New Format for the Shower of the Future

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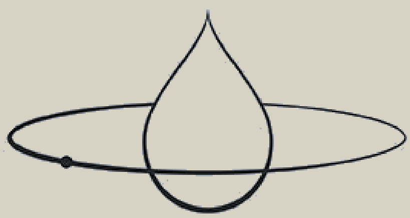
MASTER THESIS



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Abstract

Orbital Systems is a company which produce water recycling showers. Their current product is a shower cabin which is made for installation in residential or public buildings. In order to have their products installable in a wider range of environments, Orbital Systems are looking into the possibility of making a new product category where the shower system is a small module, separated from the shower compartment.

This thesis project was conducted to make a real functioning prototype of the product idea, as well as investigate and improve other aspects of the Orbital shower system. These other aspects include investigating the thermal behaviour of a shower cycle and developing a new solution for handling shower waste water.

The development of the different details was done by iterative design and testing. Also known as the design-by-prototype method. This approach was chosen to assure a functional end product.

The most significant parts of the project work were the development of the new unit for shower waste water handling, and the design of the chassis for the new product.

The final product is a functioning shower system with a new form factor compared to its predecessor. It has a set of new functions implemented, the most significant of which is the ability to empty the internal water reservoir of the shower system. Additionally, the new product is run on regular 230V/50Hz electricity, which is a significant step towards making the product easily installable in a wide variety of environments, as its predecessor runs on three phase electricity.

Keywords: Design-by-prototype, Product development

Sammanfattning

Orbital Systems är ett företag som tillverkar vattenåtervinnande duschar. Deras nuvarande duschsystem är en dusch som är gjord för att installeras i bostadshus eller allmänna byggnader. I ett steg för att göra duschsystemet installerbart i en större mängd miljöer undersöker de möjligheten att utveckla en ny produktkategori där duschsystemet ingår i en liten modul som kan vara separerad från duschutrymmet.

Detta examensarbete genomfördes för att skapa en fullt funktionsduglig prototyp för denna produktidén, samt för att undersöka och förbättra andra aspekter på Orbital Systems duschsystem. Dessa aspekter innefattar undersökningar av den termiska situationen i en duschcykel, samt utvecklingen av en ny lösning för att hantera använt duschvatten.

Utvecklingen av de olika detaljerna genomfördes genom iterativ konstruktion och testning. Även känt som Design-by-prototype-metoden. Detta tillvägagångssättet valdes för att säkerställa en funktionsduglig slutprodukt.

Projektets största delar var utvecklingen av den nya metoden för vattenhantering och konstruktionen av chassit för den nya produkten.

Den slutgiltiga produkten är ett fungerande duschsystem med en ny formfaktor jämfort med sin föregångare. Den har ett antal nya funktioner, där den viktigaste är möjligheten att tömma systemets interna vattenreservoar. Tilläggsvis går den nya produkten på 230/50Hz elektricitet, till skillnad från föregångaren som opererar på trefas. Detta är ett stort steg framåt för att göra produkten installerbar i en mängd olika tillämpningar.

Nyckelord: Design-by-prototype, Produktutveckling

Acknowledgments

This project was carried out at Orbital Systems in cooperation with the Division of Product Development, Department of Design Sciences, Faculty of Engineering, LTH, Lund University, as a master thesis within Mechanical Engineering with Industrial Design.

Gratitude is sent towards Mehrdad Mahdjoubi, for giving me the opportunity of working with an exciting project in a start-up company. My appreciation is also directed towards Richard Bodén, Development Engineer at Orbital Systems, who I worked alongside during the entire project, and to Michael Ridell and Mathias Beckius, whose input and work on the project were essential. Thanks also to Damien Motte, for his academic supervision.

Lund, June 2016

Sebastian Lundblad

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1 Introduction

1.1 Background

Orbital Systems is a shower producing company. They have Offices in Sweden, California, and Germany. Their main product is a shower system which uses filter and sensor technologies to recycle used shower water. The shower has a potential of reducing energy usage by 80% and water usage by 90% [1].

The key component of the Orbital Systems showers is their floor assembly. The floor assembly contains all the components required for the handling and filtration of used shower water. When using an Orbital Systems shower, a user stands on top of this floor, and the used shower water enters the water handling system through gravitational pull. Shown in figure 1 is the currently used shower floor with the outer dimensions and its key components specified.

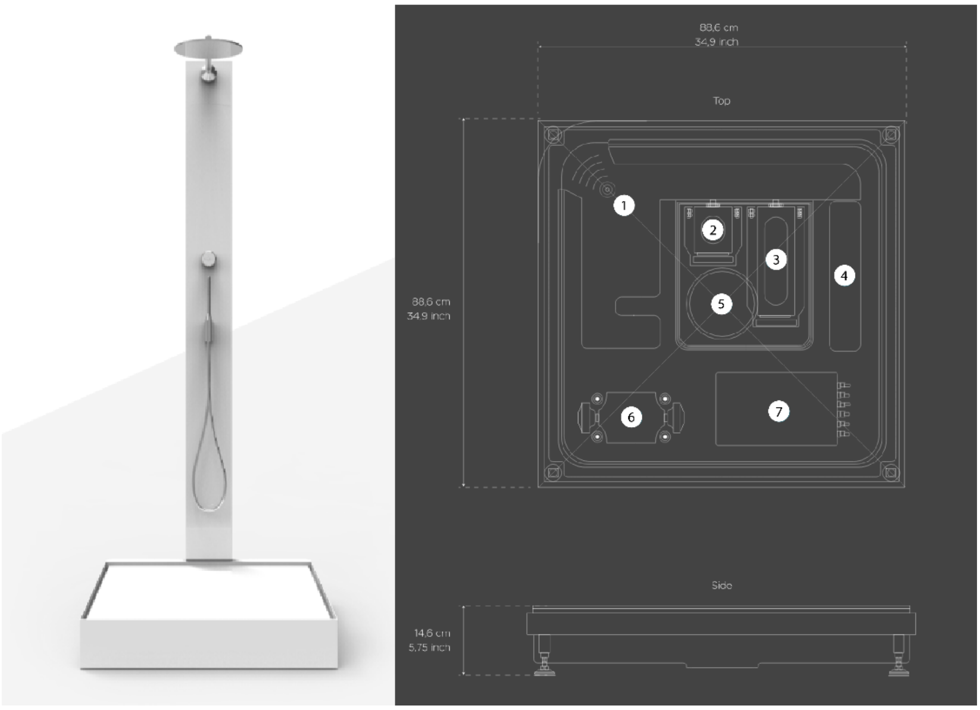


Figure 1: Current Orbital Systems shower and shower floor. Components: 1:Water quality sensor, 2: micro filter, 3: nano filter, 4: UV-filter and heater, 5: floor drain, 6: pump, 7 electronics box. [2]

The size and shape of this assembly limits the possibility of installing Orbital Systems showers to residential or public buildings under construction or renovation. Orbital Systems are looking to make their shower technology easier to install into a wider range of environments, e.g. marine vessels or non-renovated residential buildings, and are thus looking to emigrate the technical parts from the floor and into a space efficient module.

1.2 Project goal

The objective of this master thesis is to deliver a functional prototype of the Orbital Systems shower in a new configuration with an easy-to-install form factor.

This configuration will primarily be designed to fit into the engine bay of a sizable maritime vessel. The prototype will consist to as large extent as possible of existing in-house or off-the-shelf components.

1.3 System description

The prototype will consist of the necessary components for the handling, cleansing, and heating of water, but not of a shower compartment. It will essentially be a module containing the Orbital Systems core technology - the Tech Module. A principal schematic for how the prototype will work is shown in figure 2. The Tech Module will be made connectible to the shower compartments through hoses or pipes.

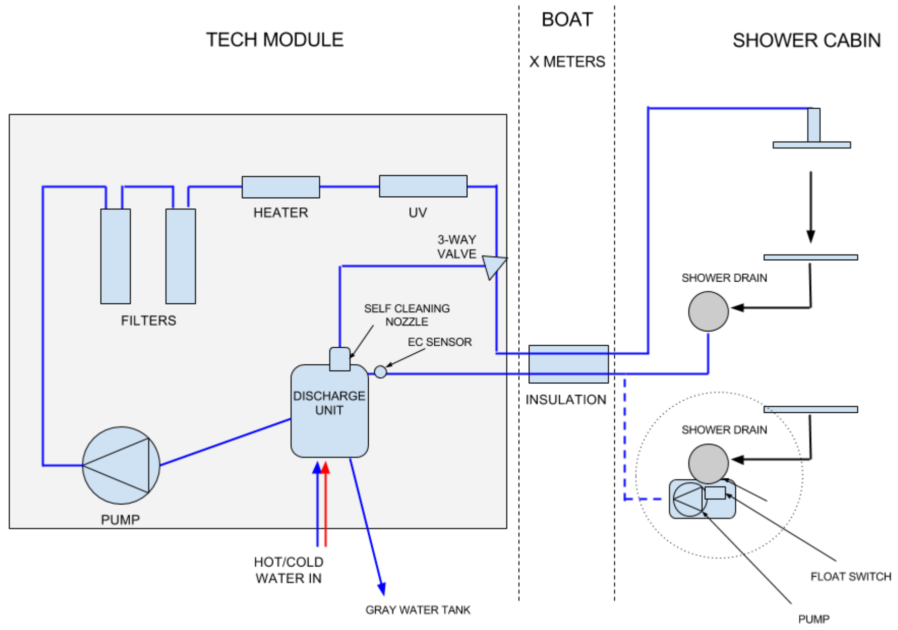


Figure 2: Schematic of new shower system.

A large difference between this shower system and the existing Orbital Systems shower will be the extended distance of pipes or hoses between the shower compartment and the water treatment. It will also need to incorporate a new design for the unit which handles the water flow - the Discharge Unit (DU).

1.4 Limitations

The product is intended to be finalized at the end of May 2016 and thereafter sent to a customer for use. This means all the components in the prototype must exist and be usable by then. The customer is aware that the product will be an early prototype, allowing for minor design flaws.

The project scope is limited to the development of the tech module. The necessary peripherals for delivering a complete shower experience, such as shower handles, plumbing, etc., are excluded from the development project.

Any new non-off-the-shelf components needed for the tech module will be produced in materials suited for mass production, but not necessarily by methods of mass production. For example, plastics may be used for certain parts, but will be 3D-printed rather than injection moulded.

The project will be executed by the student, Sebastian Lundblad, and the company supervisor, Richard Bodén, in the period February 1st – June 1st. They will work full time on the project, with approximately two weeks' worth of additional help from other company sections. These include programming, electronics, and assembly.

There is no set limit to what the project is allowed to cost, but larger expenses, such as new non-off-the-shelf components, must be approved by the company CEO or CTO.

2 Methodology

2.1 Defining demands

The demands on the new system will be collected in two ways:

1. By continuous discussions and interviews with company employees, and
2. By testing and finding physical limitations of the system.

2.2 Design

The design of the system and the new ingoing components will be performed using a version of the technique called design-by-prototype [3], which essentially is the practice of developing a product by trial and error. The work will contain many prototype iterations for fast verification of functionality, reducing the risk of childhood diseases. The technique is recommended to use in industrial design [4] but can also be applied in manufacturing and other industries [5, p. 31]. The method is believed to make the final product better equipped to be used in real applications, since many issues will be found and addressed during the product development.

2.3 Evaluation

The product will be continuously evaluated in three stages during the development cycle:

1. The first tests will be performed to evaluate how well the current system would fair in the new environment. These tests will serve to show where problems might arise for the product. The system will be installed on a testing rig for easy inspection and troubleshooting.
2. The second stage will be the new components mounted in the same testing rig. During this stage, many designs of the ingoing components may be produced and tested. This stage is completed when all components perform satisfactory.

3. The third and final stage is the system assembled as intended for use in a real life application. Tests will be conducted to ensure that components do not excessively interfere mechanically or thermally.

3 Known demands on new system

The known demands on the system were the features which the engineering team at Orbital Systems desired the new system to have. In this chapter, these demands are listed and explained.

3.1 Hygiene

Water flow through hoses and pipes was recommended to have a velocity exceeding 2m/s. In the food industry, this velocity is deemed to be sufficient to prevent biofilm growth in a closed tube system. [6]

Components which unavoidably would experience long time exposure of still standing water, i.e. filters and tank, were desired to be easily accessed for cleaning or replacement.

The overall designs of components was to be made so that there was little or no place in the system where the water flow could stagnate. This means crevices, narrow gaps, sharp corners, etc. needed to be avoided to the largest extent possible. [6]

3.2 Dimensions and shape

To make the prototype volume efficient and to have it installable in the marine application, a cuboid shape was deemed the most usable form. The shape would allow for installing several tech modules directly next to each other. The dimensions of the system could be defined by orientations and sizes of the largest components.

The bounding box dimensions of the tech module were expected to be circa 700x370x370. This size estimation was based on a preliminary generated assembly of the existing ingoing system components. These dimensions were deemed especially beneficial for the environment the tech module was supposed to be installed in, since the space in the boat engine bay is more limiting in floor area rather than height-wise.

The assembly generation was conducted in Autodesk inventor 2016, a program for Computer Aided Design (CAD).

3.3 Power requirements

The new shower system was desired to be able to run on 230V/50Hz common household electricity. This means the theoretically available power would be in the range of 1800-3600 Watts with fuse sizes of 8-16 amperes.

Of this available power, the pump and shower control system would together require at least 800W.

4 Investigation of current system.

As a first step in the project, the existing Orbital Systems shower was tested in an experimental environment. This was done to find eventual unprecedented issues the system could have in the new application. As described in this chapter, the issues would mainly be with the water flow and heat losses.

4.1 General testing rig

To be able to practically evaluate the existing system with easy overview of all the components, a testing rig was built. It was designed to be built around an EUR-pallet for mobility.

The testing rig was built to be used as a general rig for known and unknown purposes. It was built with 45x70mm wooden studs and 10mm thick Oriented Strand Board (OSB). The principal dimensions are shown in figure 3 and the actual construction in figure 4.

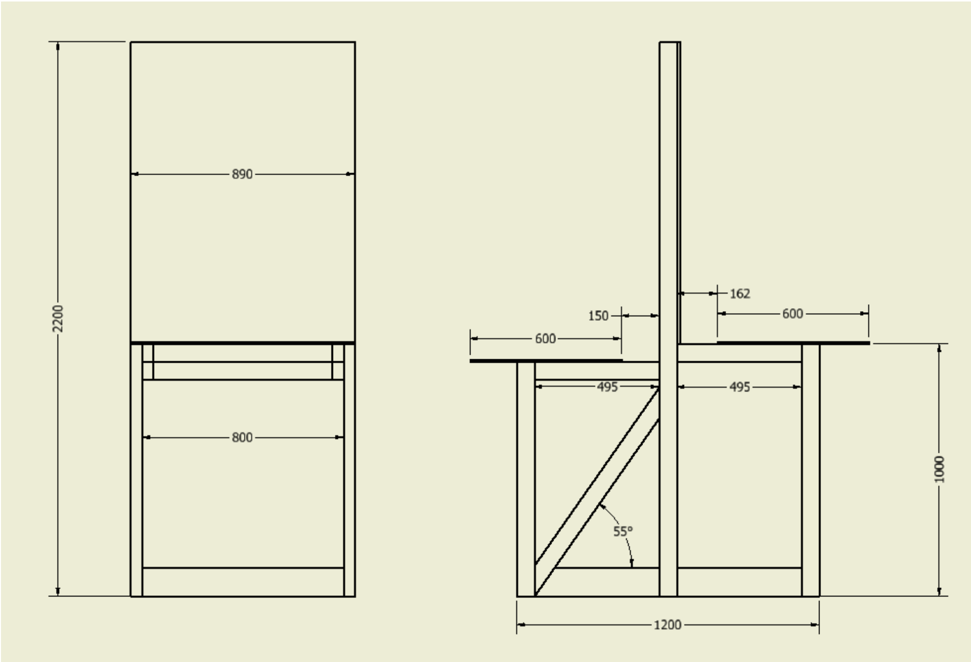


Figure 3: Dimensions of general testing rig.

Figure 4: Actual constructed testing rig.

A shower cabin mock-up was built to simulate a shower cabin. It was made to contain approximately the same volume of air as a boat shower cabin would. The dimensions were approx. 2000x700x700 mm. As shown in figure 5, the cabin rig was placed on a scissor lift to allow for testing of elevation differences.

Figure 5: Shower cabin mockup.

The cabin mock-up was placed upon an off-the-shelf shower room floor for easy drainage.

4.2 Flow rate

The initial subject of testing was the rate of water flow from shower drain to Tech Module. The goal was to find what components or specifications would be needed to achieve the same rate of water flow in the drain hose as in the shower head hose. If the drain water was to flow at a lower rate than the shower system water, there would be an overflow in the shower compartment. The two main factors affecting the flow rate were believed to be the elevation difference between shower drain and tech module, and the diameter of drain hose.

The flow rate in the shower system was at the time of testing 13 l/min.

The tests were conducted with two different hose diameters: 40mm and 1/2”. The ideal hose to use would be the 1/2”, as the water flow through this hose would reach a velocity of approx. 2m/s at a flow rate of 13l/min. This would be hygienically beneficial, as described in *3.1 Hygiene*. However, the diameter was believed to be too small to allow for sufficient flow through gravitational pull alone. The 40mm hose was believed to be sufficient in this regard.

The elevation of the shower room floor was changed in steps of 1dm per step.

4.2.1 **Result**

As shown in table 1 below, the return flow of the 40mm hose was sufficient for each elevation higher than 1dm, while the ½” hose did not allow for sufficient flow at any level difference.

Table 1: Results of elevation tests.

Elevation [dm]	40mm hose	½” hose
1	Shower overflow	Shower overflow
2	Sufficient flow	Shower overflow
3	Sufficient flow	Shower overflow
4	Sufficient flow	Shower overflow
5	Sufficient flow	Shower overflow
6	Sufficient flow	Shower overflow
7	Sufficient flow	Shower overflow

4.2.2 **Discussion and Conclusion**

The level difference proved to be of less significance to the water flow compared to the hose diameter. Additionally, a hose diameter of 40mm proved to be sufficiently large for allowing a 13l/min water flow by gravitational pull.

Since the water flow velocity of at least 2m/s was a demand, it was deemed necessary to introduce a pump to force the water flow from the shower drain. This would allow the use of a 1/2" hose. A pump would also make the water evacuation work regardless of the level difference between shower drain and tech module.

4.3 Thermal conditions

A major part of the energy consumption of the shower system is attributed to the heating of recirculated water. To minimize the heat losses with the purpose of reducing the overall energy consumption, it was necessary to identify where the shower system loses the most heat.

Since the new application would demand an extended distance of pipes between shower system and shower compartment, it was likely the shower would have to face an unprecedented heat loss.

4.3.1 **Calculations**

To calculate the temperature drop in a hose or pipe, a differential equation was derived from a formula for calculating the heat loss in a two-dimensional pipe/hose element. The formula is shown in equation 4.1.

$$q = \pi * \frac{T_F - T_a}{\left(\frac{\ln\left(\frac{D_S}{D_O}\right)}{2k}\right) + \left(\frac{1}{h_S * D_S}\right)} \qquad [4.1]$$

Where:

- T_F is the fluid temperature inside the hose or pipe in ^{o}C
- q is the heat loss in W/m
- Ta is the ambient temperature in ^{o}C.
- Ds is the outer diameter of the hose in m
- Do is the inner diameter of the hose in m
- k is the thermal conductivity of the pipe or hose material in W/m·K

- ***hs*** is the surface heat transfer coefficient of the hose/pipe material in $W/m^2 \cdot K$ [7]

To convert the heat loss to temperature drop in the two-dimensional segment, the factors of mass flow, $\dot{m}$, and specific heat, ***Cp***, were factored in. By considering the two-dimensional segment to be a small section ***dl*** of a real hose or pipe, and the temperature drop over this section to be ***–dT***, the differential equation to solve was as shown in equation 4.2.

$$dl \cdot q = -dT \cdot \dot{m} \cdot C_p \qquad [4.2]$$

The potential temperature drops in the pipes or hoses were calculated using the calculation program PTC Mathcad express. The formula for calculating the heat loss of water flowing through a pipe with a given length is shown in equation 4.3. It is the solution to equation 4.2 above.

$$T = Constant * e^{\left(-l*\left(\frac{1}{\dot{m}}\right)*\left(\frac{1}{C_p}\right)*\frac{\pi}{\frac{\ln\frac{D_S}{D_O}}{2*k}+\frac{1}{D_S*h_S}}\right)} + T_{ambient} \qquad [4.3]$$

Where:

- ***T*** is the water temperature in the end of the hose in ^{o}C
- ***l*** is the length of hose in m
- $\dot{m}$ is the massflow of water in kg/s
- ***Cp*** is the specific heat of water in $J/kg \cdot K$
- ***Tambient*** is the temperature of the ambient air in ^{o}C
- ***Constant*** is the temperature difference, in ^{o}C, between the ambient air and the incoming water.

Solving for different lengths of pipe, at given water and ambient temperatures, the results showed that the thermal losses in the pipes would be in the order of 10^{-3} ^{o}C. Which was deemed negligible.

4.3.2 Shower system tests

During these tests, the shower system was built to correspond to the existing Orbital Systems shower. In practice, this meant the shower ran on three phase electricity.

Temperature sensors were placed directly after the water heater, directly before the shower nozzle, in the shower drain, and in the water tank. With this setup, the temperature losses over the hoses and the water tank could be measured.

4.3.2.1 Thermal testing 1

The first test was performed as a warmup session, where incoming cold water (22 C^o) was warmed up by the heater set on maximum power. The system was set to recycle all water to increase the temperature over time. The shower compartment was the shower cabin shown in figure 5. In this test it was fully enclosed.

The outcome of the test is shown in table 2. The temperature drop over the hoses was, as predicted, negligible. Instead, the largest temperature difference was between the shower nozzle and the shower drain. This is reasonable, as the shower cabin is the place where the warm water has the largest contact surface against colder ambient air.

Table 2: Results of thermal testing.

	Temperature [Deg C]										
Sensor	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min	11 min
Post heater	32	34	35	36	37	38	39	40	41	41	42
Shower nozzle	32	34	35	36	37	38	40	40	41	42	42
Cabin temperature	28	28	30	30	31	32	33	34	34	35	35
Shower drain	32	32	33	34	35	36	36	37	38	39	38
Water tank	32	32	31	32	32	34	34	35	36	37	38

The heat loss of the entire system could be interpreted as the difference between the temperatures post heater and in water tank. This means, by reading table 2 above, that the water temperature dropped as much as 4 degrees C in the entire system.

Temperature readings on all sensors were made at the same moments in time. This might affect the results somewhat since the system was not in a steady state. It is also likely the temperatures would have been more accurately reported with a higher sampling rate. With a time interval of one minute between readings, a small volume of unusually warm or cold water could pass through the sensors at the moment of reading.

4.3.2.2 Thermal testing 2

Since the heat loss was consistently the largest in the shower cabin, it was deemed necessary to see how large it could reasonably become.

A series of tests was performed to investigate the heat loss of the shower cabin in different configurations.

The configurations were:

- Without shower curtain,
- With fully enclosing shower curtain,
- With shower curtain and 3dm gap, and
- With a fully enclosing wooden door.

The temperatures were measured in shower nozzle and shower drain. The readings were made when the shower nozzle temperature reached a specified value. The water flow rate was 15 l/min for all tests.

The temperature drop for the different cases is denoted as *deltaT* in figure 6 below.

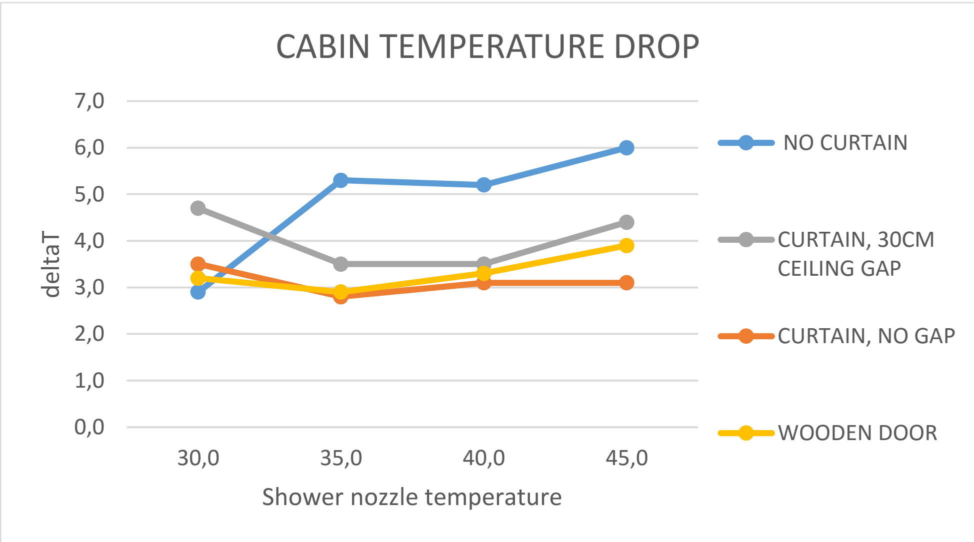


Figure 6: Measured temperature drop in cabin mockup.

These results indicate a potential temperature loss of up to six degrees C during a warm shower session.

4.3.3 **Discussion and conclusions on thermal conditions.**

As seen by the results in this chapter, the water could lose up to 6 degrees C worth of heat when passing through the shower cabin. To compensate for this, the system heater needs to have an energy output equivalent to the lost heat.

The lost heat is dependent on both the temperature drop in the system as well as the mass flow of water.

Shown in figure 7 is the calculated heat loss per second for water at different flow rates and temperature drops. The calculations were made with an assumed water density of 1 kg/l and specific heat of 4,18kJ/kg·K.

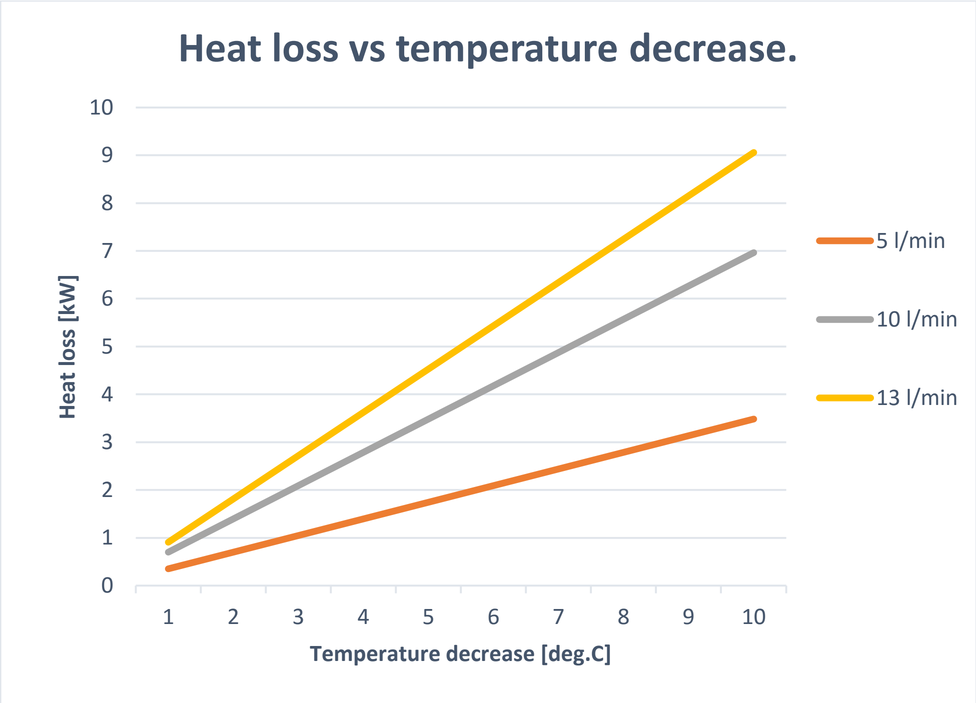


Figure 7: Calculated heat loss by temperature decrease at different flow rates.

According to figure 7 above, a temperature decrease of 3 degrees C at 10 l/min would require the system heater to deliver ~2000W of heat. This energy demand would be precisely within the frame of what could be supplied from 230V/50Hz electricity, as described in *3.3 Power requirements.*

It is important to note that the temperature drop for free flowing water in any situation is dependent on a large number of factors: Ambient air temperature, water temperature, contact surface between water and air, flow velocity, air humidity etc. Due to this environmental dependency of water, the test results may only be valid for the shower cabin mockup used in the tests. The test results should thus only serve as indication on how large the temperature drop potentially could be, and further tests should be performed to confirm or amend the results.

However, it was clear that the water mass flow was needed to be reduced to less than 10l/min for the shower system to be able to continuously deliver comfortably warm water on recycling mode. This volume flow would require the hose diameters to be reduced to 10mm to maintain the 2m/s flow velocity.

