River Trash Collector System
Prototype Development and Analysis

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CHAPTER I

SYSTEM CONCEPTION

Introduction

It well understood that our waterways and waterbodies are being increasingly polluted as a result of human activity. It is estimated that 8 million tons of plastic would enter our Oceans each year, a figure that is set to double by 2030. The problem is further exacerbated by the fact petroleum-based plastics do not decompose easily, and will very easily continue to float on the surface for millennia to come. Already, the plastic waste disposed into our water bodies is proving to have deleterious effects on marine wildlife and the ecosystem, with marine creatures often mistaking plastic waste for food and seriously injuring themselves when they get entangled with the trash. Addressing the problem would undoubtedly require a proactive solution across multiple domains, making effective use of various policy instruments, increasing public awareness, and developing solutions that actively remove such pollution from our waters.

While it is understood that there are already existing solutions that exist for collecting trash in the river (and the ocean), the solution presented herein is novel as it is an installation that can operate continuously, while still offering the flexibility of being stowed away should the need arise. This makes it possible to use the system in waterways where human activity may simultaneously take place.

In this paper, we examine in close detail the development of a River Trash Collection System (RTCS) as well as its capabilities and limitations. We also will provide detailed physics-based analysis of the RTCS's operation and lay the ground work to demonstrate that this concept can be scaled practically. Finally, we will examine the computer control logic behind the RTCS, which is implemented as Arduino Code.

History of System Development

The RTCS concept was not actually started with the intention of clearing trash in the rivers per se. Rather, the initial intention of this project was to clear trash in the oceans. To this effect, the first few concepts conceived were systems that could operate autonomously with little to no human intervention. These nascent conceptions all had a unifying factor, in that they were not fixed installations and would float on the surface of the ocean, following predefined paths according with an inbuilt GPS sensor. It was envisioned that this system would comprise of multiple trash collection devices, all of which would work cooperatively to clean a given area of ocean.

The initial concept called for 3 floating buoys spaced out equally, with a flow guide acting as a beam to connect the 3 buoys together structurally. In the outermost buoys, would be fitted 2 geared motors which would drive an auger screw. This auger screw would rotate in order to move any object pressed against it toward the center buoy. It was planned that the center buoy would house the key electrical components, namely the DC batteries, the appropriate voltage regulators, as well as the Guidance Navigation and Control Systems (GNC). In addition to these components, the center buoy would have to store all the trash collected by the system during its course of operation. This necessitated that the volume of the center buoy be much larger than the other 2 outboard buoys.

As this was conceived to be a floating platform, the appropriate propulsion systems had to be fitted. Main propulsion would be provided by a DC motor attached to an impeller, mounted on the centerline of the apparatus. This DC motor would be able to generate thrust to move the apparatus both forward and back. Control of heading is provided for by 2 smaller impellers (attached to correspondingly sized DC motors) mounted on the underside of the 2 outboard buoys. These would activate differentially to steer the system in the correct direction. This was chosen compared to servo-controlled fins as the motor would allow steering to take place even though the vehicle was not moving in the water. Steering Commands would either be issued by the onboard GNC computers in accordance with the pre-programmed route, or by a human operator if he/she was within range.

Foundationally, the system had to be autonomous in terms of it power supply, to power all of its various systems. The apparatus conceived would be fitted with solar panels spanning across the flow guide, that would charge the batteries as the vehicle performed its functions. In addition to solar power, wave power was considered as a supplemental source of power for the vehicle. The wave energy would have been harnessed by using the waves to 'windmill' the auger screw and allowing it to turn freely to drive a generator when it was not active moving trash to the center storage in the buoy.

The operator would designate an area in which he/she wanted the vehicle to clean, and would release the vehicle in the water. The apparatus would then power through the area in a pre-determined manner, forcing trash into the flow guides while simultaneously turning the Auger screw. The intended effect of this would be to move trash inward into the center storage.

Alternative methods of trash collection in the ocean included a venturi system, where water is forced through a constriction thereby reducing its static pressure. The constriction is connected to an inlet in front of the apparatus, and this creates a 'suction' force that causes trash to be sucked into the inlet. The trash will then enter the (relatively) narrower constriction, where it is flushed to a storage area located aft of the vehicle.

<u>*A jolt of reality*</u>

In the actual event, the aforementioned floating ocean trash collector was eventually abandoned in favor of the RTCS, for a multitude of reasons. Firstly, came the issue of the harsh environmental conditions that the apparatus would be expected to operate in. A problem that most (if not) ocean-based trash collectors face are waves. Any platform that is designed to operate in the ocean must be able, in some capacity, to withstand the effect of waves, more so if the platform is designed to float on the water surface. This was no doubt, very hard to do given that the apparatus must be able to continue performing its functions of collecting trash in spite of the harsh waves that may develop. At the time of writing, there was no accessible method of (physically or computationally) simulating the waves to a degree that was satisfactory.

The next issue that arose was that of power consumption. It was estimated that the energy requirements of such a system would be hard to satisfy with non-terrestrial power sources (i.e. Batteries). Relative to other onboard systems, the high torque motors required to drive the Auger Screw, in combination with the propulsion and directional control motors would have much higher power requirements. These were found to rapidly drain the batteries, even with the charging provided by the solar panels. While overcoming this problem was not impossible (the vehicle would have to sit stationary for a while to recharge) the time it would require to do so would make the system very inefficient.

There are inherent problems that would arise as a result of storing trash in a floating platform. Firstly, there has exist some mechanism to remove the water from the trash before storing the trash in the holding area in the center buoy. Without such a mechanism, the floating platform would rapidly take on water and accumulate in weight, which would affect the performance of the system in multiple ways. Beyond the obvious risk of sinking, this additional weight would increase the power draw of the motor and reduce the maneuverability of the system. While the trash itself is not very dense (since the system would collect waste that floats, namely low-density plastics), it can be compacted to increase volumetric efficiency on the vehicle and increase the amount of trash it can collect, which leads to the next point.

While it can be argued that the prototype is intended to increase the technical maturity of the concept, the overall system that was conceived was generally far too complex and too far in it nascency to be developed in a timely manner. While the Auger screw has demonstrated itself in a terrestrial trash compactor context, it has not been operated on a water-based vehicle for the same purpose, much less on an autonomous floating waste collecting platform. Not only was there a lack of understanding of how the auger compactor would operate in the water, there was also a lack of time to properly experiment and gain this understanding.

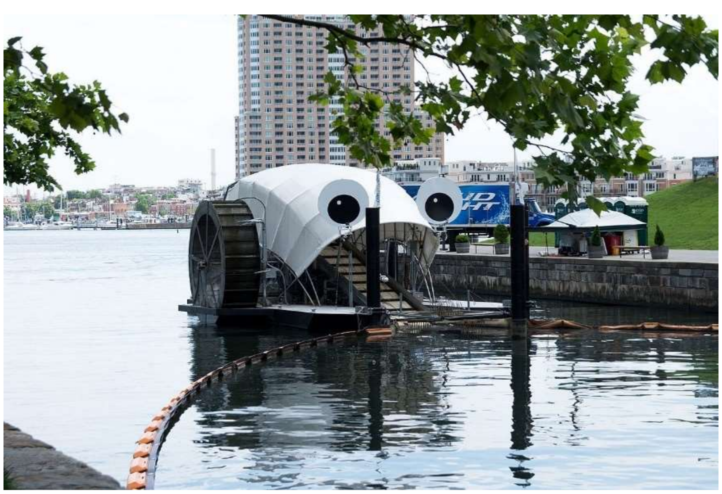
For these reasons, it was eventually decided that the concept would need to be modified to reduce its complexity.

<u>The new and improved concept</u>

Some ocean-based trash collectors have traditionally been located close to the shore, where they are easily serviceable and accessed. The underlying strategy was reconsidered. Instead of trying to clean up the waste that already existed in the ocean which spans far and wide, it would be easier to interdict it *before* it actually entered the ocean. As most of the trash that enters the oceans would need do so from the river, it would be very appropriate to tailor our solution to extracting trash from the river, thereby preventing it from eventually reaching the ocean. Such a solution incorporated elements from the previous concept. As most (if not all) rivers intrinsically have some level of flow speed, it was decided that the solution developed should seek to use this intrinsic flow to move the trash in the desired direction. Hence, the flow guide was retained, to allow for control in water flow direction.

The flow guide would be sit across the width of the river, from bank to bank, only being partially submerged. By not coming into contact with the river bed, marine life and other animals would be allowed to pass through, minimizing ecological disturbances. However, while the flow guide does allow fishes and other wildlife to pass, it does not allow water vehicles (like boats) to pass while the flow guide is deployed, which would be a nuisance to human activity in the river. Therein lies the second key feature: The flow guide would be designed to be retractable, to allow such water vehicles to continue using the waterway as per needed.

Given that waste now flows due to the intrinsic flow velocity, the need for an Auger screw is removed, and along with it, the set of high torque motors. Given that the entire installation is now mounted (partially) terrestrially, there would be now be much no concern over power requirements, as any necessary power can be supplied using existing terrestrial infrastructure. Maintenance required would be much easier, as the installation could be accessed much more easily The need for any propulsion or steering system would also disappear, and the associated GNC systems. Gone as well are the concerns of sinking or insufficient storage space on the platform.



Collection would now be done by a conveyor belt system located by the bank of the river, and the waste, stored in a temporary holding area. Such an arrangement has already been demonstrated by systems like ‘Mr Trash Wheel’ which is located at Baltimore Harbor in the USA.

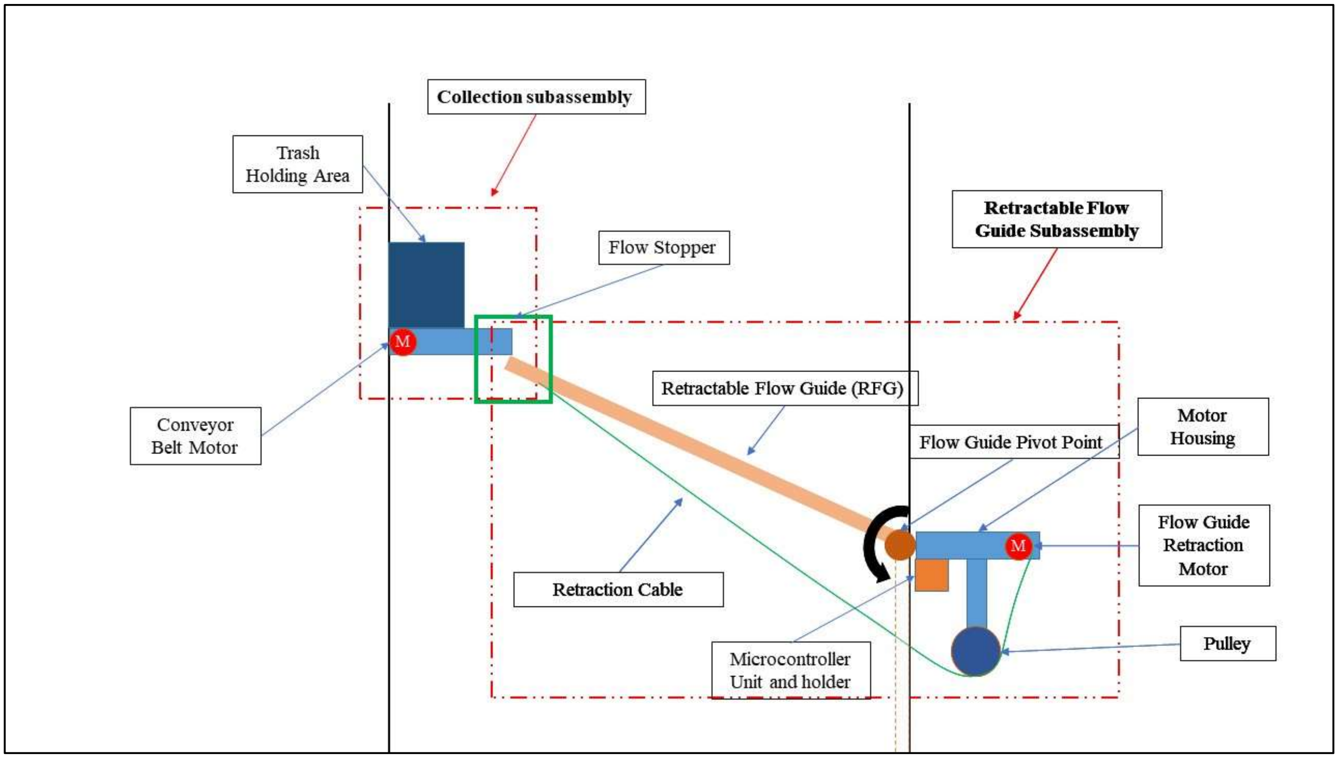
While there were other systems that floated, such as the waste shark system these were not considered as the team determined that a fixed installation would offer advantages in certain areas, such as waste storage and energy management.

For these reasons of increased simplicity and robustness, the RTCS concept was eventually chosen for further development into a prototype, and rigorous analysis conducted on it.

CHAPTER II

SYSTEM COMPONENTS AND FUNCTIONS

Mechanical System Overview



The RTCS prototype developed comprises of 2 main subassemblies the functions of which will be elaborated on in subsequent sections:

a) Retractable Flow Guide Subassembly
b) Extraction Subassembly

These 2 main subassemblies work in tandem with each other, making use of the river itself to accomplish its function. The RTCS takes advantage of the river flow itself, converting part of the downstream flow into a lateral flow component that spans the width of the river. It is this spanwise flow that will carry the trash on the river surface toward the river bank, where the Extraction subassembly will extract it from the water and move it to a temporary holding area, after which it can be readily removed. The RTCS is designed to be a permanent installation which is capable of functioning continuously so long the Flow Guide is in the 'deployed' position. At any time, the flow guide may be retracted to allow free access through the waterway.

Retractable Flow Guide Subassembly

The retractable flow guide subassembly is a collection of a number of different key components, which are illustrated in the table below. Parts which perform certain key functions or have key features would be further elaborated upon.

Name	Function

Retractable Flow Guide (RFG)	The key purpose of the RFG is to guide the flow of the river by imparting a spanwise component in what would otherwise be a fully parallel, downstream flow
Motor Housing	This component houses the geared motor which governs the retraction/deployment of the RFG. Co located on this component are the Hinge points which mount the flow guide and the pulley holder
RFG -Hinge Interface	This component interfaces the flow guide to the hinges on the motor housing, and allows the guide to rotate about the hinge freely
Pulley	Directs the retraction cable toward the flow guide
Winch Drum	Winds the retraction cable during Flow guide retraction
Retraction Cable	Mechanically links the flow guide to the Winch Drum and the Motor, allowing it to be retracted when the motor turns
Flow Guide	Completes the transition between the flow guide and the conveyor on the collector subassembly

Retractable flow guide

The RFG is a roughly semicircular, C shaped trough that is partially submerged into the water. One of the RFG is capped, and 2 M3 holes are incorporated into the cap. These holes are intended to allow the RFG to be attached to the RFG-Hinge interface, through the use of 2 standard ISO M3 x 5 Screws and Hex nuts.

The open end of the RFG is the direction in which the water (carrying with it, floating waste) will flow towards. Located at the open end of the RFG is the collection subassembly, with its conveyor belt system. Slightly inboard of the open end, a small hole is drilled into the wall of the RFG. This hole will allows the retraction cable to be attached to the RFG.

During system operation, the RFG will be deployed to an angle of 30 to 45 degrees relative to the oncoming flow stream, to allow some of the flow to form a spanwise component. When the flow guide needs to be retracted, the motor located in the motor housing will be activated, which, through the retraction cable, will apply a torque to the RFG. Mathematical Analysis of this retraction process will be made available in later sections.

Motor Housing

The motor housing is the component that houses the Winch Drum and the motor. As liberal use of Additive Manufacturing was made, this allowed multiple features to be integrated into the Motor housing. Thus, the motor housing not only houses the motor, but also serves other essential functions in the prototype.

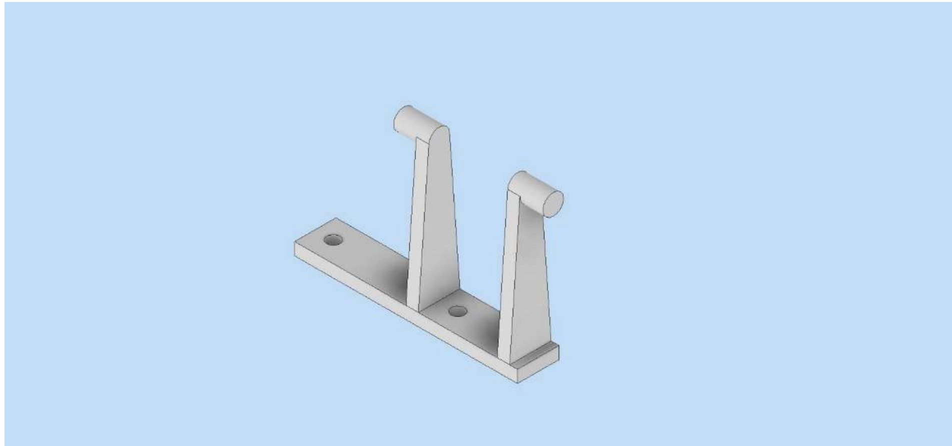
Firstly, in the main chamber where the Winch drum and motor are housed, are locating features for both drum and motor. These come in the form of holes in the wall that serve to align the rotational axis of both motor and winch drum. The motor rests on a small holder to allow its rotational axis to remain concentric with the winch drum. During assembly, it proved to be slightly difficult to insert the motor and the winch drum into the chamber without running the risk of breaking it, and this remains to be improved upon in future implementations of the system. Furthermore, due to shrinkage of the holes during printing, the stub at the end of the motor oculd not be fitted into the locating features,

Integrated with the motor housing is the hinge for the Flow guide. The hinges are 2 tabs which protrude on the end of the holder which is closest to the motor. In each tab is a Ø5 x 5 hole that allows the RFG-Hinger Interface to be mounted on.

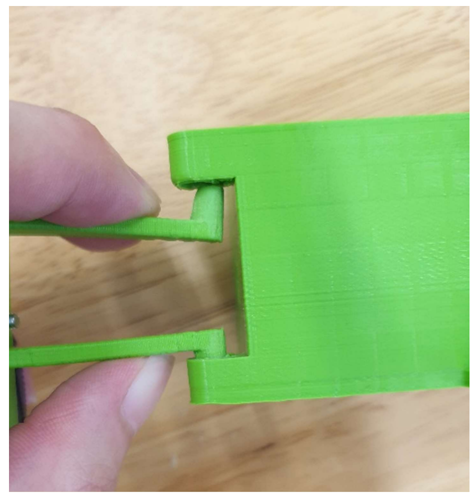
Along with the hinge tabs, is an appendage that serves as a holder for the pulley. This holder comes in the form of a cylindrical feature with a small locating pin on its end. This allows the pulley to be placed on the pin. The height of the cylinder is designed for a pulley with a midplane at 3mm for the cable to wrap around. This because the port through which the retraction cable is fed from the winch has already been aligned with the cylinder.

