generic
If complications occur, the drone should not be lost	The drone can be rescued	The drone can rescue itself	-	-	SAT	Claus Melvad
The drone should be able to extract an ice sample of a desired weight and transport it back to the boat	The controls will be operated completely by the user via remote control	The drone has (semi-) autonomous function for taken the sample when landed	-	-	Extracting test, Flight test	Dan Carlson
The drone should be able to fly unhindered with the required payload	The drone will only have one tool	The drone will have interchangable tools for different applications	The drone can carry all of its tools at once	-	Datasheet for drone, Flight test	Generic
The operator should be able to inspect if the tools are working properly when on mission	-	Videofeed to inspect operations	Monitoring operation data from the tools (rpm, drilling speed, amps)	-	Extraction test	The group

Functional requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The drone should be able to have a flighttime which is enough to get it safely to and from the iceberg	The drone can fly to and from a nearby iceberg	-	The drone can fly to and from an iceberg with a safety distance	-	Datasheet for drone, Flight test	Dan Carlson
The drone should be able to land and take off from an iceberg	Flat and almost level surface on the iceberg, no snow	More rough surface with a slight angle, little snow	-	Icebergs covered in deep snow	Take off and landing test	Dan Carlson
The drone should be able to transport and drop an EXITE GPS beacon onto the iceberg	The controls will be operated completely by the user via remote control	-	The drone has (semi-) autonomous function for releasing GPS	-	Drop test, Flight test	Dan Carlson
It should be easy for the operator to assemble the drone and get it ready to fly as well as disassemble the drone and pack it down for transport	The drone will require several people to setup and pack down	The drone can be setup and packed down by one operator in decent time	-	-	SAT	The group
The operator should be able to test all of the drones functions before take off	The drone will have a manual test program operated by the user	-	The drone will have a fully automatic test program	-	SAT	Dan Carlson
The drones landing gear should be stable and steady, with no sliding	The drone can stand on the iceberg with only little tipping	The drone can stand on the iceberg without any tipping	-	-	Take off and landing test	The group

Functional requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The drone should be delivered with a user manual	A thorough paper manual	-	A video guide	-	SAT	Dan Carlson
The drone should be able to release its tools, if they get stuck	-	The operator can release the tools if they get stuck	The drone can detect if the tools get stuck	-	Extraction test	Claus Melvad
The drone should not be of any hazards to the users	FMEA should be made to minimize risks	-	-	-	SAT	The group
The drone should have an alarm that signals if the iceberg is rolling	The program can detect and alarm the operator	-	The program can detect and alarm the operator from the controller	-	Rolling iceberg test	Dan Carlson
The drone should be able to fly several missions each day of operation	The batteries should be rechargeble	The batteries should be rechargeble and changeble on the boat	-	-	Datasheet for drone batteries, Datasheet for battery charger	Dan Carlson
The drone should be able to send a videofeed back to the operator	-	The videofeed should be in usable quality	The videofeed should be in good quality at good FPS	-	Datasheet for drone camera	The group

Functional requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The drone should be able to measure the core temperature of the iceberg	-	-	The measurement will be done by the operator manually on the ice sample	The drone has a tool for measurering core temperature	Extraction test	Dan Carlson
The drone should be able to measure the reflection from the iceberg with a light calibrated camera	-	-	The drone can take photos of the surface which can be analysed	-	SAT	Dan Carlson
The drone can circle the iceberg and take photos for a 3D scan	-	-	-	The operator should be able to manually do a 3D scan	SAT	Dan Carlson
The drone should be able to take an ice sample wihtout contaminating it with iron particles	-	The drone will not contaminate the ice with iron	-	-	Extraction test	Dan Carlson
The drone should able to be disassembled back to normal working condition	The drone can come back to stock form	-	-	-	SAT	Claus Melvad
The price of the final device, should not exceed the budget	The price of the device must be within budget	-	-	-	Final costs	Claus Melvad
Flying the drone must be done by	VLOS (Visual Line Of Sight)	VLOS + FPV (First Person View)	-	-	SAT	Dan Carlson

Functional requirements						
Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The drone must be transportable	Safe carrying case for the drone	Safe carrying case for the drone an carrying case for the tool/tools	Safe carrying case for the drone with the tool/tools mounted	-	SAT	Claus Melvad

Product requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The equipment should work in arctic temperatures	Operation temp: 0°C	Operation temp: -10°C	Operation temp: -15°C	-	Datasheet for electronics	Average day winter temperature in Greenland: -10°C
The drone should be able to fly in moderate winds	Avg. windspeed: 5m/s	Avg. windspeed: 10m/s	Avg. windspeed: 15m/s	-	Datasheet for drone	Dan Carlson
If the drone has to land on water	Float so it will not sink with a weight of 16kg	-	Landing gear with water landing capability weigth of 16kg	-	Buoyancy calculations, (Water test)	Claus Melvad
If the drone looses signal to the radio	-	Fly to home and hover within a range of 100m from the boat	Fly to home and hover within a range of 10m from the boat	-	Datasheet for drone, Flight test	The group
Ice sample weight when delivered	Between 500-1000g	-	Over 1000g	-	Extraction test	Dan Carlson
The drone should have a payload that fit the rough estimates of the weight calculations	4 kg	6 kg	-	-	Datasheet for drone, Weight estimations	The group
Camera feedback	-	The camera can be controlled in 1 direction, tilt	The camera can be controlled in 2 directions, rotate	-	Datasheet for Gimbal	The group
The battery capacity should allow the drone to fly to and from iceberg	100m away from the boat	-	2km away from the boat	-	Datasheet for drone, Flight test	Dan Carlson
The radio transmitter should have a range of at least	200m	-	2,5km	-	Datasheet for transmitter	The group

Product requirements						
Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
The drone should be able to land and take off from an angled iceberg surface	-	5° angle from waterlevel	10° angle from waterlevel	-	Take off and landing test	Dan Carlson
Recesses, snow and grooves on the surface of the iceberg may not exceed	-	2cm in depth	5cm in depth	-	Take off and landing test	Dan Carlson
The type of sediment in the ice sample	-	Sand and stones < 0,2cm in diameter	Sand and stones 1-2cm in diameter	Sand and stones < 2cm in diameter	Extraction test	Dan Carlson
The drone should be able to carry a EXITE GPS beacon	Weight: 800g	Weight : 1500g (extra housing?)	-	-	Datasheet for drone, Drop test	Dan Carlson
Setup/pack down time for the drone	1 hour with help from several users	30 minutes for one user	-	-	SAT	The group
The user can test the drones functions before flight	-	Test takes under 15 minutes	Test takes under 5 minutes	-	SAT	The group
When landed on ice, the drone may not slide before drilling more than	-	10cm from landing spot	1cm from landing spot	-	Take off and landing test	The group
The camera angling can be used to monitorize the extraction	-	Tilt on camera: <90°	Tilt on camera: 180°	-	Datasheet for Gimbal	The group
The drone should be able to detach its tools if stuck within	-	2 minutes	30 seconds	-	Extraction test	The group
The rolling alarm should have a sampling time of	-	Sampling time: 10Hz	Sampling time: 100Hz	-	Datasheet for sensor	The group
The rolling alarm should have a sensitivity of	-	Sensitivity: +- 1°	Sensitivity: +- 0,5°	-	Datasheet for sensor	The group

Product requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
Videofeed quality	-	Quality: 480p@15FPS	Quality: 720p@30FPS	-	Datasheet for drone camera	Dan Carlson
The sampling rate of reflection photos	-	2 megapixel @1FPS	5 megapixel @2FPS	-	Datasheet for reflection camera	Dan Carlson
The sampling rate of 3D scan photos	-	2 megapixel @1FPS	2 megapixel @1FPS	-	Datasheet for 3D scan camera	Dan Carlson
Iron contamination less than	-	0,1µg iron per 1g ice?	0,01µg iron per 1g ice?	-	Chemical test	Mikeal Sejr
The drone should be able to fly safely even if there is interference from the boat or from the poles	The drone should be able to fly back	-	The drone should be immune against interference	-	Datasheet for flightcontroller with GPS/Compas, Flight test	Claus Melvad
The drone should be able to fly back with engine breakdown	1 engine breakdown	-	2 engine breakdown	-	Datasheet for drone	Claus Melvad
The ice sample should have a depth of	At least 10cm	-	20cm	-	Extraction test	Dan Carlson
Time between missions	-	2 hour between test, for recharging batteries	30 minutes if batteries can be swapped	-	Datasheet for battery charger	The group
The price of the final device, should not exceed 100.000DKK	The price of the device must be under 100.000DKK	-	The price of the device should be under 50.000DKK	-	Final costs	Claus Melvad
The price of the flying platform (drone) should not ecxeed 50.000DKK	-	The price of the device must be under 50.000DKK	The price of the device should be under 25.000DKK	-	Final costs	The group

Product requirements

Description of requirement:	Must have requirement:	Should have requirement:	Could have requirement:	Won't have requirement:	Verification of requirement:	Source of requirement:
Flying capabilties in high relativ humidity (100%RH)	-	Flight in mist (impaired visibility)	-	Flight in fog (less than 1 km visibility)	SAT	Dan Carlson
The drone must have a weight under	25 kg as per Danish law	-	-	-	SAT	Claus Melvad
The drone must be transportable	Safe carrying case for the drone	Safe carrying case for the drone an carrying case for the tool/tools	Safe carrying case for the drone with the tool/tools mounted	-	SAT	Claus Melvad
For the drone to be operated from a boat, it may not exceed	2x2m in width and depth, and 1,5m in height	-	-	-	SAT	Dan Carlson

3 Methods

As this is a scientific report, several different tools and methods will be used throughout, and in this section these will be described.

3.1 MoSCoW list

This type of list is used to prioritize the requirements for the project into 4 groups from "Must have" to "Won't have", see Section 2.4 for a more detailed description.

3.2 Use-cases

Use-cases are used for organizing the functions of software where there are interactions between the user and the program. Use-cases will be used to analyse the situations where the user interacts with the program, which will help when designing the software with interactions. Use-cases will be described in more detail in Section 4.1 where it is used.

3.3 Morphology diagram

This tool is used in the design choice phase in order to make well considered and objective decisions. The diagram consists of 7 steps:

- **Step 1:** Divide the problem into subsystems, so it is easier to evaluate the different parts of the project
- **Step 2:** Brainstorm ideas on how to solve the subsystems, where any idea is welcome
- **Step 3:** Determine selection criteria, so the ideas can be evaluated equally
- **Step 4:** Make a chart evaluating the ideas, here several types of diagrams can be used, but in this report Pugh Matrix and PW diagram will be used (the two types of diagrams are described underneath)
- **Step 5:** Make a Synergy diagram containing the 2-3 best ideas for each subsystems, to get an overview of the potential solutions
- **Step 6:** Make synergies and solution tracks, where synergies can give an idea of what ideas work well together and what ideas do not work well together. The solution tracks will be complete designs which can solve the task
- **Step 7:** Evaluate the solution tracks according to a set of criteria, for instance: Is it within budget? Does it meet the Specification of Requirements? Does it fit the time frame? From here the best complete design can be found

3.3.1 Pugh Matrix

The Pugh Matrix is an evaluating tool which is good for concept ideas, as it does not give a specific number, but just says whether or not it is better, the same or worse than a given baseline. It is done by setting one idea from a subsystem as the baseline and then evaluate the others with either 1, 0 or -1. By summing up the scores the best solution will be found. If the baseline is worse than some of the other ideas, a second Matrix with a new baseline is set up and evaluated again. The 2-3 best ideas can then move on.

3.3.2 PW diagram

The PW diagram is good for component evaluation, as it assigns specific numbers for each criteria. For every selection criteria a number from 1 to 5 will be given according to premade intervals for each score. For instance a "Weight" under 200 g could give a score of 4 points. Each selection criteria will also have a weighting, according to how important it is to the project. By multiplying the score with the weighting and then adding up the criteria, a final score can be found for each idea. Again the 2-3 best ideas can then move on.

In this report, the synergy will be found on a concept level, and therefore not on component level.

3.4 7 step rocket for software

The 7 step rocket is used to design, create and debug software. In this report the 7 step rocket will be used to create the main program, and will be used in Section 7. The 7 steps are described underneath.

The 1st step: Problem definition
In this step it is specified what the program should be able to do and what the in- and out-puts will be.

The 2nd step: Specification of Requirements
In this step the need- and nice to haves for the software are specified.

The 3rd step: Software architecture and design
In this step flowcharts and Use cases are used to describe what the software should do. Also keyfunctions are identified and made into their own support functions for the main program.

The 4th step: Support functions development
In this step the support functions are split into smaller functions making them more manageable.

The 5th step: Debugging of support functions
In this step the support functions are debugged to make sure they work before they are implemented in the main program.

The 6th step: System integration
In this step the support functions are integrated into the main program.

The 7th step: Validation and integration test
The final step is to validate the software as a whole.

3.5 Experimental report

As this project contains many tests and experiments it is important to organize all the data and observations. Here "Experimental reports" will be used containing 6 items:

- Purpose
- Theory behind experiment
- Experiment; Test equipment, Test setup and Procedure
- Results and calculations
- Sources of errors
- Summary

By filling in these 6 items, all information will be stored for future use.

4 Design choices

This section will describe the process of making the different design choices for the device. In this section it is important to be as objective as possible in order to find the best solutions, and therefore two different tools have been used. The first tool is Use cases where the interaction between the user and the software is defined, and the other tool is the Morphology diagram, which helps pick out the best ideas for the final solution.

After the selection process the Final design, will be evaluated according to the different risks it may have. This Risk assessment may add additional requirements for the device.

4.1 Use-cases

In order to secure that the software which interacts with the user is behaving as expected, the drone's Use cases will now be listed. The Use case tool consists of a 7 step process to describe each case, which can be of help when the software is being developed. The process also makes sure that alternate situations which may occur are being accounted for in the software.

4.1.1 Step 1: Define the actors

To begin with the different users who will interact with the drone, will be listed.

- Drone operator
- Service personnel

Since it is a research based device, there will only be two actors of the product.

4.1.2 Step 2: Define the primary Use cases

The Use cases for each actor will now be defined. This is the different situations where the interaction happens.

Use cases for: Drone operator

- Test program before take off
- Program for replacing parts
- Initiate extraction process when on mission
- Release GPS beacon on iceberg
- Release tools if stuck in iceberg
- Tilt camera
- Take off from boat
- Take off from iceberg
- Flying to and from iceberg
- Landing on iceberg
- Landing on boat

Use cases for: Service personnel

- Test program for checking functionality
- Program for making service and replacing parts
- Release tools
- Software update
- Test take off
- Test flying
- Test landings

There are only two actors, but they will have to do many things each.

4.1.3 Step 3: Identify reuse opportunities

Next, overlapping Use cases will be listed, which will make the programming easier.

Reuse opportunities

- The test program for checking functionalities, making service and replacing parts
- Take off
- Flying
- Landing

As the project is limited to use an existing flying platform, all of the taking off, flying and landing will be handled through the software on the drone's flight controller. This will therefore not be in focus for this project. Furthermore the cameras are often an integrated part of the drones, with built in tilting systems. This will also be handled through the flight controller.

The test software can contain several functions in one program. Before taking off, the operator should be able to check all of the functions of the drone. But the same software could also be used for making service and replacing parts, if the program has several steps that the user has to go through. Therefore the test program can be reused for three things.

4.1.4 Step 4: Create an overview

The next step is to create an overview of the Use cases, in order to pick the most important ones to describe further, see Table 4.1. The table contains information about the Use case, its actors, the complexity of the software which has to be developed and how important the Use case is to the project. The complexity is rated from Low-Medium-High, where High is a hard task. The priority is also rated from Low-Medium-High, where High is the most relevant ones to the project.

ID	Name	User	Complexity	Priority
1	**Test program for checking functionality, making service and changing parts**	**Generic**	**Low**	**High**
2	**Initiate extraction process**	**Drone operator**	**High**	**High**
3	**Release GPS beacon**	**Drone operator**	**Low**	**High**
4	Release tools if stuck	Drone operator	High	Medium
5	Software update	Service personnel	Medium	Low

Table 4.1: Overview of Use cases

From Table 4.1 it is selected that the three most relevant Use cases are the Test program, Extraction and Release GPS, as they all have high priority. Other than the Extraction process, the complexity of these Use cases are Low to Medium, which makes it a less complicated task to solve an important problem.

4.1.5 Step 5: Identify key components

The 5^{th} step is to identify key components of each of the three selected Use cases. In the following tables the Use cases have been analysed by identifying: Preconditions, Success criteria and in- and outputs.

Use case ID: 1

ID	1
Name:	Test program for checking functionality, making service and changing parts
Actor:	Operator, Service personnel
Precondition:	Start Test program=TRUE, Grounded=TRUE
Success:	Test program executed
Description:	The operator is able to test all functionalities, make service and change parts before flight
Inputs:	Start "Test program"=TRUE, Grounded=TRUE
Outputs:	Test sequence over buzzer=TRUE

Table 4.2: Test program key components

Use case ID: 2

ID	2
Name:	Initiate extraction process
Actor:	Operator
Precondition:	Start Extraction=TRUE, Grounded=TRUE
Success:	Extraction of an ice sample is done
Description:	The operator is able to start the extraction of an ice sample
Inputs:	Start Extraction=TRUE, Grounded=TRUE
Outputs:	Extraction process done=TRUE

Table 4.3: Extraction key components

Use case ID: 3

ID	3
Name:	Release GPS beacon
Actor:	Operator
Precondition:	Start "Release GPS beacon"=TRUE, Grounded=FALSE
Success:	Beacon dropped
Description:	The operator is able to drop the GPS beacon onto the iceberg
Inputs:	Start "Release GPS beacon"=TRUE, Grounded=FALSE
Outputs:	GPS beacon dropped=TRUE

Table 4.4: Beacon drop key components

From these key components, it is possible to make flowcharts for the software.

4.1.6 Step 6: Create the basic flow

Next step is to visualize the basic flows of the Use cases, which describes how the software should work under ideal conditions.

Use case ID: 1

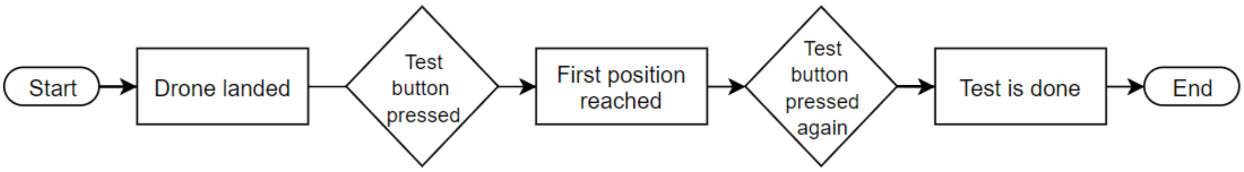

Figure 4.1: Basic flow: Test program

Use case ID: 2

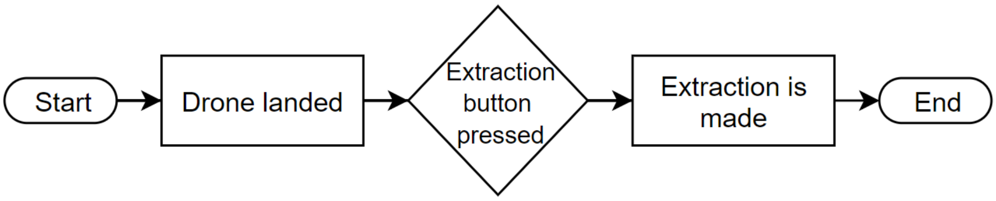

Figure 4.2: Basic flow: Extraction

Use case ID: 3

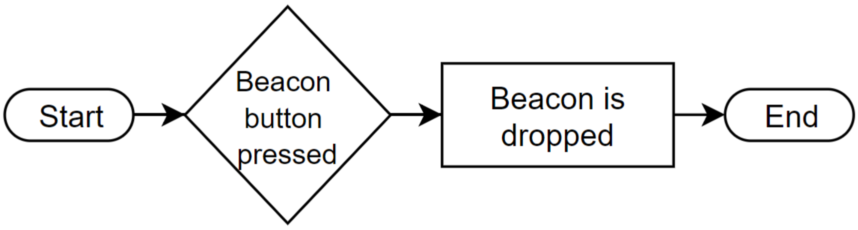

Figure 4.3: Basic flow: Release GPS

4.1.7 Step 7: Create the alternate flow

The last step is to identify the alternate flows of the Use cases. This is done by imagining what could go wrong and where in the flow process. After identifying what could go wrong a response can be added.

Use case ID: 1

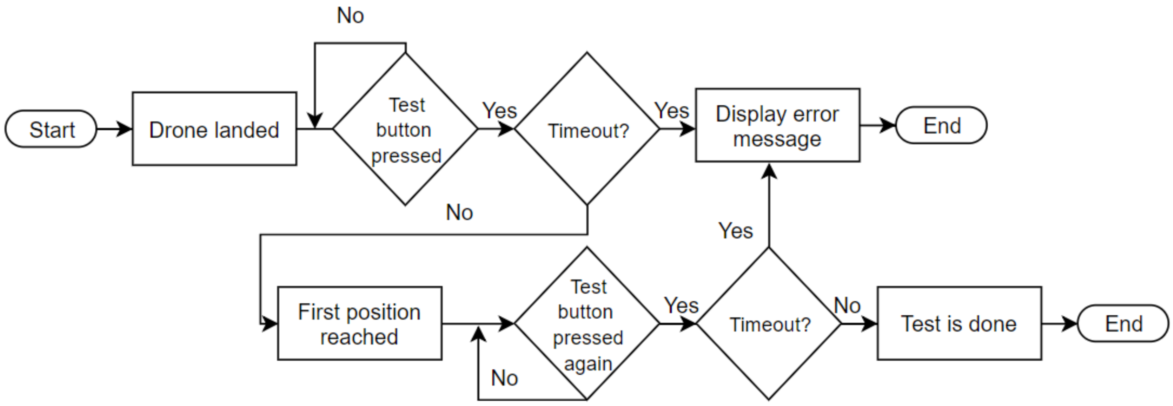

Figure 4.4: Alternate flow: Test program

Use case ID: 2

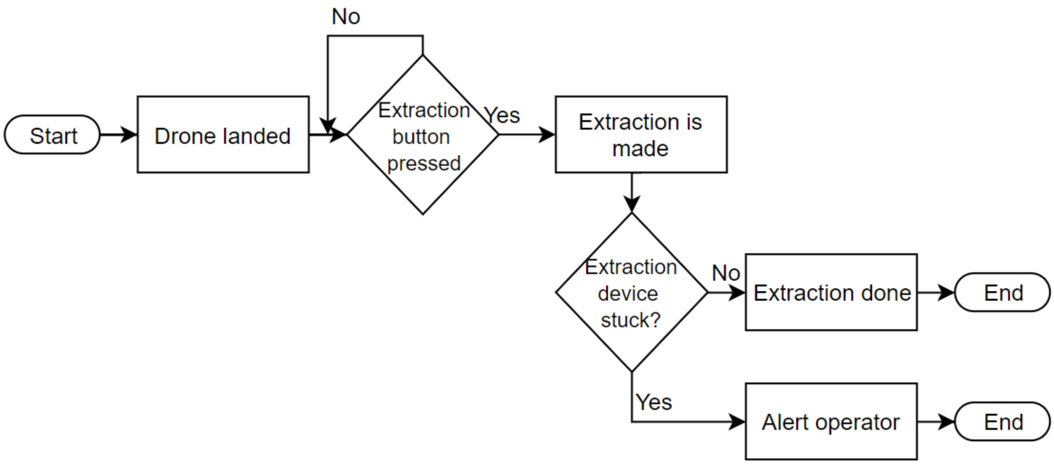

Figure 4.5: Alternate flow: Extraction

Use case ID: 3

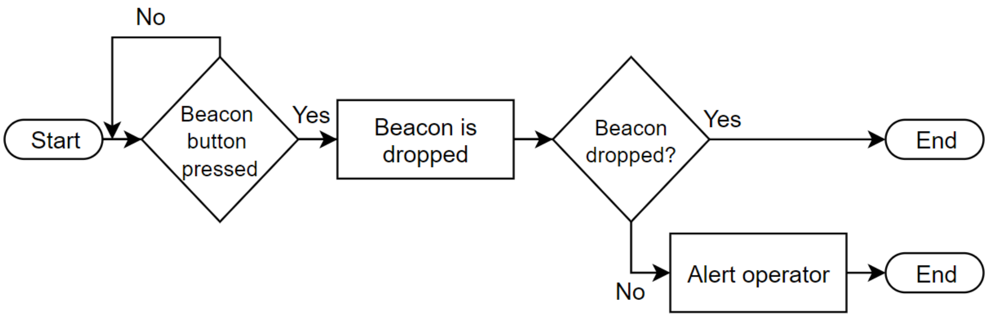

Figure 4.6: Alternate flow: Release GPS

This process is going to help develop the software for the different situations where the user and the software interacts with each other. In order to have an overview of what is wanted and what can go wrong, Use cases is a useful tool.

4.2 Morphology diagram

In order to make objective decisions when choosing a design, three methods introduced in Section 3 will be used. The first is a general tool for finding a complete solution consisting of 7 steps called Morphology diagram. The second and third are tables for evaluating a specific subsystem in Step 4 of the Morphology diagram, called Pugh Matrix and PW diagram. The Pugh Matrix is useful when choosing an idea on conceptual basis, where the PW diagram is better on component basis.

As the project is already limited to using a flying platform/drone, the first step is to find a suitable drone, to have a starting point for the evaluation of ideas. In Appendix A.3, the selection of the drone can be seen, which ended up with a **DJI Matrice 600 Pro**, see Figure 4.7 for the drone and naming of the parts. A DJI Zenmuse X3 camera with built in gimbal was recommended, which will be used as camera on the drone, as it has good image quality and is easy to control. Furthermore a NI myRIO was chosen as the microprocessor, which will be described in Section 6.1.

Figure 4.7: DJI Matrice 600 Pro with parts named

The next step in the design phase, is to make the 7 steps of the Morphology diagram using Pugh Matrix to evaluate concepts. When the Pugh selection is over, which will be done in Appendix A.3, the 2-3 best ideas will be evaluated in the main report by finding synergies between the ideas. After this two final concepts are created and the complete concepts will then be evaluated. This evaluation leads to finding the final concept of the drone.

The second and last step in the design phase is to make a second Morphology diagram (only Step 2-4) using PW diagram to evaluate the winning concept for each subsystem on component basis. As synergies has already been found on a conceptual basis, the best ideas from the PW diagrams will be the final components.

4.2.1 Design phase 1: Conceptual basis

The first step of the Morphology diagram is to divide the problems into subsystems.

4.2.1.1 Step 1: Subsystems

A total of 6 subsystems are made:

- **Sample taking and extraction:** How to free the ice and pick it up
- **Raising/lowering mechanism:** If needed, how to lower and raise the sample mechanism
- **Landing gear:** Types of landing gear
- **Beacon release:** Release system for the GPS beacon
- **Floatation:** How to keep the drone afloat if it emergency lands in the water
- **Iceberg roll alarm:** To detect if the iceberg is rolling

Step 2-4 with evaluation for each of the 6 subsystems will be covered in detail in Appendix A.3, which means that the next step in the main report will be Step 5.

4.2.1.2 Step 5: Make a Synergy diagram

In order to get an overview of which ideas have been chosen in Appendix A.3, a Synergy diagram has been put together. This diagram will be used in Step 6 to find correlations and potential solution tracks. The Synergy diagram can be seen in Table 4.5.

Subsystems:			
Subsystem:	Potential solution 1	Potential solution 2	Potential solution 3
Subsystem 1 -Sample taking and extraction	***Self collecting cup drill***	***Thermal scoop***	***Dropping wedge***
Subsystem 2 - Raise/lowering mechanism	***Scissor lift***	***Linear actuator on landing gear***	
Subsystem 3 - Landing gear	***6 legs from arms***	***3 legs, 1 from 2 arms***	
Subsystem 4 - Beacon release	***Transport in a rope with hook***	***Hook directly on beacon***	
Subsystem 5 - Floatation	***Float on landing gear***		
Subsystem 6 - Iceberg roll alarm	***myRIO acc. With alarm on drone***	***myRIO acc. With alarm on controller***	

Table 4.5: Synergy diagram for Design phase 1

4.2.1.3 Step 6: Correlations and potential solution tracks

Table 4.5 is in Step 6 used to make correlations between the different ideas. If two ideas are a good match they will be marked with a green arrow, while ideas which do not go hand in hand will be marked with a red arrow. Furthermore Table 4.5 will be used to find two potential solution tracks, which will be evaluated in Step 7. It can be seen that there are several good correlations between the Landing gears and the Sample takers, which means that they fit each other well no matter the combination.

Solution track 1
This solution track will use a Thermal scoop to take and extract the sample, and use a scissor lift mechanism to lower and raise the scoop. The beacon will be placed directly under the main frame in a hook, and the roll alarm will send a signal to the controller, see Table 4.6.

Subsystems:			
Subsystem:	Potential solution 1	Potential solution 2	Potential solution 3
Subsystem 1 -Sample taking and extraction	*Self collecting cup drill*	*Thermal scoop*	*Dropping wedge*
Subsystem 2 - Raise/lowering mechanism	*Scissor lift*	*Linear actuator on landing gear*	
Subsystem 3 - Landing gear	*6 legs from arms*	*3 legs, 1 from 2 arms*	
Subsystem 4 - Beacon release	*Transport in a rope with hook*	*Hook directly on beacon*	
Subsystem 5 - Floatation	*Float on landing gear*		
Subsystem 6 - Iceberg roll alarm	*myRIO acc. With alarm on drone*	*myRIO acc. With alarm on controller*	

Table 4.6: Correlation diagram for Solution track 1

Solution track 2
The second solution track uses a Self collecting cup drill and linear actuators on the landing gear to extract and raise the sample. The landing gear consists of three legs mounted on 2 arms each and the GPS beacon will be transported in a rope with a hook. The roll alarm will send a signal from the drone to the user, see Table 4.7.

Subsystems:			
Subsystem:	Potential solution 1	Potential solution 2	Potential solution 3
Subsystem 1 -Sample taking and extraction	*Self collecting cup drill*	*Thermal scoop*	*Dropping wedge*
Subsystem 2 - Raise/lowering mechanism	*Scissor lift*	*Linear actuator on landing gear*	
Subsystem 3 - Landing gear	*6 legs from arms*	*3 legs, 1 from 2 arms*	
Subsystem 4 - Beacon release	*Transport in a rope with hook*	*Hook directly on beacon*	
Subsystem 5 - Floatation	*Float on landing gear*		
Subsystem 6 - Iceberg roll alarm	*myRIO acc. With alarm on drone*	*myRIO acc. With alarm on controller*	

Table 4.7: Correlation diagram for Solution track 2

4.2.1.4 Step 7: Evaluate solution tracks

The last step is to evaluate the solution tracks from Step 6 in an evaluation table, to see if they satisfy the requirements for the project.

Evaluation: Solution track 1
This solution track fails as the beacon can be damaged if dropped from a height, which will happen with this release mechanism, see Table 4.8.

Requirement for Solution track	Satisfied? (✓ / ×)	Comment:
Price within budget	✓	It is estimated that the drone can be developed and build within budget
Does it fulfil the Use Cases?	✓	Yes, that should be fine
Does it fulfil the Specification of Requirements (SoR)?	×	If the beacon is dropped from a height, it could be damage
Possible to add further functions from the SoR?	✓	Yes, that should be fine
Possible within time frame of project?	✓	Yes, that should be fine

Table 4.8: Evaluation diagram for Solution track 1

Evaluation: Solution track 2
The second solution track fulfils all the criteria, see Table 4.9. Furthermore it is expected that the landing gear with linear actuators can be made more stable and weigh less, than fixed landing gear with a scissor lift, therefore this concept was chosen to move on with.

Requirement for Solution track	Satisfied? (✓ / ×)	Comment:
Price within budget	✓	It is estimated that the drone can be developed and build within budget
Does it fulfil the Use Cases?	✓	Yes, that should be fine
Does it fulfil the Specification of Requirements (SoR)?	✓	The beacon can be put on the ground safely
Possible to add further functions from the SoR?	✓	Yes, that should be fine
Possible within time frame of project?	✓	Yes, that should be fine

Table 4.9: Evaluation diagram for Solution track 2

Even though a final design has been chosen it is hard to differentiate between the three types of Sample taking ideas, as it is hard to know how they perform in real life. Therefore the next step will be to test all three Sample taking ideas in three simple experiments. These three experiments will be used to determine which of the Sample taking ideas will be used in the final concept.

4.2.1.5 Choosing the Sample taking device

As described above, it is hard to determine which of the three ideas for taking samples is the best. Therefore the three types of extracting ice have been tested.

The test for thermal drilling can be seen in Appendix A.4, where it was discovered that Thermal drilling has the problem of not being able to pump enough heat into the edge of the cutting plate. This made it impossible to drill past 1 cm. Therefore Thermal drilling is off the table.

The test with wedge dropping, can be seen in Appendix A.5, where it was discovered that the debris from the drop varied too much in size, and often without any usable pieces of ice. The drop test revealed that the wedge is too unreliable, and that the pieces flew all over the ground, which will make it hard to recover a sample. This means that wedge dropping is also off the table as a possible solution.

The last test was the most promising as mechanical drilling is often used in bigger ice drilling situations, as mentioned in Section 2.1. But these big drilling rigs are not necessarily suitable for a drone, which means that smaller drills needs to be tested, see Appendix A.6. Here it was discovered that mechanical drilling is an effective way of taking ice samples, though the test only focused on the drilling part, and not on the extraction part. Several things can be learnt from the experiment; the drill can be hard to get started, the drill has to get rid of the drilled material, and that too high of an rpm can make it unstable.

Combining the knowledge from the different drilling tests, it can be concluded that mechanical drilling is the way to go, and that it is necessary to have a center drill for keeping the drill stable during start up. Furthermore it can be concluded that the Kovac drill was really good at getting rid of the material, but that the two teeth on the drilling head made it harder to get started. In summary, the following four things should be in focus when designing the drill:

- Center drill for stability on start up
- More than two cutter teeth
- Good ability to remove material
- 500-800 rpm under load

4.2.2 Design phase 2: Component basis

In the next phase the components for the different conceptual subsystems will be found. This will be done by using Step 2-4 in the Morphology diagram; Brainstorm ideas on a component level, set up selection criteria and score tables, and then rate them in a PW diagram. As mentioned, the conceptual subsystems have already been evaluated in the Synergy diagram in Section 4.2.1.2, and therefore it was not found necessary to use the Synergy diagram on components.

Components have been selected for the following four subsystems, which can be found in Appendix A.7:

- Beacon release
- Iceberg roll alarm
- Linear actuator for landing gear
- Motor for drill

The floatation will be evaluated using tests, see Appendix A.8.

4.2.2.1 Beacon release

The chosen component for the beacon release ended up with being a solenoid actuator where the moving axle can pull back and forth, so the rope gets released. The chosen solenoid is a "Solenoid Framed 2924 Drück - 12V" from `www.elektronik-lavpris.dk`, which can be seen in Figure 4.8.

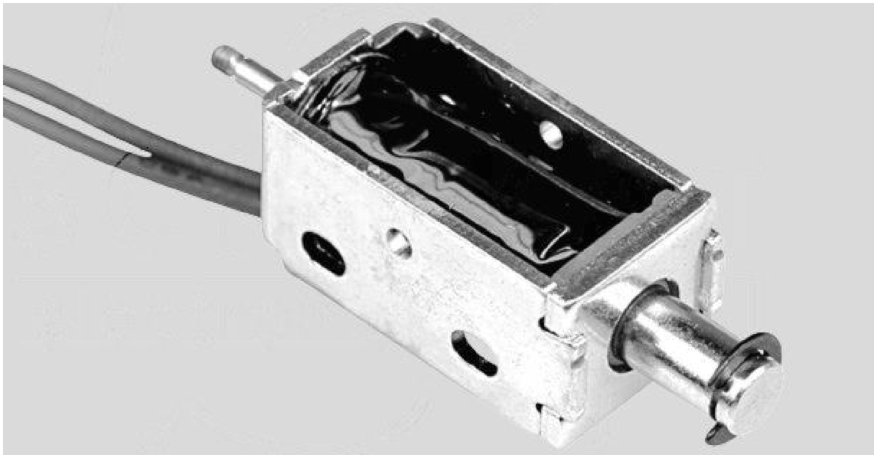

Figure 4.8: Solenoid from `www.elektronik-lavpris.dk`

4.2.2.2 Iceberg roll alarm

For the Iceberg roll alarm, a bicycle LED light from `www.cykelgear.dk` was chosen, which will be located on the drone so it is in the viewing field of the camera when drilling. The battery will be removed and cords will be soldered to the power source, so the LED can be operated from the myRIO with a transistor. This means that if the alarm is triggered from the myRIO, the LED will shine light into the camera and the operator will be alarmed. The bicycle light can be seen in Figure 4.9.

Figure 4.9: Bicycle LED from `www.cykelgear.dk`

4.2.2.3 Linear actuator for landing gear

For the landing gear, a hollow axle stepper motor with a leadscrew was chosen. This solution brings high precision and is relatively easy to implement. The hollow axle stepper can be seen in Figure 4.10.

Figure 4.10: Hollow axle stepper from `www.robotdigg.dk`

4.2.2.4 Motor for drill

The drill will be powered by a high performing brushless motor (LRP Vector K7 10.5T 3600KV) with a gearing mounted so the drill can spin at the desired speed. As the motor is turning at $3600kV * 12V = 43.200rpm$ without load, a gearing of 67:1 from `www.micromotors.com` will reduce the speed to an acceptable $\frac{43.200rpm}{67} = 645rpm$, which is within the wanted interval. The motor and gearing can be seen in Figure 4.11.

Figure 4.11: Gearing from `www.micromotors.com`, brushless motor from `www.midhobby.dk`

As the concept and the components have been selected the final design can now be described.

4.3 Final design

From the design phase a final design have been selected, and will be build around a **DJI Matrice 600 Pro**. The beacon release mechanism will be build using a **solenoid actuator**, which can open and close in order to drop the rope of the beacon. The landing gear will act as a **linear actuator** which will lower and raise the drone with **hollow axle steppers**. The drone will be fitted with a **mechanical cup drill** driven by a **brushless motor with a gearing**. If the iceberg is about to roll around, the operator will be **alarmed by an LED** which will shine light into the live feed camera. If the drone were to emergency land on the water, the **landing gear will be fitted with floats**, so it will not sink. The final design can be seen in Figure 4.12.

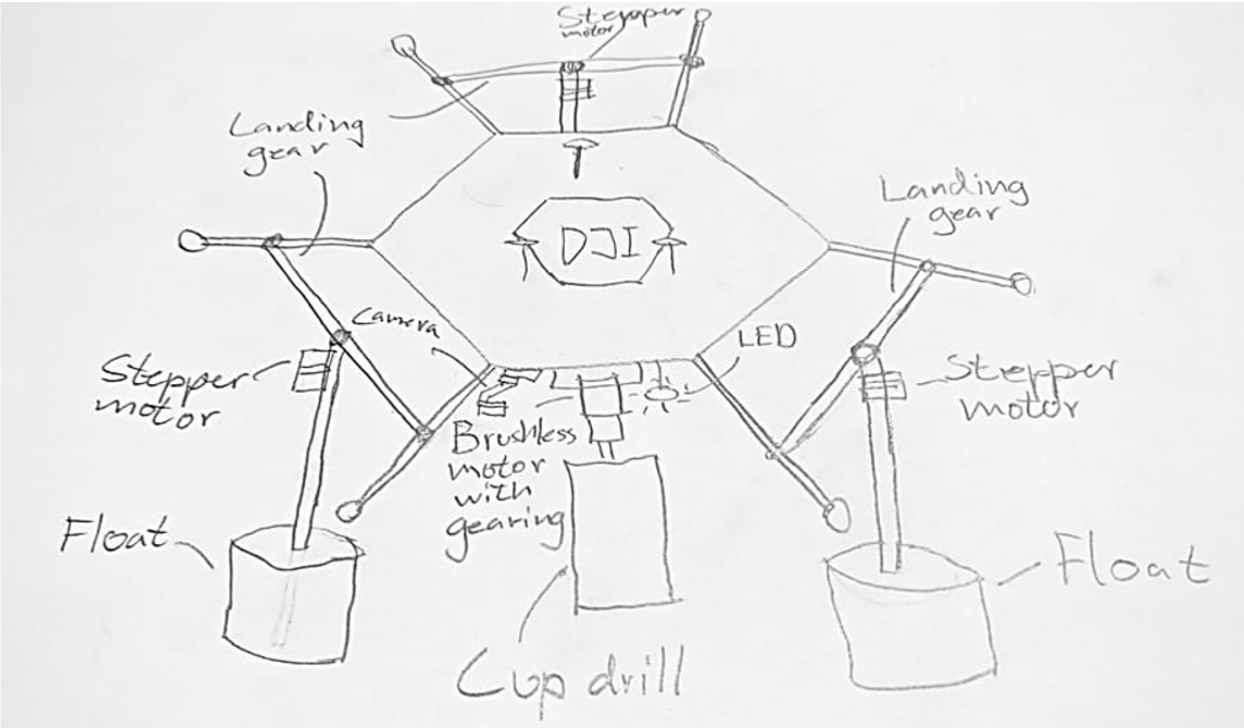

Figure 4.12: A drawing of the final design

Before the development process can begin, the last thing is to make a Risk assessment in order to catch any dangers which may occur because of the mission or the drone's design. The Risk assessment will follow in the next Section, 4.4.

4.4 Risk assessment

As part of the design process a Risk assessment has been made to evaluate the risks of the final product before, during and after using it. The Risk assessment chosen for this project is a FMEA, which is used to identify potential failures and the associated impact of the failure. The risks are then rated according to Severity, Probability and Detection. From this the Risk Priority Number (RPN) is calculated by multiplying the three parameters. Furthermore the FMEA will have recommended actions and a new RPN, after the actions have been taken. The full FMEA is shown in Appendix A.9.

4.4.1 Results of the FMEA

The Risk assessments effects on the Specification of Requirements as well as the design changes are listed in Table 4.10. It is important to note that the Risk assessment is an iterative tool as it should be evaluated often. Furthermore the Risk assessment is to be updated, if more failure modes are found, while the product is being tested in the field or while it is in storing. Therefore a Risk assessment is not only a tool to be used once and forgotten, but a tool to help improve the product through the entire lifespan.

	Risk reduction		
	Starting RPN	RPN, after actions taken	Removed RPN
	694	334	360
	Items added to Specification of Requirements		
1	The must have requirement of a detachment option for the drill will be reduced to a could have requirement, since the probability of the drill getting stuck is unlikely		
	Items added to the design		
1	Silicone was added to wires		
2	Wax added to the drill		
3	Endstops added to stepper motors		
4	Electronics compartment must be sealed		
5	Fuse added to both power sources, LiPo battery pack and drone supply output		
6	Locktite added to bolts		
7	LED's used to indicate the program is running		
	Items added to the user manual		
1	Floaters are not meant for water landings unless it is an emergency		
2	The drill should remain rotating		
3	The drone should not be operated in windy weather		
4	Electronics compartment must be checked before and after each flight		
5	Wax should be reapllied for every 5th drilling		
6	Heatpads are available if it is necesssary to heat the electronics		

Table 4.10: Changes made due to the FMEA

5 Mechanical design

This section will describe in detail how the mechanical components for the drone were developed. In Section 4.3 about Final design, the drones complete concept was described and it is from this design, that the drone's parts will be designed. There are two main mechanical systems which have taken up most of the time; the linear actuated landing gear and the ice drill with mount and motor. In this section, the first thing described will be the ice drill and afterwards the landing gear, even though these two systems were developed concurrently.

All parts are listed in Appendix A.21, and all the technical drawings for the components of the drone can be seen in Appendix A.22. The parts for the drone are primarily made without fillets, as this complicates the machining process, and makes every part more expensive. This is a compromise between the production time and price, and the parts have been evaluated to hold up, even though sharp corners can cause stress concentrations. Ideally all parts were made with appropriate fillets.

5.1 Design guidelines

First of all a set of general design guidelines will be set up for the construction phase:

- Wires and plugs should be easy to reach
- Wires should be put into bundles for the different components
- It should be easy to plug in the USB to the microprocessor for software updates
- It should be easy to reach the batteries
- Wire bundles should have plugs at the ends so it is easy to assemble and disassemble
- The center of mass from components should be kept in the middle of the drone
- Heat generating electronics should have sufficient cooling
- It should be easy to reach the components
- It should be easy to remove the drill
- Plugs should be secured with some kind of adhesive so they do not shake off
- The electric components should be able to operate in -10°C

These guidelines should be kept in mind during all constructing.

5.2 Mechanical ice cup drill

The first system is the mechanical ice drill, which was an iterative development process. It became clear very fast that ice is an unpredictable material, which makes drilling consistently a difficult task. Therefore a lot of hours were spent drilling in ice and trying to figure out what worked well and what should be improved.

From the Specification of Requirements, Section 2.4, the drill should pick up a minimum of 100 mm ice, weighing 0.5 kg. This will be used to find the dimensions of the cup drill.

5.2.1 Development of the center drill

In Appendix A.6 it was discovered that it was necessary to have a center drill as it was very difficult to get the drill started. The stable start up with the center drill is also used when using a normal wooden cup drill, so it is a proven design. The center drill and cup drill were also designed concurrently as the two designs had to work together.

Drilling in ice is, as previously said, very difficult because of the unpredictability of ice. Therefore the testing started by using three existing types of drills; a metal drill, a concrete drill and a wooden spade drill, as seen in Figure 5.1. The test was performed with an electrical drill with 4 kg of metal on top of the electrical drill, in order to have the same load when testing. The purpose of these early tests were to find a type of drill which worked well in ice, and which could then be made in an non-iron material, as this is an important requirement.

Figure 5.1: Three types of center drills

The first test showed that the concrete drill performed poorly, the metal drill worked okay, but the spade drill was the best out of the three, see Figure 5.2. From this test it became even more clear that it is very important that the drilled material can be removed from the hole as the built up material can reduce the drilling speed significantly. Here the spade drill had troubles when drilling further than the 50 mm.

Figure 5.2: The Ø16 spade drill after drilling a 50 mm hole

Therefore the next step was to improve the spade drill with canals for removing the material, with a 3D printed sleeve. The sleeve should have made it possible to keep the good drilling capabilities of the spade drill, but enable it to drill further down. Because of the size of the axle, it was not possible to make the grooves from the ribs deep enough to transport the snow away though, therefore this idea was scraped.

Figure 5.3: Spade drill with sleeve

As the removing of material was a thing which continued to be a problem, it was decided to try out a wooden snail drill, with really bit grooves for material, see Figure 5.4. This type of drill turned out to be really good at removing material even when drilling further down.

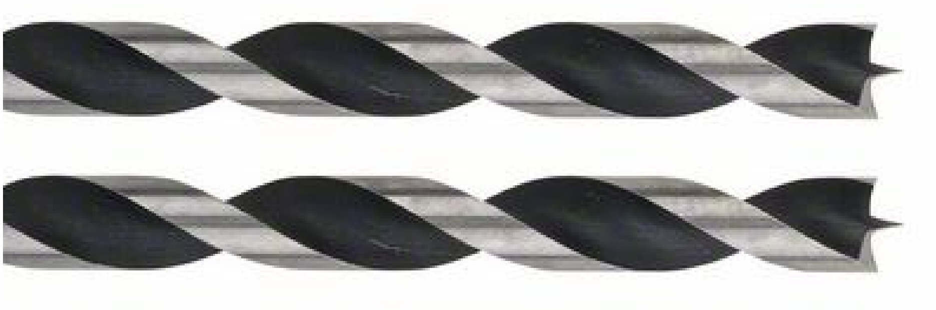

Figure 5.4: Wooden snail drill

As seen in Figure 5.4, the drill tip is really pointy and then flat, which was changed to a more conventional drill tip. This was done as a more aggressive tip was wanted, which ended up being even better. With 4 kg of metal on top of the electrical drill, the snail drill with the modified tip could drill a 200 mm hole effortless in 20 seconds. Therefore it was decided to move on with this type of drill, and see if it somehow could get manufactured without contaminating the ice core with iron.

5.2.2 Development of the cup drill

Concurrent to the center drill, the cup drill was also developed iteratively. An inspiration source for the cup drill was the ice drill from Kovac, lent by Arctic Research Center, AU, see Figure 5.5. Though a bit unstable at start-up, once the drill was going it drilled well, and with good removal of material. The Cutting head is designed with two cutter heads/teeth and on the inside with spring loaded hooks for picking up the ice, similar to the one in Section 2.1.

Figure 5.5: Kovac ice drill testing and design of cutting head

As it can be read in Appendix A.6, one of the reasons why the Kovac drill was hard at start-up was the fact that it only had 2 cutter heads/teeth. Therefore it was natural to have more teeth on the drill. In the article: "Drill Heads of the Deep Ice Electromechanical Drills"[10] it is described on page 17, that the most commonly used number of cutter heads is three, as it "provides smoother cutting and less vibrations"[10]. Furthermore the table on page 6 shows that 5 out of 7 different types of drills are using three teeth, which makes it the obvious choice to begin with.

The Kovac ice drill is produced using a Aluminium cutting head, high strength steel teeth and a glass fibre tube. In the cutting head there are two spring loaded hooks mounted, which was tested at the beginning. The tests showed that the hooks were in many cases not able to fold out, when pulling up. This made it not possible to free the ice at the bottom, which is a big concern. One thing is drilling in ice, another is to pick it up. Therefore the development had to focus on both parts.

The development of the cup drill began by seeking inspiration in the Kovac drill, just with three teeth and three hooks, see Figure 5.6. It was decided to go with a Ø70 inner diameter and a thickness of 10 mm, so the material had good access to be removed, and so that there was room for the hooks. The length of the cup was 250 mm which gave a total volumen of 0.93 L. This gave some headroom, and was a good compromise between drill diameter and length. A too big diameter makes drilling harder, and too long a drill makes the linear actuators heavier, as they need a longer stroke. The drill was designed in one piece of aluminium, which made machining complicated and expensive. The teeth were placed in an angle of 40°, as this was an average angle according to the table on page 6[10].

As the springs from the Kovac drill was too weak to engage the hooks, several ideas of spring designs were thought up. The hook itself is fine to make in aluminium, but the spring

[10] Drill Heads of the Deep Ice Electromechanical Drills

is way harder. After being in contact with "Sodemann industrifjedre" it was clear that springs in other metals than ferruginous metals (containing iron) were almost impossible. The only option was Beryllium-copper springs, but these springs have weak performance, and are expensive, with the upside being that they are non-magnetic. Whether using a leaf spring or a coil spring in ferruginous metals the spring had to be shielded off from the ice. Another alternative was to use a plastic spring, like when designing a snap-lock. These were the main ideas of how to solve the spring problem for the hooks in iteration 1.

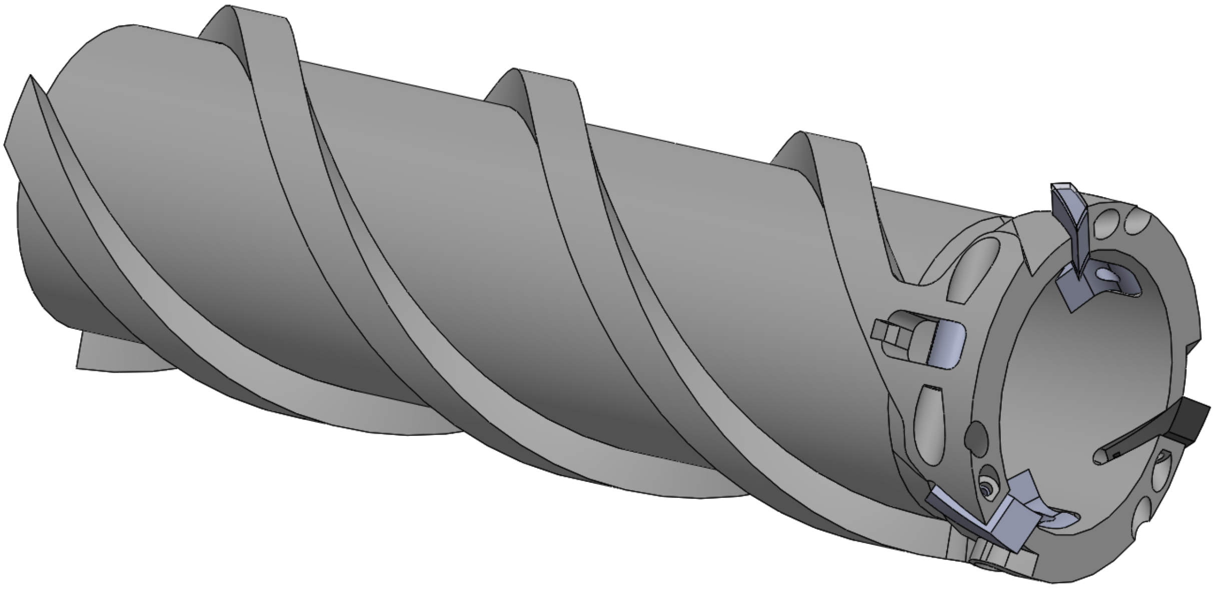

Figure 5.6: First iteration of the cup drill

As the first iteration had an overcomplicated design, and the fact that the springs were a big concern, the second iteration was to make the drill in two pieces and in a much simpler design without hooks, see Figure 5.7. As the hooks did not engage on the Kovac drill, it was hard to even know if the hooks would work as intended, therefore it made sense to make a simpler version, to test if the drilling part worked. The second iteration was made with an aluminium cutting head, an aluminium center tube and a 3D printed sleeve.