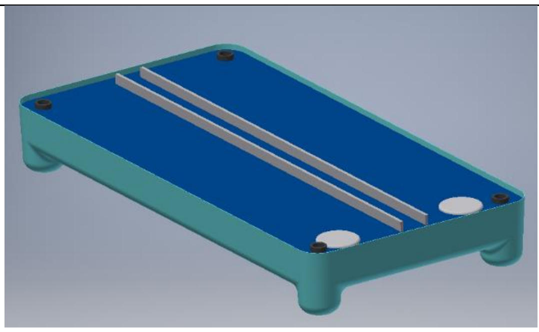
5 Carry-over components

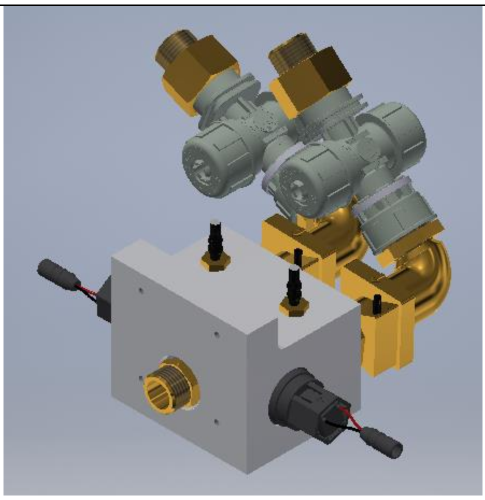
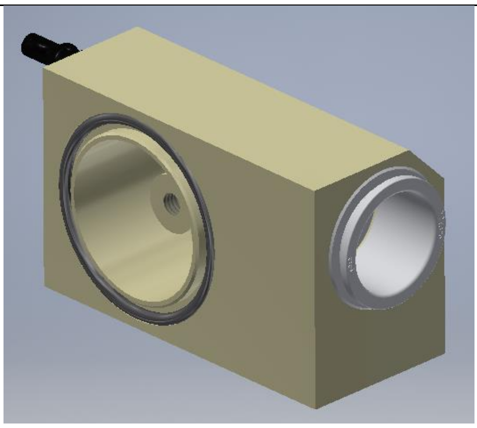
Since the new prototype was to consist of as many pre-existing components as possible, it was necessary to list which "old", or carry-over, components would be used. In this chapter, the necessary components and their roles in the shower system are listed.

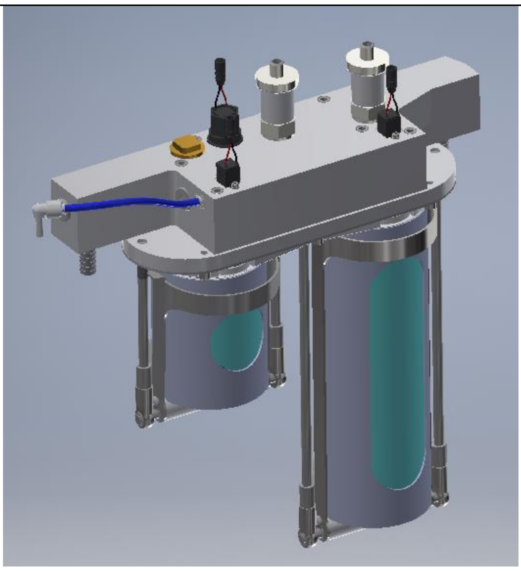
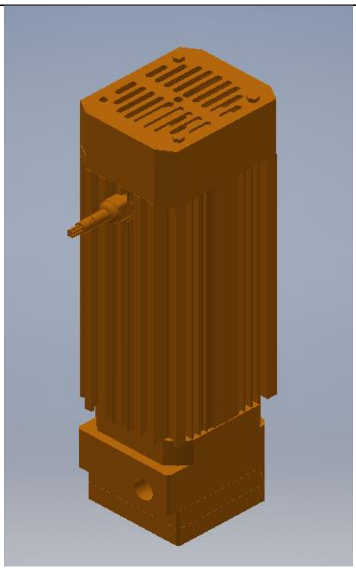
5.1 List of carry-over components

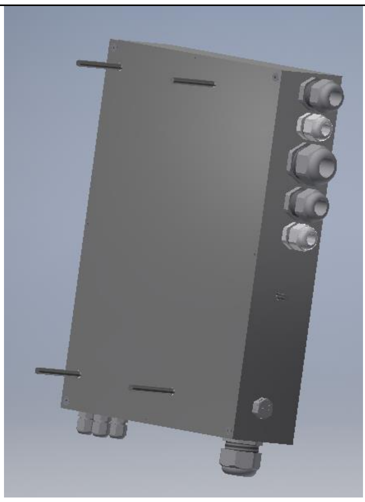
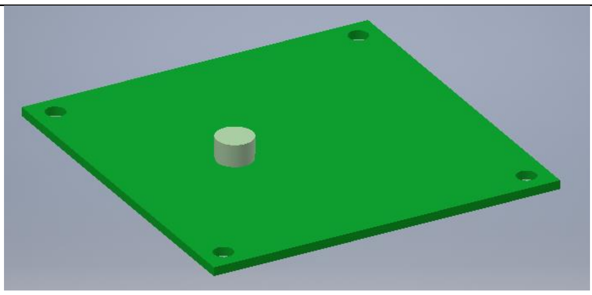
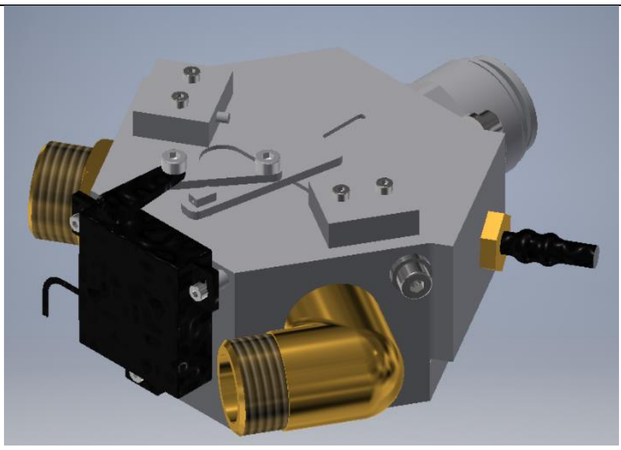
The carry-over components were the components used in the contemporarily sold or developed Orbital shower system. Listed in table 3 below are the sub-assemblies or key components which would be implemented in the Tech Module for this project. The list contains the assigned serial number from the company CAD-library, the commonly used name, a brief description of the function, and a CAD-image of each article.

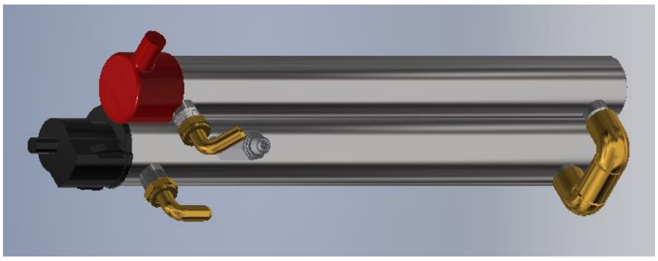
Table 3: List of carry-over components.

Part number	Name	Description	Image
1200038	Shower control system	Manages input and output signals for entire shower system. Approx. 140x20x300 mm	

1100171	Feed block	Provides shower system with fresh water. Approx. 120x110x160mm.	
1100210	Sink block	Connects water reservoir with pump, holds a temperature sensor. Approx 80x30x50mm.	

1100171, 1100198, 1100204, 1100054, 1100055	Filter condition block + filter cradles + filter capsules	Condition block measures the status of filters. Filter cradles hold filters in place. Filter capsules contain filters. Filters cleanse water of small particles. Approx. 380x150x400mm.	
10-0018	Pump	Delivers water from reservoir to shower head. Runs on 750W and generates a mass flow of 15l/min through the shower system. Approx. 110x90x400mm.	

1100457	Power switch box	Provides entire shower system with electricity. Approx. 280x80x320mm.	
1200001	Water quality control unit	Measures the quality of used shower water. Approx. 70x70x15mm.	
1300205	Three way valve	Directs water to shower head or to self-cleaning cycle. Approx. 80x80x50mm.	

1100157	UV filter & Heater	UV-filter neutralizes UV-sensitive microorganisms. Heater increases water temperature. Heater has a 6,6kW capacity. Approx. 700x170x80mm.	

6 New components

Due to different reasons, some new components had to be added to the system and some old components had to be replaced in order for it to work in its new environment. The components and their functions are explained in the following sub chapters. A major portion of this chapter addresses the development of the discharge unit.

6.1 Return pump

As described in *4.2 Flow rate*, it was deemed necessary to have a pump to deliver water from shower drain to tech module.

The pump was decided to be a part of the tech module in order to have all possible system components gathered in one place. The alternative would be in the shower room floor or somewhere between tech module and shower. Since the pump would not necessarily be placed at a lower elevation than the shower drain, it would need to have suction capacity to be guaranteed to draw water from the shower room drain.

The choice of pump was a diaphragm pump known as Gulley IC of the brand Whale Marine®.

A diaphragm pump is a pump which works on the principle of displacing the fluid using a reciprocating membrane of a flexible material inside a chamber. The membrane movement changes the volume of the chamber, which causes either a partial vacuum or an overpressure inside the chamber, depending on where in its movement cycle the diaphragm is. The pressure situation causes the fluid to either move towards or from the pump chamber. There is usually one inlet and one outlet to a diaphragm pump. The fluid can leave the pump chamber through both inlet and outlet, but only enter it through the inlet. This is achieved by the use of check valves. [8]

The Gulley IC was chosen mainly because it is delivered off-shelf with a ready-to-use water sensor. The sensor acts to start the pump whenever it detects water. Additionally, the Gulley IC pump is designed specifically for pumping shower water. [9]

This meant the pump could be used in the tech module without additional programming for the shower control system. It also meant the pump could run without the need for an activated shower system, as long as it had a power supply. This feature was considered especially advantageous since it would allow the shower to evacuate other fluids a user could pour down a shower drain while not using the shower, e.g. scrub water.

Testing of the return pump was performed continuously during the entire project, as it was used during all prototype testing of the discharge unit. Pictured in figure 8 below is the pump installed in the testing rig.

Figure 8: Rig installed Whale Gulley IC diaphragm pump.

The way the diaphragm pump works caused it to send pulses of water rather than an even stream. The pump worked at a rate of two pulses per second.

6.2 Discharge unit

A major design that had to be changed from the current Orbital Systems shower was the design of the Discharge Unit (DU).

The DU is the part of the shower system which assesses the quality of the used shower water, recycles or wastes it, and provides the shower with fresh water if necessary.

6.2.1 **Description of current Discharge Unit design**

In the current Orbital Systems shower, the DU is placed directly under the shower floor, and used water flows to it by gravitational fall. Due to its design, the current DU must stand horizontally to function properly. Depicted in figure 9 is a sawn out DU from the existing shower room floor with the different related components annotated.

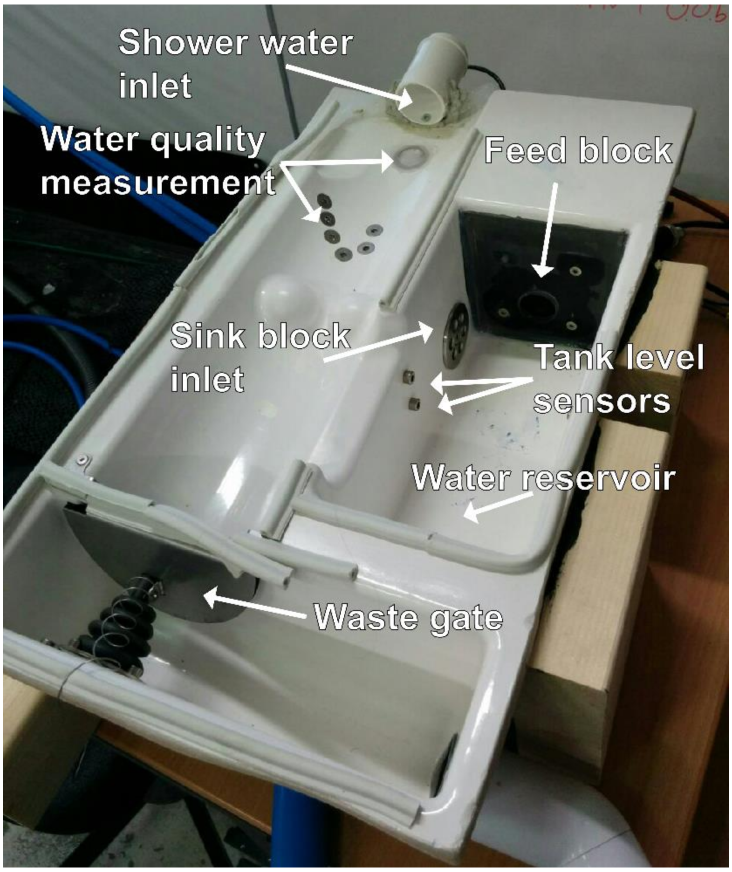


Figure 9: Description of current Orbital Systems Discharge Unit.

When the shower system enters recirculation mode, the waste gate closes and causes the water in the primary tank to overflow into the second tank, which is the reservoir for usable water. When the shower is in dumping mode, the waste gate is opened and the dirty water exits the loop.

The "open air" design of this DU practically limits its use to stationary environments, which renders it useless for the new prototype.

6.2.2 **New Discharge Unit design**

6.2.2.1 Demands

Due to the intended application for the prototype, the DU was needed to have an enclosing design in order for it not to spill out water during operation. The ideal would be for it to be a fully closed container.

An important new feature of the discharge unit which was desired to be implemented was the ability to empty the tank after a finished shower session. If this could be done, there would be less still water in the system when not in use. Less still standing water would make the system less susceptible to biofilm growth. Additionally, this function would prevent one user from showering in some of a previous users' used water.

The Discharge Unit, or at least the water reservoir part of it, was desired to be easily removable from its mounting place for easy cleaning.

The new discharge unit had to be made small enough to fit inside the system assembly. There was a designated space in the assembly for the DU to utilize in its design.

6.2.2.2 New Discharge Unit concept

With the demands in mind, a concept for Discharge Unit was generated through discussions and conceptual inputs from employees and consultants at Orbital Systems.

The idea of the Discharge Unit was to have a pipe go vertically through the water tank. The used shower water would travel through the pipe top to bottom. The pipe would be shaped to let water through a horizontal opening in its bottom. Additionally, it would be vertically movable to alternate between having the opening on the inside and on the outside of the tank, making it fill the same function as the waste gate. Shown in figures 10 and 11 is a 3D CAD model made to demonstrate the principle of this waste gate pipe and how it would be placed in relation to the water reservoir. The pipe is the red part and the water reservoir is the transparent part.

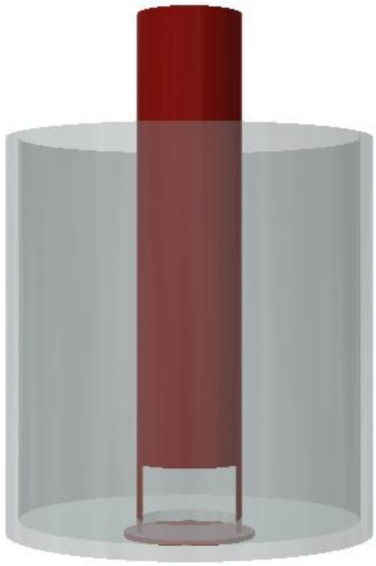


Figure 10: Closed waste gate pipe.

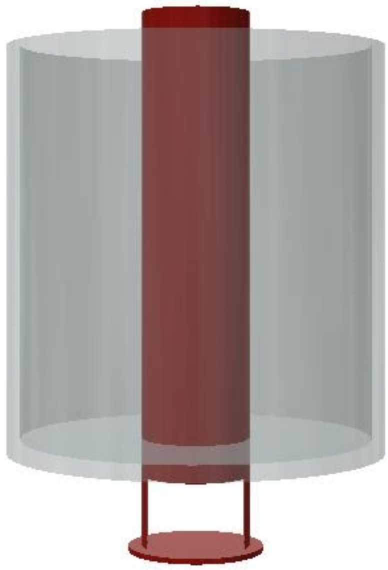


Figure 11: Opened waste gate pipe.

In the first image, the incoming shower water would be reintroduced into the water reservoir, which would be the recycle mode. In the second image, the shower water would flow through the pipe and not be introduced to the reservoir, this would be the waste mode.

The pipe could, additionally to direct the flow of shower water, also enable an emptying function to the tank. By placing the bottom in a position between waste and recycle, the water inside the tank could be evacuated through the opening.

6.2.2.3 Concept development

6.2.2.3.1 Iteration 1

In a first step of prototype iterations, a mock-up of acrylic sheets and 3D-printed PLA was made to investigate how well a pipe bottom could seal against the surface of a tank. If it could not, the concept would need to go back to the drawing board. The first prototype is shown in figure 12. The pipe was made to have a sealing surface against both the in-and outside of the tank floor. The 3D-printed pipe was covered in epoxy with micro glass balloons for added strength.

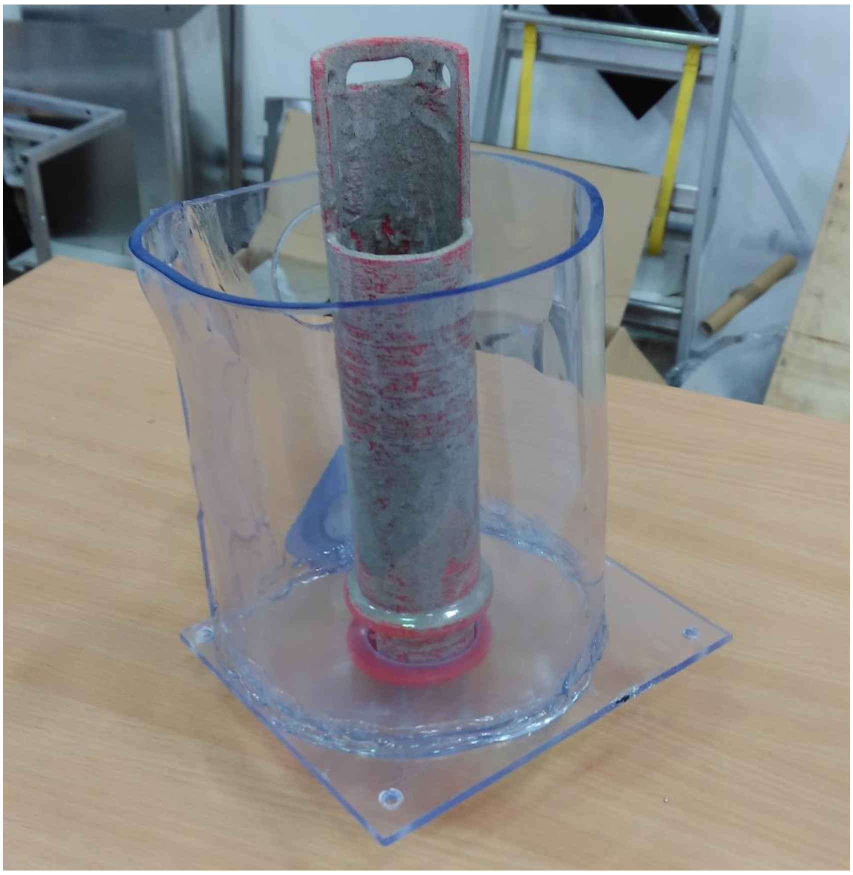


Figure 12: First prototype iteration of new Discharge Unit.

It was found that the pipe could sufficiently seal the bottom of the tank with the use of O-rings. In addition to this tentative proof of concept, the mock-up gave an indication to how the water would behave inside a tank with roughly the shape and size of what was available in the full system assembly.

6.2.2.3.2 Iteration 2

The next prototype step was a more refined model. This model was used to assess the ability of having the DU removable for cleaning and figure out how to make the waste gate pipe vertically movable.

The tank had to be connected to both sink block and feed block. Since it was desired to be dismountable, the tank was designed to have two holes on the rear side: one for feed block and one for sink block. It would seal against the holes through the use of O-rings or gaskets when mounted.

The idea for the waste gate pipe actuation was to have a horizontal axle with ex-centrically mounted wheels rotated by a stepper motor. When the axle rotated, the ex-centre wheels would lift the pipe through a ledge on the pipe. In this prototype iteration, the mechanism for the actuation was mostly 3D-printed on the in-house 3D printer. The unmounted prototype iteration is shown in figure 13.

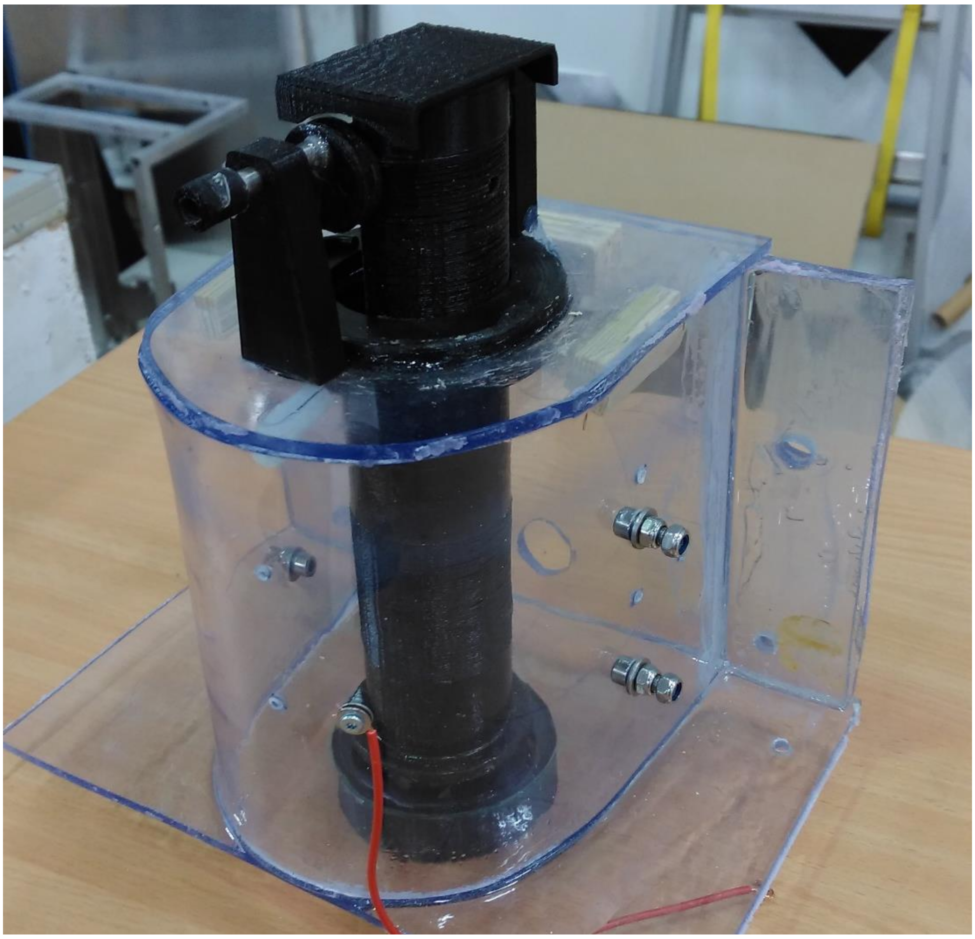


Figure 13: Unmounted iteration 2 Discharge Unit prototype.

The testing rig for the principal of the mounting was designed to demand non-invasive action on the feed and sink blocks. The blocks were essentially squeezed stuck between two wooden studs by a screw clamp to stay in position.

In this prototype iteration, the stepper motor was controlled using an Arduino and a stepped turning knob. The Arduino was programmed to make the stepping motor move by a specific increment for each step on the knob.

Shown in figure 14 is the assembled prototype with the actuation mechanism. The red, white, black, and blue wires running across the surface of the DU were the electrodes for measuring the tank level.

The ex-centre wheel actuation was deemed to function well. The waste gate pipe bottom could sufficiently seal off the bottom and kept the water where it was supposed to be. Additionally, the stepper motor proved strong enough to hold up the pipe against the pump-generated pulses of water.

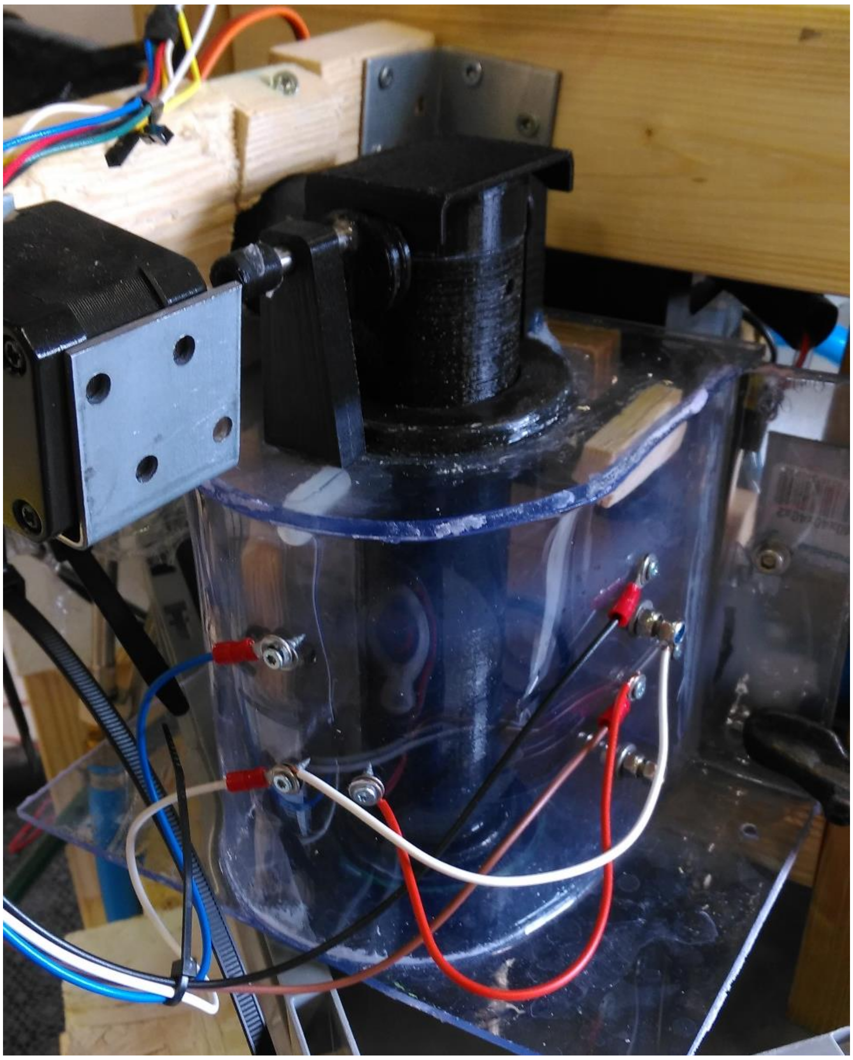


Figure 14: Rig mounted iteration 2 Discharge unit prototype.

The connection between blocks and tank was unsatisfactory, since it proved hard to make it seal sufficiently tight. This, however, was considered to be due to the general quality of the testing rig. The problem would be non-existent with the DU mounted on its metal frame.

6.2.2.3.3 Iteration 3

During the development of the Discharge Unit, a previously unconsidered demand on the relative placement between the feed block and DU was revealed: If the final prototype was, at some point in the future, to be officially approved for use in the USA, it would need to comply with the IAPMO plumbing code. The code demanded, among other things, the vertical distance between the flood level of the tank and the fresh water inlet to be no less than six inches, or 152,4mm. [10].

To comply with this, the tank faced a redesign where the feed block would be relocated to feed the water tank from above instead of from the rear. The water would go through a standard plumbing pipe from feed block to tank. The pipe would not need to seal tightly against the tank lid, since the tank needed to be floodable for the sake of code compliance.

This made the mounting of the DU less complicated since it only needed to seal against the sink block.

The third prototype iteration was intended to be used to further refine the concept of the mounting of the tank and the functionality of the waste gate actuation. This prototype was produced by gluing together in-house-3D-printed parts. The intention was to make it correspond to the CAD-design of the part. The prototype is shown in figure 15. It was decided that the tank would be fastened to the frame through four hand-rotatable screws. For this, the tank received four ears - two on each side. The screw holes in the ears were U-shaped to enable the tank to be easier withdrawn from its mounting place.

Figure 15: Iteration 3 discharge Unit prototype.

Due to poor printing resolution and time shortage, the prototype was not fully tested. The rear surface was too rough to sufficiently seal against the sink block and there was little time to refine this prototype instead of going to the next step.

6.2.2.3.4 Iteration 4

The volume of the tank was considered larger than needed. It was accordingly reduced by making the top view section of the tank smaller for the fourth prototype iteration.

The prototype was 3D-printed through Selective Laser Sintering (SLS) at GT-Prototyper in Ystad. The material used was polyamide. Shown in figures 16 and 17 is the unmounted Discharge Unit in front and rear view. The holes on the rear side were mounting points for the level sensing electrodes. The inner rim around the rear opening of the tank was made to steer the tank to correctly connect to the sink block. The outer rim was intended to hold a circular gasket in place if necessary.