RFG-Hinge Interface

The RFG-Hinge Interface is an L shaped piece with 2 M3 holes and 2 prong like appendages with a Ø5 pin at the tip.



The 2 M3 holes are attached to the RFG via 2 M3 screws and nuts as mentioned above. The M3 holes on the interface are not symmetrical about the central axis of the interface. This was necessary as the flow guide had to sit slightly below the entire motor housing so it could be immersed in the river flow.



The 2 prongs are intended to allow the hinge interface to be attached to the hinge tab, and are spaced apart to allow a certain degree of flex to develop. These 2 prongs act as springs to keep the Interface (and the RFG) attached to the 2 hinge tabs on the motor housing. Concurrently, the interface is allowed to rotate freely around the hinge axis. After manufacturing, the 2 pins on the interface were given a quick filing to make this rotary action smoother. This 2-prong arrangement allows 'plug and play' functionality with respect to fitting the interface to the hinge tabs, with no external fasteners whatsoever required. The ease of removal and attachment to the hinge tab proved to be much useful when troubleshooting and testing the entire system.

Collection Subassembly

The main role of the collection subassembly is to be the 'sink' for trash collection. It is the portion of the system that will actively remove trash from the water surface, and store it in a holding area. Like the Retractable flow guide subassembly, the collection subassembly consists of a few parts, whose functions and names are specified in the table below:

Name	**Function**
Conveyor Frame	The conveyor frame provides the main structure to mount the timing gears and the belts upon. In addition, space is also allocated to mount the driving motor.
Geared pulley	The geared pulleys prevent the belt from slipping and ensures proper power transmission between belt and motor
Belt	Extracts the trash out of water and moves it toward the Trash Collection chute, and has teeth which are complementary to the Geared Pulley(s).
Trash collection Chute	Temporarily holds the waste until it is time for servicing

Conveyor Frame

The conveyor frame sits partially below the water surface, with a portion of the bet sticking under the water surface. The frame is sized such that the motor, located beside the top pulley, will not be exposed to the water, ensuring it will not be shorted. The geared pulleys are snap fitted onto the 2 vertical supports located to the left of the motor stand, via 2 locating holes on the supports. The supports themselves are mounted upon a small platform, which protrudes out from the motor housing.

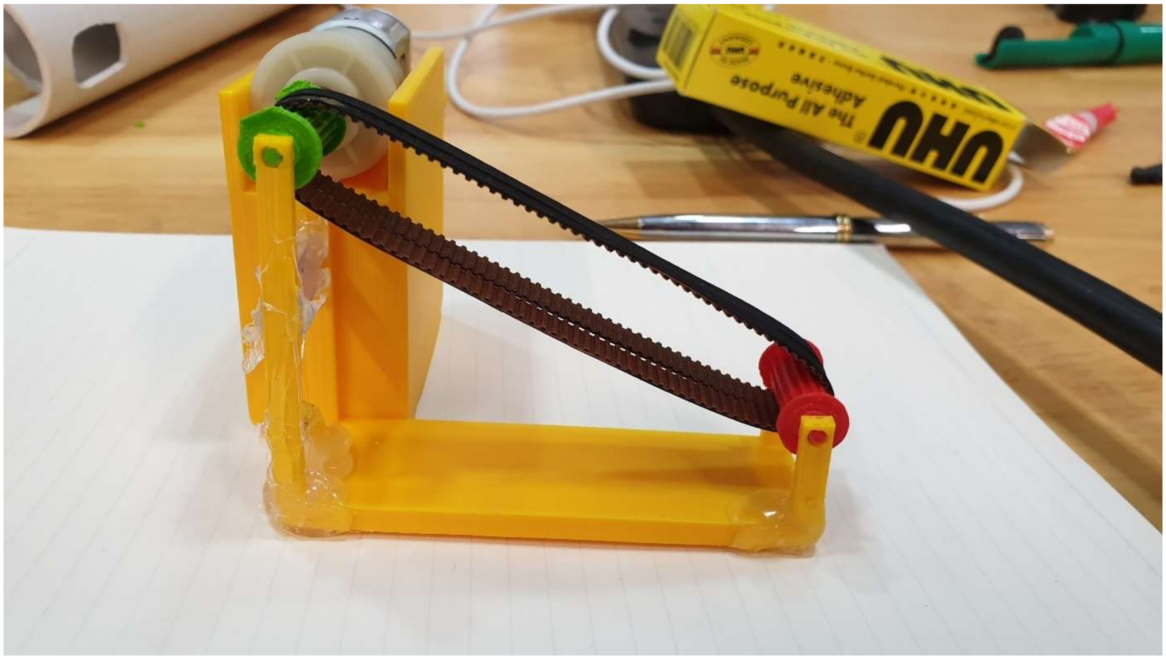
It should be notes that the conveyor frame, specifically the 2 vertical mounts for the pulley, have deficiencies as far as handling lateral loads are concerned, and will have a tendency to snap of the lateral forces become too high. This did happen a number of times during the testing and assembly process, and the offending part was fixed with glue each time. While this is not a crippling issue, and can be easily resolved by thickening the vertical supports, care should still be taken as far as handling the prototype is concerned. That being said, high lateral loads on the conveyor not expected in normal operation of the entire system, and the threat of failure posed by the river flow would be minimal.

Geared Pulley and Belt

This component ensures that power can be transferred from the motor to the belt. To avoid the belt slipping, both pulley and belt were given teeth. The belt itself was obtained from the lab, courtesy of the TSO Mr Henry. The belt was a Type 500 MXL with a width of 6.4mm, and only teeth on one side to be fitted onto the pulley. While having teeth on both side of the belt would have been beneficial from the standpoint of friction (the goal was to have the trash move up the belt), it was eventually realized that the belt itself provided enough friction to move trash up. Nonetheless, a stopgap improvement was considered which involved laying strips of glue along the width of the belt, and then letting those harden so that ridges would be formed, mimicking the effect of teeth.

The belt was then trimmed to the required length, and the free ends glued to form a closed loop which could then be fitted onto the geared pulleys. Since the width of the pulley was greater than the width, 3 such belt loops were made and fitted side by side.

The Geared pulleys were designed around the belt, and likewise, incorporated the same spline profile as the belt to allow both components to mesh. The geared pulley that is driven by the motor is given a D-hole (the ‘Motor driven gear’, in the drawings) to allow it to fit into the shaft of the motor, and ensure successful power transfer between motor and pulley. The free pulley on the other hand, is provided with a simple pin that allows it to turn freely in the frame. Initially, it was found that both the geared pulleys were too short, but this was eventually rectified by resizing and then reprinting the pulley, which fixed the issue.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Electrical/Microcontroller System

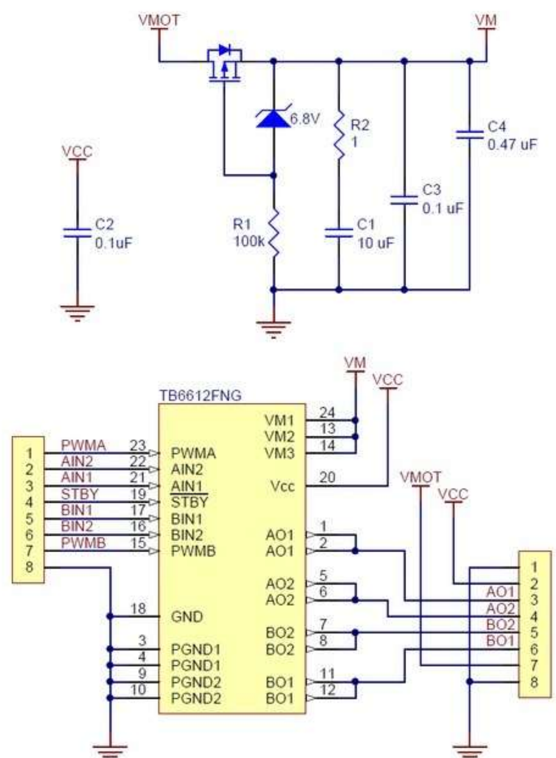
Implementation of the electrical system was mainly focused upon the need to drive the conveyor belt and the flow guide retraction. While conceptually not complex, a lot of thought was put into ensuring its reliability and robustness, and features have been implemented to allow working with the Electrical system easier. The electrical system follows the conventional sensor-controller-actuator configuration. The controller is programmed to command actuation in accordance to a certain set of criteria. Here, the electrical components used are listed in the table below:

Name	Function
12V Geared DC Motor, 160 RPM	2 motors were used, one to actuate the flow guide, the other to drive the conveyor system.
TB6612FNG Dual Motor Driver	Interfaces the motor to the MCU unit, and electrically buffers it, reducing the potential for electrical noise to interfere with the rest of the system
Arduino MCU	Microcontroller unit used for implementing control logic
Ultrasonic Sensor	Used for detecting incoming 'vehicles', to determine when flow guide retraction should be commanded
Toggle Switch	Manual override switch for commanding flow guide movement and conveyor movement

12V Geared DC Motor and Associated Motor Driver

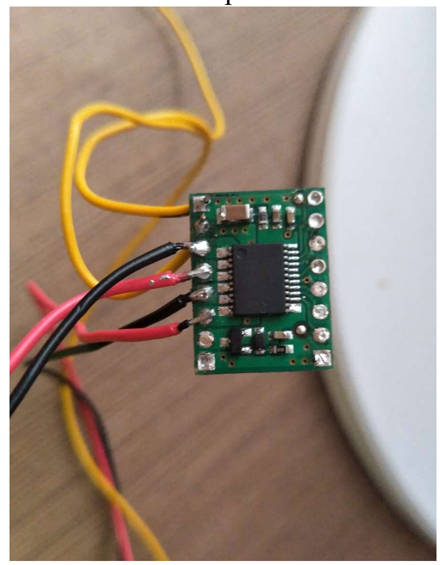
In selecting motors to drive the system, High torque geared motors were eventually decided upon as the components driven (mainly the RFG) were comparatively heavier, and needed more torque to drive. In comparison, speed was not a key deciding factor, and it was determined that 160RPM would more than suffice for the purposes of a prototype. In a real world context however, the speed of the motor driving the conveyor may have to be taken into account since it has the potential to be a limiting factor for the amount of waste that can be extracted over an interval of time, especially if there is rather high trash flow into the system.

In selecting a motor driver for the 2 geared motors, a driver that afforded the flexibility of both speed and directional control for each motor was used. In addition to that, the driver had to be able to accommodate the full 12V of the motor. The TB6612FNG was eventually selected, given that it could accomplish all 3. The pins AO1, AO2, BO1 and BO2 are the corresponding output pins that drive the motors, and the motors' 2 terminals will be soldered on here.



The pin VMOT provides supply voltage for the motor. While the motors were rated for 12V, a voltage of anywhere between 3-5V can be actually used as both motors did not have to be operated at the full 160RPM. Any further speed changes needed would be controlled by the MCU.

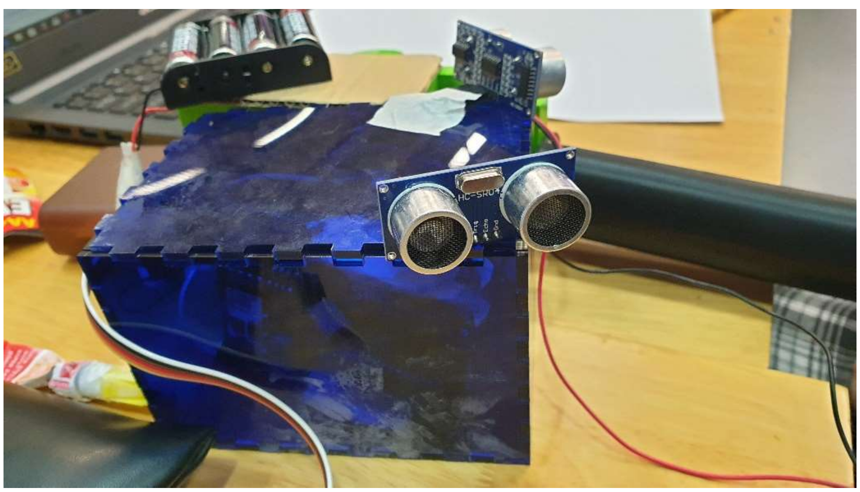
Directional control was achieved by pulling the pins AIN0/1 and BIN0/1 into logic high and logic low accordingly. Depending on the combination of high and low, the motor could be made to run forward and reverse. The AIN and BIN pins were electrically connected to 2 Digital IO pins on the Arduino. Speed control on the A and B channels were provided for on the driver by the PWMA and PWMB pins. These would respond to an PWM input below 100kHz to control the rotational speed of the motor. Both PWM pins on the driver were connected to separate Analog pins on the Arduino capable of producing PWM output.



In addition to these connections, a STBY pin on the driver had to be keyed high to enable both motor outputs on A and B. Correspondingly, this STBY pin was connected to a logic high to allow the motors to operate.

As a side note, the driver provided good noise filtering to the rest of the circuit. Electrical motors have a tendency to be very noisy, as was experienced first hand by one member of the team a few months back. Thus, another key role of the driver was to also electrically isolate the motors, and this was done so by filtering capacitors on each channel. The driver also features a thermal protection circuit, which shuts the chip down when temperatures exceed predefined limits.

<u>*Microcontroller Containment Unit*</u>



While not strictly under the purview of the electrical domain, a box was made to contain the microcontroller, as well as the motor driver IC. The box was designed with slots in the walls to allow for the wires to enter and exit the box. Frames were also provided to mount the ultrasonic sensors and face them in the correct direction. The appropriate locating and mounting features were also provided for on the box.

The box, and the complementary holder was specifically designed on Autodesk Inventor for this purpose but due to time constrain (the box kept warping/debonding from the print bed when it was being 3D printed), a laser-cut box shown in the picture was ultimately used, with key joints to allow the individual pieces to be mated. The ultrasonic sensors were attached with the help of adhesive. Nonetheless, the detailed specifications of this containment unit will still be provided for the users benefit.

Controller Logic

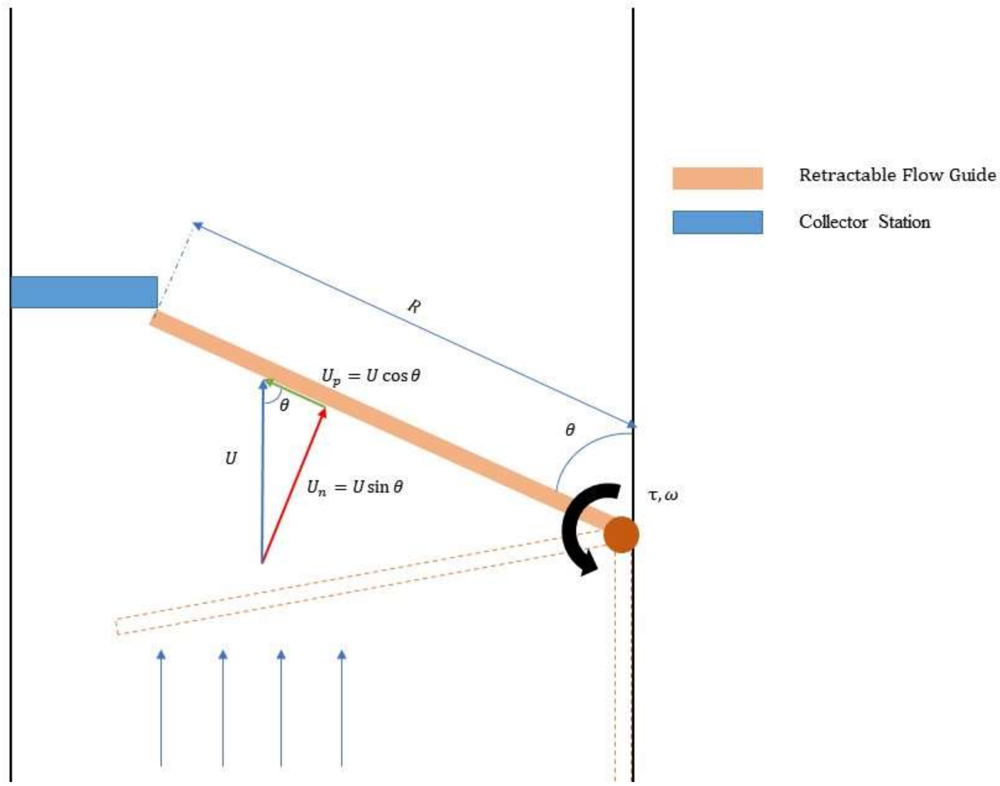
The controller code is left as an Annex for the benefit of the reader. The code, while functionally simple accomplishes a few major functions. It commands the retraction of the flow guide when a certain set of criteria are met. In this case, the criteria is a pre-configured distance threshold (set at 30cm) that is verified against either one of the 2 ultrasonic sensors installed on the system.

After retraction, the code must also be able to determine when the passing vehicle has left, and subsequently, command the winch to release the retraction cable to re-extend the flow guide and resume normal function of the system. This is implemented through a variable k, which is set to 1 when a vehicle is in transit. The extension routine would thus only be activated when the value of k is 1, and it has been determined that the vehicle has passed (ie. distance computed above 30cm on both sensors.

CHAPTER III

MATHEMATICAL ANALYSIS

Mathematical Formulation of Flow Guide Retraction



The analysis described in this section uses a combination of analytical and numerical methods to arrive at a relatively accurate estimate for torque and power requirements. While it is very much possible to undertake the analysis solely with Computation Fluid Dynamics (the numerical method), the computation cost involved would have been prohibitively high, given that the nature of the analysis would have to be transient due to the motion of the Retractable Flow Guide, and a finer mesh would have to be used to achieve a decent degree of analysis. The CFD analysis was thus only used to obtain certain key physical parameters for use in the analytical equation, allowing it to be operated in steady state mode, thus dramatically reducing the computational costs.