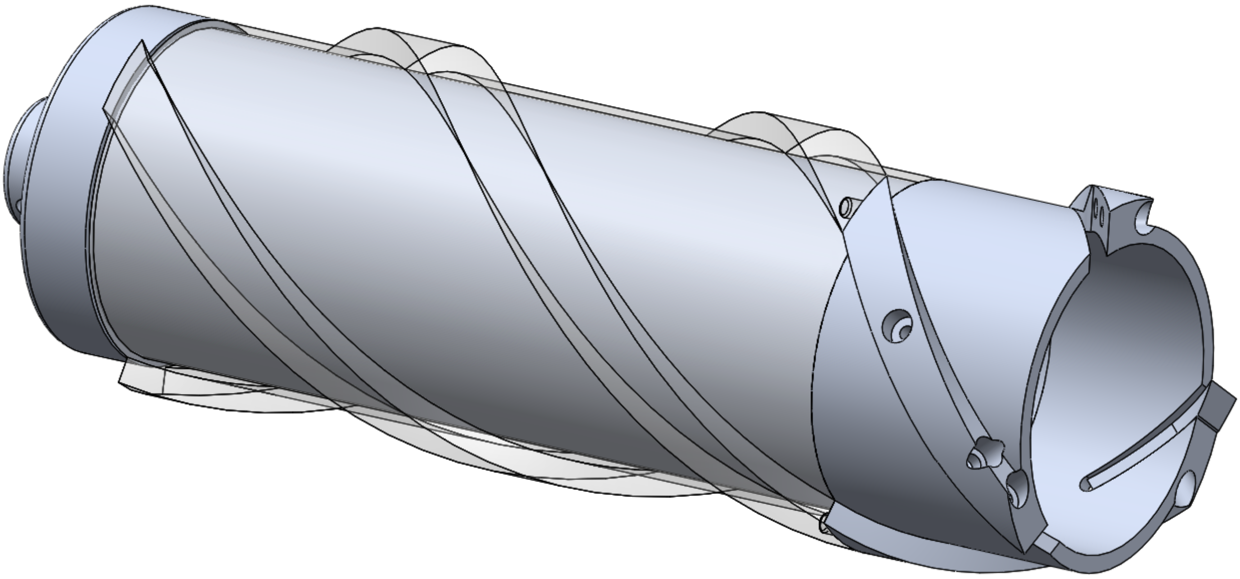

Figure 5.7: Second iteration of the cup drill

The second iteration was almost put into production, to see if the concept would work, but before the production started, it was decided to go with a 3D printed cutting head, as this was a rapid form of prototyping. The cutting head was reinforced for 3D print by making the ribs thicker, see Figure 5.8.

Figure 5.8: Third iteration of the cup drill

This cup drill was the first actual prototype, which was used for testing. The center drill was connected to the cup by a connector piece, see Figure 5.9.

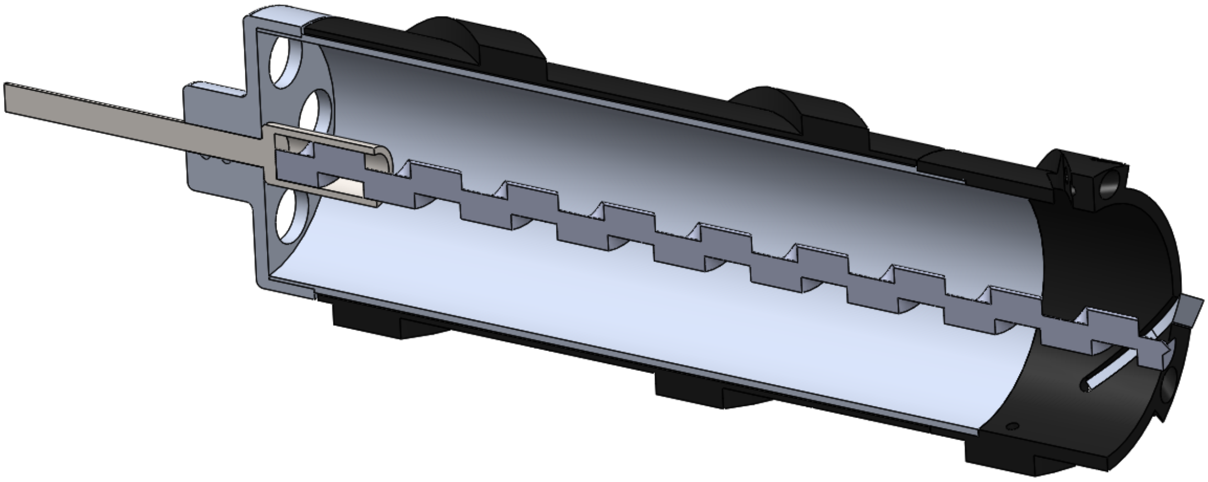

Figure 5.9: A cut through the drill

Testing with this drill was in general quite positive, and the group was able to drill out the first ever ice core, see Figure 5.10. The observations from these tests were that the drilled performed quite well but was a bit unstable when the teeth hit the surface ice. Furthermore it was also discovered that when the connector part for the center drill hit the ice, the ice core would break. The drill was tested using an electric drill with 4 kg of metal, and showed a high tendency to break off the ice without the use of hooks. The center drill provided good friction, so the ice core would stay in the drill when picked up, which was very interesting. Furthermore the 3D print held up great, so there were no need to change the material.

Figure 5.10: The first ice core drilled out

This led to the fourth iteration which was again inspired by the article: "Drill Heads of the Deep Ice Electromechanical Drills"[11]. On page 14, it is described how "Slotted and staggered cutters" are used to drill in warm ice. Even though it is cold ice on icebergs, the design makes sense, since it is also used in different conventional milling tools. By making different teeth for the cup drill, the shavings of material gets reduced in size making drilling easier, as it is less rough on the teeth. This was implemented in iteration four, see Figure 5.11, using the same cup drill.

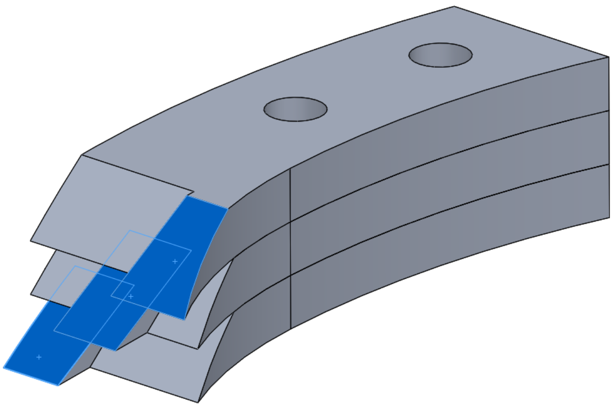

Figure 5.11: Cutter heads designed to drill in 3 different places

The three different cutter heads made a big difference in start up stability, and also made drilling easier in general. This was a big step in the right direction as the center drill and cup drill worked well, and had a high tendency to break off and pick up the ice core. So from here it was mainly small improvements. The first improvement was to add ski-wax to the

[11] Drill Heads of the Deep Ice Electromechanical Drills

cup drill and center drill. As seen in Figure 5.10, the cup drill is covered in a thin layer of snow, which had a small tendency to clog the removed material. In the world of skiing they have the exact same problem under the skies, therefore adding ski-wax on both the cup drill and center drill helped. It was discovered that the wax's effect wore off after approximately 5 drillings, which is the recommended waxing interval.

Furthermore small changes to the drilling head was made, as material was collected behind the teeth. This was fixed by removing the flat surface under the ribs, see Figure 5.12 where the chamfer is shown in blue. Furthermore fillets were added to both the drill head's and sleeve's ribs for increased strength. The last small change was the small screw holes in the ribs, which can be used to change the friction in the tube. This is a thing that can be experimented with in Greenland.

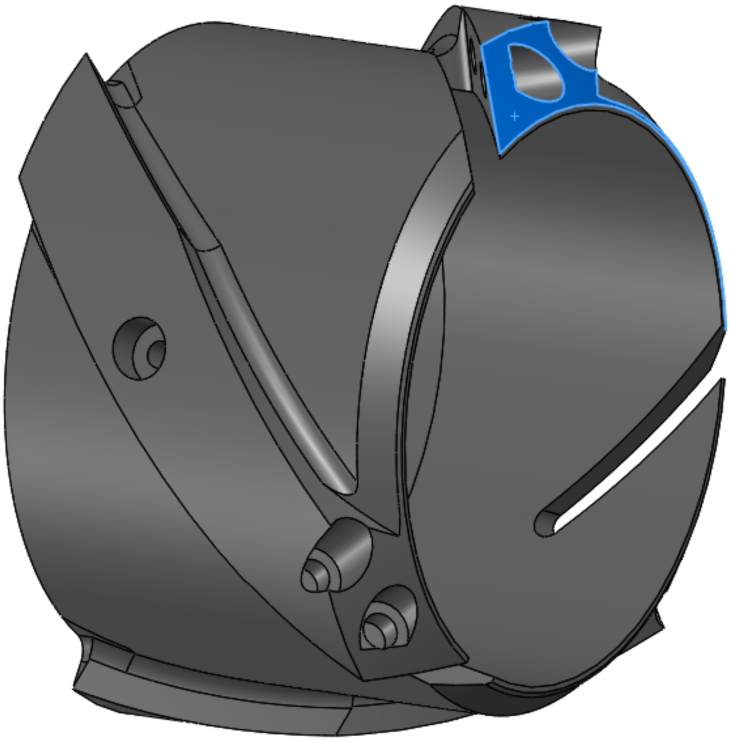

Figure 5.12: The final cutting head

The last problem was to find materials to make the center drill and cutter heads in. Here it was decided to go with the standard hardened ferruginous metal of the center drill and then PVD coat the surface. This would seal off the metal from the ice, so it will not contaminate the ice core. The cutter heads were during testing made in normal stainless steel which also will contaminate the ice core. Therefore the same treatment was used for the cutter teeth. As the stainless steel teeth showed signs of wear, it was also decided to harden them, which was done in the Material lab at Navitas, see Appendix A.10. Here an increase from 27,5HRC to 61HRC was achieved which was very satisfying. The PVD coating was done at Cemecon Scandinavia A/S with a treatment called HyperLox. PVD coating is normally used on drills, as it increases hardness and abrasion resistance, which is very useful for this application. The coat contains no iron and it is primarily Titanium which is coated onto the surface via plasma in a vacuum. The final cutter heads and center drill with PVD coating can be seen in Figure 5.13. The connector for the center drill is also PVD coated as it is in contact with the ice. The cutter heads will be fastened with zinc coated bolts, and the center drill will use painted pinion screws, so there will be no free iron in contact with the ice core.

Figure 5.13: The final cutter heads and center drill after PVD coating

The final drill can in Figure 5.14 be seen in CAD and real life. The center tube is fitted with two M74x1 fine threads so the drill top and drill head can be fixed together. This also makes it easy to do maintenance on the drill or replace parts as it is a modular construction. On top of the drill there is a bearing house, where the drill gets fixed in two Ø22x7x8 sealed bearings, so it can be driven by the motor.

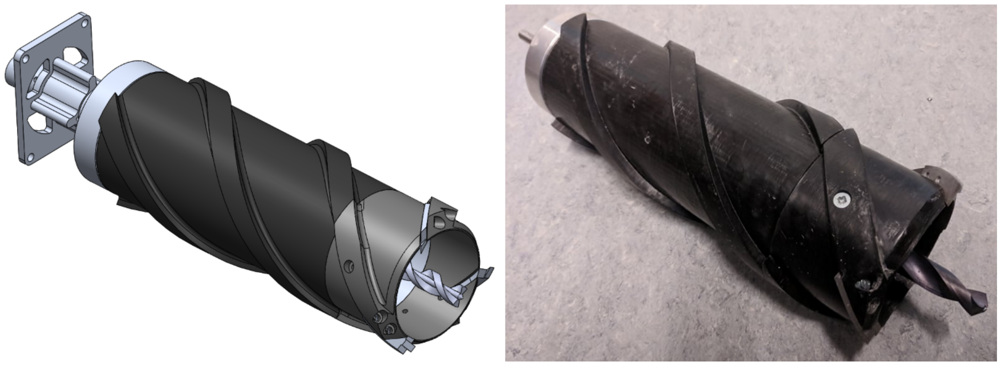

Figure 5.14: The final drill

The testing with this drill confirmed that the drill worked well and that the ice core had a tendency to break off, see Figure 5.15. In the cases where the core did not break, the drill could easily be pulled out, with the ice core still standing in the hole.

Figure 5.15: The drill and a core

The drill assembly is made in such a way that the drill including the bearing house and the connector part for the motor comes off the drone very easily. By doing this, it is possible to use an extraction tool to remove the ice sample, see Figure 5.16. The bearing house has been made with cut outs, so the Extraction tool can be used without disassembling the bearings and axle from each other.

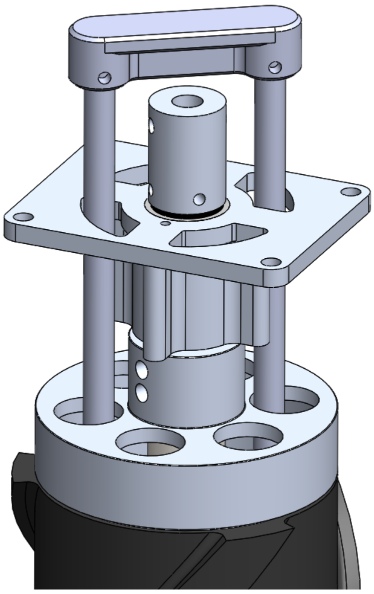

Figure 5.16: Extraction tool for removing ice sample

The ice cores drilled out had good sizes and most of the drilled out cores was over the limit of 500 g, see Figure 5.17. Here it can be seen that the cores are just over 500 g in most cases, which is acceptable, as it will be even harder to control a bigger drill.

Figure 5.17: Weight of 6 of the drilled out ice cores

5.3 Development of the landing gear

In Section 4.2.2 it was decided to use a hollow axle stepper with leadscrews for the landing gear actuator. The mechanism had to be light weight and stable when drilling, which is challenging when the whole landing gear can move up and down. It was decided to use the leadscrew for linear movement only, and use a slider tube for stability in the x- and y-plane. The tube would be held in place by linear bearings, but first the size of the tube had to be determined.

5.3.1 Slider tube dimensioning

The slider tube will act as the primary source of stability on the landing gear. Therefore it will also have to hold up to rough landing situations, where the landing gear acts as 3 legs for the drone.

To find the dimension for these legs, a landing scenario was established, where the drone comes in for a landing but has a horizontal speed of 1 m/s. The worst case scenario is that one leg has to absorb all the energy on impact.

By using a kinetic energy calculation where the landing gear leg is subjected to the energy from the drones mass and velocity it was possible to find the force put onto the leg.

The calculation can be seen in Appendix A.11, where it showed that a Ø16x1,5mm aluminium tube was suitable.

5.3.2 Landing gear mounts

From here the landing gear could be designed. The two most obvious methods of creating the mounts for the landing gear were decided to be aluminium, which is the go to light weight metal, and 3D print. As CNC aluminium parts are expensive to manufacture, a simple test of 3D printed mounts capabilities were made, see Appendix A.12. Here it was clear that 3D printed mounts was suitable for fixing tubes as long as the mount had a big surface to tighten around. Therefore the mounts for the bar between the arms, see Figure 4.12 for the concept, could be made in 3D print. Furthermore the mount for the stepper motor and linear bearings was also suitable for 3D print, see Figure 5.18 for the upper bar with 3D printed mounts. The leadscrew and the slider tube are mounted on each side of the bar, and held in place by a bracket, which also act on the end stop.

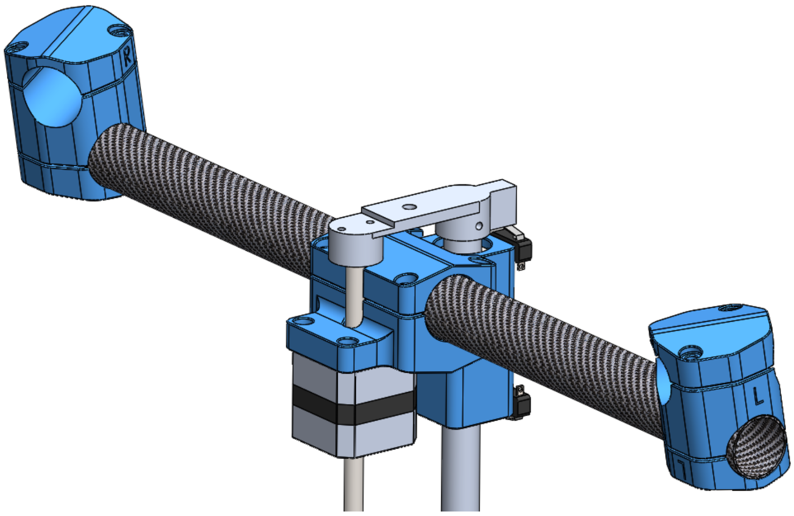

Figure 5.18: 3D printed parts for the landing gear marked with blue

From Appendix A.13 it was discovered that the landing gear needed stabilisation, therefore a triangular frame at the top and at the bottom of the landing gear was added, see Figure 5.19 for the complete landing gear assembly. Here the float can also be seen which was developed with inspiration from Section 2.1 and can be read about in Appendix A.8.

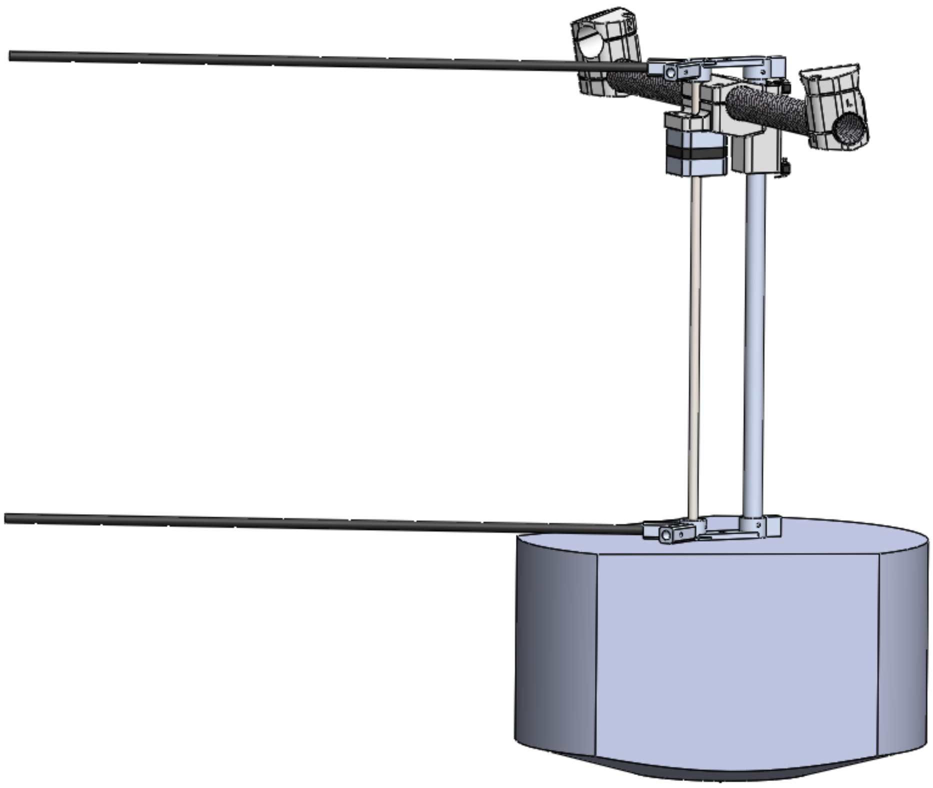

Figure 5.19: Complete landing gear assembly

5.4 Mounting plate

The mounting plate is where all the electronics are placed, and where the drill and motor is mounted. A big benefit of having the linear actuation on the landing gear is that the mounting of the drill can be made more steady, as it does not have to move. By moving the whole drone and not only the drill, the inertia of the drone also helps with taking up small impacts from the drill, before it is distributed into the landing gear legs.

The mounting plate is made from a 6 mm aluminium plate, where the 6 mm are used for ribs to keep the plate stiff and light weight along with cut outs in the plate, see Figure 5.20. The same principle with ribs is used for the camera mount, which is located in the front, see Figure 5.21.

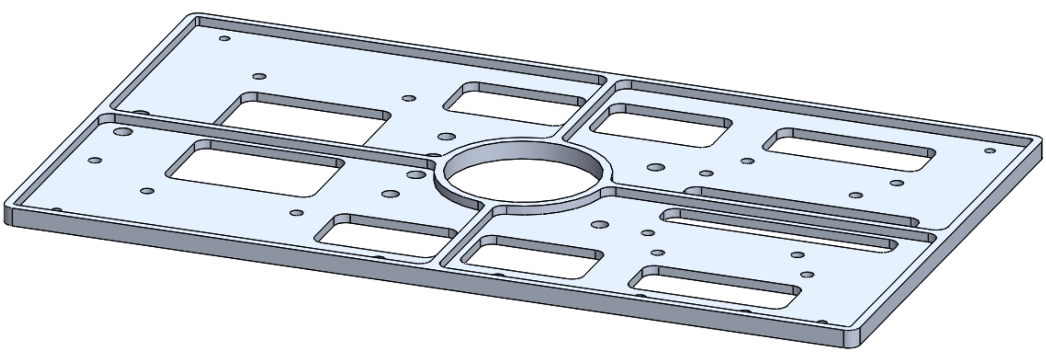

Figure 5.20: Mounting plate

The whole assembly with motor, myRIO, camera, fans, ESC, circuit board, drill and GPS Beacon can be seen in Figure 5.21. In Figure 5.21, the small reflection camera can also be seen. The reflection camera will be mounted with a GoPro adhesive mount.

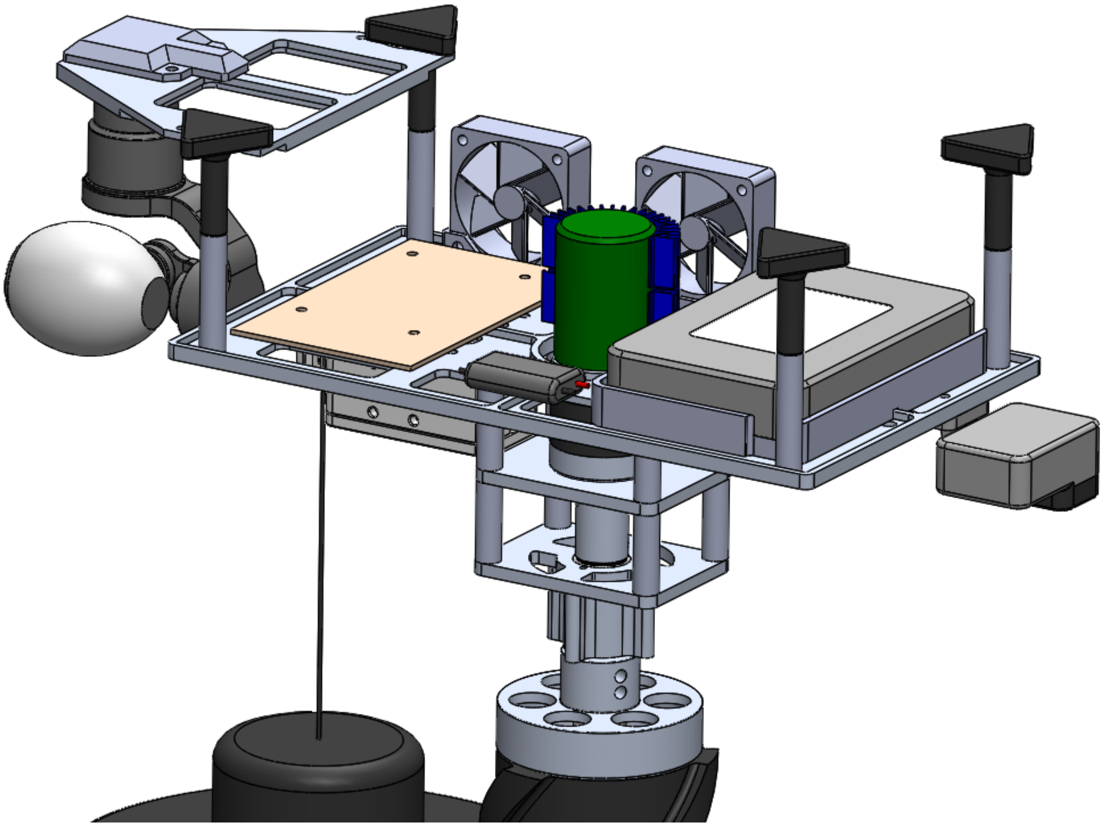

Figure 5.21: Mounting plate assembly

5.5 Beacon release

Underneath the mounting plate, the GPS beacon release is mounted. It consists of a Solenoid, which axle opens and closes for the rope release. The shell is made from 3D print which mounts to the mounting plate, see Figure 5.22. The mechanism is always closed as it is spring operated, which mean that it will not drop the beacon by accident, if it looses power.

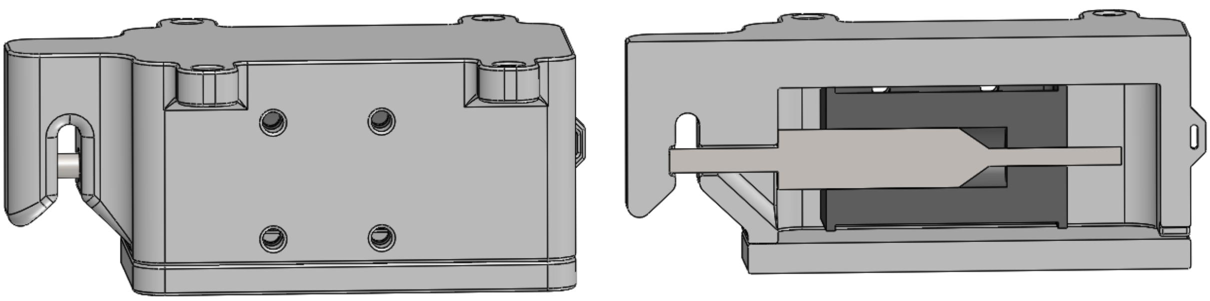

Figure 5.22: GPS beacon release mechanism

5.6 Angle of cutter heads

As described when designing the cup drill, a commonly used angle for the cutter heads are 40°, which is also angle of the current cutter teeth, see Figure 5.23. The angle at which the teeth are placed can change the way the drill performs. When going to Greenland, a cutting head with 30° teeth and 50° teeth will be brought along, to see if that can improve drilling in sea ice and glacier ice which has not been possible to test in Denmark.

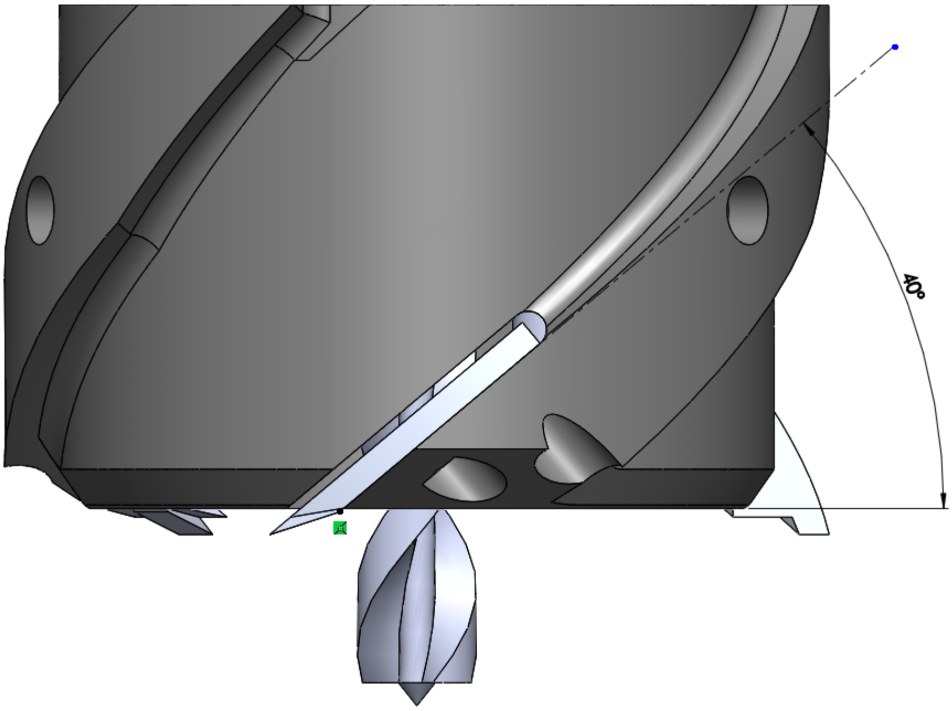

Figure 5.23: Angle of the current cutter heads/teeth

5.7 Table of considered materials in the construction phase

As mention all the way through this section, different material have been considered and tested, for the different systems. In the Table underneath a complete list of the considered materials and the material which ended up being used can be seen, along with comments on each material.

Systems:	Considered materials for the system:	Description of the material:	Comments on materials:	Materials used for the systems:
Center drill	Aluminium drill	Creating the selected drill type in aluminium on a CNC lathe	The center drill has to be made really accurately, therefore self made drills was avoided	PVD coated steel drill
	Aluminium drill with diamond coated egdes	Again create the selected drill type in aluminium and the coat the edges in industrial diamonds		
	Titanium drill	Creating the selected drill type in titanium on a CNC lathe		
	PVD coated steel drill	Use the existing drill and sealing the surface with PVD coating		
Cup drill	Aluminium cup drill	Making the whole cup drill in a single piece of aluminium rod	The cup drill is a really complicated part to manufacture, and if new iterations had to be tested, 3D printed parts was preferable	Aluminium center tube and top, with 3D printed cutting head and sleeve
	Titanium cup drill	Same principle, but with a bit higher strenght by using titanium		
	Aluminium center tube, top and cutting head	Make a modular drill in aluminium which can be disassembled easily		
	Aluminium center tube and top, with 3D printed cutting head and sleeve	Modular drill where the most complicated geometries are made in 3D print		
Springs for potential hooks	Steel springs shielded off	Using exiting springs from spring steel, either leaf springs or normal coil springs	The spring loaded hooks ended up being removed because of the risk of getting stuck, but the most promising solution was to shield off steel springs, as the other options were really limited or expensive	Springs was removed
	Aluminium springs	Special made aluminium springs		
	Beryllium-copper springs	Special made Beryllium-copper springs		
	Plastic spring	Using a plastic, which can withstand cold, and using the same principle as a snap-lock		
Cutter heads	Steelite: Cobalt-chromium alloy	An extremely hard titanium alloy used in areospace	The cutter heads had to have good abrasion resistance, and it would be really expensive if it had to be made in special materials out of the house	Hardened stainless knife steel
	Wolfram/tungsten carbid	An alloy often used in machining tools		
	Aluminium with a diamond coated egde	Making the cutter heads, and coating the edges with industrial diamonds		
	Hardened tool steel	Using normal tool steel, which can be hardened		
	Hardened stainless knife steel	Using a stainless steel used for knives which can be hardened		
3D printed parts	PLA	Making the parts in PLA plastic	PLA is not the strongest material to use, but as ABS and PETG was not available during the development on Navitas, PLA was the only thing tested, and held up fine	PLA
	ABS	Making the parts in ABS plastic		
	PETG	Making the parts in PETG plastic		

5.8 Testing at the testbench

After constructing all systems for the drone, a testbench, see Figure 5.24, was made in order to test drilling without human interference, see Appendix A.13. As mentioned in Section 5.3.2 it was discovered that the 3 legs were too unstable, which a triangular frame improved. Furthermore it was discovered that step drilling was better that drilling in one go. The step drilling was set to 14 seconds down and then 0,8 second up, which improved the reliability of the drilling. Furthermore it was discovered that the small metal spikes on the testbench were melting into the ice, which could end up in them getting stuck, therefore it was decided to go with POM-C (plastic) spikes. It was also tested that the steppers could lift the set target of double the drones weight, 32 kg. The rpm under load was measured using a optical tachometer, which showed a rotation speed of 590 rpm.

Figure 5.24: Testing with the testbench

With everything tested as best a possible, it was decided to go forth with building the complete prototype drone, which will be described in detail in Section 8.

6 Electronics

The following section will describe the electronics chosen for the project during the selection phase as well as the components not described during the selection (transistors, voltage regulators etc.). Furthermore the circuit will be described using Multisim, as well as a draft example of the circuit board alongside the final board.

6.1 Electric components

In this section all components which are supplied with voltage are mentioned, limited to the parts used as equipment attached to the drone and not the drone's own electronics. As an exception the controller and expansion kit are described because they will act as the user interface.

6.1.1 Controller + expansion kit

The DJI Matrice 600 Pro is delivered with a remote controller, which is used to control the drone and the Zenmuse X3. To access the extra communication ports on the drone, an expansion kit has been bought. The expansion kit is fitted onto the controller and makes the controller the user interface for the software. The expansion kit has access to 8 switches:

- 2 knobs with indents in the rotation
- 2 knobs with a smooth rotation
- 2 spring loaded toggle switches
- 2 toggle switches with 3 positions

The controller is shown in Figure 6.1, along with the expansion kit. The red circles indicate the controller pins for the drone.

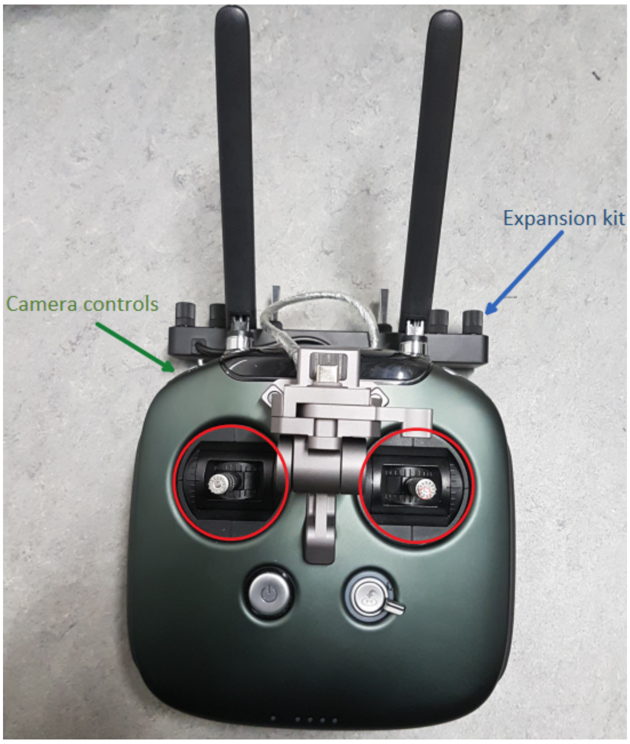

Figure 6.1: Controller + Expansion kit

6.1.2 myRIO

This is the controller used to control all of the electric components that have been added as part of the equipment. The myRIO from National Instruments is shown in Figure 6.2 along with the pin-out.

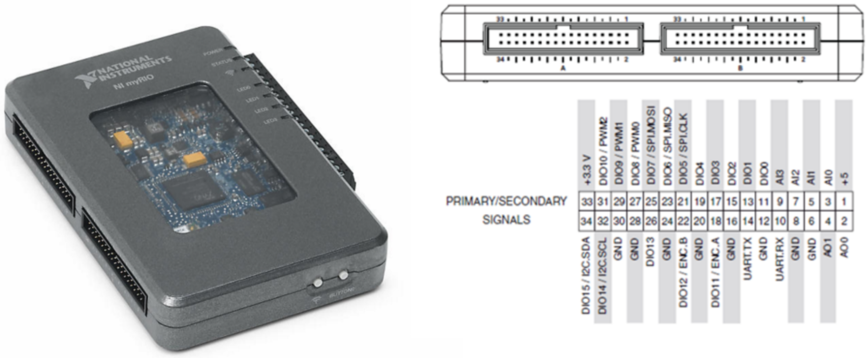

Figure 6.2: myRIO
12

The myRIO is able to send PWM, digital- and analog signals and supply a voltage of either 5V or 3,3V. Furthermore the myRIO is also able to receive these signals. The ports used in this project are limited to PWM, digital in/out (DIO), supply of 3,3V and analog in (AI). The myRIO is versatile in the matter of the supply voltage as it can receive from 6-16VDC. Furthermore it has an internal accelerometer[13].
The myRIO was chosen as controller because of previous knowledge of the unique programming language (LabVIEW), which is an intuitive program language based on a graphical interface. Another benefit from the myRIO is the ability to embed software, which means that when the myRIO powers on, the program will start running.

6.1.3 DC-DC converter LM2596

This voltage regulator is used to regulate the supply voltage from the drone (18V) down to 12V for the myRIO, fans, solenoid and LED. In Figure 6.3 the voltage regulator is shown. It was chosen based on the availability as well as the wide span of the supply voltage of 4,5-40VDC [14].

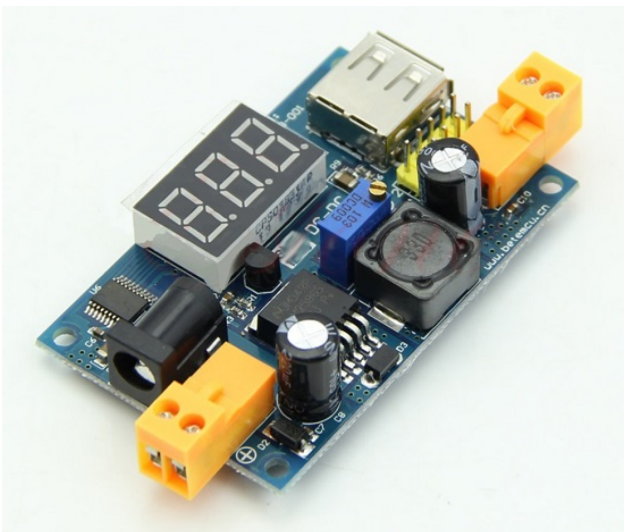

Figure 6.3: LM2596

[13] http://www.ni.com/pdf/manuals/376047c.pdf
[14] http://www.ti.com/lit/ds/symlink/lm2596.pdf

6.1.4 Fans

Two fans are placed on the drone to keep the brushless motor and the stepper drivers from overheating as this was a concern in the early testing phase. Both fans run on 12V and are being controlled by the same transistor since they only need to run simultaneously during drilling.

6.1.5 Solenoid

This component is used to drop the GPS beacon and the selection is described in Appendix A.7. A solenoid is a type of electromagnet and when used along with a spring it is able to push/pull a rod back and forth. When the electromagnet is energized it pulls the rod in, therefore it can be used as a release mechanism. Furthermore it will hold on to the beacon even if power is lost, due to the push spring. The power supply is 12V and with a connected transistor it is possible to energize the coil on command. The solenoid used in this project is shown in Figure 6.4.

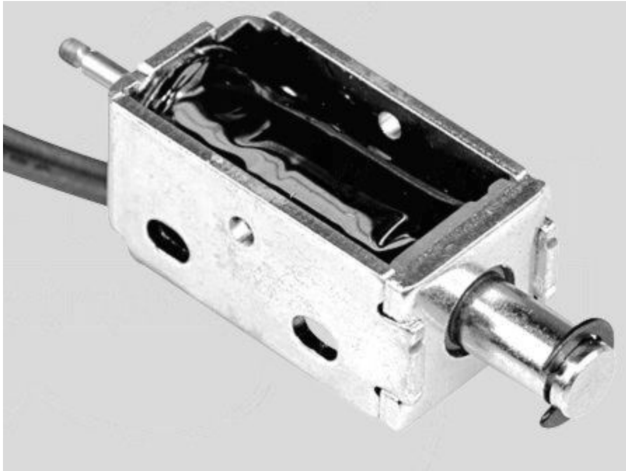

Figure 6.4: Solenoid

6.1.6 Red LED for Roll alarm

This component is placed in the camera view to alert the operator if the iceberg is rolling. It was chosen in Appendix A.7 as the roll alarm. The red LED is actually two LED's connected serially and are normally supplied by two batteries of 3V in series and a current of 90mA. Those were removed and wires were soldered on. The supply voltage used in the circuit for the LED's is 12V and therefore a current limiting resistor was added, based on the following calculation: $R = 6V/0,09A \approx 68\Omega$. The LED's are shown in Figure 6.5 with their casing.

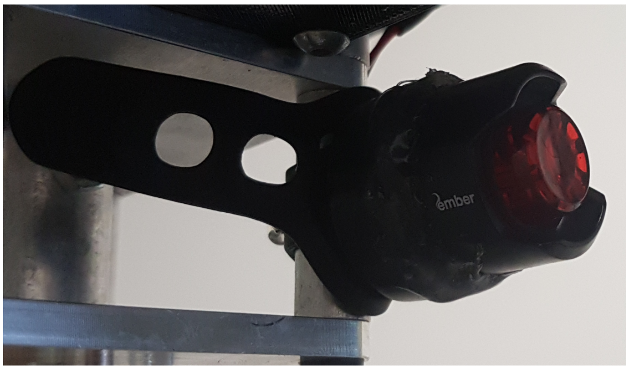

Figure 6.5: Roll alarm LED

6.1.7 Mosfets

To be able to control the LED's, solenoid and fans with the myRIO, transistors were needed. The chosen transistor type was a N-channel enhancement mode Mosfet. The benefit of choosing these was that a digital signal of 3,3V could power on the mosfet, with the correct placement, and thereby energizing the components connected. The mosfet was connected with Drain on the powerline, source on GND and gate was connected to a DIO port, shown on Figure 6.6 .

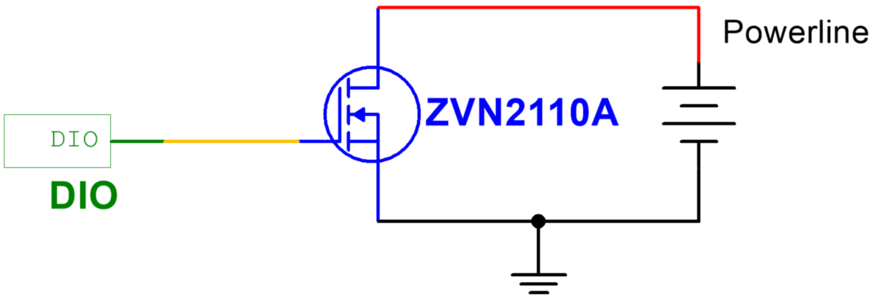

Figure 6.6: Mosfet configuration

6.1.8 Micro switches

Because of the potential hazard found in the FMEA, see Appendix A.9, endstops needed to be integrated into the landing gear. The endstops chosen are DB1-A1LB, with a lever arm making contact more predictable. The switch is shown in Figure 6.7.

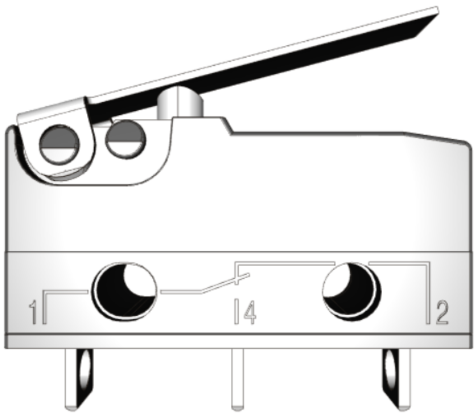

Figure 6.7: Microswitch

When wires are soldered on they follow this configuration: "1" is connected to the myRIO 3,3V output, "4" is connected to a DIO as signal and "2" is GND. With this configuration a "high" signal is send when the switch is pressed.

6.1.9 Big Easy driver

The stepper motors are controlled by using "Big Easy drivers", since they are small, available and easy to use. The "Big Easy driver" is shown in Figure 6.8.

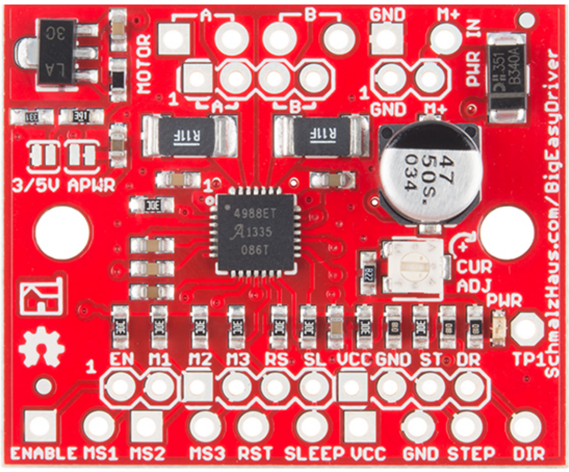

Figure 6.8: Big easy driver

The driver is fitted with many configurable pins, where the pins used for this project are: Motor coils A and B, Power in, GND and M+, Enable, M2, M3, GND, STEP and DIR. The driver works by sending a PWM signal to the STEP pin where the frequency will be the number of steps taken per second, which can then be added up to find the distance according to the gearing of the leadscrew.

The M1, M2 and M3 pins can be used to configure if the stepper will be taking full-steps, half-step and so on. The default step mode is $\frac{1}{16}$ stepping and by following the diagram shown in Figure 6.9, the driver can be configured to half-stepping by grounding the M2 and M3 pins.

MS1	MS2	MS3	Microstep Resolution
L	L	L	Full Step
H	L	L	Half Step
L	H	L	Quarter Step
H	H	L	Eigth Step
H	H	H	Sixteenth Step

Figure 6.9: Micro stepping configurations

Furthermore the enable pin can be used to stop a single stepper at a time, which is wanted according to the FMEA in Appendix A.9. The Driver can be powered with 8-30V and 0-2Amps, and the current sent to the stepper motor can be adjusted by turning the current limiting potentiometer. In the setup of this project the stepper driver will receive 18V and set to 1A for each of the stepper drivers. The driver is fitted with a heatsink to help with keeping it cool.

6.1.10 Stepper motors

During the component selection phase shown in Appendix A.3, hollow axle stepper motors were chosen as the linear actuators for the landing gear. The stepper motors are rated to a voltage of 3,2V and a maximum current of 1,67A[15]. The motors work by having two

[15] www.kortlink.dk/jugetek/w93k

separate coils energized by the stepper driver, depending on the PWM and the microstepping configuration. In Figure 6.10 the stepper can be seen.

Figure 6.10: Stepper motor

6.1.11 ESC

The Electronic Speed Controller (ESC) is used to power and control the brushless motor for the drill. The ESC works by determining the [ms] a signal is high in a PWM signal. If the signal is high for 2ms the ESC will make the motor go forward at maximum rpm and if the signal is high for 1,5ms the motor will be in idle (not rotating). With a frequency of 50Hz a full cycle will be 20ms and with a duty cycle of 0,1 a single high signal will be 2ms. The control is shown in Table 6.1.

Motion	Frequency [hz]	Single cycle time [ms]	duty cycle	High time [ms]
Backwards	50	20	0,05	1
Idle	50	20	0,075	1,5
Forward	50	20	0,1	2

Table 6.1: ESC control

The ESC used in this project is being powered by a 11,1V LiPo battery as the drone cannot deliver enough power from its output (14A needed, see Appendix A.13), the max rated amps for the ESC is 30A continuous and 45A in peak, which should be fine.

6.1.12 Brushless motor

The brushless motor was selected during the selection phase described in Appendix A.7. A brushless motor consists of 3 coils being energized separately with the output from the ESC. The motor will be plugged into the ESC according to the colours of the wires.

6.1.13 LiPo

To power the brushless motor's ESC a LiPo battery has been chosen, because the output connection on the drone is rated to a maximum of 10A as mentioned before. By powering the motor with a separate power source, it is possible to utilize the ESC to the max rated current. The flexibility added by going above 10A will help the motor in regard to its torque during drilling. The capacity of the LiPo has been calculated in Appendix A.14, where it was found that 4000mAh is the required amount, based on the motor using 14A continuously.

6.1.14 Summary

On Table 6.2 there is a quick summary of the voltage's and amps needed for the different components along with the ports used on the myRIO.

Component	Voltage [V]	Amp [A]	myRIO connection
Fams	12	0,75	A- DIO0
Solenoid	12	1	A- DIO1
Red LED	12	0,09	A- DIO2
Stepper driver 1	18	1	DIR - B-DIO0 STEP- B-PWM0/DIO8 EN-B-DIO1
Stepper driver 2	18	1	DIR - B-DIO0 STEP- B-PWM0/DIO8 EN-B-DIO2
Stepper driver 3	18	1	DIR - B-DIO0 STEP- B-PWM0/DIO8 EN-B-DIO3
Endstop 1-Top	3,3	0,025	B-DIO4
Endstop 1-Bottom	3,3	0,025	B-DIO5
Endstop 2-Top	3,3	0,025	B-DIO6
Endstop 2-Bottom	3,3	0,025	B-DIO7
Endstop 3-Top	3,3	0,025	B-DIO10
Endstop 3-Bottom	3,3	0,025	B-DIO11
Drill motor	11,1	[5;30]	B-PWM1/DIO9

Table 6.2: Component overview

When Table 6.2 is used along with Table 6.3 it will be easier to make the circuit diagram in Section 6.2.

Component	Use	myRIO connection
Drone signal S1	Grounded	A- AI3
Drone signal S3	Drill gear	B-AI0
Drone signal S4	Beacon drop	B-AI1
Drone signal S5	Boost	B-AI2
Drone signal S6	Stepper	B-AI3

Table 6.3: Input controls

Every component listed are rated for a working temperature below -10°C and should therefore be able to operate in Greenland. If the electroincs suffer from the cold, heat pads will be brought along to keep the electronics warm as determined in the Risk assessment, see Appendix A.9.

6.2 Circuit diagram

In order to get an overview of how the different components are connected to each other as well as to the myRIO, a circuit diagram has been made in NI-Multisim-14.1. In figure 6.11 the full diagram can be seen with the myRIO ports on the right.

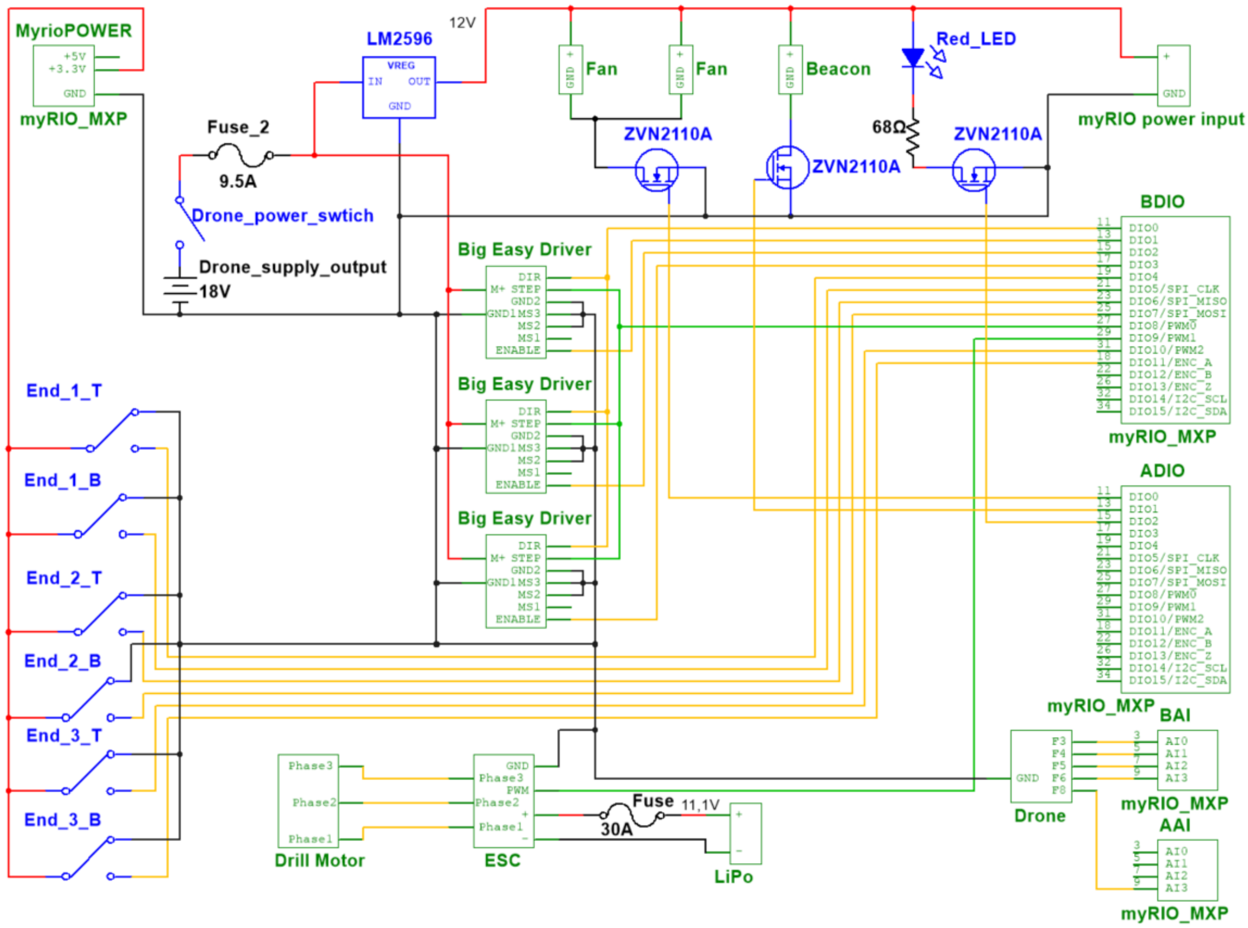

Figure 6.11: Circuit diagram

As seen on Figure 6.11 the stepper motors drivers are connected to 18V directly from the drone's power supply output, while the other electric components are connected through the DC-DC converter (LM2596). The endstops are supplied directly through the myRIO at 3,3V. Also shown are two fuses, one is used to limit the amps taken from the drone, the other is used to limit the current to the ESC from the LiPo battery, so the current will not exceed the rated capacity of the ESC as mention in Section 6.1. The colour coding used in the circuit diagram follows Table 6.4 and will also be used for the wiring.