Figure 16: Iteration 4 Discharge Unit prototype in front view.

Figure 17: Iteration 4 Discharge Unit Prototype in rear view.

The waste gate pipe was designed to allow for easy disassembly of the Discharge Unit. The top ledge which would be in contact with the ex-centre wheels was a large external circlip. The bottom surface of the pipe was a dismountable piece, which was held in place on the pipe using an internal circlip. The appearance and ingoing parts of the waste gate pipe is shown in figure 18. In this iteration, there were considerations to make the pipe producible by other means than by 3D-printing, primarily by machining or injection moulding.

Figure 18: Waste gate pipe assembly.

During testing, the waste gate pipe broke at one point in the top ring where the circlip was attached. The cause was a failure to place the circlip in its intended grooving before releasing the circlip pliers. The damage was repaired using Loctite® 401, or ethyl cyanoacrylate, and it held together for the duration.

The testing rig for this design iteration was made to simulate the compliance with the air gap rule. This was made by mounting the feed block in a provisional fashion as depicted in figure 19.

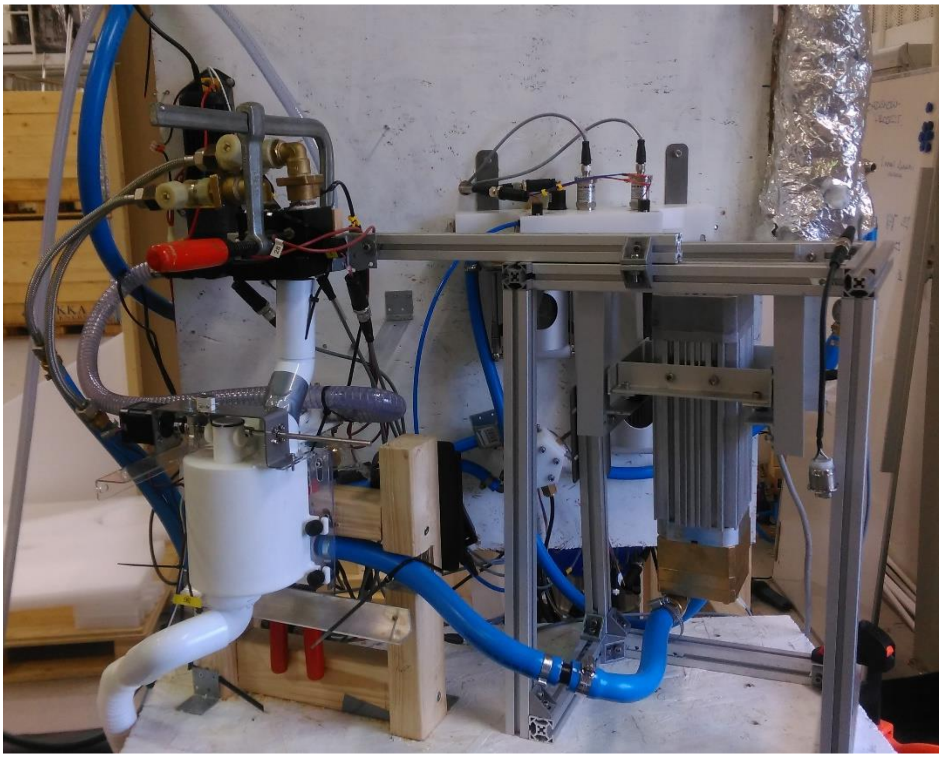


Figure 19: Iteration 4 Discharge Unit prototype testing.

In the testing for this iteration, a rigid mechanism with ball bearings and shaft couplings was implemented for the waste gate actuation. This mechanism was mounted in a designated metal plate frame made from 2mm stainless steel. The frame is shown partially done in figure 20. Apart from the mechanism of stepper motor-axle-ex-centre wheel, two limit switches were implemented. These switches were installed to signal to the system when the waste gate pipe reached an end position. The top position switch was placed to be triggered by the top of the waste gate pipe when it reached its top position. The bottom position switch was placed to be triggered by an ex-centre wheel when the waste gate pipe was in its bottom position.

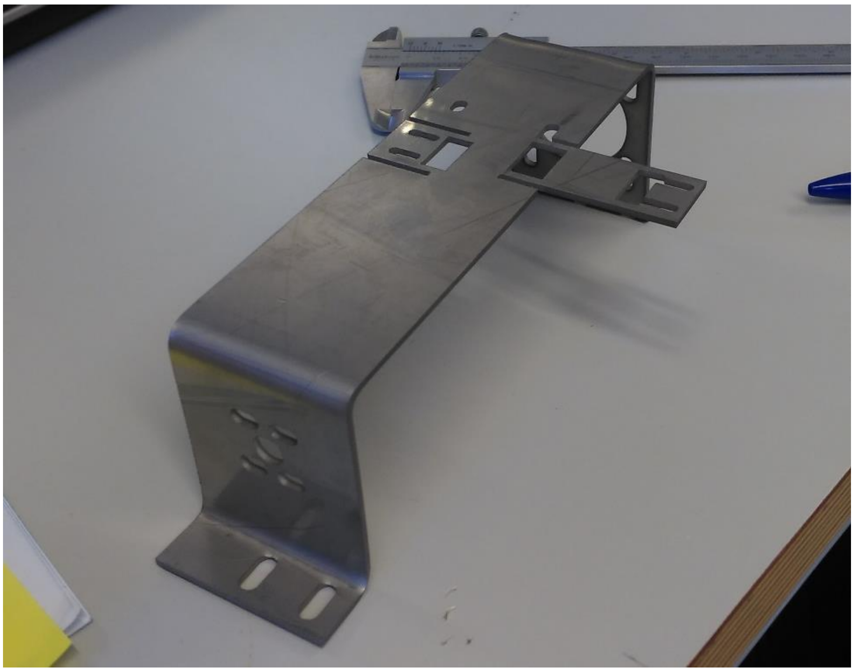


Figure 20: Mounting frame for components for waste gate pipe actuation.

In this iteration, the programming for the Discharge Unit actuation was implemented in the shower systems' control unit. This means the discharge unit, for the first time, could act on the water quality readings by itself. The autonomy marked the end of this prototype iteration.

The mounting of the Discharge Unit proved to still be of poor quality. The tank surface would simply not seal sufficiently against the sink block. Visual inspection of the tank rear showed that the placement of the mounting "ears" caused the tank to tilt when the screws where tightened.

6.2.2.3.5 Iteration 5

To handle the issue of the insufficient sealing, the mounting ears were rearranged in a rectangular pattern symmetrically about the sink block hole. At this stage, the designs for the mounting plates were already set and sent for manufacturing. Consequently, the ears had to be placed where there were available attachment points in the mounting plate.

The prototype for this iteration was 3D-printed in acrylic in order to enable visual inspection during operation. Being able to see inside the tank during operation was needed to enable the troubleshooting of possible water flow based issues. The 3D-printed product was not transparent, but rather translucent.

Shown in figure 21 is the Discharge Unit mounted in the supporting frame for the tech module during testing.

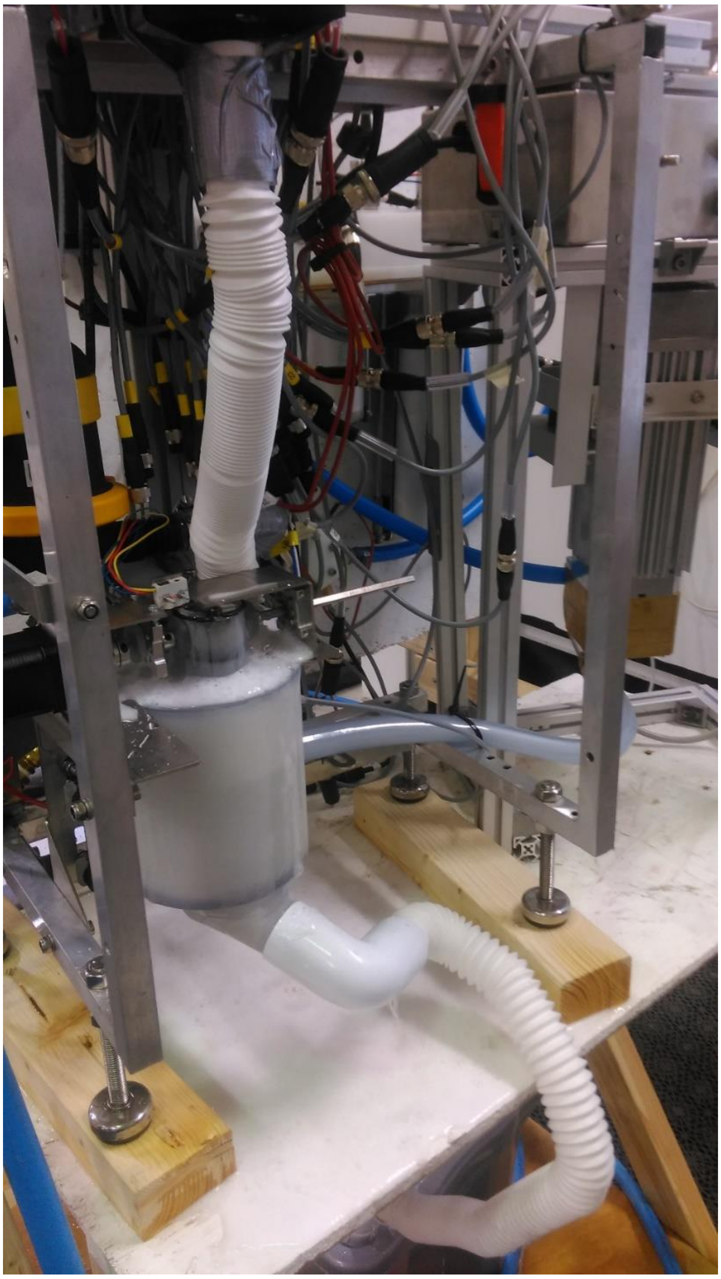


Figure 21: Iteration 5 Discharge Unit prototype during testing.

Since the concept for the waste gate pipe actuation proved to be reliable, it was kept from the previous iteration. Some small changes were made to the placement and sizes of the mounting holes and plate width to allow for easy assembly and adjustment in the frame. The mechanism in a partially assembled state is shown in figure 22. The ex-centre wheels were 3D-printed on an in-house 3D printer.

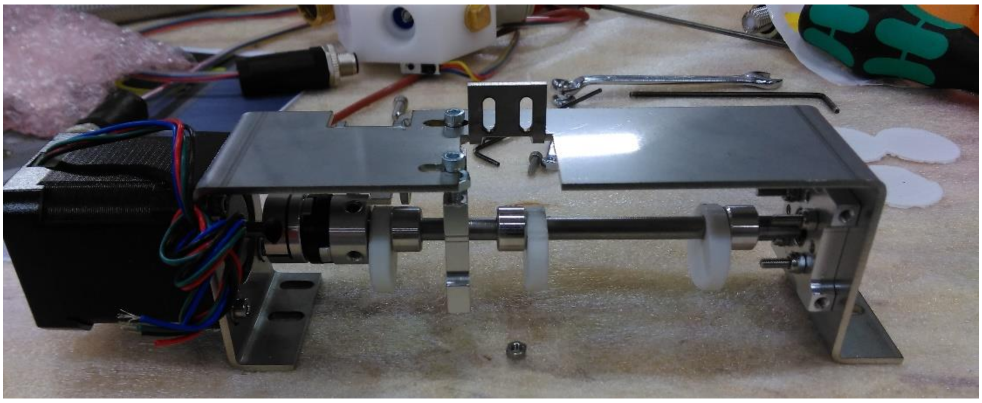


Figure 22: Partially assembled waste gate pipe actuation mechanism.

With this iteration, the Discharge Unit design was deemed to function well enough to be used in the tech module.

6.2.3 Water quality measurement unit housing

The design of the water quality measurement unit was made to make the already existing solution work in the new environment. The idea was to make a housing for the measuring parts annotated in figure 9 in chapter 6.2.1 above. Water would flow inside the housing and make contact with the measuring components. The housing would then lead the water directly into the waste gate pipe. Shown in figure 23 below is a demonstration of what the connection between tank and housing would look like. The green part under the housing in the figure is the actual water quality measurement unit. Due to its design, it was required to be placed there.

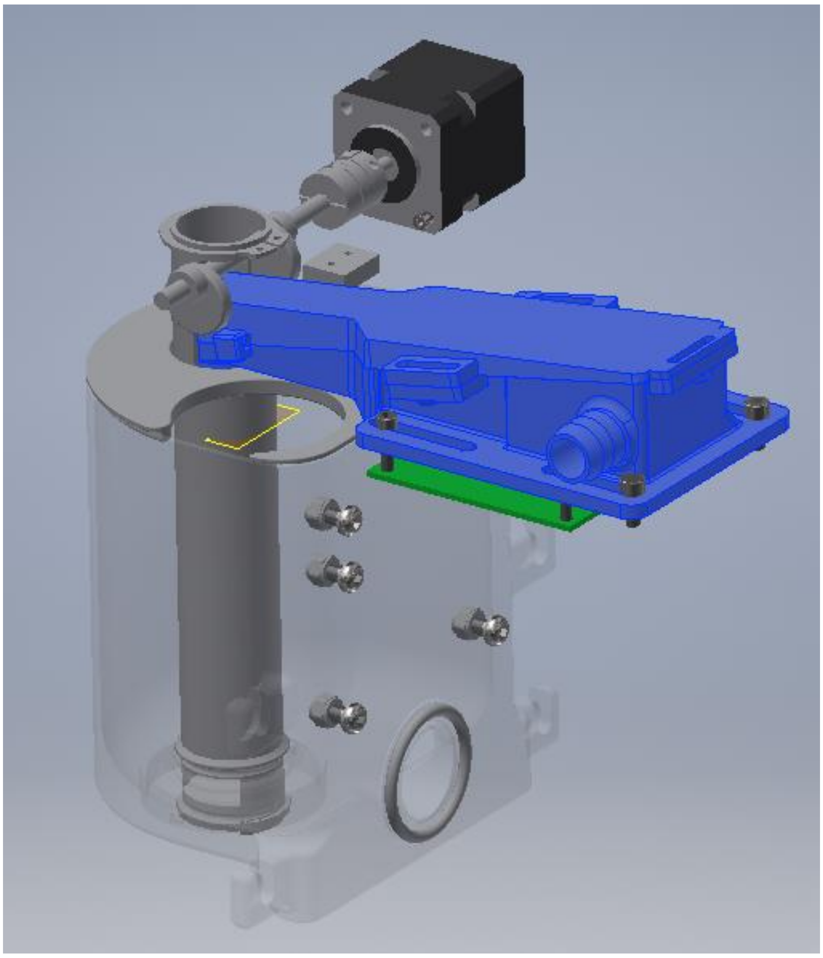


Figure 23: Principle of connection between water quality measurement unit housing and waste gate pipe.

The housing was designed and 3D-printed in two iterations: The first housing iteration was produced in the same batch as the Discharge Unit iteration 4 and the second housing iteration was made in the same batch as the Discharge Unit iteration 5.

6.2.3.1 Iteration 1

The housing was designed to accommodate the necessary inlets and outlets in a space defined by the empty room left inside the tech module. The design came to look as shown in figure 24. The housing was designed to be disassembled in two pieces, to allow for manual cleaning of the sensors. Accordingly, it was made to be assembled using screw joints. The screw joints were to be placed in the slots made on the flanges shown in the figure below. The shower water would enter the housing through the hose spud shaped part shown on the right in figure 24, and exit through the downward facing tube on the left.

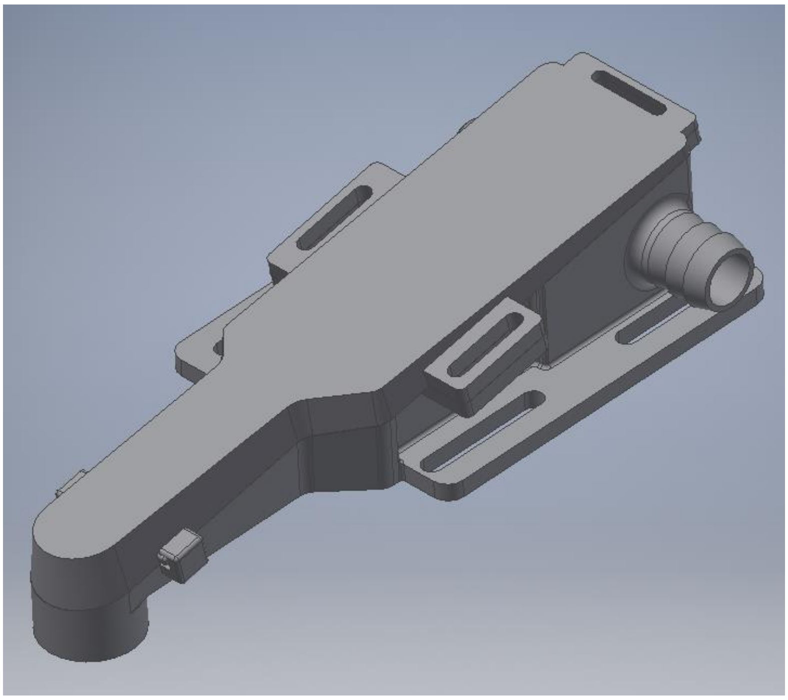


Figure 24: Iteration 1 housing for water quality measurement unit.

To make the housing seal tight, a 1mm thick rubber gasket was clamped between the two pieces.

During testing, the design proved to be flawed. The pressure inside the chamber made the contained water push out the gasket and squirt through the split line of the housing. This happened along the whole split line except for places in the vicinity of a screw joint.

The assessment was that the lid needed to be made stiffer and there needed to be more screw joints placed evenly around the perimeter of the housing.

6.2.3.2 Iteration 2

The housing was accordingly redesigned to be stiffer and utilize more screw joints than the previous iteration. The stiffness was increased by increasing the wall thickness and adding stiffening ribs on the top surface of the lid. The appearance of the new housing was as shown in figure 25.

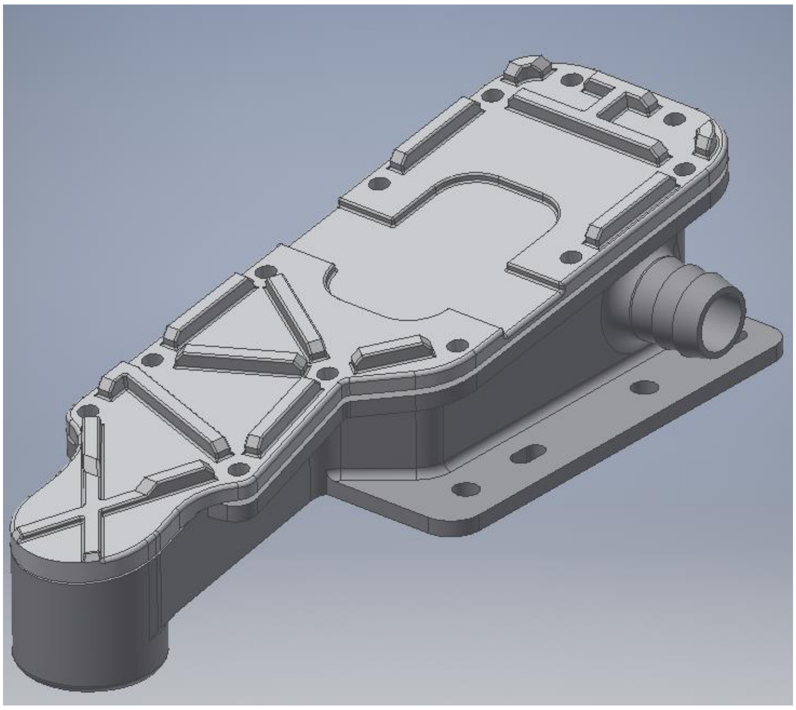


Figure 25: Iteration 2 water quality measurement unit housing.

The housing was rigid enough to not let any water through the split line anywhere but in the front end of the housing. The front end being the part which goes into the waste gate pipe. This proved to be problematic, since the water spout which went through the split line in the front end would hit the waste gate pipe wall and squirt upward, entering a space not intended for water containment.

This iteration was supposed to be sent to a customer, so there was no time for redesign. The fix was to glue the entire housing shut, eliminating the possibility of disassembling the parts for easy cleaning. The adhesive used was a two component epoxy, known as Loctite® 9466.

7 Chassis Design

The chassis is composed of a load bearing framework made of welded rectangular profiles, a protective shell, and a set of screw-attached metal plates designed to enable mounting of the shower system components. The mounting principles for the pump of the system required additional attention since the pump is heavy and generates vibrations during operation. This chapter addresses the development of the most important plates.

7.1 System assembly

Before the chassis of the shower system could be designed, it was necessary to have a good estimation of how the components would be placed in relation to each other and a user. To get a good understanding of how the components would be placed, all the carry-over components were virtually assembled in the CAD-program Autodesk Inventor 2016.

The components' placement and orientation were decided with respect to a number of factors: Components which would need to be replaced often, like filters, were placed to be easily accessible. Components which potentially would require maintenance and troubleshooting work, like electronics box, UV-lamp, and control unit, were placed to be relatively easily accessed or dismounted. Components which would be interconnected with stiff hoses were oriented to not put unnecessary strains or bends on the hoses. Components which could generate heat, like pump and heater, were placed to have as little interference as possible with heat sensitive parts.

The placement was also made with the size of the shower system in mind. The assembly was desired to contain as little empty space as possible.

Parts which were not design-wise completed yet were assigned a space to exist in. Their size and shape was to be decided by how much space there was available for them. To not make this a bottle neck for the design however, the space assignment was made generous.

7.2 Load bearing framework

It was early decided that the shower unit would use a framework made of welded rectangular profiles to hold all components in place. Tubes with rectangular profiles would be easy to mount flat metal plates on and could allow for simple design alterations if necessary.

The framework was designed, produced, and evaluated in two iterations: In the first iteration, the frame was built using standard aluminium profiles with T-slots. All frame members were attached using screws and brackets. This iteration was made to ensure it was possible to make a sufficiently rigid frame with the intended design.

The second frame iteration was made with welded standard hollow square aluminium profiles. This frame became the final design and was used in the final prototype.

7.2.1 **Evaluation frame**

Early in the design stage of the frame, it was deemed necessary to practically ensure the structural integrity. While the system assembly was not fully decided upon, the placement of the heaviest components had been established. The rigidity of the framework could thus be evaluated. Shown in figure 26 is a CAD-model of the early stage system assembly with the intended evaluation framework. The major subject of evaluation was how well the frame would handle the 14kg heavy pump. The pump was intended to be placed in a corner without a vertical frame member. The frame was designed this way to allow for more of the pumps bottom attachment points to be positioned directly on the bottom structural members.

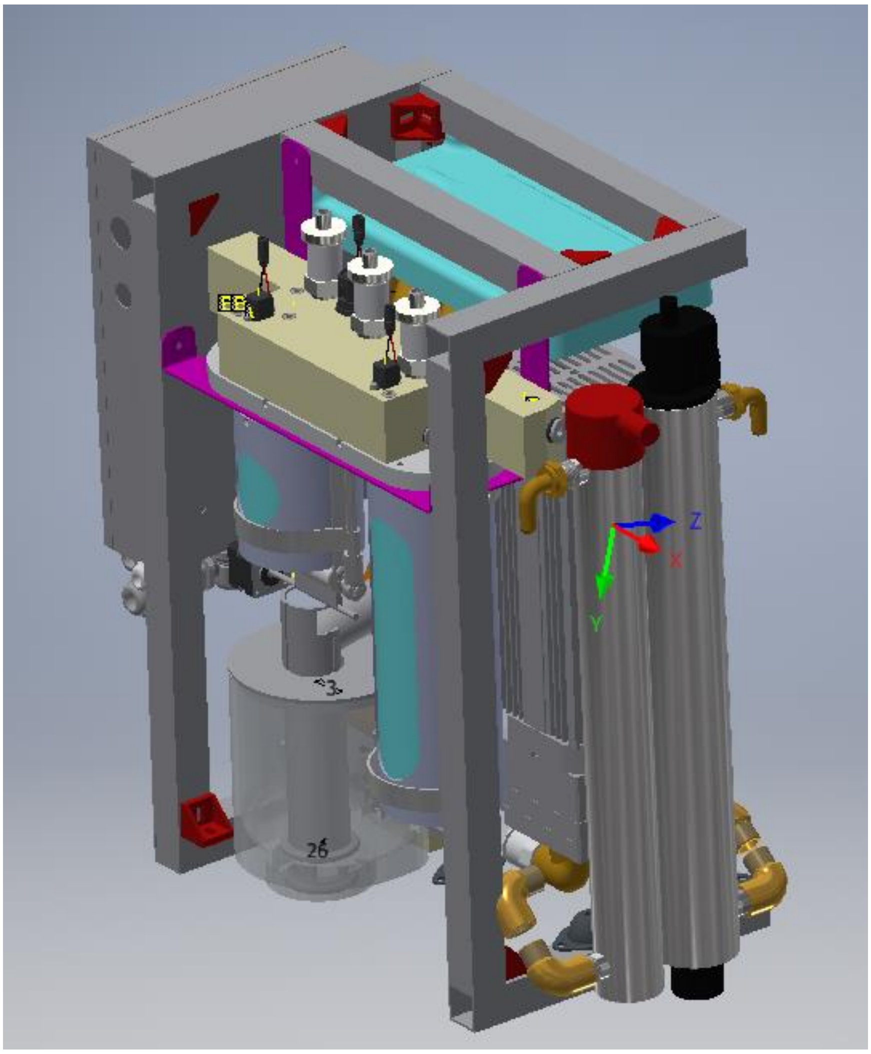


Figure 26: Early stage CAD-model of the Tech Module.

The first frame iteration was built using square 30x30mm aluminium beams with 7mm T-slots. The beam dimension was chosen by estimations of what would be sufficiently rigid.

The frame assembly is shown in figure 27. All mounting was made using off-shelf corner brackets, M6 slot nuts, and M6x12 hexagonal socket screws.

Figure 27: Assembled evaluation frame.

The framework proved to be sufficiently rigid for the loads it would encounter. There was no requirement of stiffness, but a quick test showed that when loaded with ~40 kg, the corner without a vertical frame member was displaced by ~5mm. More importantly, there was no evidence of plastic deformation in the structure.

Due to additions of components and re-evaluations of the placements of some components, the framework became obsolete. The iteration, however, did serve its purpose as an evaluation model.

7.2.2 **Calculations**

Knowing that the evaluation frame was structurally sound, it was considered wise to transfer its mechanical properties to the final welded frame.

The welded frame was intended to be made of rectangular tubes of stainless steel. The material was chosen for its known reliability and widespread use in other products made by the company. The tubes were decided to have external dimensions of 20x20mm in order to reduce the spatial demand of the supporting frame.

The area moment of inertia, *I*, for the T-slot aluminium profiles is $3*10^4$ mm^4. [11]

The area moment of inertia of a beam, multiplied with the Young's modulus, *E*, of the beam material, is the factor that will decide if a beam of a given length and type of attachment will buckle or not when loaded in its axial direction. The same factor, *EI*, is the factor which decides how large the deflection of a beam of a given length will be when exerted to bending loads. [12, pp.198, 344]

The goal was accordingly to dimension the stainless steel tubes to have the same product of *EI* as the aluminium profiles. As demonstrated in figure 28, the calculated thickness of the stainless steel tube would need to be ~1.6mm, assuming Young's moduli of 60GPa and 210GPa for aluminium and stainless steel respectively. The calculations were performed in PTC Mathcad express™.

$$E\_steel := 210\ GPa$$
$$E\_aluminium := 60\ GPa$$
$$t := 1.6\ mm$$
$$b := 20\ mm$$
$$h := 20\ mm$$
$$I\_square\_tube := t \cdot \frac{b^3}{6} + \frac{1}{2} \cdot t \cdot b^2 \cdot h = \left(8.533 \cdot 10^3\right)\ mm^4$$
$$I\_aluminium\_profile := 3 \cdot 10^4\ (mm)^4$$
$$E\_steel \cdot I\_square\_tube = \left(1.792 \cdot 10^6\right)\ GPa \cdot mm^4$$
$$E\_aluminium \cdot I\_aluminium\_profile = \left(1.8 \cdot 10^6\right)\ GPa \cdot mm^4$$

Figure 28: Tube stiffness calculations.

The formula for the area moment of inertia for a rectangular tube was retrieved from [12 p.334]

7.2.3 **Welded frame**

Since standard rectangular tubes come with wall thicknesses in increments of half millimetres, the chosen dimension of tube was 1.5mm. While the frame would become somewhat weaker than the calculated stiffness in *7.2.2 Calculations*, it was still believed to be rigid enough for its application.

One of the three vertical structural members was replaced with a custom made mounting plate in order to reduce part count and to make the mounting plate a rigid holder for its designated components. This part is specified as 1100455 in appendix B.1, as a part of the frame structure weld assembly. Its primary purpose was to support the power switch box and the diaphragm pump. Additionally, one of the frame members had to be a 20x40mm profile instead of 20x20mm in order to properly uphold its components.