In undertaking this mathematical analysis of the flow guide retraction, a few assumptions were made when characterizing the problem:

a) The drag coefficient of the guide does not change with respect to time (ie. C_D is constant)
b) The spanwise velocity component does not affect drag
c) Lateral forces will not affect the torque/power requirements
d) Friction at the hinge point is negligible
e) Flow velocity is constant and uniform

To obtain a reasonable estimation of drag force (and by extension, torque and power requirements), an expression for the relative flow velocity of the water normal to the Retractable Flow Guide (RFG) has to be first developed. To do so, the total normal velocity of the water can be decomposed into 2 components

$$U_n = U_n(\theta) + U_n(\omega)$$

Where $U(\theta)$ represents normal velocity due to the Angle of the RFG with respect to the oncoming river flow and $U(\omega)$ represents normal velocity due to the instantaneous angular speed of the RFG. The formulation of the drag force using these normal velocity components accounts for drag both due to the inherent water speed, as well as the commanded (rotational) speed of the RFG

Expanding the equation further:

$$U_n = U \sin\theta + \omega\boldsymbol{r}$$

Where **r** is a variable that describes the spanwise position on the RFG. It is necessary to express the latter component as a function of the **r** as the local linear speed will vary with respect to the span wise position. With that in mind, a basic equation for drag, using the standard drag Equation can be formulated:

$$F_d = \frac{1}{2}\rho U_n^2 C_D S$$

Where C_D is the non-dimensional drag coefficient, S is the surface area and ρ is the density of the water. For the ease of notation, it is possible to define a Hydrodynamic Drag Coefficient β:

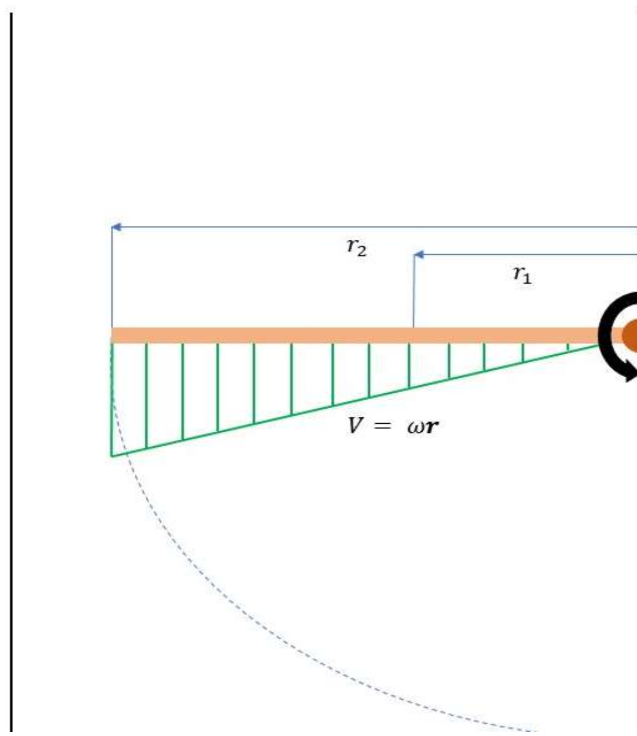
$$\beta = \frac{1}{2}\rho C_D$$

The Drag Equation can now be expressed as

$$F_d = \beta U_n^2 S$$

Thus, to calculate the drag force, the expression for Normal Flow Velocity is substituted into the new drag equation. However, the expression cannot be substituted into the equation 'as is' since the expression for normal flow velocity has a dependency on **r**, whereas the resulting expressions for torque and power have to be descriptive of the entire RFG (no **r** dependency). The Force equation then has to be expressed in terms of an infinitely small force acting on an infinitely small element of the flow guide, before summing these up (integrating) over the entire span of the flow guide to get a definitive value for torque and power:

$$dF_d = \beta(U \sin\theta + \omega\boldsymbol{r})^2\, dS$$



Here, dS represents the surface area of an infinitesimally small element of the guide, divided along the span axis. Expanding the quadratic term yields:

$$dF_d = \beta[(U \sin\theta)^2 + 2(U \sin\theta)(\omega\boldsymbol{r}) + (\omega\boldsymbol{r})^2]\, dS$$

Where $dS = d\boldsymbol{r} \times h$

Integrating the expression above across the Span R, the force across the guide is obtained:

$$\int_0^R dF_d = \int_0^R \beta[(U\sin\theta)^2 + 2(U\sin\theta)(\omega\boldsymbol{r}) + (\omega\boldsymbol{r})^2]\,dS$$

$$\int_0^R dF_d = \int_0^R \beta h[(U\sin\theta)^2 + 2(U\sin\theta)(\omega\boldsymbol{r}) + (\omega\boldsymbol{r})^2]\,d\boldsymbol{r}$$

$$F_d = \beta h\left[R(U\sin\theta)^2 + 2(U\sin\theta)\left(\omega\frac{R^2}{2}\right) + \omega^2\frac{R^3}{3}\right] \quad (Drag\ Force\ Equation)$$

To obtain the torque acting upon the guide, the following relation is used:

$$d\tau_d = dF \times \boldsymbol{r}$$

Thus, like force, the product of dF and r is taken, and then integrated across the span of the guide, yielding the Drag Torque Equation.

$$\int_0^R d\tau_d = \int_0^R dF_d \times \boldsymbol{r} = \int_0^R \beta h[(U\sin\theta)^2\boldsymbol{r} + 2(U\sin\theta)(\omega\boldsymbol{r}^2) + \omega^2\boldsymbol{r}^3]\,d\boldsymbol{r}$$

$$\tau_d = \beta h\left[(U\sin\theta)^2\frac{R^2}{2} + 2(U\sin\theta)\left(\omega\frac{R^3}{3}\right) + \omega^2\frac{R^4}{4}\right] \quad (Drag\ Torque\ Equation)$$

Finally, with the torque Equation, the power equation can be derived, with which the motor can be sized appropriately. Firstly, the relationship between torque and power is defined to be:

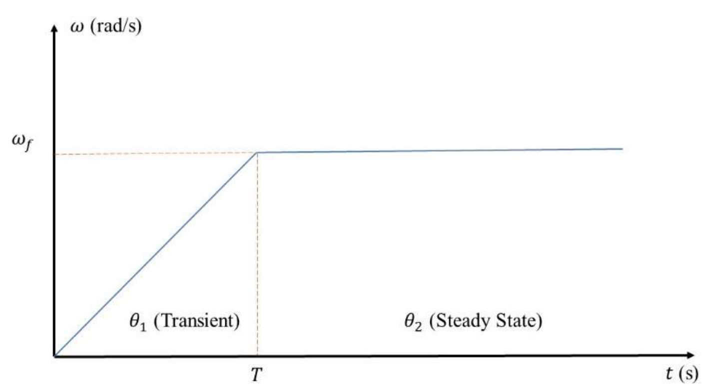
$$P_d = \tau_d \times \omega$$

Thus, the resulting power required to overcome the drag and maintain force equilibrium:

$$P = \omega\beta h\left[(U\sin\theta)^2\frac{R^2}{2} + 2(U\sin\theta)\left(\omega\frac{R^3}{3}\right) + \omega^2\frac{R^4}{4}\right] \quad (Power\ Equation)$$

Now that an expression has been developed for force, torque and power in terms of angular speed and displacement, the equations that govern the RFG's physical behavior at each stage of retraction may be formulated. To start off, the equation that governs the resultant torque, $I\alpha$:

$$I\alpha = \tau_a - \tau_d$$



However, only the applied torque τ_a is of interest, since $I\alpha$ will be prescribed based on a pre-determined velocity profile, which includes a short period of constant angular acceleration followed by a constant angular velocity period. While this velocity model does not include the deceleration period leading to the point before the RFG is fully retracted, the aim of the analysis is to determine motor torque and power requirements, the maximum limits of which are primarily determined in the period of initial acceleration from the deployed position and the steady velocity state.

Rearranging the equation and substituting in the expression for the drag caused by torque, the function for the torque required is thus obtained:

$$\tau_a = I\alpha + \tau_d$$

$$\tau_a = I\alpha + \beta h\left[(U\sin\theta)^2\frac{R^2}{2} + 2(U\sin\theta)\left(\omega\frac{R^3}{3}\right) + \omega^2\frac{R^4}{4}\right]$$

Using the above general function for torque expressions for the transient and steady state operational stages may then be developed. While in this context the term 'steady state' does not strictly obey $\frac{\partial\tau_a}{\partial t} = 0$ due to its dependence on θ, the term is used in relation to the velocity profile, where ω has reached a constant value and can thus be considered 'steady state'

Transient State Equations

The procedure for deriving the transient and steady state equations remain roughly the same, albeit with a few differences. As the RFG is in the process of being accelerated to steady state speed, the term $I\alpha$ describing resultant torque will have to be defined. However, given that a velocity profile with a constant acceleration has already been prescribed, it is rather simple to determine the $I\alpha$ term. As the final velocity is also prescribed, the acceleration is derived from ω_f by using an acceleration time period T, which is a constant defined by the user.

The required angular acceleration is very simply:

$$\alpha = \frac{\omega_f}{T}$$

It should however be noted, that the total angular displacement in the transient stage, $\frac{1}{2}\alpha T^2$ should be constrained to be less than the total angular displacement required θ_{total}

In the transient case, both the angular velocities and displacements do not remain constant due to the nonzero acceleration. Thus, they have to be expressed as functions of time, which can be easily done so with the relations

$$\theta = \frac{1}{2}\alpha t^2$$

$$\omega = \alpha t$$

Thus, substituting the above 2 relations into relevant terms in the general torque and power equations, will yield the Transient state equations:

$$\tau_a = I\alpha + \beta h\left[\left(U\sin\frac{1}{2}\alpha t^2\right)^2\frac{R^2}{2} + 2\left(U\sin\frac{1}{2}\alpha t^2\right)\left(\alpha t\frac{R^3}{3}\right) + (\alpha t)^2\frac{R^4}{4}\right]$$

$$P = I\alpha^2 t + \alpha t\beta h\left[\left(U\sin\frac{1}{2}\alpha t^2\right)^2\frac{R^2}{2} + 2\left(U\sin\frac{1}{2}\alpha t^2\right)\left(\alpha t\frac{R^3}{3}\right) + (\alpha t)^2\frac{R^4}{4}\right]$$

To account for the fact that the RFG does not necessarily start off parallel (0 degrees) relative to the flow, an angular offset term is added to the argument of the Sine Functions:

$$\tau_a = I\alpha + \beta h\left[\left(U\sin(\frac{1}{2}\alpha t^2 + \theta_0\,)\right)^2\frac{R^2}{2} + 2\left(U\sin\frac{1}{2}\alpha t^2 + \theta_0\,\right)\left(\alpha t\frac{R^3}{3}\right) + (\alpha t)^2\frac{R^4}{4}\right](Torque, TN)$$

$$P = I\alpha^2 t + \alpha t\beta h\left[\left(U\sin\frac{1}{2}(\alpha t^2+\theta_0)\right)^2\frac{R^2}{2} + 2\left(U\sin\frac{1}{2}(\alpha t^2+\theta_0)\right)\left(\alpha t\frac{R^3}{3}\right) + (\alpha t)^2\frac{R^4}{4}\right](Power, TN)$$

Where θ_0 represents the starting position of the guide

Steady State Equations:

Given that there is no further (angular) acceleration and that ω has reached a constant value, then by definition, the resultant torque $I\alpha$ must be equal to 0. Thus, the general equation for torque required becomes:

$$\tau_a = \beta h\left[(U\sin\theta)^2\frac{R^2}{2} + 2(U\sin\theta)\left(\omega\frac{R^3}{3}\right) + \omega^2\frac{R^4}{4}\right]$$

which is exactly equal to the torque experienced by the RFG due to drag. Now, given that the intent is to obtain power and torque requirements for a given retraction speed, it is thus appropriate to express θ as a function of ω, which is easily done so through the relation $\theta = \omega t$, given that ω is constant. Substituting in the above equation, we obtain:

$$\tau_a(t) = \beta h\left[\left(U\sin\omega_f t\right)^2\frac{R^2}{2} + 2(U\sin\omega t)\left(\omega_f\frac{R^3}{3}\right) + {\omega_f}^2\frac{R^4}{4}\right]$$

$$P(t) = \omega_f\beta h\left[\left(U\sin\omega_f t\right)^2\frac{R^2}{2} + 2\left(U\sin\omega_f t\right)\left(\omega_f\frac{R^3}{3}\right) + {\omega_f}^2\frac{R^4}{4}\right]$$

However, the RFG has already travelled a displacement during the transient, accelerating period. This has to be accounted for by adding in the acceleration displacement term (and the initial angular offset) to the arguments of the Sine function. Furthermore, given that steady state operation does not start at $t = 0$, the time in the Sine argument has to be offset by a fixed value T, which once again, is the acceleration time period. The expression for power and torque will thus become:

$$\tau_a(t) = \beta h\left[(U\sin\theta_s)^2\frac{R^2}{2} + 2(U\sin\theta_s)\left(\omega_f\frac{R^3}{3}\right) + {\omega_f}^2\frac{R^4}{4}\right](Torque, SS)$$

$$P(t) = \omega_f\beta h\left[(U\sin\theta_s)^2\frac{R^2}{2} + 2(U\sin\theta_s)\left(\omega_f\frac{R^3}{3}\right) + {\omega_f}^2\frac{R^4}{4}\right](Power, SS)$$

Where $\theta_s = \omega_f \times [t-T] + \frac{1}{2}\alpha T^2 + \theta_0$

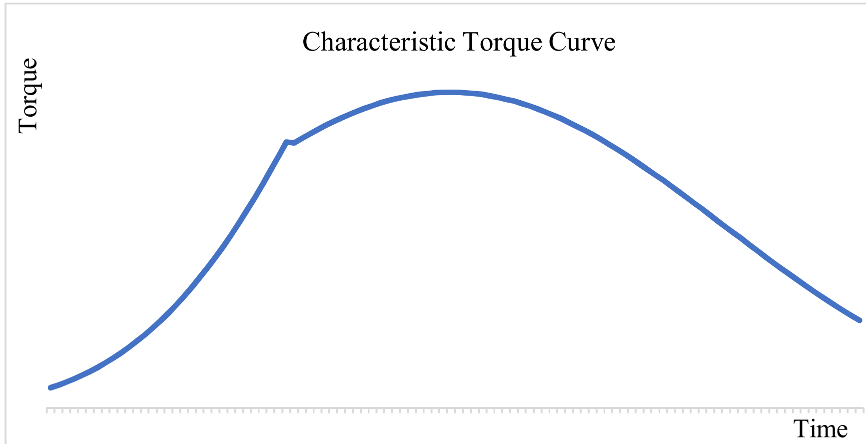
With both transient state and steady state equations developed, a piecewise function may now be developed that describes the state of the RFG at any time

$$\tau_a = \begin{cases} I\alpha + \beta h\left[\left(U\sin(\frac{1}{2}\alpha t^2+\theta_0)\right)^2\frac{R^2}{2} + 2\left(U\sin(\frac{1}{2}\alpha t^2+\theta_0)\right)\left(\alpha t\frac{R^3}{3}\right) + (\alpha t)^2\frac{R^4}{4}\right] & (0 \le t < T) \\ \beta h\left[(U\sin\theta_s)^2\frac{R^2}{2} + 2(U\sin\theta_s)\left(\omega_f\frac{R^3}{3}\right) + {\omega_f}^2\frac{R^4}{4}\right] & (T \le t) \end{cases}$$

$$P = \begin{cases} I\alpha^2 t + \alpha t\beta h\left[\left(U\sin\frac{1}{2}(\alpha t^2+\theta_0)\right)^2\frac{R^2}{2} + 2\left(U\sin\frac{1}{2}(\alpha t^2+\theta_0)\right)\left(\alpha t\frac{R^3}{3}\right) + (\alpha t)^2\frac{R^4}{4}\right] & (0 \le t < T) \\ \omega_f\beta h\left[(U\sin\theta_s)^2\frac{R^2}{2} + 2(U\sin\theta_s)\left(\omega_f\frac{R^3}{3}\right) + {\omega_f}^2\frac{R^4}{4}\right] & (T \le t) \end{cases}$$

$\theta_s = \omega_f \times [t - T] + \frac{1}{2}\alpha T^2 + \theta_0$

Estimating C_D To Compute Torque and Power Requirements



Now that the expressions for both torque and power have been developed, it is possible to mathematically characterize the problem by assigning numerical values to terms in the equation. However, before that, the Hydrodynamic Constant β has to be determined.

For reference, β is once again:

$$\beta = \frac{1}{2}\rho C_D$$

Where ρ is the density of the fluid (water in this case, which has a density of 1000 kg/m3), and C_D is the drag coefficient. Thus, before any calculations can actually be done, a concrete, numerical value of C_D is required.

In order to find the value of C_D, a 'snapshot' of the drag force during retraction is required, which can then be used to solve for C_D, by rearranging the basic drag equation:

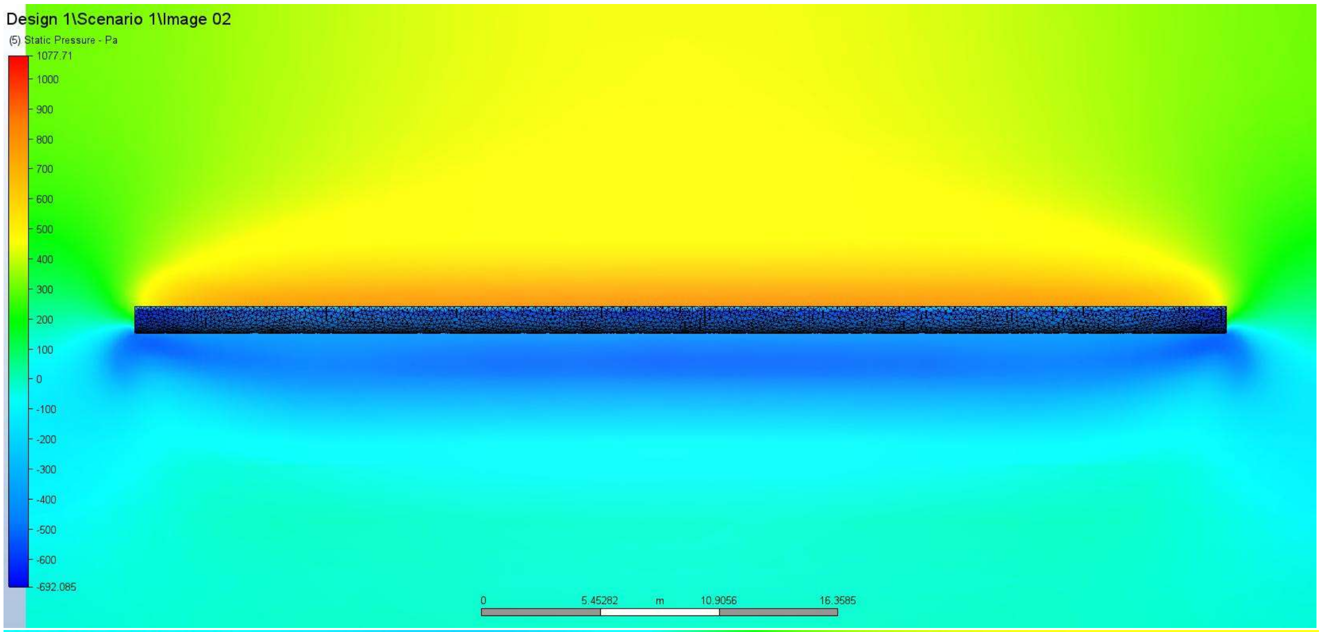
$$C_D = \frac{2F_d}{\rho U_n^2 S}$$

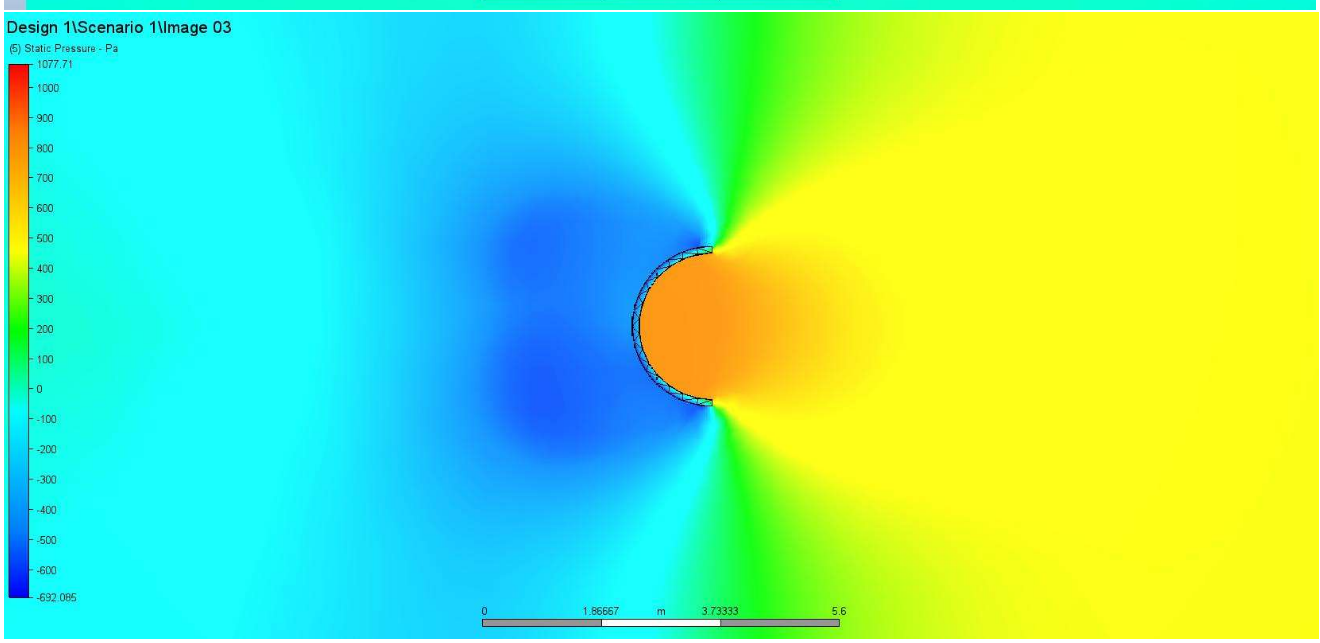
Based on preliminary trials, it is understood that the torque and power curves have characteristic shapes like the curve shown above. The peak of the curve will always occur at an angular displacement of $\frac{\pi}{2}$ radians, corresponding to an incidence angle of 90 degrees relative to the flow Using this understanding, a Computational Fluid Dynamics (CFD) study (using *Autodesk CFD*) was set up to study the force acting on the RFG at an angle of 90 degrees. This angle was chosen as it would allow the most conservative force estimates, given that the RFG would be subject to the highest forces during this period of time.