Color code	Use
Black	GND
Red	Power
Yellow	Signal
Green	PWM

Table 6.4: Color code

6.3 Circuit board

To make the wiring more manageable, it was decided to produce a circuit board with as many of the components as possible. It should be possible to connect the different components with plugs so each item could easily be attached. The circuit board was connected to the myRIO with a ribbon cable, to enable the circuit board to act as a motherboard.

The draft example of the circuit board is shown in Figure 6.12

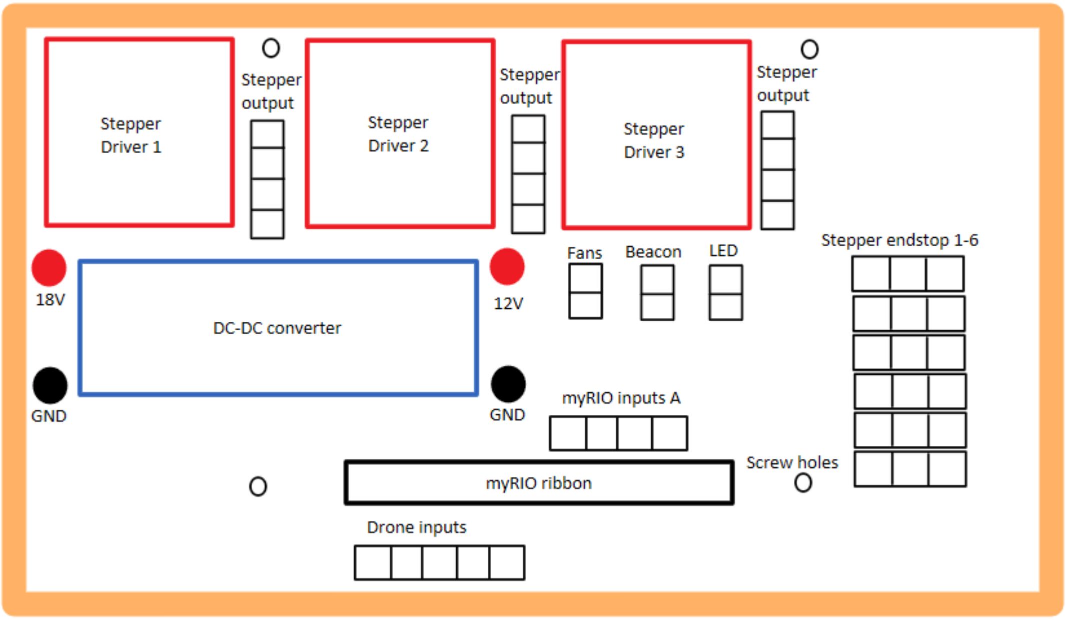

Figure 6.12: Draft circuit board

The final circuit board is shown in Figure 6.13. As seen the board has pins for easy connection of the components and integrated drivers for the stepper motors.

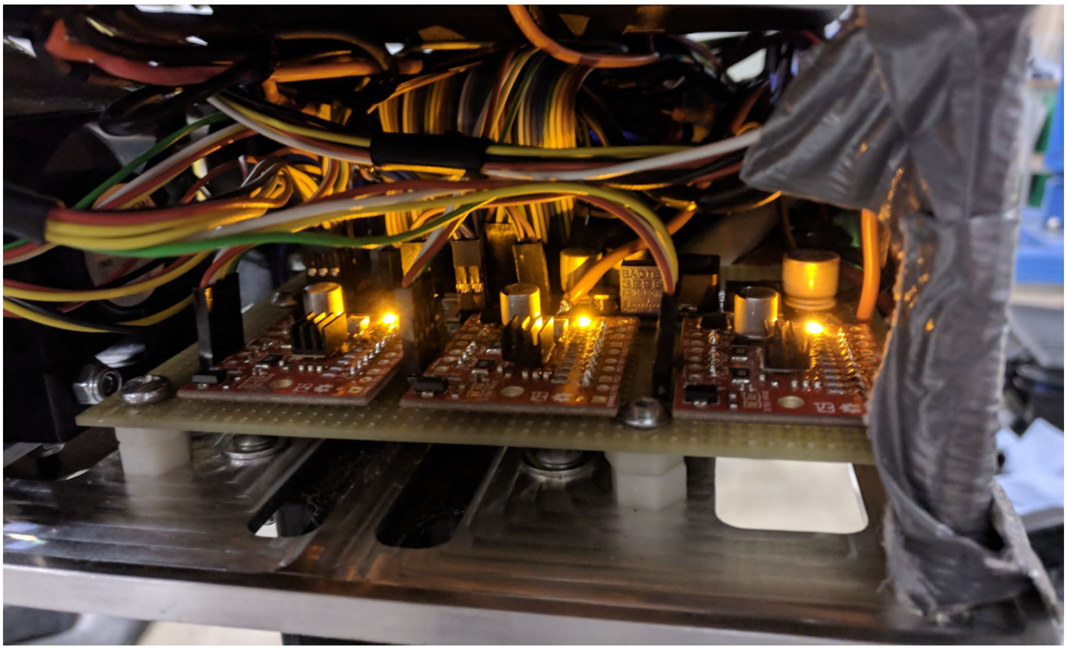

Figure 6.13: Final circuit board

6.4 Wiring

The wiring was done by following the colour code specified in Table 6.4 and the design guidelines specified concerning wires:

- Wires and plugs should be easy to reach
- Wires should be put into bundles for the different components
- Wire bundles should have plugs at the ends so it is easy to assemble and disassemble

A draft example of the wiring was made and shown in Figure 6.14, where the wires used for the stepper motors and endstops are guided back to the circuit board.

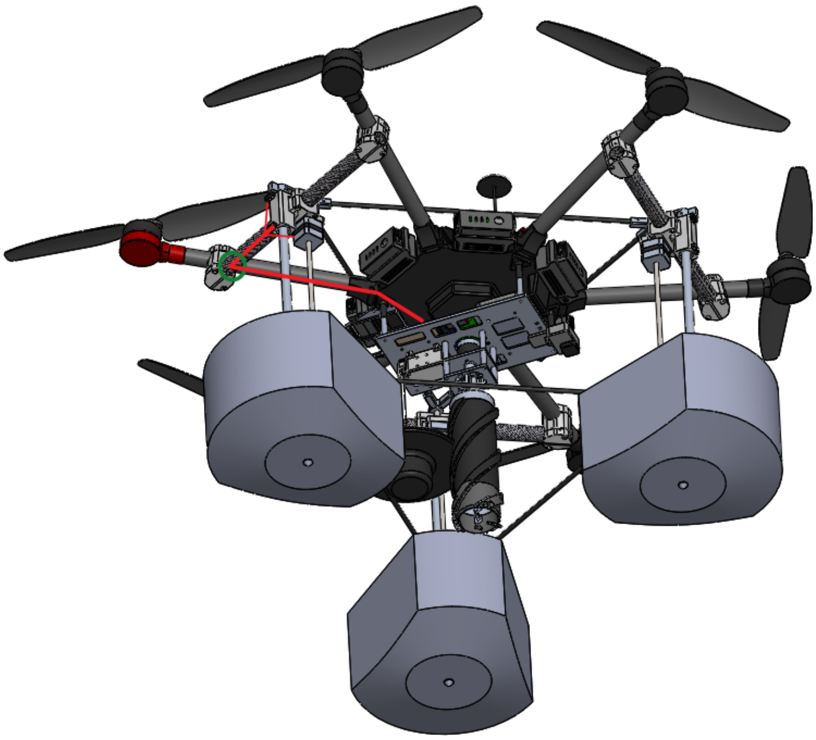

Figure 6.14: Wiring from one leg to the circuit board

Shown with red in Figure 6.14 is the placement of the wire bundle to the stepper and endstops, containing 10 wires, 3 for each endstop and 4 for the 2 coils on the stepper. The green circle indicates a junction point, where the bundle is connected with plugs. By making the wiring this way, it is possible to remove the landing gear and fold the arms in without removing the wires.

7 Software

This section contains the software development which was done by using the method "7-step-rocket" described in Section 3. The software will be made in LabVIEW 2018.

7.1 7 step rocket

The 7 step rocket is a method used to make complex software tasks more manageable by breaking it up into smaller parts. The 7 steps are described below.

7.1.1 Step 1: Problem definition

This program needs to be able, to control the equipment for taking an ice sample and dropping a GPS beacon, as well as receiving control signals from the drone.

The key inputs are:

- The PWM controls from the drone (analog)
- Endstop signals (digital)

The key outputs are:

- Stepper motors (PWM)
- Brushless motor (PWM)
- Fans (digital)
- Beacon release solenoid (digital)
- Roll alarm LED (digital)

Since the program is integrated on the drone and the end user is not supposed to interact with the LabVIEW software, a LabVIEW user interface is not required. The user interface will instead be the controller for the drone along with the expansion kit, see Figure 7.1.

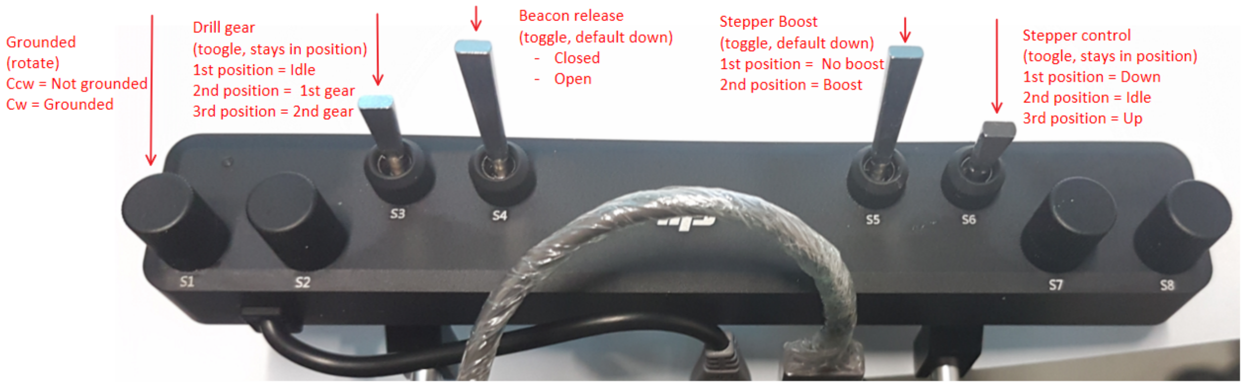

Figure 7.1: User interface, with the specific controls

7.1.2 Step 2: Specification of requirements

These are the requirements for the software, which the program has to be able to do.

Need-to-have

- Start 3 Stepper motors
- Start 1 Brushless motor
- Start 2 fans
- Read PWM signals from the drone
- Start the Roll alarm LED
- Use a "Grounded" signal from the operator to disable the drill and landing gear motors so they cannot start unless the drone is on the ground
- Stop a single stepper at a time, so the individual steppers will stop when they hit their endstops
- Roll alarm to alert the user if the iceberg is rolling

Nice-to-have

- More LED signals to inform the user about the drilling progress and if the drone is "Grounded"

7.1.3 Step 3: Software architecture and design

In this step the Use cases, specified in Section 4.1, are used to identify key components of the program that can be made as support functions.
First of all the Use case "Test program" has been discarded, because it was decided that the extraction procedure should be a manual control. Therefore the test program will instead be a systems check during the setup, which will be specified in the User manual, Appendix A.24.
Next the Use case "Extraction" has been modified to a manual program, the same as for the "Test program", and therefore it will have more controls than one button. The actor is still the operator and the preconditions are still the same, but the operator has to control the drill as well. The beacon drop program follows the Use case specified.

A flowchart of the main program was made to help identify the support functions, see Figure 7.2.

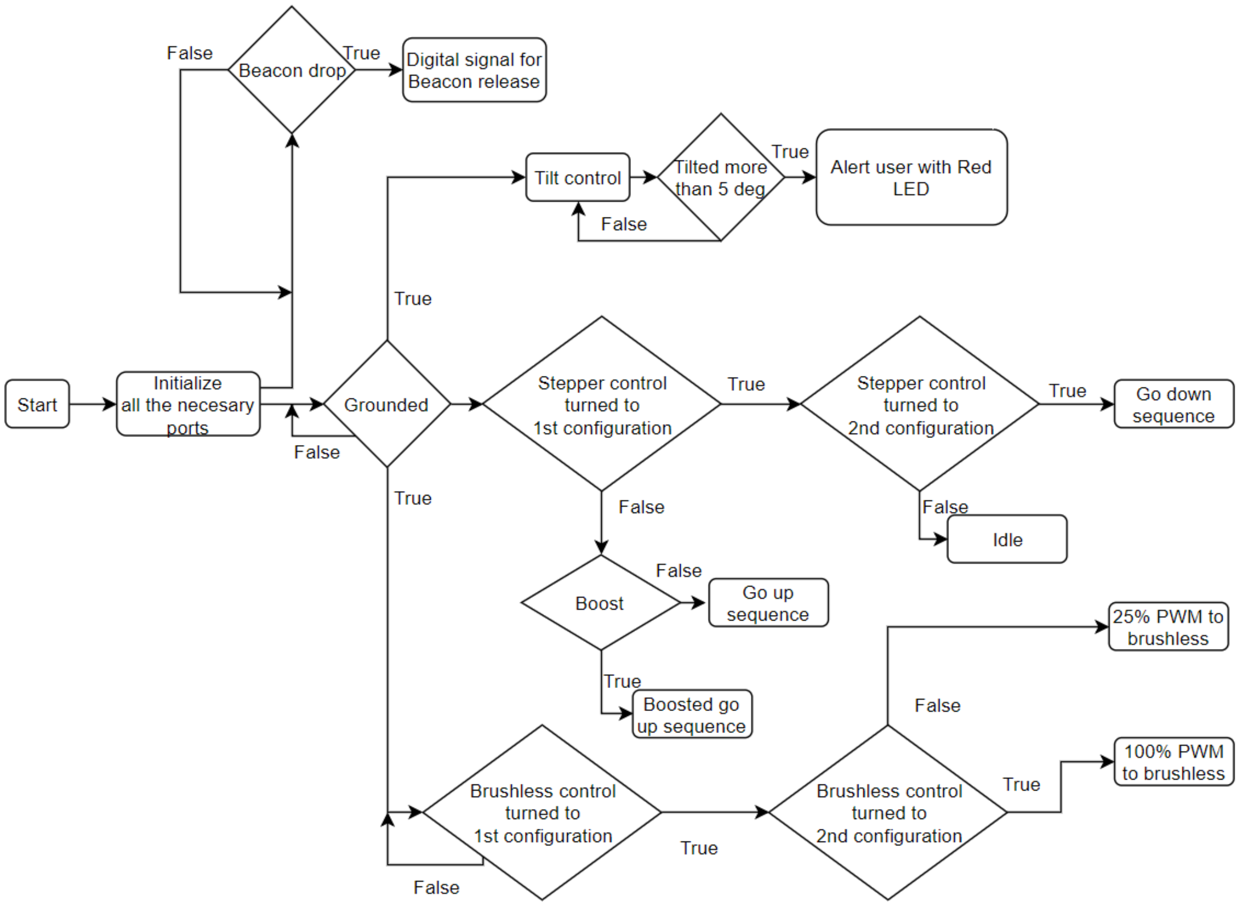

Figure 7.2: Software flowchart

The following parts of the software will be made as support functions:

- Initializing ports used on the myRIO, along with a function which closes them again
- Reading PWM signals from the drone
- Roll alarm
- Roll alarm range checking
- Ramping the brushless motor

The program will be made with parallel while loops to take advantage of the multi-core processor on the myRIO.

7.1.4 Step 4: Support functions development

Development of the support functions.

7.1.4.1 Initialize

By initializing all the needed ports at the beginning and bundling them together in a cluster, it is possible to call the needed port in the main program by *"unbundling by name"*. This makes it more manageable to make a low level program. In Figure 7.3 a piece of the function is seen; on the left the bundling is seen and on the right the *"unbundling by name"* is used.

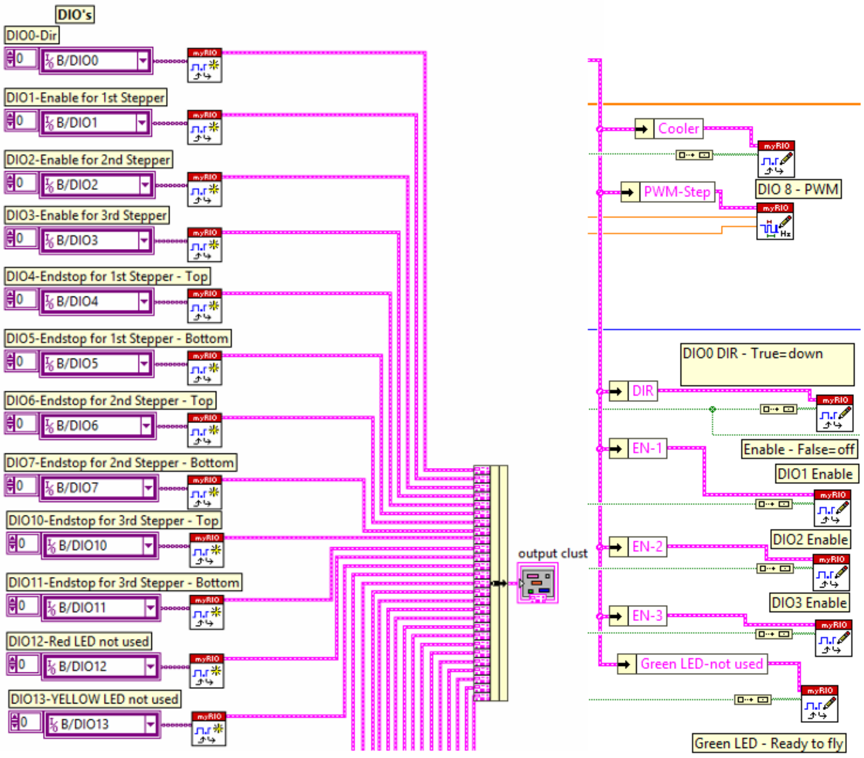

Figure 7.3: The support function: Intialize

7.1.4.2 Input PWM

The drone uses PWM as control signals, where it sends 0V and 3,3V, with a frequency depended on how the controls on the expansion kit are positioned. For this reason the program needs to be able to find an average. This is done by sampling the signals in an array and finding the average of the last 100 samples. In Figure 7.4 the sampling program is shown, the same program will be used for all of the 5 control signals from the drone.

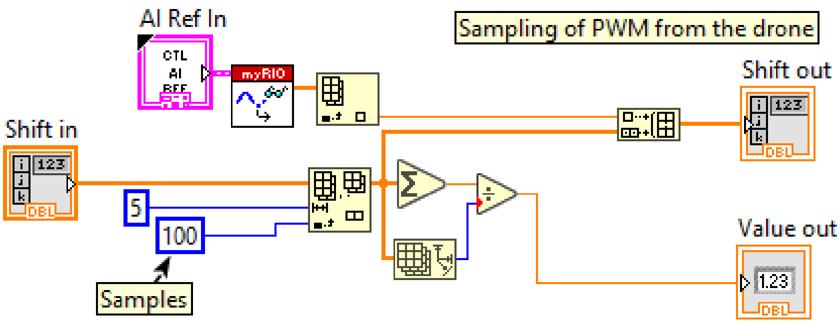

Figure 7.4: The support function: Input PWM

7.1.4.3 Roll alarm

The roll alarm works by using the myRIO's internal accelerometer and storing the first value received after the "Grounded" signal has been toggled on the expansion kit. Since the myRIO sends out a lot of values differing by a small amount they are first averaged. After this the values are turned into degrees compared to vertical, such that when the myRIO is laying flat the X&Y-axis is 90°, see Figure 7.5 for an illustration, where gravity is marked with a black arrow.

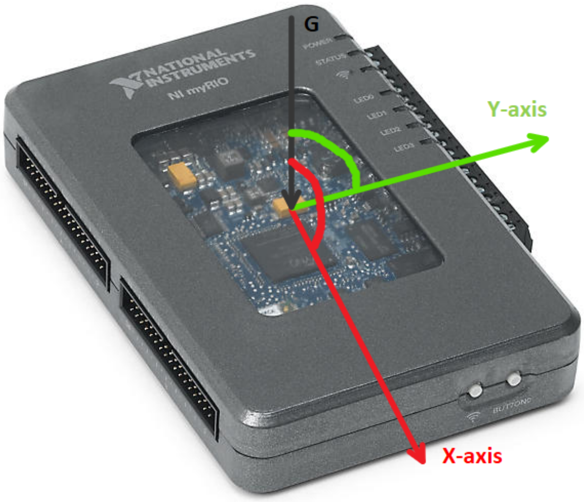

Figure 7.5: Angle illustration

The stored angle and the actual angle is sent to the "Alarm range" subVI. In Figure 7.6 the sampling and storing is shown.

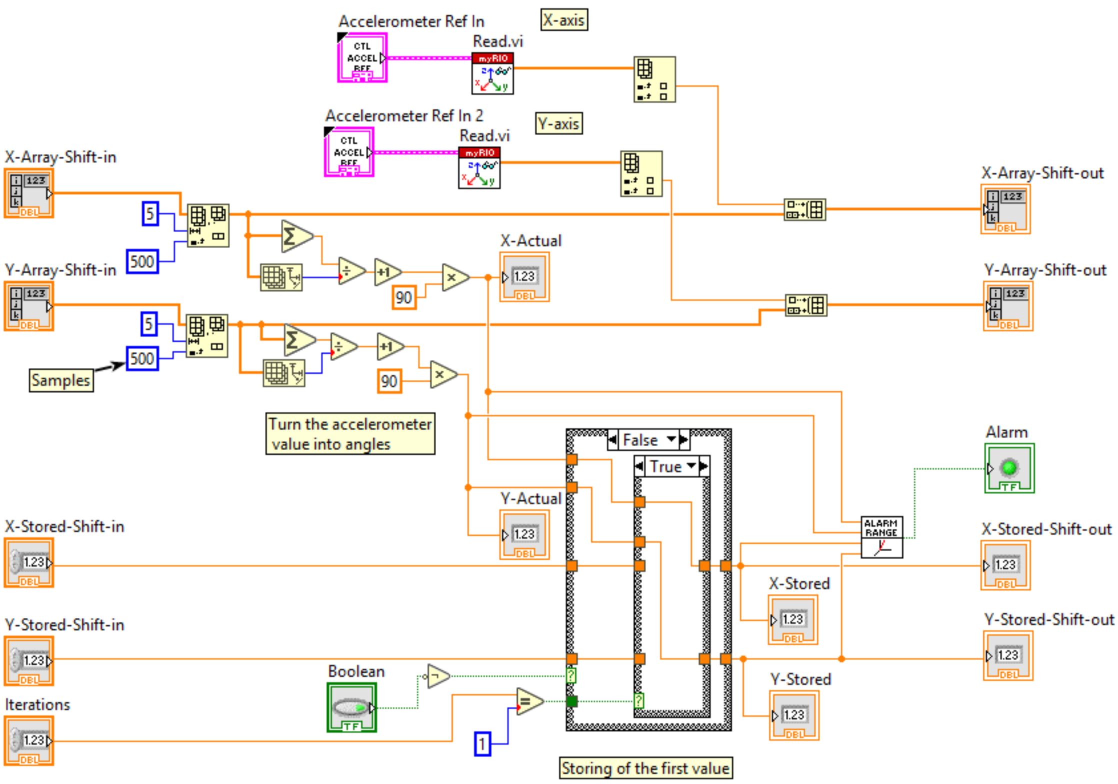

Figure 7.6: The support function: Roll alarm

7.1.4.4 Alarm range

In this subVI it is determined whether the actual angle differs from the stored angle by a margin great enough to trigger the alarm. The program is made with the following equation in mind: $x^2 + y^2 = r^2$, which is an equation for a circle. In the equation X&Y are the difference between the actual and stored angles. The radius of the circle is set according to a vector with a 5° angle, and the principle is shown in Figure 7.7.

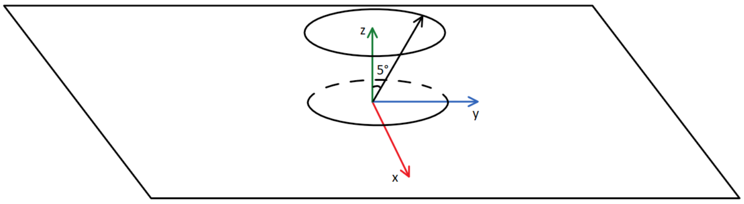

Figure 7.7: Alarm range principle

The support function is shown in Figure 7.8.

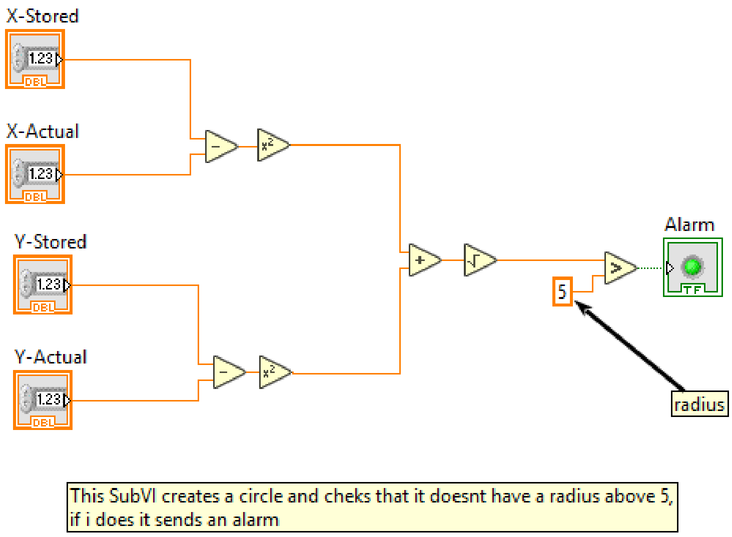

Figure 7.8: The support function: Alarm range

7.1.4.5 Ramping

This SubVI ramps the duty cycle for the ESC, since it cannot start from 0 to 100. This is done by counting iterations from 0 to 2500 and multiplying the current iteration by a value, so that when the iterations are at 0 the duty cycle are at 0,075 and once it reaches 2500 the duty cycle will be 0,1, the reason for these numbers are described in Section 6.1.11. For the drill 2 gears are wanted, the first with 25% of full rpm and the second with 100%. In Figure 7.9 the ramping of the output when put into 1^{st} gear is seen.

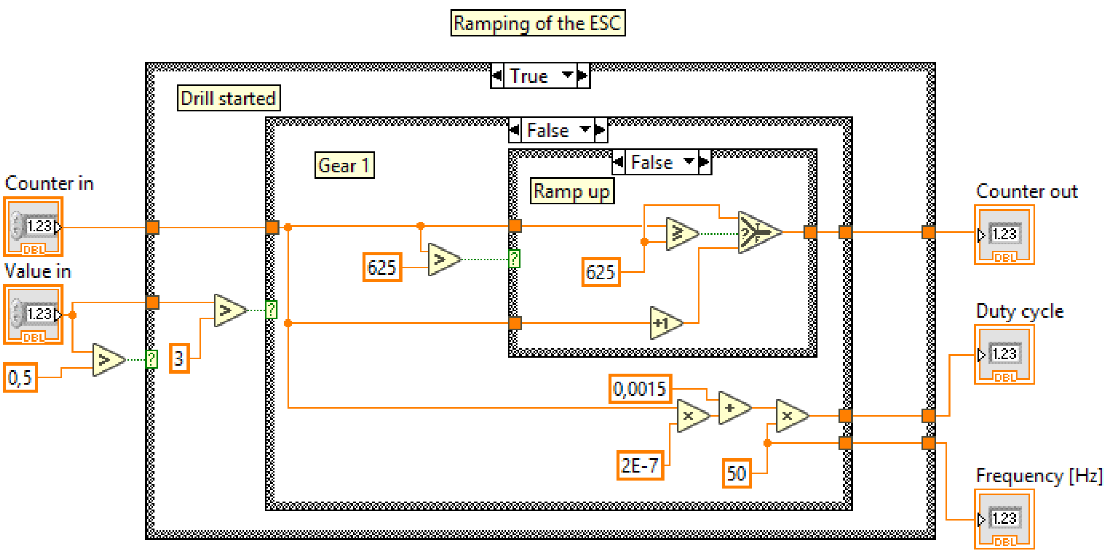

Figure 7.9: The support function: Ramping

7.1.5 Step 5: Debugging of support functions

Debugging of the support functions for the main program.

Initialize

Debugging of the "Initialize" program, was done by calling the LED's located on the myRIO and then unbundling the diodes by name and setting one LED to high. The program worked as expected and is shown in Figure 7.10.

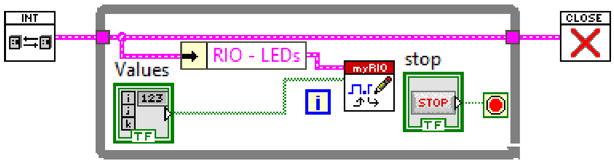

Figure 7.10: The support function: Initialize Debugging

PWM reader

Debugging of the "PWM reader" program, was done by connecting the myRIO to the drone and toggling the buttons on the expansion kit and checking if the signals behaved as expected. If the signal was bouncing the number of samples was turned up, so it could average over more samples. At first the number of samples was set to 20, but the signal was bouncing, therefore the number of samples was turned up to 100 to get a steady signal. The debugging program is shown in Figure 7.11.

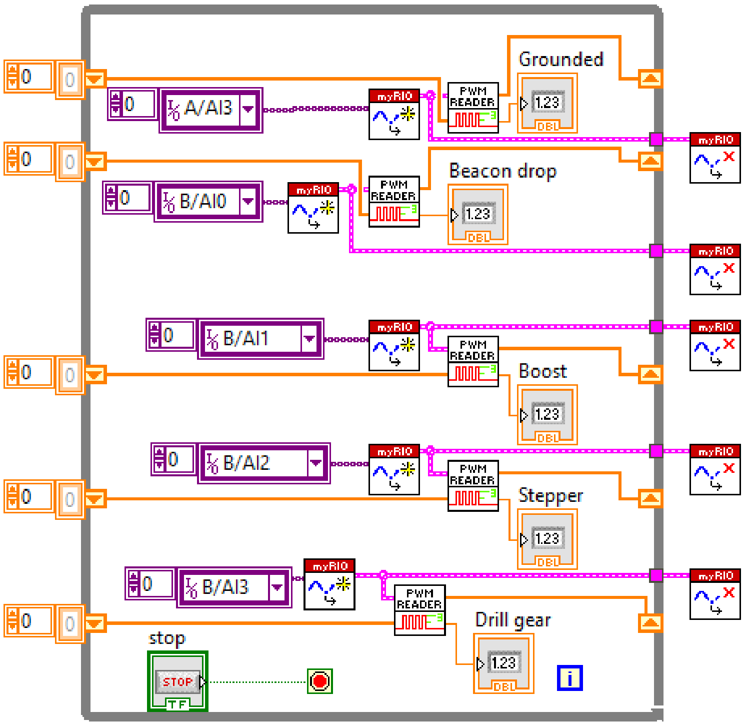

Figure 7.11: The support function: Input PWM debugging

Roll alarm

Debugging of the "Roll alarm" program, was done by moving the myRIO and observing if it triggered the alarm. The program worked as expected with only the x direction connected at the beginning, before the y-axis was added to make it work on both directions. The debugging program is shown in Figure 7.12.

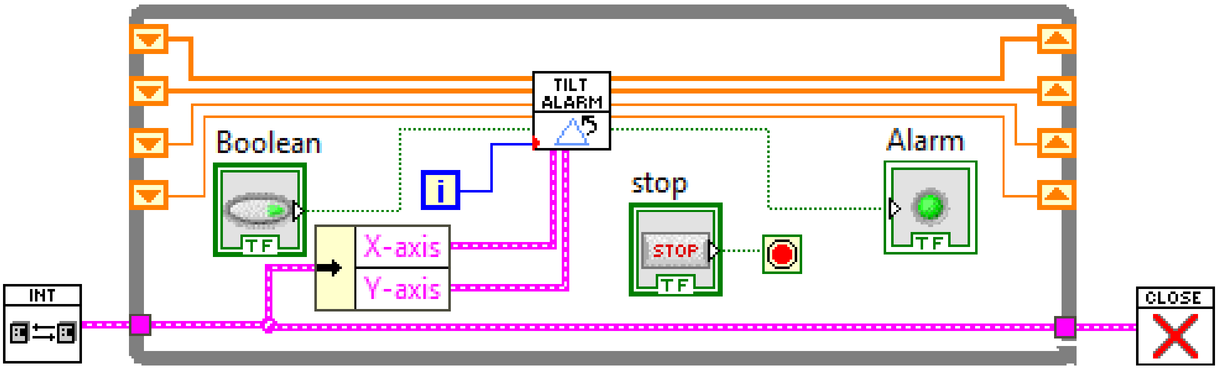

Figure 7.12: The support function: Roll alarm debugging

Alarm range

Debugging of the "Alarm range" program is an iterative process, as it controls the angle at which the alarm is triggered. This has to be made in collaboration with the end user, to find an appropriate angle at which the alarm goes off.

Ramping

Debugging of the "Ramping" was done by connecting the myRIO to an ESC with the Brushless motor connected, and checking if it behaved as expected. Once the ramp was adjusted in acceleration the program worked as expected. The debugging program is shown in Figure 7.13.

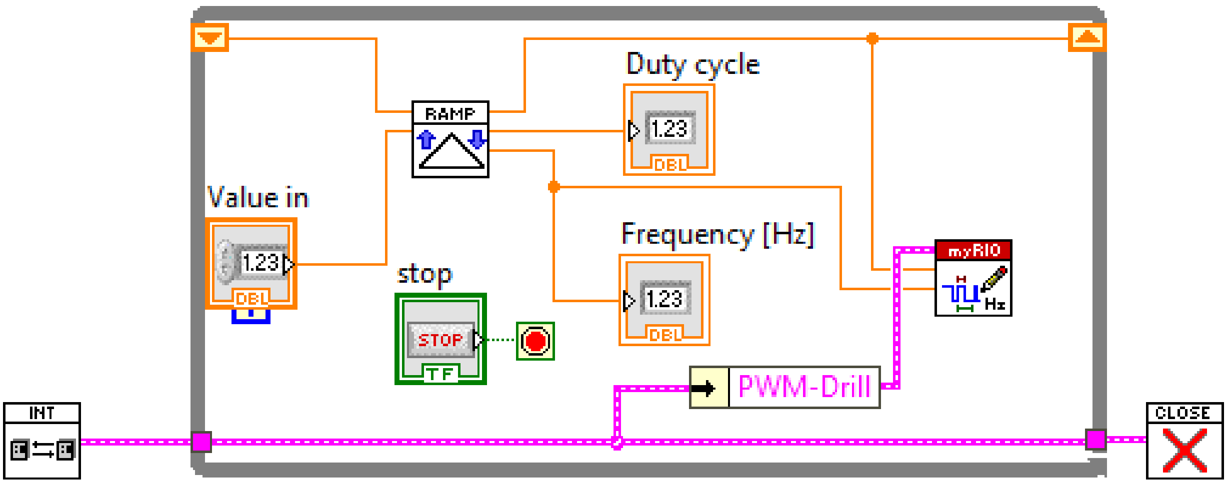

Figure 7.13: The support function: Ramping debugging

7.1.6 Step 6: System integration

With all the support functions done they were integrated into the main program. The different parts were split up into parallel while loops. Furthermore a while loop for the LEDs located on the myRIO was added, to indicate if the correct program was running. In Figure 7.14 the final program can be seen. The parallel while loops are as stated:

The while loops:

1. Grounded (top left)
2. Roll alarm (top middle)
3. Drill (top right)
4. Beacon drop (middle right)
5. Bouncing LED (bottom right)
6. Stepper state

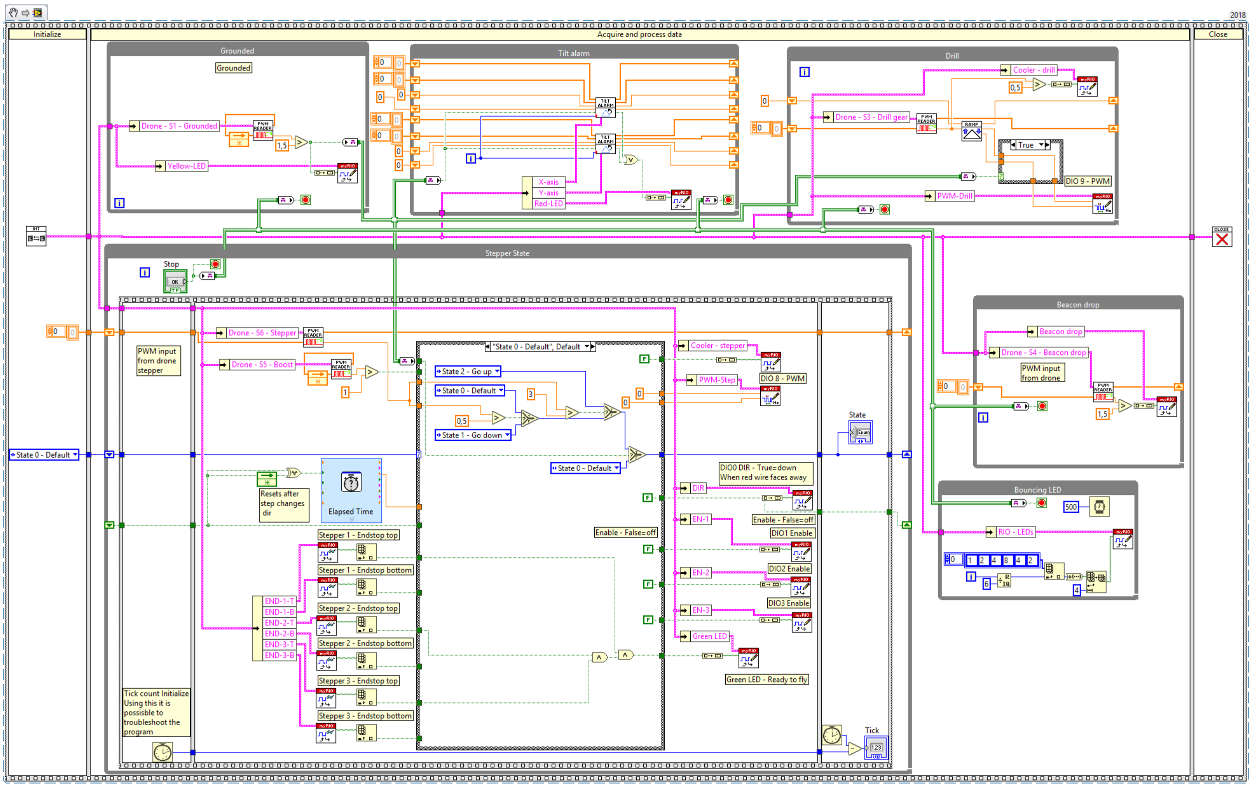

Figure 7.14: The Final program

7.1.7 Step 7: Validation and integration test

The last phase is for validating and debugging the main program. The validation was done by connecting everything to the myRIO and checking the different controls. With everything working, the stepper movement was calibrated using the results from the Testbench, see Appendix A.13, and the downward pace was set to 20mm/min, including the step drilling.

8 Final prototype

As all mechanical development, electronics and software has been completed the final prototype can now be revealed. The prototype has been tested as best as possible, and now further testing will be done in Greenland, January 2019. The drone was named "The ISAS-Drone", which stands for: **I**ce **S**ampling for **A**nalysing **S**ediment-Drone. The following sections will describe the final prototype.

8.1 Landing gear

From the Testbench experiment, see Appendix A.13, it was discovered that the landing gear legs needed further stability, therefore a triangular frame in carbon tubes were added at the top and at the bottom. The frames are mounted to the aluminium brackets of the landing gear, and adds a lot of stability, see Figure 8.1.

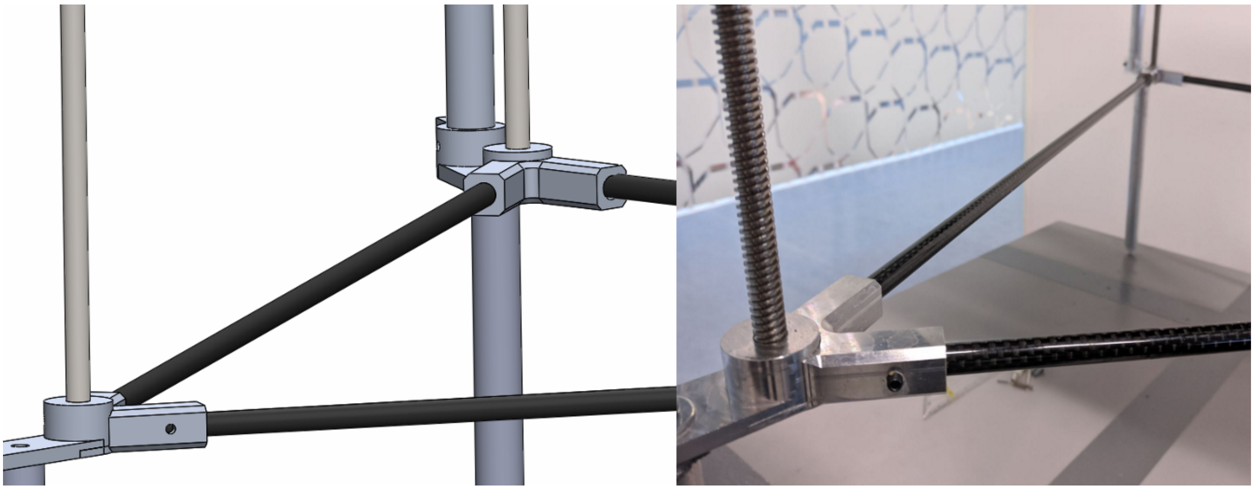

Figure 8.1: Close up of landing gear frame in CAD and real life

8.2 Mounting plate

The mounting plate contains all the electronics and holds the drill and the motor, therefore it is an important part of the drone. The mounting plate is shielded off with duct tape, to keep the electronics safe, see Figure 8.2. The duct tape does a good job of keeping the electronics safe, but can be improved in the future.

Figure 8.2: Close up of mounting plate in CAD and real life, with duct tape shielding

8.3 Complete prototype drone

The complete prototype can be seen in Figure 8.3, during float testing with everything mounted; the camera, the drill, the mounting plate with electronics, landing gear with frames at the top and bottom, the replica GPS beacon on top and with the floaters, which could also be improved in the future with further testing.

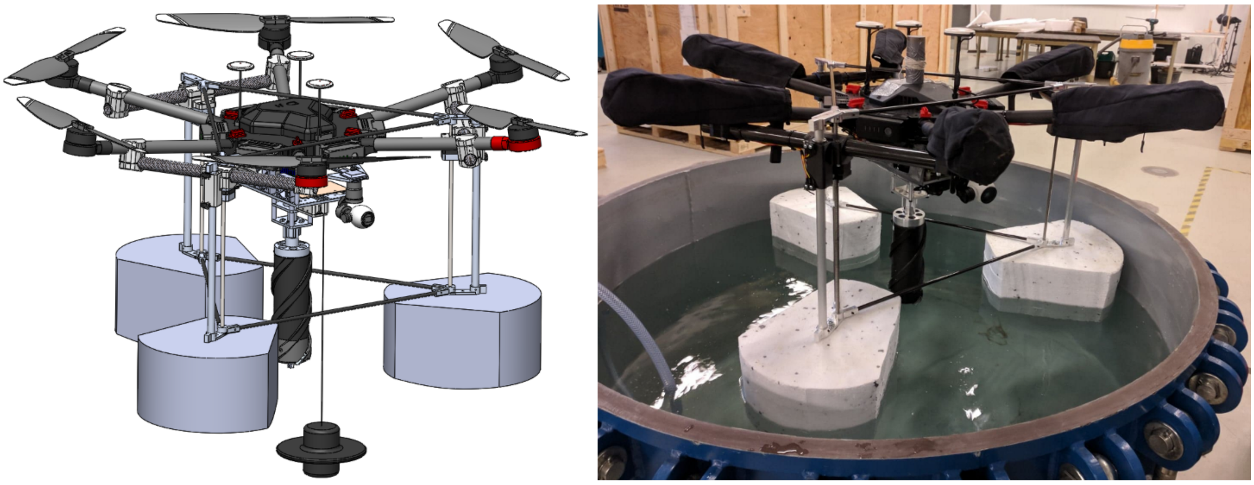

Figure 8.3: Complete prototype drone in CAD and real life during float test

8.4 Final testing

The final prototype has been tested both for functions on land and in the air, see Appendix A.15 and Appendix A.16 for experimental reports of the tests. The whole prototype ended up being a bit heavier than the recommended maximum take off weight of 15.5 kg, as the drone weighed 16.04 kg without the beacon. Even though this is more than recommended, the flying capabilities were not affected, and therefore the added weight was approved.

First of all the drone did well in the testing on land, Appendix A.15. Here the drill performed well and did a complete drilling test and extraction with success. The spikes also performed well with no sliding during drilling. The power consumption was also reasonable and within specification of the drones output, which can deliver 180W. The Roll alarm was also tested which showed that the program was able to detect if the drone had an angle above 5°. Lastly, the landing gear was tested for its lifting power, which went well as the linear actuator lifted the drone as well as 16 kg.

The second big test was the final flight test, Appendix A.16. This test revealed that the drone was stable during flight with the new landing gear and drill, and that is was able to release the GPS safely onto the ground. Furthermore the test also showed that the drone could land and take off from a 2x2m platform, even at an angle of 5°.

The drone was also tested for what might happen if the electronics were cold. This was done by putting the drone in the freezer at -18°C for two hours, before taking it out and putting in batteries, see Appendix A.17. The test showed that after 5 seconds of "Warming up", the drone was ready, and everything worked well.

The drones camera range was also tested, see Appendix A.18. Here it was determined that the drone's camera performed well at the maximum tested distance of 0.44 km, which is over the requirement.

When on mission in Greenland the drone might be exposed to large iron deposits, either from the underground or from the boat, therefore a test on iron disturbance was done by putting the drone next to a large container, see Appendix A.19. The test showed that the compass signal could be interfered by the iron, therefore it was concluded to add it to the User manual, that the operator should be aware of this danger and be prepared to fly in ATTI mode.

Disturbance from the poles might also interfere with the compass signal, but this will be tested on Greenland. According to the mail correspondence in Appendix A.20 with `Dronevolt.dk`, who supplied the DJI drone, there might be a good chance that the drone can fly without interference due to the A3 Pro flight controller with triple redundancies on GPS and compass.

The prototype will be tested further in Greenland where testing on sea ice and icebergs will be performed.

9 Conclusion

It can be concluded that the group from Aarhus School of Engineering was able to construct a drone which can live up to the requirements specified for the project. The different parts for the drone have been tested thoroughly and developed through iterative processes.

Drilling in ice was a difficult challenge, and a lot of hours were spent trying to figure how to drill effectively. The group was able to develop a cup drill and a center drill which has good drilling capabilities, and a lot of experience and knowledge was gained from all these tests. The knowledge has been put to use when developing new iterations of the drill, which has been a really educational process, with a fine end product. All tests have been stored as Experimental reports, which is used for documentation. The drill is designed for easy removal of the ice core as well as for easy changing of parts because of its modular construction.

For the drill to operate, a new linear actuated landing gear was developed, which ended up having good stability, good lifting capabilities and precise movement. This is necessary in order to adjust the drilling speed perfectly. The final parameters for the drill will be determined when the drone will drill in ice under "real" conditions in Greenland, January 2019. Along with the drilling the drone is also capable of releasing a GPS beacon safely onto the icebergs, and collect reflection data using a colour calibrated camera.

The drone was tested for landing capabilities from where it could be concluded that it should be able to operate the drone from a boat. Adding to that an iron disturbance test was also performed which stated that the drone may have to be flown in ATTI mode, which has been added to the User manual, see Appendix A.24.

All the electronics on board the drone has been selected and constructed by the group, and ended up with an easy access motherboard solution, where all the wires are unbundled and plugged in. The drone's wiring enables it to be disassembled and packed down for transport.
The software needed for the drone has also been created by the group, and embedded on a myRIO, which receives the signals directly from the drone's flight controller, which ended up working really well and with a really easy and intuitive user interface.

For the drone all parts has been made in CAD, using SolidWorks 2018. Technical drawings and Parts lists has been made for every part, see Appendix A.21 and A.22. As well as the part drawings, assembly drawings for the sub-assemblies and the final assembly is also included. This makes is possible to pick up the project when further development is wanted.

All this allows Daniel Frazier Carlson to receive the data needed to continue and hopefully complete his current studies of ice/ocean interactions in the fjords of Greenland.

10 Design evaluation

The first step of the Design evaluation will be going through the requirements in the Specification of Requirement, Section 2.4. In this section both Functional and Product requirements were given, and in this section all the Product requirements will be accounted for to see if the drone lives up to the requirements.

10.1 Answering the Specification of Requirements

In this section all the requirements will be answered.

The equipment should work in arctic temperatures
The drones and its electronics is designed and tested in sub -10°C conditions, which lives up to the Should have requirement, also see Appendix A.20.

The drone should be able to fly in moderate winds
The drone is build to withstand 10m/s winds, and test were performed in even heavier winds, which lives up to the Should have requirement.

If the drone has to land on water
The drone has floats mounted to the landing gear which keeps it stable in the water, which lives up to the Could have requirement.

If the drone looses signal to the radio
The drone's flight controller has a built in "Return to home" functions, which lives up to the Could have requirement, depending on how much the boat drifts.

Ice sample weight when delivered
The test with the drilled samples showed an average weight over 500g, which lives up to the Must have requirement.

The drone should have a payload that fit the rough estimates of the weight calculations
The drone has a payload of 6kg, but can actually carry even more, which was tested, and which lives up to the Should have requirement.

Camera feedback
The camera can tilt in 2 directions directly from the controller, which lives up to the Could have requirement.

The battery capacity should allow the drone to fly to and from iceberg
The drone's batteries allows for up to 10 minutes of flight with payload with speed up to 65 km/hr, which lives up to the Could have requirement.

The radio transmitter should have a range of at least
Camera transmission range was tested at 0.44 km without problems, which lives up to the Must have requirement.

The drone should be able to land and take off from an angled iceberg surface
The drones was successfully tested at an angle of 5°, which lives up to the Should have requirement.

Recesses, snow and grooves on the surface of the iceberg may not exceed
This could not be directly tested, but the drone had no problem landing in grass and gravel, which lives up to the Should have requirement.

The type of sediment in the ice sample
The drill was successfully tested with sand in the ice, which lives up to the Should have requirement.

The drone should be able to carry an EXITE GPS beacon
The drone was tested by flying and delivering a replica GPS beacon with good results, which lives up to the Must have requirement.

Setup/pack down time for the drone
The drone can be partly disassembled and packed down for transport in a decent amount of time, but will not be tested completely until Greenland. This will live up to the Must have requirement.

The user can test the drones functions before flight
The operator can control all functions from the controller, and can therefore test the drone before flight in under 5 minutes, which lives up to the Could have requirement.

When landed on ice, the drone may not slide before drilling more than
The spikes were developed in POM-C as aluminium spikes melted into the ice. The POM-C spikes showed no signs of sliding when testing, which lives up to the Could have requirement.

The camera angling can be used to monitorize the extraction
The camera can be angled and rotated to monitorize the drill during extraction, which lives up to the Could have requirement.

The drone should be able to detach its tools if stuck within
This requirement was tested and in the Risk assessment it was determined that the Probability of the drill getting stuck was too low to justify a release mechanism.

The rolling alarm should have a sampling time of
The roll alarm samples at up to 800Hz, which lives up to the Could have requirement.

The rolling alarm should have a sensitivity of
The roll alarm has a sensitivity according to the program of +-0,25°, which lives up to the Could have requirement.