Holes were placed in the frame at all points where components would be attached. The holes were drawn and drilled to be 7mm in diameter. This dimension was in compliance with the ASME B18.2.8-1999 loose standard for clearing holes for M6 screw joints [13].

Due to an executive decision, the frame was decided to be made of aluminium instead of stainless steel. The frame members, however, were to maintain their specified dimensions. This resulted in a frame with reduced stiffness compared to the evaluation model. Despite protests from the student, it was not considered a problem by company employees.

The frame was produced according to the drawings in appendix B.1 by a metals workshop in Serbia. Shown in figure 29 below is the frame with the bottom tray, machine feet and a couple of pump mounting plates attached.

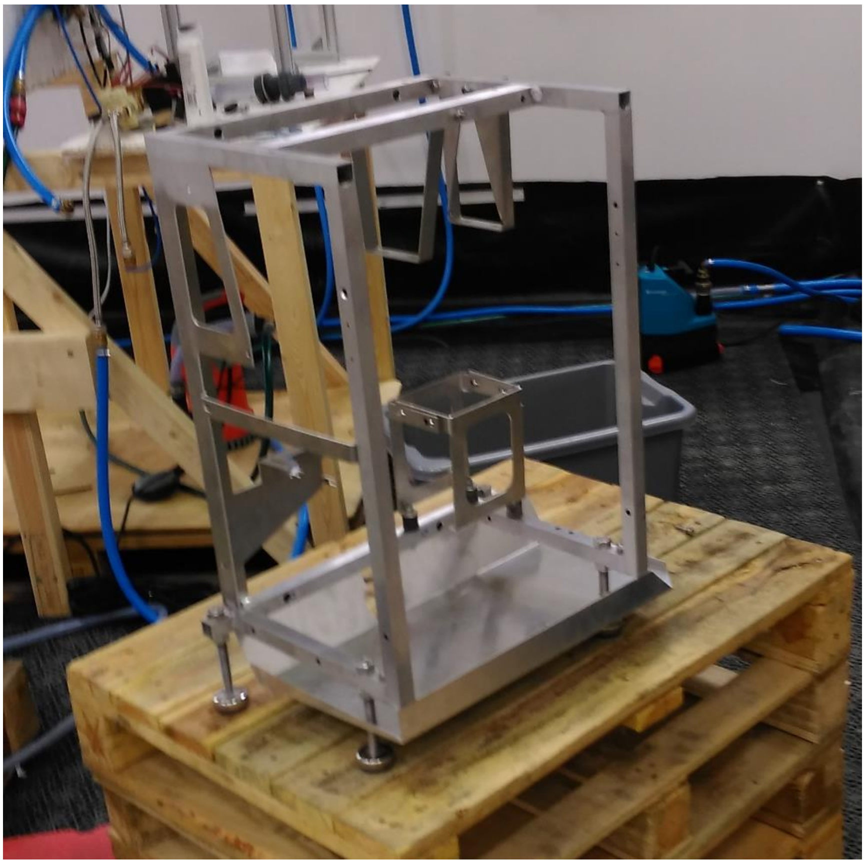


Figure 29: Welded frame.

Visual inspections of the frame indicated it probably was rigid enough for its application, despite the lower stiffness explained above.

7.3 Component mounting plates

To hold all components in place in the tech module, a set of mounting plates needed to be designed, produced, and installed in the framework. These plates were to be made of aluminium or stainless steel, depending on what components they were designed to hold.

All plates which would hold heavy or heavily loaded components were designed to be made of 2mm stainless steel sheets. The components which would not be as highly stressed were instead designed for 2mm aluminium sheets.

The mounting plates were produced in two iterations: The first batch of plates were designed to fit in the evaluation frame model. The purpose of these plates was to evaluate early stage design ideas for the different plates. The evaluation processed how the components' relative placements would work in terms of mechanical interference, hose placement, and wiring. The second batch of plates were the final plates to be used in the functional prototype.

Shown in appendix B.2 are the final plates' appearances and specifications in terms of both material choice and area of use.

7.3.1 Iteration 1

The first set of plates was produced in the waterjet cutter in the Ingvar Kamprad Design Centre at LTH. Their designs were based on an early draft of the system assembly. These plates were produced in 2mm regular steel sheets as their function only was needed for a short period of time. Shown in figure 30 below are the plates in their unfolded forms. The set did not include all plates necessary for a complete prototype, but instead the plates that needed to be tested for their applications. The practical issues with each plate made in this iteration is described below.

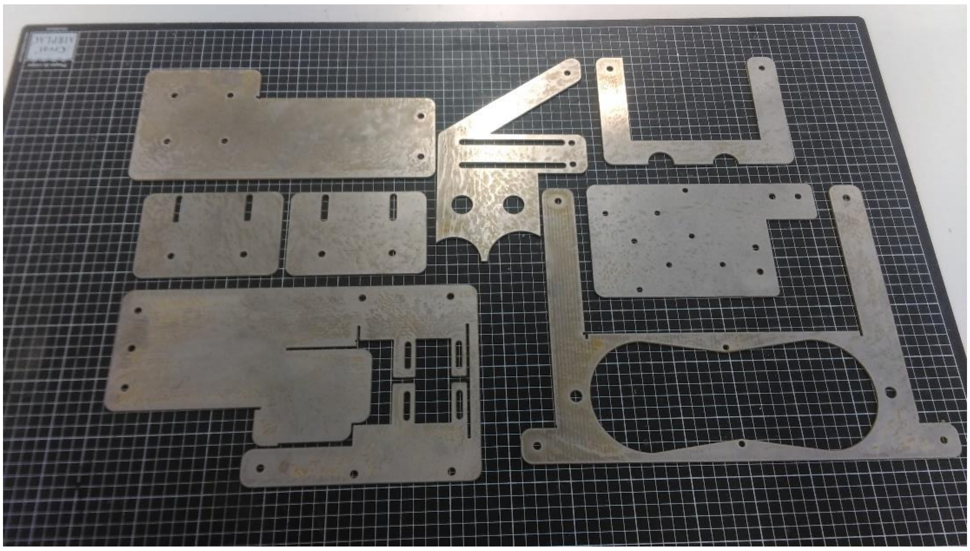


Figure 30: Unbent iteration 1 evaluation plates.

The DU-plate was initially designed to hold the Discharge Unit as well as the feed- and sink blocks in place. This resulted in a production-wise complicated geometry. The complexity was discernible not only in CAD, but in practice as well, since the first batch of metal plates were bent by the student. As seen in figure 31, the difficult design resulted in a poor production quality.

Figure 31: Iteration 1 Discharge Unit mounting plate.

Apart from being difficult to produce, the design also proved to be too weak to rely on. The design was accordingly revised for the next iteration. The changes are explained in *7.3.2 Iteration 2.*

The filter block mount plate proved to be sufficiently stable. No changes were needed to make the plate more reliable for the sake of holding the filter block rigidly in place. As an extra precaution, the mounting plate was mounted to hold the filter block in the testing rig as shown in figure 32. The mounting plate stayed there, intact, until the end of the project.

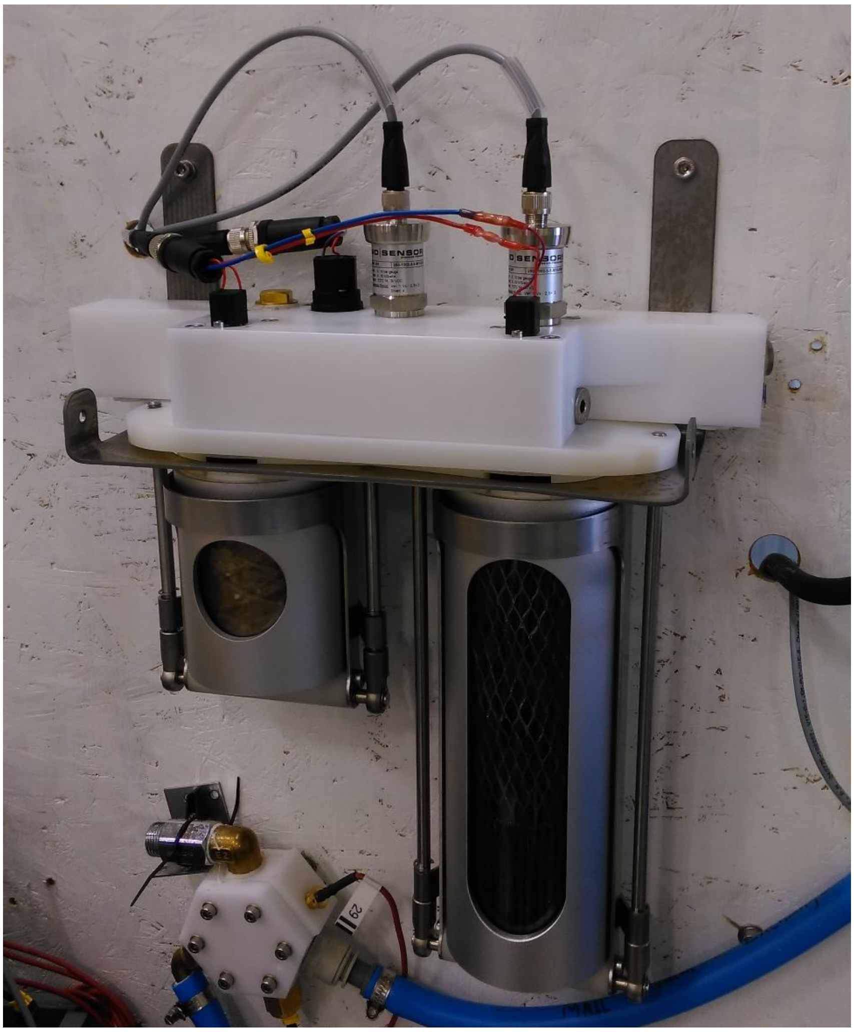


Figure 32: Filter condition block mounting plate placed in rig for long term testing.

The brackets for the UV/Heater assembly were designed to accommodate the assembly in a specific place in the prototype. The position, however, proved to be disadvantageous since the outgoing hose would collide with the filter block. In figure 33, both the hoses for in-going and out-going water are shown to be straining against the edge of the filter block. This situation could cause the hoses to rupture in the long run. The UV/Heater was accordingly relocated for iteration two.

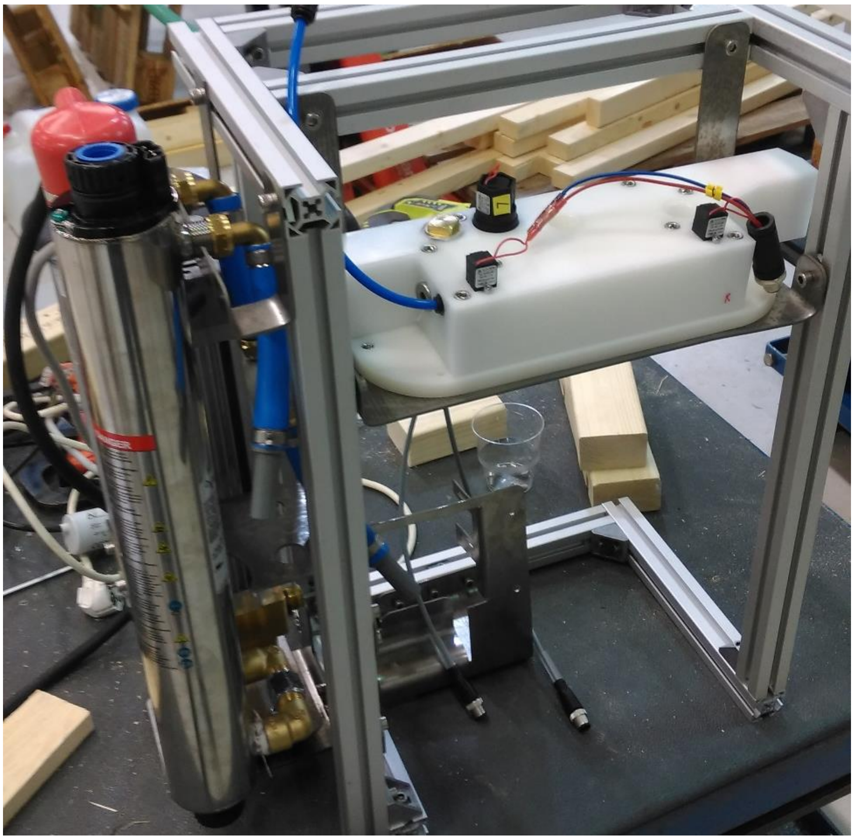


Figure 33: Collision between heater/UV hoses and filter condition block.

7.3.2 Iteration 2

After iteration 1, it was realized it would be more beneficial to use many plates with simple bends rather than few plates with complicated bends. While this would result in an increased part count it would decrease the risk of incorrectly produced geometries. Additionally, when using more plates for the same purpose as one plate, some incorrect bends could be adjusted for, as the plates could be screwed together with specified positions post bending.

The second batch of mounting plates were the ones to be used in the prototype. The plates were designed to be attached using M6 screw joints. The plates' positions were desired to be adjustable in relation to each other in order to compensate for eventual faulty bending. This was achieved by making the holes for the screw joints shaped as slots, in which screws could be slid to their desired positions.

The DU plate was redesigned to consist of three different plates instead of one. This was done due to two reasons;

1. The complicated design in iteration 1
2. The change of position of the feed block as described in *6.2 Discharge unit*.

The necessary change of feed block position as explained in *6.2.2.3.3 Iteration 3* above resulted in it being removed from the DU-assembly, which in turn reduced the geometrical complexity on the plates. The mounting plates' final appearance is shown in figure 34.

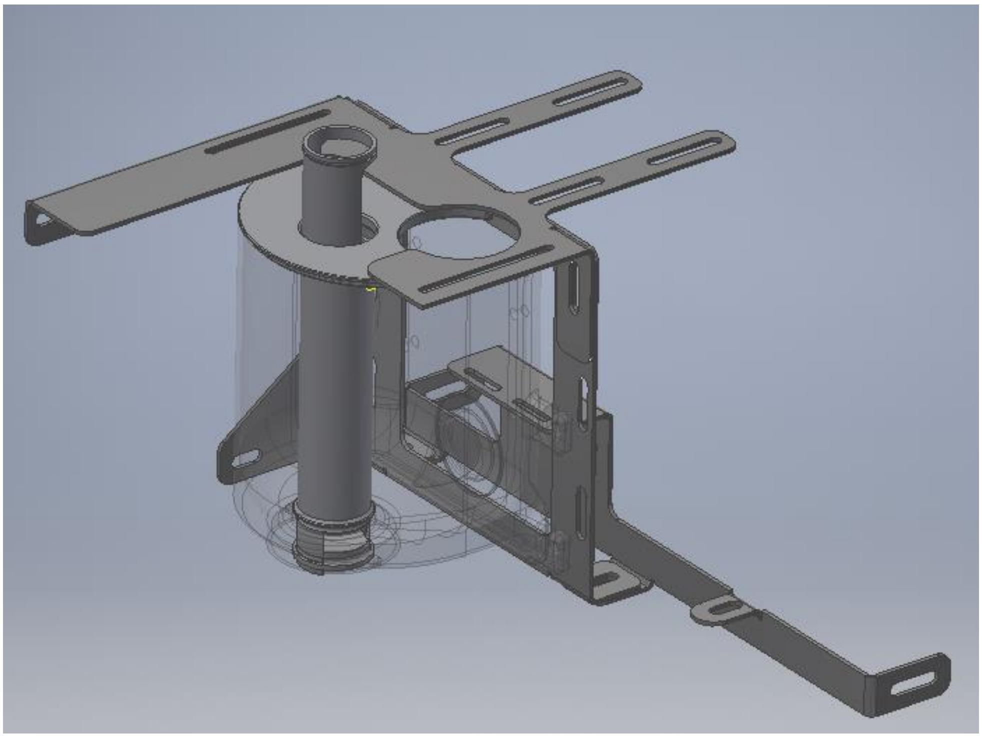


Figure 34: final Discharge unit mounting plates.

The feed block needed to be attached on an elevated position relative to the Discharge Unit. Since there were few attachment points available for a new plate and overall little space to place a new mounting plate in, the filter condition block plate was redesigned to carry the feed block as well.

The filter condition block plate was also redesigned to be the top support bracket for the UV/Heater assembly as well. Shown in figure 35 are the iterations 1 and 2 of the plate.

Figure 35: First and second iteration of filter condition block mounting plate.

Note the indent on the right edge of the first mount plate. This was made because the outgoing hose from the filter condition block otherwise would collide with the metal plate.

The technical drawings for all mounting plates can be found in appendix B.2, including the ones not covered in this chapter.

7.4 Pump suspension

The pump suspension refers to the vibration dampers and metal plates designed for the attachment of the pump assembly to the frame. The pump assembly is denoted as 10-0018 in *5.1 List of carry-over components.*

7.4.1 Pump specifications

The pump motor used was a single phased induction motor. It operated at 2830 rpm and 750 W. It weighed 14 kg.

The pump type used had no suction ability, this meant that the pump house had to be placed as low as possible in the system assembly in order to draw water from the DU through gravitational fall. Due to this and the goal to have the prototype as small as feasible, the pump and motor were to be placed in an upright position.

The pump motor was, by default, covered by an aluminium profile with T-slots. There were two slots each on two opposite sides of the motor. These slots were the primary way for attaching the pump to other components.

In the first moment when the pump motor started, it would make a twitch. This movement, if not properly addressed, could generate damage to close by components in the prototype assembly.

7.4.2 Vibration Dampers

In order to cancel out vibrations and subsequent noise, all attachments between pump motor and frame were to be through rubber vibration dampers.

Two different types were tested: The damper used in the current Orbital Systems shower, and a 20x20mm cylindrical damper with a hardness of 40 Shore A. The dampers are denoted as 23-0007 and 23-0032 respectively in the company CAD-library.

The dampers' performance was tested by mounting them in the current Orbital Systems shower system and running the motor. The cylindrical dampers were rated by Orbital Systems employees to be either equal to or slightly better than those dampers used in the currently produced showers.

The cylindrical dampers were chosen by this result and for their beneficially small shape.

7.4.3 Pump suspension mounting plates

Initially, the mounting plates were designed to hold the pump at a position outside of the framework in order to keep it from possibly hitting other components during start-up. This was however flawed, since the attachment points would be asymmetrically placed around the pump and the bottom mounting plate would bend under the pumps weight. Shown in figure 36 is a CAD-model of the principal damper and plate placement. The plates design for this iteration was decided before the damper type had been chosen.

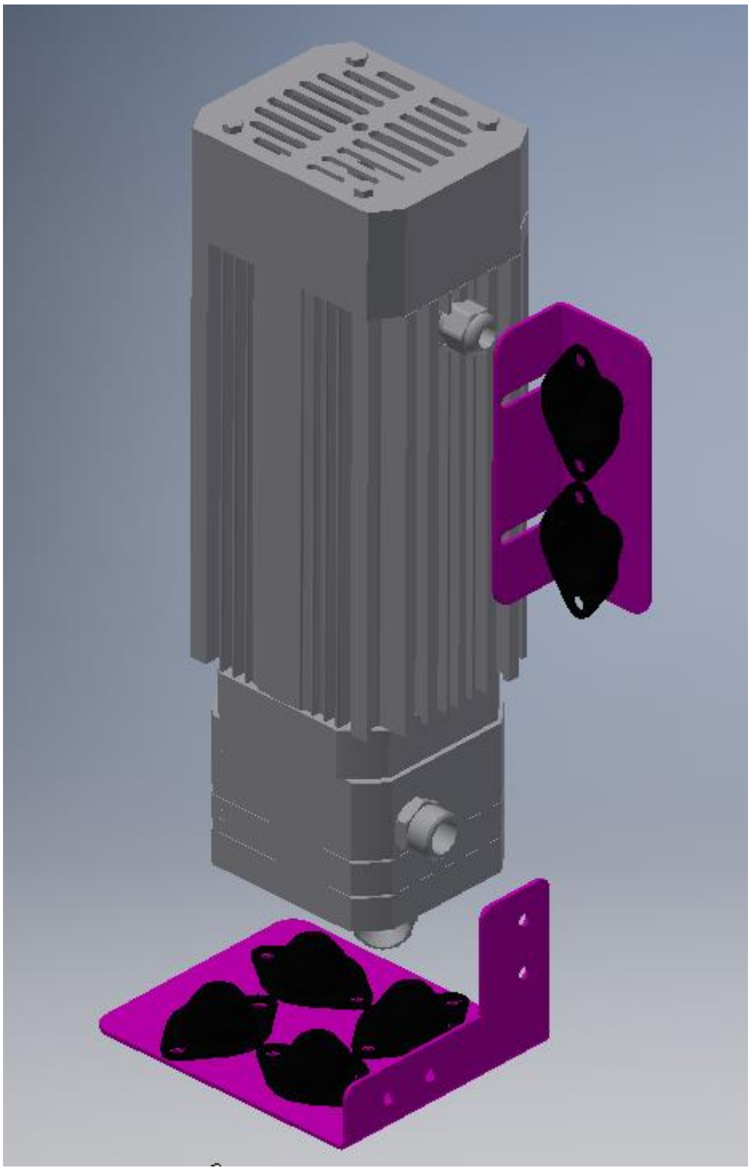


Figure 36: Early principle for pump attachment.

This design was never evaluated in damping capacity, since the structural integrity of it was too bad. The plate which would connect the pump with the bottom dampers was drawn to only be attached to the pump on one side of the motor. As demonstrated in figure 37, this design resulted in the pump exerting a bending moment on the plate, causing a large deformation.

Figure 37: Weight-induced bending of pump bracket.

The pump plates were redesigned and produced to distribute the load more evenly on all metal plates and vibration dampers. The new CAD-design with the new dampers placed is shown in figure 38 below. The general idea was to have all dampers loaded axially by the pump and to place them symmetrically placed around the pump axis. The plates were designed to allow for large vertical adjustability of the pump position. This was achieved by making the attachment slots between the plates and T-profiles long.

Figure 38: final CAD-design for pump suspension.

This design became the final one. All the technical drawings for the final mounting plates are provided in appendix B.1.

7.4.4 **Validation**

To ensure the functionality of the pump suspension design, it was tested in its final configuration. To do this, the pump was mounted in the welded frame, connected to a water container through hoses, and run. Shown in figure 39 is the test in action.

No noise could be attributed to vibrations, and a tactile inspection found the vibrations in the frame to be existing, but of low amplitude.

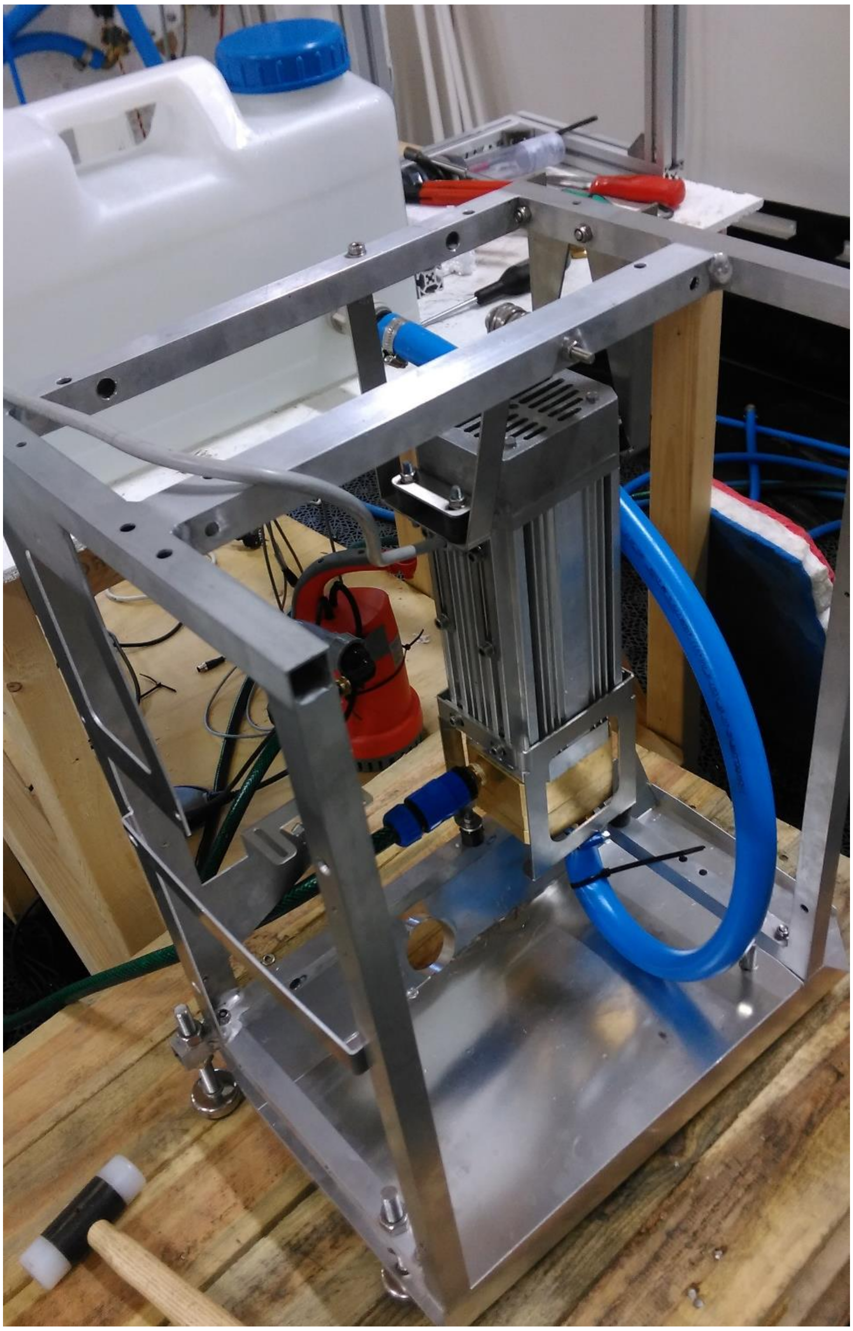


Figure 39: Testing of pump suspension.

By this test, the pump suspension was deemed sufficient for its intended use.

7.5 Casing

The casing for the prototype was designed to protect the innards from foreign objects, dirt, and other potentially harmful items. It was not intended to take up any structural loads or to support any components. This meant it did not have to be especially stiff or rigid.

The shape and colour of the casing, as well as ideas on how to access the innards of the prototype was decided through a drawing session and discussions with two people from the design team of Orbital Systems. In figures 40-41 below is an excerpt from the drawings made. At the time of the session, the system assembly was only partially set. All components' placements were not completely fixed yet, but the general shape and dimensions of the system were specified, and the placement of the important components to easily access was known. The prototype casing was decided to be rectangular with rounded corners, as this was the most space efficient shape while being true to the Orbital Systems design language. For the same reason, the colour was decided to be white.

