Miniature Fish Respirometry System with Integrated Cameras

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Acknowledgements

I would like to thank my two supervisors, Filippo Sanfilippo and Marta Moyano, for their incredibly positive attitude regarding the project, and the many fun and interesting conversations that have been had in our weekly project meetings.

Abstract

A respirometry system for small fish up to 30 mm in length has been developed and a prototype has been produced to verify the design. The developed system has two integrated cameras for top and side filming of the specimen during testing. The report details the development of an axial impeller pump based on a theoretical pump head loss analysis of the system and max flow velocity of 20 cm/s. A PI regulator has been implemented to accurately control the rotational velocity of the impeller. Control software for the operation of the respirometry system has been conceptualized and partly implemented.

Contents

List of Figures

Chapter 1

Introduction

This report comprises the development of a miniature respirometry system for measuring the oxygen consumption of larval stage fish and other small fish species. A prototype of the developed system is pictured below in Figure 1.1.

A GitHub page containing all code and 3D files for this project is located at: https://github.com/stianKristensen/fish_respirometry_system.

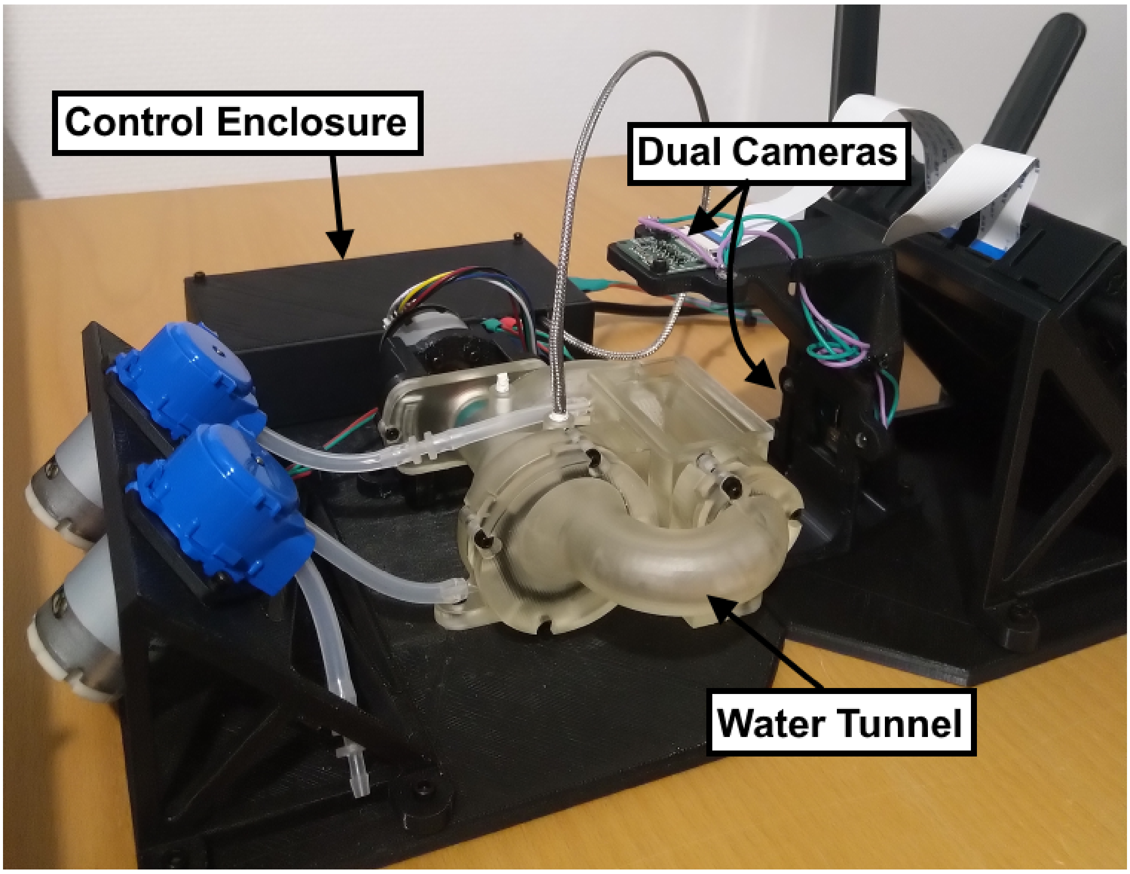

Figure 1.1: Respirometry System Prototype.

Fish respirometry systems are used for measuring the oxygen consumption of fish in order to determine, among other things, the metabolism rate of the specimen. Some respirometry system have the fish in a tank while logging the oxygen consumption over longer periods, whereas the type of system explored in this report subjects the fish to water flow which forces it to swim and therefore increases its respiration rate.

1.1 State of the Art

Commercially available respirometry system are available however these systems are highly expensive. Below in the following subsections are two commercial examples from the brand "Loligo Systems", and a custom resin-printed miniature system presented in a recent paper from the National Taiwan Ocean University.

1.1.1 "Loligo Systems" Standard Respirometry System

The standard range of respirometry systems from "Loligo Systems" range from a tank volume of 170 ml all the way up to 850 L. These 170 ml system can be seen pictured in Figure 1.2 while the system design used for the models in the range 5 *sim* 850 L is pictured in Figure 1.3.

The complete kit for the 170 ml respirometry system is 23,629.00 EUR and the 850 L is 64,684.00 EUR [13] (at the time of writing this report).

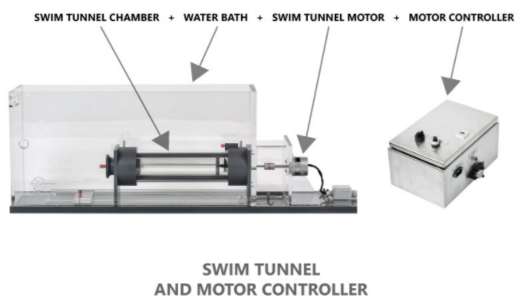

Figure 1.2: 170 ml swimming respirometry system from "Loligo Systems" [13].