Key Parameters of the CFD study are summarized in the table below:

Parameter	**Value/Setting**
RFG Length	50 meters
RFG Wetted Height/Diameter	2.5 meters
Analysis Type	3D External Flow, Steady State Incompressible
Fluid	Water
Inlet Boundary Condition	Normal Velocity, 1m/s into domain
Outlet Boundary Condition	Gauge Pressure, 0 Pa
Wall Boundary Condition	Slip/Symmetry
Turbulence Model	Shear Stress Transport (SST), K-Omega
Advection Scheme	ADV 5, Modified Petrov-Galerkin (unique to Autodesk CFD)

While a steady state analysis does not describe the complete, physical picture of the RFG (given turbulence vortex formations etc.), such an analysis would suffice since only the forces acting on the RFG (ie. The pressure field) is of concern. Thus, the pressure field was monitored for convergence, using the Residual Out Metric. Once satisfactory convergence had been reached (when the pressure readings stopped fluctuating too much), the analysis was stopped, and the wall forces calculated using the wall calculator native to Autodesk CFD. All in all, 66 iterations were run, which took approximately 30 to 45 minutes. A visual representation of the static pressure field and the wall forces calculated are provided below.



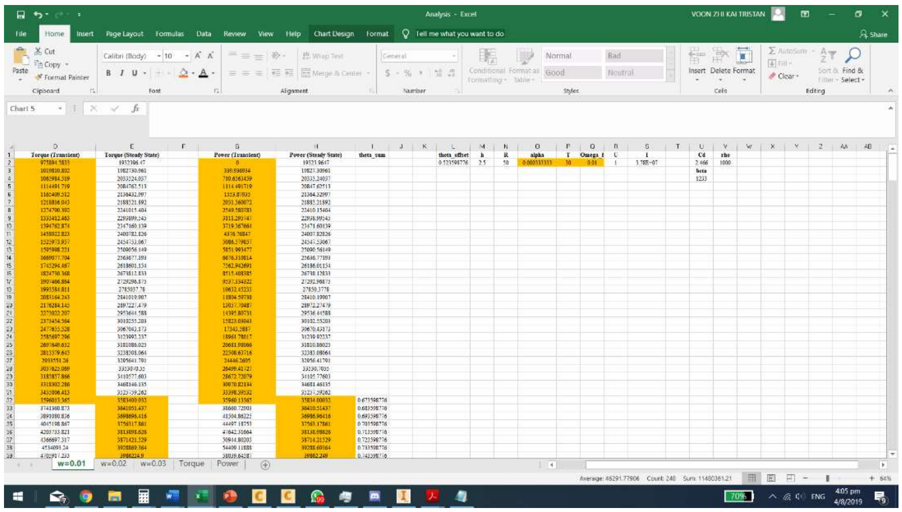


Summary			
~~**Total area**~~	~~387.212~~	~~m^2~~	
TOTAL FX	-154143	Newton	
TOTAL FY	-2624.95	Newton	
TOTAL FZ	1.83643	Newton	
Center of Force about X-Axis (Y-Z)	-0.01175	-24.9769	m
Center of Force about Y-Axis (X-Z)	-0.66118	-26.4303	m
Center of Force about Z-Axis (X-Y)	-1.77416	1.41123	m

The **TOTAL FX** force represents the drag experience by the RFG, and is numerically equivalent to F_d. For the purposes of Drag coefficient calculations, the total area calculated by the software would not be used, but rather, the area of the RFG that is projected onto the normal plane of the water flow direction (ie, a rectangle with length equal to the length of the RFG, and height equal to the diameter of the RFG).

Thus, using the above equation, we obtain $C_D \approx 2.466$, and correspondingly, a hydrodynamic drag coefficient $\beta \approx 1233$.

Numerical Calculation and Discussion Of Analysis Results



To obtain the solutions to the expressions that have been developed, an Excel Spreadsheet was created and the equations were keyed in. Following that, a time domain was created in the spreadsheet and the appropriate cells were assigned for the physical parameters of the equation. The transient and steady state expressions for torque and power were then automatically solved, and the results plotted into a graph. Along with the values for power and torque, the total angular displacement travelled was also calculated, and these were used as a basis of comparison in the graphs. The spreadsheet will be made available for the reader's use. Calculations performed were based off the following values:

Parameter	Value
Angular Speed, ω	0.01, 0.02, 0.03 rad/s
Acceleration Time Period, T	30 seconds
RFG Moment of Inertia, I	37840000 kgm2
RFG Height, h	2.5 m
RFG Length, R	50
Density of Water, ρ	1000 kg/m3
Drag Coefficient, C_d	2.466
River Flow Speed, U	1 m/s
Initial Angular Offset, θ_0	0.52359878 rad

Calculations for power and torque were performed for 3 different values of ω, at 0.01, 0.02, and 0.03 radians per second. In all 3 cases, it was oberved that the peak power requirement increased with increasing angular velocity, as per expected. Peak power values for the 3 different speeds are 69kW, 218kW, and 476kW respectively. The current draw for hypothetical motor actuating the RFG would have virtually the same exact shape as the power curve, given that the power is related to the current by the product of the voltage. Indeed, there are motors which have output power ranges like those that have been calculated by the equations. Thus, the ability of the system to scale up has been satisfactorily demonstrated. The torques required for the 3 different speeds range from 4 to 10 meganewton meters. Like power, while these values look extremely high, it is not impossible to achieve the torques required. This can be done by the use of a reduction geartrain, which trades angular speed for increased torque. With the forumlae and expressions developed, the foundational framework for future developments and iterations of these system has been laid, and its scalcability, demonstrated.

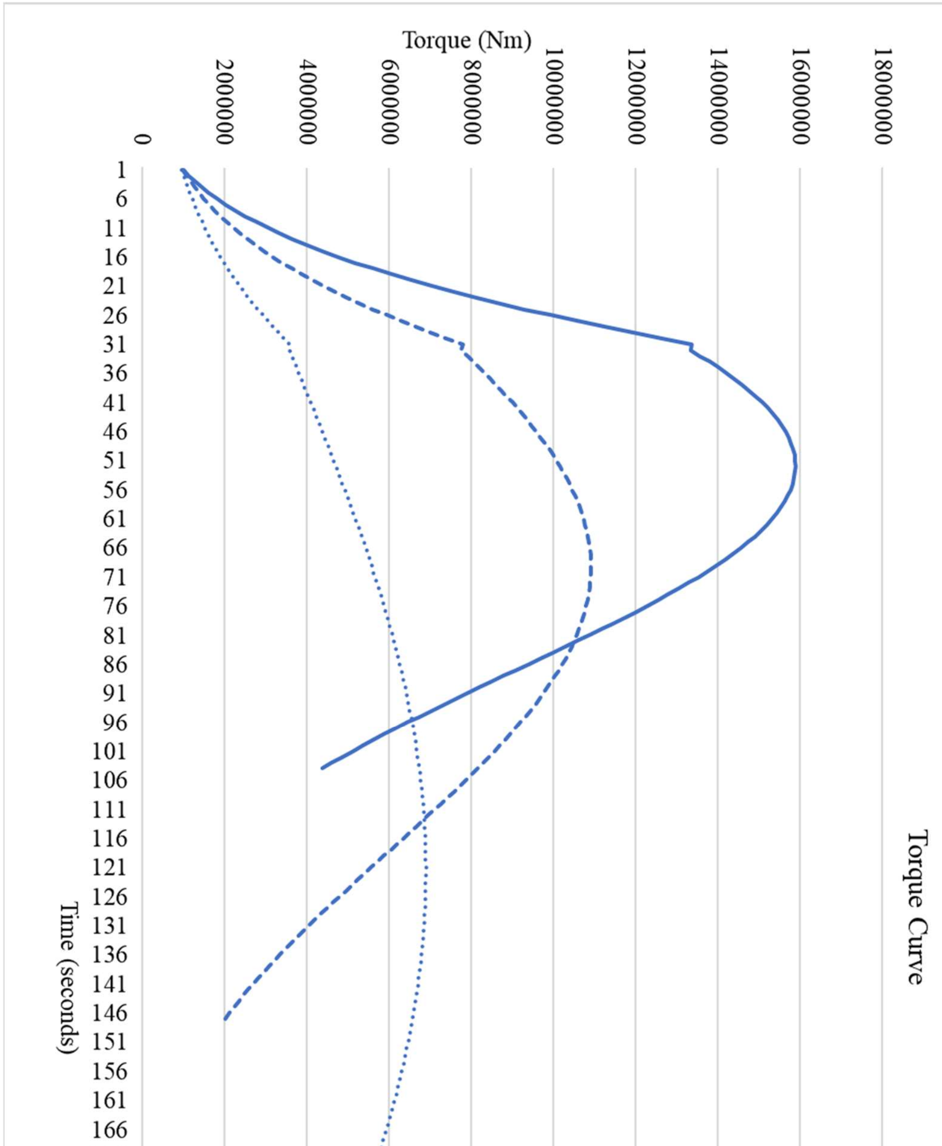
Future Developmental Considerations

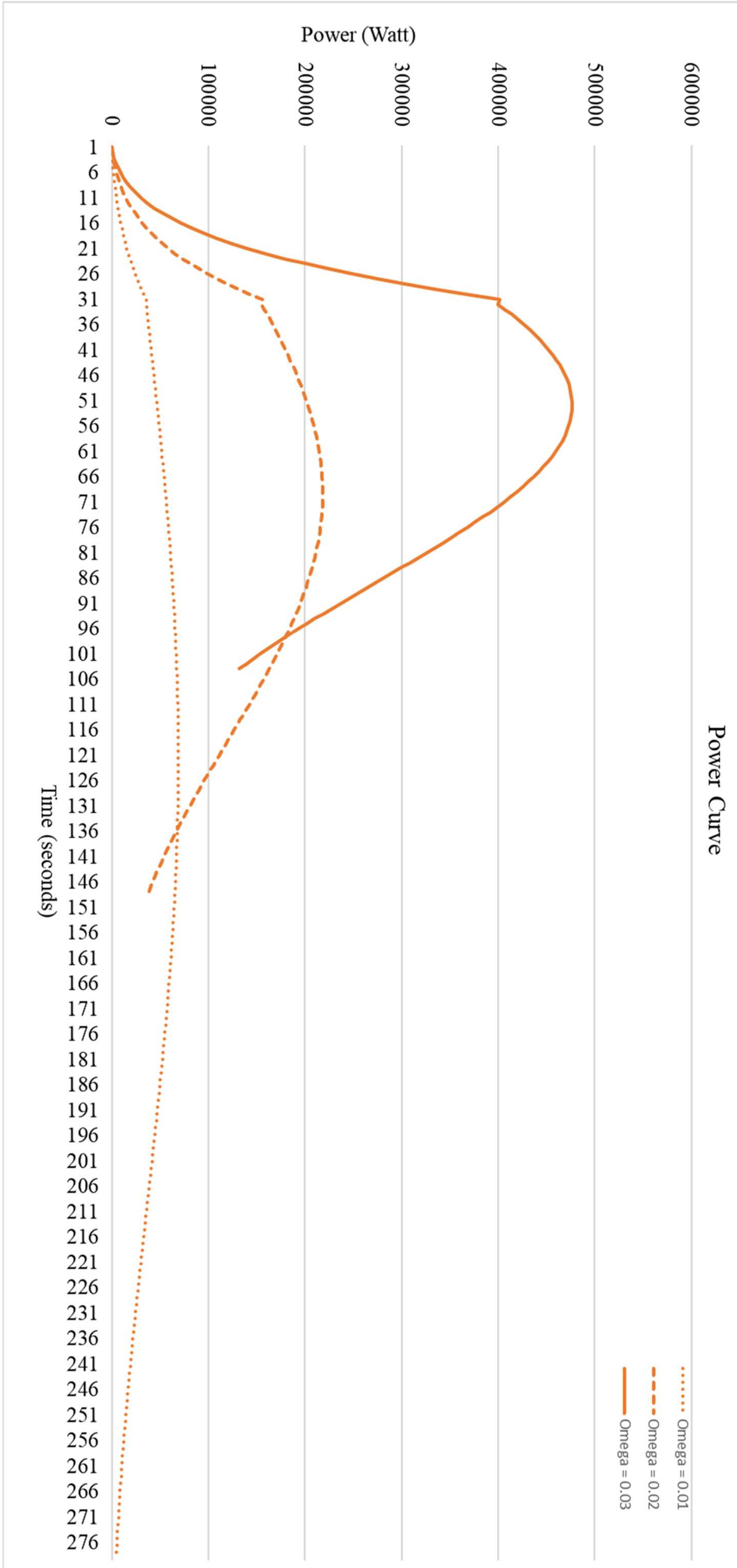
The present work focuses mainly on the torque and power requirements required to retract the RFG. However, work has yet to be done to describe the full kinematics of the RFG, which includes the decceleration at the end of the RFG movement. Furthermore, analysis on the lateral forces can be performed, and the present model made more accurate by taking into account effects that have, at present, been unaccounted for. One such prominent effect is the determination of the drag coefficient, which currently, has received very little attention.

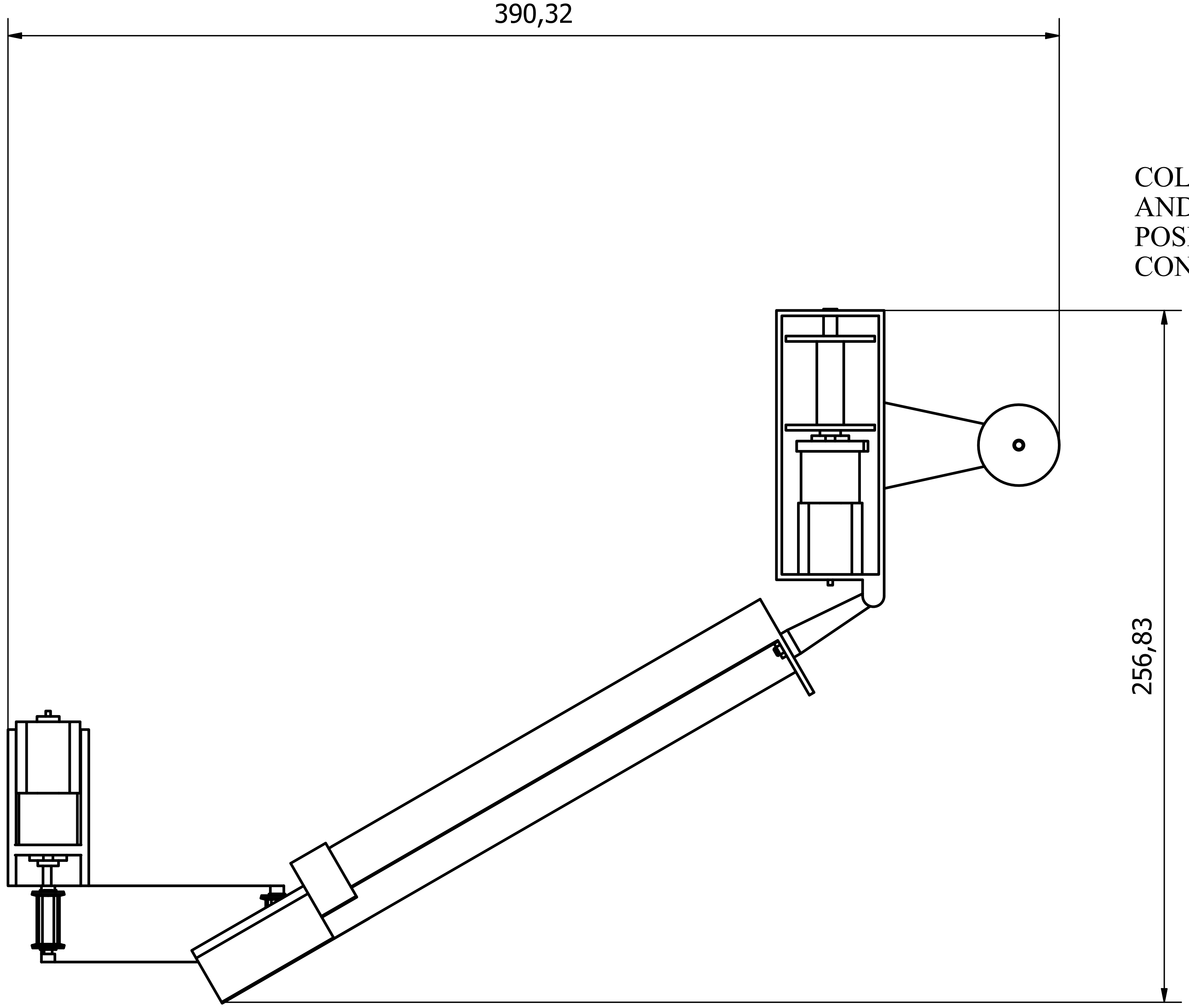
In addition to kinematic analysis, further work also has to be done with regard to structural limitations of the RFG. FEM stress analysis may be conducted to indentify which areas of the RFG are particularly supsceptible to failure, and apprpriate measures taken to reinforce these parts. Closely related to this aspect is that of Material Selection. A material that has satisfactory performance, while still being economical has yet to be selected. This can only be fully evaluated when the stresses and strains placed on the structure are determined.