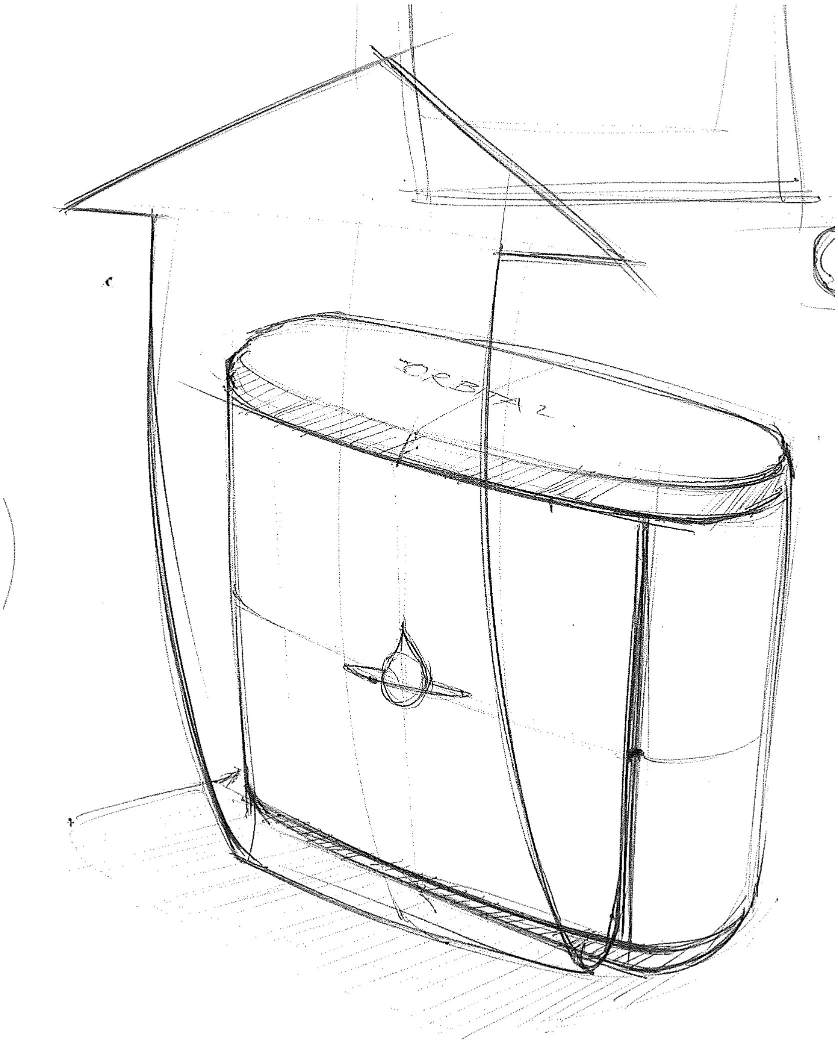


Figure 40: Concept art for appearance of Tech Module. [14]

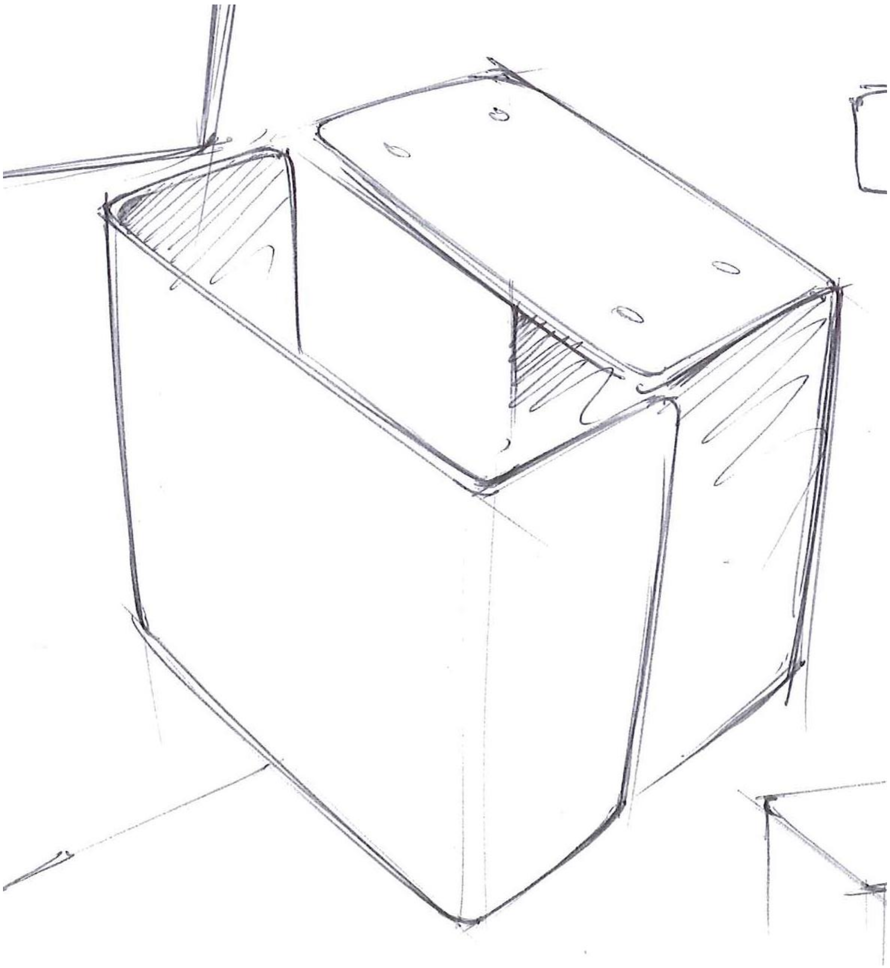


Figure 41: Concept art for assembly of Tech Module enclosure. [15]

The casing consisted of five parts; rear plate, main body, bottom tray, hatch, and top lid. All parts except for the lid and hatch were made of 1mm aluminium sheets in order to save weight. An exploded view with these components is shown in figure 42.

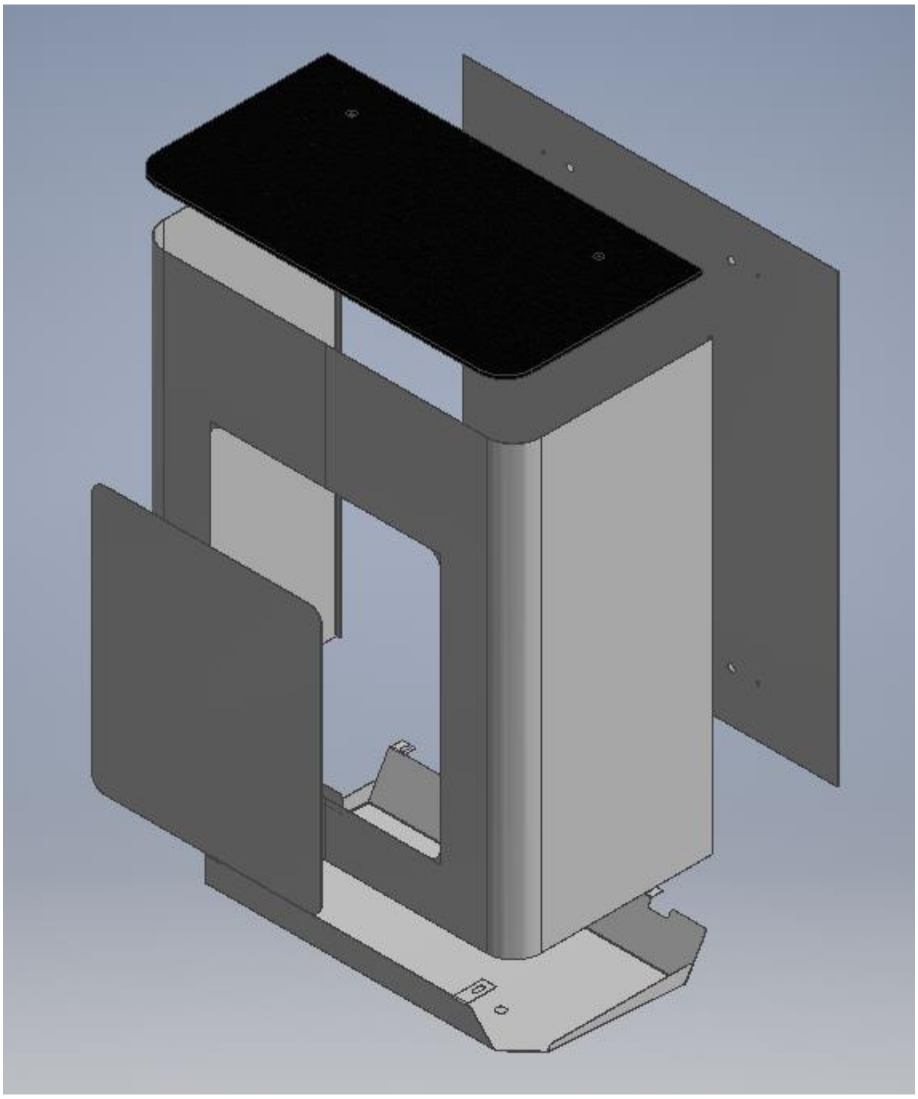


Figure 42: Exploded view of enclosure design.

The top lid was made of a black plastic in order to give the prototype an aesthetically beneficial appearance. It was made black to make a contrast to the rest of the body, and it was made out of nylon to make it 10mm thick and maintain lightweight. The thickness was needed to be able to make the attachment screw holes countersunk. The holes were countersunk to make the top surface of the prototype flat.

The hatch, shown on the far left in figure 42, for accessing the filters and the tank was designed to be attached without the use of hinges or screws, but through magnets. The hatch was to be held up by three magnets positioned in a V-formation.

The two top magnets were spring loaded magnetic touch latches. The bottom magnet was a neodymium magnet.

The latches would make the hatch protrude from the casing by ca 20mm when pushed to their extended position, allowing its removal for accessing the innards of the prototype. The hatch would be held flush with the casing surface when the latches were in their compressed position. Shown in figures 43 through 45 is the hatch in its closed, opened, and removed states.

Figure 43: Closed hatch.

Figure 44: Opened hatch.

Figure 45: Removed hatch.

8 Results

In this chapter, the specifications of the final prototype are presented alongside some important findings which were not covered in the previous chapters, as well as some info as to what became of the prototype after it was made.

8.1 CAD-geometries

The full prototype assembly is available in the company's internal database. It is labelled 1100343. All components needed to build a tech module are included in this model.

8.2 Existing prototype

The tech module was assembled and sent to a customer on June 3rd, 2016. Shown in figure 46 below is the assembled prototype. Due to a delay in the production of the intended power switch box, the prototype had to be sent with an older version, which would not fit inside the protective casing.

Figure 46: Final assembled prototype.

The final prototype measures ca 680x560x300mm. It weighs approx. 50kg.

8.3 Tests of the final assembled prototype

Prior to shipment, the prototype was tested by in-house personnel. The tech module seemed to deliver an equivalent experience as the contemporarily sold Orbital Systems shower.

While the prototype did not show any obvious signs of failure, the pump had trouble with transporting water out of the discharge unit tank, and there seemed to be overall leakage in the system. However, as the product was made as a prototype, and all parties involved were aware of this, its functionality was deemed good enough for it to be delivered.

9 Discussion

In this chapter, the main elements of the project are discussed with respect to what could be done different, why the results are what they are, and what further studies or developments should be conducted to ensure a safe, reliable, and mass producible product.

9.1 System assembly

The overall size and shape of the prototype is in many ways the result of the sizes and shapes of the carry-over components in the assembly as they constitute the majority of the prototype's components. In its current state, it is relatively hard to make the assembly of the tech module a closer fit due to the sizes and form factors of the various components. The new tech module is in volume only approx. 7 litres smaller than the old shower floor.

The tech module could be reduced in size through an amount of measures listed below:

- **Changing the pump motor to a weaker alternative:** The currently used pump motor is oversized for its application. It can deliver a mass flow of 15 l/min in a shower which probably, power-wise, only can afford to have a mass flow below 10 l/min, as explained in chapter *4.3.3.* A weaker pump motor would probably be smaller in size and weigh less.
- **Changing the heater:** The heater, the shape of which was largely responsible for the height of the tech module, is drastically oversized for the application. When the maximum power input to the heater can be around 3kW, there is no need to have a heater that is made to be able to deliver 6,6kW of heat. A more appropriately dimensioned heater would probably be a smaller heater.
- **Redesigning the filter condition block:** The filter condition block has a relatively wide shape. If it was redesigned to be as narrow as the total width of the two filters, the space in the tech module could be more efficiently used.

- **Reconsidering the discharge unit design:** The discharge unit could be designed to work in a different way compared to its current design.

9.2 Chassis design

The currently designed chassis could be remade to not need the majority of the screwed on mounting plates. With sufficient production precision, all mounting interfaces for the shower system's components could be incorporated in one large welded framework. This framework could even be the same part as the external casing. The idea would essentially be to utilize the principles of the monocoques used in the aviation and automotive industries.

By doing this, the part count would drastically decrease, possibly resulting in reduced in-house production times.

As partially proven with the current tech module, a monocoque-inspired framework could probably be made in 2mm aluminium sheets.

9.3 Thermal testing

The thermal testing performed in this project should only serve as indications to where the major sinkholes for the water temperature would be.

The results described in chapter *4.3.2* are likely to be even more polarized in the prototype: All the components of the shower system are placed together in a small, closed compartment, which likely will accumulate spilled heat and maintain a generally high air temperature inside. Additionally, since the discharge unit has changed from an open air design to a more enclosed one, there will be less contact surface between shower water and ambient air in that part of the shower system.

With these two factors combined, the temperature drop in any given shower compartment will probably be more visible than it will be between any other two points inside the tech module.

9.4 Discharge unit

The conceptual solution for the redirection of water flow in the Discharge unit design is essentially the same as a three-way valve. The possibility of actually replacing the discharge unit with an off-shelf valve should be seriously considered. In this project, it was proven that a stepper motor could be used to actuate an axle which could turn ex-centrically mounted wheels to lift a pipe. The position of said pipe would direct the water flow.

If the stepper motor would be used to instead actuate a properly chosen off-shelf three-way valve with a t-port, it could probably reach the same functionality. Shown in figure 47 below is a schematic explaining the different positions a t-ported three-way ball valve can have.

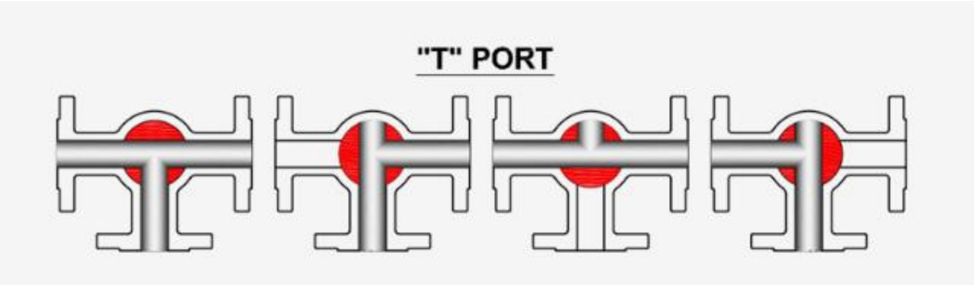


Figure 47: Different positions of a t-port three-way valve. [16]

In the figure above, consider the left opening to be the used shower water, the right opening to be the port to the water reservoir and the bottom opening to be the waste direction. In the first position, the system would be in full emptying mode, leading all water to the waste port. The second position would be redundant. The third position would be full recycle mode, activated when the water is clean enough to be recycled. The fourth position would be the waste mode, activated when incoming shower water is too dirty to be recycled.

Using an off shelf three-way valve instead of 3D-printed custom parts would reduce part count, cost, and assembly time.

There could be issues with the hygiene inside of the valve, however, since it would be harder to access the innards for manual cleaning after a long stand still of the shower system.

There is no guarantee this would be the case, and the only way to know for sure is to try. It is strongly recommended that the possibility of using a three-way valve is thoroughly assessed for the next prototype.

9.5 Further product tests

To ensure there are no significant design flaws in the tech module prototype, long term tests should be performed. The long term tests could reveal several issues which, by their nature, only would be revealed over time. Some of these are:

- Mechanical failures caused by vibration fatigue or abrasion.
- Galvanic corrosion caused by the direct contact between different metals.
- Creep, especially for the new details made of plastics.
- Software errors caused by unprecedented situations.

The prototype should also undergo tests where it is subjected to extreme circumstances to see how it would fare and to make sure such circumstances would not endanger a user. Examples of such circumstances could be:

- Heater overheating.
- Filter collapse.
- Emptying of foreign or dangerous substances in shower drain.
- Pump failure.
- Hose connections suddenly disconnecting.

Since some scenarios are more likely to happen than others, there should be a priority list for the order of testing.

9.6 Reflection on the method

The trial and error-approach which was widely used in this project was energy craving but rewarding to conduct. The nature of building and testing prototypes in an iterative fashion is time consuming, making a large time portion of the master thesis dedicated to building test rigs and mounting and dismounting prototypes.

However, when working with making new products of this kind, there are many unknowns, and the only way to find out what might work and what might not is to try it. Within a reasonable frame of thinking.

Had this project been conducted without revisiting any designs, the final product would have been structurally and operatively undependable.

10 References

[1] Savings. (n.d) Retrieved June 21, 2016, from https://orbital-systems.com/savings/.

[2] Technology. (n.d) Retrieved June 21, 2016, from https://orbital-systems.com/technology/.

[3] G.M Mulenbeurg & D.P Gundo: Design by Prototype: Examples from the National Aeronautics and Space Administration. In: Proceedings of the 11th International Conference on the Management of Technology; 10-14 Mar. 2002; Miami, FL; United States. Moffet field, CA: NASA; 2002. Available from: http://ntrs.nasa.gov/search.jsp?R=20040081092.

[4] Kelley, T. & Littman, J. (2001). The Art of Innovation - Lessons in Creativity from IDEO, America's Leading Design Firm. New York, NY: Currency/Doubleday.

[5] Ulrich, K. T. & Eppinger, S. D. (2012). *Product Design and Development* (5th ed.). London, United Kingdom: McGraw-Hill.

[6] Uvnäs, K. Development engineer at Join Business & Technology AB. Engineer team design meeting at Orbital Systems Factory (2016, 9 February).

[7] Heat Loss from a Pipe Calculator. (n.d) Retrieved June 14, 2016, from http://www.engineersedge.com/heat_transfer/HeatConductionPipeInsulation/heat_loss_from_a_pipe_calculator_12921.htm

[8] Diaphragm Pump Working Principle. (2015) retrieved June 14, 2016, from https://www.911metallurgist.com/blog/diaphragm-pump-working-principle.

[9] Gulley IC. (2016) retrieved June 14, 2016, from http://www.whalepumps.com/marine/product.aspx?Category_ID=10020&Product_ID=10039&FriendlyID=Gulley-IC

[10] Ridell, M, Chief Technical Officer at Orbital Systems AB. Engineer team design meeting at Orbital Systems Factory (2016, 9 February).

[11] Structural system XF. (2016). Retrieved June 14, 2016, from http://www.flexlink.com/zcms/zpublish/45/uploads//45/tech_lib/1417101599776437377_16XF.pdf

[12] B. Sundström. *Handbok och formelsamling i Hållfasthetslära.* Instant book AB, Stockholm, 7th print, 2010.

[13] Clearance Holes for Metric Fasteners. (2013). Retrieved June 14, 2016, from http://www.amesweb.info/Screws/ClearanceHolesMetricFasteners.aspx

[14] Dawod, D. Chief Design Officer at Orbital Systems AB. Enclosure design session at Orbital Systems factory (2016, 17 March)

[15] Linge, S. Industrial Designer at Orbital Systems AB. Enclosure design session at Orbital Systems factory (2016, 17 March)

[16] Three-way ball valve different position. (n.d). retrieved June 21, 2016, from http://www.threewayballvalve.com/

Appendix A Work distribution and time plan

A.1 Work distribution

The majority of the designs of the new components were made in cooperation between Sebastian Lundblad and Richard Bodén. The CAD-designs were created by one person and improved upon or changed by the other, either through oral input or by revisions of the CAD-files.

All programming and implementation of new electronics software and hardware was made by the Orbital Systems employees Mathias Beckius and Simon Lindholm.

A.2 Project plan and outcome

Provided in figures A.1 and A.2 are the planned project plan and the actual project outcome. The main reason for the large time-wise differences is the iteration-based nature of the project methodology. New off the shelf components that were needed were unknown of before the prototype development - an obvious planning error in hindsight.

Take note that the project outcome does not necessarily reflect how the work was distributed over the weeks. It is primarily to mark at what points in time the first and last work was performed for the different activities.

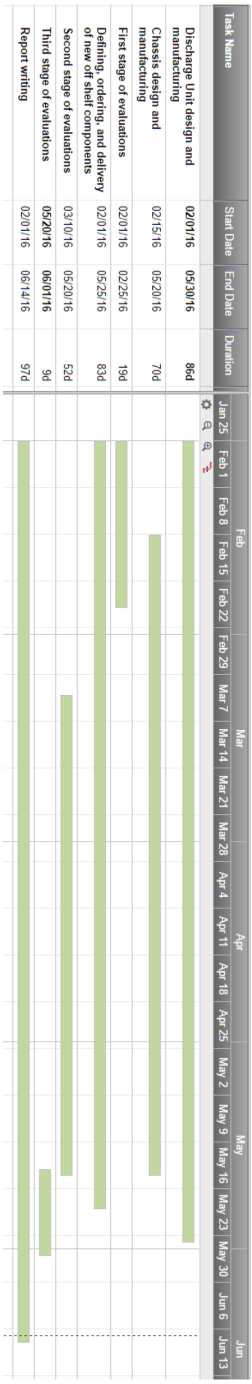


Figure A. 2: Actual project outcome.

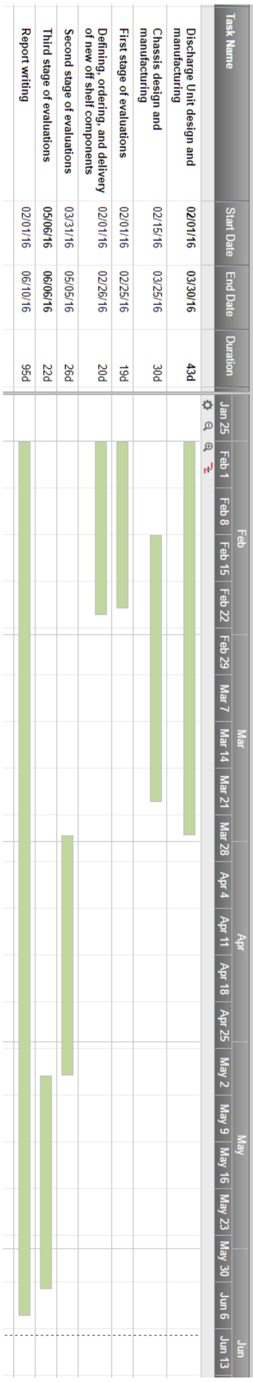
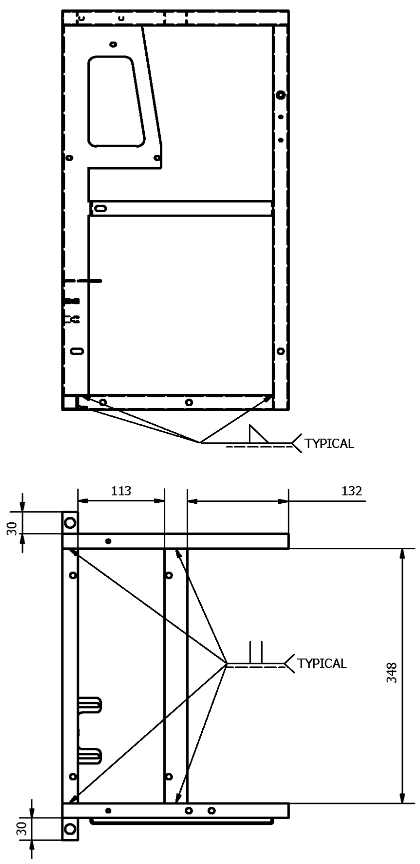
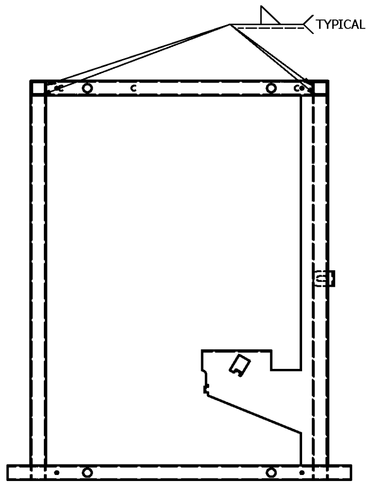


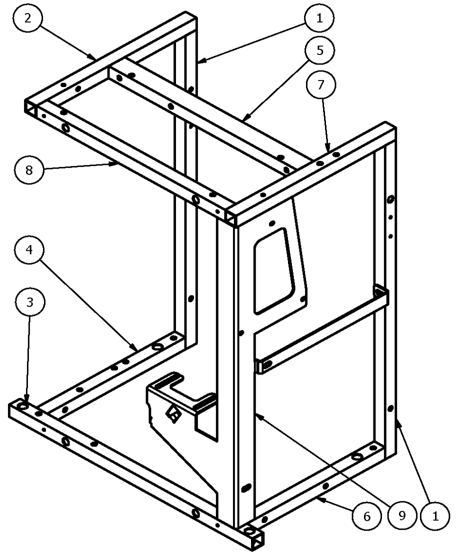
Figure A. 1: Planned project plan.

Appendix B Technical drawings of chassis components

B.1 Frame weld assembly







NOTE: TYPICAL FILLET AND BUTT WELDS WHERE APPLICABLE

Item	Qty	Description	Comments	Material	Part number
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8	1	Frame member 348mm 20x20 profile	20x20x1,5mm	Aluminum	1100340_9
7	1	Frame member 295mm top right		Aluminum	1100340_4
6	1	Frame member 255mm Bottom right	20x20x1,5mm	Aluminum	1100340_7
5	1	Frame member 348mm 20x30 profile	20x30x1,5mm	Aluminum	1100340_8
4	1	Frame member 255mm Bottom left	20x20x1,5mm	Aluminum	1100340_6
3	1	Frame member 448mm	20x20x1,5mm	Aluminum	1100340_3
2	1	Frame member 295mm	20x20x1,5mm	Aluminum	1100340_2
1	2	Frame member 525mm	20x20x1,5mm	Aluminum	1100340_1

Drawn By	Checked By	Approved By	Design State	
OS	N/A	N/A	WorkInProgress	Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken

Orbital Systems AB
Stora Varvsgatan 6A
SE-211 19 MALMÖ, Sweden
Tel. +46 40 619 5555
contact@orbital-systems.com

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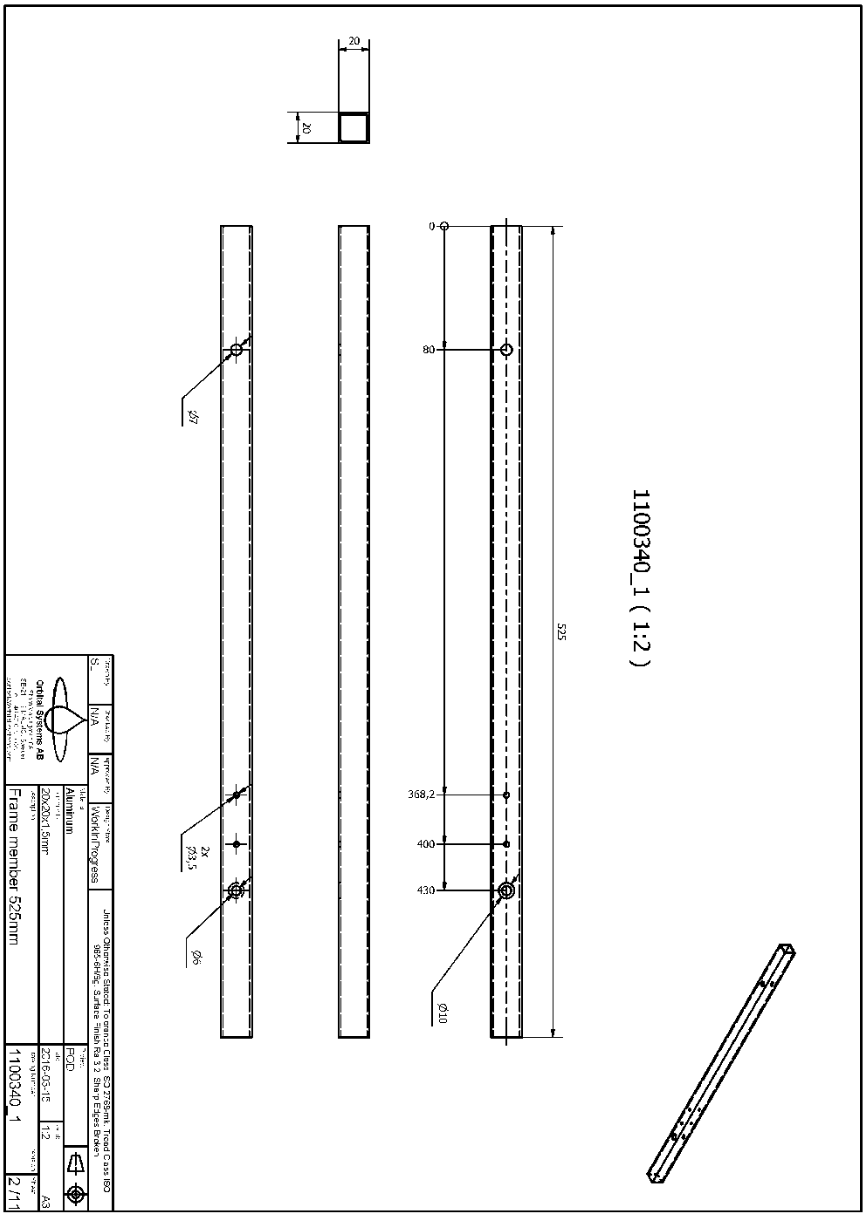
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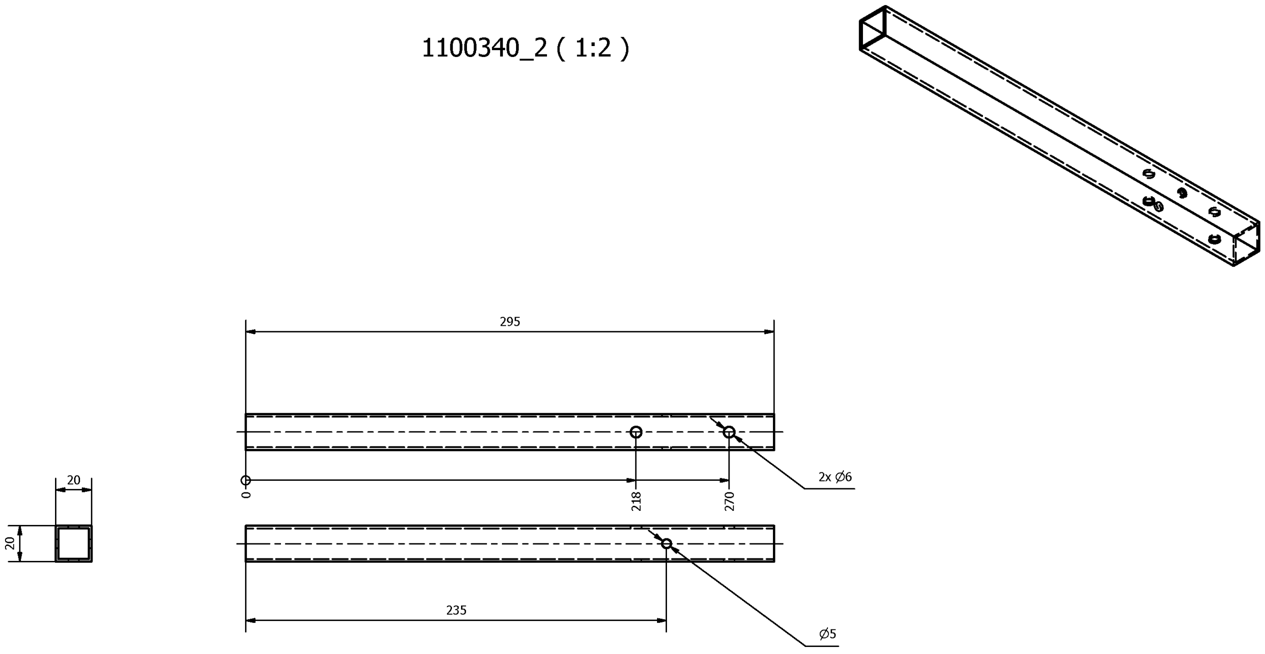