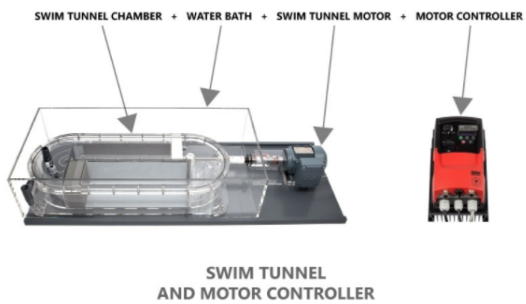

Figure 1.3: 5 *sim* 850 L swimming respirometry system from "Loligo Systems" [13].

1.1.2 "Loligo Systems" Glass Chamber System

A "glass chamber" system housing the fish in glass tubes with inner diameter ranging from 9 to 45 mm is available from "Loligo Systems". This system is designed to accommodate smaller fish than their other systems. An illustration and a demonstration of the system can be seen in respectively Figure 1.4 and 1.5 below. The complete kit for this system costs 15,873.00 EUR for the largest version with 45 mm inner diameter, whereas the smallest version with 9 mm inner diameter costs 17,684.00 EUR [12] (at the time of writing this report).

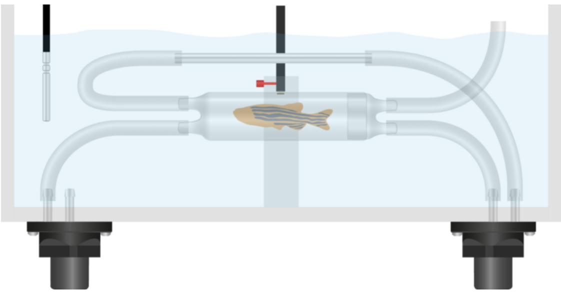

Figure 1.4: Illustration of the glass chamber respirometry system from "Loligo Systems" [12].

Figure 1.5: Demonstration of the glass chamber respirometry system from "Loligo Systems" [12].

1.1.3 Miniature Respirometry System

A custom resin-printed miniature system presented was recently presented in a paper published from the National Taiwan Ocean University [9]. The system can be seen pictured below in Figure 1.6 and features a testing chamber size of 1x1x3 cm. A system similar to this design is far cheaper to manufacture as compared to the other commercial alternatives previously mentioned.

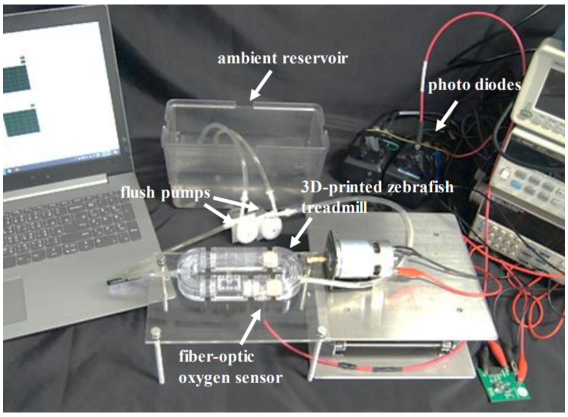

Figure 1.6: The miniature respirometry system developed at the National Taiwan Ocean University [9].

Chapter 2

Project Description

The full project description as it was presented to the students is appended in Appendix A. One of the drivers for this project is the substantial cost of commercially available systems (see Section 1.1). Therefore, the cost of the developed system should be kept in mind and kept as low as possible.

2.1 Product Specification

The product specification covers the necessary and desired specifications of the developed system. It is built based on the project description (Appendix A) and discussions during the initial project meetings between the student and the Supervisors for this report, Filippo Sanfilippo and Marta Moyano. The product specification is made in order to have a list of specific points that one can refer back to after the project to be able to form a clear and concise conclusion for the development of the system.

The product specification is made up of necessary specifications noted as "Needs", and a set of desired specifications noted as "Wants".

2.1.1 Needs

The following points have been deemed necessary for the system.

1. 3 cm long 1x1 cm testing chamber.
2. See through walls on the top and side of the testing chamber for recording purposes.
3. Temperature Control. The system has to maintain the temperature in the system equal to the tank water as several species planned for testing need water at lower than room-temperature.
4. Salt water compatible components. Several of the species planned for testing are salt water species.
5. Max internal volume of system under 100 ml.
6. Max flow rate of 20 cm/s. This flow rate is based on the maximum flow of the miniature respirometry system introduced in Section 1.1.3.
7. Min flow rate of 0.5 cm/s.
8. Adjustable flow rate in 0.2 cm/s steps.
9. Material selection for the system to prevent oxygen storage.

2.1.2 Wants

The following points have been deemed desirable if possible to implement into the system.

1. AI monitoring of the fish to determine additional data from the fish during the tests.
2. AI control. Automatically stop the system if the fish is unable to continue swimming against the flow.

Chapter 3

Theory

3.1 Hydraulic Loss of Head

This section covers several relevant equation for calculating the loss of head[1] in a hydraulic system.

3.1.1 Friction in Pipes

By using the "Darcy-Weisbach" equation, see Equation 3.1, along with retrieving the roughness coefficient f from the "Moody Diagram", see Figure 3.1, one can calculate the loss of head in a pipe due to friction while also accounting for the diameter of the pipe and viscosity of the fluid within it [3]. The Moody Diagram gives the roughness coefficient f based on the Reynolds number, $R = d \cdot V/\upsilon$, and relative roughness, ϵ/d.

$$h_f = f \cdot \frac{l \cdot V^2}{d \cdot 2 \cdot g} \tag{3.1}$$

Explanation of symbols used in this section can be found in Table 3.1 below.

Table 3.1: Explanation of symbols.

Symbol	Description	[Unit]
h_f	Head loss due to friction	$[m]$
f	Roughness coefficient	$[-]$
l	Pipe length	$[m]$
V	Fluid velocity	$[m/s]$
d	Inner diameter of pipe	$[m]$
g	Gravitational acceleration	$[m/s^2]$
υ	Kinematic viscosity	$[m^2/s]$
ϵ	Magnitude of wall roughness	$[m]$

[1] "In fluid dynamics, head is a concept that relates the energy in an incompressible fluid to the height of an equivalent static column of that fluid" [6].