The entire system can also be further improved by making use of renewable power, like solar cells and energy from the water flow. This improves the overall environmental impact of the system. Furthermore, it was noted that the controller box was located fairly far away from some components, especially the motor on the collector subassembly. This leads to another potential improvement, where wireless technologies can be used to bridge the components together, instead of wires. This also ties in very closely to the idea of fitting the system with sensors which can collect real time data, to form an IoT solution.

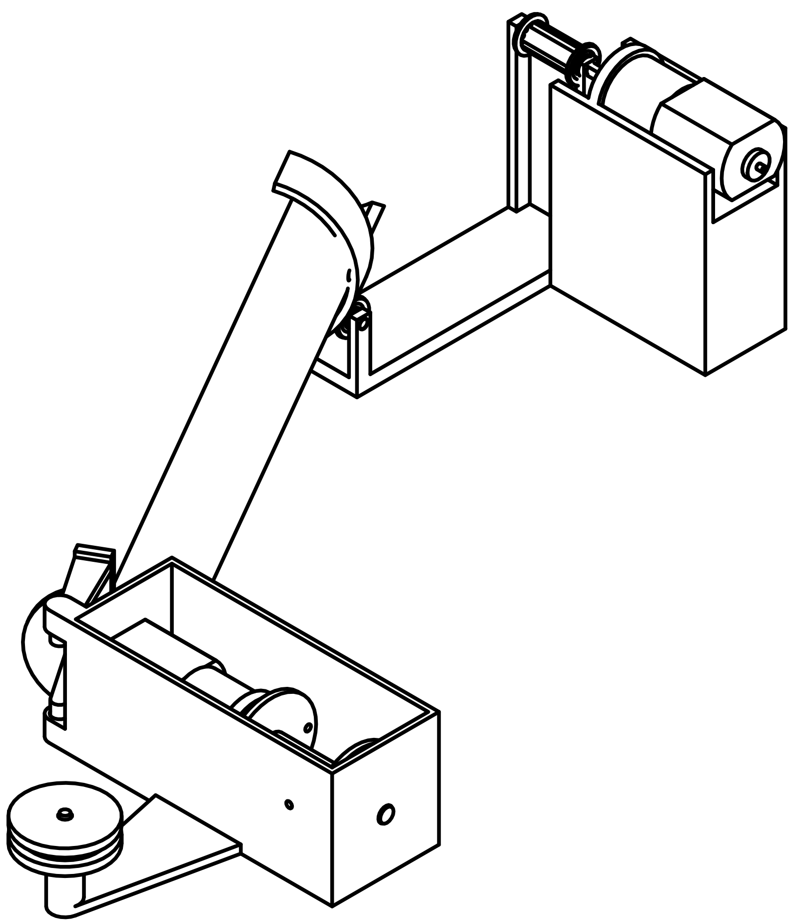
On the mechanical aspect, an improvement was considered where in which the hinge to mount the flow guide on would be allowed to slide vertically, to compensate for river water level changes, making the system more robust.


Torque Curve
Torque (Nm)
0
2000000
4000000
6000000
8000000
10000000
12000000
14000000
16000000
18000000
Time (seconds)
Omega = 0.01
Omega = 0.02
Omega = 0.03


Power Curve
Power (Watt)
0
100000
200000
300000
400000
500000
600000
Time (seconds)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
156
161
166
171
176
181
186
191
196
201
206
211
216
221
226
231
236
241
246
251
256
261
266
271
276
Omega = 0.01
Omega = 0.02
Omega = 0.03



COLLECTOR POSITION
AND FLOW GUIDE
POSITION ARE
CONFIGURABLE



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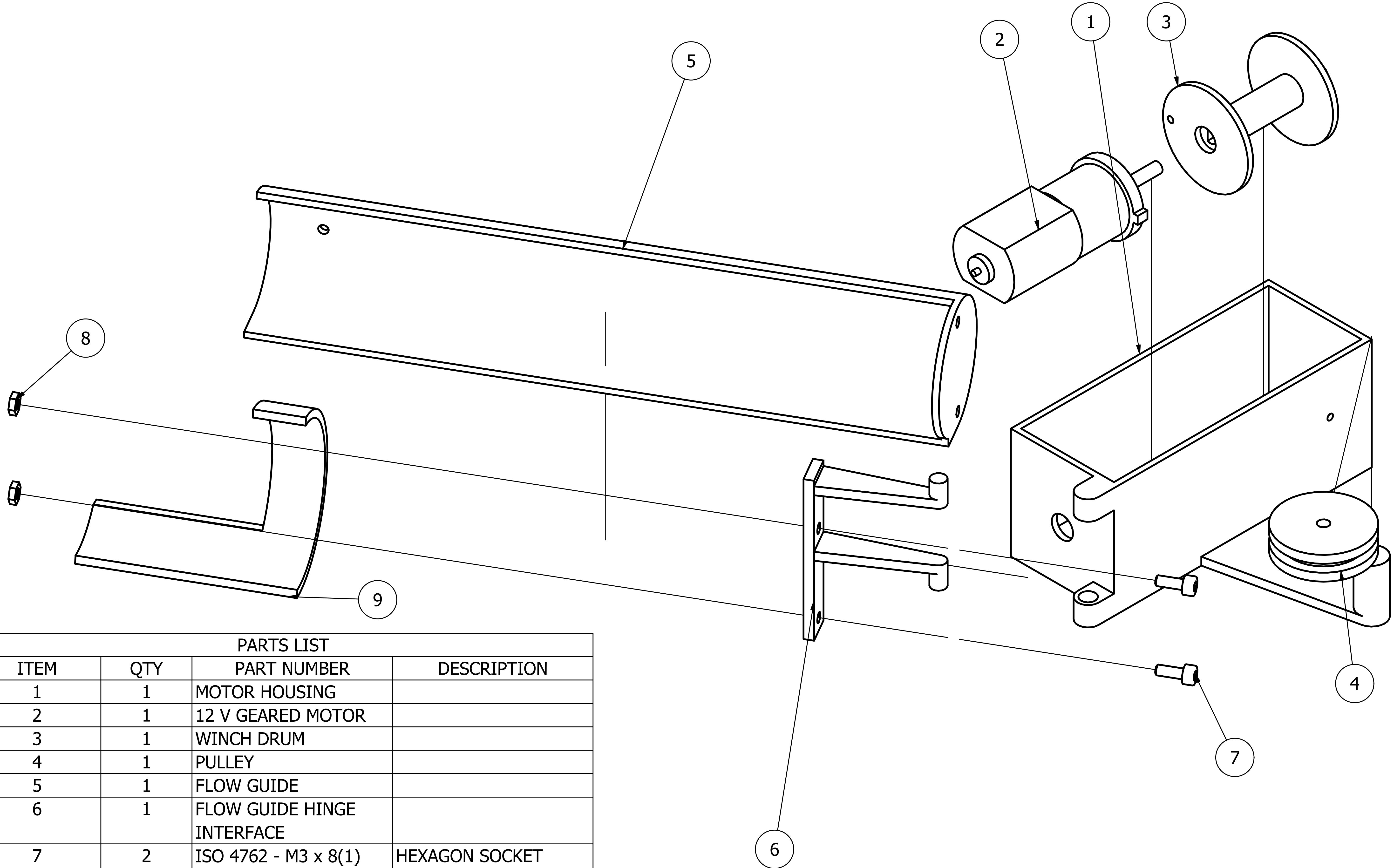
TRISTAN VOON				1:2	14/8/2019	

FULL SYSTEM VIEW		
FULL SYSTEM ASSEMBLY	Edition	Sheet 1 / 1



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	MOTOR HOUSING	
2	1	12 V GEARED MOTOR	
3	1	WINCH DRUM	
4	1	PULLEY	
5	1	FLOW GUIDE	
6	1	FLOW GUIDE HINGE INTERFACE	
7	2	ISO 4762 - M3 x 8(1)	HEXAGON SOCKET HEAD CAP SCREW
8	2	ISO 4036 - M3	HEXAGON THIN NUT (UNCHAMFERED) PRODUCT GRADE B
9	1	FLOW GUIDE BRACKET	

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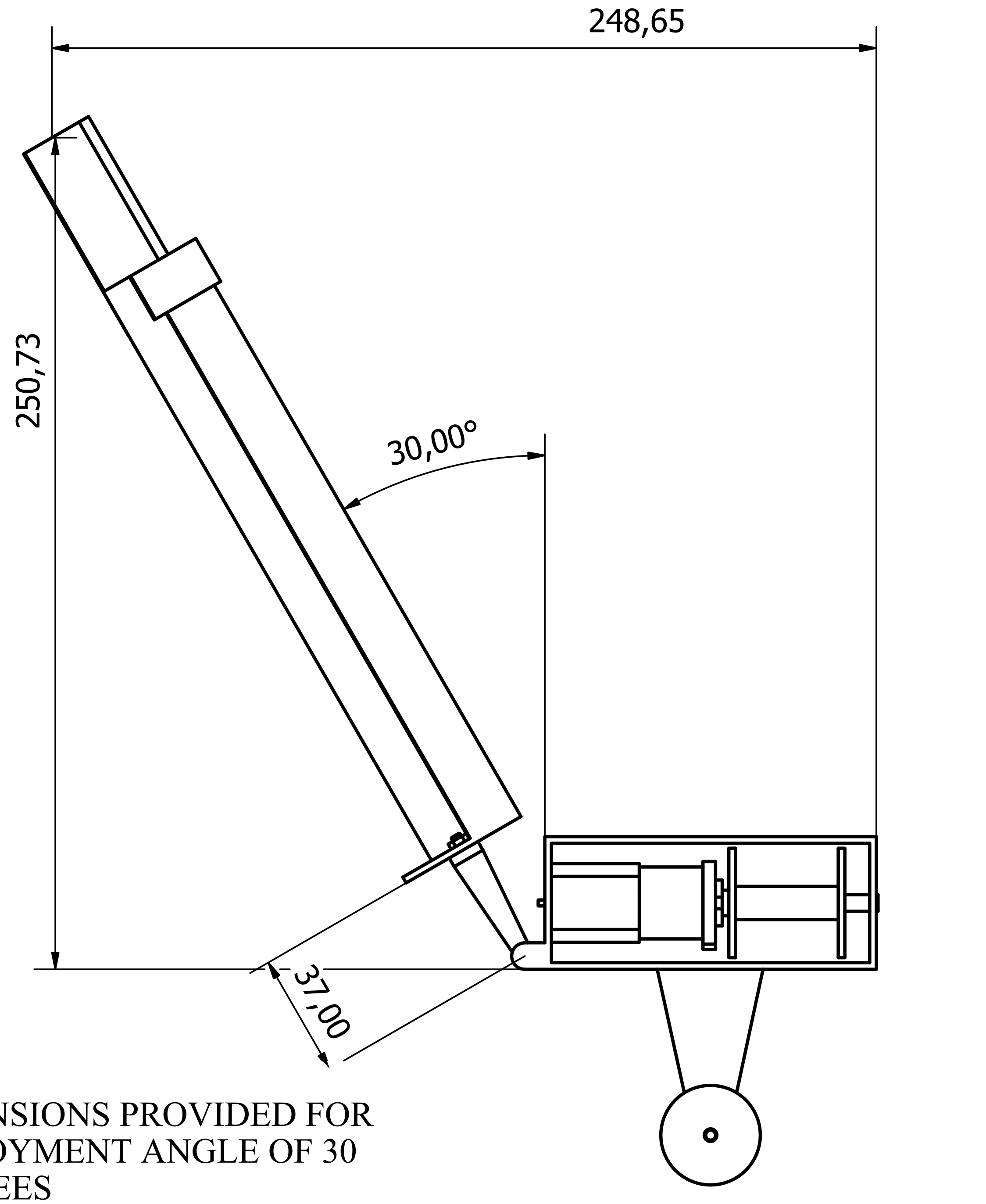
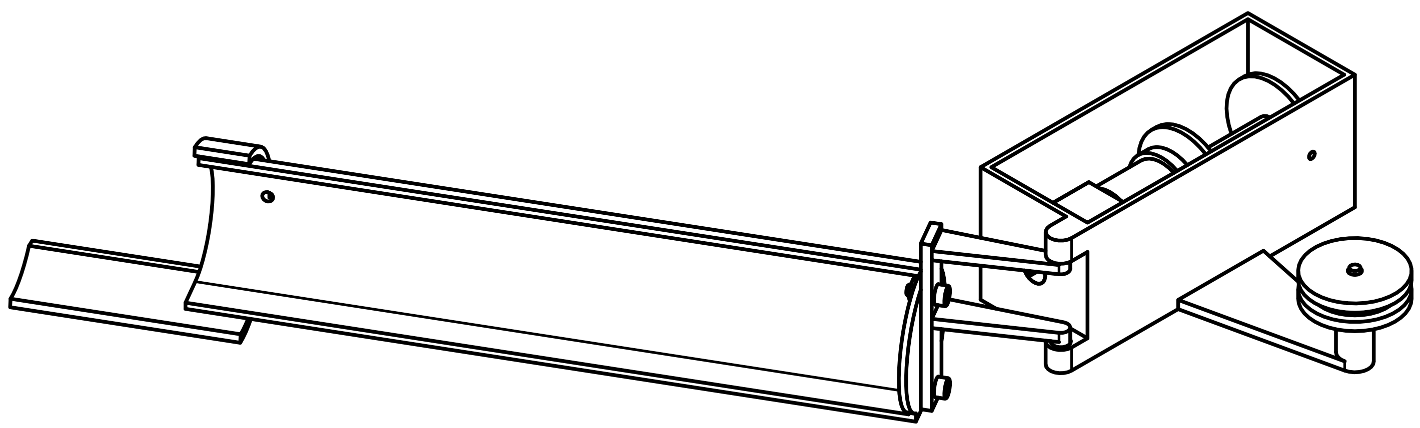
EXPLODED VIEW	RIVER TRASH COLLECTOR SYSTEM		
	RFG SUBASSEMBLY	Edition	Sheet 1 / 7





DIMENSIONS PROVIDED FOR
DEPLOYMENT ANGLE OF 30
DEGREES

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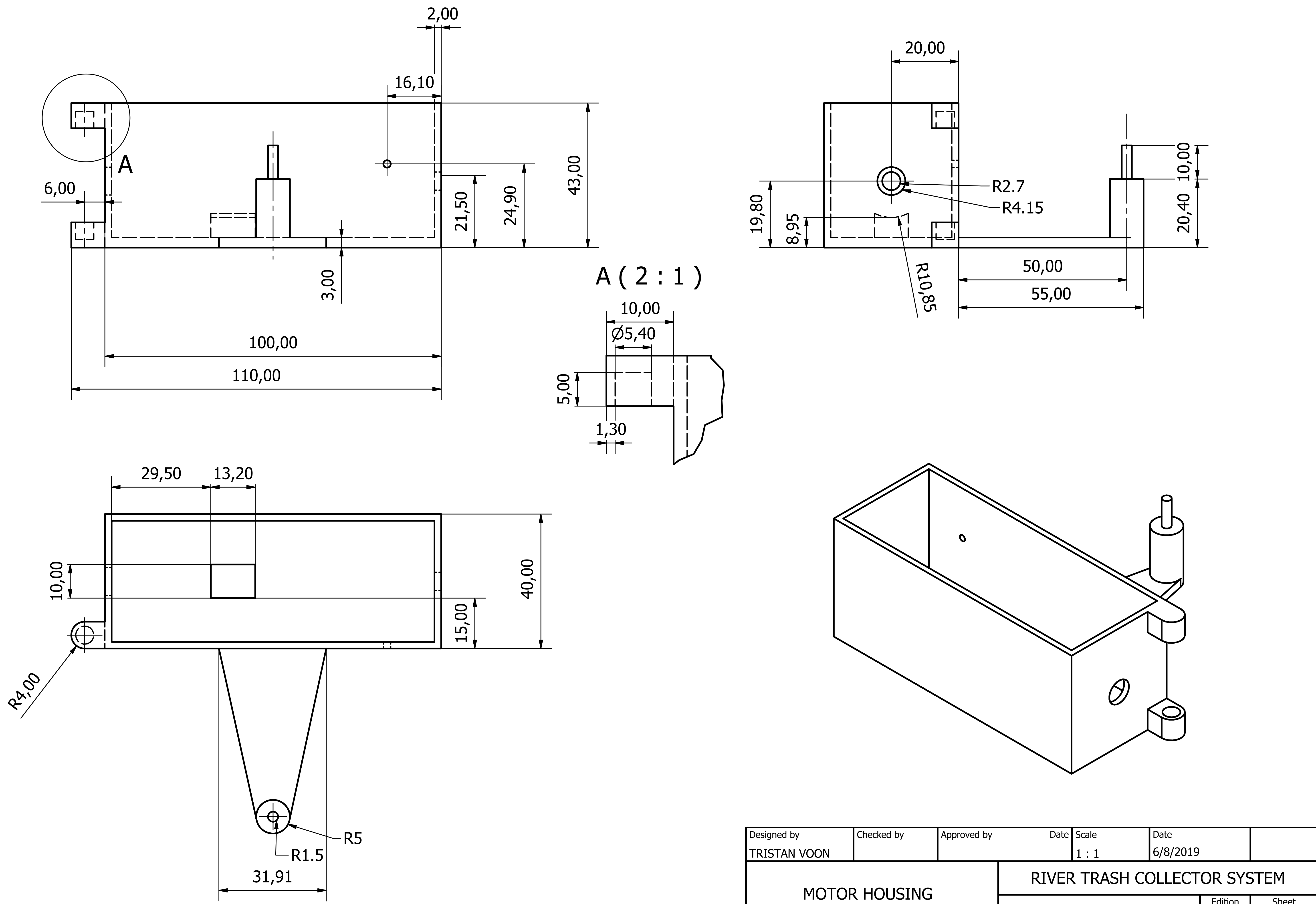
ASSEMBLED VIEW	RIVER TRASH COLLECTOR SYSTEM		
	RFG SUBASSEMBLY	Edition	Sheet 2 / 7