Videofeed quality
The camera can send Full HD video feed, and more if wanted, which lives up to the Could have requirement.

The sampling rate of reflection photos
The reflection camera can record in over 30FPS at 1080P, which lives up to the Could have requirement.

Iron contamination less than
This was not tested, but the PVD coating is believed to seal the iron. Furthermore the group was in contact with Mikael Sejr of Arctic Research Centre, who explained that the samples could be cleaned on the surface by letting the outer layer melt away, when the ice core was brought onto the boat.

The drone should be able to fly safely even if there is interference from the boat or from the poles
Iron interference has been tested, and there is a possibility that it can cause the drone to switch to ATTI mode, which lives up to the Must have requirement.

The drone should be able to fly back with engine breakdown
The drone can fly with 2 broken engines, and emergency land with 3 broken engines, which lives up to the Could have requirement.

The ice sample should have a depth of
The drill is design and tested to extract an ice sample of about 200mm, which lives up to the Could have requirement.

Time between missions
The batteries for the drone and the drill can be changed in under 5 minutes, which lives up to the Could have requirement.

The price of the final device, should not exceed 100.000DKK
The prize of the final drone is 88.331DKK,which is within the budget of 100.000DKK, and it lives up to the Must have requirement, see Section 10.4.2.

The price of the flying platform (drone) should not ecxeed 50.000DKK
The price of the drone without extra equipment was just over 30.000DKK, but even with extra equipment it is still under 50.000DKK, which lives up to the Must have requirement.

Flying capabilties in high relativ humidity (100%RH)
The drone should be able to handle mist and light rain, see Appendix A.20, which lives up to the Should have requirement.

The drone must have a weight under
The drones final weight is just under 17kg, which lives up to the Must have requirement, the Danish law.

The drone must be transportable
A hardcase transport box has been brought which the drone fits into, which lives up to the Must have requirement.

For the drone to be operated from a boat, it may not exceed
The drones dimensions are roughly 1,6x1,6x0,7m, which lives up to the Must have requirement.

Measuring the core temperature
It was dicided that the user should be able measure the core temperature of the iceberg, by measuring the temperature at the bottom of the ice sample, which lives up to the Should have requirement.

10.2 Discussion

The drone ended up in many ways as a successful prototype, where all of the functions are working and has be tested. The drone will be able to go away for its first mission in Greenland, January 2019, but that does not mean that it cannot be improved.

The drone's drilling capabilities is the most important thing to test in Greenland, as the ice is different from the ice created in a freezer. It is made up over thousands of years, and made with sediment and compressed snow. Therefore gaining the knowledge of how the drill performs in Greenland is very important. These observations can, and shall be used if further development is wanted.

Other than that there are also a few minor things that can be improved even further; landing gear stability, drill stability, drill motor gearing and many more. These are minor things, but should not affect the test in Greenland.

As of December 2018, the electronics are shielded off by duct tape, which is also a thing that can be improved, to make it more durable and professional looking.

Lastly, the floats can also be improved, maybe in other materials, and by testing the floatation abilities even more, it may also be possible to decrease them in size.

The user interface and manual controls are functioning really well, and the group do not see a reason for changing that, unless it is wanted to have a (semi)-autonomous function.

10.3 Environmental impact of the drone

As mentioned in Section 1.6, the impact of the research that is being done on icebergs, can have a large impact in understanding the climate. The drone will contribute as a data collecting device, and therefore it is an important piece of the puzzle.

Considering the environmental impact that the drone can have for the research, it is almost not of interest to mention, the small amount of materials and equipment used to develop this device. If the drone were to be mass produced, it might make sense to make a MEKA analysis, to see if the materials could be changed for greener alternatives.

The drone comes pre-assembled from DJI, who is a member of the "Global Citizenship Program", and is determined to help the global research through aerial cameras and sensors. Therefore DJI is a committed partner to scientists world wide.

The biggest concern about the drone, is if it crashes into the water and sinks. This means that the LiPo batteries can leak into the fjord, which is polluting the local area. But, as the quantity of batteries is so low, it is a risk that everyone involved in the project is willing to take.

The biggest negative impact the drone and this project will have on the environment is the transporting of equipment and people, to and from the mission in Greenland. These commercial airline pollute the atmosphere, but again it is a sacrifice that has to be made in order to collect the needed data.

10.4 The project as a whole

This section describes different considerations involving the project in general.

10.4.1 Work environment

The working environment on board the boat will be tight as the drone will take up much space, and the fact that the team has to keep a safety distance when taking off and landing. In the User manual in Appendix A.24, it is described how the drone operator should always be the person closest to the drone when flying. The boat should also have capable emergency equipment, such as survival suits for the whole crew, if the boat were to sink.

10.4.2 Economics

In Table 10.1 the final budget for the drone can be seen.

Purchased parts	Price [DKK]	Comment	Source
Drill assembly	279,5	The purchsed parts from the parts list	Parts list
Actuator_system_assembly	235,7	The purchsed parts from the parts list	Parts list
Landing_gear_assembly	721	The purchsed parts from the parts list	Parts list
Motor_mount_assembly	807	The purchsed parts from the parts list	Parts list
Beacon_release_assembly	185	The purchsed parts from the parts list	Parts list
Mounting plate assembly	203	This price does not include the myRIO + Zenmuse	Parts list
Total	2431,2	This price does not include delivery or the items used during the development	
Made parts	**Price [DKK]**	**Comment**	**Source**
Working hours for workshop	38500	Based on one person working 7hr*11days, at 500DKK/hr, not including spare parts	The workshop made an estimate
Materials	1500	Most materials where avialable at ASE	The workshop made an estimate
3D print	900	The 3D at ASE where avialable for use, free of charge	Based on the use of around 900m and a price of 100DKK pr.100m
Total	40900	This price includes all the help/items recieved/used during the development	
Drone	**Price [DKK]**	**Comment**	**Source**
Drone + extra equipment	45000	This price is whitout spare parts	Dronevolt.dk
Summary	**Price [DKK]**	**Comment**	**Source**
Total	88331,2	The project ended up being quite expensive due to the many machined parts and an expensive drone	

Table 10.1: Economics table

This shows that the drone is within budget, and that the final prize for the drone, without spare parts, ended up costing: 88.331DKK, which is within budget.

10.4.3 Social consequences

The social consequences for this project can involve the employment of more people, if the research done on iceberg can lead to innovative engineering solutions. Furthermore this study in icebergs may also bring more attention to the arctic research field, which can make more scientists join the research area.

11 Bibliography

In this report, the following sources have been used. The list consists of all the Web pages and Articles used in both the Main report and Appendix. Many of the links contain information about the parts used for the drone, while the articles are used for scientific references, from where information has been gathered.

11.1 Web pages

Website: http://www.nordiclandscapes.com/Glaciers-Icebergs/index.html
Released: 2002
Last visited: 18.12.2018

Website: https://shop.spheredrones.com.au/products/custom-solutions-peristaltic-water-sampling-unit-for-m600-series-inc-switch-electronics
Released: 2015
Last visited: 18.12.2018

Website: https://www.kickstarter.com/projects/dronerafts/waterstrider-perfect-footage-confident-landings-an
Released: 2016
Last visited: 18.12.2018

Website: https://www.youtube.com/watch?v=14iKxSUET2M
Released: 2017
Last visited: 18.12.2018

Website: https://icecores.org/icecores/drilling.shtml
Released: 2015
Last visited: 18.12.2018

Website: http://www.ni.com/da-dk/support/model.myrio-1900.html
Released: 2016
Last visited: 18.12.2018

Website: http://www.ni.com/pdf/manuals/376047c.pdf
Released: 2016
Last visited: 18.12.2018

Website: http://www.ti.com/lit/ds/symlink/lm2596.pdf
Released: 2016
Last visited: 18.12.2018

Website: https://www.jugetek.com/product-page/non-captive-nema17-linear-stepper-with-300mm-length-tr8-4-lead-screw
Released: 2013
Last visited: 18.12.2018

Website: https://www.dji.com/matrice600-pro/info#specs
Released: 2016
Last visited: 18.12.2018

Website: https://www.dji.com/d-rtk/info
Released: 2017
Last visited: 18.12.2018

Website: https://www.dronevolt.com/en/expert-solutions/hercules-10/
Released: 2017
Last visited: 18.12.2018

Website: https://www.dronevolt.com/en/expert-solutions/hercules-20/
Released: 2017
Last visited: 18.12.2018

Website: https://www.aerialtronics.com/en/products/altura-zenith#pensar
Released: 2014
Last visited: 18.12.2018

Website: https://www.droneland.dk/da/droner-med-kamera/13-dji-s1000-professionel-drone.html
Released: 2014
Last visited: 18.12.2018

Website: https://freeflysystems.com/alta-8/specs
Released: 2018
Last visited: 18.12.2018

Website: http://versadrones.com/products/heavy-lift-octocopter/
Released: 2015
Last visited: 18.12.2018

Website: https://elektronik-lavpris.dk/p103821/its-ls2924bd-12-solenoid-framed-2924b-d-12v/
Released: -
Last visited: 18.12.2018

Website: https://morfars.dk/products/punisher-servo-5p
Released: -
Last visited: 18.12.2018

Website: https://minielektro.dk/nema-17-step-motor-4kg-cm.html
Released: -
Last visited: 18.12.2018

Website: https://www.elextra.dk/main.aspx?page=article&artno=H19139&gclid=Cj0KCQiAgMPgBRDDARIsAOh3uyKSoBg2TGmX6ZgOe0PmqM21n-7MXzQFIyPOe13IUG4_GwfwvJLitf8aArlMEALw_wcB
Released: -
Last visited: 18.12.2018

Website: https://www.cykelgear.dk/tilbehor/lygter/cykellygter/force-double-lygtesaet-elastikmontering-rodhvid
Released: -
Last visited: 18.12.2018

Website: https://dk.rs-online.com/web/p/piezo-buzzer-komponenter/6173097/
Released: -
Last visited: 18.12.2018

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Released: -
Last visited: 18.12.2018

Website: https://minielektro.dk/nema-17-step-motor-4kg-cm.html
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Website: https://www.robotdigg.com/product/32/Non-captive-Nema17-Linear-Stepper
Released: -
Last visited: 18.12.2018

Website: https://www.actuonix.com/T16-S-Micro-Track-Actuator-with-Limit-Switches-p/t16-s.htm?1=1&CartID=0
Released: -
Last visited: 18.12.2018

Website: https://www.cnc4you.co.uk/MOD1-Rack?search=rack
Released: -
Last visited: 18.12.2018

Website: https://hobbyking.com/en_us/540-6527-brushed-motor-90w.html
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Website: https://elektronik-lavpris.dk/p136260/e1921218-dc-motor-405-mm-med-transmission-181-12-vdc-e1921218
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Website: https://midhobby.dk/produkter/96-motorer-el/53470-lrp-vector-k7-brushless-motors—105t
Released: -
Last visited: 18.12.2018

Website: www.kortlink.dk/lehigh/wa28
Released: 2014
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Website: http://michaelwest.dk/knive/rwl34-datasheet.pdf?fbclid=IwAR050 _owHqfQS1dLjxLEb611DPJgshK7GGmczAUYXca82Pg5ap9pdKtMhcI
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Website: www.loeberute.dk
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11.2 Scientific articles

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Calson DF, Boone W, Meire L, Abermann J and Rysgaard S. (2017). Bergy Bit and Melt Water Trajectories in Godthåbsfjord (SW Greenland) Observed by the Expendable Ice Tracker. Front. Mar. Sci. 4:276. doi:10.3389/fmars.2017.00276

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Pavel G. Talalay, W. (2014). DRILL HEADS OF THE DEEP ICE ELECTROMECHANICAL DRILLS. Jilin University, Polar Research Center, China. ScienceDirect. doi: `https://doi.org/10.1016/j.coldregions.2013.09.009`

A Appendices

This section contains the material made by the group during the development of the drone. The appendices comes in chronological order as they are presented in the main report, except for the Parts lists, Technical drawings, Time schedule and User manual which are placed as the last Appendices.

List of appendices:

- Appendix 1: Mail correspondence with Dan Carlson
- Appendix 2: Weight estimations
- Appendix 3: Morphology diagram: Design phase 1
- Appendix 4: Experimental report: Preliminary thermal drilling test
- Appendix 5: Experimental report: Preliminary wedge drop test
- Appendix 6: Experimental report: Preliminary mechanical drilling test
- Appendix 7: Morphology diagram: Design phase 2
- Appendix 8: Experimental report: Float test
- Appendix 9: Risk assessment
- Appendix 10: Experimental report: Hardening of cutter heads
- Appendix 11: Landing gear calculations
- Appendix 12: Experimental report: Test of 3D printed mounts
- Appendix 13: Experimental report: Testbench
- Appendix 14: Battery drilling time calculations
- Appendix 15: Experimental report: Final test of the drone on land
- Appendix 16: Experimental report: Final flying test of the drone
- Appendix 17: Experimental report: Cooling Test
- Appendix 18: Experimental report: Camera Range
- Appendix 19: Experimental report: Iron Disturbance
- Appendix 20: Mail correspondence with Dronevolt.dk
- Appendix 21: Parts lists
- Appendix 22: Technical drawings
- Appendix 23: Time schedule
- Appendix 24: User manual

A.1 Mail correspondence with Dan Carlson

Fra: Dan Carlson <danfcarlson@gmail.com>
Sendt: Wednesday, September 5, 2018 3:10:02 PM
Til: Mathias Edslev Jacobsen
Emne: Re: Start up meeting

Hi Mathias-

On Wed, Sep 5, 2018 at 11:50 AM Mathias Edslev Jacobsen <edslev94@hotmail.com> wrote:
Hi Dan

Thank you for the meeting yesterday, we just have a few follow-up questions:

1. What sediments do you expect the ice samples contains? (Rock, sand, organic material or?)

The icebergs probably contain sediments from the region around where the glacier meets the water. The kinds of rocks vary all over Greenland. GEUS has mapped rock types and minerals around Greenland.

1. What does the melt with sediment do to the Water in the fjord?

What do you mean?

1. Is the amount of sediment in the ice sample wanted to determine melt speed?

No. The amount of sediment is desired to understand how much sediment an iceberg can deliver to the ocean/fjord and where these sediments can be injected

1. Is the amount of freshwater (salt) in the icebergs relevant?

No

1. Can we expect many peppels? (it will make drilling really hard)

Depends on the iceberg

6. We will contact som chemist about iron contamination, but how important is it to you?

If we can measure iron it would be very significant. Like Nature Geoscience significant

6. Is 3D scans only to determine volume, or does it have a bigger purpose?

What do you mean by "only"? Volume/mass are very important parameters when modeling melt and drift. The 3D scans can also be used in CFD studies of icebergs and for comparisons with satellite remote sensing studies of iceberg area/volume

6. What is the scope of your research, what impact can it have, and what is it called?

I study ice-ocean interactions. Understanding how icebergs melt and how much freshwater they produce is important for climate. I summarize this info in this paper- https://www.researchgate.net/publication/319321042_Bergy_Bit_and_Melt_Water_Trajectories_in_Godhabsfjord_SW_Greenland_Observed_by_the_Expendable_Ice_Tracker

6. Can you send some Pictures of the icebergs? (possibly the 3D scans, if we can open them?)

I can send pictures. Do you have agisoft photoscan? If not, you can view some of these models in meshlab. here's one I put on sketchfab
https://sketchfab.com/models/c75fdc83b5894ff1849f9902d280b8eb

Hi Dan

Thank you for the Quick answers! Just to elaborate on 3 of the questions.

1. What does the melt with sediment do to the Water in the fjord? Meaning, if we determine the amount of melt that comes from the icebergs into the Water in the fjord, and what this melt contains, what impact will it have on the Water in fjord? Will it change the wildlife, or the freezingpoint, or what is it we want to know with these informations?

2. Is the icebergs 100% freshwater?

3. Will we then choose icebergs with low amounts of peppels, in order to drill samples?

4. Have you uploaded more 3D scans to sketchfab, since it Work perfect for what we need?

Best

Jonathan and Mathias

Hi Mathias-

The sediment can change the turbidity of the water, which can affect the biology. As you increase turbidity you decrease the amount of light that can travel through the water (through absorption and scattering). Phytoplankton need sunlight for photosynthesis so turbidity can be important. If the sediments contain iron then they can have a huge impact on biology. https://en.wikipedia.org/wiki/Iron_fertilization

Understanding the amount, composition, and size distribution of the sediments will also help us understand how quickly they sink and how far they can spread once they are in the water. There's an entire field of engineering that is devoted to marine sediment transport. It's also important for geologists to understand their samples of the ocean floor. Sometimes they find rocks and sand on the ocean floor that should not normally be there and one explanation is melt from icebergs.

The interior of the iceberg should be a combination of freshwater and air. The exterior can have salt water intrusion, depending on how old and weathered the iceberg is and how much its orientation has changed.

We don't really get to choose the icebergs. They come in all kinds of shapes and sizes and sediment concentrations. Once we get there, we will look and see.

I don't have anything else on sketchfab. Do you have Agisoft Photoscan? If not, meshlab is free. I don't want to put too many of the models on sketchfab yet since it is public and I'm not ready to release these yet.

best,
Dan

A.2 Weight estimations

The weight estimations for the Specification of Requirements can be seen in Table A.1.

Number	Part	Link	Weight	Unit
1	Zenmuse X3 with gimbal and camera	https://forum.dji.com/thread-88272-1-1.html	247	g
2	Gopro replica	https://community.gopro.com/t5/Cameras/What-is-the-weight-of-the-different-cameras/td-p/2668	147	g
3	Gopro mount	Estimate	50	g
4	myRIO	http://www.ni.com/pdf/manuals/376047c.pdf	193	g
5	11,1V 5000mAh LiPo	https://hobbyking.com/en_us/turnigy-battery-5000mah-3s-25c-lipo-pack-xt-90.html	412	g
6	GPS release servo	https://www.conradelektronik.dk/p/savoex-standard-servo-sc-1256tg-digital-servo-453588?vat=true&utm_source=kelkoo&utm_medium=&utm_campaign=kelkoo_feed&utm_term=453588	52	g
	GPS release mechanisme and hook	Estimate	250	g
7	GPS beacon	Estimate	800	g
8	2x Sonar distance sensor	Estimate	100	g
9	Foam	Estimate	300	g
10	3x Spikes	Estimate	100	g
11	Alarm	Estimate	5	g
12	Wiring	Estimate	200	g
13	Ice sample picker	Estimate	1500	g
14	Raising/lowering mechanism	Estimate	1500	g
Total		5856		g

Table A.1: Weight estimations

A.3 Morphology diagram: Design phase 1

This appendix contains a detailed description of the selections done in Section 4.2.1. The first thing covered is the selection of the drone for the project, where 8 candidates will be evaluated. After this 6 conceptual subsystems will be evaluated using Pugh Matrix before the final selection will be done back in Section 4.2.1.

A.3.1 Drone selection

The drone selection started with a brainstorm of potential drones, that could be used in the project.

A.3.1.1 Potential candidates

List of ideas for drones:

- **DJI Matrice 600**
  A hexacopter with an A2 flight controller, can still be purchased even though it has been retired from DJI's assortment.
- **DJI Matrice 600 Pro** [16] [17]
  A hexacopter with an A3 Pro flight controller and redundant GPS's and compass's.
- **DJI Matrice 600 Pro with RTK module** [18]
  A hexacopter with an A3 Pro flight controller and redundant GPS's and compass's, delivered with a RTK module, which is a base station that gives extra redundancies and increased precision.
- **Hercules 10** [19]
  An octocopter developed by Dronevolt, using a PixHawk flight controller.
- **Hercules 20** [20]
  A larger version of the Hercules 10.
- **Aerialtronics Altura Zenith** [21]
  Another octocopter developed by Dronevolt, using a PixHawk flight controller.
- **DJI AGRAS MG-1P / Wind 8** [22]
  An octocopter with an A3 flight controller and no redundant GPS's.
- **DJI S1000** [23]
  An octocopter with an A2 flight controller and no redundant GPS's.
- **Freefly Alta 8** [24]
  An octocopter developed by FreeFly.
- **Versa HLO (Heavy Lift Octocoptor)** [25]
  An octocopter heavy lifting drone.

[16] www.kortlink.dk/dji/w7gs
[17] https://store.dji.com/product/matrice-600-pro
[18] https://www.dji.com/d-rtk/info
[19] https://www.dronevolt.com/en/expert-solutions/hercules-10/
[20] https://www.dronevolt.com/en/expert-solutions/hercules-20/
[21] www.kortlink.dk/aerialtronics/w7gv
[22] www.kortlink.dk/dji/w7gz
[23] https://www.droneland.dk/da/droner-med-kamera/13-dji-s1000-professionel-drone.html
[24] https://freeflysystems.com/alta-8/specs
[25] http://versadrones.com/products/heavy-lift-octocopter/

A.3.1.2 Selection criteria

The following criteria are used to determine the most suited drone for the project.

Criteria 1: Flight time
How long the drone can fly with the maximum rated payload. If the data sheet only specifies flight time without payload the flight time is halved.
Weighting: 1
Low priority since all the drones have a flight time above 10 min.

Criteria 2: Water resistance
How well the drone can handle water.
Weighting: 3
Medium priority since there is a chance of moisture in the air in Greenland.

Criteria 3: Wind resistance
How well the drone can handle high winds.
Weighting: 2
Low priority since there is a high possibility that strong winds will cancel the mission.

Criteria 4: Price
How expensive the drone will be, the price shall be within the budget of 100.000DKK, though it would be preferable if the price is below 50.000DKK, which is a "should have" requirement.
Weighting: 4
The price has a high priority, since the drone should not end up using the whole budget.

Criteria 5: Pre flight set up
How long it will take for the user to set up the drone for a mission.
Weighting: 2
Low priority since all drones have a relatively short set up time and the requirements specify that the set up time only needs to be under 1 hour.

Criteria 6: Complexity of drone/controller system
The user friendliness of the drone.
Weighting: 4
High priority since it is important that the final product is as user friendly as possible.

Criteria 7: Payload
How much the drone can lift.
Weighting: 5
Highest priority since the drone shall be able to carry the tools, sample, camera and batteries.

Criteria 8: Mounting possibilities
How good the mounting options are on the drone.
Weighting: 3
This is weighted as a middle criteria since permanent modifications are not wanted.

Criteria 9: GPS
Which flight modes with GPS are available for the drone, and whether or not the drone has redundancy systems.
Weighting: 4
This is a high priority since it creates a more safe flight.

Criteria 10: Extra control channels
If it is possible to use control signals directly from the flight controller.
Weighting: 2
Low priority criteria since externally communications systems exists though an integrated system is preferable.

Criteria 11: Transport options
If it is possible to get a freight case for the drone.
This is a deal breaker criteria since it should be possible to transport the drone.

A.3.1.3 Scoring table

Table A.2 will indicate what it takes to gain points in the PW diagram.

Points	Flight-time	Water resistance	Max rated windspeeds	Payload	Flight ready price
1	10 min	No flight in rain or mist	2 m/s	4kg	≥80.000DKK
2	12 min	Flight in mist	4 m/s	6kg	65.000DKK
3	14 min	Flight in light rain and mist	6 m/s	8kg	50.000DKK
4	16 min	Flight in moderate rain	8 m/s	10	25.000DKK
5	≥18 min	Flight on all type of weather (IP rating)	≥10m/s	≥12kg	10.000DKK

Points	Setup and use of drone	Complexity	Mounting options
1	Programming and assembly	Much work needed to use the system	Mounting brackets need to be made
2	Programming and light assembly	Light work needed to use the system	Existing mounting brackets needs to be modified
3	Light programming and light assembly	Functioning system	Existing mounting brackets needs to be modified lightly
4	Light assembly	Functioning system with a few extra functions	Mounting brackets are ready to for use
5	Plug and play	Functioning system with extra functions	Many possible mounting options

Points	GPS flight modes	Extra control channels
1	No GPS or compass modes	No control channels or possibilities of them
2	GPS flight modes	No control channels but possibilities of them
3	GPS and compass flight modes	Control channels which can be used for an external system
4	GPS and compass flight modes with redundancies	Control channels which can be added on the controller system
5	GPS and compass flight modes with redundancies and base station	Control channels ready to be used on the controller system

Table A.2: Points given for each criteria

A.3.1.4 PW diagram

Next step is to evaluate the ideas with a PW diagram and selecting the best ideas.

Selection criteria:	Flight-time	Water resistant	Wind resistant	Price	Pre flight setup	Complexity	Payload	Mounting posibilities	GPS	Extra control channels	Transport	Sum:
Wheighting	1	3	2	4	2	4	5	3	4	2	✓ ×	
DJI Matrice 600 Pro	4	3	4	3	5	5	2	5	4	4	✓	112
DJI Matrice 600 Pro med RTK modul	4	3	4	1	4	5	2	5	5	4	✓	106
Hercules 10	5	4	5	1	3	3	2	2	4	3	✓	87
Hercules 20	5	4	5	1	3	3	5	2	4	3	✓	102
DJI AGRAS MG-1 / Wind 8	1	5	3	1	5	5	4	4	4	4	✓	112
DJI S1000	4	3	3	4	5	5	2	5	3	4	✓	110
FreeFly Alta 8	4	4	3	1	4	4	3	4	3	3	✓	95
Versa HLO	3	3	2	1	2	2	5	4	3	3	✓	87

Table A.3: PW diagram for the drone

From Table A.3 the 3 best suited drones are:

- **DJI Matrice 600 Pro**
- **DJI AGRAS MS-1 / Wind 8**
- **DJI S1000**

First of all the AGRAS is discarded because of the price, which is nearly the entire budget. Next the S1000 is discarded because it has an A2 flight controller with no redundancies, which is wanted in Greenland because of the possibility of compass interference. Therefore the drone for the project is is going to be **DJI Matrice 600 Pro**.

A.3.2 Subsystem: Sample taking and extraction

From Section 4.2.1 the next step in the Morphology diagram for concepts is to brainstorm ideas of how to solve the subsystems. First up is the Sample taking and extraction subsystem.

A.3.2.1 Step 2: Brainstorm

List of ideas to solve the subsystem:

- Pickaxe with separate collector
- Laser cutter with separate collector
- Dropping wedge with separate collector
- Cup drill with separate collector
- Self collecting cup drill
- Self collecting Thermal scoop/drill

A.3.2.2 Step 3: Selection criteria

As the ideas will be evaluated with a Pugh Matrix, there will be no weighting of criteria.
Criteria 1: Power consumption
How much power the idea consumes.
Criteria 2: Weight
How heavy the idea will be.
Criteria 3: Sample size guarantee
How reliable the idea is to get the right amount of ice.
Criteria 4: Ease of collecting
How easy the collection is.
Criteria 5: Complexity
How complex the idea is to build and operate.
Criteria 6: Ease of use
How easy it is to use the idea when extracting the sample.
Criteria 7: Stability during flight
How stable the idea is expected to be when flying.
Criteria 8: Test possibilities
How easy it is to test the idea.

A.3.2.3 Step 4: Evaluate ideas with Pugh Matrix

Next step is to evaluate the ideas with the Pugh Matrix. The baseline is decided to be: Self collecting cup drill. See Table A.4.

Criteria:	Power consumption	Weight	Sample size guarantee	Ease of collecting	Complexity	Ease of use (removal of sample)	Stability during flight	Test possiblities	Sum
Cupdrill with collector									0
Laser with collector	-1	1	0	1	-1	-1	0	-1	-2
Pickaxe with collector	0	0	-1	-1	0	0	-1	0	-3
Cup drill with separate collector	-1	-1	0	-1	-1	0	0	0	-4
Dropping wedge	1	0	-1	0	1	0	-1	0	0
Thermal scoop, self collecting	-1	1	0	1	0	0	-1	0	0
Ice auger feeding system	0	-1	-1	1	1	-1	0	0	-1

Table A.4: Pugh matrix of sample taking

From here it is decided that the three best potential solutions are: Self collecting cup drill, Thermal scoop and Dropping wedge, which will be used in Step 5 in the main report, Section 4.2.1.

A.3.3 Subsystem: Raising/lowering mechanism

Next step in the Raising/lowering mechanism subsystem is to brainstorm ideas of how to solve the subsystem.

A.3.3.1 Step 2: Brainstorm

List of ideas to solve the subsystem. The subsystem of raising and lowering is needed for all three Sample taking solutions from before.

- Upside down scissor lift at the bottom of the drones main frame
- Pivoting arm on drone's main frame
- Pivoting arm with linear actuator on drone's main frame
- Linear actuator on landing gear

A.3.3.2 Step 3: Selection criteria

Criteria 1: Complexity
How complex the mechanism is.
Criteria 2: Precision
How precise the mechanism can lower the sample taker.
Criteria 3: Weight
How heavy the mechanism is.
Criteria 4: Stability during flight
How stable the idea is expected to be when flying.
Criteria 5: Versatile mounting options
How easy it is to mount the mechanism.

A.3.3.3 Step 4: Evaluate ideas with Pugh Matrix

The baseline is decided to be: Scissor lift. See Table A.5.

Criteria:	Complexity	Precision	Weight	Stability during flight	Versatile mounting options	Sum
Scissor lift						0
Pivoting arm	1	-1	0	0	-1	-1
Pivoting arm with linear actuator	0	0	-1	0	-1	-2
Linear actuator on landing gear	1	1	0	-1	-1	0

Table A.5: Pugh matrix of Raise/lowering mechanism

From here Scissor lift and Linear actuator on landing gear moves on to Step 5 in the main report.

A.3.4 Subsystem: Landing gear

Next step is to brainstorm ideas of how to solve the Landing gear subsystem.

A.3.4.1 Step 2: Brainstorm

List of ideas to solve the subsystem.

- 6 legs from propeller arms with spikes
- Standard landing gear
- Tripod from main frame with spikes
- 3 legs, 1 per 2 arms with spikes

A.3.4.2 Step 3: Selection criteria

All of the ideas for landing gear is expected to be able to be modified into a raising/lowering mechanism, if the idea of a having linear actuation of the landing gear ends up being the best solution for the Raising/lowering subsystem.
Criteria 1: Stability
How stable the landing gear type will be during extraction.
Criteria 2: Sliding
How well the landing gear prevents sliding on ice.
Criteria 3: Weight
How heavy the landing gear is.
Criteria 4: Mounting space
How much space will be available to the sample taker.
Criteria 5: Water landing
How well the landing gear handles emergency water landing.

A.3.4.3 Step 4: Evaluate ideas with Pugh Matrix

The baseline is decided to be: 6 legs from arms with spikes. See Table A.6.

Criteria:	Stability	Sliding	Weight	Mounting space	Water landing	Sum
6 legs from arms with spikes						0
Standard landing gear	-1	-1	0	-1	0	-3
Tripod from frame with spikes	1	0	-1	-1	0	-1
3 legs, 1 per 2 arms with spikes	1	0	0	1	0	2

Table A.6: Pugh matrix of Landing gear types

From here 6 legs from arms and 3 legs, 1 per 2 arms moves on to Step 5 in the main report.

A.3.5 Subsystem: Beacon release

Next step is to brainstorm ideas of how to solve the Beacon release subsystem.

A.3.5.1 Step 2: Brainstorm

List of ideas to solve the subsystem.

- Transported in a rope with a release mechanism
- 2 robot arms which holds and releases the beacon
- A band around the GPS beacon hanging in a hook
- Hook directly in the GPS beacon

A.3.5.2 Step 3: Selection criteria

Criteria 1: Complexity
How complex the mechanism is.
Criteria 2: Weight
How heavy the mechanism is.
Criteria 3: Ease of use
How easy it is to use the mechanism and reload a GPS beacon.
Criteria 4: Stability during flight
How stable the idea is expected to be when flying.
Criteria 5: Safe delivery of GPS beacon
How safe the mechanism is when releasing, to avoid damaging the beacon when dropping.

A.3.5.3 Step 4: Evaluate ideas with Pugh Matrix

The baseline is decided to be: Transported in a rop with a release mechanism. See Table A.7.

Criteria:	Complexity	Weight	Ease of use	Stability during flight	Safe delivery of GPS	Sum
Transported in a rope with a hook						0
2 robot arms	-1	-1	0	1	-1	-2
A band around GPS beacon and a hook	0	0	-1	1	-1	-1
Hook directly from beacon	0	0	1	0	-1	0

Table A.7: Pugh matrix of Beacon release ideas

From here Transport in rope and Hook directly in beacon moves on to Step 5 in the main report.

A.3.6 Subsystem: Floatation

Next step is to brainstorm ideas of how to solve the Floatation subsystem.

A.3.6.1 Step 2: Brainstorm

List of ideas to solve the subsystem.

- Foam on landing gear
- Self-inflating life jacket
- Foam on main frame
- Foam on propeller arms

A.3.6.2 Step 3: Selection criteria

Criteria 1: Stability during flight
How stable the floatation device is during flight.
Criteria 2: Stability on water
How stable the floatation is when landed on water.
Criteria 3: Weight
How heavy the floatation is.
Criteria 4: Guarantee of floating
How reliable the floatation device is.
Criteria 5: Guarantee of dry electronics
How secure the floatation is in keeping the electronics dry.

A.3.6.3 Step 4: Evaluate ideas with Pugh Matrix

The baseline is decided to be: Foam on landing gear. See Table A.8.

Criteria:	Stability during flight	Stability in water	Weight	Guarantee of floating	Guarantee of dry electronics	Sum
Foam on landing gear						0
Self-inflating life jacket	1	-1	-1	-1	-1	-3
Foam on main frame	1	-1	0	0	-1	-1
Foam on propeller arms	0	-1	0	0	-1	-2

Table A.8: Pugh matrix of Floatation ideas

From here only Foam on landing gear moves on to Step 5 in the main report, as it is the only one that keeps the electronics dry.

A.3.7 Subsystem: Iceberg roll alarm

Next step is to brainstorm ideas of how to solve the Iceberg roll alarm subsystem.

A.3.7.1 Step 2: Brainstorm

List of ideas to solve the subsystem.

- myRIO accelerometer with alarm on drone
- myRIO accelerometer with alarm on controller
- Pendulum with contacts and alarm on drone
- An iron bell that makes noise if the iceberg is rolling

A.3.7.2 Step 3: Selection criteria

Criteria 1: Ease of recognizing signal
How easy it is for the operator to recognize that the alert is triggered.
Criteria 2: Electronic complexity
How complex the electronics for the device is.
Criteria 3: Software complexity
How complex the software will be.
Criteria 4: Weight
How heavy the device will be.
Criteria 5: Precision during measurement
How precise the device can measure the rolling of an iceberg.

A.3.7.3 Step 4: Evaluate ideas with Pugh Matrix

The baseline is decided to be: myRIO accelerometer with alarm on drone. See Table A.9.

Criteria:	Ease of recognizing signal	Electronics complexity	Software complexity	Weight	Precision during measurement	Sum
myRIO with alarm on drone						0
myRIO with alarm on controller	1	0	-1	0	0	0
Pendulum with contacts and alarm on drone	0	0	1	-1	-1	-1
A bell	-1	0	1	0	-1	-1

Table A.9: Pugh matrix of Rolling alarm ideas

From here myRIO accelerometer with alarm on drone and on the controller moves on to Step 5 in the main report.

A.4 Experimental report: Preliminary thermal drilling test

This experimental report will focus on the preliminary thermal drilling test to determine if this method is suited to extract ice from an iceberg.

A.4.1 Purpose

This experiment was done to determine if it is possible to use thermal drilling as a tool to extract ice samples.

A.4.2 Theory behind experiment

Ice has a low melting point and with a small plate of heated aluminium it should be possible to cut out a sample of ice.

A.4.3 Experiment

The experiment was done outside the container freezer at Navitas, AU.

Test equipment

- Ice bucket
- Round heat bed from a 3D printer
- Welding glove
- 12V power supply

Test setup

The experiment will be done by heating the bed and use it to cut through the ice, see Figure A.1.

Figure A.1: Thermal drill setup

Procedure

1. Plug in power supply
2. Heat the bed (use welding glove)
3. Pull the ice bucket out of the freezer
4. Grab the heat bed with the welding glove
5. Stick the heat bed into the ice surface
6. Observe

A.4.4 Results and calculations

The heat bed only drilled about a centimetre into the ice before the was too cold to drill any more, see Figure A.2.

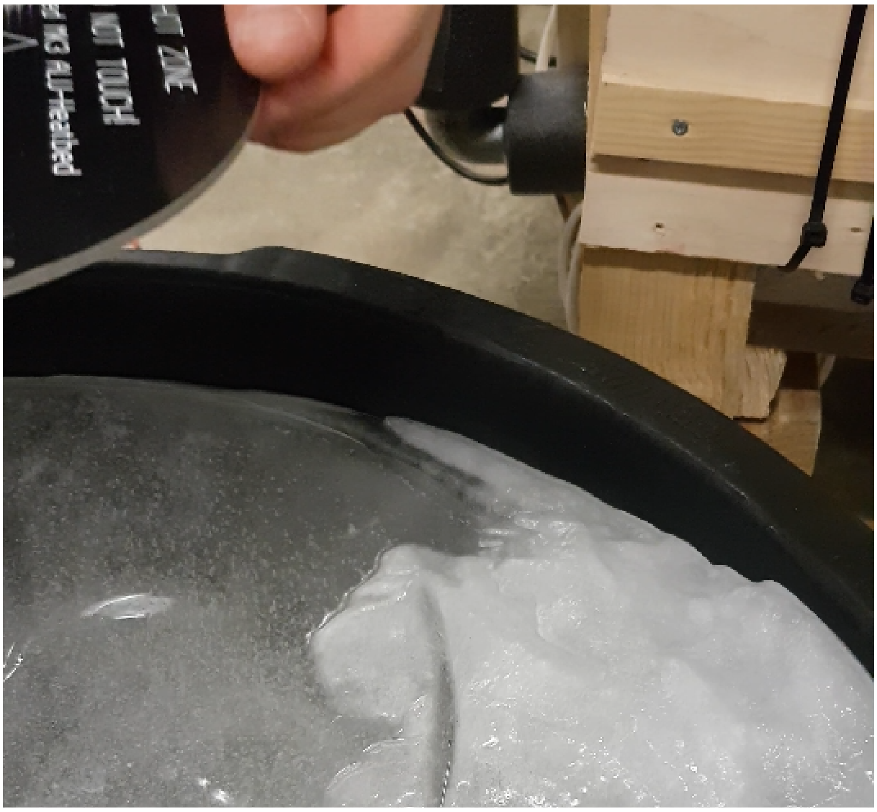


Figure A.2: Thermal drill test

A.4.5 Sources of errors

First of all the heat bed could not keep itself heated through the test. Secondly the copper wires placed on the heat bed, did not go all the way to the edge of the bed and therefore the edges were not heated thoroughly, which will be hard to solve.

A.4.6 Summary

In summary thermal drilling is not suited to extract ice samples this way as the heat was lost too fast and it took too long to heat it up again. For these reasons it would probably require too much power to keep it heated, which is a problem because of the lifting capacity and the weight of batteries.

A.5 Experimental report: Preliminary wedge drop test

This experimental report will focus on the preliminary wedge drop test to determine if this method is suited to extract ice from an iceberg.

A.5.1 Purpose

This experiment was done to determine if it is possible to drop a wedge into a bucket of ice and then collecting an ice sample from the debris.

A.5.2 Theory behind experiment

Ice is a brittle material and with enough impact it should be possible to break it into smaller pieces and then collect a sample.

A.5.3 Experiment

The test was done outside Navitas, AU.

Test equipment

- Ice bucket
- Metal rod with a 45° tip, with a weight of 1,07kg
- Metal plate with a 45° tip, with a weight of 2,28kg
- Duct tape for stable flight

Test setup

The experiment was done by dropping the Rod wedge and the Plate wedge from 5 meters into the ice bucket and observing the impact. After the impact the debris will be checked to see if there were any samples that could be used. Before being dropped a tail of duct tape was made so the wedges were stable during the straight fall, see Figure A.3.

Figure A.3: Wedge drop test setup

Procedure

1. Make a duct tape tail and attach it to the Plate wedge
2. Make a duct tape tail and attach it to the Rod wedge
3. Place the ice bucket
4. Stand 5 meters above the bucket
5. Drop the Plate wedge twice
6. Observe the debris on both impacts
7. Drop the Rod wedge twice
8. Observe the debris on both impacts

A.5.4 Results and calculations

Both drop test resulted in debris. In the case of the Rod wedge, it split the ice in the bucket in half. But it did not break off any suitable parts to collect, see Figure A.4.

Figure A.4: Wedge drop test with a rod

The Plate wedge broke off some small parts but none were big enough to collect, also they did not meet the depth specified in the Requirements of 10 cm, see Figure A.5.

Figure A.5: Wedge drop test with a plate

In both tests it was also clear that if any debris could be used, they were scattered all over the ground, which would make it hard to collect them.

A.5.5 Sources of errors

First of all a bucket of ice will not correctly represent an iceberg, because the crack line only needs to be as long as the diameter of the bucket. Therefore it is hard to predict if the results were representable to a real iceberg. The debris where inconsistent in sizes, which may or may not be caused by the bucket size.

A.5.6 Summary

In summary dropping wedges onto ice is not the best way of extracting ice samples since the wedges needs to be dropped more than once to create debris suitable for collection. The dropping of wedges where also too inconsistent to rely on as a solution.

A.6 Experimental report: Preliminary mechanical drilling test

This report will cover the preliminary mechanical drilling tests done to determine which method of extracting ice is the most effective.

A.6.1 Purpose

This experiment is performed in order to evaluate how difficult it is to drill mechanically in ice, and to see which problems may occur during drilling. The report will cover the drilling of three different types of cup drills, and comment on their performance.

A.6.2 Theory behind experiment

As ice is a hard but brittle material, mechanical drilling can have some downsides, as it can be hard to predict how the ice acts on the cup drill. The drilling will be done with a hand-held electrical drill, and where possible also by hand, and observations of the drilling will be noted.

A.6.3 Experiment

In order to perform the experiments, it is necessary to create some ice, which was done by freezing water buckets in the container freezer at Navitas, AU, seen in Figure A.6.

Figure A.6: Container freezer at Navitas

Test equipment
The test equipment contains the following parts:

- Electrical drill - Makita
- Bucket of ice
- Cup drill 1: Ø110x50mm normal wooden cup drill, with and without center drill
- Cup drill 2: Ø60x450mm cup drill made from a steel tube
- Cup drill 3: Ø120x1200mm Kovac ice drill, lent from Arctic Research Center, AU

The three drills can be seen in Figure A.7, from 1 to 3, left to right.

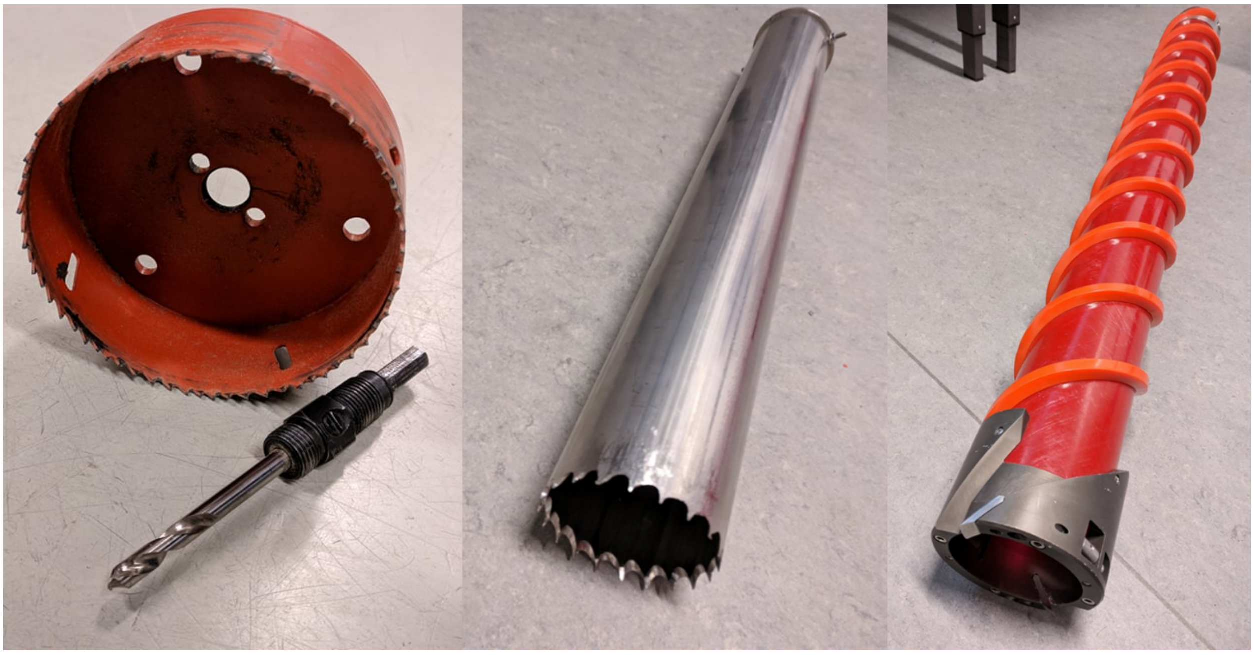


Figure A.7: The three cup drill which will be tested

Test setup

The test will be done by pulling the ice bucket out of the freezer, and test the drills one by one. The bucket can be seen in Figure A.8.

Figure A.8: The bucket which was used for testing

Procedure

The test will be done primarily with the electrical drill as all three drills are made for that purpose. The Kovac drill will also be tested by hand, as it comes with a handle for drilling by hand. The test will be done at least two times for each drill.

The test will focus on three things; how easy it is to get the drill started, how fast and effective the drilling is, and how easy it is to get the drill back up from the ice. This first test will not focus on how to break off the ice and extract the sample, but only on the drilling part.

As the electrical drill has two gears for rotation speed, the different drills will be tested at both rpm's ($\approx$ 500 rpm and $\approx$ 1200 rpm under load). Therefore a total of 9 tests will be carried out:

- Wooden cup drill (no center drill) - Low rpm
- Wooden cup drill (no center drill) - High rpm
- Wooden cup drill (with center drill) - Low rpm
- Wooden cup drill (with center drill) - High rpm
- Ø60 steel tube cup drill - Low rpm
- Ø60 steel tube cup drill - High rpm
- Kovac drill - Low rpm
- Kovac drill - High rpm
- Kovac drill - By hand

A.6.4 Results and calculations

The first test was the normal Ø110 wooden cup drill without center drill, where the observations can be seen in Table A.10.

Wooden cup drill (no center drill)			
Rotation speed	Start up	Drilling	Pulling drill out
Low rpm	Difficult to get the drill started but possible for a single person	The drilling was fine but the cup drill is restricted to only 50mm of drilling, so not a deep hole	Easy to pull out the drill
High rpm	A bit harder than at low rpm, but still possible for one person	Drilling was again fine, but a bit faster and smoother	No problem again

Table A.10: Observations from tests with the wooden cup drill without center drill attached

Next up are the observations for the wooden drill with center drill attached, which can be seen in Table A.11.

Wooden cup drill (with center drill)			
Rotation speed	Start up	Drilling	Pulling drill out
Low rpm	Easy and stable at start up	Same effort required as without center drill, fine drilling	No problem
High rpm	Stable at start up	Same as before, just a bit faster drilling	No problem

Table A.11: Wooden cup drill with the center drill attached

Observations for Steel tube cup drill can be seen in Table A.12.

Steel tupe cup drill			
Rotation speed	Start up	Drilling	Pulling drill out
Low rpm	Possible but a bit unstable because of the lenght	Really poor, and stopped after 30mm because the drilled ice could not be removed from the hole	No problem because the hole was so small
High rpm	Really difficult and unstable	Same as before where the snow compacted under the drill	No problem

Table A.12: Observations from the steel tube cup drill test

The last test was with the special made Kovac ice drill, where the observations can be seen in Table A.13.

Kovac ice drill			
Rotation speed	Start up	Drilling	Pulling drill out
Low rpm	Almost impossible for one person to start	Fine drilling with good transport of material	No problem as the hooks of the drill were not engaged
High rpm	Impossible to start, even for two persons	To fast for such a big drill, which made it uncontrollable	No drilling done
Hand power	Possible for two persons, but hard as the two cutter heads of the drill makes it unstable	Slow but steady	No problem

Table A.13: Observations from the three tests with the Kovac ice drill

A.6.5 Sources of errors

The tests and observations were done by hand and are not measurable, which means that it was a subjective opinion by the group. But as the tests were carried out several times, the objectiveness of what happened should be increased.

A.6.6 Summary

In summary it can be concluded that is is definitely possible to drill in ice, and that some types of cup drills are quite effective. Furthermore is can be really hard to get the drill started, but as seen in Table A.11, the center drill made a big difference in start up stability. The rpm's should not be too high as it can make the drilling unstable, but too low rpm makes the drilling too slow.

A.7 Morphology diagram: Design phase 2

Design phase 2 with the selection of 4 subsystems on component level.

A.7.1 Subsystem: Beacon drop - Transported in a rope with a release mechanism

This subsystem will be responsible for dropping the GPS beacon onto the iceberg.

A.7.1.1 Step 1: Brainstorm

List of ideas for the subsystem.

- **Solenoid** [26]
  A component that moves a small rod back and forth which can then be used to drop a rope.
- **Servo with a hook** [27]
  A servo motor which can activate a hook and then release the beacon rope.
- **Stepper with connecting rod** [28]
  A stepper motor used along with a connecting rod, so when stepper rotates the beacon rope is released.

A.7.1.2 Step 3: Selection criteria

The following criteria are used to determine which component is the best fit for the project.

Criteria 1: Weight
Since the drone has a limited payload it is important that this subsystem is light weight.
Weighting: 4
Because of the payload limitations this is weighted as a high priority.

Criteria 2: Price
How much the component costs.
Weighting: 2
This criteria has a relatively low priority since all components are well within budget.

Criteria 3: Complexity
How complex the component is to work with, as well as how many parts are needed for the idea.
Weighting: 5
This is a high priority criteria since this subsystem should be plug and play.

[26] https://elektronik-lavpris.dk/p103821/its-ls2924bd-12-solenoid-framed-2924b-d-12v/
[27] https://morfars.dk/products/punisher-servo-5p
[28] https://minielektro.dk/nema-17-step-motor-4kg-cm.html

Scoring table:
Table A.14 will indicate what it takes to gain points in the PW diagram.

Points	Weight	Price	Complexity
1	> 300g	> 200 DKK	Much work needed to use the system
2	250g	160 DKK	Light work needed to use the system
3	200g	120 DKK	Functioning system with light work
4	150g	80 DKK	Functioning system
5	100g	< 40 DKK	Plug and Play

Table A.14: Points given for each criteria

A.7.1.3 Step 4: Evaluate ideas with PW diagram

Next step is to evaluate the components with a PW diagram and selecting the best idea.

Selection criteria:	Weight	Price	Complexity	Sum:
Wheighting	4	2	5	
Solenoid	3	2	5	41
Servo	5	1	3	37
Stepper motor with connecting rod	2	3	1	19

Table A.15: PW diagram for the beacon release subsystem

From Table A.15 the best suited component for the project is chosen as the **Solenoid**.

A.7.2 Subsystem: Iceberg roll alarm - myRIO accelerometer with alarm on drone

This subsystem will be responsible for alerting the operator if the iceberg begins to roll.

A.7.2.1 Step 1: Brainstorm

List of ideas for the subsystem.

- **LED panel control light** [29]
  A LED mounted inside a threaded house for easy mounting, which alerts the operator by shining into the camera.
- **Bike light** [30]
  A simpel LED bike light with 2 LED's and tinted glass, which alerts the operator by shining into the camera.
- **Piezo buzzer** [31]
  A buzzer with flange mounting, which alerts the operator by sending out a loud buzzing sound.
- **Speaker** [32]
  A small speaker, which alerts the operator by sending out a loud sound.

A.7.2.2 Step 3: Selection criteria

The following criteria are used to determine which component is the best fit for the project.

Criteria 1: Weight
Since the drone has a limited payload it is important that this subsystem is light weight.
Weighting: 3
Because of the payload limitations this is normally weighted as a high priority. But because of the relatively light weight of the components the priority is decreased.

Criteria 2: Signalling capabilities
How good the component is at alerting the operator.
Weighting: 5
This criteria is the most important because it is a critical component.

Criteria 3: Mounting options
How much work is needed to mount the component to the drone.
Weighting: 2
This is a low priority criteria because of the relatively small sizes of the components.

[29] https://www.elextra.dk/main.aspx?page=article&artno=H19139&gclid=Cj0KCQiAgMPgBRDDARIsAOh3uyKSoBg2TGmX6Zg0e0PmqM21n-7MXzQFIyPOe13IUG4_GwfwvJLitf8aArlMEALw_wcB
[30] www.kortlink.dk/cykelgear/w8v6
[31] https://dk.rs-online.com/web/p/piezo-buzzer-komponenter/6173097/
[32] https://www.sparkfun.com/products/14023

Scoring table:
Table A.16 will indicate what it takes to gain points in the PW diagram.