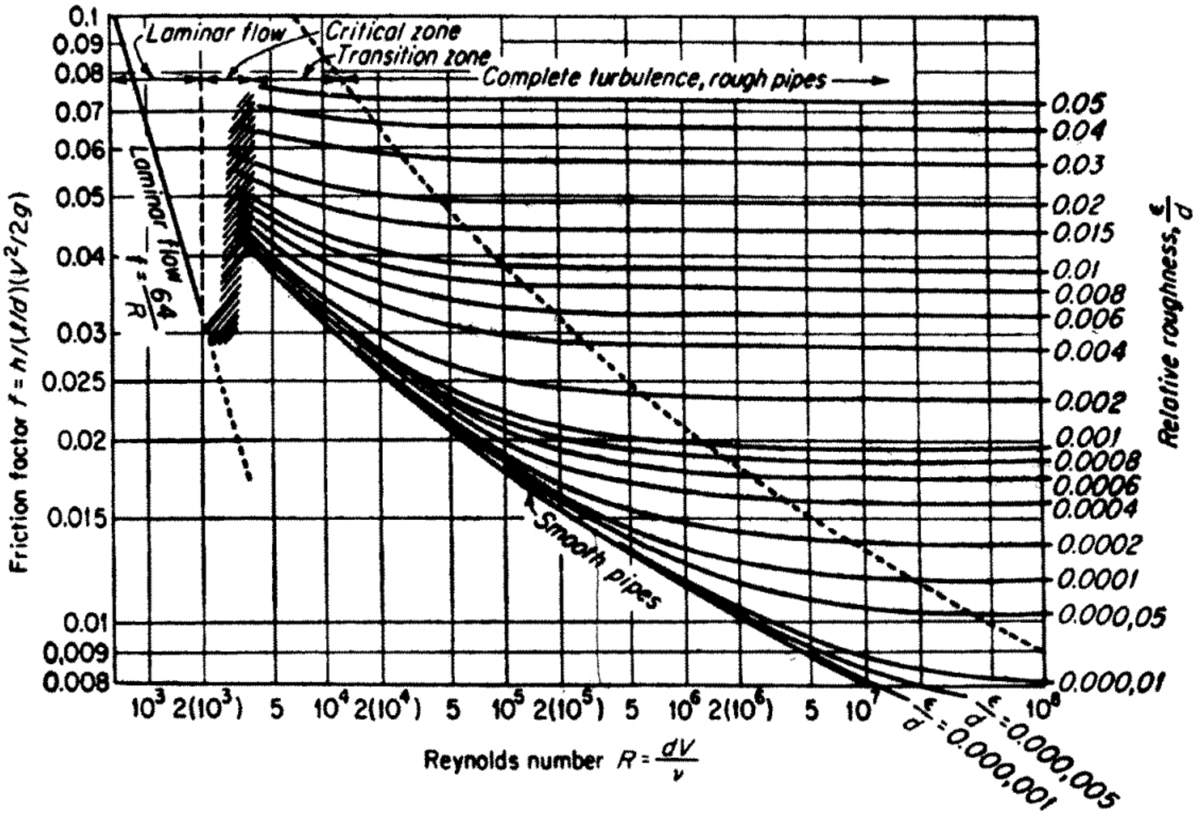

Figure 3.1: Moody Diagram [3]

3.1.2 Sudden Enlargement

The loss of head due to sudden enlargement in pipes can be calculated using Equation 3.2 [3] where values of K_2 are given in Figure 3.2.

$$h_e = K_2 \cdot \frac{{V_1}^2}{2 \cdot g} \tag{3.2}$$

Explanation of symbols used in Equation 3.2 and Figure 3.2 can be found in Table 3.2 below.

Table 3.2: Explanation of symbols.

Symbol	Description	[Unit]
h_e	Head loss due to enlargement	$[m]$
K_2	Enlargement loss coefficient	$[-]$
V_1	Fluid velocity in smaller pipe	$[m/s]$
d_1	Inner diameter of smaller pipe	$[m]$
d_2	Inner diameter of larger pipe	$[m]$
g	Gravitational acceleration	$[m/s^2]$

TABLE 6.5 Values of K_2 for Determining Loss of Head Due to Sudden Enlargement in Pipes, from Formula $h_2 = K_2(V_1^2/2g)$

	Velocity V_1, m/s*										
d_2/d_1*	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1.2	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1.4	0.26	0.26	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21
1.6	0.40	0.39	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.32	0.32
1.8	0.51	0.49	0.46	0.45	0.44	0.43	0.42	0.42	0.41	0.41	0.41
2.0	0.60	0.58	0.54	0.52	0.52	0.51	0.50	0.50	0.49	0.48	0.48
2.5	0.74	0.72	0.67	0.65	0.64	0.63	0.62	0.62	0.61	0.60	0.59
3.0	0.84	0.80	0.75	0.73	0.71	0.70	0.69	0.68	0.67	0.67	0.66
4.0	0.93	0.89	0.83	0.80	0.79	0.77	0.76	0.75	0.74	0.74	0.73
5.0	0.97	0.93	0.87	0.84	0.83	0.81	0.80	0.79	0.78	0.77	0.76
10.0	1.00	0.98	0.92	0.89	0.87	0.85	0.84	0.83	0.82	0.82	0.81
∞	1.00	1.00	0.94	0.91	0.89	0.87	0.86	0.85	0.84	0.83	0.82

*d_2/d_1—ratio of diameter of larger pipe to diameter of smaller pipe; V_1—velocity in smaller pipe.

Figure 3.2: Values of K_2 [3].

3.1.3 Sudden Contraction

The loss of head due to sudden contraction in pipes can be calculated using Equation 3.3 [3] where values of K_3 are given in Figure 3.3.

$$h_c = K_3 \cdot \frac{{V_2}^2}{2 \cdot g} \tag{3.3}$$

Explanation of symbols used in Equation 3.3 and Figure 3.3 can be found in Table 3.3 below.