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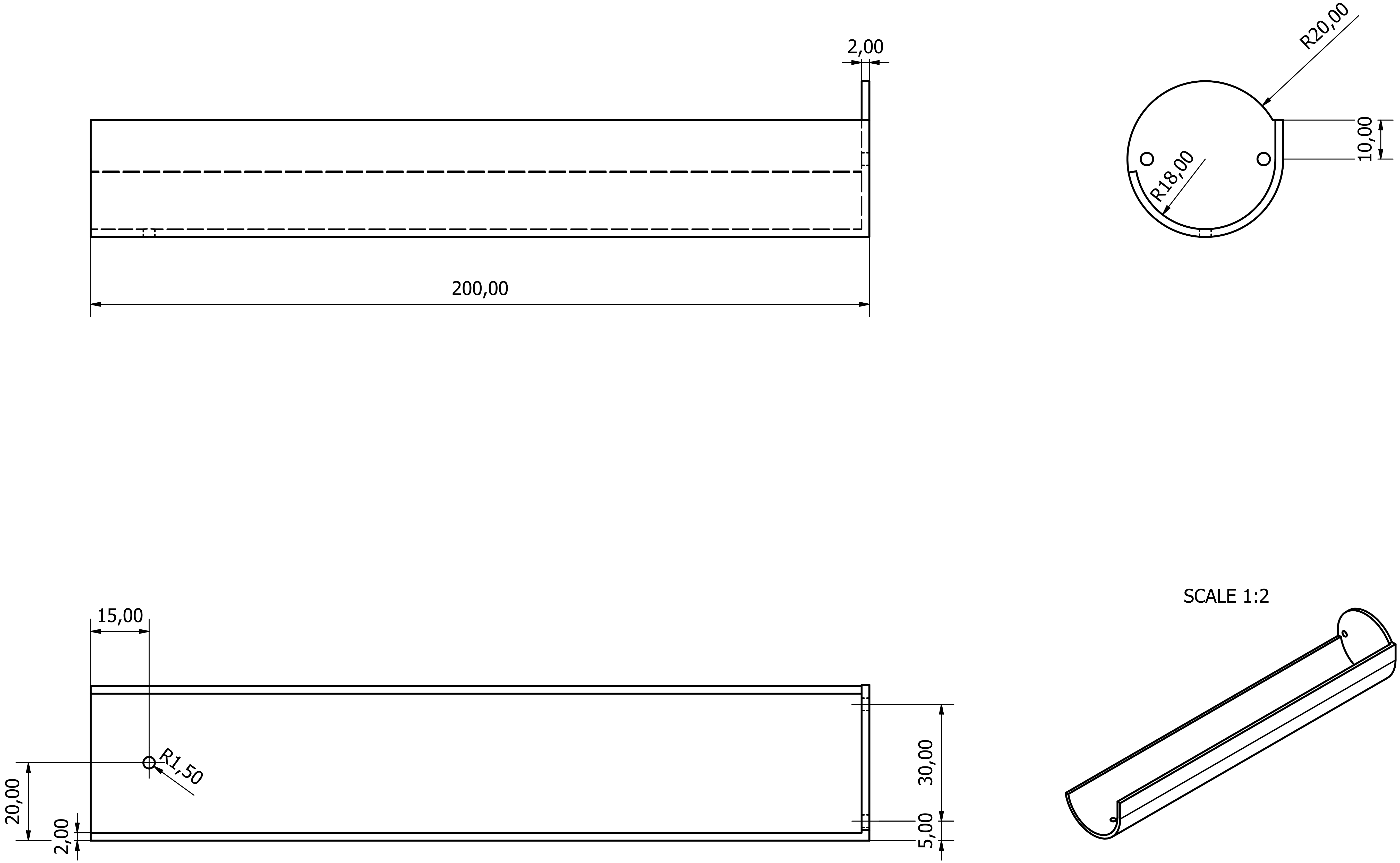
MOTOR HOUSING	RIVER TRASH COLLECTOR SYSTEM					
	RFG SUBASSEMBLY				Edition	Sheet 3 / 7



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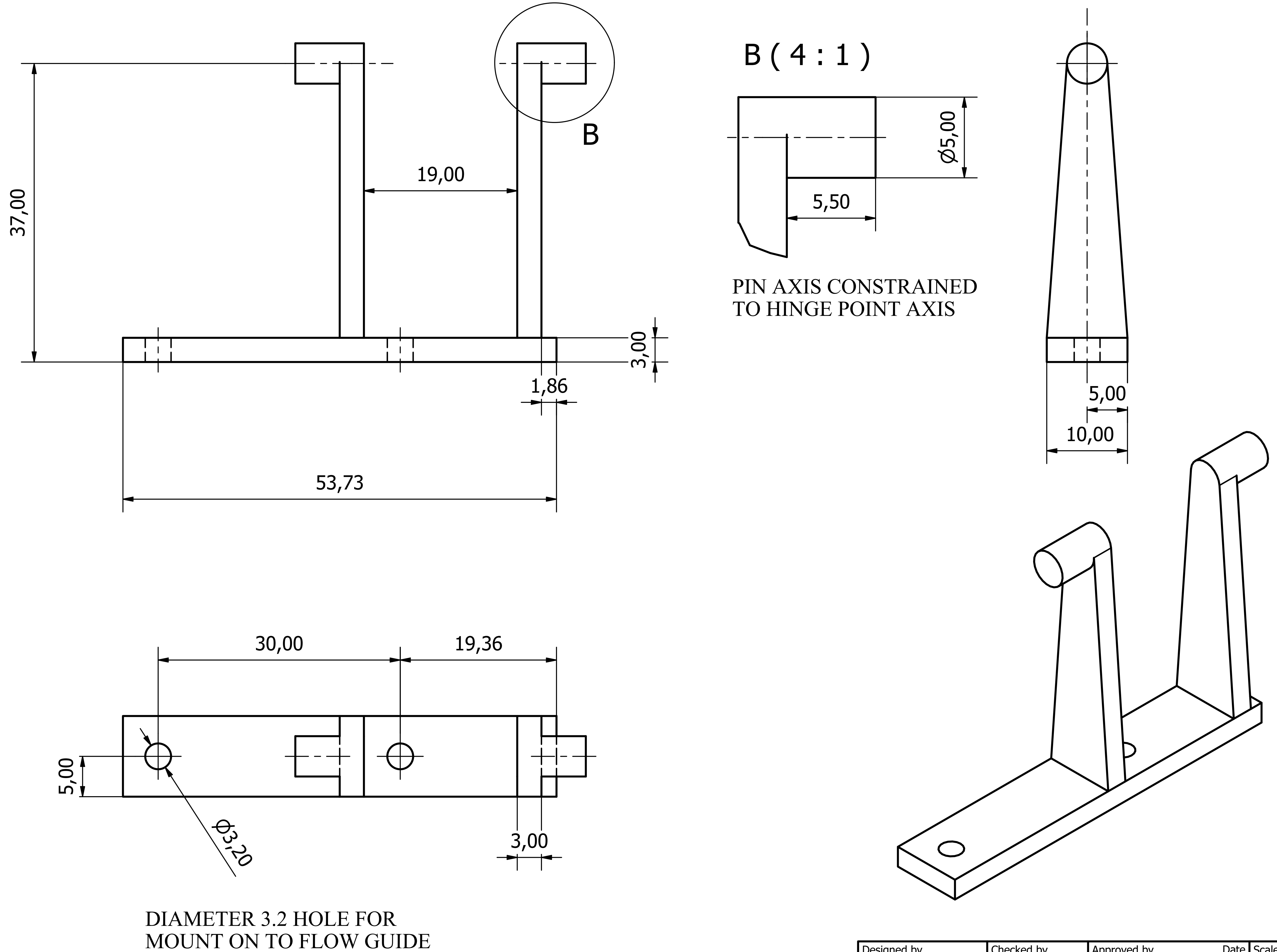
FLOW GUIDE		RIVER TRASH COLLECTOR SYSTEM			
		RFG SUBASSEMBLY		Edition	Sheet 4 / 7



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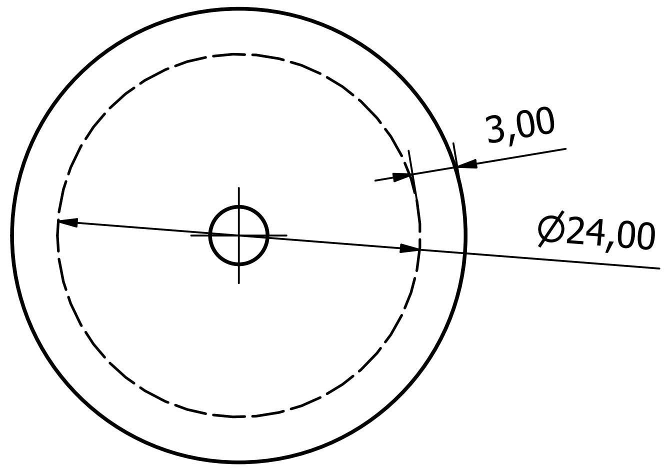
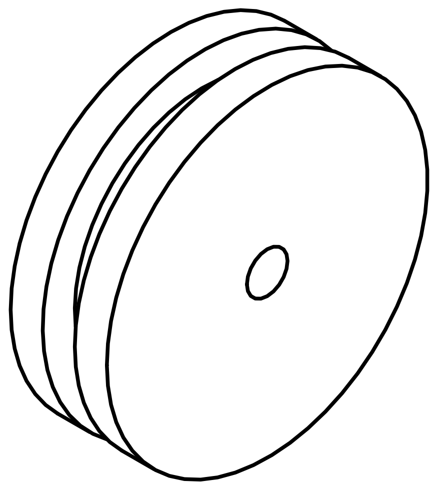
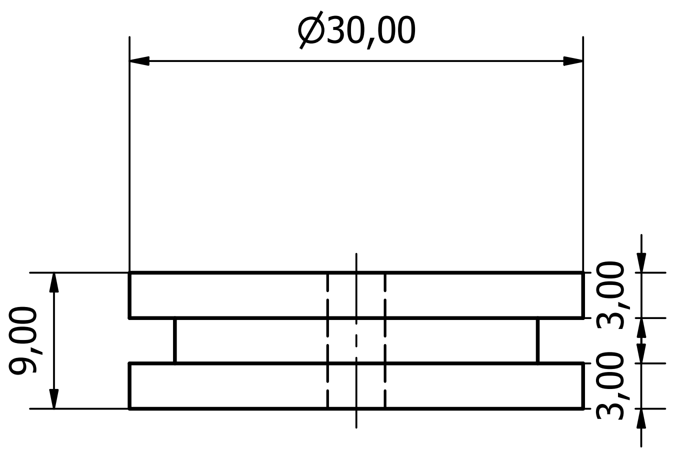
TRISTAN VOON				2 : 1	6/8/2019

FLOW GUIDE - HINGE INTERFACE	RIVER TRASH COLLECTOR SYSTEM		
	RFG SUBASSEMBLY	Edition	Sheet 5 / 7







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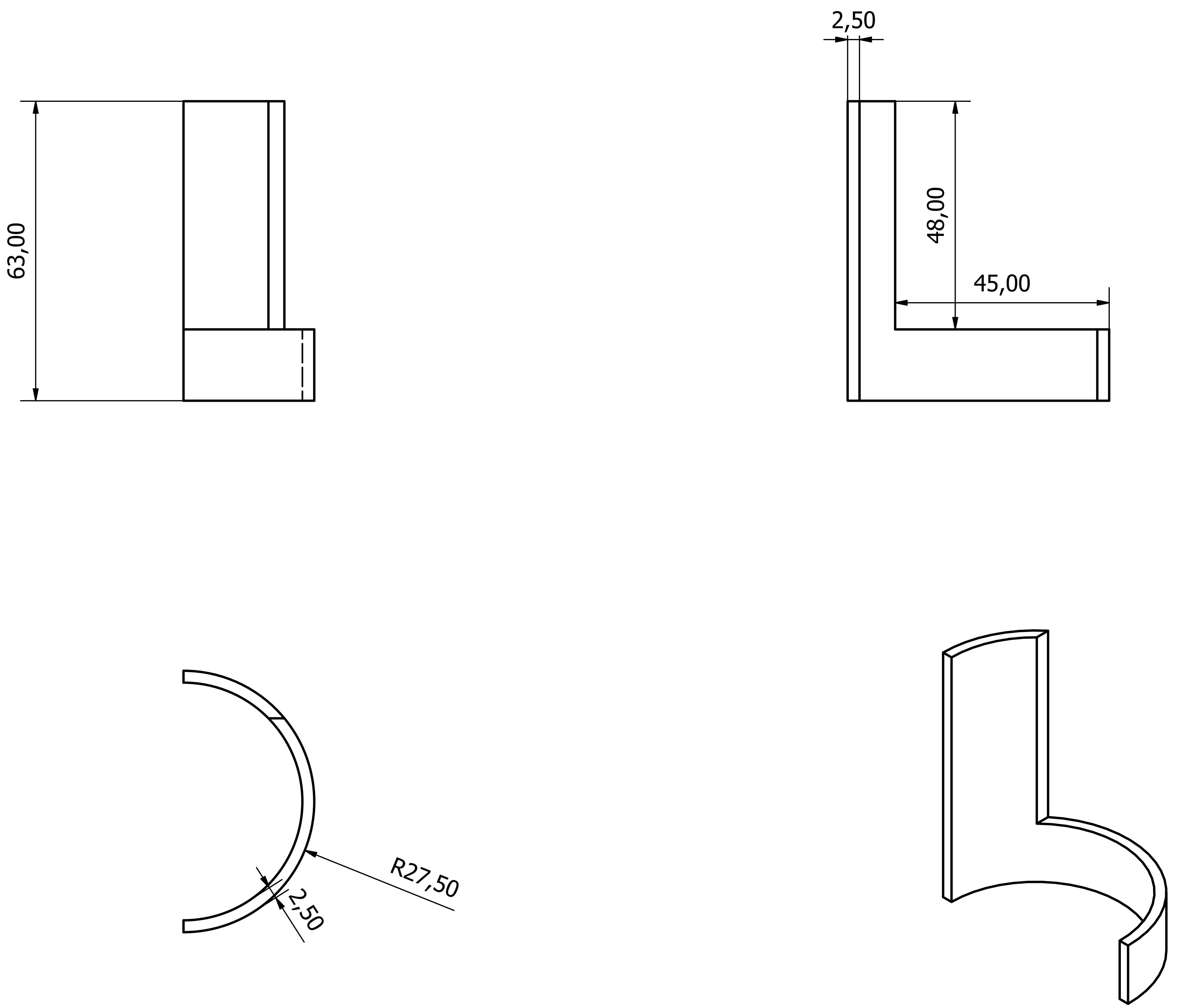
TRISTAN VOON				2	6/8/2019	
PULLEY	RIVER TRASH COLLECTOR SYSTEM					
	RFG SUBASSEMBLY			Edition	Sheet	
					6 / 7	



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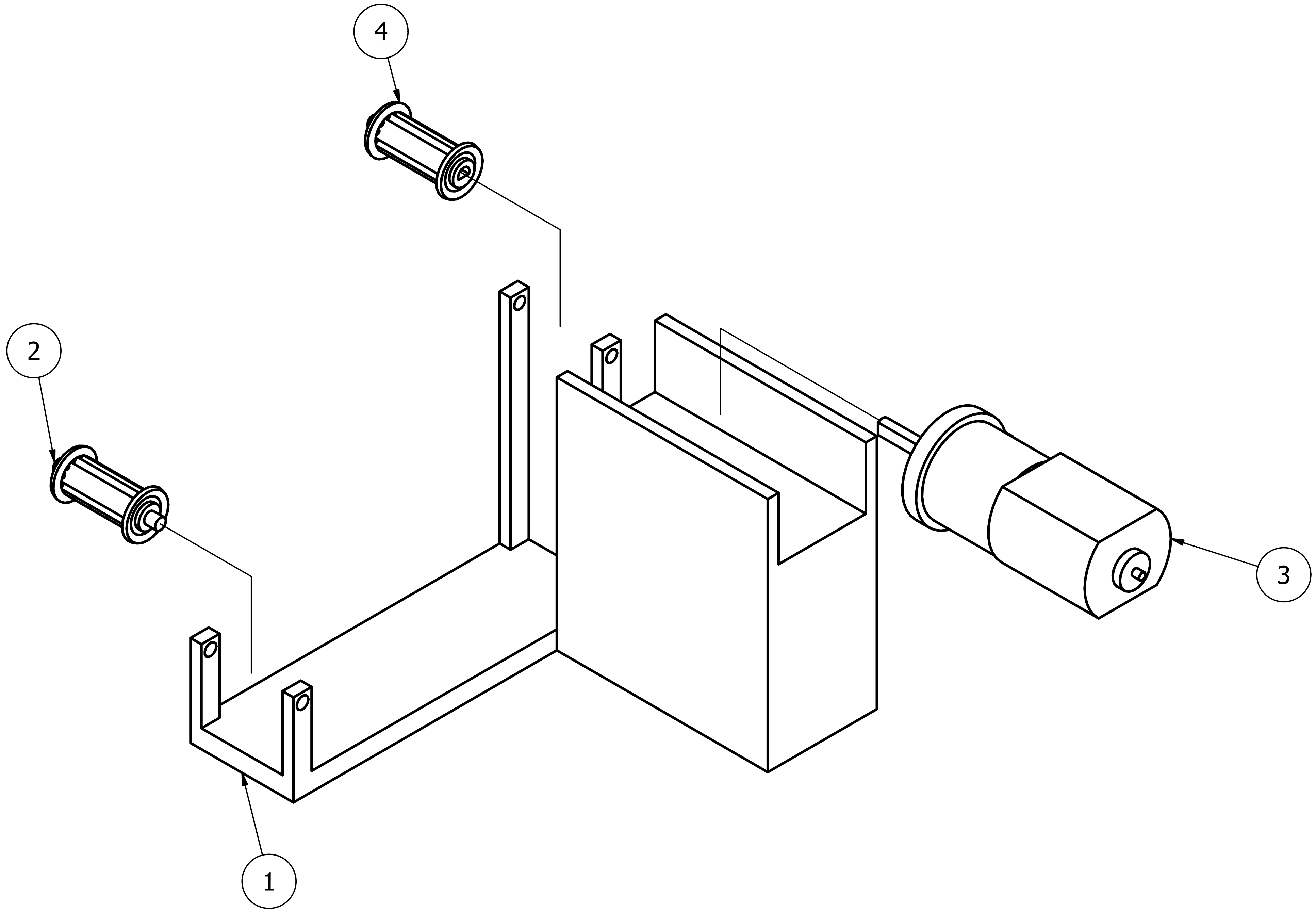
FLOW GUIDE BRACKET	RIVER TRASH COLLECTOR SYSTEM		
	RFG SUBASSEMBLY	Edition	Sheet 7 / 7



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	CONVEYOR FRAME	
2	1	FREE GEAR	ATPMXL019
3	1	12V GEARED MOTOR	
4	1	MOTOR DRIVEN GEAR	ATPMXL019