Points	Weight	Signalling capabilities	Mounting options
1	> 100g	< 80dB / Low signal light	Permanent modification needed to mount the system
2	75g	85dB / Signal light	Much work needed to mount the system
3	50g	90dB / Strong signal light	Light work needed to mount the system
4	25g	95dB / Signal light with tint	Mounting option available
5	< 10g	> 100dB / Strong signal light with tint	More than one mounting option available

Table A.16: Points given for each criteria

A.7.2.3 Step 4: Evaluate ideas with PW diagram

Next step is to evaluate the components with a PW diagram and selecting the best idea.

Selection criteria:	Weight	Signaling capabilities	Mounting options	Sum:
Wheighting	3	5	2	
Signal light	3	1	5	24
Bike light	3	5	4	42
Sirene 96dB	5	4	3	41
Sirene 85dB	1	2	2	17

Table A.17: PW diagram for the roll alarm subsystem

From Table A.17 the best suited component for the project is chosen as the **Bike light**.

A.7.3 Subsystem: Linear actuator for landing gear

This subsystem is focused on the type of actuator used for making the landing gear move up and down. It was decided that the linear actuator should be able to lift two times the weight of the drone, 32 kg.

A.7.3.1 Step 1: Brainstorm

List of ideas for the subsystem. All of the ideas underneath can lift the required weight when working in groups of three, therefore torque is not a criteria.

- **Stepper motor driving a leadscrew** [33]
  The stepper motor drives the leadscrew which moves the drone up and down the landing gear.
- **Stepper motor with a hollow axle with a leadscrew** [34]
  Special type of stepper where the stepper, and therefore drone, moves up and down the leadscrew.
- **Linear piston** [35]
  An electrical linear piston which can move the drone up and down.
- **Stepper motor with a gear rack** [36]
  The gear rack enables the drone to be moved up and down.

A.7.3.2 Step 3: Selection criteria

The following criteria are used to determine which component is the best fit for the project.

Criteria 1: Precision
How precisely the actuator can move the drone up and down.
Weighting: 4
It is important that the drill speed and distance can be adjusted precisely.

Criteria 2: Power consumption
How much power the system consumes.
Weighting: 3
It is important that the system does not drain the drones batteries.

Criteria 3: Weight
How much the system weighs.
Weighting: 5
The system should not be too heavy.

Criteria 3: Complexity
How complex the system is to construct and operate.
Weighting: 3
The system should not be too complicated, but not the main priority.

[33] https://minielektro.dk/nema-17-step-motor-4kg-cm.html
[34] https://www.robotdigg.com/product/32/Non-captive-Nema17-Linear-Stepper
[35] https://www.actuonix.com/T16-S-Micro-Track-Actuator-with-Limit-Switches-p/t16-s.htm?1=1&CartID=0
[36] https://www.cnc4you.co.uk/MOD1-Rack?search=rack

Scoring table:
Table A.14 will indicate what it takes to gain points in the PW diagram.

Points	Precision	Power consumption	Weight	Complexity
1	8mm	12W	500g	Much work needed to use the system
2	6mm	10W	400g	Light work needed to use the system
3	4mm	8W	300g	Functioning system with light work
4	2mm	6W	200g	Functioning system
5	1mm	4W	100g	Plug and Play

Table A.18: Points given for each criteria

A.7.3.3 Step 4: Evaluate ideas with PW diagram

Next step is to evaluate the components with a PW diagram and selecting the best idea, see Table A.19.

Selection criteria:	Precision	Power consumption	Weight	Complexity	Sum:
Wheighting	4	3	5	3	
Stepper with leadscrew	5	4	3	2	41
Stepper with hollow axle and leadscrew	5	4	3	4	47
Linear piston	2	2	4	3	37
Stepper with gear rack	5	4	1	2	31

Table A.19: PW diagram for the Linear actuator subsystem

From Table A.19 it is determined that the best solution for the linear actuator on the landing gear is **Stepper motor with hollow axle and leadscrew**.

A.7.4 Subsystem: Motor for drill

This subsystem is focused on the motor which drives the drill.

A.7.4.1 Step 1: Brainstorm

List of ideas for the subsystem.

- **Brushed DC motor with a H-bridge** [37]
  Using a brushed DC motor to drive the drill.
- **Brushed DC motor with gearing and a H-bridge** [38]
  Micromotors complete package with motor and 18:1 gearing.
- **Brushless motor with an ESC** [39]
  Using a brushless motor with an ESC.
- **Brushless motor with an ESC and gearing from Micromotors** [40]
  Using a brushless motor and an ESC in combination with a gearing from Micromotors.

A.7.4.2 Step 3: Selection criteria

The following criteria are used to determine which component is the best fit for the project.

Criteria 1: Adjusting the rpm to ≈ 500-800 rpm
How easy it is to adjust the rpm without loosing all power.
Weighting: 4
It is important that the drill can run at the correct speed.

Criteria 2: Power delivery
How much power the motor can deliver to the drill.
Weighting: 4
It is important as the drill must not stop during drilling.

Criteria 3: Weight
How much the system weighs.
Weighting: 3
The system should not be too heavy.

Criteria 3: Complexity
How complex the system is to control.
Weighting: 2
The system should not be too complicated, but not the main priority.

[37] `https://hobbyking.com/en_us/540-6527-brushed-motor-90w.html`
[38] `www.kortlink.dk/elektronik-lavpris/w8v7`
[39] `https://midhobby.dk/produkter/96-motorer-el/53470-lrp-vector-k7-brushless-motors---105t/`
[40] `https://midhobby.dk/produkter/96-motorer-el/53470-lrp-vector-k7-brushless-motors---105t/`

Scoring table:
Table A.20 will indicate what it takes to gain points in the PW diagram.

Points	Adjustment of rpm	Power delivery	Weight	Complexity
1	Poor adjust to 500-800rpm	50W	500g	Much work needed to use the system
2	Decent adjust to 500-800rpm	100W	400g	Light work needed to use the system
3	Fine adjust to 500-800rpm	150W	300g	Functioning system with light work
4	Good adjust to 500-800rpm	200W	200g	Functioning system
5	Exellent adjust to 500-800rpm	250W	100g	Plug and Play

Table A.20: Points given for each criteria

A.7.4.3 Step 4: Evaluate ideas with PW diagram

Next step is to evaluate the components with a PW diagram and selecting the best idea, see Table A.21.

Selection criteria:	Precision	Power consumption	Weight	Complexity	Sum:
Wheighting	4	4	3	2	
Brushed motor with H-bridge	1	2	4	4	24
Brushed motor with H-bridge and gearing	4	1	2	4	30
Brushless motor with ESC	2	5	4	5	30
Brushless motor with ESC and gearing	5	5	2	5	36

Table A.21: PW diagram for the Drill motor subsystem

From Table A.21 it is determined that the best solution for the Drill motor is **Brushless motor with ESC and gearing**.

A.8 Experimental report: Float test

This report describes the testing and development of the floats.

A.8.1 Purpose

If there is an emergency during flight, the drone will have to land on water. Therefore the floats will have to keep the drone afloat and stable in the water.

A.8.2 Theory behind experiment

The simply theory behind buoyancy is that the displaced waters mass is equal to the lifting force. Furthermore the placement of these floats will have to be appropriate according to the center of mass. The center of mass is very close to the middle of the drone as all is symmetric. Therefore the placement of the floats on the triangular landing gear is ideal.

The volume of the floats are determined according to the weight of the drone, plus a small safety margin for the first test. Therefore three floats of 5,8L was manufactured (Ø200x200mm with Ø16 hole in the middle), as the drones weight is 16,04 kg without the beacon of 800g, see Figure A.9.

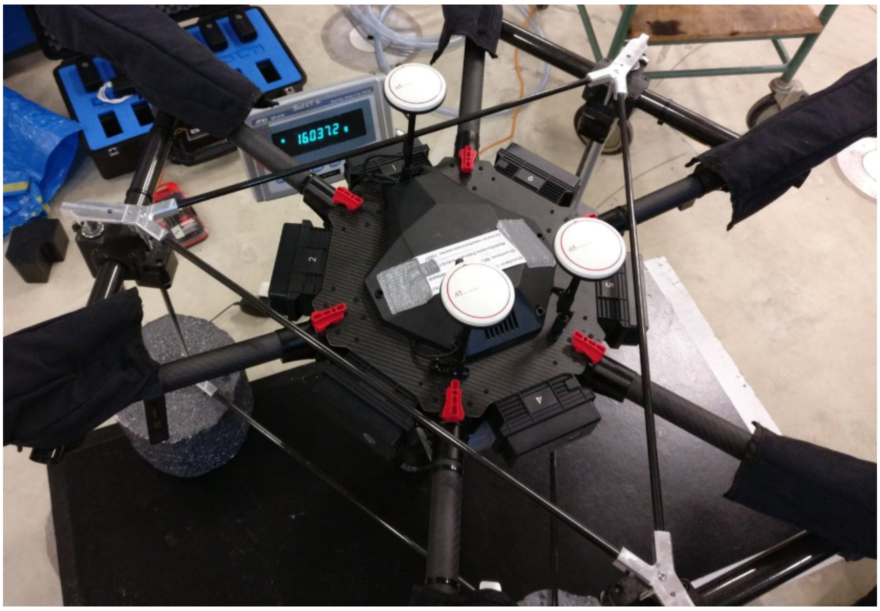


Figure A.9: Weight of the drone with every thing except beacon on-board

A.8.3 Experiment

Put the drone into the water with everything on-board.

Test equipment

- Ø2m tank with water
- Drone
- Scale

Test setup
The water tank in "Projekthallen" at Navitas, AU.

Procedure
Put the drone into the water and test floatation and stability.

A.8.4 Results and calculations

The test with the 5,8L floats showed that the safety margin was too small and that the floats where barely above water. Therefore the stability of the drone was very poor, see Figure A.10.

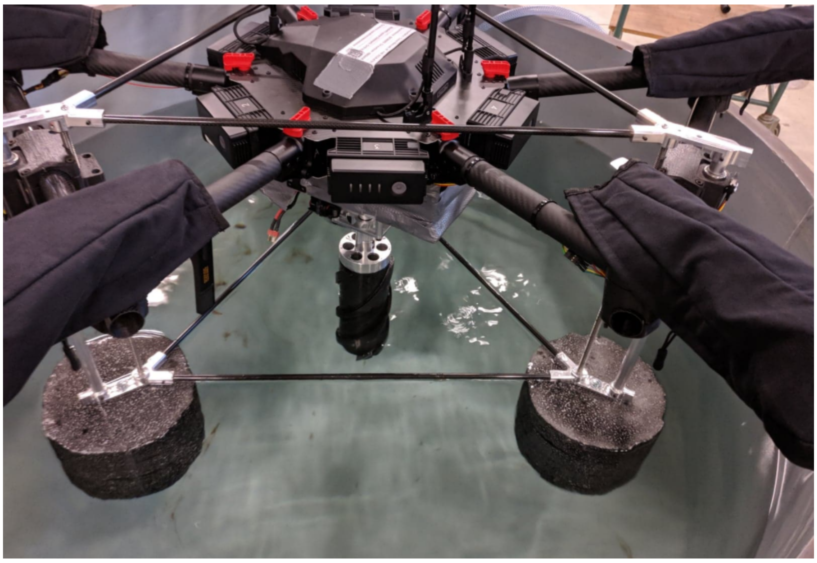


Figure A.10: Drone float test with 5,8L floats

Therefore bigger floats were needed, and three Ø350x200mm floats (15L) were created. In order not to destroy the air flow from the propellers, the floats were sliced on each side. The result were a stable drone with good floatation, see Figure A.11.

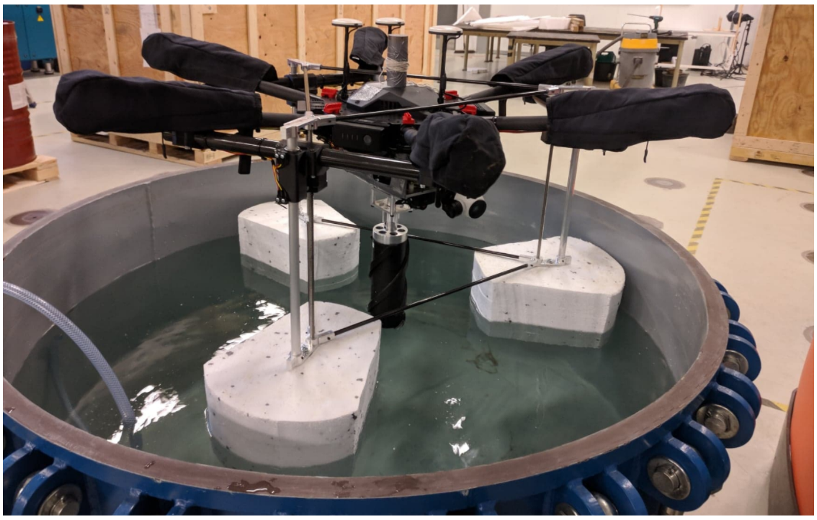


Figure A.11: Drone float test with 15L floats

These floats are quite big, but it was decided that the stability on water was important, and therefore they were kept this way.

A.8.5 Sources of errors

The water was not saltwater, but this only helps with better floatation if landed in sea water because saltwater has a greater density than freshwater.

A.8.6 Summary

It was decided to emphasize stability as the water might get a bit rough in Greenland, and therefore the floats ended up being bigger than expected, but without destroying the flight.

A.9 Risk assessment

The Risk assessment is made as a FMEA (Failure Mode and Effects Analysis), and the FMEA template used in this project is a modified version of A.Dembski's FMEA Worksheet from 1998[41]. Here the risks are analysed for Severity, Probability and Detection. Points are then distributed based on the following tables.

Effect	SEVERITY of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning	10
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe system operation with warning	9
Very High	System inoperable with destructive failure without compromising safety	8
High	System inoperable with equipment damage	7
Moderate	System inoperable with minor damage	6
Low	System inoperable without damage	5
Very Low	System operable with significant degradation of performance	4
Minor	System operable with some degradation of performance	3
Very Minor	System operable with minimal interference	2
None	No effect	1

Table A.22: Risk assessment scoring table for Severity

Detection	Likelihood of DETECTION by Design Control	Ranking
Absolute Uncertainty	**Design control cannot** detect potential cause/mechanism and subsequent failure mode	10
Very Remote	**Very remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	9
Remote	**Remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	8
Very Low	**Very low** chance the design control will detect potential cause/mechanism and subsequent failure mode	7
Low	**Low** chance the design control will detect potential cause/mechanism and subsequent failure mode	6
Moderate	**Moderate** chance the design control will detect potential cause/mechanism and subsequent failure mode	5
Moderately High	**Moderately High** chance the design control will detect potential cause/mechanism and subsequent failure mode	4
High	**High** chance the design control will detect potential cause/mechanism and subsequent failure mode	3
Very High	**Very high** chance the design control will detect potential cause/mechanism and subsequent failure mode	2
Almost Certain	**Design control will** detect potential cause/mechanism and subsequent failure mode	1

Table A.23: Risk assessment scoring table for Detection

[41] https://www.lehigh.edu/~intribos/Resources/

PROBABILITY of Failure	Ranking
Very High: Failure is almost inevitable	10
-	9
High: Repeated failures	8
-	7
-	6
Moderate: Occasional failures	5
-	4
Low: Relatively few failures	3
-	2
Remote: Failure is unlikely	1

Table A.24: Risk assessment scoring table for Probability

One of the modifications to the FMEA can be seen on Table A.24 and was to remove the coloum specifying the number of failures, as the group was unable to perform the required amount of tests (1 out of 1.500.000 or 1 out of 2.000 for example). Therefore the Probability score is based on observations from the tests.

The other modified part of the FMEA is the column specifying the responsible person and the date by which the action should be done, which has also been removed from the FMEA Table.

Otherwise the point system from the three Tables is used, and if a specific Risk ends with a Risk Priority Number (RPN) of 30 or higher (marked with red), recommended actions will added. An "Effect of failure" with a RPN of 20-30 (marked with yellow), will be evaluated to see if it needs an action or not. Once an action has been taken, the "Effect of failure" is evaluated again and a new RPN is calculated to determine if further action is needed.

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Action Results: Actions Taken	New Sev	New Prob	New Det	New RPN
Drone	Disfunctioning or damage to the drone leading to a crash landing on water	Loss of drone and equipment	1	Wind, animals, faulty telemetry data, low battery	3	Floaters on the drone so it can make an emergency landing on water	9	27	Specify in the user manual, that the floaters are not meant for water landings unless it is an emergency	The user manual specifies, that the floaters are not meant for water landings unless it is an emergency	1	3	9	27
	Drone unable to communicate with myRIO	Loss of time	5	Wires disconnecting due to vibrations	3	Every system is checked before flight, but wires can disconnect during flight or landing	3	45	Use silicone to secure wires	Silicon was used to secure wires	5	1	3	15
	Drone stuck on iceberg	Loss of drone and equipment	1	Crashlanding/drill stuck	3	The drone is able to be rescued by lifting it off the iceberg with helicopter, with a hook attached to the frame	9	27	A seperate hanger could be made and attached to the drone frame, for lifting	None	1	3	9	27
	Drone blades hits personnel	Human endangerment and damage to drone parts	10	Personnel standing to close to the drone	1	The user manual specifies that the operator is the closest person to the drone.	1	10	Use current design control	None	10	1	1	10
Beacon drop	Beacon unable to detach	Loss of time	5	Rope wrongly attached	3	Part of the startup is to check the rope	1	15	Use current design control	None	5	3	1	15
			5	Solenoid failure	1	Part of the startup is to check the solenoid	1	5	Use current design control	None	5	1	1	5
	Rope entagelment on other parts	Human endangerment and damage to drone parts	10	Wind	3		1	30	Make sure not to fly in windy weather	There was added a recommadation in the user manual not to fly with wind speeds above 10m/s	10	2	1	20
			10	Length of rope	7	The operator can check the rope	1	70	Shortening rope length	Rope lenght was shortened	10	2	1	20
	Beacon dropped unintentionally	Loss of time and possibly beacon	5	Human error	3		1	15	Implement some kind of two step procedure to drop beacon	None	5	3	1	15

Drill	Drill stuck in ice	Loss of drone and equipment	10	Freezing, loss of motor power	3		1	30	Use wax to make sure snow does not stick and keep drill rotating	The user manual specifies that the drill should remain rotating as long as its is in the ice	8	1	2	16
	Drill starting unintentionally	Human endangerment and damage to drone parts	10	Human error	1	Two step procedure for starting the drill	1	10	Use current design control	None	10	1	1	10
Landing gear	Landing gear starting unintentionally	Loss of time and minor damage	6	Human error	1	Two step procedure for starting the landing gear	1	6	Use current design control	None	6	1	1	6
	Landing gear continuing once it reaches outer positions	Loss of time and minor damage	6	Human error, should stop it before it reaches the maximum	3		4	72	Add endstops like on a 3D printer	Enstops added	6	1	1	6
	Landing gear stuck to the iceberg	Loss of drone and equipment	8	Freezing	1	Landing gear spikes are made from POM, not able to freeze like metals would	2	16	Use current design control	None	8	1	2	16
Electronics	Water gets into the electronics print board	Failure of equipment except drone	7	Flying in light rain	3	The operator is able to see/feel rain	3	63	Add protection to electronics compartment	Compartment has been mostly sealed off and there has been added moisture soaking pack	7	1	3	21
	myRIO executing failure	Loss of time	5	Errors within the software	1		5	25	Add LED's to indicate program is running as expected	LED's on myRIO are blinking back and forth if the program is running as expected	5	1	1	5
	Overheating components	Loss of time and minor damage	6	Stepper drivers and Brushless motor tend to get hot	1	Fans are checked as part of the startup	4	24	Use current design control	None	6	1	4	24
	Brushless motor failure, high power consumption	Loss of time and equipment damage	7	If the ice is to hard the motor will keep ramping up the amps	1		8	56	Use a fuse to limit the motor	Fuse added	3	1	8	24
	Freezing components	Loss of time and minor damage	6	myRIO and the LiPo battery could get to cold	3		4	72	Heatpads should be bought and attached if needed	Heatpads bought and is part of the kit	6	1	4	24
Environment	Iceberg rolling	Loss of drone and equipment	8	Icebergs nature	2	Roll alarm alerts operator of rolling iceberg	1	16	Use current design control	None	8	2	1	16
Other	Loosening of bolts	Equipment might begin to fall of and be lost in the ocean	6	Small wibrations and plastic fatiggue	5		2	60	Use locktite on bolts	Locktite used	6	1	2	12

As it can be seen in the FMEA Table above, the Risks have been evaluated and the worst Risks have been accounted for. The FMEA has also let to changes in the Specifications of Requirements and additional parts in the User manual. Furthermore the FMEA has let to minor changes in the design, see Table A.25 for the changes to the project. The Risk assessment is an iterative process, and has therefore been evaluated during the project.

Risk reduction			
	Starting RPN	RPN, after actions taken	Removed RPN
	694	334	360
Items added to Specification of Requirements			
1	The must have requirement of a detachment option for the drill will be reduced to a could have requirement, since the probability of the drill getting stuck is unlikely		
Items added to the design			
1	Silicone was added to wires		
2	Wax added to the drill		
3	Endstops added to stepper motors		
4	Electronics compartment must be sealed		
5	Fuse added to both power sources, LiPo battery pack and drone supply output		
6	Locktite added to bolts		
7	LED's used to indicate the program is running		
Items added to the user manual			
1	Floaters are not meant for water landings unless it is an emergency		
2	The drill should remain rotating		
3	The drone should not be operated in windy weather		
4	Electronics compartment must be checked before and after each flight		
5	Wax should be reapllied for every 5th drilling		
6	Heatpads are available if it is necesssary to heat the electronics		

Table A.25: Changes made due to the FMEA

A.10 Experimental report: Hardening of cutter heads

This experimental report will focus on the hardening process of the cutter heads.

A.10.1 Purpose

This experiment was done to determine the hardness of the knife steel, used for the cutter heads, before and after it was hardened.

A.10.2 Theory behind experiment

The steel will be hardened in order to have "Maximum edge sharpness" according to the datasheet[42] and in theory the knife steel should end up having a hardness of 61HRC after hardening, when using the process shown in Figure A.12.

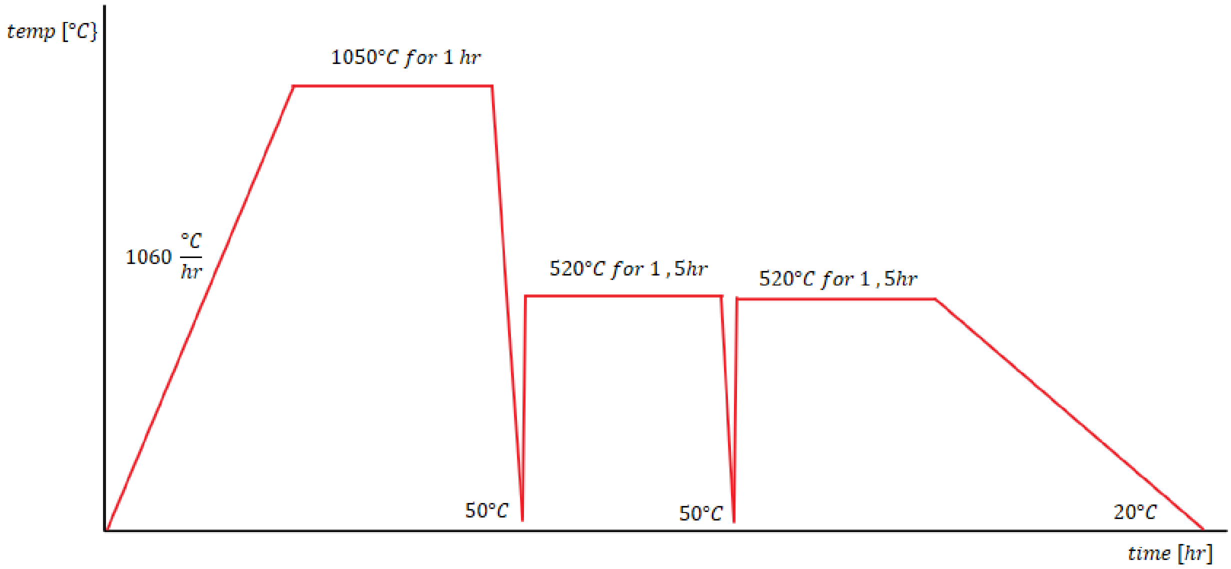


Figure A.12: Hardening process

A.10.3 Experiment

The hardening and testing was done in the Material lab at Navitas, AU.
Test equipment

- 10xCutter heads
- 3xSteel foil
- Hardening oven
- Zwick/Roell ZHU250 hardness tester (EN ISO 6508) [43]

Test setup
The test will be done by testing the steel's hardness before hardening with the hardness tester. Next the CNC cutter heads will be placed inside steel foil and hardened. During the hardening the steel needs to be quenched, which was done by placing the packages of

[42] http://michaelwest.dk/knive/rw134-datasheet.pdf?fbclid=IwAR050_owHqfQS1dLjxLEb611DPJgshK7GGmczAUYXca82Pg5ap9pdKtMhcI
[43] https://www.zwickroell.com/en/universal-hardness-testing-machines/zhu250

steel foil between two aluminium plates. After the hardening the cutter heads will be tested again. The foil packages can be seen on Figure A.13. An important part of the process is to not let air inside the packages as this makes the surface have a poor finish.

Figure A.13: Steel foil packages

The hardness tester can be seen in Figure A.14. The 64,39HRC is from a calibration test, to check if the machine is measuring correctly, which it did, since the calibration plate was rated at a hardness of 64,4HRC.

Figure A.14: Hardness tester

Procedure

1. Place the control cutter head inside the hardness tester
2. Determine the hardness (HRC) 3 times on the control blade

3. Place the cutter heads inside foil packages and close them tight
4. Turn on oven to 1050°C
5. Place foil packages inside the oven for 1Hr
6. Quench packages between aluminium plates
7. Turn the oven down to 520°C
8. Place foil packages inside the oven for 1,5Hr
9. Quench packages between aluminium plates
10. Place foil packages inside the oven for 1,5Hr
11. Slowly cool down packages to room temperature
12. Place the hardened steel cutter heads inside the hardness tester again
13. Determine the hardness (HRC) once for each blade (9 total)

A.10.4 Results and calculations

The results of the hardness test are shown on Tabel A.26. The average of the tests before hardening was 27,54±0,57HRC and the test after hardening was 60,66±0,4HRC.

Speciment	HRC before	HRC after
1	27,06	60,62
2	28,34	60,88
3	27,23	60,66
4		61,12
5		60,3
6		60,07
7		61,4
8		60,23
9		60,68
Avg	27,54	60,66
ST.Dev	0,57	0,40

Table A.26: Hardness comparison

A.10.5 Sources of errors

There were complications in getting the oven to follow the right procedure and therefore there were a difference between the theoretical and actual hardening process, see Figure A.27, for the actual temperature process. The complications could have resulted in differences between the expected hardness and the actual hardness, but as the cutter heads reached the right temperature for a decent amount of time, it did know signs of errors as the hardness was spot on.

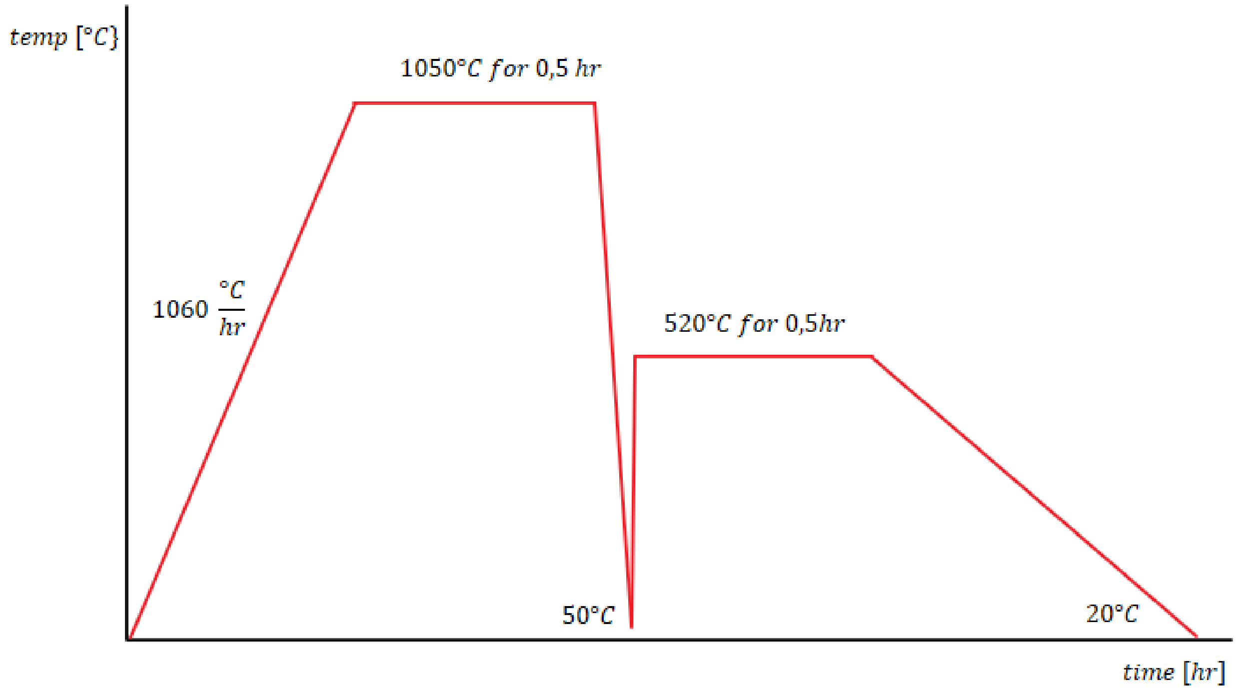


Table A.27: Hardness process actual

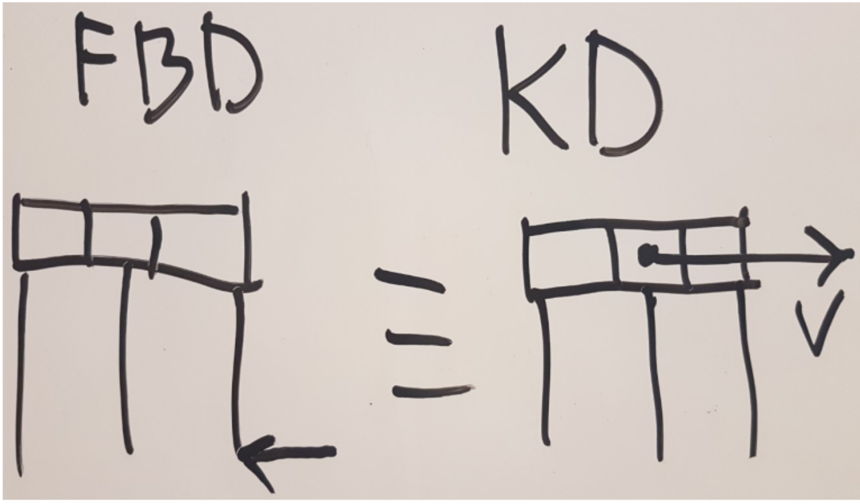
A.10.6 Summary

In summary the test was successful since the hardness has been doubled after the hardening. Couple that with the relatively small standard deviation, the hardening process did not suffer from the complications of keeping the temperature.

A.11 Landing gear calculations

This appendix contains the kinetic energy calculations for dimensioning the drones landing gear legs.

Calculations for one leg hitting ground before the others. Based on kinetic calculations.



Mass of drone

$M_{drone} := 16\ kg$

Velocity of drone on impact

$V_{drone} := 1\ \frac{m}{s}$

Load partial coefficient
Acc. Eurocode 3(steel)

$\gamma_{mf} := 1.35$

Material partial coefficient
Acc. Eurocode 3(steel)

$\gamma_{m0} := 1.1$

Yield strength for alu 6082 T6 acc. Mechanical and Metal trades handbook

$f_{y.alu6082} := 250\ MPa$

Design yield strength

$f_{yd} := \frac{f_{y.alu6082}}{\gamma_{m0}} = 227.273\ MPa$

E-modulus for alu.

$E_{alu} := 70\ GPa$

Outer diameter of the fixed rod

$D_{out} := 16\ mm$

Inner diameter

$d_{in} := 13\ mm$

Length of a leg in outer position

$L_{leg\_upper} := 525\ mm$

Energy absorbed for one leg acc. to kinetic energy.

$E_{hit} := 0.5 \cdot M_{drone} \cdot \left(V_{drone}\right)^2 = 8\ J$

Design energy

$E_{Ed} := E_{hit} \cdot \gamma_{mf} = 10.8\ \boldsymbol{J}$

Moment of inertia

$I_{tube} := \frac{\pi}{4} \cdot \left(\left(\frac{D_{out}}{2} \right)^4 - \left(\frac{d_{in}}{2} \right)^4 \right) = \left(1.815 \cdot 10^3\right)\ \boldsymbol{mm}^4$

The next step is an interative process for finding the load required to get a deflection, and thereby an energyl, that's similar to the design energy

Force on one leg (last iteration)
$P := 169\ \boldsymbol{N}$

Deflection of the leg

$\delta_B := \frac{P \cdot L_{leg\_upper}^{\ 3}}{3 \cdot E_{alu} \cdot I_{tube}} = 64.16\ \boldsymbol{mm}$

Energy from deflection, needs to equal the design energy

$E_{hit\_d} := \delta_B \cdot P = 10.843\ \boldsymbol{J}$ $\qquad E_{Ed} = 10.8\ \boldsymbol{J}$

Once a force is found that makes $E_{hit\_d} = E_{Ed}$, the calculations continue

Bending moment
$M_b := P \cdot L_{leg\_upper} = 88.725\ \boldsymbol{N \cdot m}$

Modulus of tube

$W := \pi \cdot \frac{\left(D_{out}^{\ 4} - d_{in}^{\ 4}\right)}{16 \cdot D_{out}} = 453.752\ \boldsymbol{mm}^3$

Bending stress

$\sigma_b := \frac{M_b}{W} = 195.537\ \boldsymbol{MPa}$

It is under the limit?

$\textbf{check} := \textbf{if} \left(\sigma_b \le f_{yd}, \text{“OK!”}, \text{“NOT OK”}\right)$

$\textbf{check} = \text{“OK!”}$

A.12 Experimental report: Test of 3D printed mounts

This experimental report will focus on the strength test of 3D printed mounts, to see if they are reliable for further use.

A.12.1 Purpose

This experiment was done to determine the strength of 3D print to be sure they can handle the stress before making the mounts.

A.12.2 Theory behind experiment

Not much is known about the material characteristic of 3D printed PLA, therefore testing had to be done before it could be trusted as a method for creating mounts. The printed mount will be made with 4 outlines, full honeycomb structure, infill percentage of 45 and a layer height of 0,15mm. The mounts will be made on a **Craftbot 2** with **Simplify 3D** as the slicer software.

A.12.3 Experiment

The 3D printed mounts were manufactured in X-lab at Navitas, AU.
Test equipment

- Craftbot 2
- STL file of mount
- PLA filament
- 60cm aluminium tube
- 10kg of weight

Test setup
The experiment will be done by placing the mount inside a metal clamp in a horizontal position and placing an aluminium tube inside. The mount will then be tested by placing weights on the tip of the aluminium rod, see Figure A.15 for the setup.

Figure A.15: 3D print mount test setup

Procedure

1. Clamp the mount
2. Place tube inside
3. Tighten bolts around the tube
4. Place the weight on the end
5. Check for cracks
6. Apply force with the hand until the tube is moving up and down
7. Check for cracks

A.12.4 Results and calculations

The results were promising since the only failure that happened was caused by the clamp as it was tighten to hard. Otherwise the mount held the weight as a static load as well as with a changing force applied by hand, dynamic. See Figure A.16 for the broken mount by clamp.

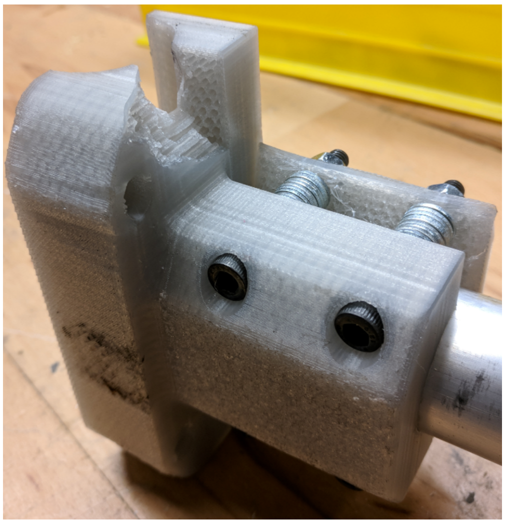


Figure A.16: 3D Print mount test, broken mount due to clamp

A.12.5 Sources of errors

The break that happened because of the clamping made it impossible to test the strength to failure.

A.12.6 Summary

Even though the test stopped before failure, it was determined that $10kg * 9,81\frac{N}{kg} * 60cm \approx 60Nm$ of bending moment that the mount were able to lift, was enough to decide the 3D print was reliable. Furthermore it was observed that in order to tighten the 3D print properly, the surface area of the mount has to be large.

A.13 Experimental report: Testbench

This experimental report will focus on the testbench, made to simulate the drone's drilling process. The testbench was made by creating a triangular frame from 3D printed mounts and 3 aluminium tubes, where the landing gear was mounted on. Furthermore a mounting plate was made for the drill motor assembly. The testbench can be seen in Figure A.17.

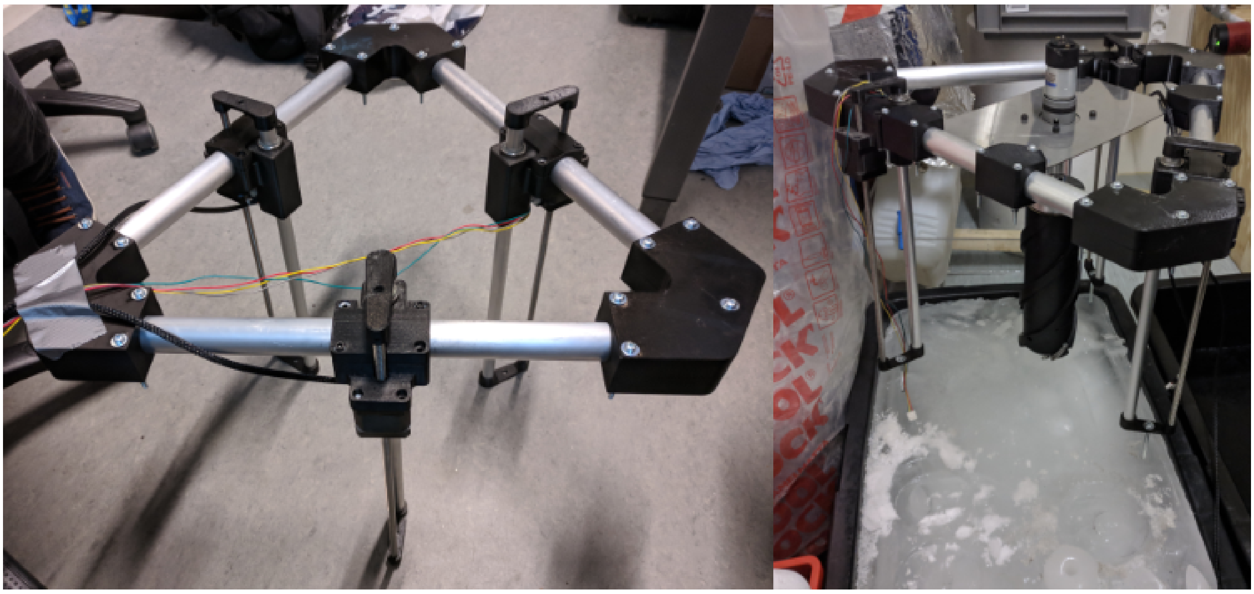


Figure A.17: Testbench

A.13.1 Purpose

This experiment was made to test the developed landing gear in combination with the developed drill. The experiment was also made in order to figure out different parameters for drilling such as drilling speed and rpm. A test was also made to determine if the stepper motors could lift the required weight of 2 times the weight of the drone (32 kg).

A.13.2 Theory behind experiment

By adjusting the parameters for the drilling it should be tested if the setup worked without human interference when drilling. The drill was set to 700 rpm, and the linear actuated landing gear was set to a pace of 24mm/min.

A.13.3 Experiment

The test was performed outside the container freezer at Navitas, AU.

Test equipment

- Testbench
- 3xPower supplies of 12V and 1A for the stepper drivers
- 1xPower suppliy of 12V and 10A for the drill motor
- 80L bucket full of firm ice
- 10kg of weight to simulate the drone's weight
- 32kg of weight for lifting test

Test setup
The experiment was done by placing the testbench on the ice and start the drilling procedure, see Figure A.18.

The lifting test was done after the drill test by placing the added weight on top of the testbench.

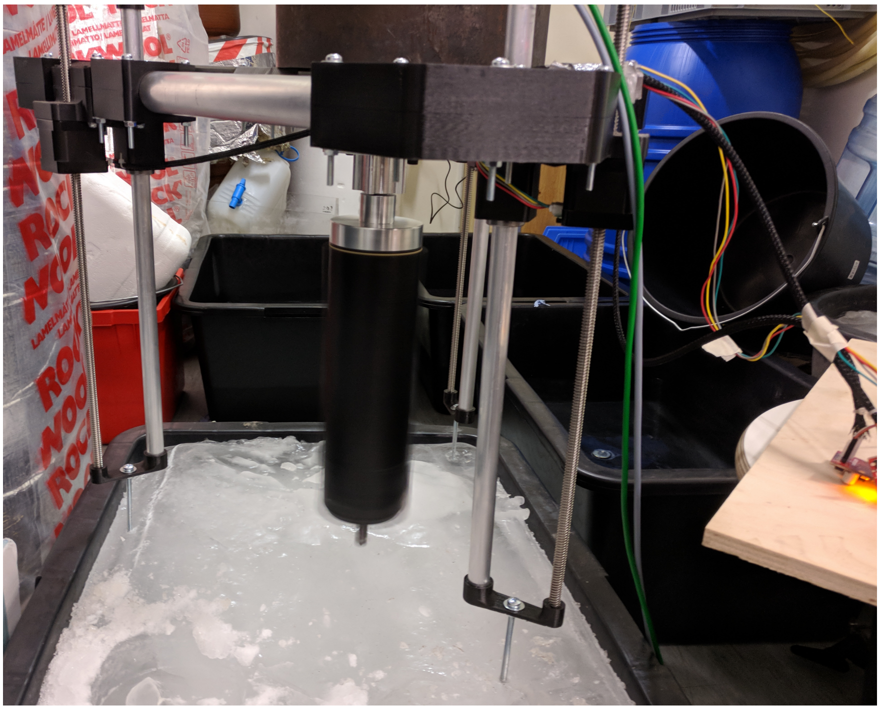


Figure A.18: Testbench setup

Procedure

1. Freeze 80L of water
2. Place testbench on ice
3. Connect the 3 power supplies of 12V and 1A to the stepper drivers
4. Connect the power supply of 12V and 10A to the drill motor
5. Connect stepper drivers and drill motor to myRIO
6. Place 10kg on the testbench
7. Start drilling and observe
8. When the drilling tests are done, remove the plate for mounting the motor
9. Place 32kg on the testbench and observe

A.13.4 Results and calculations

During the testing it was observed that the testbench was shaking during the drilling. To reduce the shaking a frame was created by 3D printing angle pieces and joining them with Ø8mm aluminium rods, see Figure A.19 for the added frame.

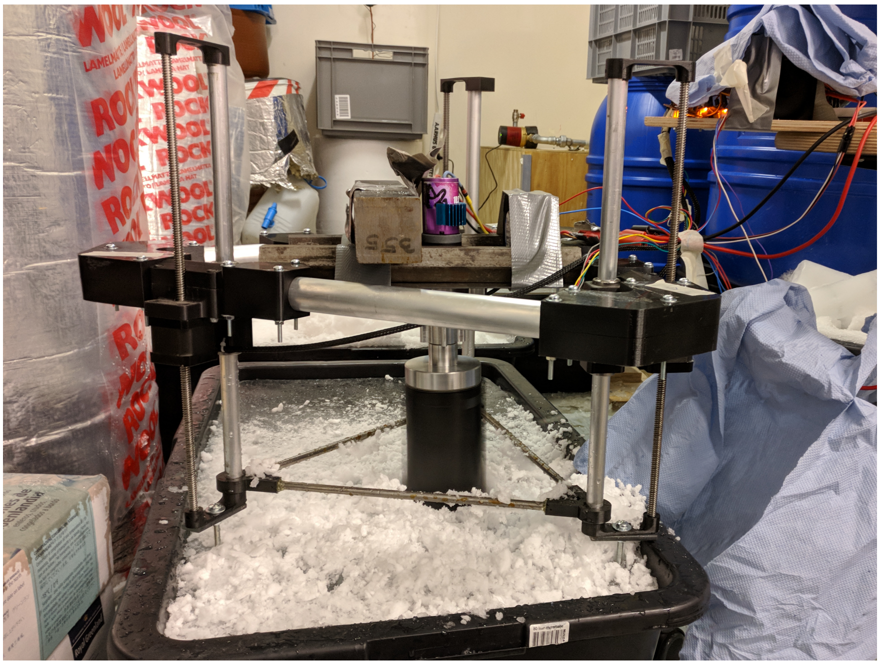


Figure A.19: Testbench frame

After the frame had been added the drilling went more smooth for about 100mm but then the drill had a tendency to stop.

3 hypothesises were considered as the root of the problem for why the drill stopped.

1. The drill was going down too fast, and would cause too much pressure on the drill cutter heads which would make the motor stop. This could be seen by one of the legs beginning to lift itself from the ice and pivoting the drill in the hole.
2. The small metal spikes melted the ice under the tip and sank in, making the testbench drill at an angle, which would cause the motor to stop. One extra problem added by this was that the spikes would get stuck to the ice.
3. Unstability due to shaking, even with the added frame, subjected the drill to unexpected forces which could cause it to stop.

For the first hypothesis step drilling was implemented, so the drill would go down for 14s at a pace of 24 mm/min and then go up for 0,8s at a pace of 120 mm/min. After step drilling was added the drill would still stop after 100mm, but the drilling until then was smoother.

The second hypothesis was tested by placing wood pieces under the spikes to make the landing gear even when drilling, but the drill would still stop after $\approx 100\,\text{mm}$. Even though the drilled still stopped, it is very much unwanted that the spikes can get stuck, therefore changes to the spikes will have to be made.

To test the third hypothesis human interference was required in order to try and make the testbench more unstable by shaking it, but the drill still went $\approx$ 100mm down before stopping.

With none of the hypothesis being confirmed as the problem, the torque of the motor was turned up, by using a different power supply capable of delivering 30A. The drill could now go all the way downs, with a maximum power draw of 14A.

The final test showed that the landing gear was able to lift the required 32 kg, see Figure A.20.

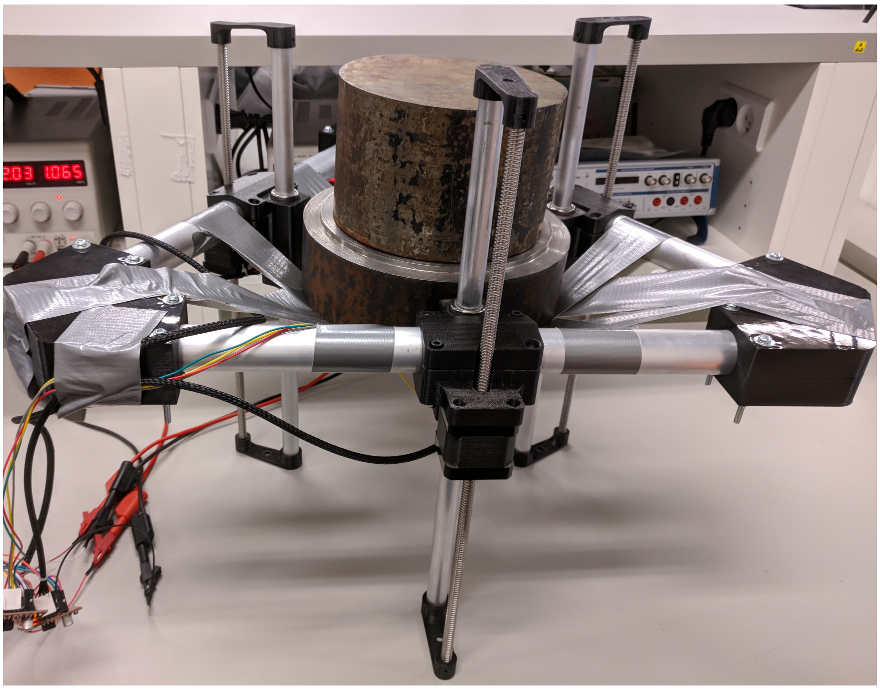


Figure A.20: Cooling test result

A.13.5 Sources of errors

Many parameters were changed during the testing, which made it hard to interpret, what made things worse and what helped. But by setting up the hypothesises it was possible to test the things one by one.

A.13.6 Summary

Even though the drill stopped several times, it was possible to complete whole ice drilling tests with the testbench. It was also possible to determine different values for the drilling parameters where the speed for step drilling, the drill rpm, and the power draw from the drill was found in these tests. Furthermore it was discovered that the spikes should be made from a non metal material as this would melt into the ice and possibly get stuck.

A.14 Battery drilling time calculations

This appendix contains the calculations for the LiPo battery drilling time calculations.

Power consumption during drilling, worst case = 14A continuously:

$$P_{drilling} := 12\ V \cdot 14\ A = 168\ W$$

11,1V LiPo 1500mAh capacity:

$$E_{1500} := 11.1\ V \cdot 1500\ mA \cdot hr = 16.65\ W \cdot hr$$

Drilling time with :

$$t_{1500} := \frac{E_{1500}}{P_{drilling}} = 5.946\ min$$

11,1V LiPo 4000mAh capacity:

$$E_{3000} := 11.1\ V \cdot 4000\ mA \cdot hr = 44.4\ W \cdot hr$$

Drilling time:

$$t_{3000} := \frac{E_{3000}}{P_{drilling}} = 15.857\ min$$

11,1V LiPo 5000mAh capacity:

$$E_{5000} := 11.1\ V \cdot 5000\ mA \cdot hr = 55.5\ W \cdot hr$$

Drilling time:

$$t_{5000} := \frac{E_{5000}}{P_{drilling}} = 19.821\ min$$

A.15 Experimental report: Final test of the drone on land

This report will the describe the final testing of the prototype on land, where 4 things were tested.

A.15.1 Purpose

The purpose was to test 4 things on the final prototype, so it can be decided if the drone lives up to the requirements in Section 2.4.

- Drilling test, where power consumption from the drone was also measured
- Spikes test to see if the POM-C spikes were capable of keeping the drone from sliding
- Roll alarm to see if the alarm was working as wanted
- Stepper lifting test

A.15.2 Theory behind experiment

The tests are performed to answer the Specification of Requirements.

A.15.3 Experiment

The test was done at the container freezer at Navitas, AU.

Test equipment

- Ice buckets, one for drilling in, with added sand to simulate glacier ice, two for testing spikes while drilling
- Drone, controller and batteries
- Multimeter with ampere meter
- 16 kg of metal

Test setup

The drilling test was performed outside the container freezer, see Figure A.21.

Figure A.21: Set up for drilling test

Procedure
For drilling the drones spikes will be placed on ice, and the drill will begin its drilling, until the ice core breaks off or the linear actuators are at the bottom. At the same test the spikes performance will be observed as well as measuring the power consumption from the electronics, when in idle and when moving up and down.

The Roll alarm test is very simple, "Ground" the drone on the controller, and lift the drone to 5°, to see if the LED is triggered.

The lifting test will be done by placing 16 kg of metal on top of the completed drone and see if the steppers will lift the weight. The power consumption will also be measured.

A.15.4 Results and calculations

The drilling test was generally a success, see Figure A.22, even though the bucket of ice was not completely frozen. Therefore the ice core did not break off, but there was actually water at the bottom, so when the drill hit the water, the ice was free. Furthermore the spikes were stable during the whole drilling which was a success.

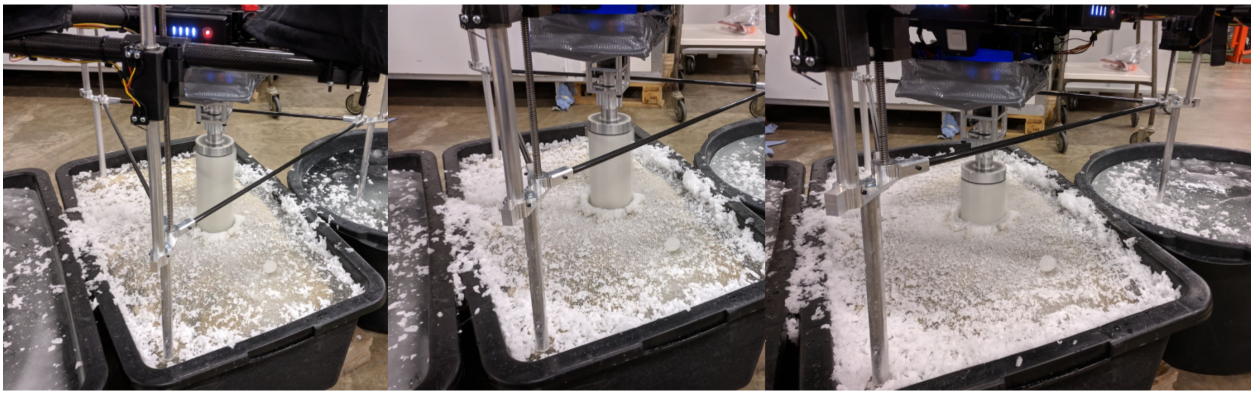


Figure A.22: Final drilling test

The power consumption of the drones electronics when in idle and when moving up and down was also tested, see Figure A.23.