Table 3.3: Explanation of symbols.

Symbol	Description	[Unit]
h_c	Head loss due to contraction	$[m]$
K_3	Contraction loss coefficient	$[-]$
V_2	Fluid velocity in smaller pipe	$[m/s]$
d_1	Inner diameter of smaller pipe	$[m]$
d_2	Inner diameter of larger pipe	$[m]$
g	Gravitational acceleration	$[m/s^2]$

TABLE 6.7 Values of K_3 for Determining Loss of Head Due to Sudden Contraction in Pipes, from Formula $h_3 = K_3(V_2^2/2g)$

	Velocity V_2, m/s										
d_2/d_1*	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1.1	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
1.2	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.10	0.10	0.10
1.4	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.19
1.6	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.24
1.8	0.34	0.34	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28
2.0	0.38	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.31	0.30
2.2	0.40	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.34	0.33	0.32
2.5	0.42	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.34	0.33
3.0	0.44	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35
4.0	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.38	0.37	0.36
5.0	0.48	0.48	0.46	0.45	0.45	0.44	0.42	0.41	0.39	0.38	0.37
10.0	0.49	0.48	0.47	0.46	0.46	0.44	0.43	0.42	0.41	0.40	0.39
∞	0.49	0.49	0.47	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40

*d_2/d_1—ratio of diameter of larger pipe to diameter of smaller pipe; V_2—velocity in smaller pipe.

Figure 3.3: Values of K_3 [3].

3.1.4 90° Bends

The loss of head due to 90° bends in pipes can be calculated using Equation 3.4 [3]. The values for the bend loss coefficient, K_b, can be retrieved from Figure 3.4. Explanation of the symbols used can be found in Table 3.4.

$$h_b = K_b \cdot \frac{V^2}{2 \cdot g} \tag{3.4}$$

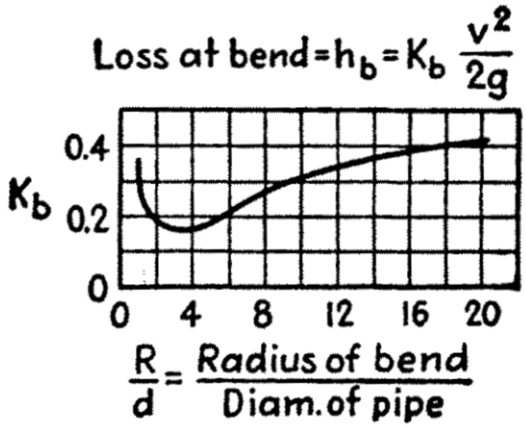

Figure 3.4: Energy loss in pipe bends [3].

Table 3.4: Explanation of symbols.

Symbol	Description	[Unit]
h_b	Head loss due to 90° bend	$[m]$
K_b	Bend loss coefficient	$[-]$
V	Fluid velocity	$[m/s]$
d	Inner diameter of pipe	$[m]$
R	Bend radius	$[m]$
g	Gravitational acceleration	$[m/s^2]$

3.1.5 Hydraulic Diameter

When applying the "Darcy-Weisbach" equation, see Equation 3.1, on non-circular pipes or open ducts the hydraulic diameter[2] can be used instead [7]. The hydraulic diameter can be calculated as shown in Equation 3.5, where A is the cross-sectional area and p is the wetted perimeter[3].

$$d_h = \frac{4 \cdot A}{p} \tag{3.5}$$

3.2 Axial Flow Pump

This section covers the equations necessary for designing an axial flow pump. This section and all of its equations follows the methods used and explained in the paper "Design Calculation of Impeller for Axial Flow Pump" [17] and "Design of Propeller Pump (Impeller) for fertilizer Industry" [22]. Explanation of all the symbols used in this section can be found in Table 3.5 below.

Table 3.5: Explanation of symbols.

Symbol	Description	[Unit]
N	Motor rotational velocity	$[rpm]$
N_s	Specific speed	$[-]$
Q	Volumetric flow rate (discharge)	$[m^3/s]$
H	Pump head	$[m]$
D_d	Impeller hub-ratio	$[-]$
D_h	Impeller hub diameter	$[m]$
D_o	Impeller outer diameter	$[m]$
δ	Wall clearance	$[m]$
$D_{1\sim5}$	Impeller section diameter	$[m]$
z	Number of impeller blades	$[-]$
g	Gravitational acceleration	$[m/s^2]$
K_H	Head coefficient	$[-]$
l_o	Chord length at D_o	$[m]$
l_h	Chord length at D_h	$[m]$
$l_{1\sim5}$	Chord length at section	$[m]$
t_o	Vane spacing at D_o	$[m]$
t_h	Vane spacing at D_h	$[m]$
$l_{1\sim5}$	Vane spacing at section	$[m]$
β	Runner vane angle	$[degrees]$
v_z	Flow velocity	$[m/s]$
u	Peripheral velocity	$[m/s]$
v_u	Tangential component of absolute fluid velocity	$[m/s]$
ω	Angular velocity of impeller	$[rad/s]$
η_{hyd}	Hydraulic efficiency of pump	$[-]$

[2]"Hydraulic diameter - dh - is the "characteristic length" used to calculate the dimensionless Reynolds Number to determine if a flow is turbulent or laminar." [7]

[3]Perimeter that is in direct contact with the water.

3.2.1 Specific Speed

"Specific speed is defined as the speed in revolutions per minute at which an impeller would operate if reduced proportionately in size so as to deliver one unit of capacity against one unit of total head" [17]. Specific speed is calculated using Equation 3.6. The calculated specific speed can be used with Table 3.6 in order to derive an appropriate impeller hub-ratio, D_d, and number of blades, z [17]. The hub ratio is equal to the diameter of the hub divided by the outer diameter of the impeller as shown in Equation 3.7.

$$N_s = \frac{3.65 \cdot N \cdot \sqrt{Q}}{H^{3/4}} \tag{3.6}$$

Table 3.6: Specific speed versus impeller hub-ratio and number of blades [17].