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EXPLODED VIEW

RIVER TRASH COLLECTOR SYSTEM

COLLECTOR SUBASSEMBLY

Edition	Sheet
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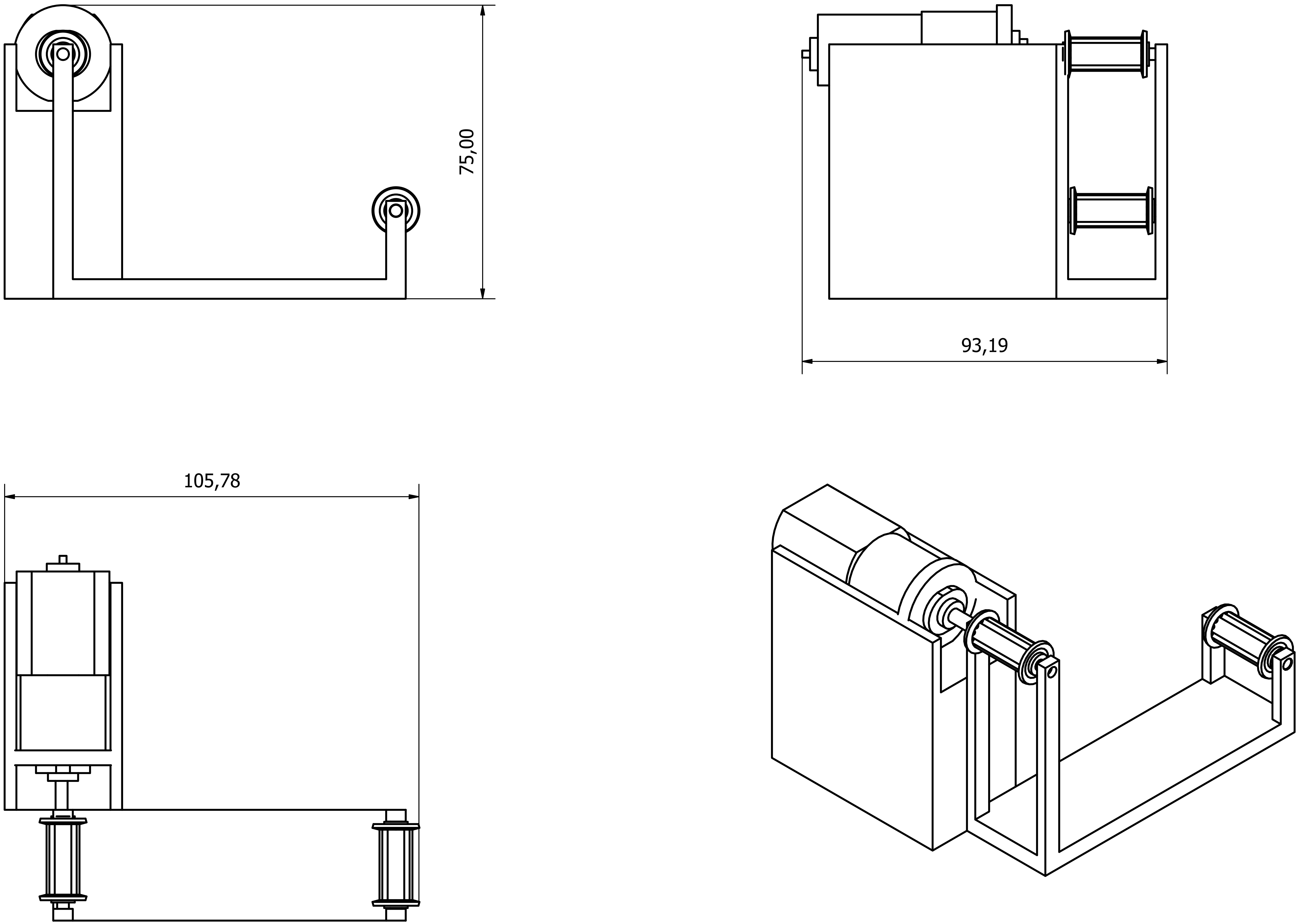

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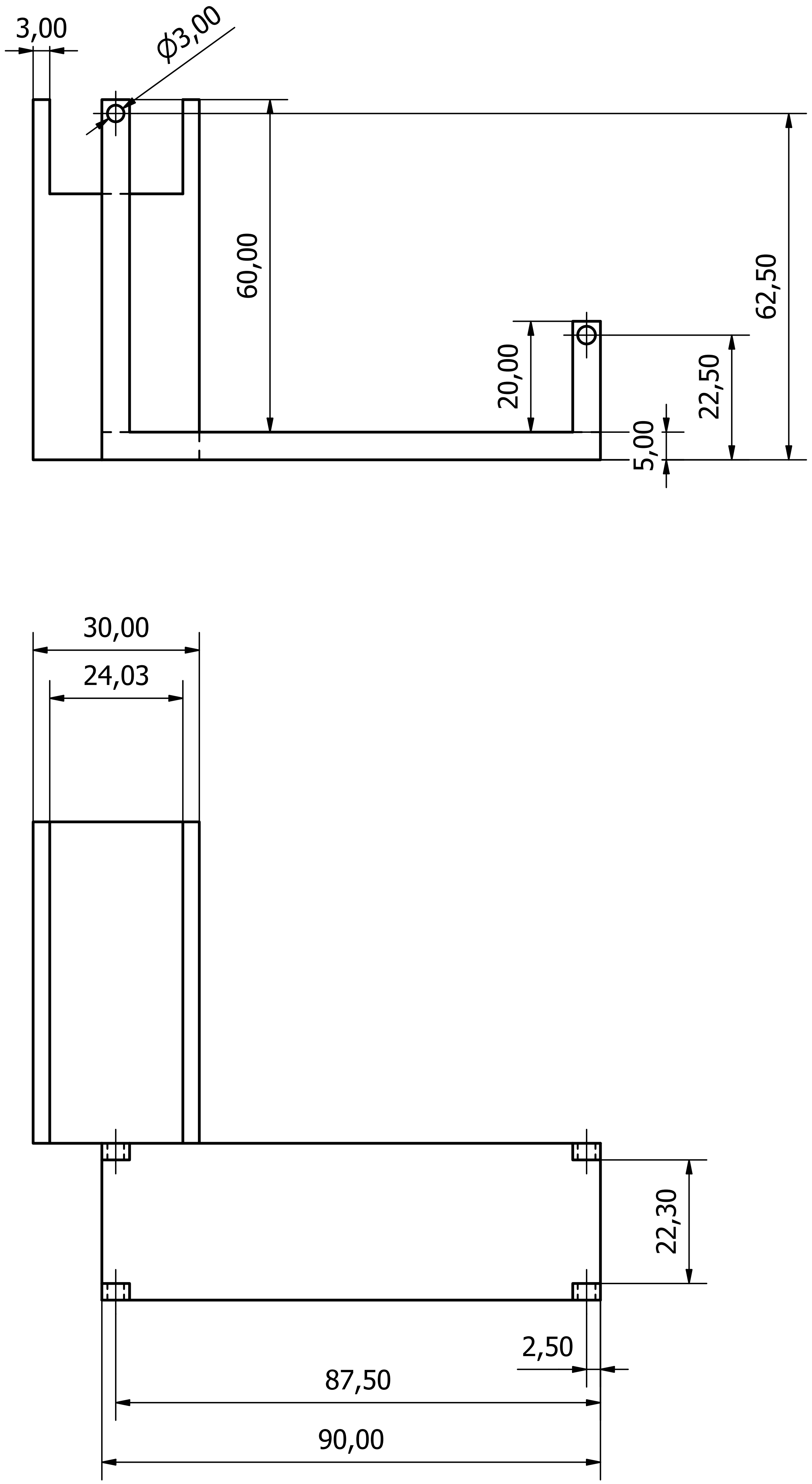
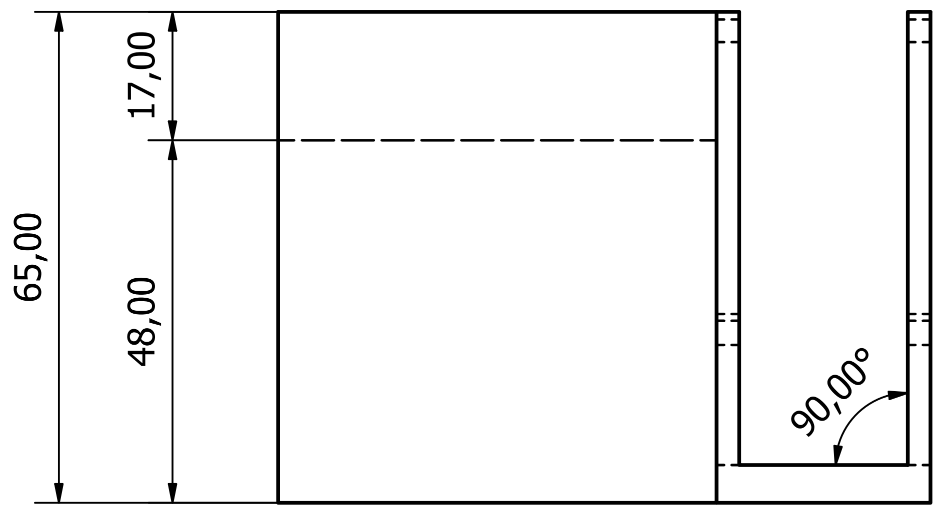
TRISTAN VOON				1	7/8/2019	

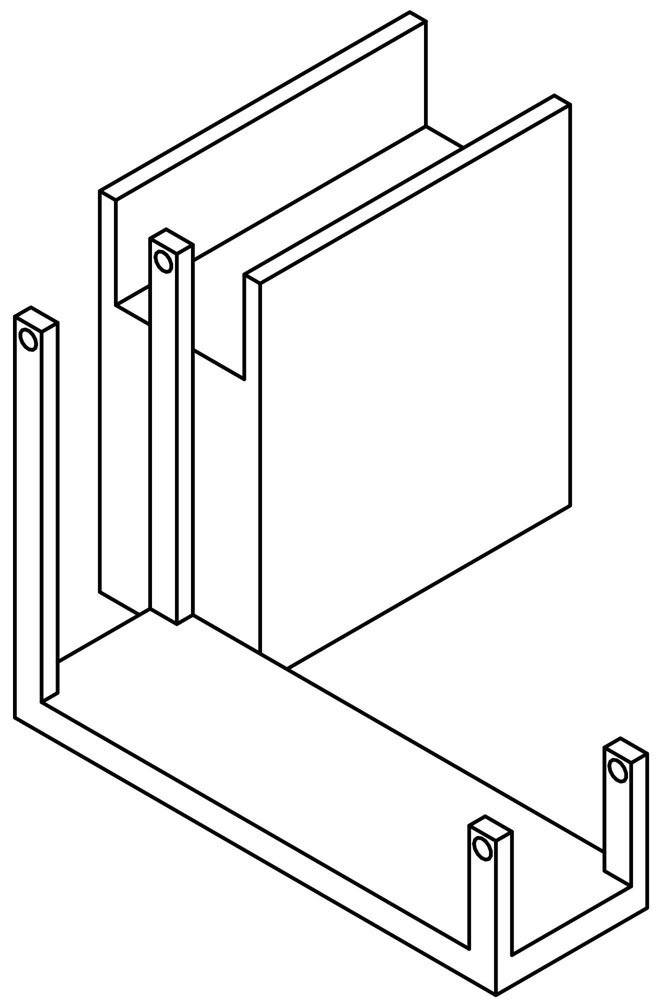
ASSEMBLED VIEW

RIVER TRASH COLLECTOR SYSTEM

	Edition	Sheet
COLLECTOR SUBASSEMBLY		2 / 5







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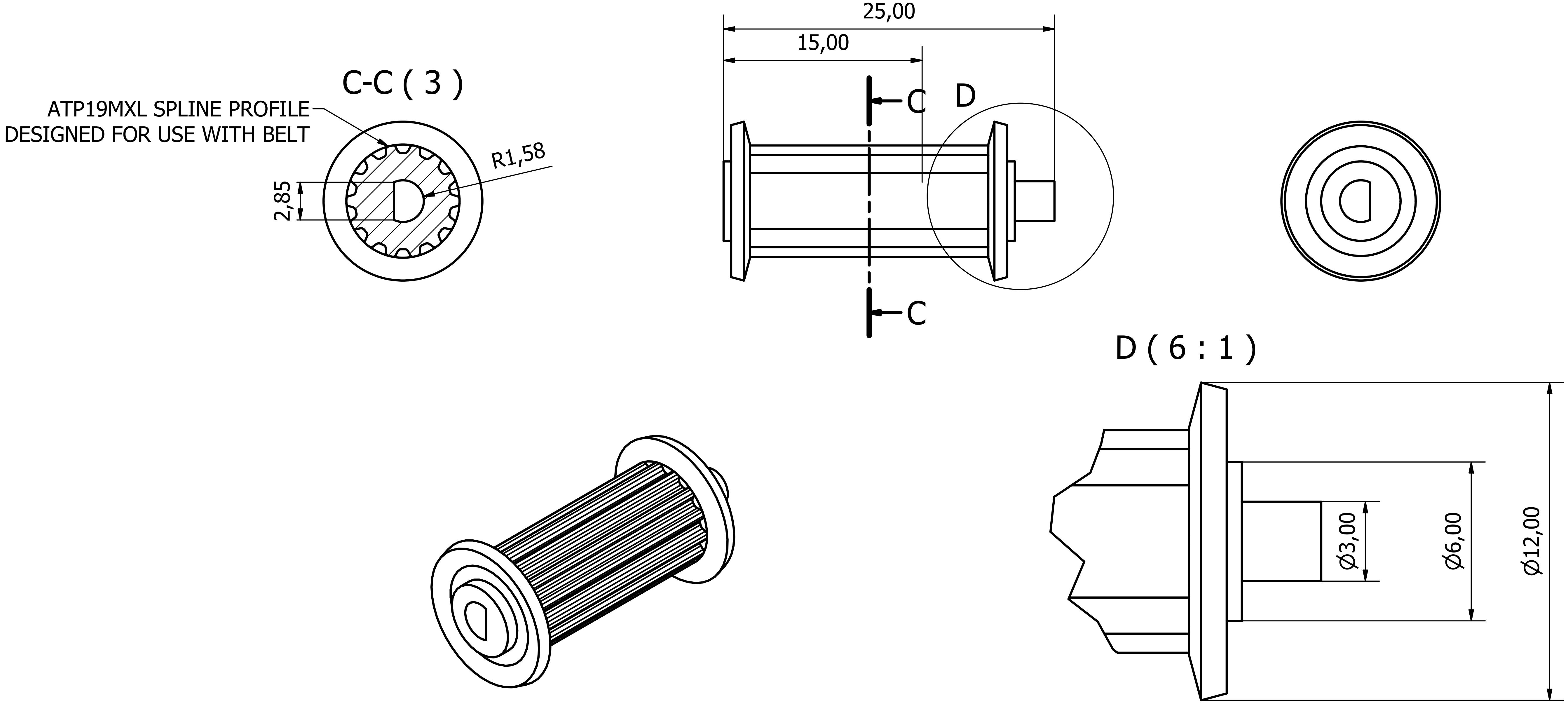
CONVEYOR FRAME	RIVER TRASH COLLECTOR SYSTEM		
	COLLECTOR SUBASSEMBLY	Edition	Sheet 3 / 5



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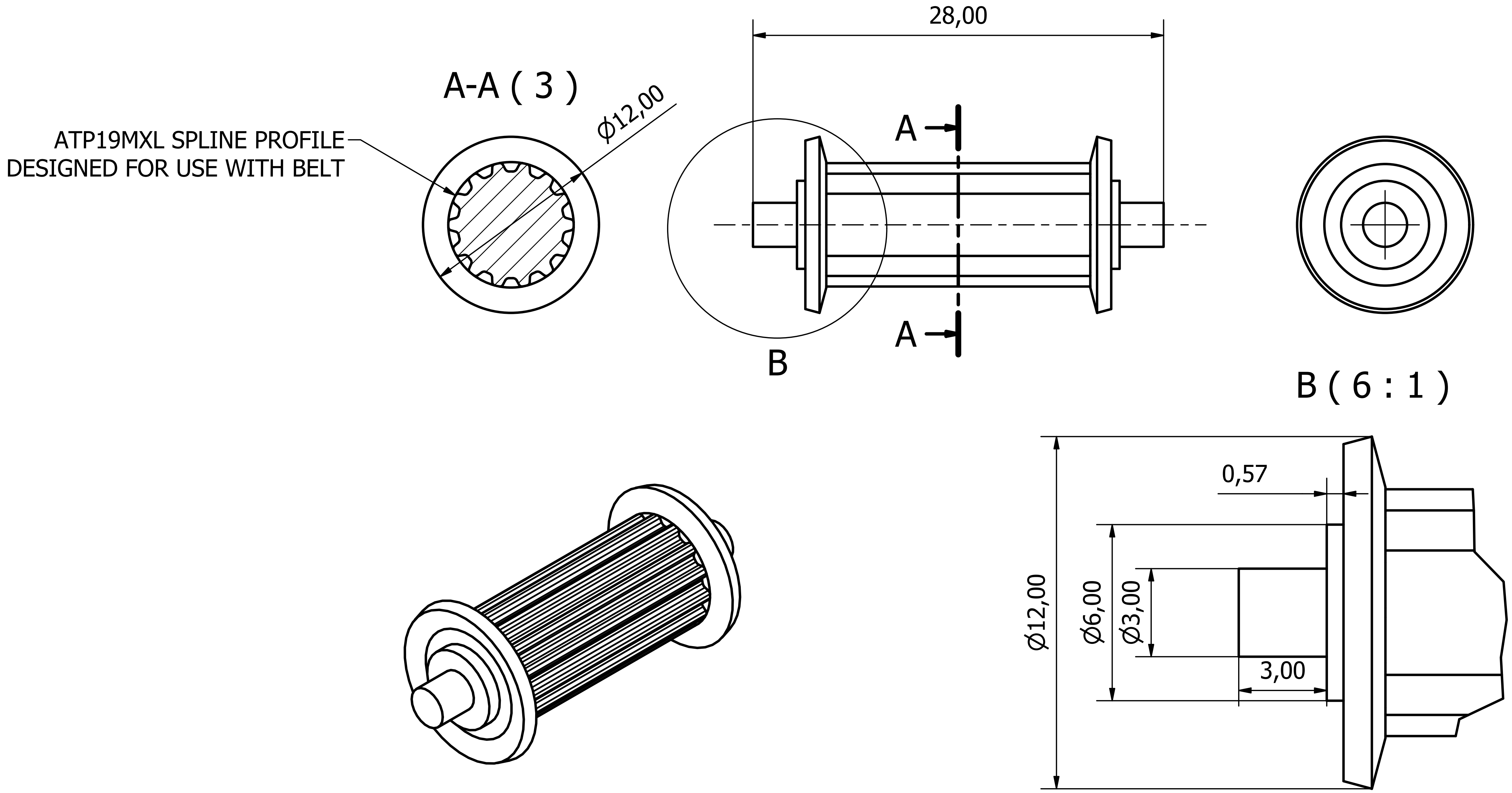
MOTOR DRIVEN GEAR	RIVER TRASH COLLECTOR SYSTEM		
	COLLECTOR SUBASSEMBLY	Edition	Sheet 4 / 5