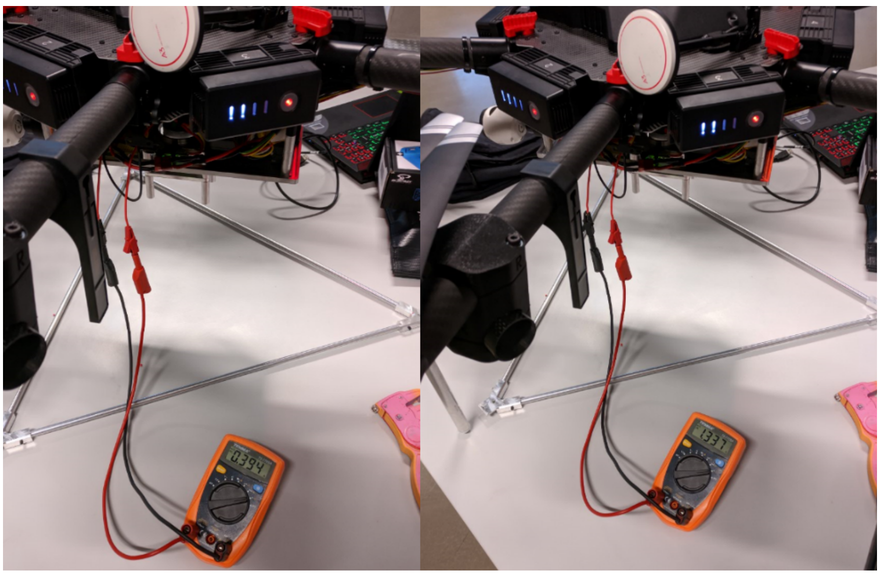


Figure A.23: The power consumption of the steppers, electronics and myRIO which is provided by the drone

This means that the drone has to deliver: $0.39A*18V = 7,02W$ in idle and $1,34A*18V = 24,12W$ when moving up and down to the electronics on-board.

The roll alarm was also tested with satisfying results, see Figure A.24, where it can be seen how the LED shines light into the camera when lifted.

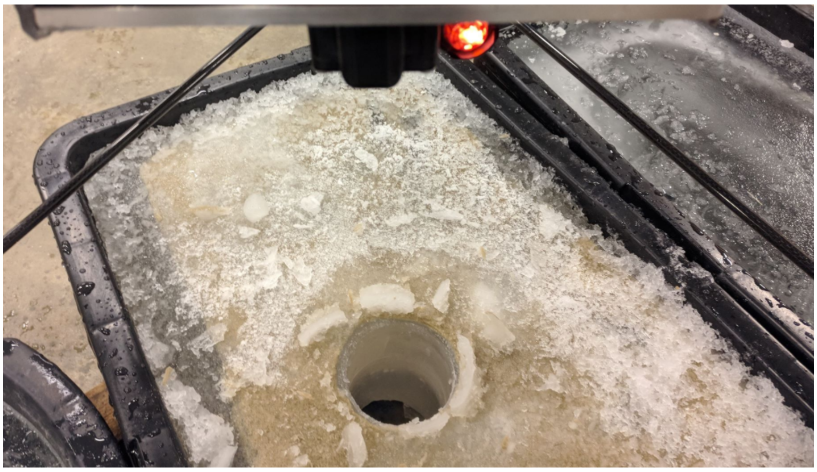


Figure A.24: Roll alarm LED shining when the drone was lifted

The last test was the stepper lifting test, which also went well as the drone was able to lift the added weight of 16 kg, see Figure A.25. The power consumption of the electronics were measured at $1,45A * 18V = 26,1W$, which is only slightly above the drone lifting only its own weight, which is impressive.

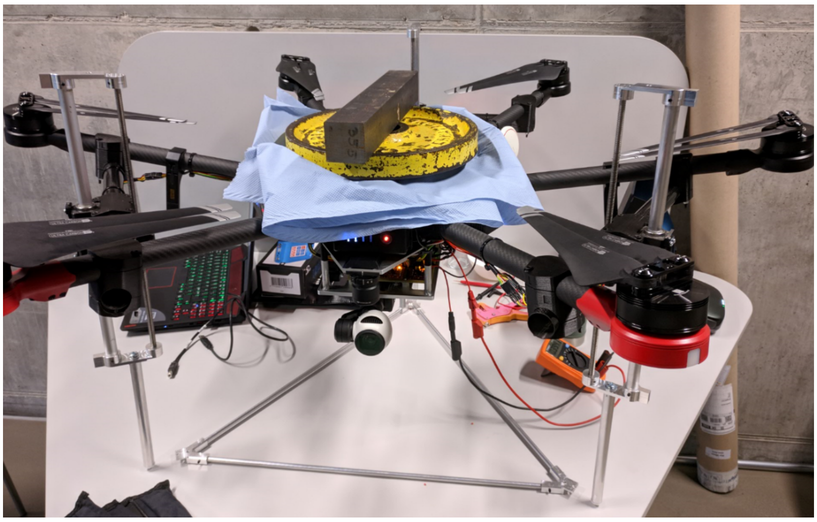


Figure A.25: Drone lifting test

A.15.5 Sources of errors

The ice bucket was not fully frozen which made the ice core free it self. Furthermore the ice from a freezer, even with sand, is not expected to be the same as sea ice and glacier ice, therefore further drilling test will be done in Greenland.

A.15.6 Summary

The drone was able to perform well in all test, and therefore it fulfils the requirements. For better results the drilling will be done in Greenland.

A.16 Experimental report: Final flying test of the drone

This report will be used to describe the final flight test of the drone. There are 4 main things that will be tested.

A.16.1 Purpose

The purpose of this experiment is to test the drones flying capabilities with the new landing gear, drill and drill mount on the mounting plate. The drone should be tested to see if it can live up the the requirements in Section 2.4. The 4 things that will the tested are:

- Take off and landing from a 2x2m platform to simulate operation from a boat
- Take off and landing from an angled surface as the icebergs may no be perfectly flat
- GPS beacon drop test to see if the drone can fly with the beacon and drop it safely
- Imitated drilling test to test the drilling functions without the drill

A.16.2 Theory behind experiment

The drone should be able to live up to the requirements, and therefore these 4 things will need to be tested, in order to answer the Specification of Requirements.

A.16.3 Experiment

The experiment took place at "Østjydsk R/C Modelflyveklub", where different equipment was broad along to test the 4 things. In Figure A.26 the drone with full equipment can be seen.

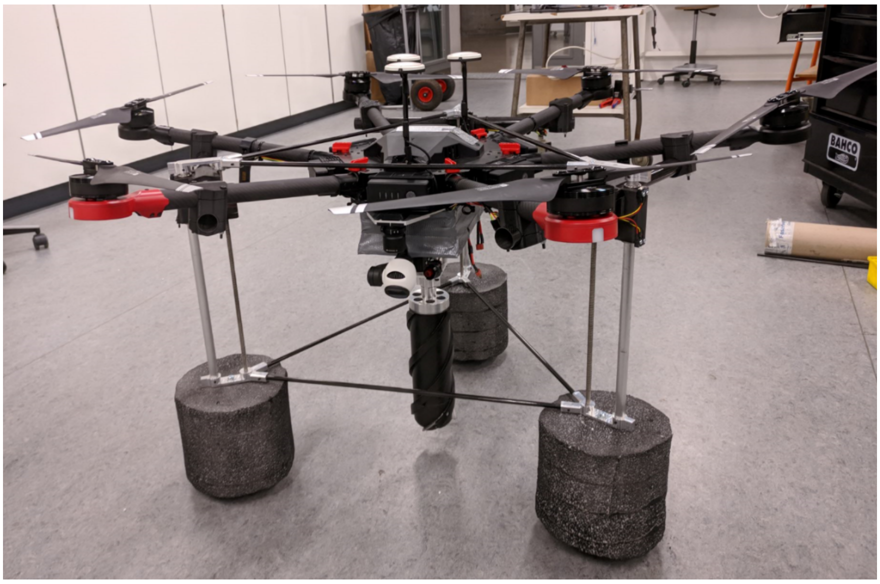


Figure A.26: Drone before final flight test

Test equipment

- Platform
- Drone, controller and batteries
- 1 kg beacon replica
- Drone operator: Claus Melvad

Test setup

The setup for all of the tests were using the platform. In Figure A.27 the test facilities can be seen, note the difficult changing weather conditions.

Figure A.27: Test facilities at Østjydsk R/C Modelflyveklub

Procedure

- The procedure for the platform is very simple, take off and land the drone on the platform, with the drone in visual sight, as out of sight test using the camera only were too difficult in the windy conditions
- Angled test will be with the same platform raised to an angle of 5° and do take off and landing
- The beacon drop test will be a test to see which rope length is be best, and see if the drone can take off with the beacon, and release it safely by laying the beacon gently on the ground and then release the rope
- The imitated drilling test will simply be take off, flying around, land and then test the drilling functions

A.16.4 Results and calculations

Here are the following observations from each of the 4 tests.

A.16.4.1 2x2m platform

It was observed that the drone was able to take off and land on the platform, even in bad weather conditions, as the wind speeds were over 10 m/s with gusts over 20 m/s. This is a worst case scenario and way over the limit for what is recommended, see Figure A.28. The test was also done with a smaller platform to see what was possible.

Figure A.28: Platform test

A.16.4.2 Angled surface

The platform was raised into a 5° angle and the same test was performed, with good results, see Figure A.29. As the platform was made from plastic the drone had a tendency to slide as the spikes are also made from plastic, but this should not be a problem on ice.

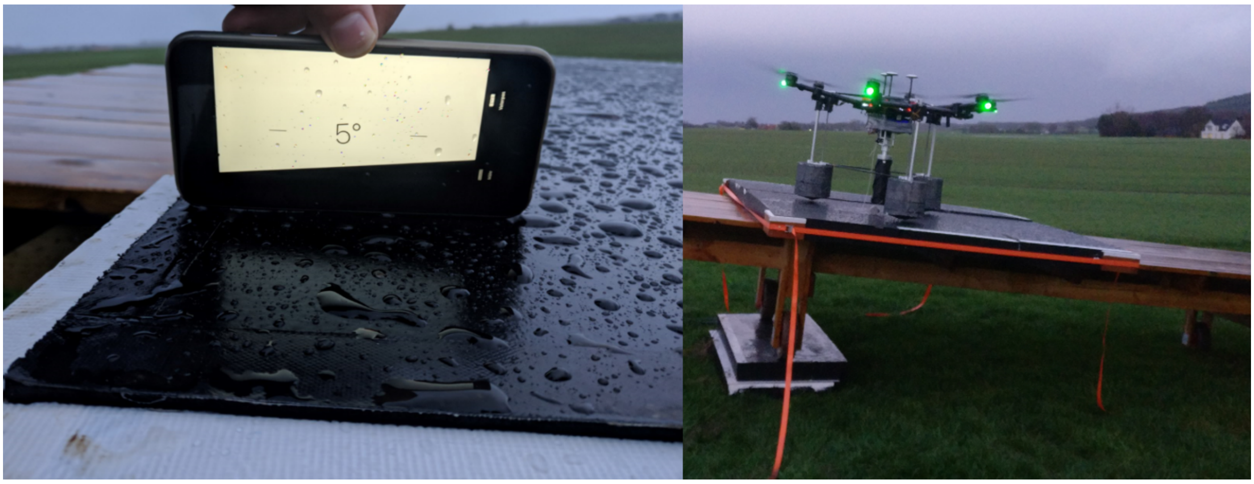


Figure A.29: Angled surface test

A.16.4.3 Beacon release test

The Beacon replica was hooked to the release, and the length of the rope was tested, see Figure A.30. The first test with a 4 m rope made the drone very unstable as the beacon acted like a pendulum. Furthermore the rope also interfered with the drill in this test. The second test was with a 2 m rope, which was much better, and it was possible to release the beacon safely onto the ground.

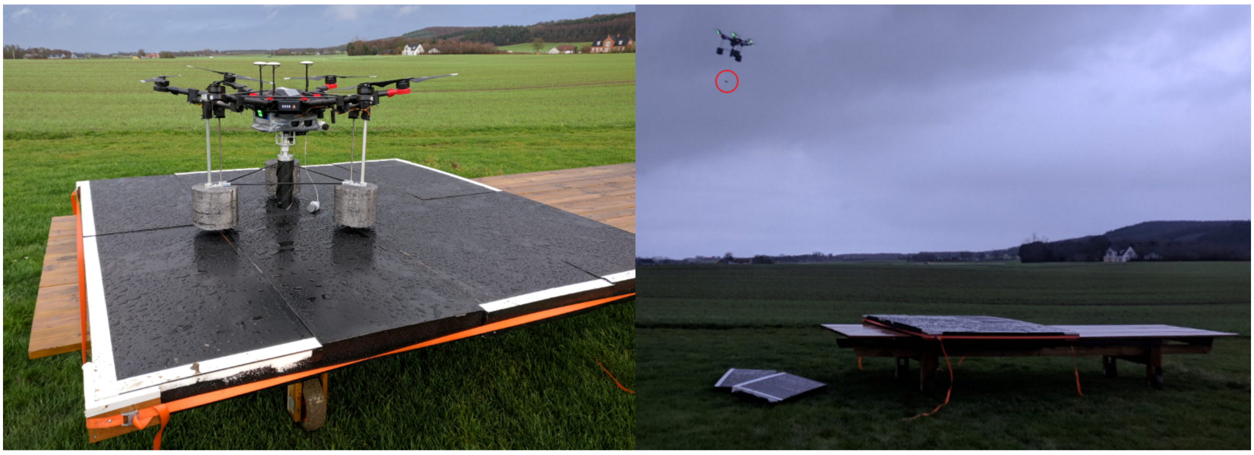


Figure A.30: Beacon drop test at take off and in the air, beacon marked with red circle

A.16.4.4 Imitated drilling test

After the platform flying tests, a test of all the drilling functions were carried out, which showed that all features functioned as wanted, even after flying and landing.

A.16.5 Sources of errors

Weather conditions were poor but that only made the test a worst case scenario, and it still succeeded.

A.16.6 Summary

It can be concluded that the drone still flies great even after the modifications. It passed all 4 test, which was impressive considering the weather.

A.17 Experimental report: Cooling Test

This experimental report will focus on cooling the drone and the attached equipment, to make sure that it still works, when the batteries are plugged in.

A.17.1 Purpose

This experiment was done to determine if it is possible to use the equipment while it is freezing, as in Greenland.

A.17.2 Theory behind experiment

The test is done to see if the drones electronics will work even if they are freezing cold. The batteries will not be frozen, as these will be kept warm between missions in Greenland. When putting in the batteries and starting the drone, the batteries should be able to keep themselves heated during the mission.

A.17.3 Experiment

The test was done in the container freezer at Navitas, AU.
Test equipment

- Container freezer
- DJI Matrice 600 Pro
- Attached equipment for DJI Matrice 600 Pro
- Batteries and controller for DJI Matrice 600 Pro

Test setup
The experiment was done by placing the drone inside the freezer and leaving it for two hours at -18°C. After the two hours were up, the drone was placed outside the freezer and its functionalities were tested , see Figure A.31.

Figure A.31: Cooling test setup

Procedure

1. Remove all batteries from drone
2. Place drone in freezer
3. Note starting temperature (-11°C)
4. Leave it for 2 hours
5. Check temperature after 2 hours (-18°C)
6. Open freezer and add all batteries again
7. Perform full test
8. Note any systems not working properly

A.17.4 Results and calculations

After the cooling test was done, the drone was checked to see if it was thoroughly cooled down, see Figure A.32 for condensate on the cold aluminium brackets. The full test was performed and every system worked well, after the drone had turned on a "Warming up" feature for 5 seconds.

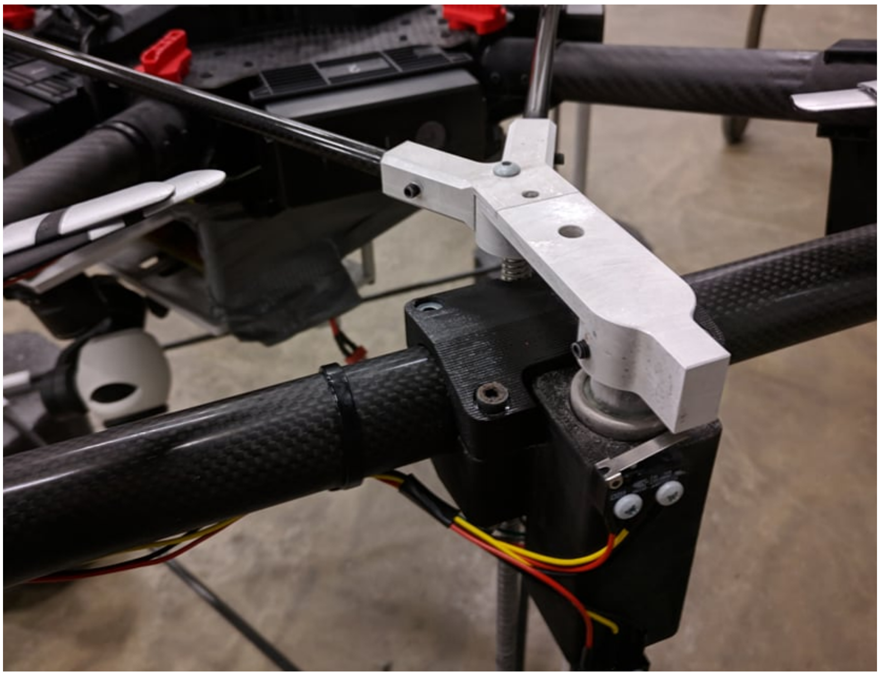


Figure A.32: Cooling test result showing condensation on the mounts

A.17.5 Sources of errors

It was expected that all parts where cooled down.

A.17.6 Summary

In summary the experiment was successful and every system worked even when the drone had been cooled down. Furthermore the "Warming up" feature was also discovered.

A.18 Experimental report: Camera Range

This experimental report will focus on the camera range, because it is important that there is live feed from the drone while on mission.

A.18.1 Purpose

This experiment was done to determine, if it is possible to use the Zenmuse X3 and DJI software, to keep visual connection with the drone. It is wanted to know if the drone and controller can maintain a steady connection, at distances greater than the 100 m specified in the requirements.

A.18.2 Theory behind experiment

In previous tests with the drone, the camera had a weak signal and lost connection to the controller at 50 m, which is not acceptable. Therefore the camera range was tested with the recommended settings from `Dronevolt.dk`. The transmission range is, according to the DJI [44], supposed to be 5 km for the camera.

A.18.3 Experiment

The test was done outside Navitas, AU.

Test equipment

- DJI Matrice 600 Pro
- Zenmuse X3
- Controller
- Crystalsky tablet
- Distance measuring device, `www.loeberute.dk`

Test setup

The experiment will be done by placing the drone in an open area and walking away with the controller and then determine the distance between controller and drone in a straight line with `loeberute.dk`. On Figure A.33 the red circle indicates the place where the controller was.

Figure A.33: Carmera range setup

[44] `https://www.dji.com/newsroom/news/dji-introduces-first-integrated-aerial-zoom-camera`

Procedure

1. Turn on controller
2. Turn on Crystalsky
3. Turn on DJI Matrice 600 Pro
4. Bring up the camera live feed
5. Place the drone in an open area
6. Walk away from the drone
7. Stop once the signal is lost and note the place
8. Determine the distance using `loeberute.dk`

A.18.4 Results and calculations

The greatest distance available to test unobstructed was 0.44 km. At this distance the camera still worked without any problems and the controller could connect to the drone. See Figure A.34 for a view of what the camera filmed while the controller was on the other side.

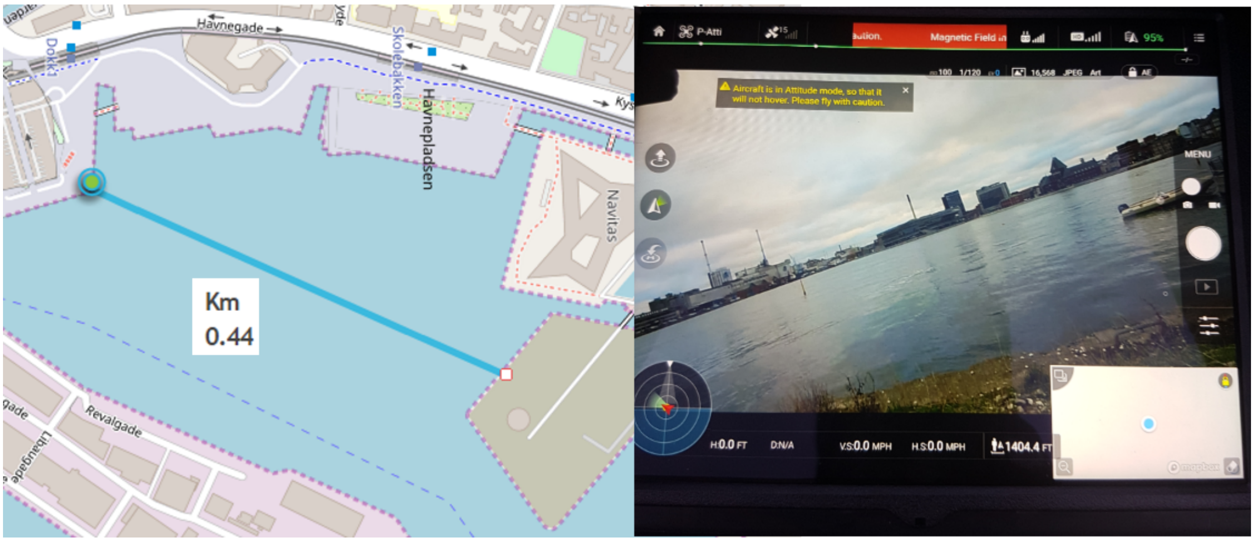


Figure A.34: Carmera range result

A.18.5 Sources of errors

It was not possible to determine the range at any further distance than 0.44 km, because there were obstructions like buildings.

A.18.6 Summary

In summary the test was successful since it was possible to determine that the camera range is greater than the range specified in the Requirements. But as it was not possible to test the range to it limits, it is not possible to confirm if the datasheet is correct. This test can be repeated when the drone is in Greenland if wanted.

A.19 Experimental report: Iron Disturbance

The drone has the ability to fly in a GPS/compass mode (vertical and horizontal stable) and an ATTI mode (Vertical stable). When GPS mode (P-mode) is used, there is a possibility, that an iron deposit might disturb the compass signal and make the drone change mode to ATTI. This would be unfortunate as the drone in ATTI mode is more difficult to operate. If the drone determines to go into ATTI mode, while the operator is not prepared, there might be an accident due to the sudden change in controls.

A.19.1 Purpose

This experimental report will be used to determine, if an iron deposit will have any influence over the drone's controls. As the mission will take place in Greenland which has a lot of iron deposits, and the fact that the mission is from a boat containing iron, it is a good idea to see how the drone behaves when close to iron.

A.19.2 Theory behind experiment

Iron will disturb the readings from compass and therefore a large enough deposit will influence the drones readings of direction.

A.19.3 Experiment

The test was done outside Navitas, AU.
Test equipment

- DJI Matrice 600 Pro
- Controller
- Crystalsky tablet
- Iron container

Test setup
The experiment was done by placing the drone next to an iron container and determine if it had any influence on the compass read out, see Figure A.35.

Figure A.35: Iron disturbance setup

Procedure

1. Turn on controller
2. Turn on Crystalsky
3. Turn on DJI Matrice 600 Pro
4. Bring up the compass read out on the Crystalsky
5. Place the drone next to an iron container
6. Determine if it has any influence on the compass' function

A.19.4 Results and calculations

During the test it was clear, that there was interference from the container. The controller could pick-up the signal from 11 satellites, but would still tell the operator that the signal was weak and flight should be made in ATTI. See Figure A.36 for the warning: "Magnetic Field Interference".

Figure A.36: Iron disturbance result

A.19.5 Sources of errors

Since all of the iron containers available, were close to a tall building, it is not entirely possible to determine, that the interference only came from the containers. But the test showed that when the drone was moved away, the "Magnetic Field Interference" warning disappeared, so the containers are expected to influence the compass.

A.19.6 Summary

Interference from iron is a possibility and therefore it is necessary to make sure, that the operator is competent and capable of flying the drone in ATTI mode. It is also important to specify that the operator needs to be aware of possible interference in the User manual, in Appendix A.24.

A.20 Mail correspondence with Dronevolt.dk

The mail correspondence is in Danish, and follows on the next page.

Fra: Mathias Edslev Jacobsen [mailto:edslev94@hotmail.com]
Sendt: 10. oktober 2018 09:00
Til: Benjamin Hansen <benjamin.hansen@dronevolt.com>
Emne: DJI Matrice 600 Pro uddybende spørgsmål

Hej Benjamin

Vi har nu i gang med projektet her på ingeniørhøjskolen, men har et par opklarende spørgsmål til DJI M600 Pro'en.

Generelle spørgsmål:

1. Først og fremmest står der i data bladet at der ikke kan flyves i P-mode (positioning) i "Polar regions", det lyder jo umiddelbart ikke lovende?
2. Der står at rækkevidde på dronen er op til 5km ved uforstyrret signal, men kan et isbjerg have stor indvirkning på dette, og gælder denne range både controller og videofeed?
3. Er det lige så let af styre en Gimbal (tilt og rotate fra controlleren) med GoPro monteret som at bruge en af DJI egne Zenmuse kamera'er, og kan der sendes livefeed fra dette GoPro til app'en?
4. Er det rigtigt forstået at dronen godt kan klare flyvning i let regnvejr/tåge så længe den bare tørres ordentligt efter brug?

Spørgsmål til batterier:

1. Er det rigtigt forstået at batterierne godt kan holde sig selv varme under drift, selv når den flyver i minus grader (fx -15C)?
2. Kan det forventes at flyvetid nedsættes ved flyvning i minus grader (fx -15C)?
3. Hvis der kommer en "jakke" (hvis vi vil vandsikre den yderligere) på dronen kan der så opstå problemer med for høj varme, eller er det ikke et problem når vi flyver i minusgrader?

Hilsen
Mathias Edslev Jacobsen
40197590
Aarhus School of Engineering

Fra: Benjamin Hansen <benjamin.hansen@dronevolt.com>
Sendt: Wednesday, October 10, 2018 9:31:08 AM
Til: 'Mathias Edslev Jacobsen'
Emne: SV: DJI Matrice 600 Pro uddybende spørgsmål

Hej Mathias

Tak for mail, jeg skal svare på dine spørgsmål efter bedste evne.

1. Der kan opstå problemer når der flyves meget tæt på nordpolen, men ud fra min erfaring med Grønland og havet omkring, er der normalt ingen problemer.
2. Hvis der flyves om på bagsiden af et isbjerg vil rækkevidden for signalet selvfølgelig blive forringet, men kontrol prioriteres før video, så man vil altid se udfald på video før mistet kontrol signal. Men også vigtigt at men har styr på sin Return to home indstilling, så dronen flyver højt nok op ved mistet signal og at den vender retur til pilotens posistion
3. Du kan kun styre gimbal, når du benytter en DJI enhed, f.eks. en GoPro vil være fast og bruges som FPV kamera, eller til at sigte med, for jeres boreenhed. Der kan sendes live fra 2 kameraer på dronen i standard setup.
4. Dronen har ikke en IP certificering, men vi har ikke oplevet problemer med flyvning i tåge/støvregn, det er som du selv skriver vigtigt at dronen ikke opbevares fugtigt.

Angående batterier

1. Du kan sagtens flyve i -15°C, men det er vigtig at batterierne er 15°– 20° når dronen startes op, og alt efter vindforhold og belastning af dronen kan der forventes lidt forkortet flyvetid
2. Så ovenstående
3. Jeg vil ikke mene I får problemer grundet de forhold I flyver under, men man kan evt. sætte ekstra køleprofiler på f.eks. IMU og Controller, hvis man fornemmer at de bliver meget varme. Test kan med fordel gennemføres under danske forhold

Håber ovenstående svarer på dine spørgsmål, ellers er du altid velkommen til at kontakte mig.

Med venlig hilsen - Kind Regards

Benjamin Hansen

DRONE VOLT

Product & Technical Manager – Drone Volt Scandinavia ApS

Tel: **+ 45 21 64 91 63**

Park Allé 380A
2625 Vallensbæk
Denmark

Fra: Mathias Edslev Jacobsen [mailto:edslev94@hotmail.com]
Sendt: 10. oktober 2018 11:02
Til: Benjamin Hansen <benjamin.hansen@dronevolt.com>
Emne: SV: DJI Matrice 600 Pro uddybende spørgsmål

Hej Benjamin

Tak for de fine og hurtige svar, det er vi meget glade for.

Der kan være mulighed for at dronen skal operere på antarktisk, som jo et tættere på sydpolen end Grønland er på nordpolen, kan vi forvente at det kun er ATTI mode der fungerer der?

Hilsen
Mathias Edslev Jacobsen

Sendt fra Mail til Windows 10

Fra: Benjamin Hansen <benjamin.hansen@dronevolt.com>
Sendt: Wednesday, October 10, 2018 11:04:30 AM
Til: 'Mathias Edslev Jacobsen'
Emne: SV: DJI Matrice 600 Pro uddybende spørgsmål

Hej Mathias

I kan godt forvente at kompasset driller, men det er jo så når I nærmere jer den magnetiske syd/nordpol. Så jeg ville selv sørge for at have nok erfaring, så man nemt kan betjene dronen, også uden GPS hjælp.

Med venlig hilsen - Kind Regards

Benjamin Hansen

DRONE VOLT

Product & Technical Manager – Drone Volt Scandinavia ApS

Tel: + 45 21 64 91 63

Park Allé 380A
2625 Vallensbæk
Denmark

A.21 Parts lists

This appendix contains the parts lists for both the manufactured parts and the purchased parts for the drone. The parts names are given according to which assembly they are in, if it is a purchased part or manufactured and lastly a number, followed by the part name.

Example: the first (001) manufactured (M) part in the Drill assembly (DA): `DA_M_001`
Example: the second (002) purchased (P) part in the Drill assembly (DA): `DA_P_002`

A.21.1 Drill assembly

Drill_assembly_v3 - Manufactured parts			
Part name	Material	Part nr.	Quantity
Bearing_mid_spacer_v3	Aluminium	DA_M_001	1
Bearing_mount_v3	Aluminium	DA_M_002	1
Center_drill_mount_v3	Stainless steel AISI 304	DA_M_003	1
Cutter_head_v3_inner	Stainless steel RML 54	DA_M_004	1
Cutter_head_v3_middle	Stainless steel RML 54	DA_M_005	1
Cutter_head_v3_outer	Stainless steel RML 54	DA_M_006	1
Drill_connector_v3	Stainless steel AISI 304	DA_M_007	1
Drill_head_v3	3D print - PLA	DA_M_008	1
Drill_center_tube_v3	Aluminium	DA_M_009	1
Drill_sleeve_v3	3D print - PLA	DA_M_010	1
Drill_top_v3	Aluminium	DA_M_011	1
Drill_sleeve_pin_v3	Stainless steel AISI 304	DA_M_012	3
Extraction_tool	Aluminium	DA_M_013	1

Drill_assembly_v3 - Purchased parts			
Part name	Part nr.	Origin of part	Quantity
Bearing_Ø22	DA_P_001	Prototypeværkstedet	2
Bearing_shim_v3	DA_P_002	Prototypeværkstedet	2
Center_drill	DA_P_003	https://www.harald-nyborg.dk/p8983/traebor-13x400mm	1

Table A.28: Parts in the Drill assembly

A.21.2 Actuator system assembly

Actuator_system_assembly - Manufactured parts			
Part name	Material	Part nr.	Quantity
Button_leg	Aluminium	ASA_M_001	1
Button_leg_thread_mount	Aluminium	ASA_M_002	1
Float	Flamingo	ASA_M_003	1
Landing_gear_actuator_mount	3D print - PLA	ASA_M_004	1
Landing_gear_actuator_mount_top	3D print - PLA	ASA_M_005	1
Landing_gear_rod_mount	Aluminium	ASA_M_006	1
Slider_rod	Aluminium	ASA_M_007	1
V_part	Aluminium	ASA_M_008	1
Spike_POM	POM_C	ASA_M_009	1

Actuator_system_assembly - Purchased parts			
Part name	Part nr.	Origin of part	Quantity
Glider_bushing	ASA_P_001	https://ehandel.mw.dk/da/products/kh0622b---kh5070pp/kugleboesning-med-taetninger-kh1630pp	2
Leadscrew	ASA_P_002	https://www.robotdigg.com/product/32/Non-captive-Nema17-Linear-Stepper	1
Microswitch	ASA_P_003	X-lab	2
Nema_17	ASA_P_004	https://www.robotdigg.com/product/32/Non-captive-Nema17-Linear-Stepper	1

Table A.29: Parts in the Actuator system assembly

A.21.3 Landing gear assembly

Landing_gear_assembly - Manufactured parts			
Part name	Material	Part nr.	Quantity
Left_bracket_top	3D print - PLA	LGA_M_001	2
Left_upper_bracket	3D print - PLA	LGA_M_002	1
Right_bracket_top	3D print - PLA	LGA_M_003	2
Right_upper_bracket	3D print - PLA	LGA_M_004	1

Landing_gear_assembly - Purchased parts			
Part name	Part nr.	Origin of part	Quantity
Ø28_carbon_Upper_bar	LGA_P_001	https://shop1.r-g.de/en/art/740908	1
Ø8_carbon_frame	LGA_P_002	https://shop1.r-g.de/en/art/740908	2

Table A.30: Parts in the Landing gear assembly

A.21.4 Motor mount assembly

Motor_mount_assembly - Manufactured parts			
Part name	Material	Part nr.	Quantity
Motor_mount_bar_bottom	Aluminium	MMA_M_001	4
Motor_mount_bar_top	Aluminium	MMA_M_002	4
Motor_mounting_plate	Aluminium	MMA_M_003	1

Mounting plate assembly - Purchased parts			
Part name	Part nr.	Origin of part	Quantity
Camera_socket	MPA_P_001	Dronevolt.dk	1
ESC_30A	MPA_P_002	X-lab	1
Fan_12V	MPA_P_003	Prototypeværkstedet	2
Reflection_camera	MPA_P_004	Dan Carlson	1
GPS_beacon	MPA_P_005	Dan Carlson	1
Mounting_bar_bracket	MPA_P_006	Dronevolt.dk	4
myRIO	MPA_P_007	Instrument depotet	1
Zenmuse X3	MPA_P_008	Dronevolt.dk	1

Table A.31: Parts in the Motor mount assembly

A.21.5 Beacon release assembly

Beacon_release_assembly - Manufactured parts			
Part name	Material	Part nr.	Quantity
Mount_top	3D print - PLA	BRA_M_001	1
Solenoid_axle	Stainless steel AISI 304	BRA_M_002	1
Solenoid_mount	3D print - PLA	BRA_M_003	1

Beacon_release_assembly - Purchased parts			
Part name	Part nr.	Origin of part	Quantity
Solenoid	BRA_P_001	https://elektronik-lavpris.dk/p103821/its-ls2924bd-12-solenoid-framed-2924b-d-12v/	1

Table A.32: Parts in the Beacon release assembly

A.21.6 Mounting plate assembly

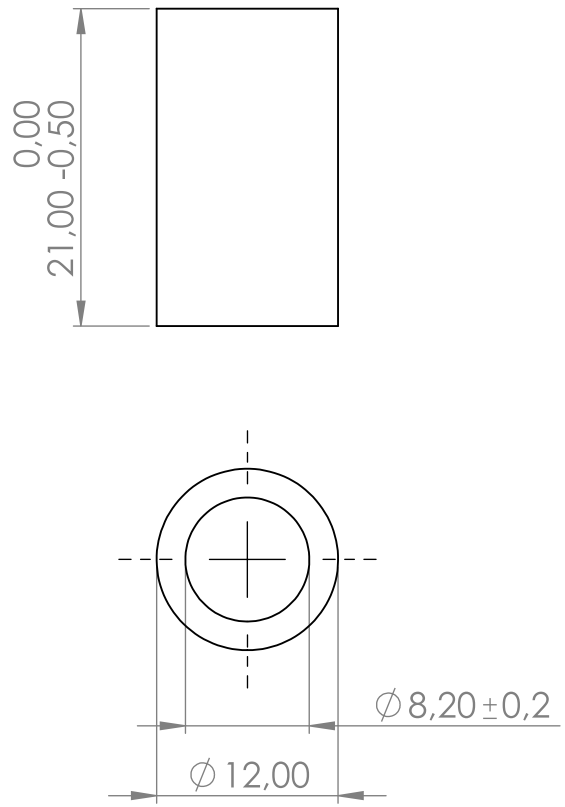
Mounting_plate_assembly - Manufactured parts			
Part name	Material	Part nr.	Quantity
Camera_mount	Aluminium	MPA_M_001	1
Camera_mount_shield	3D print - PLA	MPA_M_002	1
Electronic_plate	Print board	MPA_M_003	1
Fan_high_mount	3D print - PLA	MPA_M_004	1
Fan_low_mount	3D print - PLA	MPA_M_005	1
Mounting_bar_bracket_extension	Aluminium	MPA_M_006	1
Mounting_plate	Aluminium	MPA_M_007	1
myRIO_mounting_slot	3D print - PLA	MPA_M_008	1

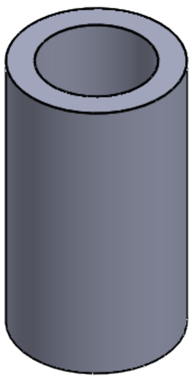
Drill assembly - Purchased parts			
Part name	Part nr.	Origin of part	Quantity
Camera_socket	MPA_P_001	Dronevolt.dk	1
ESC_30A	MPA_P_002	X-lab	1
Fan_12V	MPA_P_003	Prototypeværkstedet	2
Reflection_camera	MPA_P_004	Dan Carlson	1
GPS_beacon	MPA_P_005	Dan Carlson	1
Mounting_bar_bracket	MPA_P_006	Dronevolt.dk	4
myRIO	MPA_P_007	Instrument depotet	1
Zenmuse X3	MPA_P_008	Dronevolt.dk	1

Table A.33: Parts in the Mounting plate assembly

A.22 Technical drawings

This appendix contains all the technical drawings for the drone's manufactured parts. The naming of the parts as well as the parts lists for the different assemblies can be seen in Appendix A.21.





Qty.	Material
1	Alu

AARHUS UNIVERSITY
SCHOOL OF ENGINEERING
Department of Mechanical Engineering

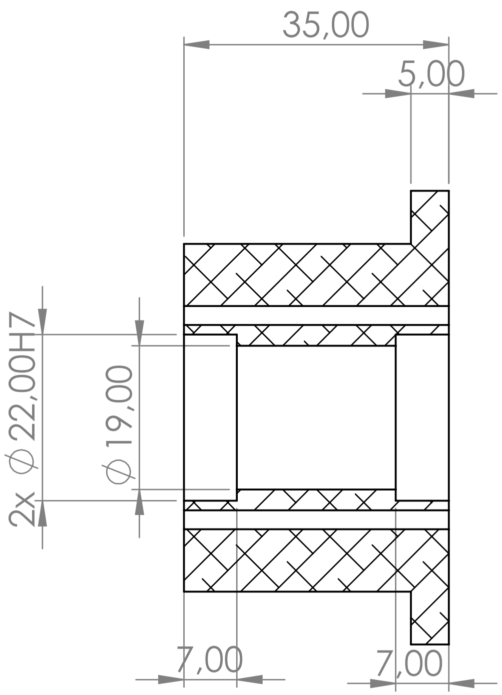
Scale: 2:1

Date: 10-12-2018

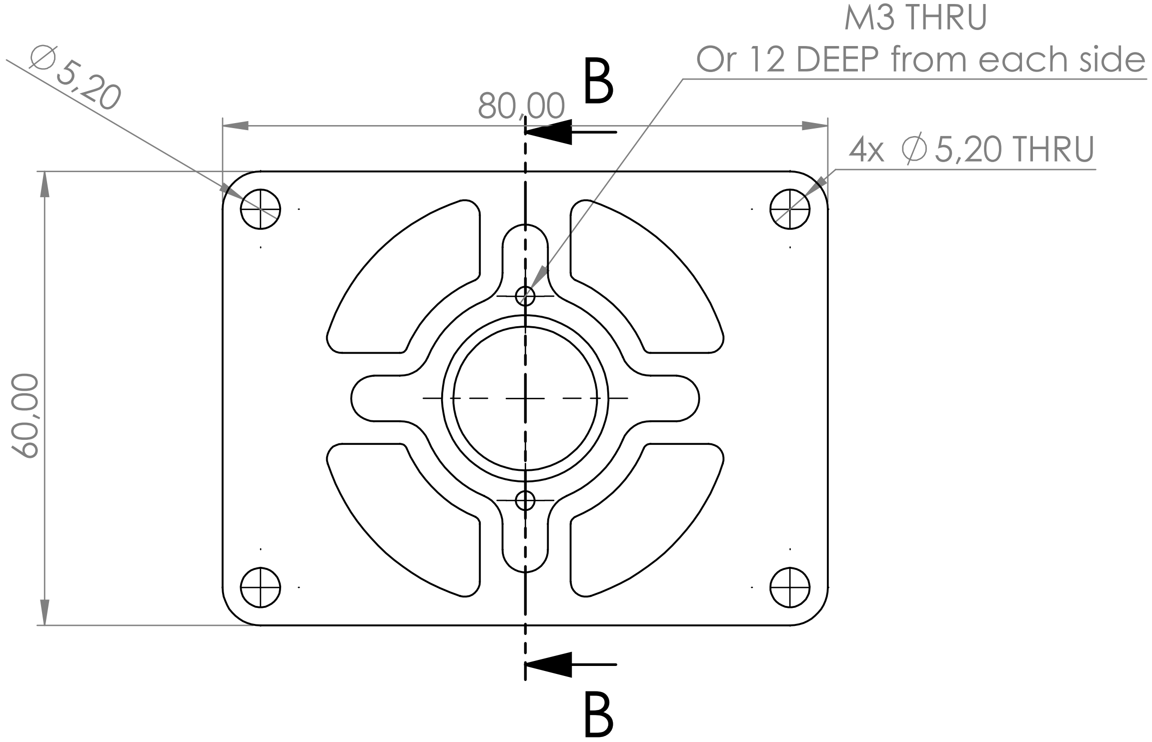
Group ID: Group 30

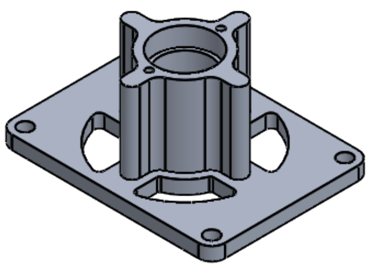
Description:

DA_M_001_Bearing_mid_spacer_v3



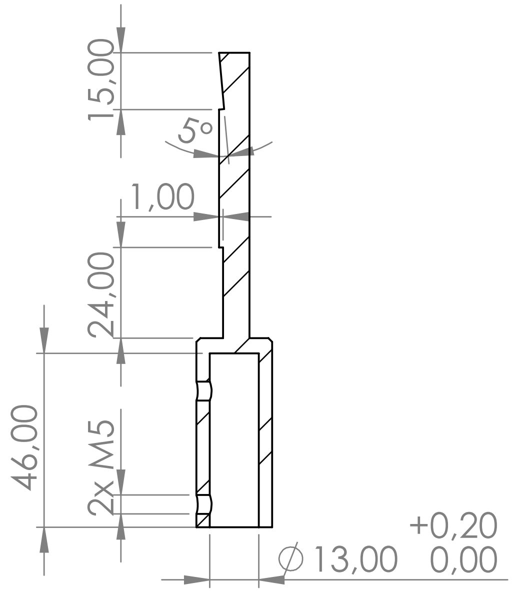
SECTION B-B



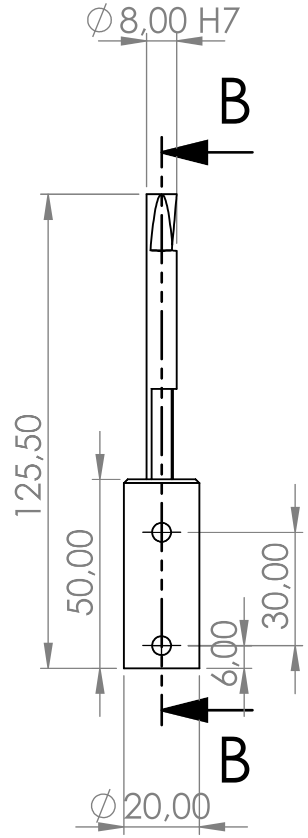


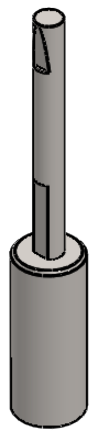
Fillets and geometry of the part are given in the DXF file by agreement with the workshop

Qty.		Material	
1		Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering		Scale: 1:1	Date: 10-12-2018
			Group ID: Group 30
Description: DA_M_002_Bearing_mount_v3			



SECTION B-B





Qty.	Material
1	AISI 304

AARHUS UNIVERSITY
SCHOOL OF ENGINEERING
Department of Mechanical Engineering

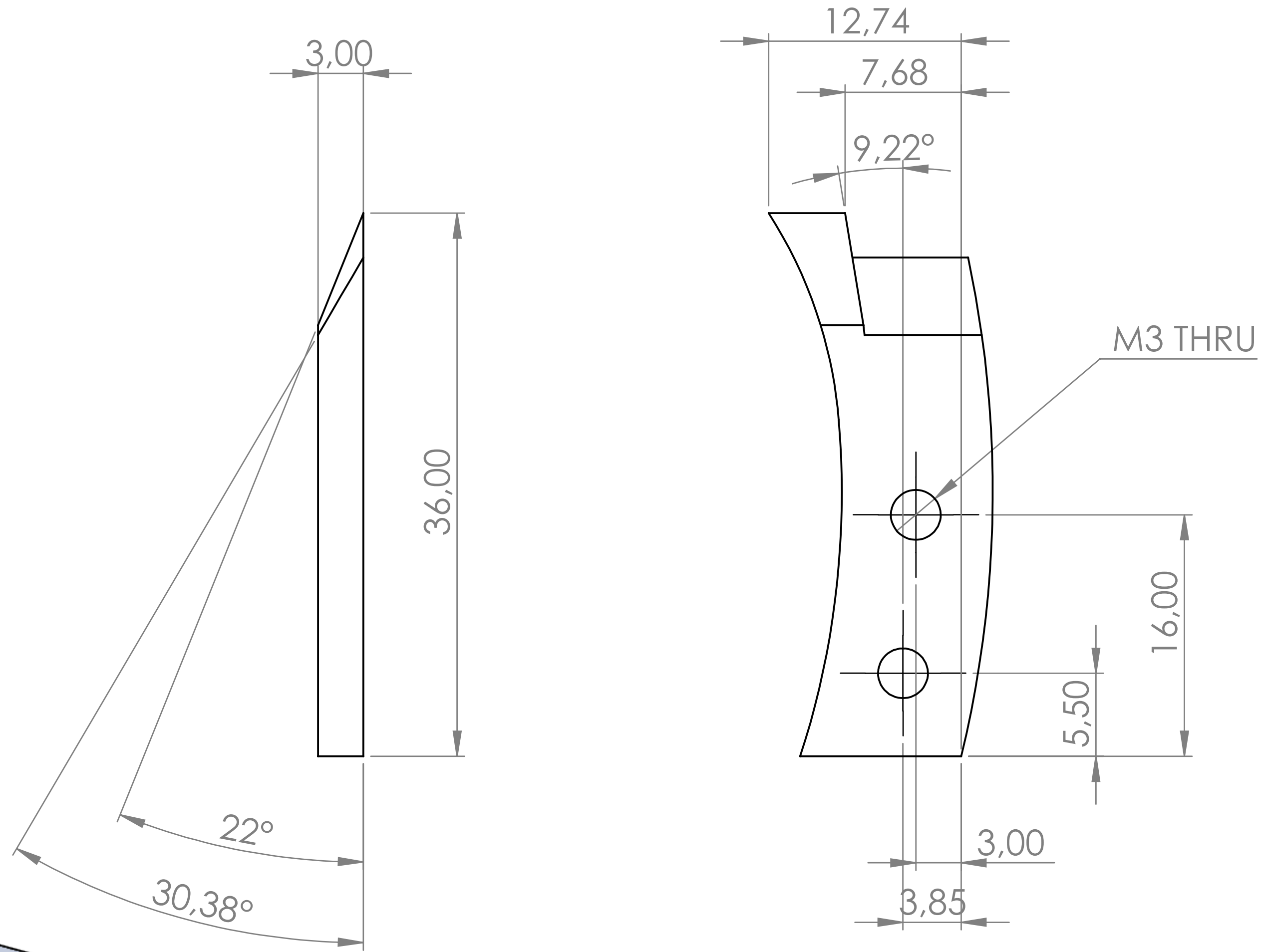
Scale: 1:2

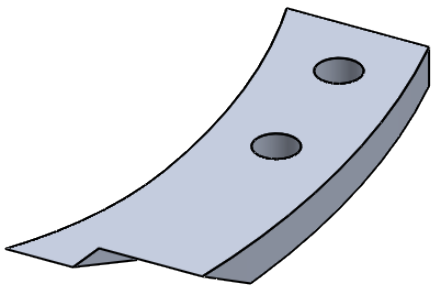
Date: 10-12-2018

Group ID: Group 30

Description:

DA_M_003_Center_drill_mount_v3





Fillets and geometry of the part are given in the DXF file by agreement with the workshop

Qty.	Material	
1	RML 54	

AARHUS UNIVERSITY
SCHOOL OF ENGINEERING
Department of Mechanical Engineering

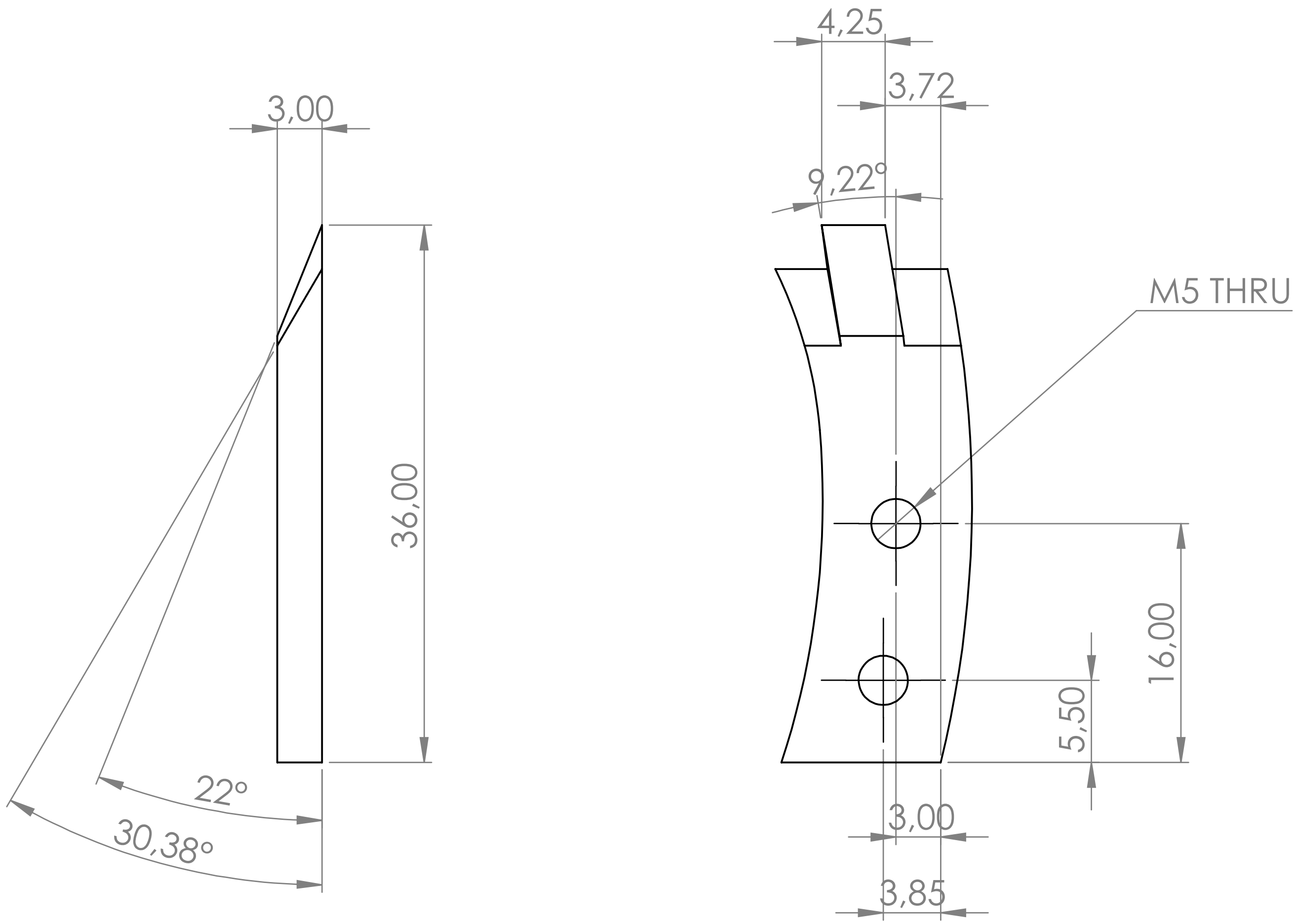
Scale: 2:1

Date: 10-12-2018

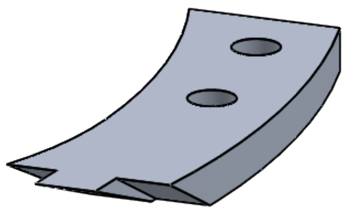
Group ID: Group 30

Description:

DA_M_004_Cutter_head_v3_inner



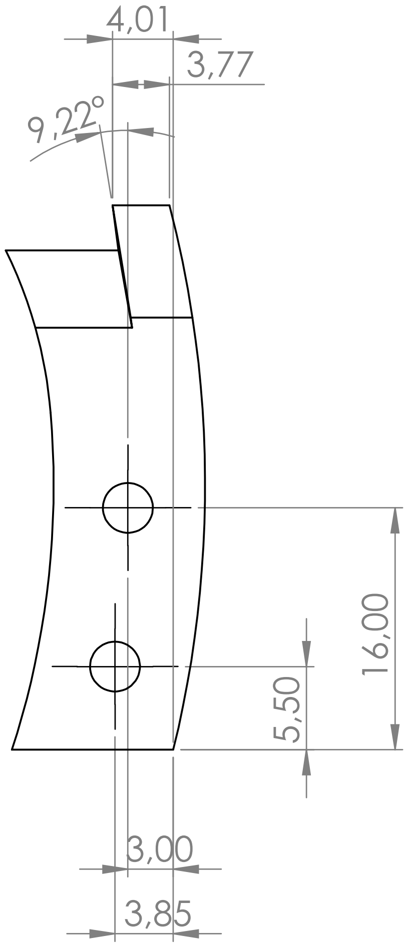
Fillets and geometry of the part are given in the DXF file by agreement with the workshop

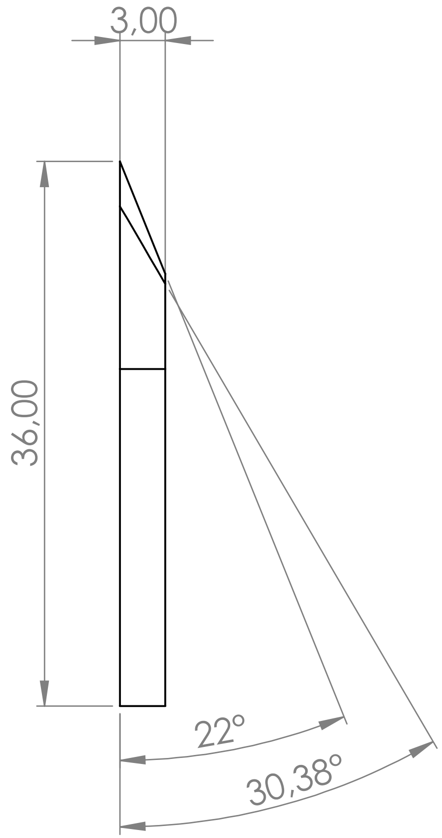


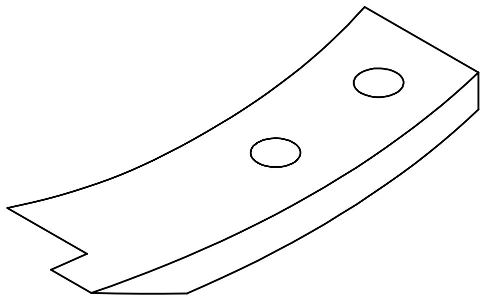
Qty.	Material	
1	RML 54	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 2:1	Date: 10-12-2018 Group ID: Group 30

Description:

DA_M_005_Cutter_head_v3_middle





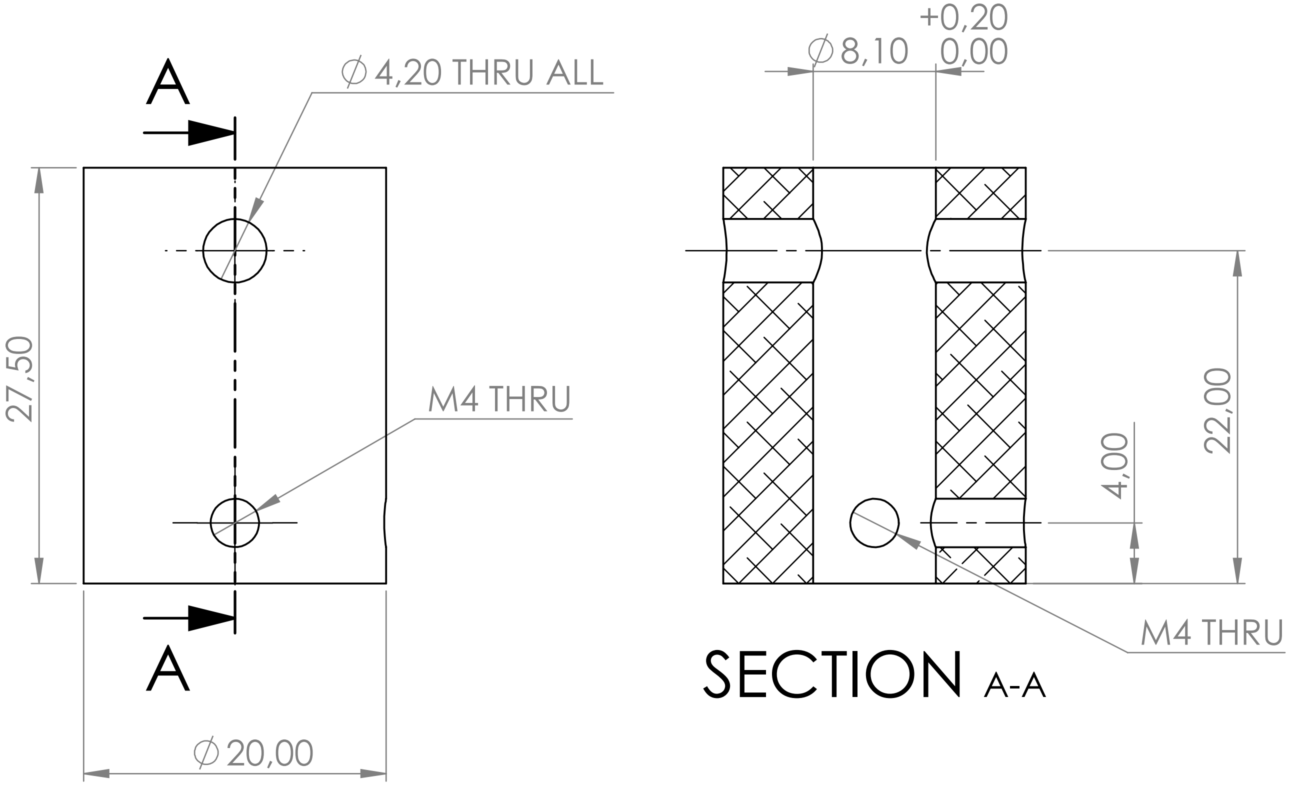


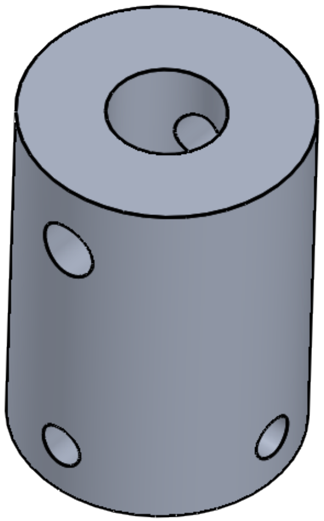
Fillets and geometry of the part are given in the DXF file by agreement with the workshop

Qty.	Material	
1	RML 54	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 2:1	Date: 10-12-2018 Group ID: Group 30

Description:

DA_M_006_Cutter_head_v3_outer

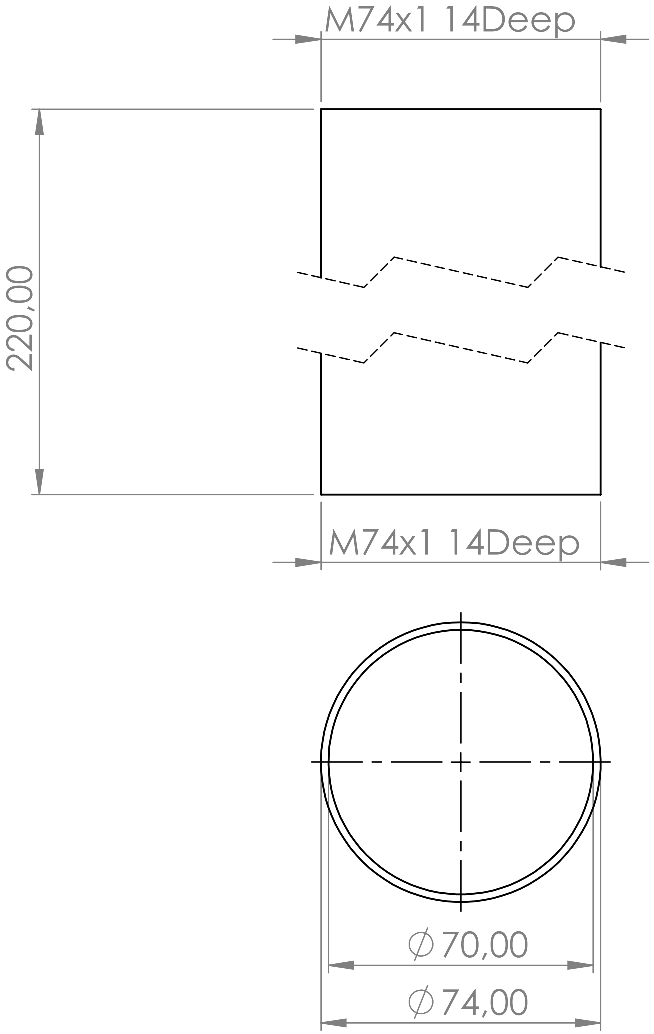


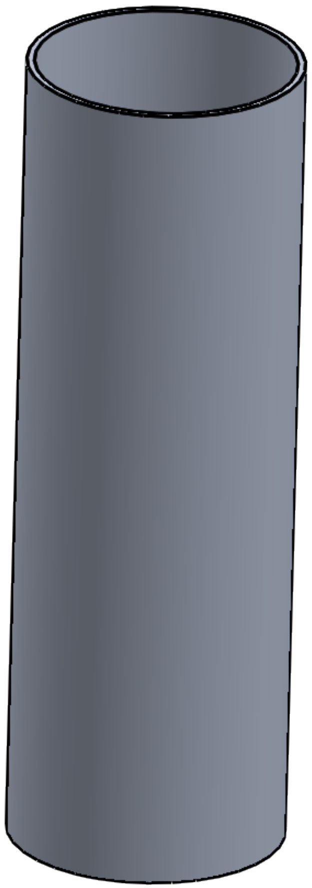


Qty.	Material	
1	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	**Scale:** 2:1	**Date:** 10-12-2018 **Group ID:** Group 30

Description:

DA_M_007_Drill_connector_v3





Qty.
1

Material
Alu

AARHUS UNIVERSITY
SCHOOL OF ENGINEERING
Department of Mechanical Engineering

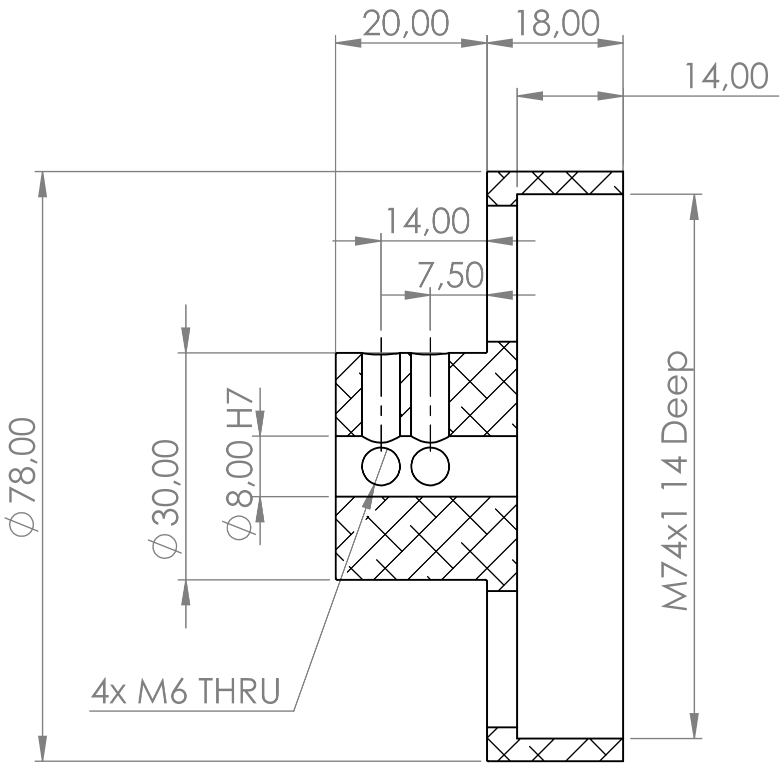
Scale: 1:2

Date: 10-12-2018

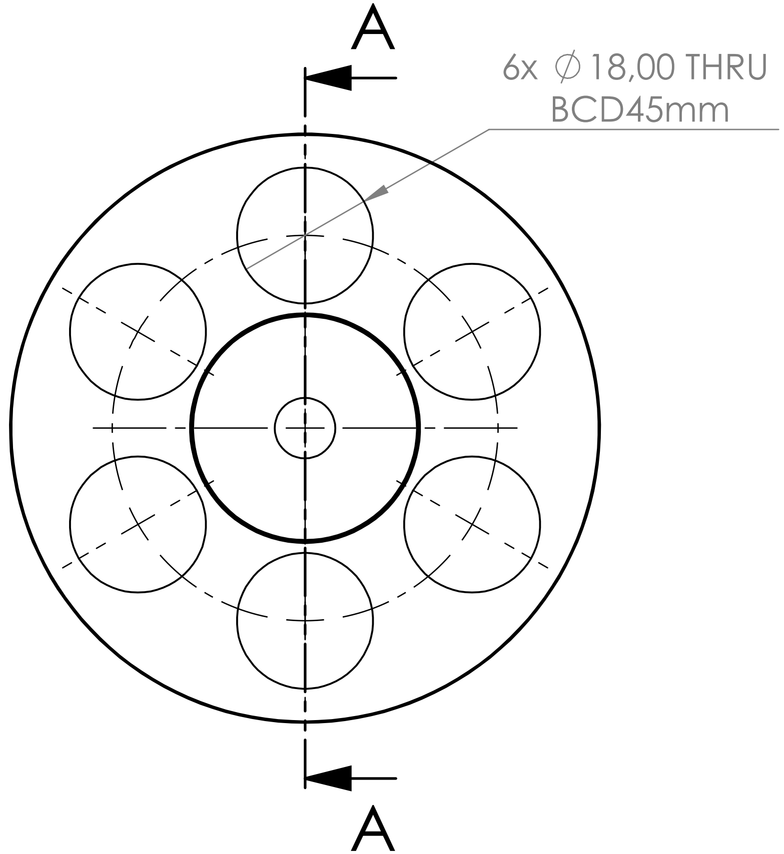
Group ID: Group 30

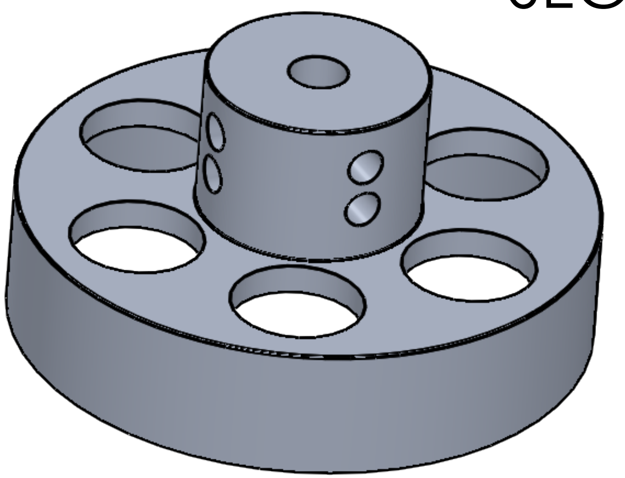
Description:

DA_M_009_Drill_center_tube_v3

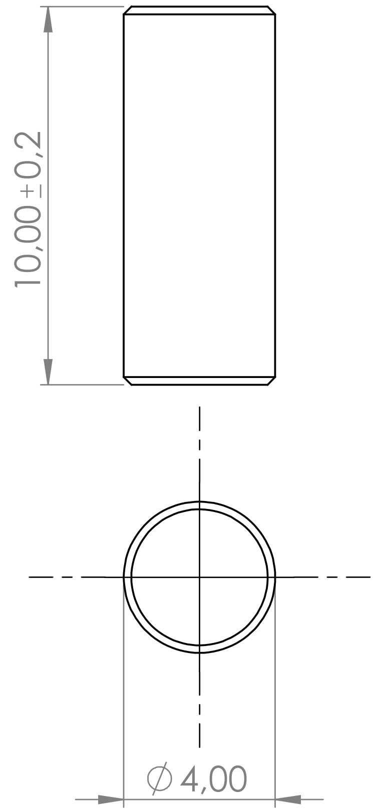


SECTION A-A





Qty.	Material	
1	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:1	Date: 10-12-2018 Group ID: Group 30
Description: DA_M_011_Drill_top_v3		



Qty.	Material
3	AISI 304

AARHUS UNIVERSITY
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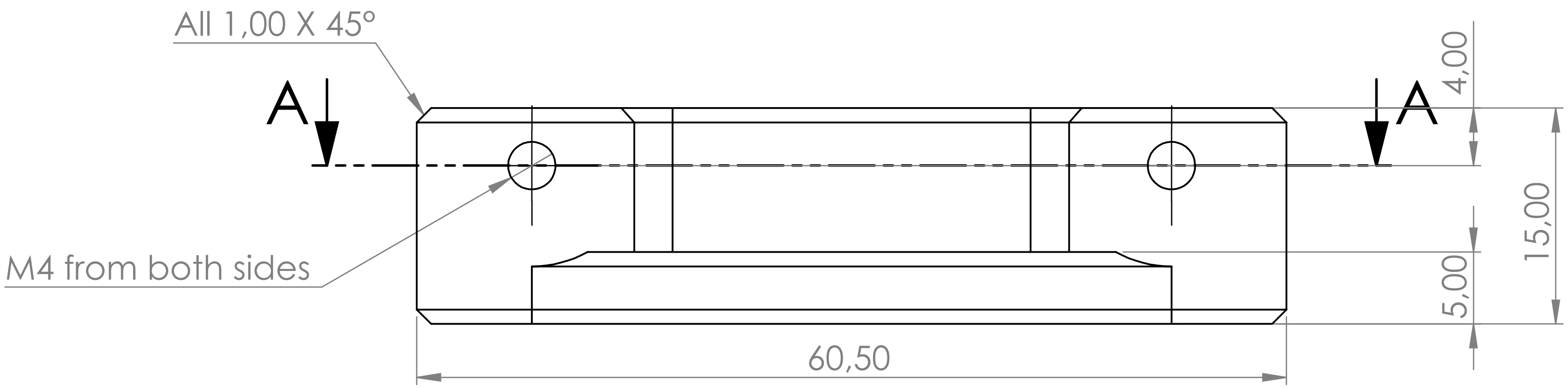
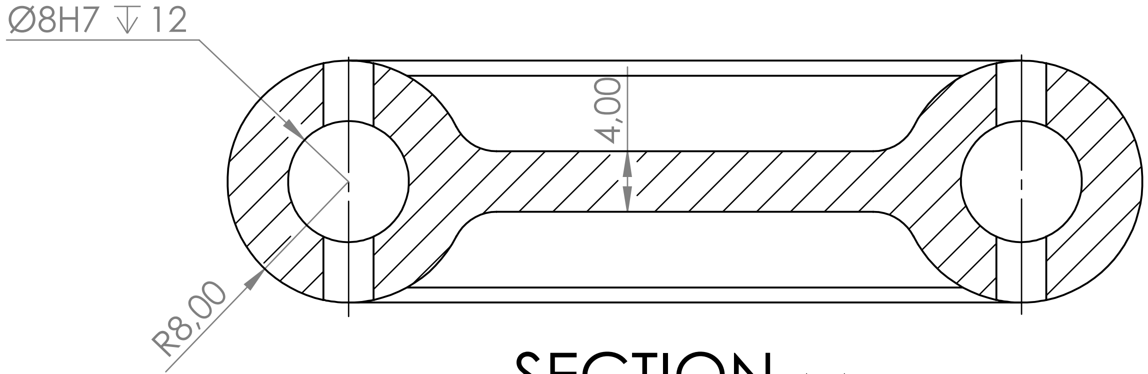
Scale:	Date: 10-12-2018
5:1	Group ID: Group 30

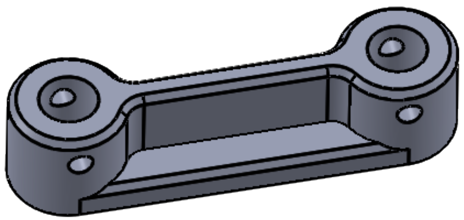
Description:

DA_M_012_Drill_sleeve_pin_v3





SECTION A-A

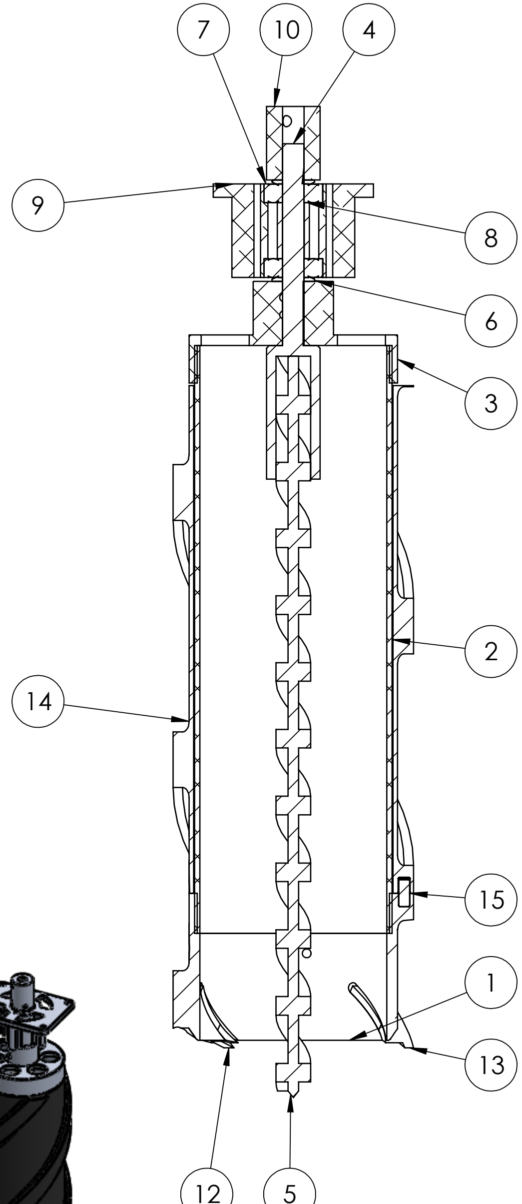


Fillets and geometry of the part are given in the DXF file by agreement with the workshop

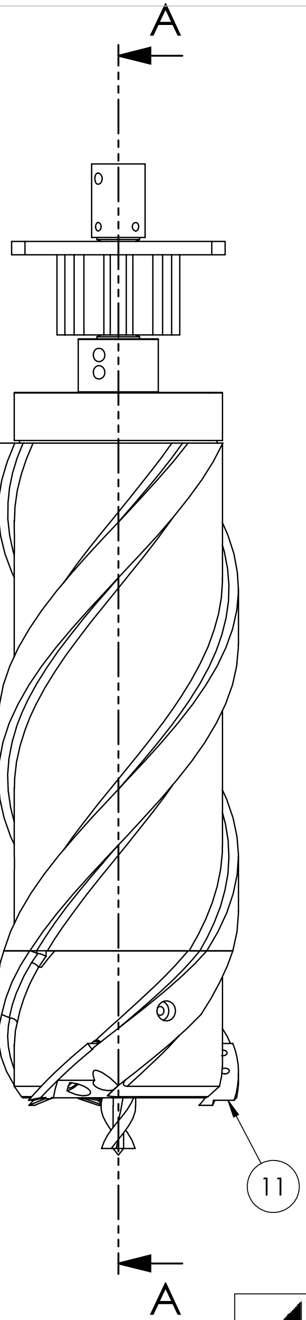
Qty.	Material	
1	AISI 304	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 2:1	Date: 12-12-2018 Group ID: Group 30

Description:

DA_M_13_Extraction_tool

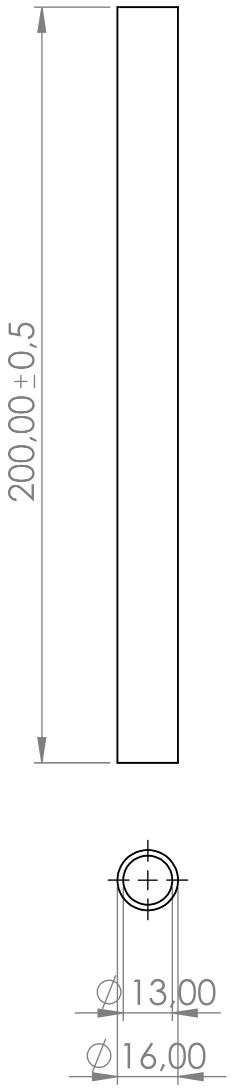


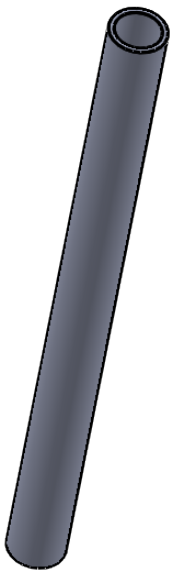
SECTION A-A



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DA_M_008_Drill_head_v3		1
2	DA_M_009_Drill_center_tube_v3		1
3	DA_M_011_Drill_top_v3		1
4	DA_M_003_Center_drill_mount_v3		1
5	DA_P_003_Center_drill		1
6	DA_P_002_Bearing_shim_v3		2
7	DA_P_001_Bearing_Ø22		2
8	DA_M_001_Bearing_mid_spacer_v3		1
9	DA_M_002_Bearing_mount_v3		1
10	DA_M_007_Drill_connector_v3		1
11	DA_M_004_Cutter_head_v3_inner		1
12	DA_M_005_Cutter_head_v3_middle		1
13	DA_M_006_Cutter_head_v3_outer		1
14	DA_M_010_Drill_sleeve_v3		1
15	DA_M_012_Drill_sleeve_pin_v3		3

AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:2	Date:	10-12-2018
		Group ID:	Group 30
Drawing nr. and description: Drill_assembly_v3	Drawing no.:		





Qty.	Material
1	Alu

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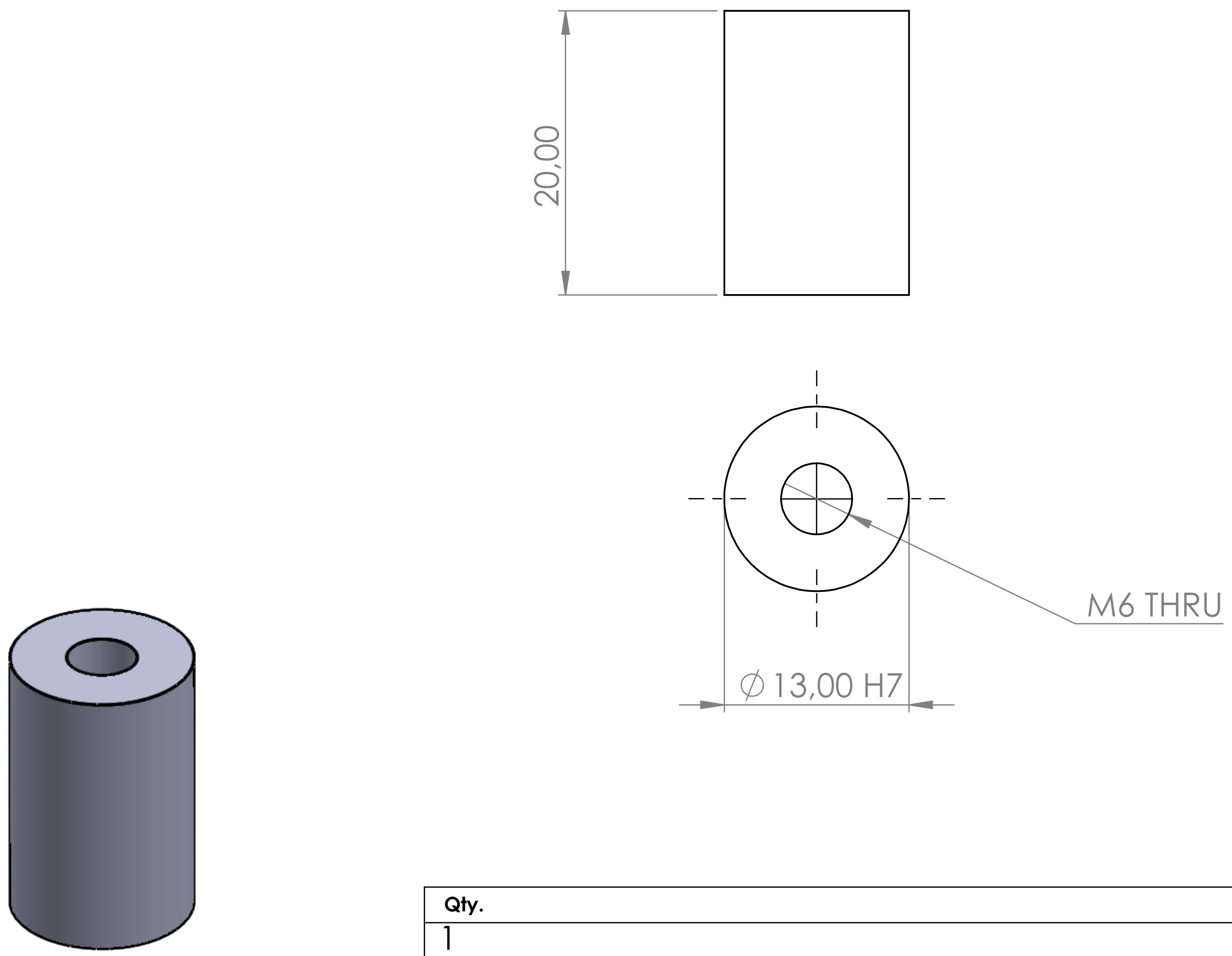
Scale:	Date:	10-12-2018
1:2	Group ID:	Group 30

Description:

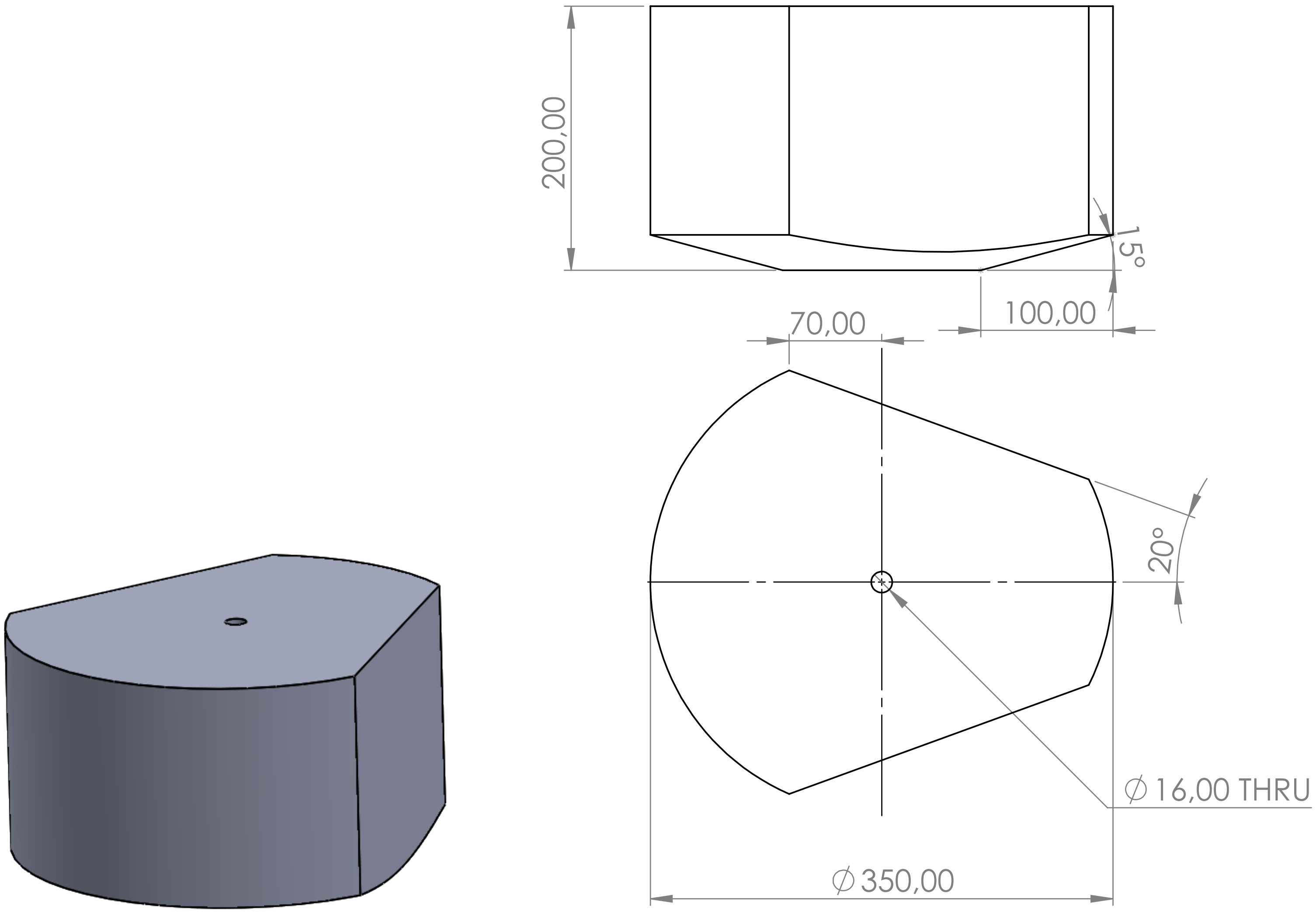
ASA_M_001_Button_leg



Qty.	Material	
1	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 2:1	Date: 10-12-2018 Group ID: Group 30

Description:

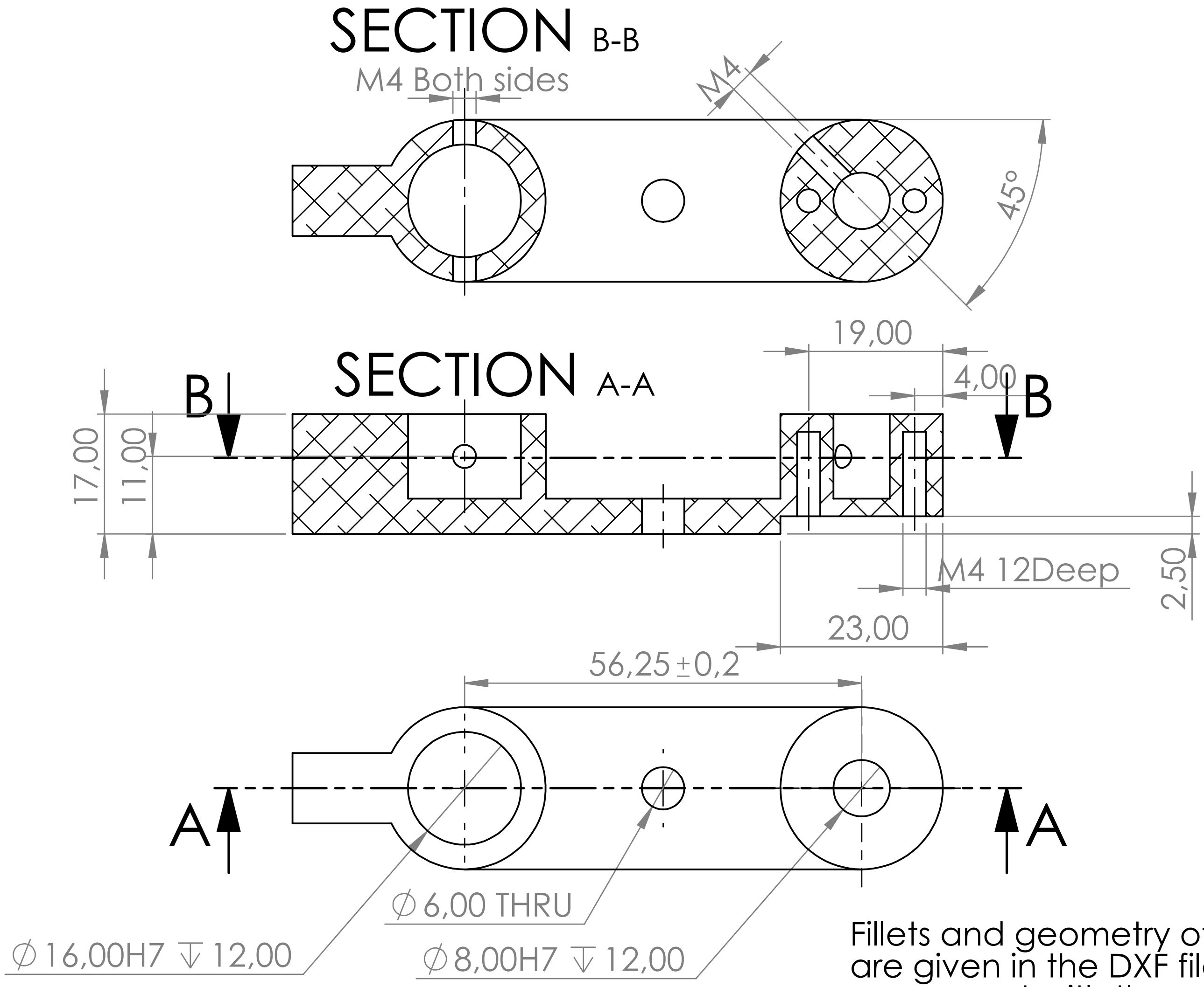
ASA_M_002_Button_leg_thread_mount



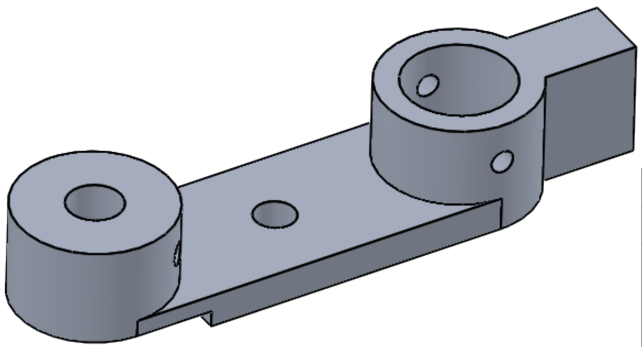
Qty.	Material		
1	Flamingo		
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:5	Date:	14-12-2018
		Group ID:	Group 30

Description:

ASA_M_003_Float



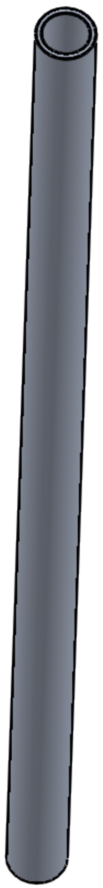
Fillets and geometry of the part are given in the DXF file by agreement with the workshop

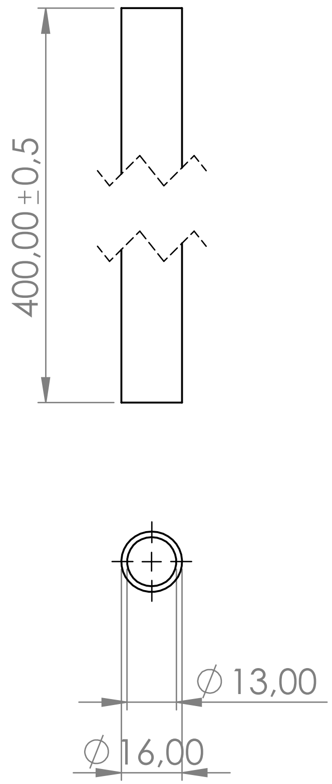


Qty.	Material	
2	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:1	Date: 11-12-2018
		Group ID: Group 30

Description:

ASA_M_006_Landing_gear_rod_mount





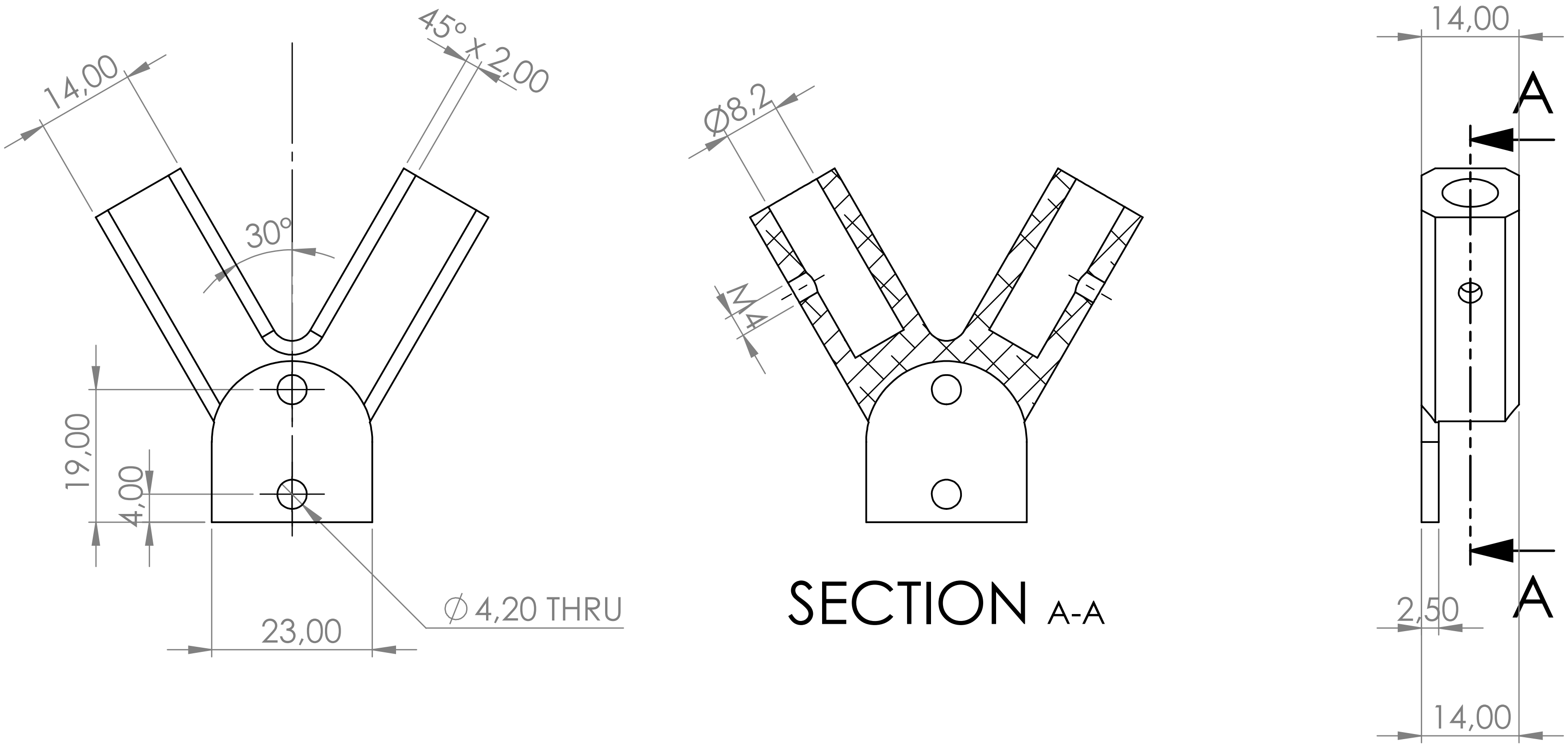
Qty.	Material
1	Alu

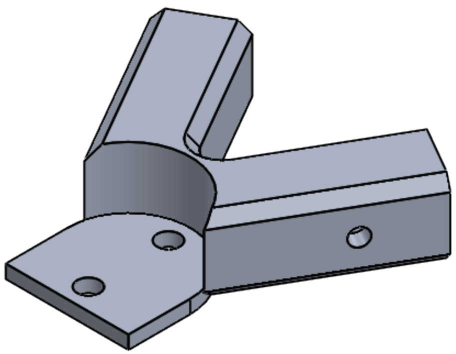
AARHUS UNIVERSITY
SCHOOL OF ENGINEERING
Department of Mechanical Engineering

Scale:	Date: 10-12-2018
1:2	Group ID: Group 30

Description:

ASA_M_007_Slider_rod



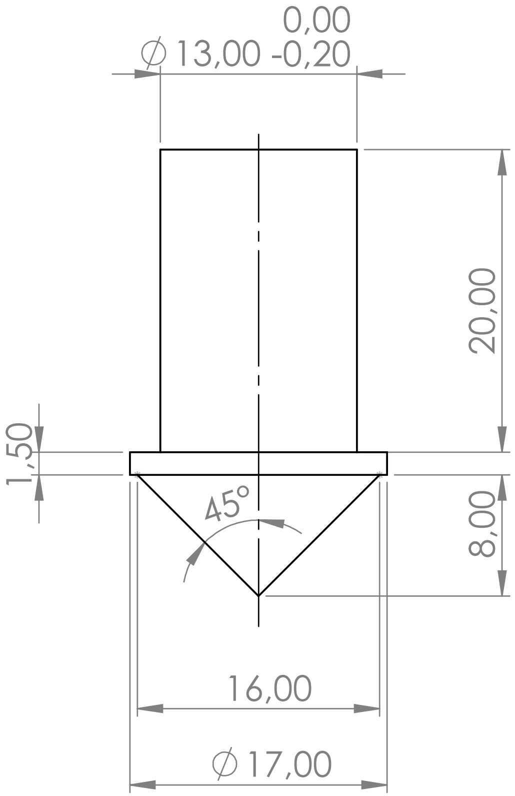


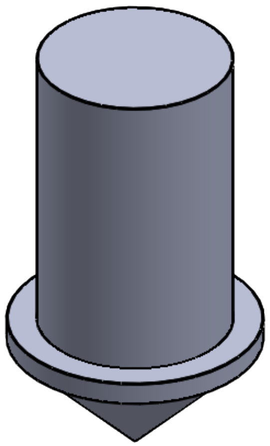
Fillets and geometry of the part are given in the DXF file by agreement with the workshop

Qty.	Material	
2	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:1	Date: 10-12-2018 Group ID: Group 30

Description:

ASA_M_008_V_part

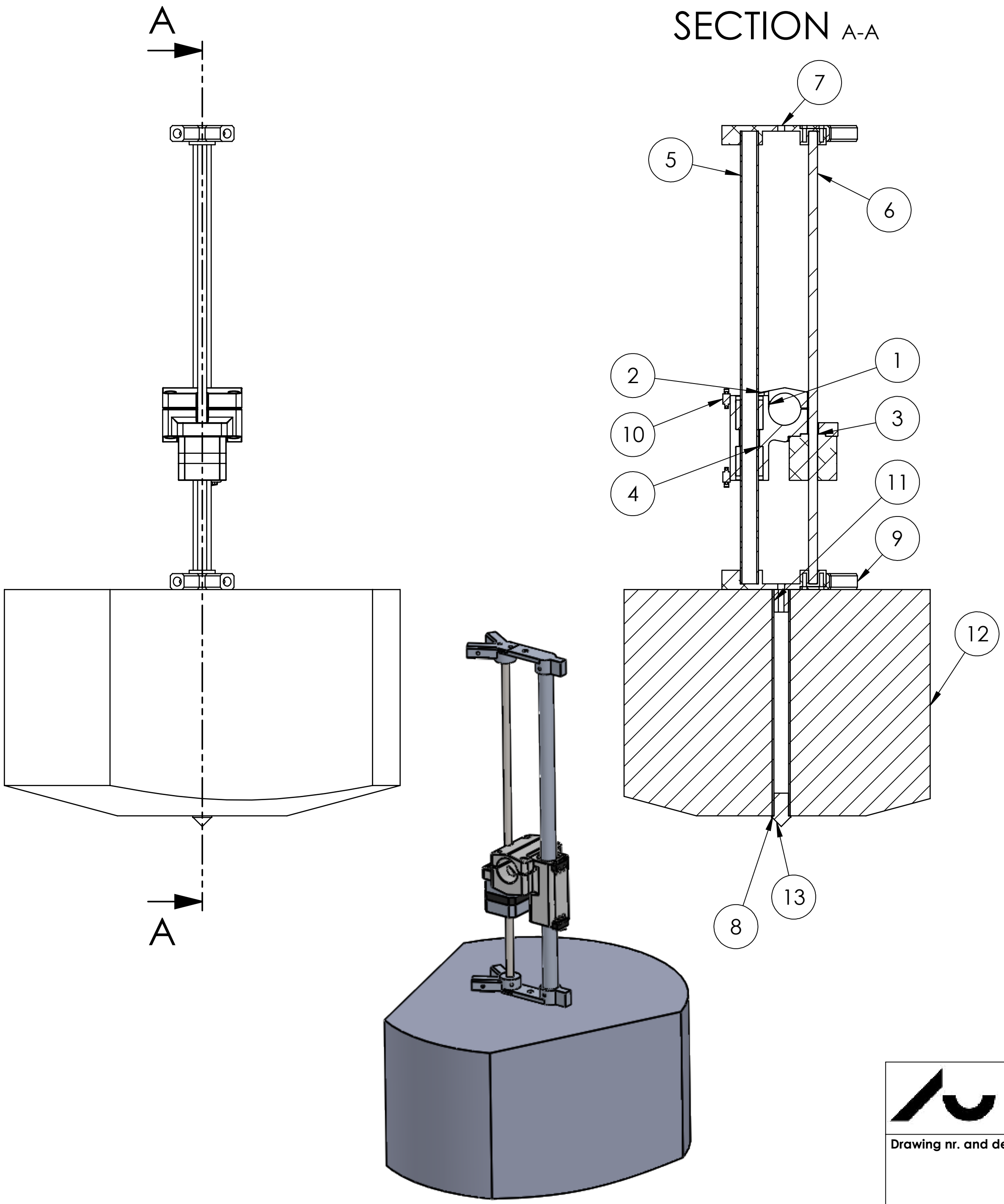




Qty.	Material	
1	POM-C	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 2:1	Date: 10-12-2018 Group ID: Group 30

Description:

ASA_M_009_Spike_POM



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ASA_M_004_Landing_gear_actuator_mount		1
2	ASA_M_005_Landing_gear_actuator_mount_top		1
3	ASA_P_004_Nema_17		1
4	ASA_P_001_Glider_bushing		2
5	ASA_M_007_Slider_rod		1
6	ASA_P_002_Leadscrew		1
7	ASA_M_006_Landing_gear_rod_mount		2
8	ASA_M_001_Button_leg		1
9	ASA_M_008_V_part		2
10	ASA_P_003_Microswitch		2
11	ASA_M_002_Button_leg_thread_mount		1
12	ASA_M_003_Float		1
13	ASA_M_009_Spike_POM		1