Specific speed, N_s	400	600	800	1000	1200
Impeller hub-ratio, D_d	0.6	0.55	0.5	0.45	0.4
Number of blades, z	6	5	4	3	2

$$D_d = \frac{D_h}{D_o} \tag{3.7}$$

3.2.2 Impeller Diameter and Clearance

The allowable range for the outer impeller diameter, D_o, can be calculated using Equation 3.8 [17]. The optimal range for the outer impeller diameter can be calculated using Equation 3.9 [17]. A value that is within the allowable range, and close to or within the optimal range, should be chosen for the outer impeller diameter. The hub diameter can then be derived by solving Equation 3.7 for D_h as shown in Equation 3.10. The clearance between the outer diameter and the surrounding pipe, δ, can be calculated using Equation 3.11 [17].

$$D_{o_{allowable}} = (0.08 \sim 0.1) \cdot \sqrt{Q \cdot 60} \tag{3.8}$$

$$D_{o_{optimal}} = (4 \sim 4.6) \cdot \sqrt{\frac{1}{1 - D_d^2}} \cdot \sqrt[3]{\frac{Q}{N}} \tag{3.9}$$

$$D_h = D_d \cdot D_o \tag{3.10}$$

$$\delta = 0.001 \cdot D_o \tag{3.11}$$

3.2.3 Runner Vane Dimensions

This section covers the necessary equations for properly dimensioning the runner vanes[4] of the impeller.

Sections

The runner vanes are divided into five circle-sections expressed by their respective diameter as shown in Figure 3.5. These diameters are calculated using Equations 3.12 through 3.16 [17].

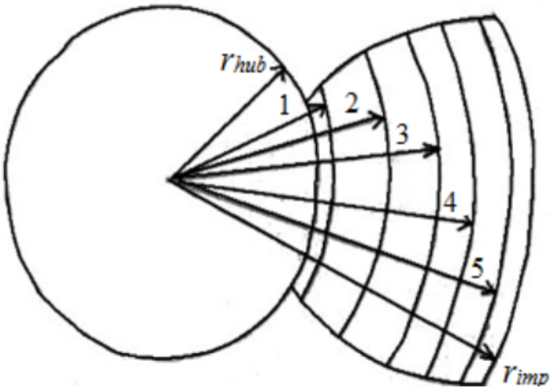

Figure 3.5: Impeller sections [17].

$$D_1 = D_h + (0.03 \sim 0.05) \cdot D_h \tag{3.12}$$

$$D_3 = D_o \cdot \sqrt{\frac{(1 + D_h)^2}{2}} \tag{3.13}$$

$$D_2 = D_1 + \frac{D_3 - D_1}{2} \tag{3.14}$$

$$D_5 = D_o - (0.03 \sim 0.05) \cdot D_o \tag{3.15}$$

$$D_4 = D_3 + \frac{D_5 - D_3}{2} \tag{3.16}$$

[4]The "blades" or "fins" of the impeller.

Chord Length

The chord length, l, of the runner vanes varies along the radius. The chord length ratio at the outer diameter, l_o/t_o, can be determined using Equation 3.17 [17] where t is the circular-arc spacing between the center of adjacent vanes, and K_H is the head coefficient. t and K_H can be calculated using respectively Equation 3.18 and 3.19 [17]. The chord length at the hub diameter, l_h, can then be calculated using Equation 3.20 [17]. The maximum allowable ratio for the five circle-sections are given and are shown in Table 3.7 below.

$$\frac{l_o}{t_o} = 5.95 \cdot K_H \tag{3.17}$$

$$t = \frac{D \cdot \pi}{z} \tag{3.18}$$

$$K_H = \frac{H}{D_o^2 \cdot (N/60)^2} \tag{3.19}$$

$$\frac{l_h}{t_h} = (1.25 \sim 1.30) \cdot \frac{l_o}{t_o} \tag{3.20}$$

Table 3.7: Allowable chord length ratios of the five sections [17].

Section:	1	2	3	4	5
$(l/t)_{allowable}$	0.800	1.000	0.660	0.500	0.500

Runner Vane Angle

The runner vanes are shaped based on an inlet and outlet angle which is the angle between the tangent of the curve of the vane at respectively the inlet and outlet, and the rotation direction of the impeller itself. These angles are marked as $/beta_1$ for the inlet angle and $/beta_2$ in the inlet-outlet velocity diagram of the impeller illustrated in Figure 3.6 to the right.

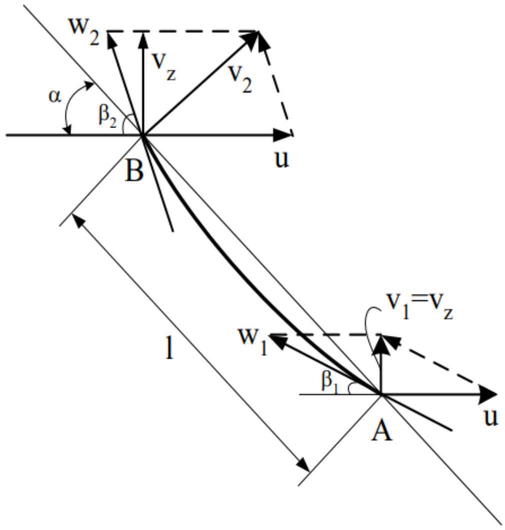

Figure 3.6: Inlet-outlet velocity diagram of impeller vane [22]. The inlet and outlet points are respectively marked "A" and "B".

The vane angles are individually calculated for each impeller section using Equation 3.21 [22], where v_z is the flow velocity calculated as shown in Equation 3.22, u is the peripheral velocity of the impeller vane calculated as shown in Equation 3.23, and v_u is the tangential component of the absolute velocity of the fluid and can be calculated using Equation 3.24 where ω is the angular velocity of the impeller calculated using Equation 3.25 and η_{hyd} is the hydraulic efficiency of the system.

$$\beta = atan(\frac{v_z}{u - v_u}) \tag{3.21}$$

$$v_z = \frac{4 \cdot Q}{\pi \cdot ({D_o}^2 - {D_h}^2} \tag{3.22}$$

$$u = \frac{\pi \cdot D \cdot N}{60} \tag{3.23}$$

$$v_u = \frac{2 \cdot g \cdot H}{\omega \cdot \eta_{hyd} \cdot D} \tag{3.24}$$

$$\omega = \frac{2 \cdot \pi \cdot N}{60} \tag{3.25}$$

Chapter 4

Initial Concept

This chapter briefly covers the initial concept that was made in order to identify needed parts and components for the system.