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Orbital Systems AB Stora Varvsgatan 6A SE-211 19 MALMÖ, Sweden Tel. +46 40 619 5555 contact@orbital-systems.com	Material: Aluminum			Project: POD		
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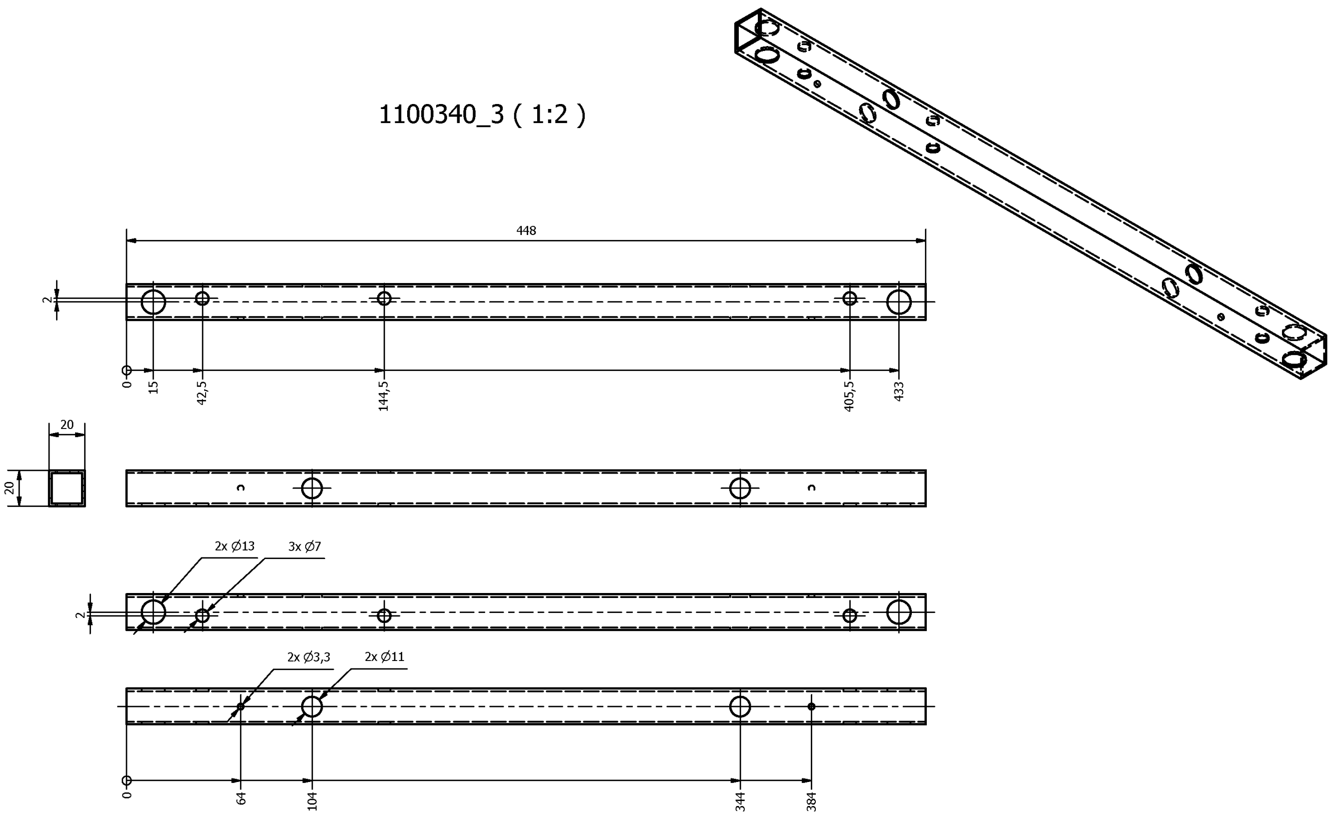
	Description: Frame member 295mm			Drawing Number: 1100340_2	Revision:	Sheet: 3 /11



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SL	N/A	N/A	WorkInProgress		
Orbital Systems AB Stora Varvsgatan 6A SE-211 19 MALMÖ, Sweden Tel: +46 40 619 5555 contact@orbital-systems.com	Material: Aluminum			Project: POD	
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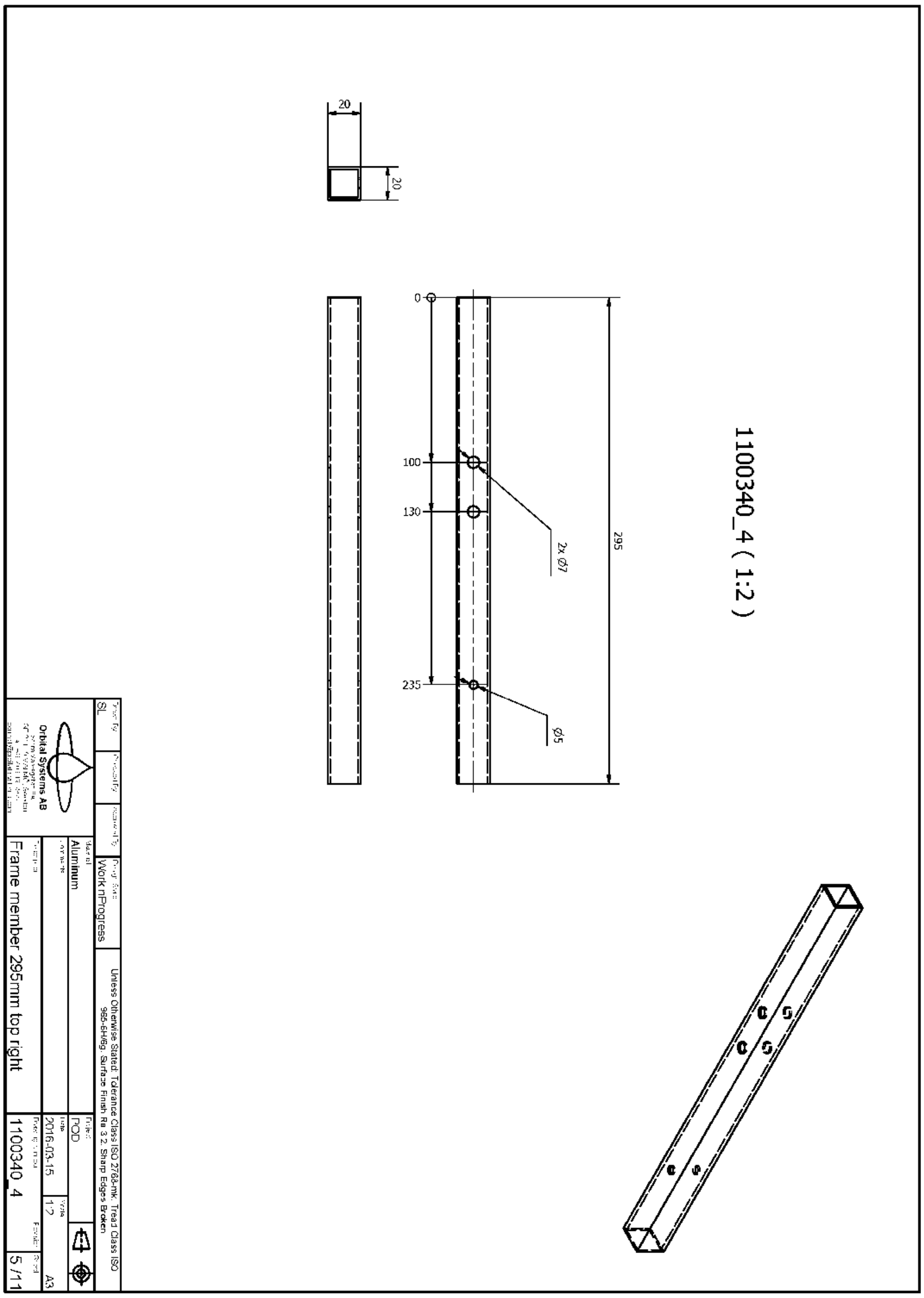

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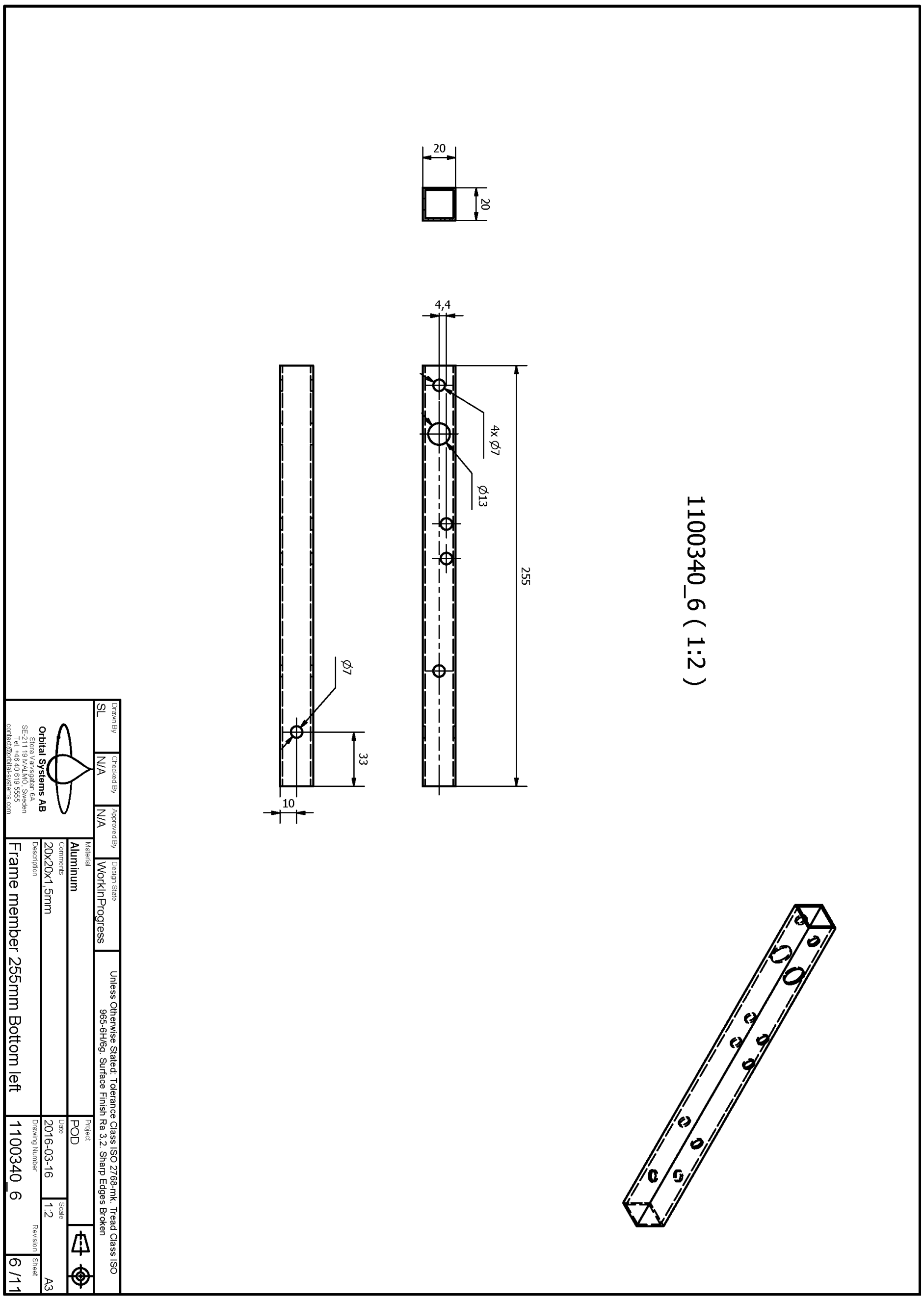
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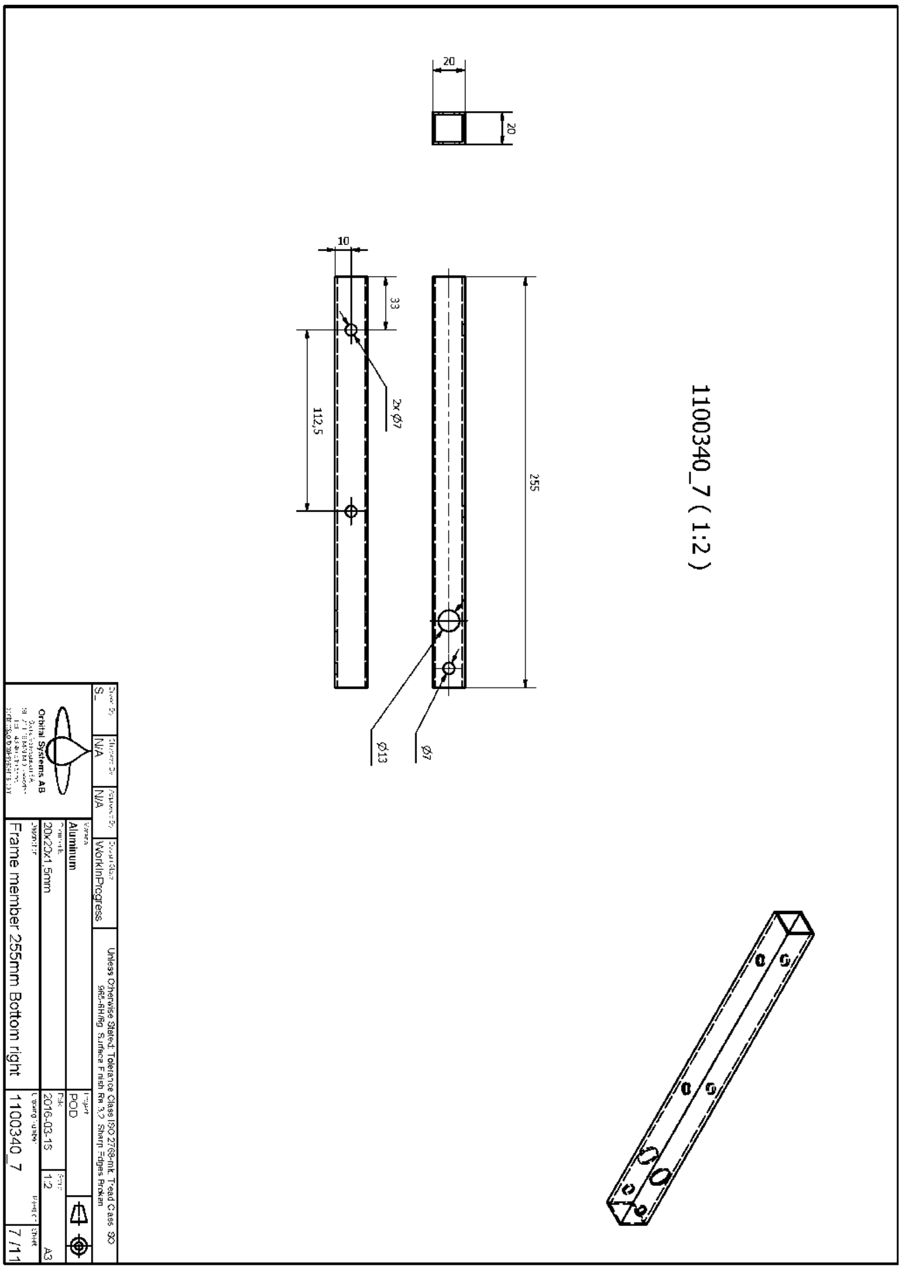
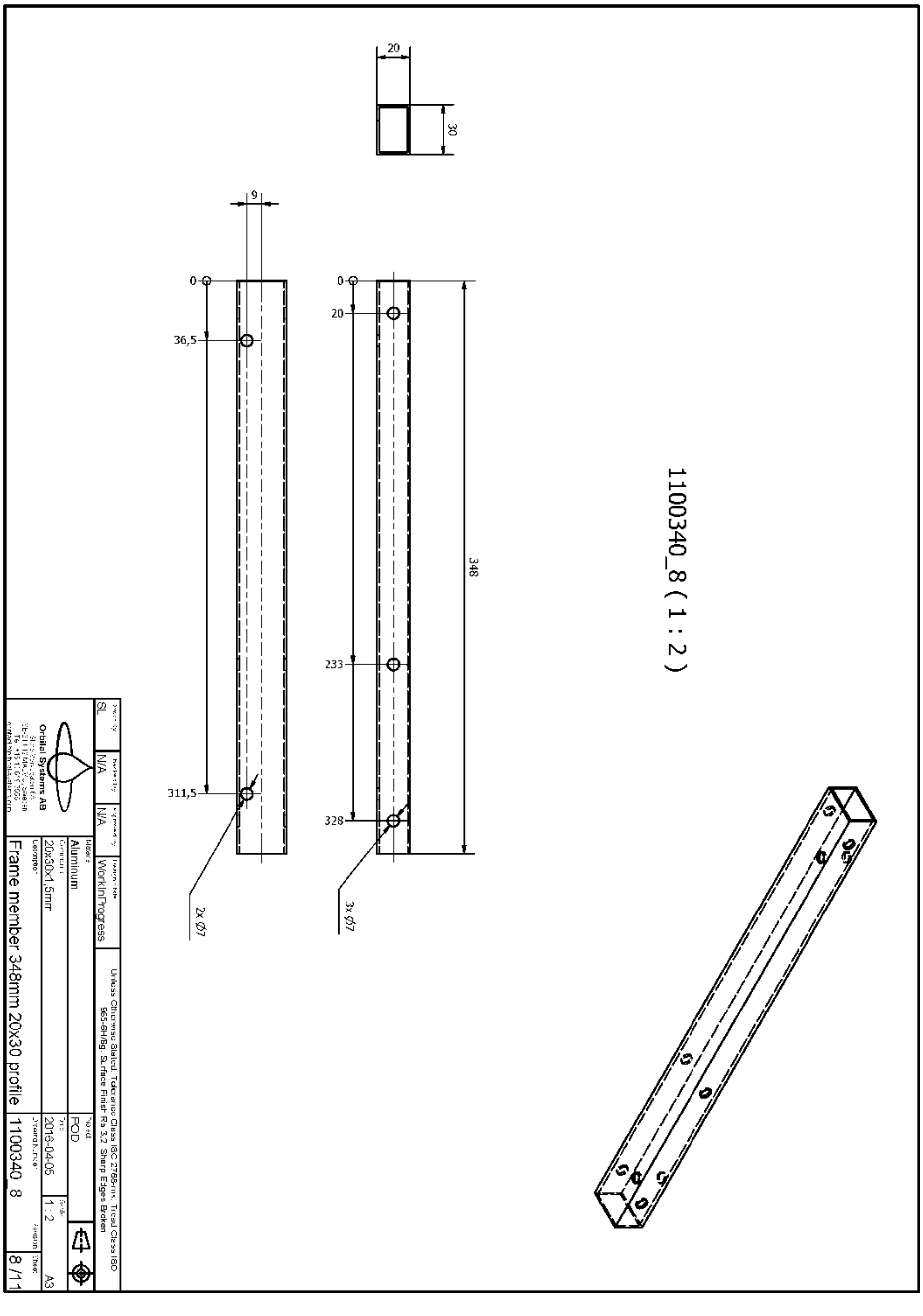
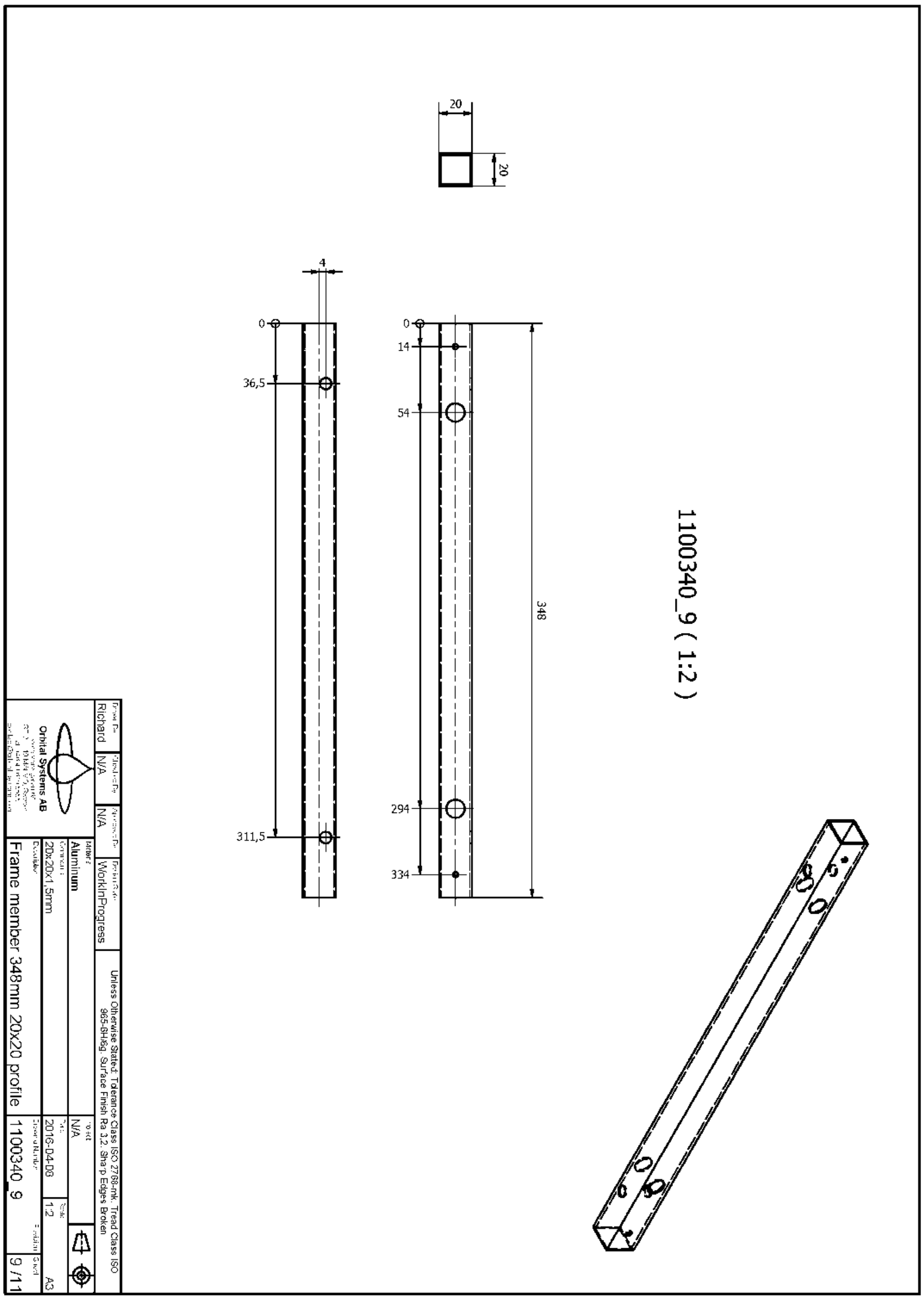
Ø13
255
Ø7
33
10
1100340_6 (1:2)
Drawn By
SL
Checked By
N/A
Approved By
N/A
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk, Tread Class ISO 965-6H/6g, Surface Finish Ra 3.2, Sharp Edges Broken
Orbital Systems AB
Material
Aluminum
Comments
20x20x1,5mm
Description
Frame member 255mm Bottom left
Project
POD
Date
2016-03-16
Scale
1:2
A3
Drawing Number
1100340_6
Revision
Sheet
6 /11

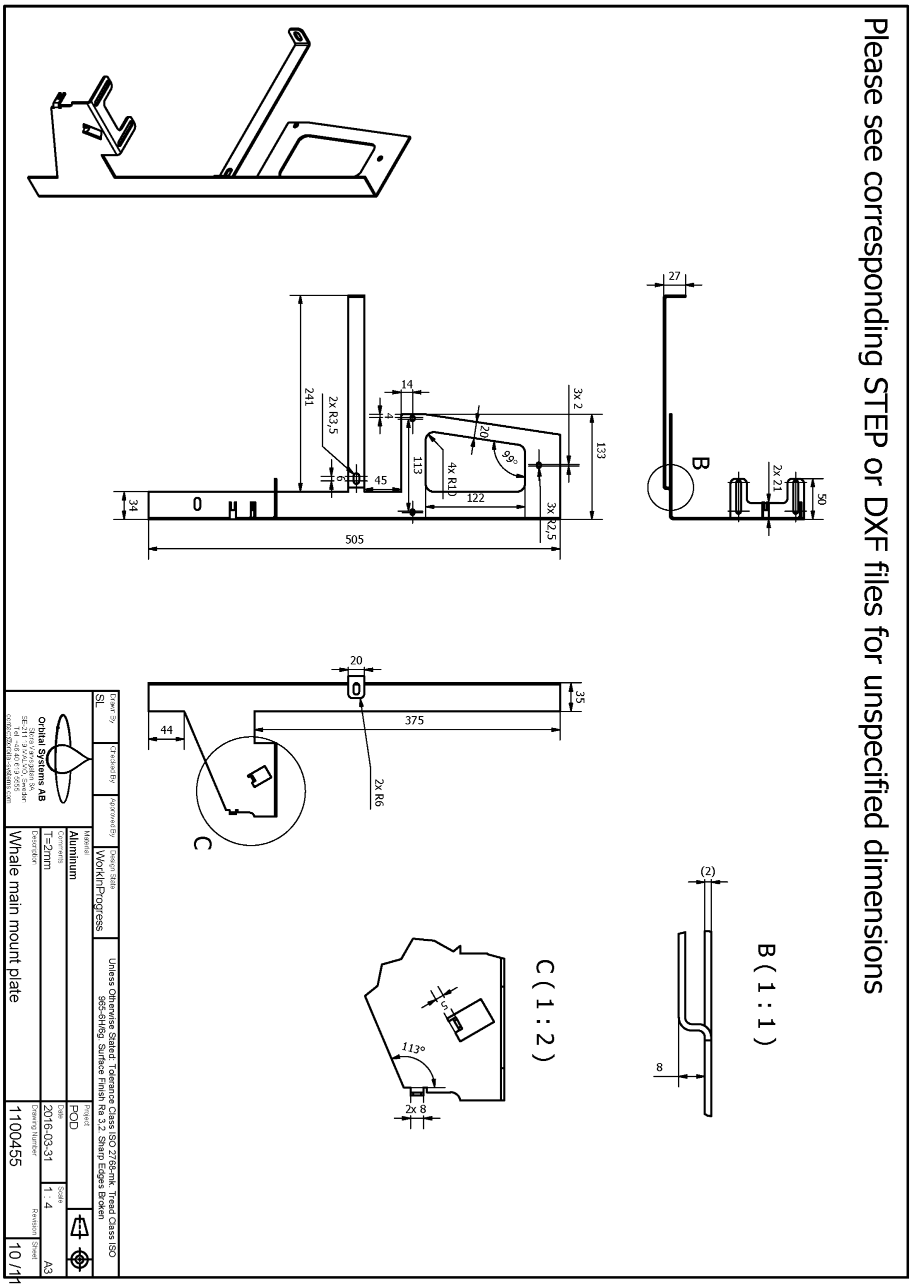

1100340_7 (1:2)
20
20
255
Ø7
Ø13
33
2x Ø7
10
112,5
Drawn By
S_
Checked By
N/A
Approved By
N/A
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk, Tread Class ISO 965-6H/6g, Surface Finish Ra 3,2, Sharp Edges Broken
Orbital Systems AB
Material
Aluminum
Project
POD
Dimensions
20x20x1,5mm
Date
2016-03-15
Scale
1:2
A3
Description
Frame member 255mm Bottom right
Drawing number
1100340_7
Sheet
7 /11