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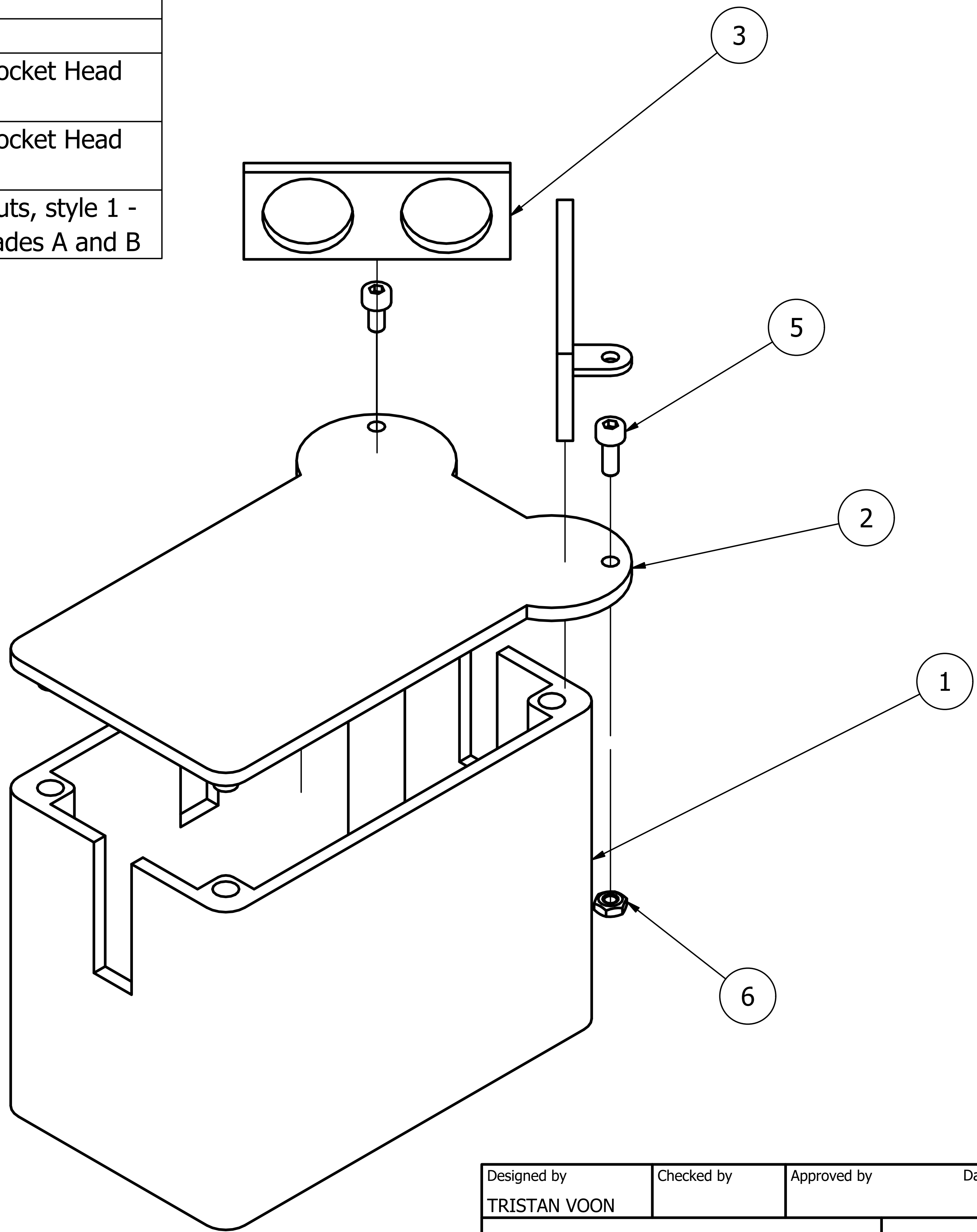
TRISTAN VOON				3	7/8/2019	

FREE GEAR	RIVER TRASH COLLECTOR SYSTEM		
	COLLECTOR SUBASSEMBLY	Edition	Sheet 5 / 5

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	CONTROLLER BOX	
2	1	CONTROLLER BOX COVER	
3	2	SENSOR FRAME	
4	1	ISO 4762 - M3 x 6(1)	Hexagon Socket Head Cap Screw
5	1	ISO 4762 - M3 x 8(1)	Hexagon Socket Head Cap Screw
6	2	ISO 4032 - M3(4)	Hexagon nuts, style 1 - Product grades A and B



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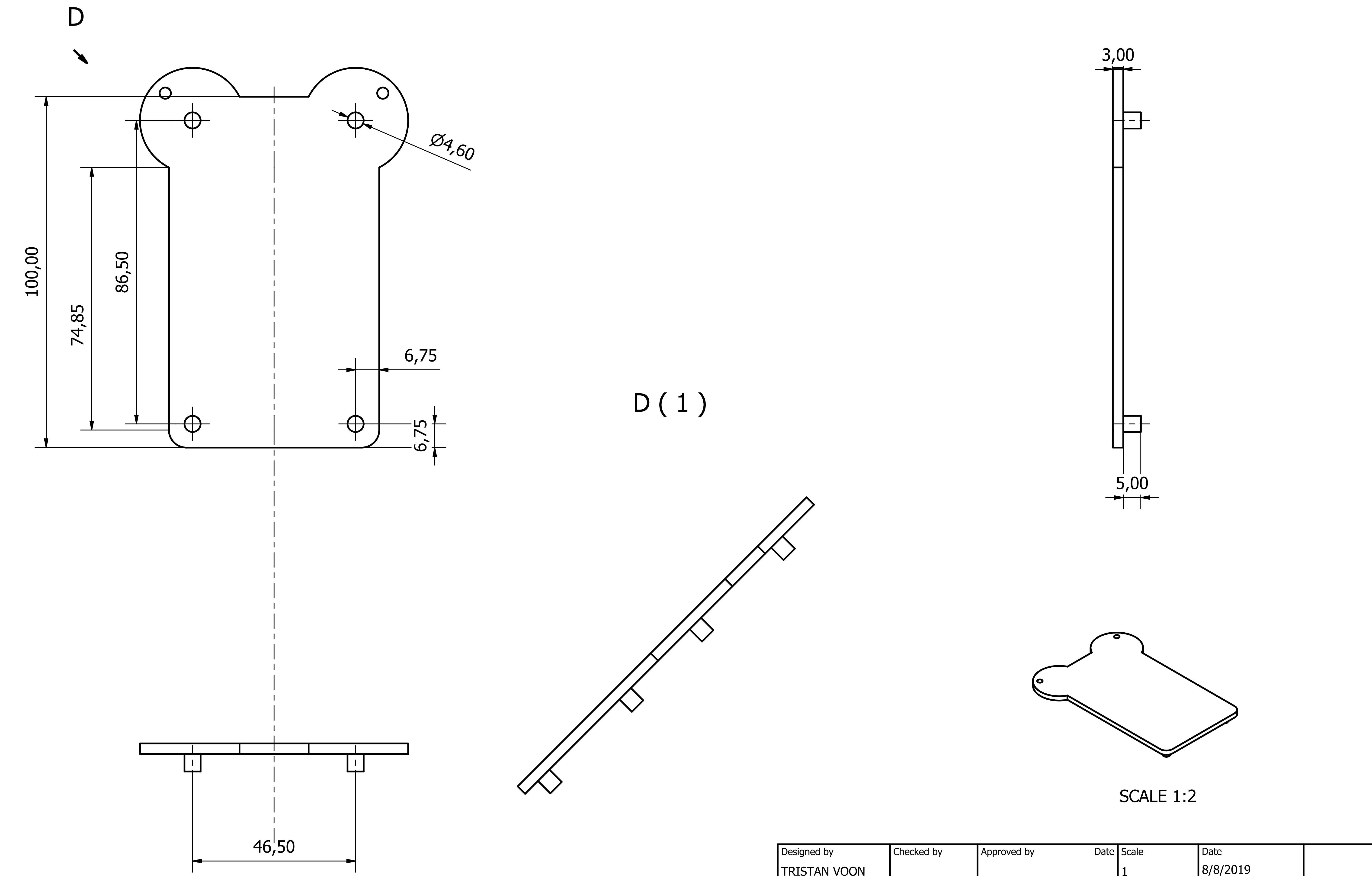
CONTROLLER BOX EXPLODED	CONTROLLER BOX DRAWINGS		
	CONTROLLER BOX	Edition	Sheet 1 / 4



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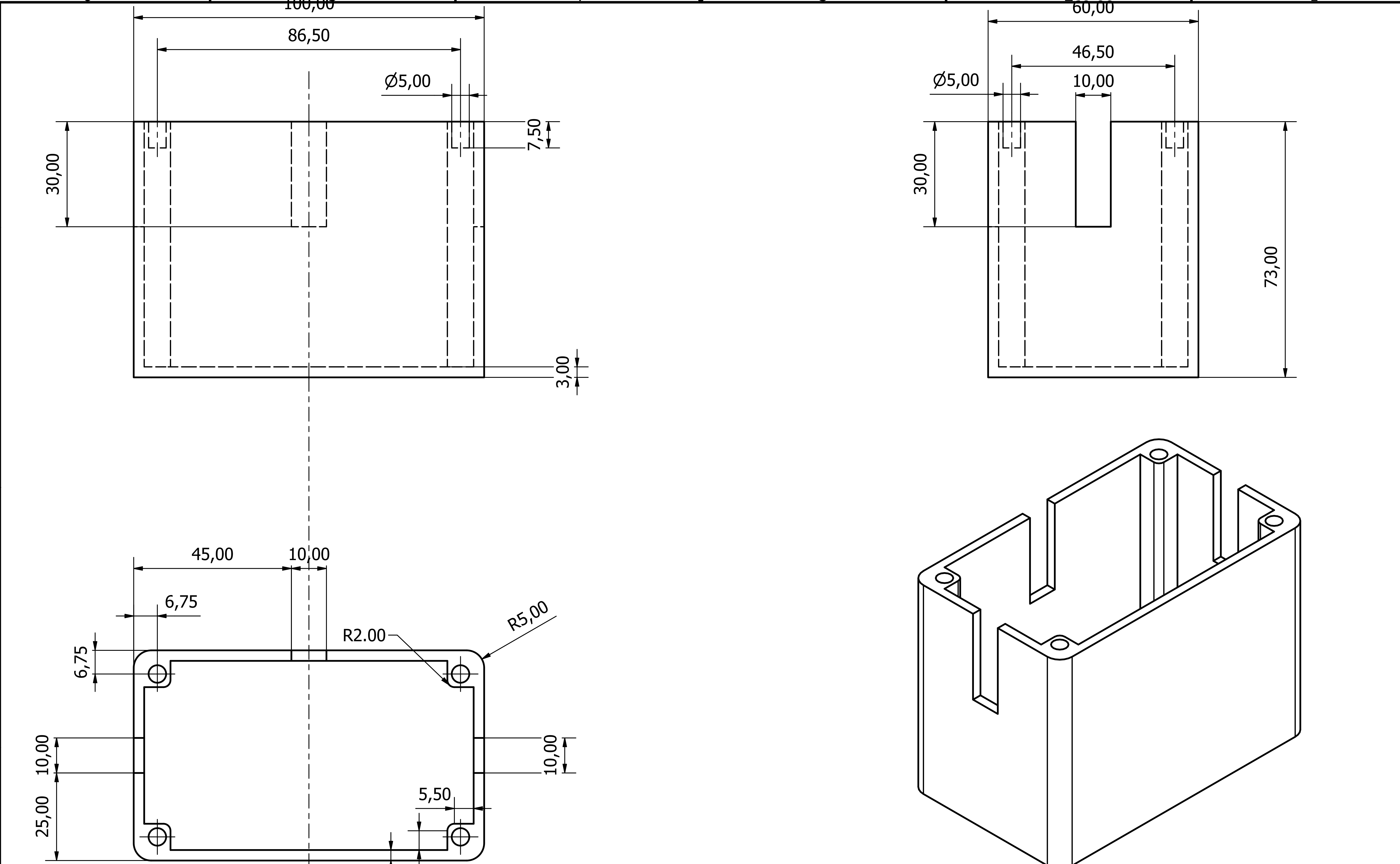
CONTROLLER BOX COVER	CONTROLLER BOX DRAWINGS		
	CONTROLLER BOX	Edition	Sheet 2 / 4



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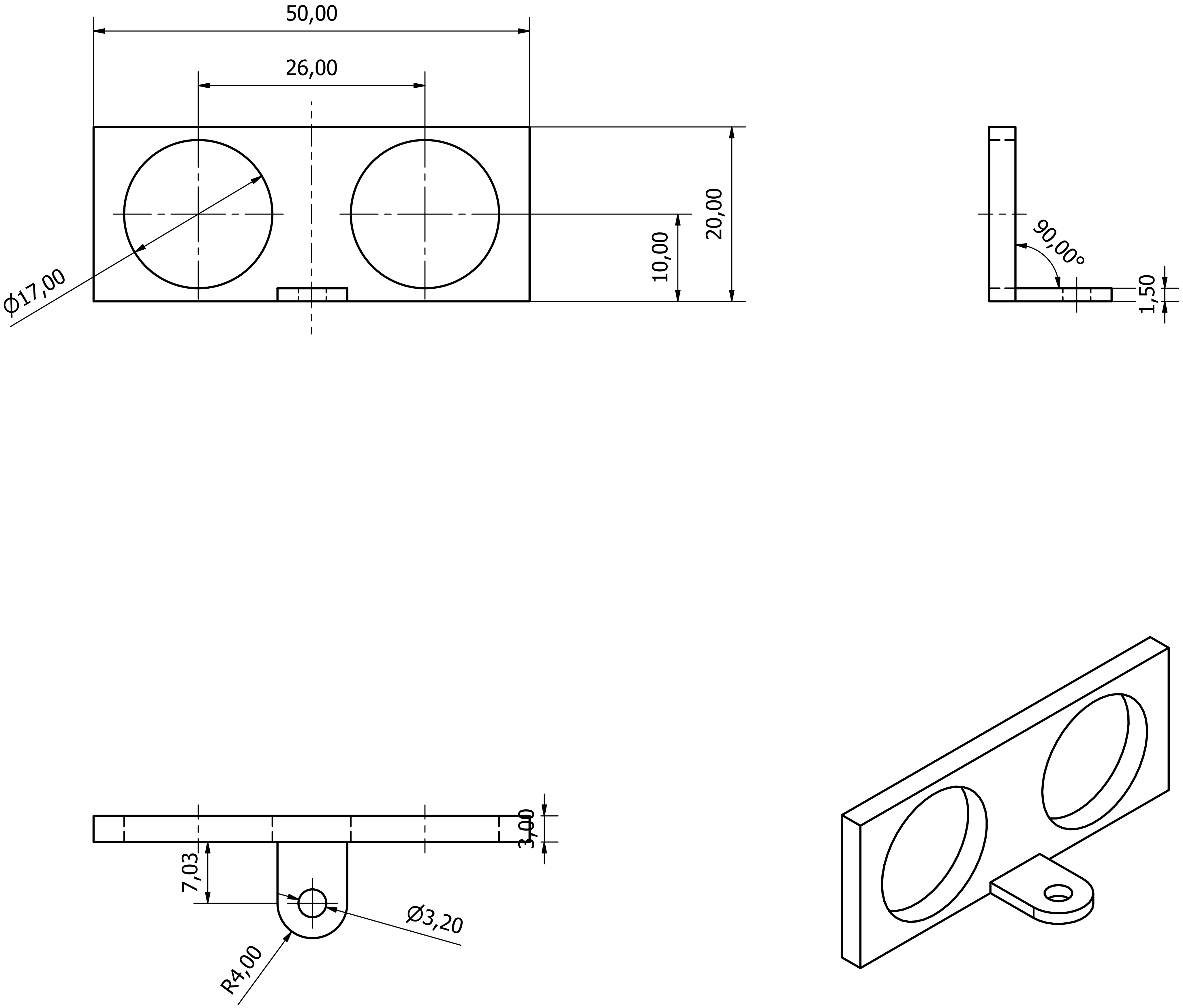
CONTROLLER BOX

CONTROLLER BOX DRAWINGS

CONTROLLER BOX

Edition

Sheet 3 / 4



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TRISTAN VOON				2 : 1	8/8/2019	
ULTRASONIC SENSOR HOLDER				CONTROLLER BOX DRAWINGS		
				CONTROLLER BOX	Edition	Sheet 4 / 4

```
//Channel A for flow guide
//Channel B for conveyor
#define trigpin 3     // For Sensor1
#define echopin 2
#define tpin 5        // For Sensor2
#define epin 4
#define InA1 13
#define InA2 12
#define InB1 9
#define InB2 8
#define button 7
#define pwmA 11        // Fixed Speed
#define pwmB 10

void setup() {
  // put your setup code here, to run once:
   Serial.begin(9600);
   pinMode(trigpin,OUTPUT);
   pinMode(echopin,INPUT);
   pinMode(tpin,OUTPUT);
   pinMode(epin,INPUT);
   pinMode(InA1,OUTPUT);
   pinMode(InA2,OUTPUT);
   pinMode(InB1,OUTPUT);
   pinMode(InB2,OUTPUT);
   pinMode(button,OUTPUT);
   pinMode(pwmA,OUTPUT);
   pinMode(pwmB,OUTPUT);

   analogWrite(pwmB,170);
   digitalWrite(button,HIGH);
   digitalWrite(InB1,HIGH);  //Command retraction rotation
   digitalWrite(InB2,LOW);
   delay(1000);
}
```

```
long   duration,distance,Sensor1,Sensor2;
int  pwmValue=0;
int k = 0;

void loop() {

     Sensor(trigpin, echopin);
     Sensor1 = distance;
     Sensor(tpin, epin);
     Sensor2 = distance;



   Serial.println("Sensor1:  ");
   Serial.print(Sensor1);
   Serial.println("  cm");
   Serial.println("Sensor2:  ");
   Serial.print(Sensor2);
   Serial.println("  cm");



   if  ((k  ==  1)&&(Sensor2>=30)&&(Sensor1>=30))
     {
     digitalWrite(InA1,HIGH);   //Command  release  rotation
     digitalWrite(InA2,LOW);
     pwmValue  =  100;
     analogWrite(pwmA,  pwmValue);   //Slow  winch  release  to
allow  water  pressure  to
                                       //move  the  flow  guide

     delay(3000);

     digitalWrite(InA1,LOW);   //Command  motor  stop
     digitalWrite(InA2,LOW);
     pwmValue  =  0;
     analogWrite(pwmA,  pwmValue);
     Serial.print(pwmValue);
```

```
    Serial.println(" Pwm");

    k = 0; //reset vehicle transit detector variable
   }




  if  (((Sensor1<=30)||(Sensor2<=30))&&((Sensor1!=0)&&(Sensor2
=0)))
  //Detects approaching vehicle from sensor 1 or 2 direction
  {
    digitalWrite(InA1,LOW); //Command retraction rotation
    digitalWrite(InA2,HIGH);
   pwmValue = 100;
    analogWrite(pwmA, pwmValue);
    Serial.print(pwmValue);
    Serial.println(" Pwm");

   delay(3000);        //Motor movement duration

    digitalWrite(InA1,LOW); //Command Stop
    digitalWrite(InA2,LOW);
   pwmValue = 0;
    analogWrite(pwmA, pwmValue);

   k = 1; //Vehicle in transit
  }



}

void Sensor(int trigPin,int echoPin)
{
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
```

```
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = (duration/2) / 29.1;
}
```