4.1 Innovation

This section covers innovations added to the system developed in this project. The following ideas are innovative as they add relevant functionality to the system that is not found in the other respirometry systems introduced in Section 1.1.

4.1.1 Dual Cameras

Two cameras are added to the system, one above and one on the side of the fish. These cameras allow for further data collection either through manual review or AI solutions. Examples of data that could be determined:

- Dynamics of the fish when swimming at different velocities.
- Direction of the fish within the system to find swimming velocity relative to the fish rather than the flow velocity of the system.
- Exhaustion level of fish based on visual cues such as activity level or position relative to flow.

The data collected could be useful in fields such as marine biorobotics

4.1.2 Integrated AI Platform

By using an AI capable platform to control the system, future AI solutions could be implemented to add additional utility and capabilities to the system.

4.2 System Voltage

The system will use a 12V supply as it poses very low risk for electrocution, of fish and/or operators should a water spill or other accident occur, along with allowing for higher strength pumps and motors. 12 V is also very close to the necessary 5V used to drive the on board logic so very little energy is lost when stepping it down. 24 volts was also considered, however it was rejected in favor of 12 V due to the seemingly higher availability of affordable 12 volt equipment

Chapter 5

Component Selection

This chapter contains information on all components used for the developed system with explanations for their selection.

5.1 Controller Platform

An AI capable platform is necessary for the system. Two affordable and well documented platforms were considered in this project, the Raspberry Pi 4 and the Nvidia Jetson Nano. Both of these are affordable AI capable platforms. However, as the recent Jetson development boards come with two CSI camera-ports, allowing for easy integration of two cameras, along with a more powerful GPU, useful for implementing AI solutions, it was chosen over of the Raspberry Pi.

Note that the Jetson Nano discussed here is the "B01" revision of the regular 4 GB version and not any older version nor the cheaper 2 GB alternative as these only have a single CSI camera-port.

5.1.1 SD Memory Card

The Jetson Nano uses a micro SD memory card for storage. A minimum of 32GB UHS-1 type SD card is recommended for use with the Jetson Nano [16]. A Class 10 UHS-1 memory card is chosen for this project as it is the fastest UHS-1 SD card class which will allow for faster loading times when developing on, and using the Jetson Nano. 128 GB is chosen to have some overhead for video and data storage.

The exact SD card sourced for this project is an "Intergral Memory" branded 128 GB UHS-1 U3 MicroSDXC Card Class 10 with part number "INMSDX128G-100/90V30".

5.1.2 Wireless Functionality

The Jetson Nano does not have WiFi capabilities built in to it. In order to enable easy development and the potential for remote control of the system it is desirable to add wireless functionality. The Jetson Nano has an M.2 2230 slot that can be used to interface with a wireless controller.
The specific wireless controller sourced for this project is an "Intel" branded "Dual Band Wireless-AC 8265 Desktop Kit" with part number "958156". As an added bonus, this controller also adds Bluetooth 4.2 functionality to the system.

5.1.3 Additional PWM

The Jetson Nano only has two PWM outputs available and the proposed system requires up to 6 PWM lines (impeller motor, 2-3 pumps, camera lights). Therefore an additional controller is necessary to provide these signals. An Arduino Micro and Teensy 4.0 where considered for this purpose due to their availability and low form-factor. The Teensy 4.0 was chosen as it has a higher chip clock-speed, 600 MHz [19] compared to the 16 MHz of the Arduino Micro [2], while still being comparable in price. The higher clock speed allows for more computational power to be used without infringing on the accuracy when dealing with high speed encoders.

5.2 Impeller Motor

In order to induce water flow through the system an impeller based pump will be used. A suitable motor to drive the impeller has to be determined. Following the product specification, refer to Section 2.1, the motor also has to include an encoder for accurate RPM control.
For an idea of the RPM necessary to produce a water flow of 20cm/s the data presented in the paper "A Miniature Intermittent-Flow Respirometry System ..."[9] is reviewed. This paper comprises a similar system to the one presented in this thesis so the resulting data of this thesis may potentially be similar to that of the paper. Appended to the mentioned paper is a diagram showing the measured water velocity in relation to applied DC voltage to the motor. The diagram comprises of water velocity flow resulting from a voltage between 2 and 9 Volts, resulting in a linearly increasing water flow from 1 to approx 8.5 cm/s. The motor used in their system was a "RS-775" DC motor [10] which according to its specifications, see Appendix D.3, has a no load velocity of 17350 RPM at 14.4V. Assuming the linear relationship between voltage and flow velocity continues after 9V, and the RPM and applied DC of the motor also is linear, along with an arbitrarily decided RPM loss of 20% when under load, the necessary RPM to produce 20cm/s of flow velocity is approx 17930 RPM as calculated in Equations 5.1 to 5.3.

$$\frac{9-2V}{8.5-1cm/s} \approx 0.93\frac{V}{cm/s} \rightarrow 20cm/s \cdot 0.93 = \underline{18.6V} \tag{5.1}$$

$$\frac{17350RPM}{14.4V} \approx 1205\frac{RPM}{V} \rightarrow 18.6V \cdot 1205 = 22413RPM \tag{5.2}$$

$$22413 \cdot 0.8 \approx 17930RPM \tag{5.3}$$

In order to keep the costs of the complete system low, affordable and readily available options where explored. As other parts were ordered through amazon, the two highest available RPM 12 V motors with encoders where ordered as well. These motors have a no load speed of 800 and 10,000 RPM at 12 V and their respective specifications can be seen in Appendix D.4 and D.5. As no available (at the time) motors could supply the calculated necessary RPM (Equation 5.3) for a system identical to the previously mentioned system, it was not clear if either of these motors were suitable for the system proposed in this thesis. However, as available alternatives with encoders are several times more expensive than the combined cost of both these motors, it was deemed worth the risk to preemptively purchase these motors and instead research other alternatives should neither prove usable. For future reference in this report the two motors are dubbed the "800RPM" motor and "10kRPM" motor.