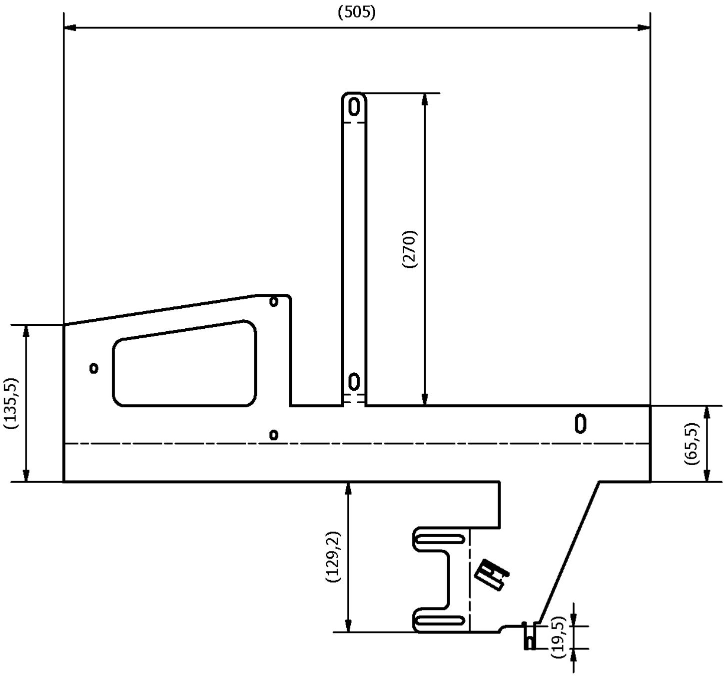
20
30
9
0
36,5
311,5
2x Ø7
0
20
233
328
3x Ø7
348
1100340_8 (1 : 2)
SL
N/A
N/A
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mK, Thread Class ISO 965-6H/6g, Surface Finish Ra 3,2, Sharp Edges Broken
Orbital Systems AB
Aluminum
20x30x1,5mm
POD
2016-04-06
1 : 2
A3
Frame member 348mm 20x30 profile
1100340_8
8 / 11



20
20
4
0
36,5
311,5
0
14
54
294
334
348
1100340_9 (1:2)
Richard
N/A
N/A
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk, Tread Class ISO 965-6H/6g, Surface Finish Ra 3,2, Sharp Edges Broken
Aluminum
20x20x1,5mm
N/A
2016-04-08
1:2
A3
Orbital Systems AB
Frame member 348mm 20x20 profile
1100340_9
9 / 11


Please see corresponding STEP or DXF files for unspecified dimensions
B (1 : 1)
C (1 : 2)
B
C
505
241
133
122
113
375
2x R3,5
4x R10
2x R6
3x 2
3x R2,5
2x 21
99°
113°
2x 8
(2)
Drawn By
SL
Checked By
Approved By
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
Orbital Systems AB
Material
Aluminum
Comments
T=2mm
Description
Whale main mount plate
Project
POD
Date
2016-03-31
Scale
1 : 4
Drawing Number
1100455
Revision
Sheet
A3
10 /11

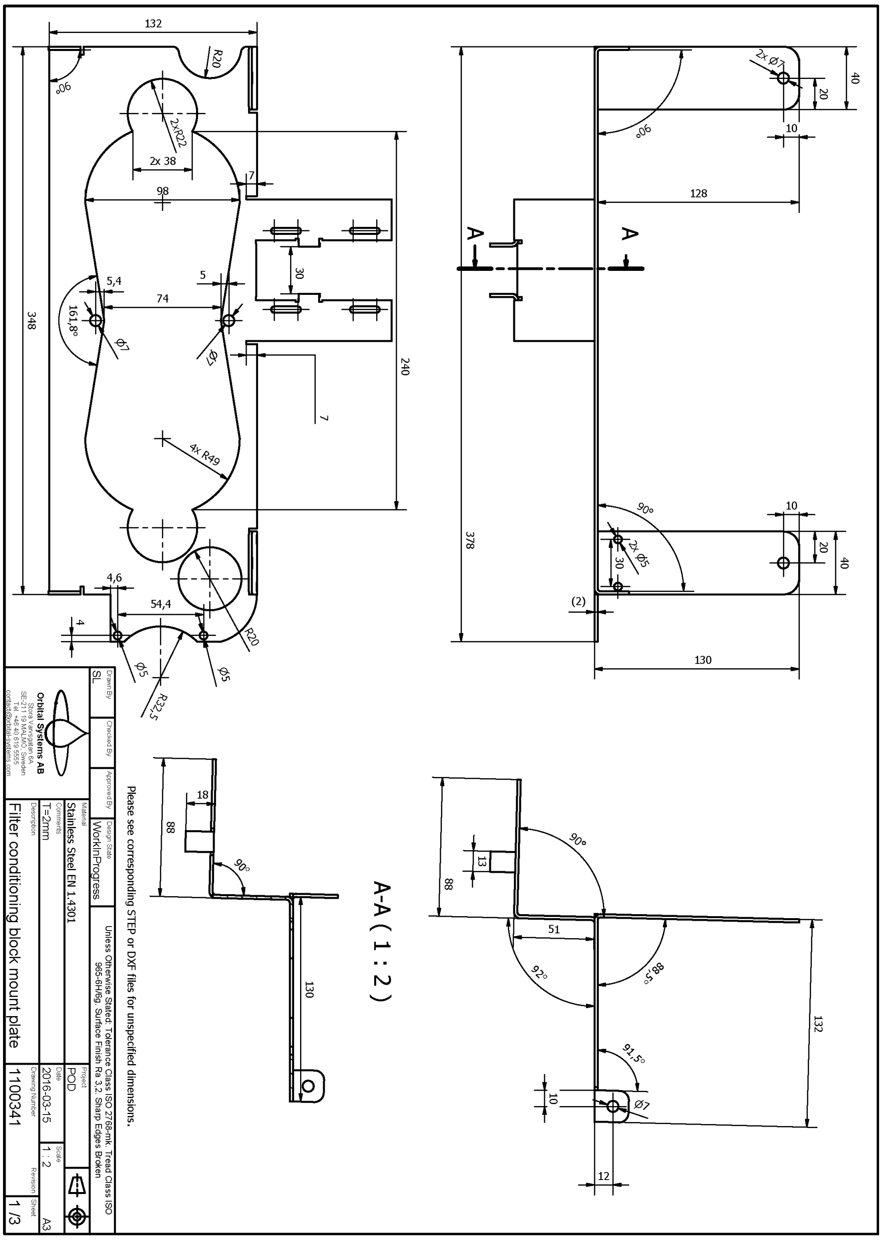
Flat pattern (1 : 4)



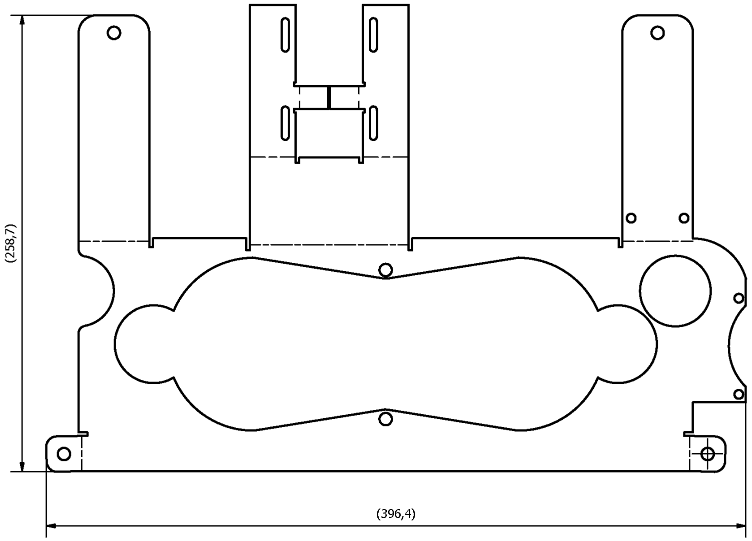
Drawn By	Checked By	Approved By	Design State	Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
SL			WorkInProgress	

Orbital Systems AB Stora Varvsgatan 6A SE-211 19 MALMÖ, Sweden Tel. +46 40 619 5555 contact@orbital-systems.com	Material **Aluminum**	Project POD		
	Comments T=2mm	Date 2016-03-31	Scale 1 : 4	A4
	Description Whale main mount plate	Drawing Number 1100455	Revision	Sheet 11 /11

B.2 Mounting plates

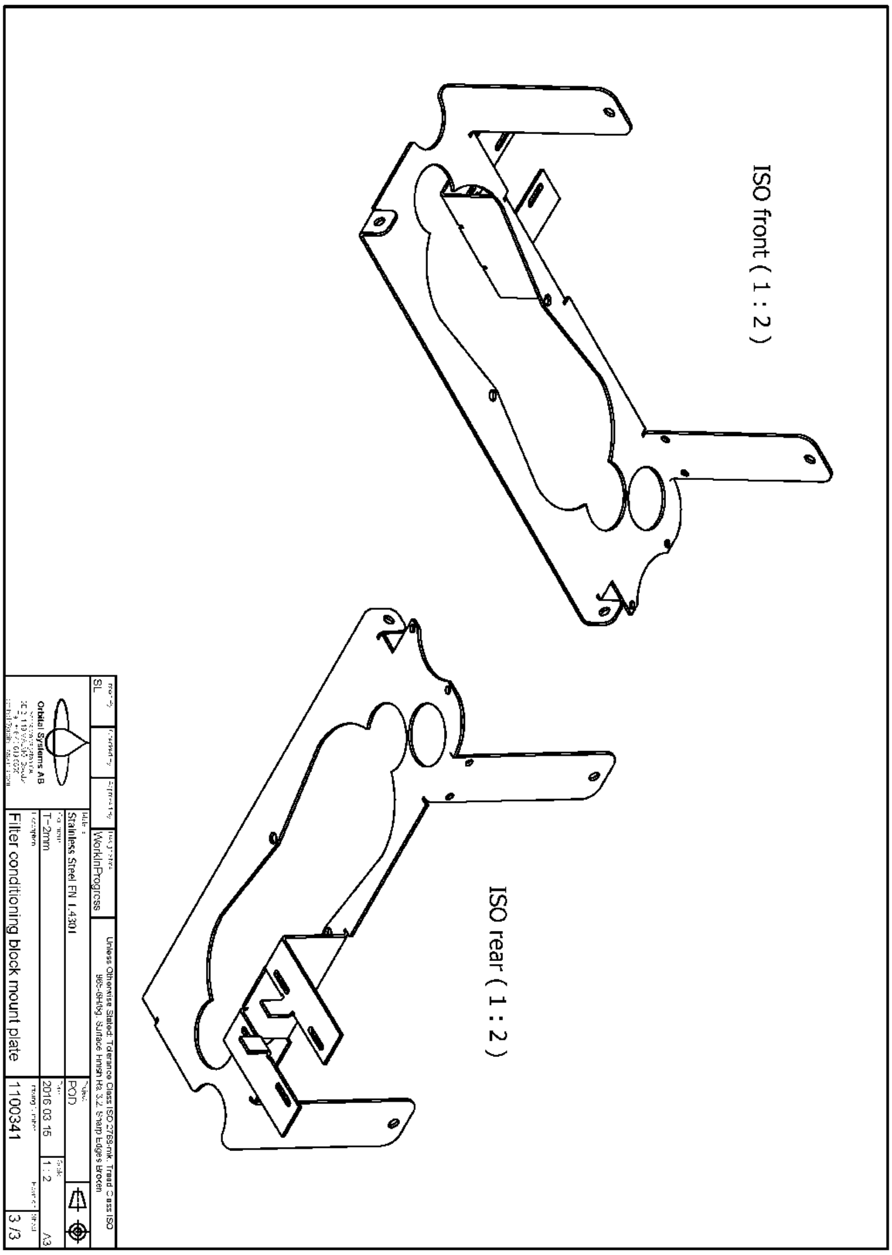

A-A (1 : 2)
Please see corresponding STEP or DXF files for unspecified dimensions.
Unless Otherwise Stated: Tolerance Class ISO 2768-mk Tread Class ISO 965-6H/6g Surface Finish Ra 3.2 Sharp Edges Broken
SL
WorkInProgress
Stainless Steel EN 1.4301
T=2mm
Filter conditioning block mount plate
POD
2016-03-15
1100341
1 : 2
A3
1 /3
Orbital Systems AB

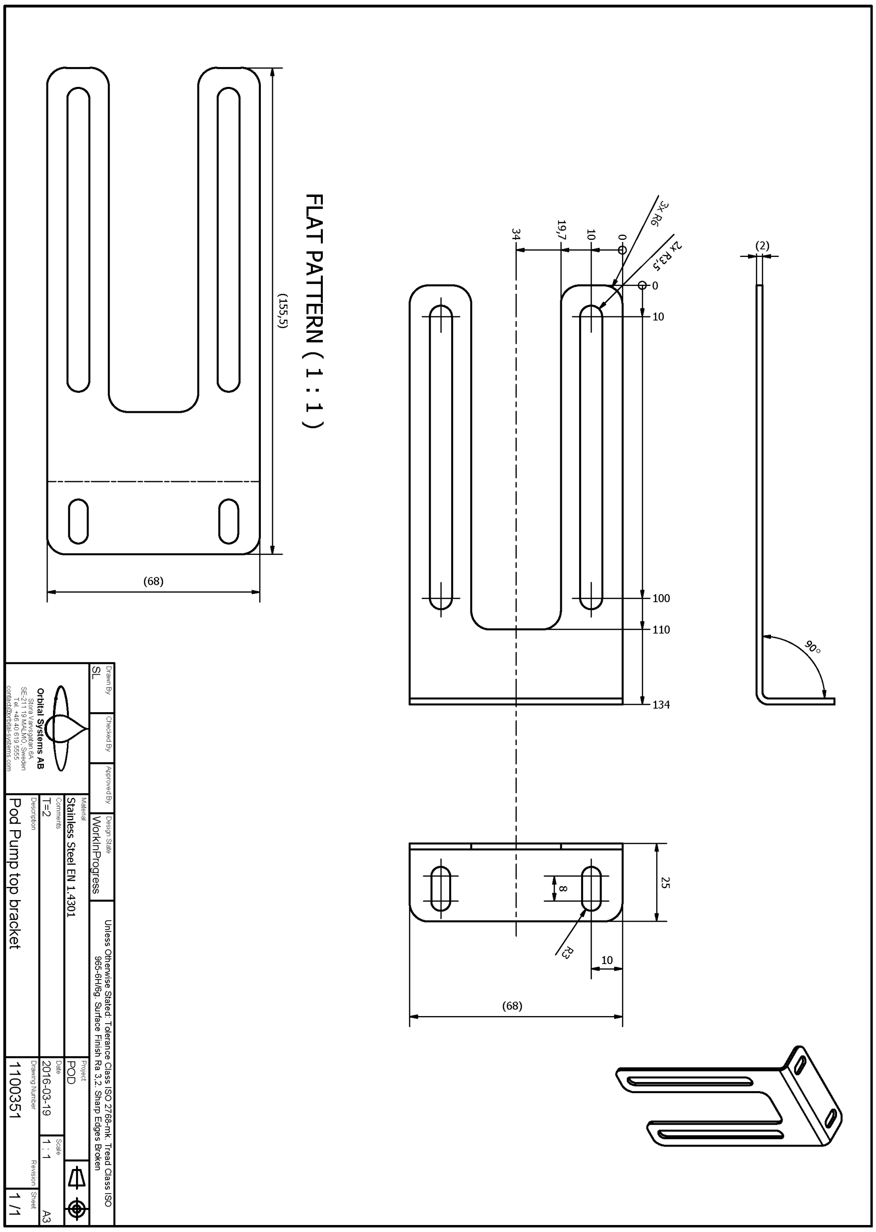
Flat pattern (1 : 2)

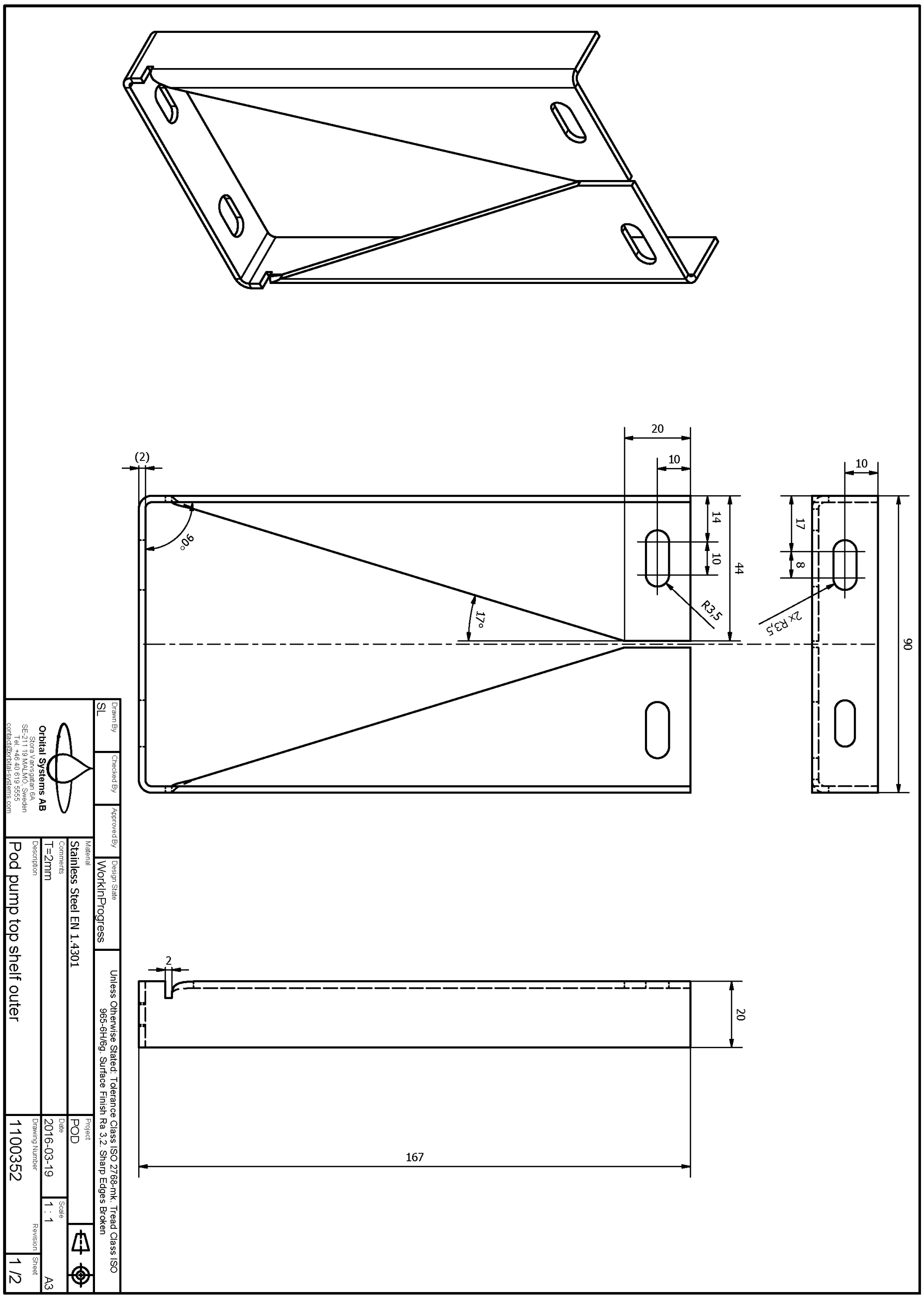


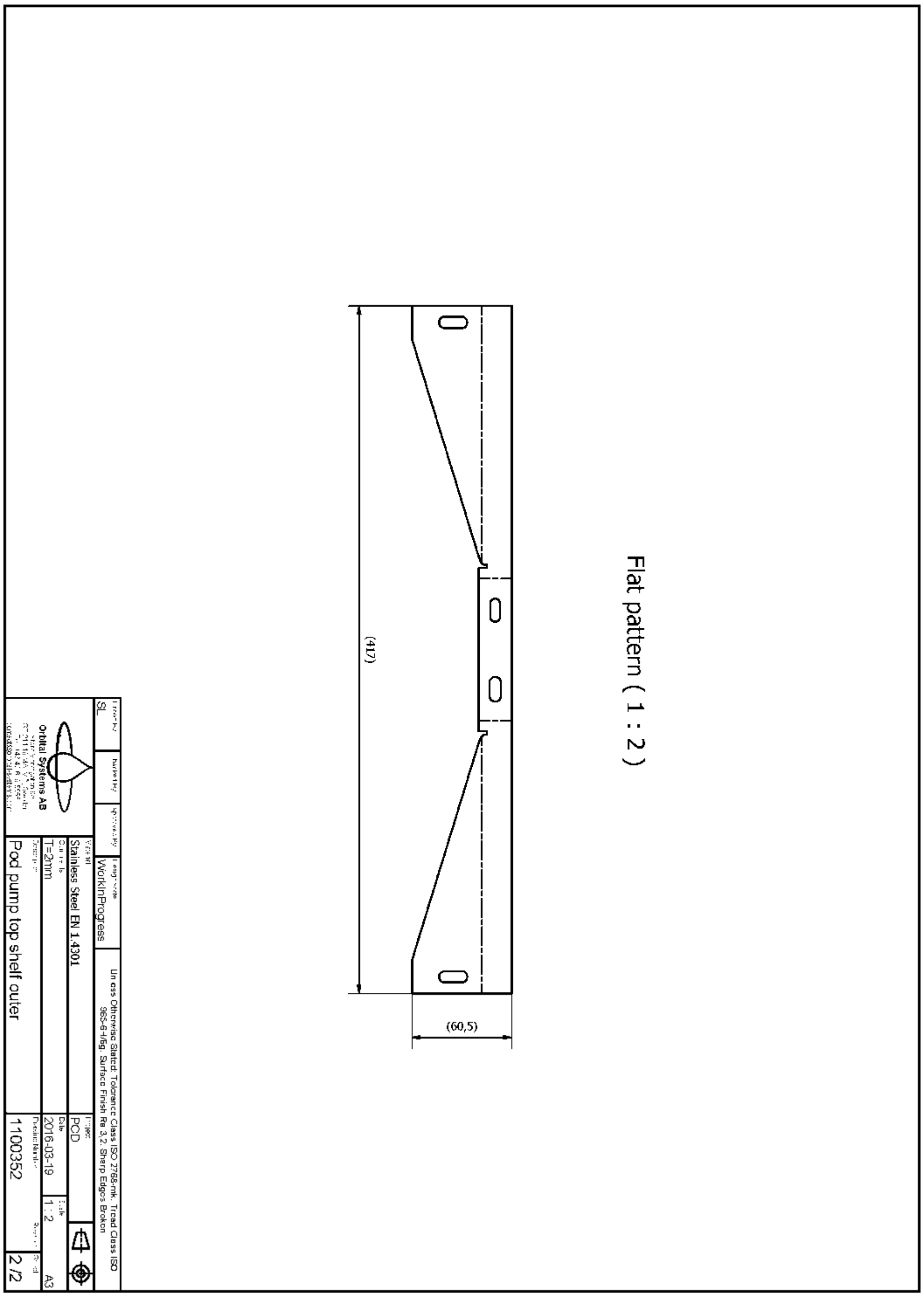
Drawn By	Checked By	Approved By	Design State	Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
SL			WorkInProgress	

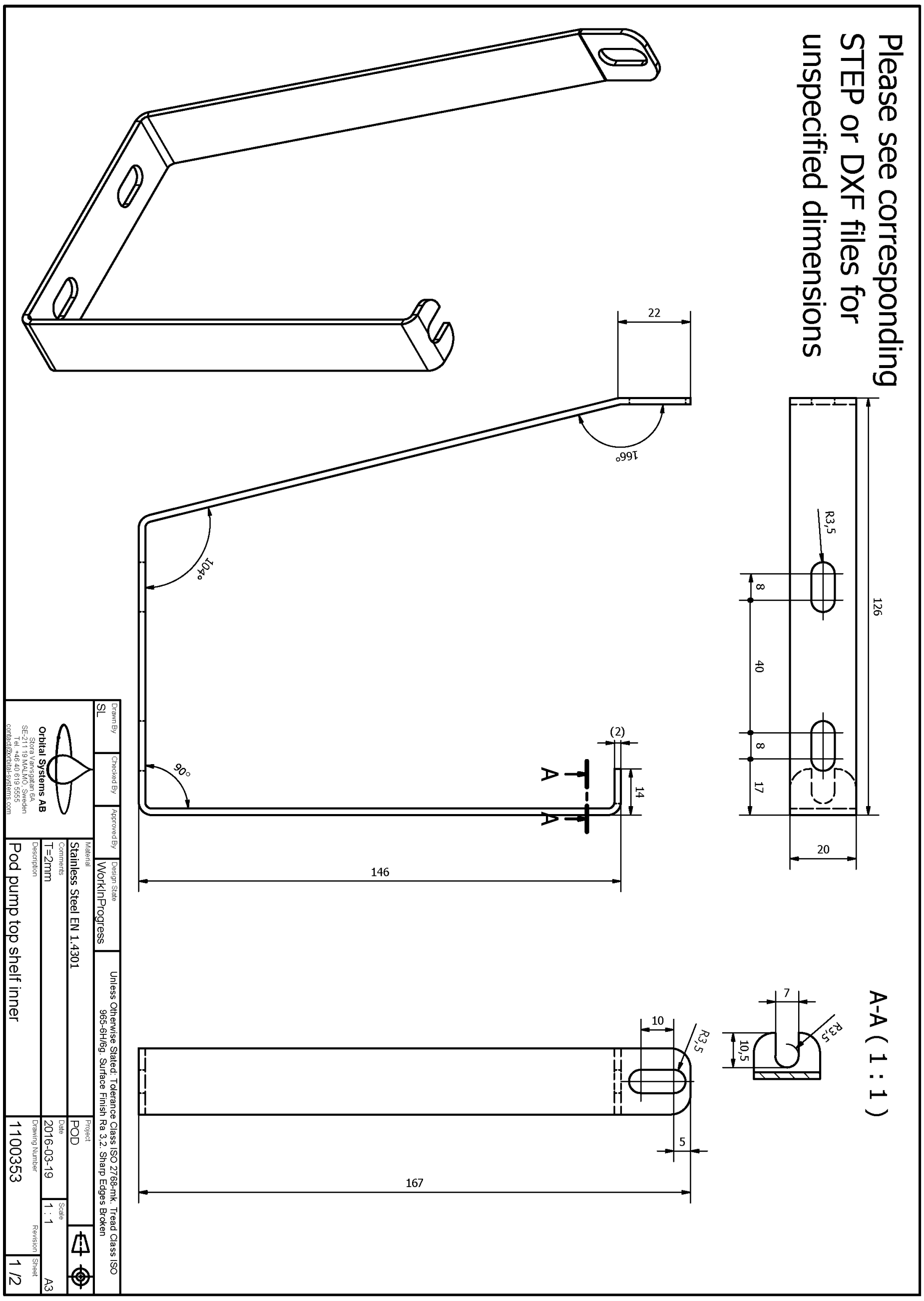
Orbital Systems AB Stora Varvsgatan 6A SE-211 19 MALMÖ, Sweden Tel. +46 40 619 5555 contact@orbital-systems.com	Material: Stainless Steel EN 1.4301	Project: POD		
	Comments: T=2mm	Date: 2016-03-15	Scale: 1 : 2	A3
	Description: Filter conditioning block mount plate	Drawing Number: 1100341	Revision:	Sheet: 2 /3


ISO front (1 : 2)
ISO rear (1 : 2)
SL
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mK. Tread Class ISO 965-6H/6g. Surface Finish Ra 3.2. Sharp Edges Broken
Orbital Systems AB
Stainless Steel EN 1.4301
T=2mm
Filter conditioning block mount plate
POD
2016 03 15
1 : 2
A3
1100341
3 /3

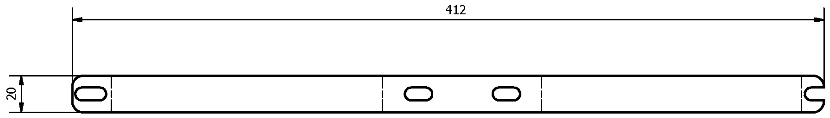

FLAT PATTERN (1 : 1)
(155,5)
(68)
34
19,7
10
0
3x R6
2x R3,5
100
110
134
(2)
90°
25
8
R3
Orbital Systems AB
Drawn By
SL
Checked By
Approved By
Design State
WorkInProgress
Material
Stainless Steel EN 1.4301
Comments
T=2
Description
Pod Pump top bracket
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3.2. Sharp Edges Broken
Project
POD
Date
2016-03-19
Scale
1 : 1
Drawing Number
1100351
Revision
Sheet
1 /1
A3


20
10
(2)
14
10
44
17
8
90°
17°
R3,5
2x R3,5
90
2
20
167
Drawn By
SL
Checked By
Approved By
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3.2. Sharp Edges Broken
orbital Systems AB
Material
Stainless Steel EN 1.4301
Comments
T=2mm
Description
Pod pump top shelf outer
Project
POD
Date
2016-03-19
Scale
1 : 1
Drawing Number
1100352
Revision
Sheet
A3
1 /2