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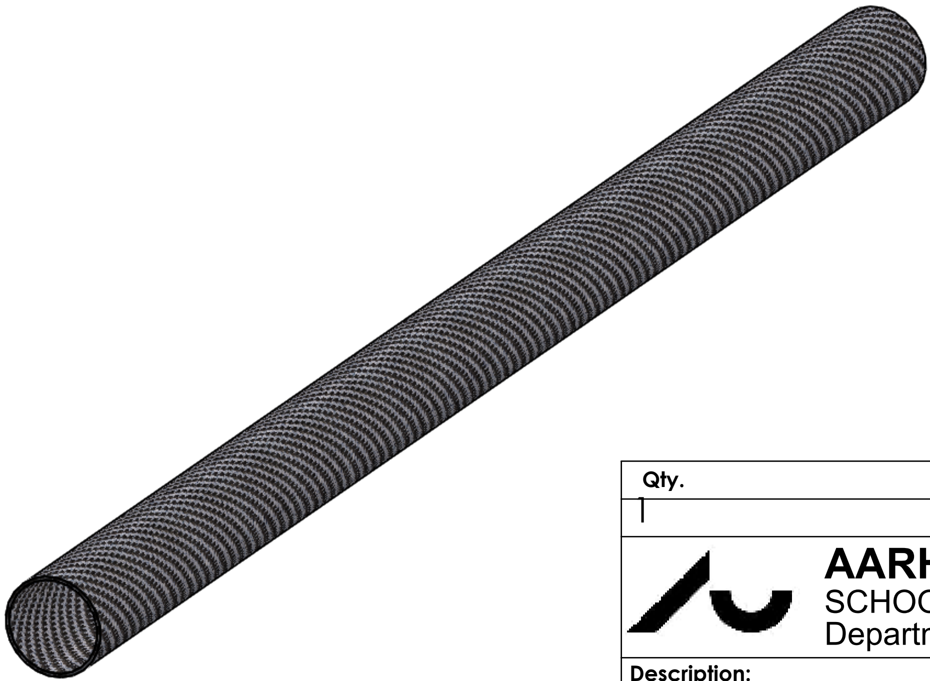
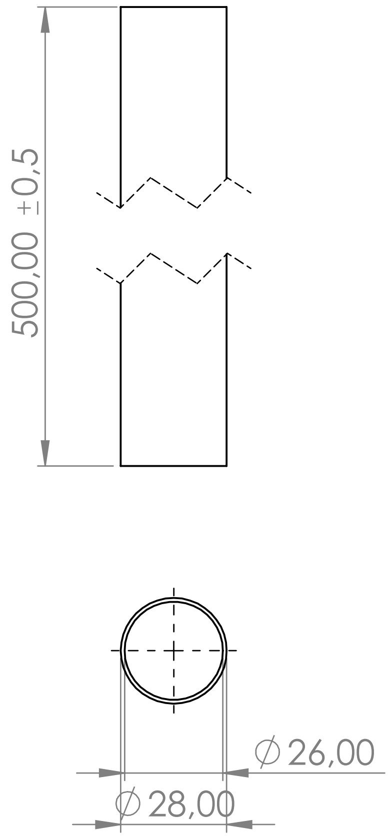
Scale:	1:4
Date:	14-12-2018
Group ID:	Group 30

Drawing nr. and description:

Drawing no.:

Actuator_system_assembly

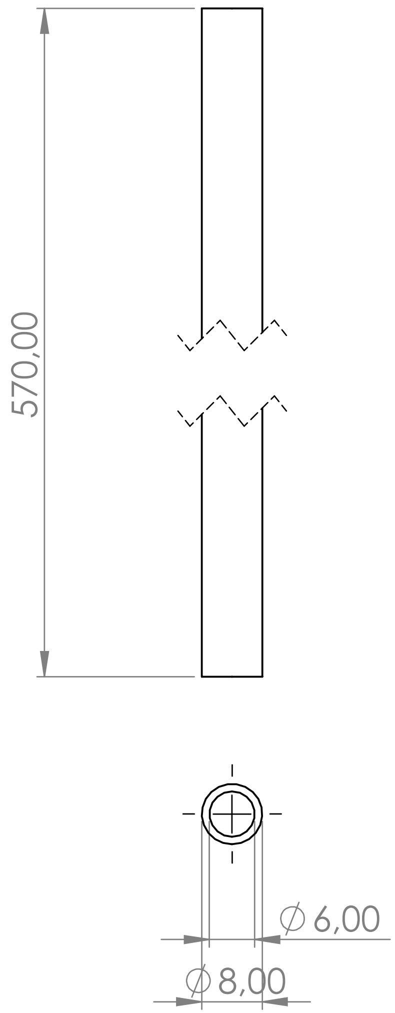




Qty.	Material	
1	Carbon	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:2	Date: 10-12-2018 Group ID: Group 30

Description:

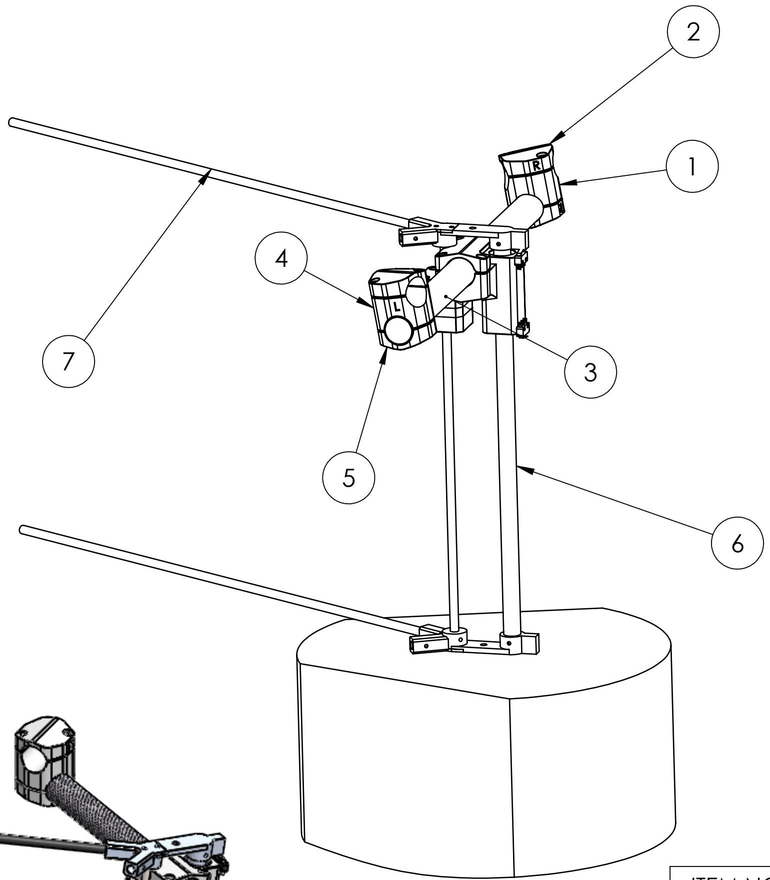
LGA_P_001_Ø28_carbon_Upper_bar

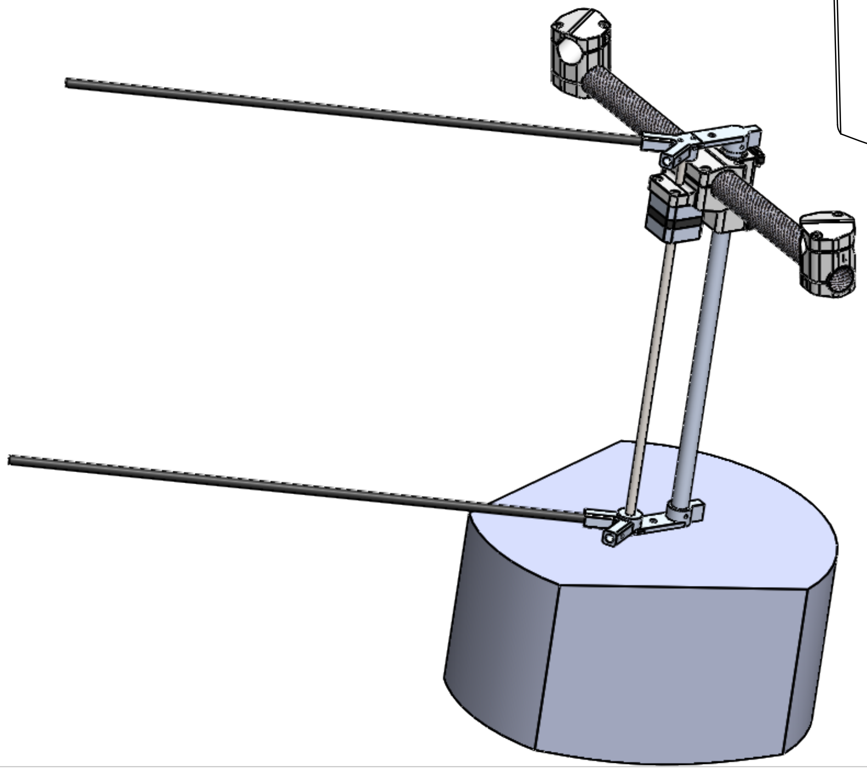


Qty.	Material	
2	Carbon	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	**Scale:** 1:1	**Date:** 10-12-2018 **Group ID:** Group 30

Description:

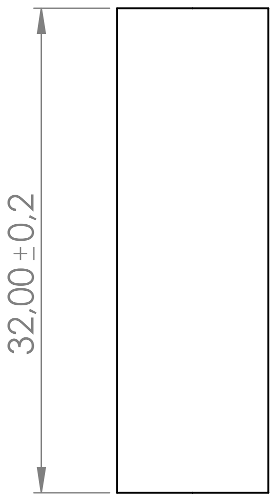
LGA_P_002_Ø8_carbon_frame

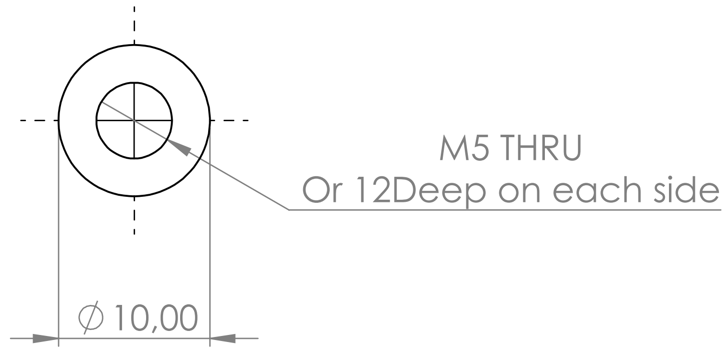


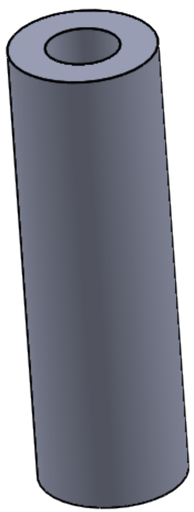


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	LGA_M_004_Right_upper_bracket		1
2	LGA_M_003_Right_bracket_top		2
3	LGA_P_001_Ø28_carbon_Upper_bar		1
4	LGA_M_002_Left_upper_bracket		1
5	LGA_M_001_Left_bracket_top		2
6	Actuator_system_assembly		1
7	LGA_P_002_Ø8_carbon_frame		2

AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:5	Date:	14-12-2018
		Group ID:	Group 30
Drawing nr. and description:	Drawing no.:		
Landing_gear_assembly			



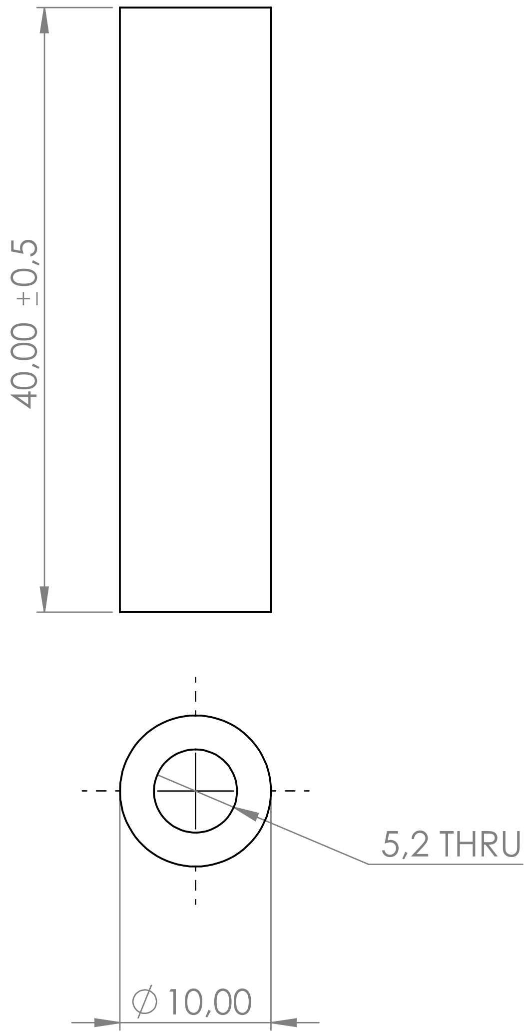


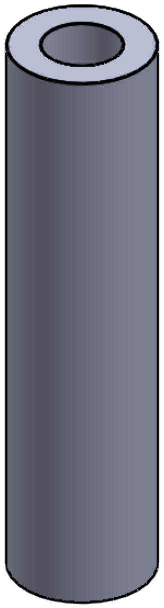


Qty.		Material	
4		Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering		Scale: 2:1	Date: 10-12-2018 Group ID: Group 30

Description:

MMA_M_001_Motor_mount_bar_bottom

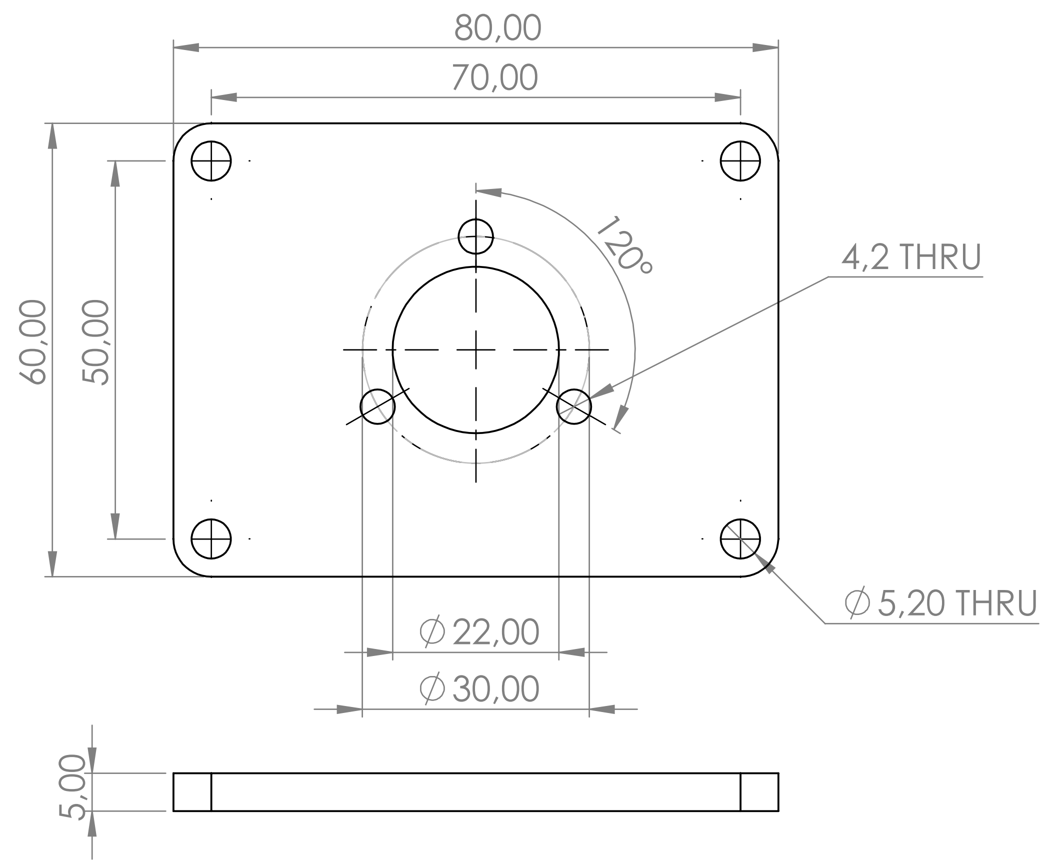


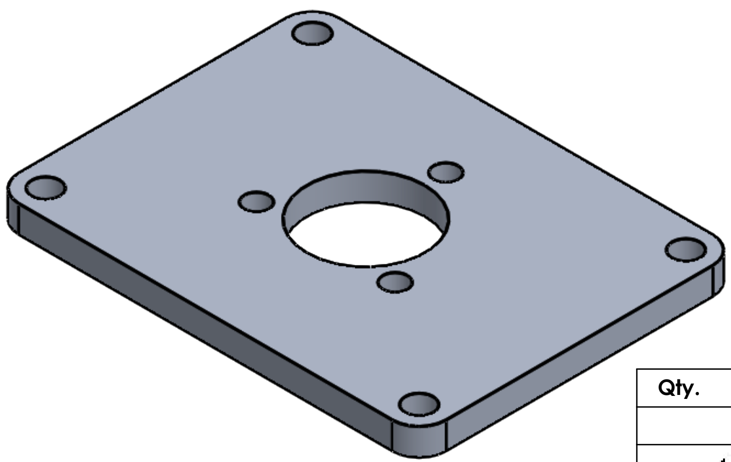


Qty.	Material	
4	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 2:1	Date: 10-12-2018 Group ID: Group 30

Description:

MMA_M_002_Motor_mount_bar_top



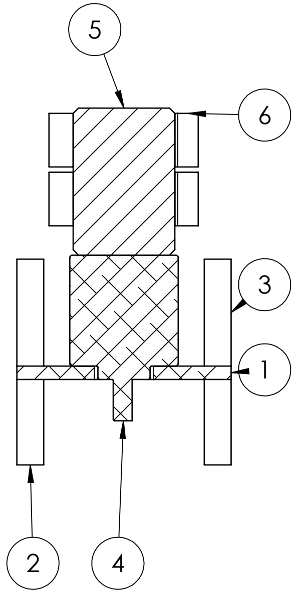


Fillets and geometry of the part are given in the DXF file by agreement with the workshop

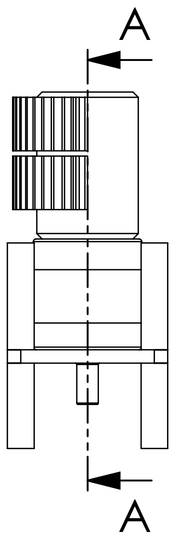
Qty.	Material	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:1	Date: 10-12-2018 Group ID: Group 30

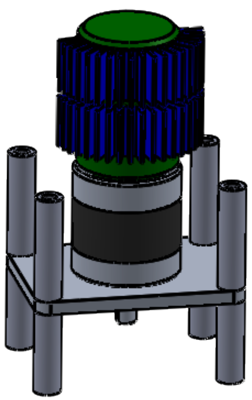
Description:

MMA_M_003_Motor_mounting_plate



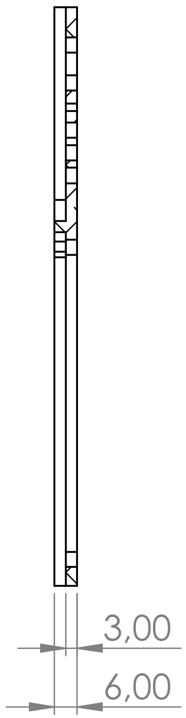
SECTION A-A



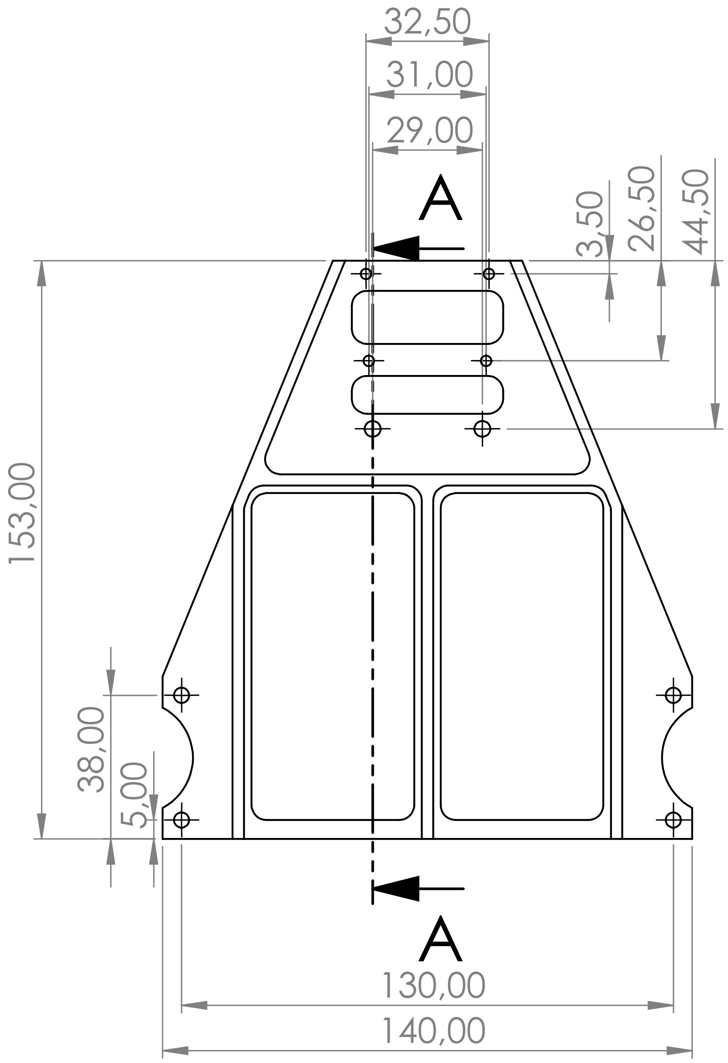


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MMA_M_003_Motor_mounting_plate		1
2	MMA_M_001_Motor_mount_bar_bottom		4
3	MMA_M_002_Motor_mount_bar_top		4
4	MMA_P_001_Micro_motor_gear		1
5	MMA_P_002_Brushless_motor		1
6	MMA_P_003_Motor_heat_sink		2

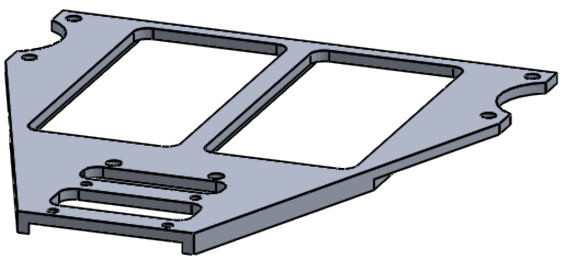
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	Scale: 1:2	Date:	10-12-2018
		Group ID:	Group 30
Drawing nr. and description: Motor_mount_assembly	Drawing no.:		



SECTION A-A



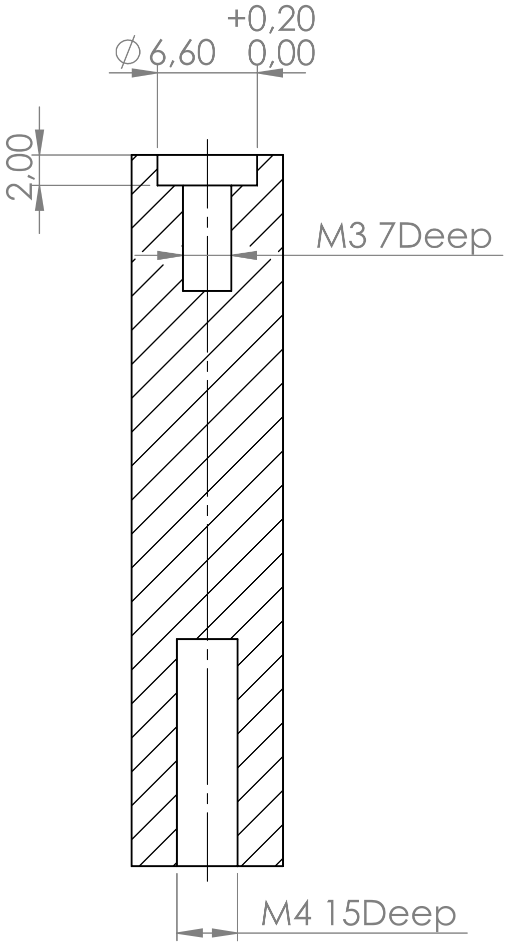
Fillets and geometry of the part are given in the DXF file by agreement with the workshop



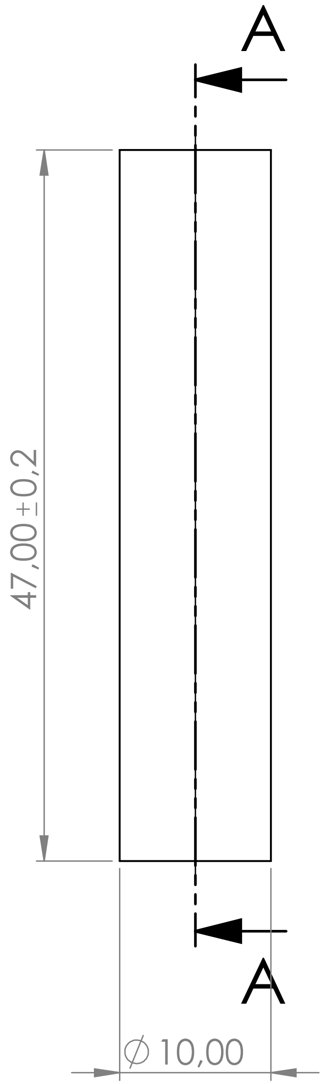
Qty.	Material	
1	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	**Scale:** 1:2	**Date:** 14-12-2018 **Group ID:** Group 30

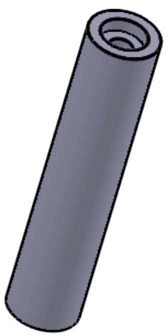
Description:

MPA_M_001_Camera_mount



SECTION A-A

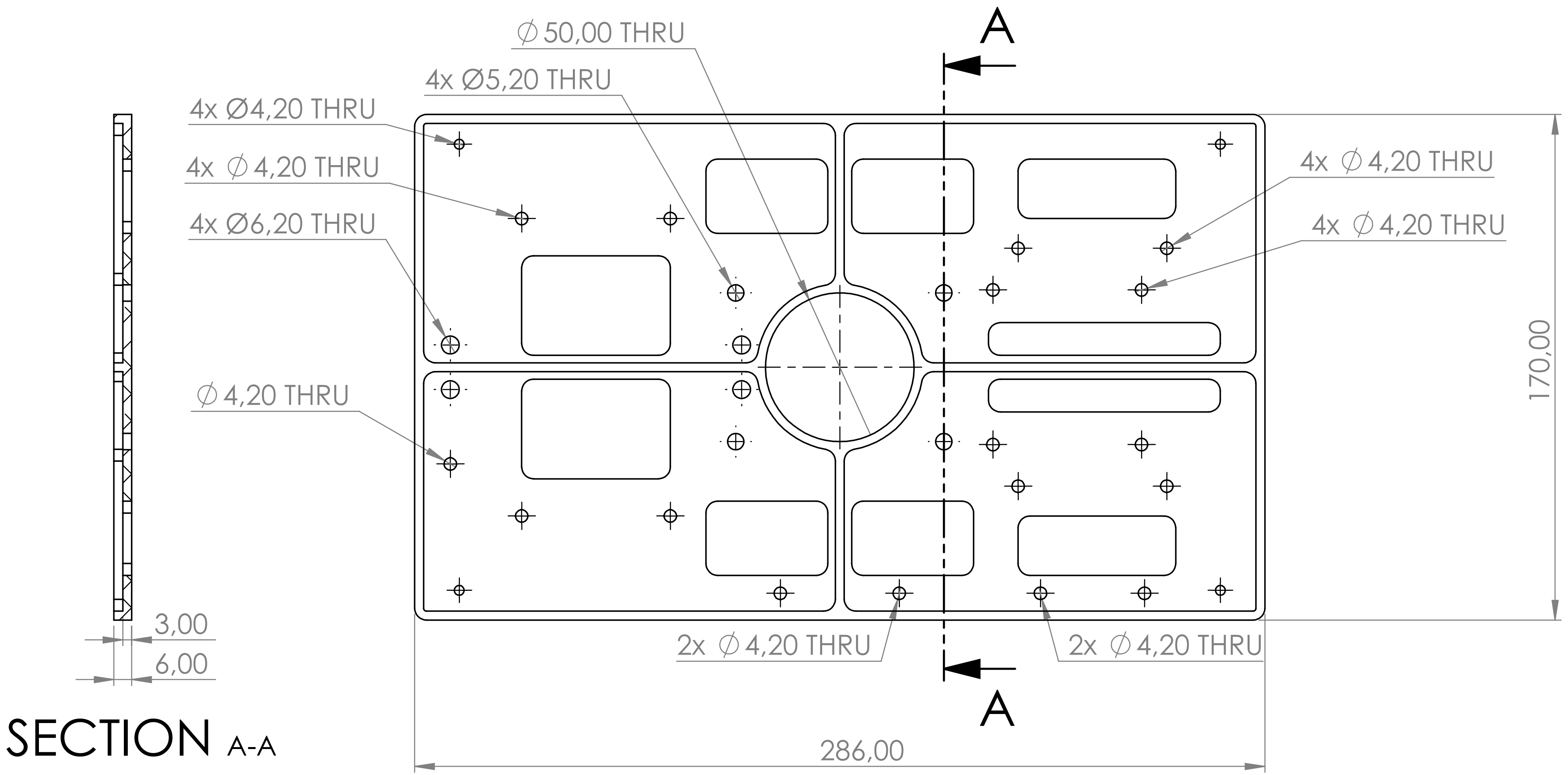




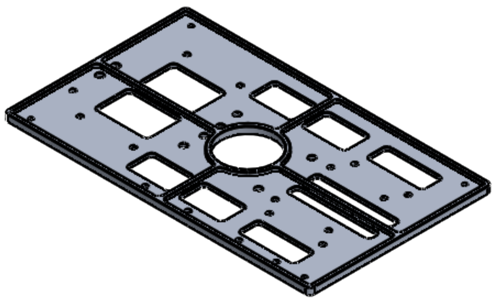
Qty.	Material		
4	Alu		
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	**Scale:** 2:1	**Date:** 10-12-2018	**Group ID:** Group 30

Description:

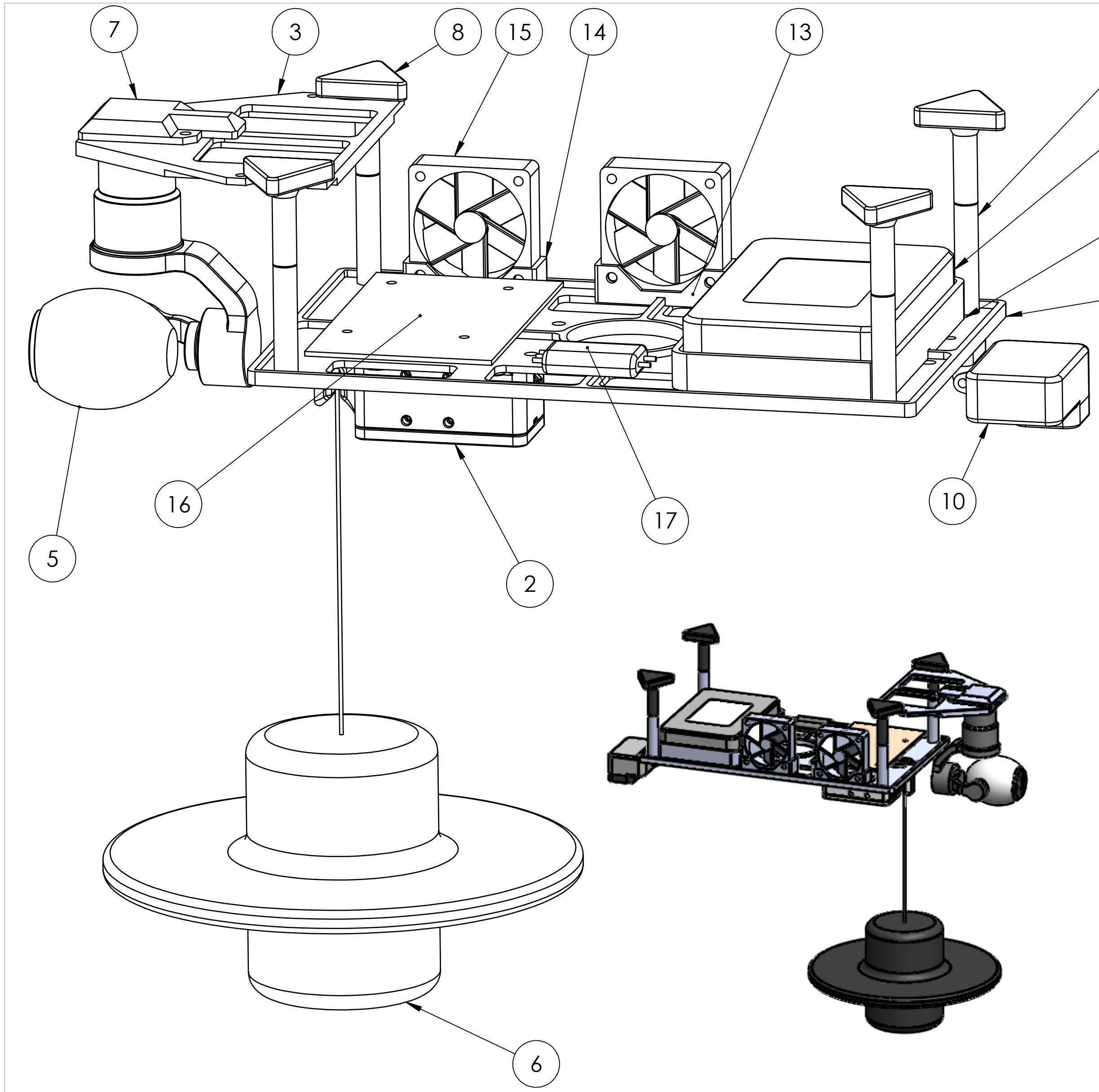
MPA_M_006_Mounting_bar_bracket_extension



Fillets and geometry of the part are given in the DXF file by agreement with the workshop



Qty.	Material	
1	Alu	
AARHUS UNIVERSITY SCHOOL OF ENGINEERING Department of Mechanical Engineering	**Scale:** 1:2	**Date:** 10-12-2018
		Group ID: Group 30
Description: MPA_M_007_Mounting_plate		



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	MPA_M_007_Mounting_plate		1
2	Solenoid_mechanism		1
3	MPA_M_001_Camera_mount		1
4	MPA_P_001_Camera_socket		1
5	MPA_P_008_Zenmuse_X3		1
6	MPA_P_005_GPS_beacon		1
7	MPA_M_002_Camera_mount_shield		1
8	MPA_P_006_Mounting_bar_bracket		4
9	MPA_M_006_Mounting_bar_bracket_extension		4
10	MPA_P_004_Reflection_camera		1
11	MPA_M_008_myRIO_mounting_slot		1
12	MPA_P_007_myRIO		1
13	MPA_M_004_Fan_high_mount		1
14	MPA_M_005_Fan_low_mount		1
15	MPA_P_003_Fan_12V		2
16	MPA_M_003_Electronic_plate		1
17	MPA_P_002_ESC_30A		1

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Scale: 1:2

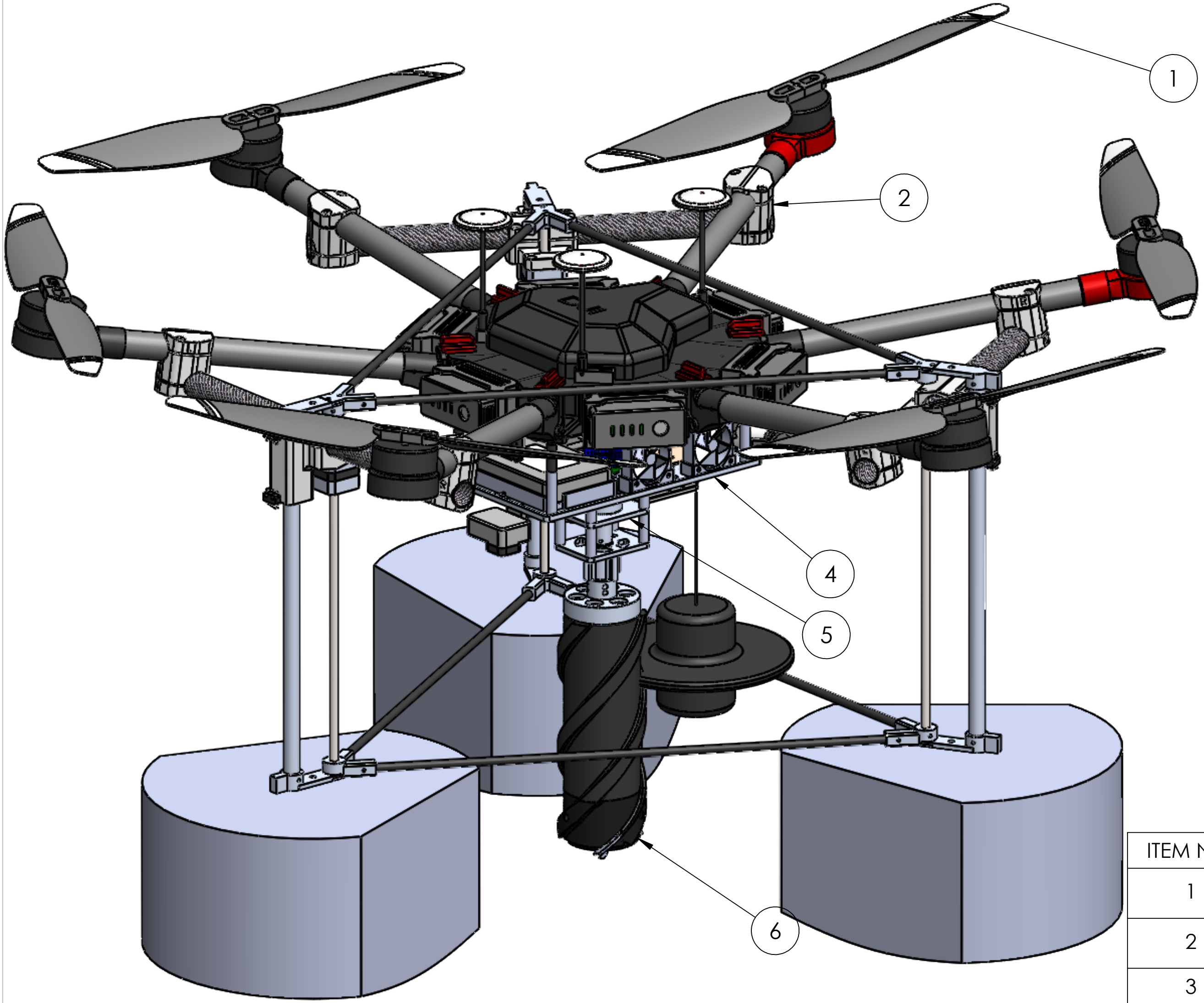
Date: 10-12-2018

Group ID: Group 30

Drawing nr. and description:

Drawing no.:

Mounting_plate_assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DJI_Matrice_600_Pro_assembly		1
2	Landing_gear_assembly		3
3	Ground		1
4	Mounting_plate_assembly		1
5	Motor_mount_assembly		1
6	Drill_assembly_v3		1

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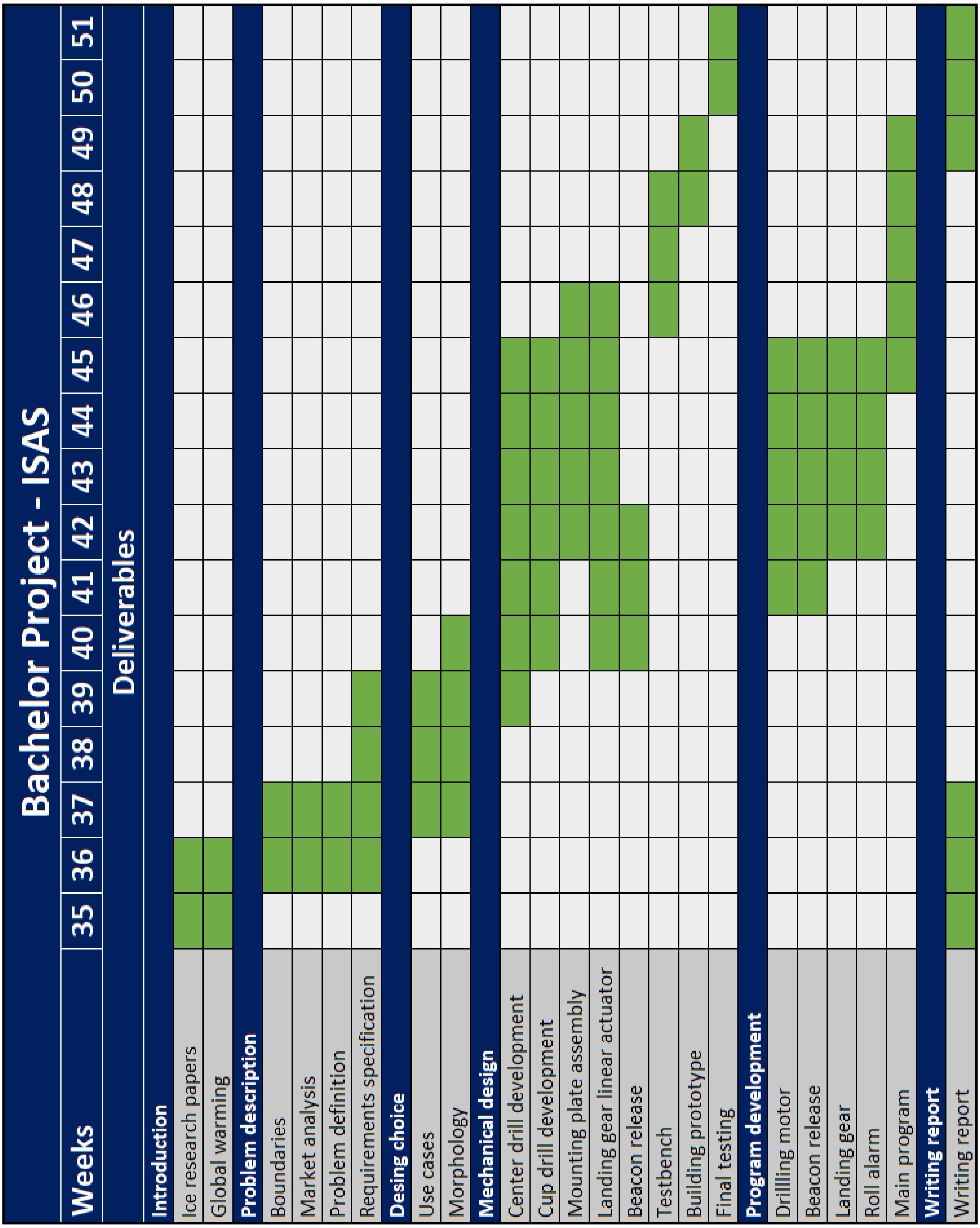
Scale:	1:5
Date:	14-12-2018
Group ID:	Group 30
Drawing nr. and description:	ISAS_v2_Assembly
Drawing no.:	

A.23 Time schedule

This is the final Time schedule for the project as it has been updated, since it is hard to make a perfect time schedule from the beginning.



A.24 User manual

This Appendix contains the User manual for the ISAS.

A.24.1 Prerequisites for flying the drone

- Register drone (flight in town) `https://indberet.virk.dk/myndigheder/stat/TS/Registrering_af_droner_til_flyvning_i_bymaessigt_omraade`
- Register drone (flight on the countryside) `URohttps://blanket.virk.dk/blanketservice/orbeon/fr/tbst/droneregistrering-udenfor-bymaessigt-omraade/newL`
- 0.75 million SDR insurance
- Flight experience: At least 5 hours of practice, 15 landings within the last 12 months
- Drone license for the correct weight category and type certification
- Drone marked with Registration number, Name and Pphone number
- Maintenance program for every 200th flight or 50hr of flight

A.24.2 Flight planning (not night flight)

- Determine your needs
  - Decide the flight route/flight area
  - Decide the flight height
  - Decide the flight length (minutes and km)
  - Take off weight
- Determine your possibilities
  - Check restrictions on "Naviar Droneluftrum"
  - Safety distances
    - Minimum distances (without permit)
      1. Buildings and power grid
         - Countryside: 100 m
         - Urban: 5 m (though no fence/hedge or wall overflight)
         - Special buildings: 150 m
      2. Accident area: 150 m
      3. Airfield
         - Helipad: 2 km
         - Public: 5 km
         - Military: 8 km
      4. Ships and offshore instalments: 50 m
      5. 70 km/h public roads, trains and people without consent
         - Countryside: 50 m

- · Urban area and a flight height of 0 m-15 m: 15 m
- · Urban area and a flight height of 15 m-50 m: The flight height
- · Urban area and a flight height of 50 m-120 m: 50 m

- ∗ Max flight height
  1. Countryside: 100 m
  2. Urban: 120 m
  3. Airfield: 40 m above the field
  4. Helipad: 50 m above the pad
  5. Overflight: height + 25 m

- – Determine location and plan
  - ∗ Risks
    1. Turbulence
    2. Collision
    3. Radio and cell towers
    4. Flocks of birds
    5. Power grid
    6. Passers
    7. Needs of redundancies on drone systems
  - ∗ Breach of privacy
  - ∗ Nuisance to others
  - ∗ Barring the area
  - ∗ Pilots position for VLOS
  - ∗ Starting area
  - ∗ Landing area
  - ∗ Safety zone
  - ∗ Need of walkie-talkie

- Adapt your needs according to the possibilities
  - Obtain special permits
  - Apply for a special permit at DJI for flying in a No Flight Zone (NFZ)
- Set in calender for pilot and helper
- Safety briefing
  - Where will the flight happen
  - Who has responsibility for what
  - Indications of failure
  - Plan of action at failure
  - Crash landing area
- Send notice to the police: `kortlink.dk/politi/wa5f`

A.24.3 The day before flight

- Check weather forecast on UAV Forecast
- Check restrictions on Naviair Droneluftrum
- Check drone, controller, tablet and camera firmware
- Charge drone batteries, tablet and controller

A.24.4 Guide lines for using equipment

- Make sure the operator is competent and ready to fly the drone in ATTI mode
- Make sure when operating the drone and equipment that the closest person to the drone is the operator (the only exception is under maintenance or when beacon is being attached)
- Follow the orders of the operator
- Wax should be applied for every 5th drilling
- The drone should not be operated in wind speeds above 10m/s
- Heat pads are available and should be applied if any part of the electronic compartment or drone is in danger of being too cold
- Floaters are not for water landings, they are only meant for emergency landings
- Make sure the S1 is turned all the way counter clockwise (seen from above of the controller), S3 is in the first position and S6 is in the middle position when the drone is not in operation, See Figure A.37

Figure A.37: Default position

- If at any point during drilling the warning LED from the Roll alarm lights up continuously, start emergency procedure
- Make sure to do the preflight check-list for the equipment

A.24.5 Before flight (Drone)

1. The flight area
    - Check weather forecast on UAV Forecast
    - Check restrictions on Naviair Droneluftrum
    - Hazard areas
    - Barring the area
    - Starting and landing area
2. The Drone
    - The drone is marked with Registration number, Name and Phone number
    - Propellers ok
    - Motors ok
    - Battery ok
    - Positions light ok
    - Warning light green
    - Max speed 50 km/h
3. Controller
    - Battery ok
    - Antenna parallel surfaces facing the drone
    - Tablet ok
    - Mode ok (A, P, S)
4. Software
    - IMU ok
    - Compass ok
    - GNSS ok
    - Return to home height
    - Max flight height
    - Max flight lenght from controller
    - Battery warning at 30
    - Drone battery balancing (max 0,2V variation)
5. Camera
    - SD card
6. Log
    - Starting time
7. Pilot
    - Health
    - Coldness
    - Tiredness
    - Alcohol

A.24.6 Pre-flight checklist for equipment

- Check the rope attached to the beacon for damage and make sure it is not too long (should be 2 m)
- Make sure the rope is coiled around the beacon
- Make sure the LiPo battery is charged and connected to the ESC
- Check the electronics compartment for moisture
- Follow this guide to check the systems

  1. Turn on the controller
  2. Turn on the drone
  3. Wait for the program to start running, can be seen by the blinking lights on the myRIO
  4. Toggle S4 to check beacon release, should click if working probably, see Figure A.38 for controls
  5. Toggle S1 by turning it CW and check the Roll alarm by tilting the drone, see Figure A.38 for controls
  6. Toggle S3 by moving it upwards to check the drill motor, see Figure A.38 for controls
  7. Toggle S6 by moving it downward to check the stepper motors, no more than a few seconds, make sure there is room under the drill,
  8. Toggle S6 upward and try boosting by toggling S5, continue until steppers are at the top and endstops are triggered
  9. If no failure occurred, system check is done

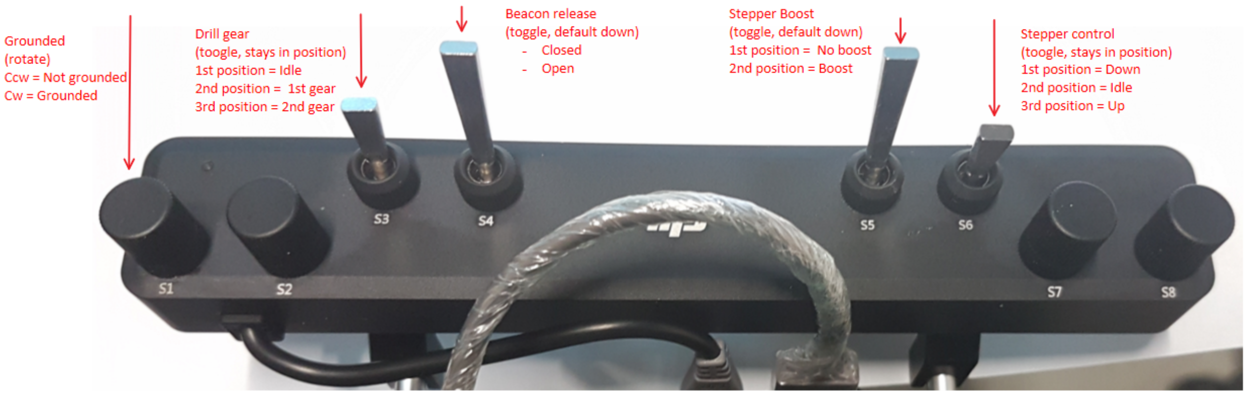


Figure A.38: Manual controls for equipment

- Place the end of the rope inside the beacon release mechanism, by moving S4 to the open position (controller and drone needs to be powered to do this)
- Get ready to fly

A.24.7 Guide for beacon release

1. Hover above the desired iceberg
2. Angle camera down to see the beacon and rope
3. Slowly descend until the beacon is on the iceberg and the rope is slack
4. Toggle S4 on the expansion kit to release the rope
5. Check with the camera that the rope has been released
    - If the rope is still attached abort mission, and return home at a slow and steady pace
    - If the rope has detached continue to step 6
6. Ascend to a safe height
    - If the mission also includes drilling, move to a desired location (preferably a flat surface without rocks) Land and continue in the guide for drilling
    - If mission is without drilling. Mission over and return home

A.24.8 Guide for drilling

1. After landing turn the knob marked S1 all the way clockwise, see Figure A.39
2. Start drill in first gear by placing the S3 lever in the middle position, see Figure A.39
3. Start drilling down by placing the S6 lever in the lower position, see Figure A.39

Figure A.39: 1st Drill configuration

4. Monitor the drilling process with the onboard camera
5. Once the centerdrill has entered the ice for about 1 cm and the drill has become steady, place the S3 lever in the top position to enter gear 2, see Figure A.40

Figure A.40: 2nd Drill configuration

6. Monitor the drilling process with the onboard camera
7. Once the steppers reaches the end or the ice core has broken off (should be visible in the live feed), stop the downwards process by placing the S6 lever in the middle position, see Figure A.41
8. Turn the drill down to gear 1, by placing S3 in the middle position, see Figure A.41
9. Start going up by placing the S6 lever in the top position, see Figure A.41

Figure A.41: 3rd Drill configuration

10. Monitor the process with the onboard camera
11. Once the drill is all the way out of the ice stop the upwards process by placing S6 in the middle position, see Figure A.42
12. Turn the drill off by placing S3 in the lower position, see Figure A.42
13. Turn off the the grounded knob by turning S1 all the way counter clockwise, see Figure A.42

Figure A.42: 4th Drill configuration

14. Takeoff
15. When returned home remove the sample with the included Extraction tool

A.24.9 Guide after mission (beacon release and drilling)

1. Check the electronic compartment for moisture and temperature
2. Check cutter heads for damage
3. Check landing gear for damage
4. Check batteries

A.24.10 After flight (Drone)

1. Inspect the drone
2. If the drone is to be stored make sure it is wiped for excess moisture, and let it dry completely before storing
3. Fill out the log
4. Discuss events and shortcomings in the planning
   - Update this document
5. Set batteries at storage voltage (3,7V)

A.24.11 Warning light emergency guide

1. Place S6 in top position for upward movement
2. Place S3 in middle position for drill gear 1
3. Toggle S5 for boosting the upwards movement
4. Wait for the drill to be out of the hole
5. Turn S1 counter clockwise
6. Take off and return to home

A.24.12 Water landing emergency guide

1. Visually follow the drone until it has landed in the water
2. Be quick to get there and rescue it
3. Dry it off
4. Check all systems