5.3 Shaft Seal

The motor has to be able to drive the pump while not causing a leak in the system. For this a rubber shaft seal is implemented. The specific shaft seal sourced for this project is from a hobby submarine store named "Alexander Engel KG" and is the smallest one they offer. The shaft seal accepts 3 mm shafts and has an outer diameter of 10 mm and a depth of 6 mm. The listing description can be seen in Appendix D.6.

5.4 Motor Shaft

As recommended by the listing of the shaft seal, Section 5.3, a 3 mm stainless steel rod is used for the motor shaft.

5.5 Shaft Coupler

Two different shaft couplers are needed to connect the two motors, Section 5.2, to the motor shaft. The output shaft of the "800RPM" and 10kRPM" motors are respectively 6 and 2 mm in diameter. The listing information of the 3mm to 6mm and 2mm to 3mm rigid shaft couplers sourced for this project can be seen in respectively Appendix D.7 and D.8.

5.6 Gaskets

A 1 mm rubber sheet is purchased for cutting out custom gaskets for the system. The online Biltema listing for the article is appended in Appendix D.9.

5.7 Grease

A grease is necessary for both lubricating the shaft seal and gaskets and for water-proofing the gasket connections and shaft seal. "SUPER LUBE SILICONE DIELECTRIC AND VACUUM GREASE - 91003" is chosen as it is both water proof and food grade rated. The technical data sheet of the grease can be viewed in Appendix D.12.

5.8 Ball Bearing

A ball bearing for the motor shaft is desired to provide extra stability to the motor shaft and limit vibration. The chosen ball bearing has an inner diameter of 3 mm, outer diameter of 10 mm and a depth of 4 mm. The bearing is an SKF branded bearing with part number "623-2Z".

5.9 Motor Driver

For this project two widely available motor drivers were considered for driving the impeller motor and pumps. These two drivers are the L298N and TB6612FNG. Using a motor driver allows a controller to drive and adjust the output of the motors using a low-current PWM signal, along with changing the polarity of the motors through digital pins. The L298N offers a higher maximum voltage rating and current delivery, while the TB6612FNG offers a smaller form-factor and a much lower voltage drop. As the components the motor driver will be controlling are only at 12 V and no component exceeds the 1.2 A current limit, the TB6612FNG is chosen. The specific breakout board used for the chip is from SparkFun (Listing name: SparkFun Motor Driver - Dual TB6612FNG (1A)). The data sheet of the TB6612FNG motor driver can be seen in Appendix D.13.

5.10 Cooling

As some fish requires lower than room temperature water, a cooling system is necessary for long tests in order to hinder the gradual warming of the internal water in the system. As cold water can not be continuously fed into the system during testing, as it would conflict with the oxygen levels, a different approach has to be used. A design using mini heat-sinks meant for electronics is developed in this project. The heat-sinks purchased are "Fischer Elektronik" branded 8x8x6 mm 74 K/W heat sinks with part number "ICK SMD F 8 SA". The data sheet of the heat-sinks can be seen in Appendix D.15.

5.11 Pump

Peristaltic pumps are chosen for filling and flushing of the system, along with driving a cooling loop. Peristaltic pumps are chosen for two reasons: They are able to consistently deliver a low level of flow to gradually flush the low volume of the system, and they block flow when turned off which allows for the pumps to be constantly connected to the system without any valves in between. As the the respirometry system requires a pressure differential in the system to create flow, valves would have been necessary to prevent pressure from escaping through the pump if another pump design where used. The gradual flushing of the system is also necessary as a fast flush could potentially harm the fish either through not allowing enough time for temperature acclimation should the tank water differ from the internal water of the respirometry system, or through exposing the fish to flow velocities above what they can handle.

The specific peristalitic pumps used for this system are "Kamoer" branded 12V DC pumps with a tube size of 3mm ID and 5mm OD. The specification of the pumps can be seen in Appendix D.10. These pumps where chosen for their low cost and apparent increased quality compared to other similarly priced alternatives.

5.12 Oxygen Sensor

The oxygen sensor sensor used for the system is the "Pyroscience" branded "OXROB3" sensor with an accompanying "FireSting-PRO" meter. This sensor system is used as it was part of the available in-house equipment used for research at the University of Agder. The meter also has a connector for a Pt100 temperature probe which logs the tank temperature.

5.12.1 Connector

According to the data sheet of the "FireSting-PRO" meter, see Appendix D.14, it can be configured to output the oxygen and temperature sensor data via UART through a connector on the back of the device. This connector can be interfaced with using a "Phoenix Contact" branded plug with item number 1778887. This connector is purchased to be able to log the oxygen level and tank temperature directly on the Jetson Nano instead of having to manually combine the testing data from the device with the data of the respirometer system at after each test.

5.13 Internal Temperature

Two widely used temperature probes were considered for use for monitoring the internal temperature of the system. These temperature probes are the K-Type thermocouple and the Pt100 temperature probe. The K-Type thermocouple was chosen in favor of the Pt100 due to the faster response to temperature change. This is to allow for future regulated cooling of the system which likely requires a quick response due to the small volume of the system in order to result in accurate short-term temperature regulation. However, the K-Type thermocouple can be less accurate than the Pt100. For this reason the Pt100 temperature probe of the oxygen sensor system, see Section 5.12, will be used to calibrate the K-Type thermocouple.

5.13.1 K-Type Thermocouple Amplifier

The K-Type thermocouple requires an amplifier in order to read data from it. An "Adafruit" branded breakout board with the "MAX31855" thermocouple amplifier has been purchased for this project. This amplifier sends out the temperature data through an SPI connection and will directly connect to the Jetson Nano.