Flat pattern (1 : 2)
(417)
(60,5)
SL
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
Orbital Systems AB
Stainless Steel EN 1.4301
PCD
T=2mm
2016-03-19
1 : 2
A3
Pod pump top shelf outer
1100352
2 /2


Please see corresponding STEP or DXF files for unspecified dimensions
22
166°
104°
90°
(2)
14
A
A
146
R3,5
8
40
8
17
126
20
A-A (1 : 1)
7
R3,5
10,5
10
R3,5
5
167
Drawn By
SL
Checked By
Approved By
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk, Tread Class ISO 965-6H/6g, Surface Finish Ra 3,2, Sharp Edges Broken
Orbital Systems AB
Material
Stainless Steel EN 1.4301
Comments
T=2mm
Description
Pod pump top shelf inner
Project
POD
Date
2016-03-19
Drawing Number
1100353
Scale
1 : 1
A3
Revision
Sheet
1 /2

Flat pattern (1 : 2)



Drawn By	Checked By	Approved By	Design State	Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken		
SL			WorkInProgress			
Orbital Systems AB Stora Varvsgatan 6A SE-211 19 MALMÖ, Sweden Tel. +46 40 619 5555 contact@orbital-systems.com			Material: Stainless Steel EN 1.4301	Project: POD		
			Comments: T=2mm	Date: 2016-03-19	Scale: 1 : 2	A3
			Description: Pod pump top shelf inner	Drawing Number: 1100353	Revision:	Sheet: 2 /2

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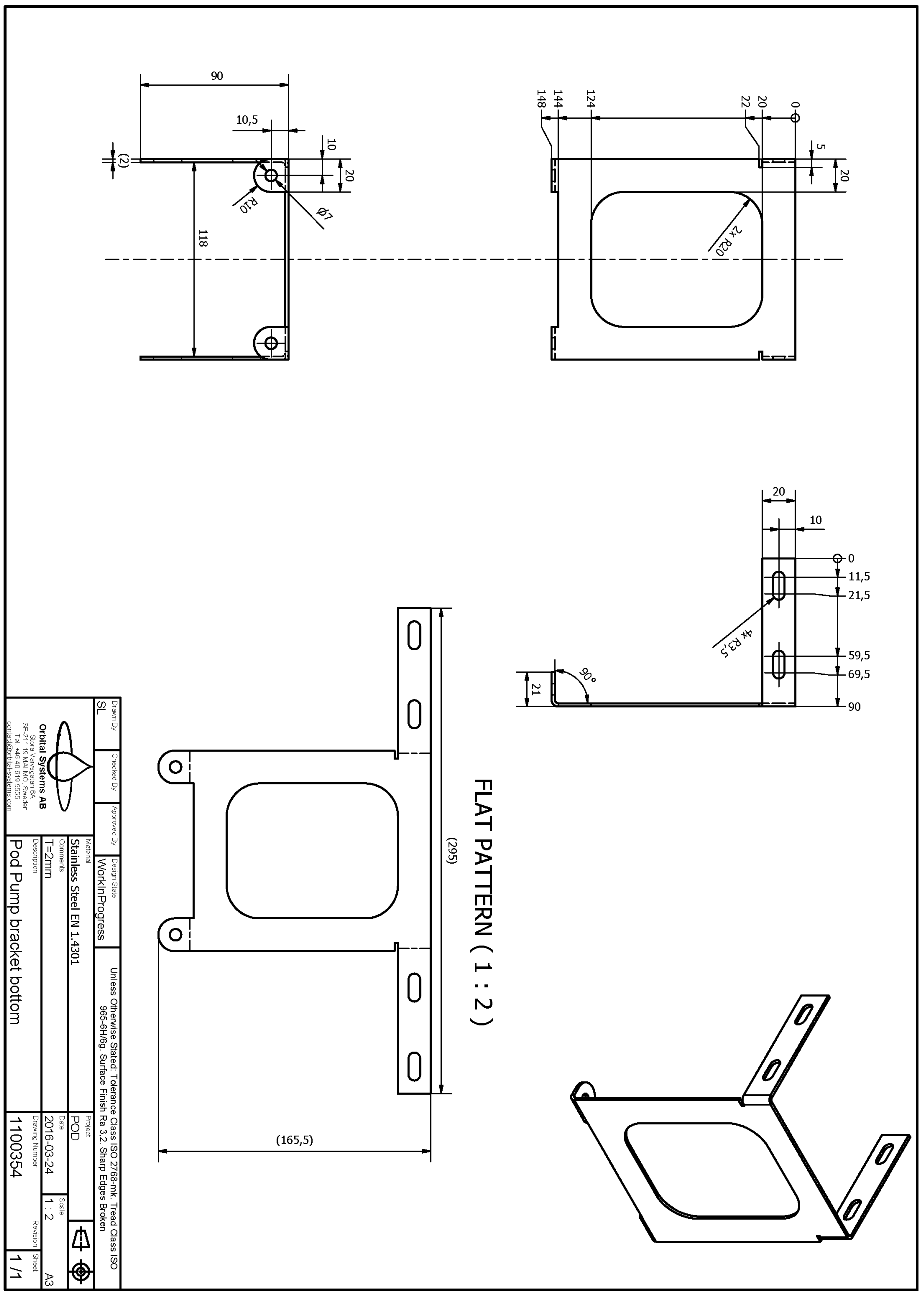
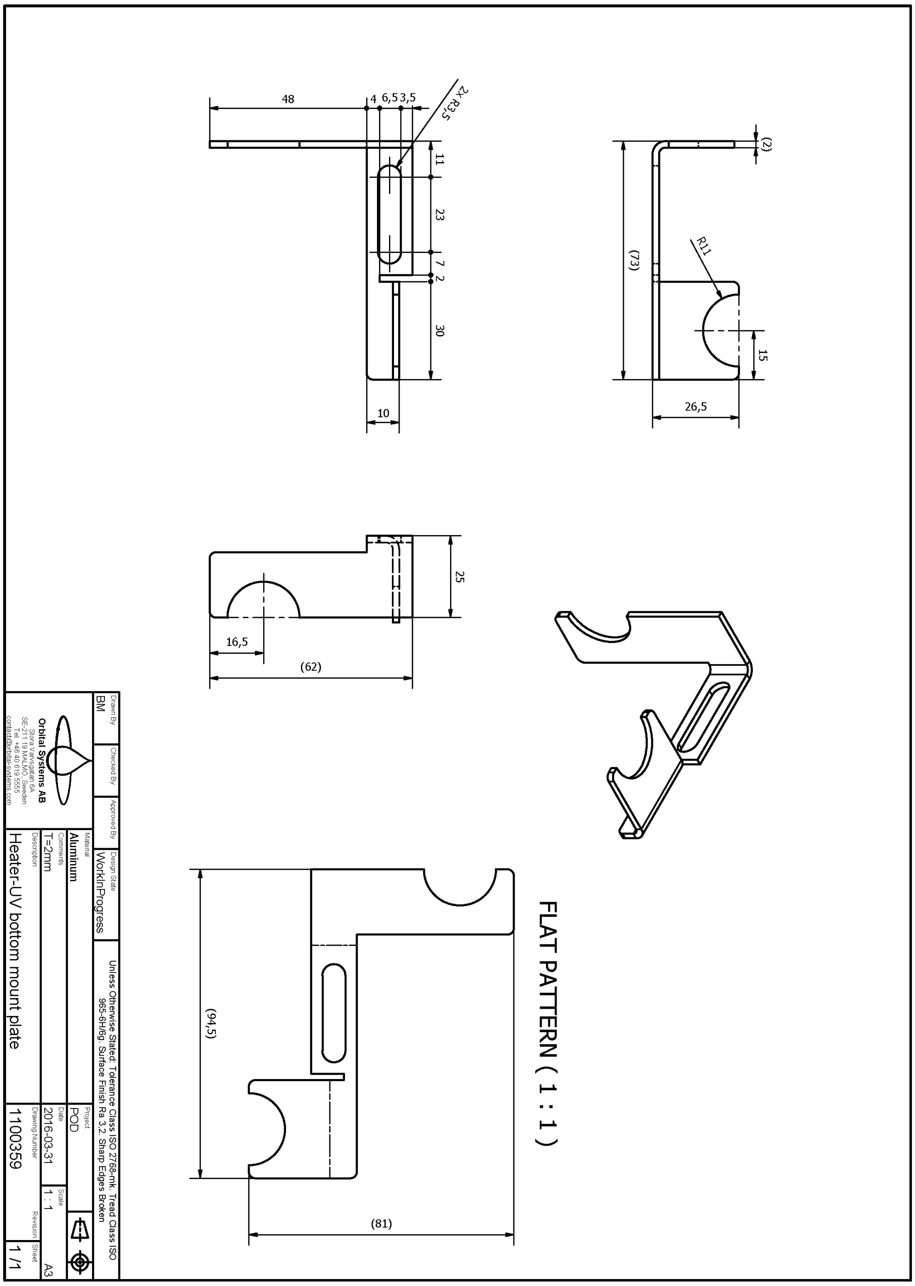
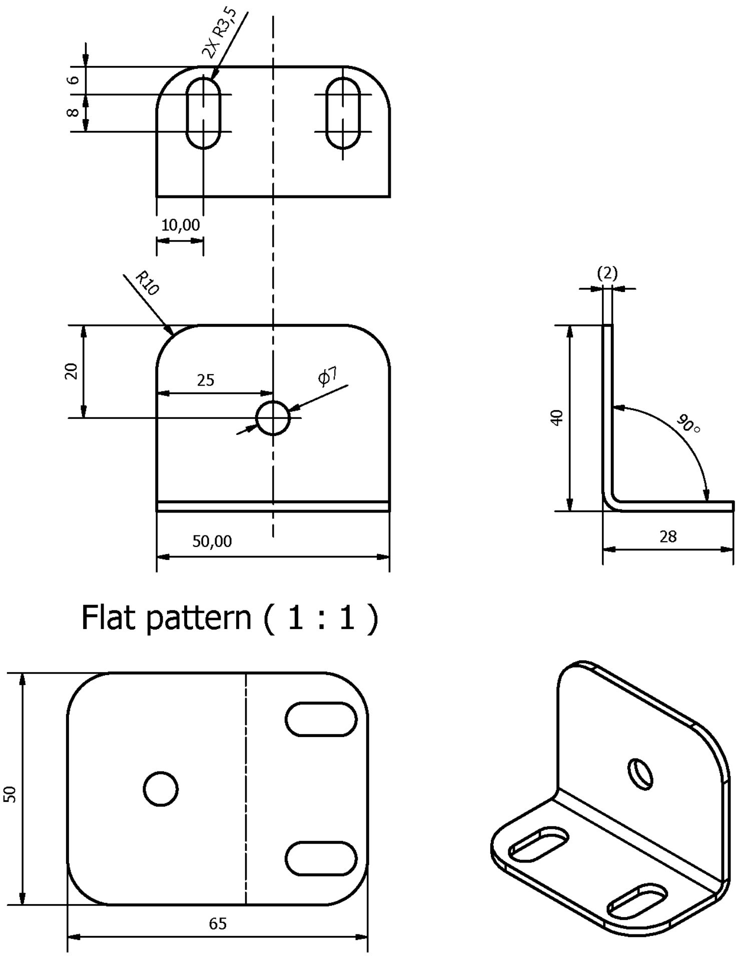


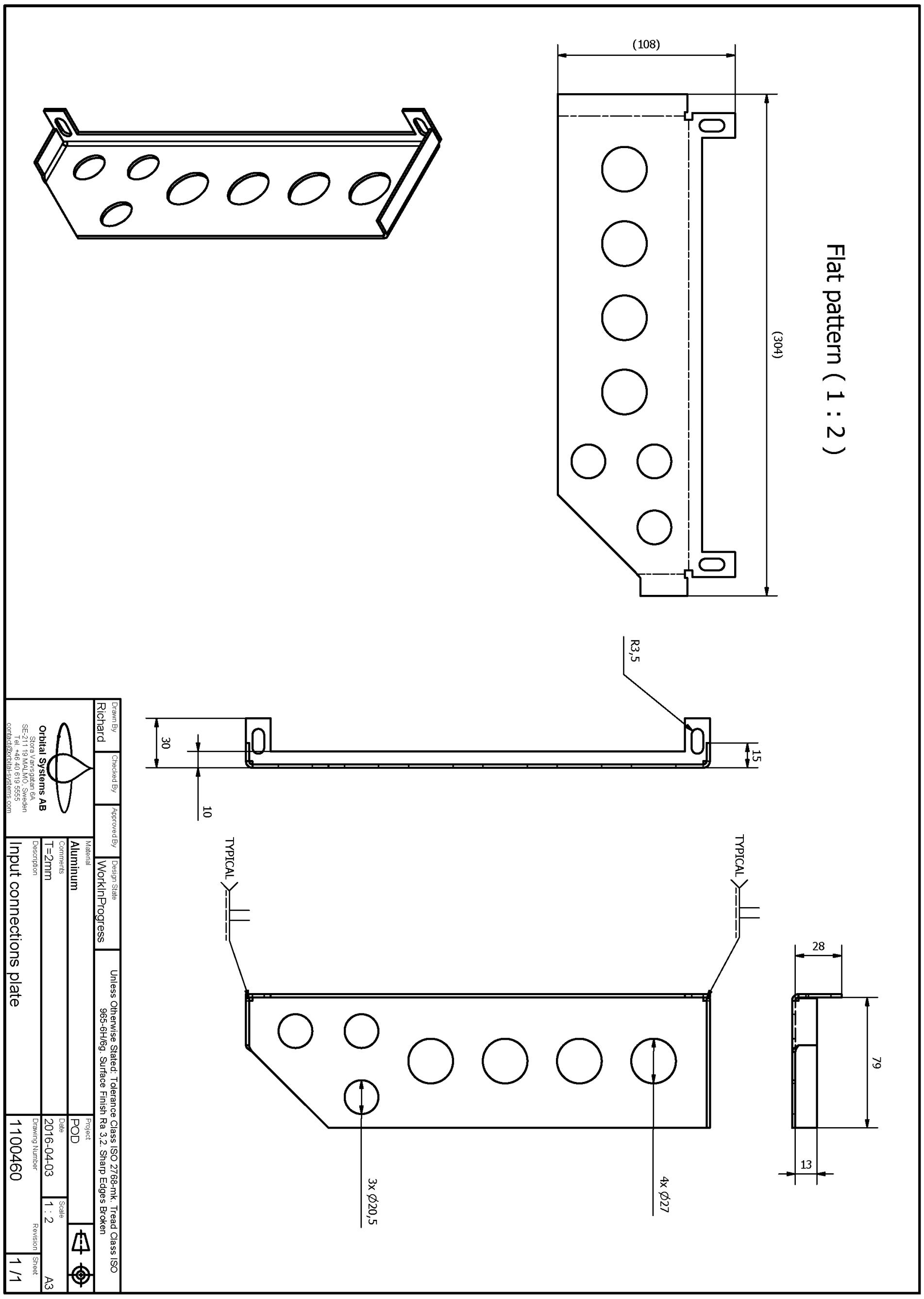

48
4
6,5
3,5
2X R3,5
11
23
7
2
30
10
(2)
(73)
R11
15
26,5
25
16,5
(62)
FLAT PATTERN (1 : 1)
(94,5)
(81)
Drawn By
BM
Checked By
Approved By
Design State
WorkInProgress
Material
Aluminum
Comments
T=2mm
Description
Heater-UV bottom mount plate
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
Project
POD
Date
2016-03-31
Scale
1 : 1
Drawing Number
1100359
Revision
Sheet
1 /1
A3
Orbital Systems AB

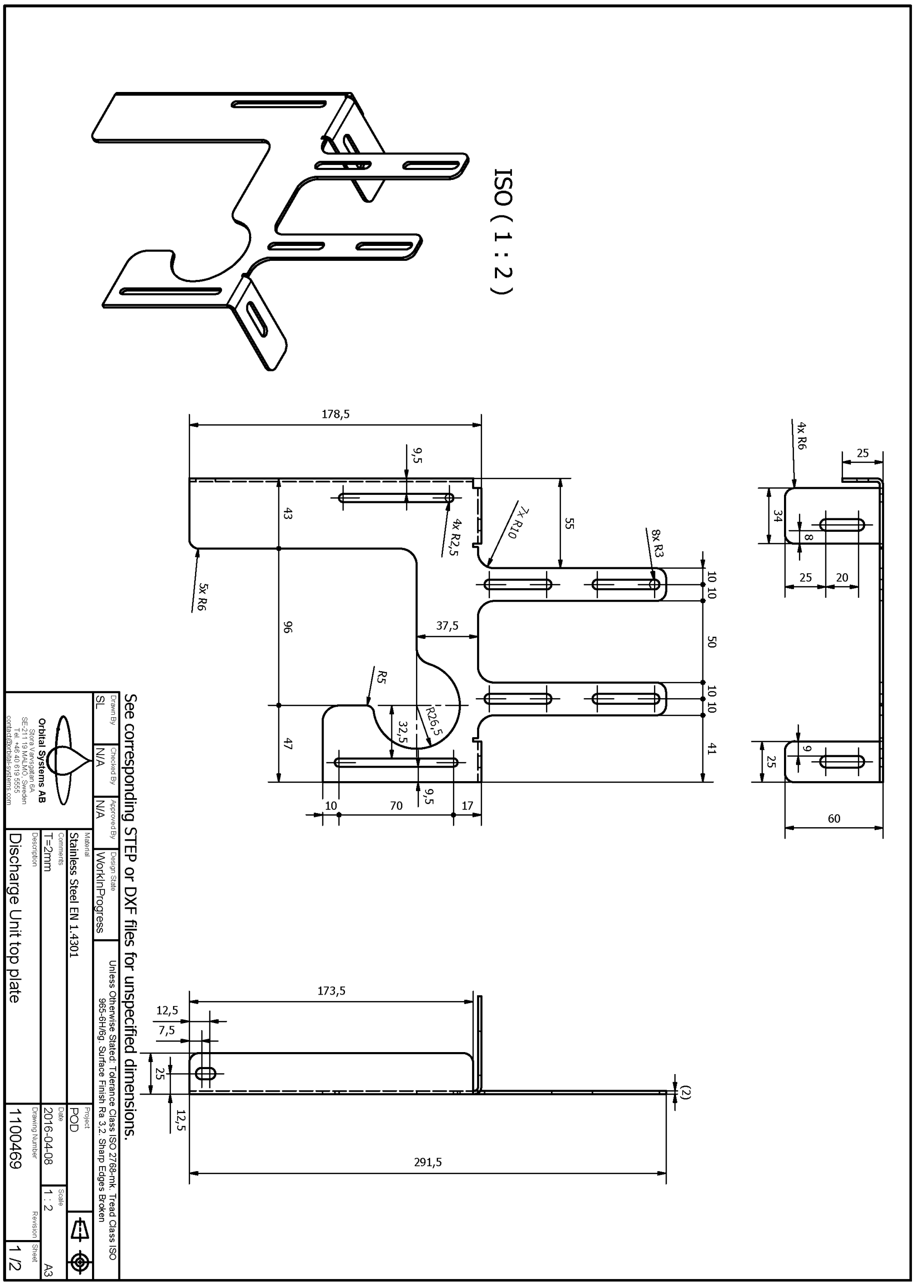
Please see corresponding STEP or DXF files for unspecified dimensions



Drawn By	Checked By	Approved By	Design State	Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
SL			WorkInProgress	

Orbital Systems AB Stora Varvsgatan 6A SE-211 19 MALMÖ, Sweden Tel. +46 40 619 5555 contact@orbital-systems.com	Material: Aluminum	Project: POD	
	Comments: T=2mm	Date: 2016-03-31	Scale: 1 : 1 A4
	Description: Power switch box mount plate	Drawing Number: 1100456 Revision:	Sheet: 1 /1


(108)
(304)
Flat pattern (1 : 2)
R3,5
30
10
15
TYPICAL
TYPICAL
28
79
13
3x Ø20,5
4x Ø27
Drawn By
Richard
Checked By
Approved By
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
Orbital Systems AB
Stora Varvsgatan 6A
SE-211 19 MALMÖ, Sweden
Tel. +46 40 619 5555
contact@orbital-systems.com
Material
Aluminum
Comments
T=2mm
Description
Input connections plate
Project
POD
Date
2016-04-03
Scale
1 : 2
A3
Drawing Number
1100460
Revision
Sheet
1 /1


ISO (1 : 2)
See corresponding STEP or DXF files for unspecified dimensions.
Drawn By SL
Checked By N/A
Approved By N/A
Design State WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
Orbital Systems AB
Material Stainless Steel EN 1.4301
Project POD
Comments T=2mm
Date 2016-04-08
Scale 1 : 2
A3
Description Discharge Unit top plate
Drawing Number 1100469
Sheet 1 /2

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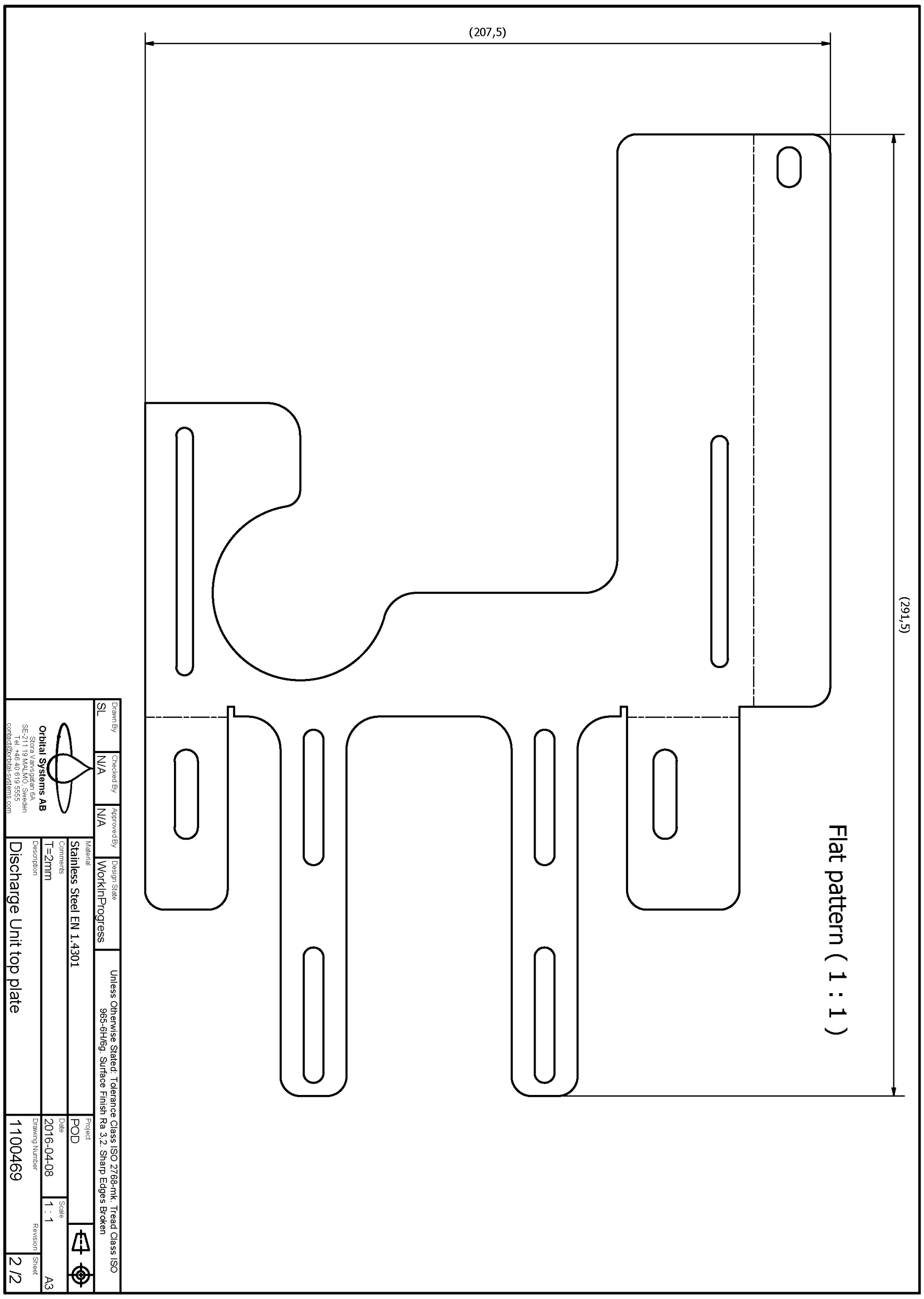

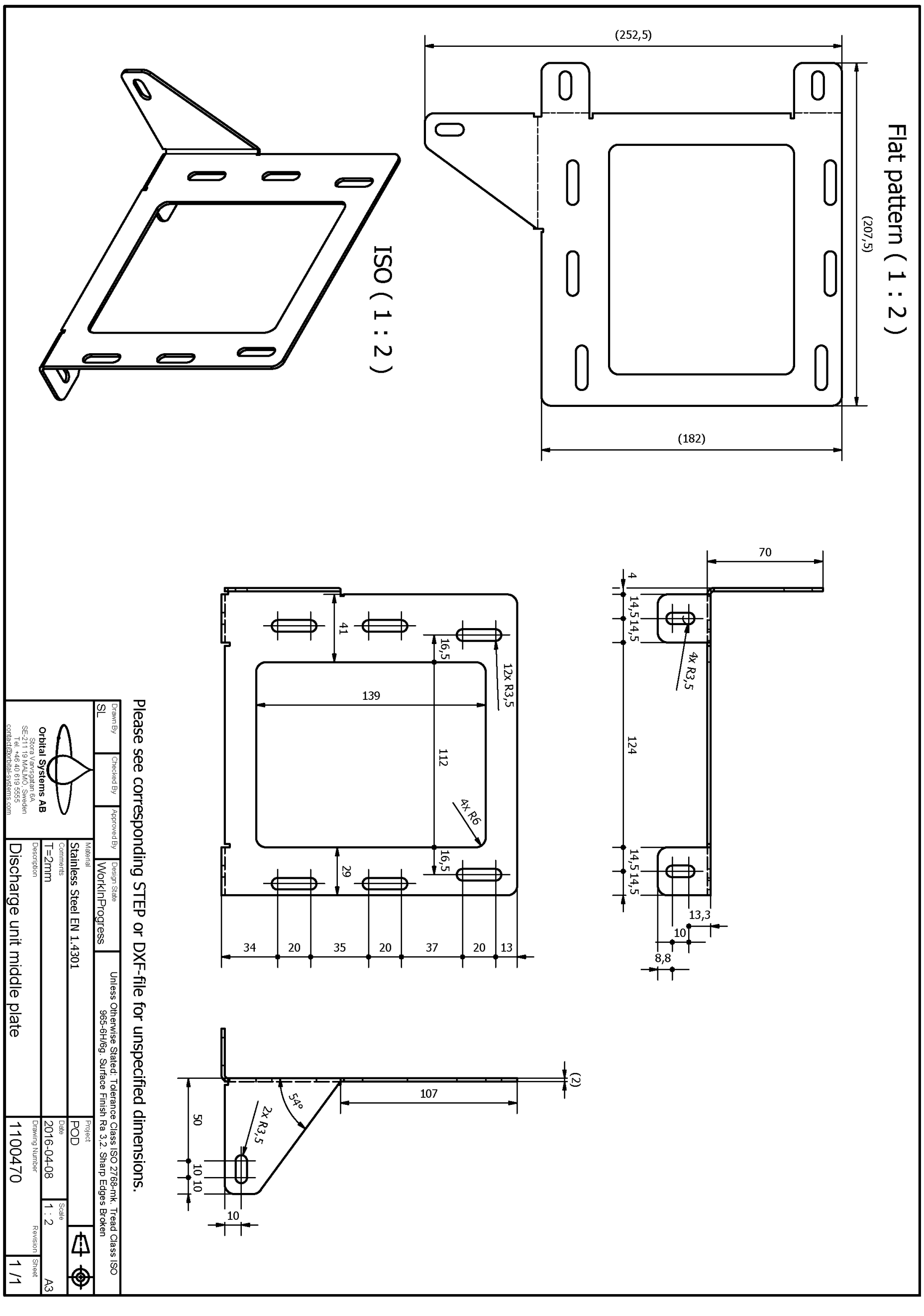
ISO (1 : 2)
Flat pattern (1 : 2)
(252,5)
(207,5)
(182)
Please see corresponding STEP or DXF-file for unspecified dimensions.
Drawn By
SL
Checked By
Approved By
Design State
WorkInProgress
Unless Otherwise Stated: Tolerance Class ISO 2768-mk. Tread Class ISO 965-6H/6g. Surface Finish Ra 3,2. Sharp Edges Broken
Orbital Systems AB
Stora Varvsgatan 6A
SE-211 19 MALMÖ, Sweden
Tel. +46 40 619 5555
contact@orbital-systems.com
Material
Stainless Steel EN 1.4301
Comments
T=2mm
Description
Discharge unit middle plate
Project
POD
Date
2016-04-08
Scale
1 : 2
Drawing Number
1100470
Revision
Sheet
1 /1
A3
12x R3,5
4x R6
4x R3,5
2x R3,5
54°

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