5.14 Breadboard

Three mini modular breadboards are purchased to be used for mounting several of the electronic components. The breadboards purchased are the "Breadboard - Mini Modular" from the brand "Sparkfun" with the item number "PRT-12047".

5.15 Cameras

As explained in Section 4.1.1, two cameras are needed for this system. As the testing chamber windows are only 3x1 cm in area the camera will have to be mounted as close as possible in order to maximize the area of the camera view that actually records the relevant section of the system. The closest focus range officially compatible CSI camera module that was identified and sourced for this project is the "ArduCam" branded "IMX219AF" camera module with part number "B0181". This camera module has a close range motorized lens that is able to focus on objects in the range of $5 \sim 30$ cm away from the camera [1], allowing for very close positioning (relative to the testing chamber) while maintaining focus. This differs from other widely used CSI cameras such as the official Raspberry Pi Camera Modules which have a focus range of one meter to infinity [20], meaning that this camera would have to be fitted a minimum of one meter away from the testing chamber in order to properly focus on it.

The camera module comes fitted with a 15 cm ribbon cable for connecting via CSI camera-connectors.

5.16 Power Supply

A 12 V 5 A power supply is purchased to power the components of the system. According to the user guide, Appendix D.1, the Jetson Nano Developer Kit is expected to require approximately 5 V 2 A, with a maximum of 5 V 4 A being deliverable through the on-board "J25" power jack if other power hungry devices are powered using the Jetson Nano. As Jetson Nano Developer Kit will be powering two cameras (see Section 5.15) in addition to itself, a total of 2.5 A at 5 V is expected to be drawn to add some safety for the additional current drawn by the cameras. 2.5 A at 5 V, assuming a conversion efficiency of 80%, results in a current draw of approximately 1.3 A as shown in Equation 5.4 below.

This leaves 3.7 A at 12V left for rest of the 5V logic and the motors and pumps. This was assumed enough to drive the remaining components, as data regarding the power usage of the motors and pumps were not included in their listings. Furthermore, the highest wattage rating of the 12V power supply compatible power jacks available from the vendor used for purchasing the power supply was rated at 12V 5A, so no higher wattage power 12V supplies could be used without going to a different vendor.

The exact power supply sourced is a "MEAN WELL" branded 12V 5A power supply with part number "GST60A12-P1J". The compatible power jack used for connecting the power supply to the system is an "RND Connect" branded 2.1x5.5mm 12V 5A rated power jack with part number "RND 205-00908".

$$2.5A \cdot 5V \cdot \frac{1}{0.8} \approx 15.6W \rightarrow \frac{15.6W}{12V} = 1.3A \tag{5.4}$$

5.16.1 5 V Regulator

A 5 V regulator is needed to step the 12 V of the power supply down to 5 V which can be used by the Jetson Nano and the other logic of the system. As described in Section 5.16, the Jetson Nano Developer kit with cameras are expected to use about 2.5 A at 5 V. The Teensy 4.0 (see Section 5.1.3) uses approximately 100 mA of current [19]. A small form-factor 3 A 5 V regulator is sourced for this project. This leaves 400 mA available for the remaining 5 V logic which is more than enough considering the thermocouple amplifier (see Section 5.13.1) and motor driver (see Section 5.9) logic uses very low power consumption chips.

The exact regulator sourced is a 5 V 3 A "XP Power" branded regulator accepting an input voltage of 9∼36 V. The part number of the regulator is "DTJ1524S05".

5.16.2 Power Switch

A power switch for the system allows for turning off all power without having to unplug the power supply from the system. An unbranded 250V/3A M6 thread is used in this project as they were on hand at the start of the project. The listing information for the switch can be seen in Appendix D.11.

5.16.3 Jetson Nano Compatible Power Cable

The Jetson Nano accepts a 9.5 mm deep, 2.1 mm inner diameter, and 5.5 mm outer diameter plug with positive polarity (inner positive, outer negative). A compatible power cable sourced for this project is an "RND Connect" branded cable with part number "RND 205-01292", rated at 12 V 3 A. The cable is right angled for a more sleek look when connected to the Jetson Nano developer kit.

5.17 Resin

The system will be resin printed for its high resolution and water-tight abilities. This choice was made in order to design complex designs at a small scale with minimal worry to feasibility regarding production. As students at the University of Agder only have access to a "Formlabs" branded "Form 2" resin printer, the Formlabs catalog of resins were exclusively considered for this project. Two candidates were identified for use: The "Standard Clear" resin (datasheet appended in Appendix E.1) and the "BioMed Clear" resin (datasheet appended in Appendix E.2).

A clear resin is desirable for the system as it allows easy identification of air trapped in the system. Additionally, a fully translucent resin would allow the fish to be fully visible from the outside without having to install windows of another material. The "Standard Clear" resin is used in this project for the prototyping of the system to avoid the extra manufacturing needed to add windows to the "BioMed Clear" resin as it is in reality more opaque than clear.

The "Standard Clear" resin does not however, specifically claim bio-compatibility as the "BioMed Clear" resin does. It is also questionable how long it is able to withstand alcohol solutions used for sterilization without the degradation of the physical integrity of the material. The system will therefore be designed in a way that allows for the insertion of glass windows so that a version using the "BioMed Clear" could be produced after the conclusion of this project.

Chapter 6

Development

This chapter comprises the design of the final revision of the complete respirometry system, including the dimensioning of a custom axial-flow impeller pump used to create the water flow through the system.

6.1 Pump Design

This section covers an analysis of the hydraulic system along with the design of an impeller capable of delivering 20 cm/s flow velocity in the testing chamber as specified by the product specification (Section 2.1).

6.1.1 Pump Head

Even though the pump in the water tunnel does not necessarily have to pump the water against gravity, a certain pump head is still necessary to overcome the energy losses of the water tunnel itself. Three areas of energy loss has been identified in the water tunnel design: Energy loss due to friction in the pipes, the two 180° bends, and finally the change in pipe diameter throughout the water tunnel. Following in this subsection is an estimated pump head loss for the system.

Estimated System

The pump head calculations are based on an estimated system shown in Figure 6.1. The system is based on an arbitrarily decided 10 mm of straight flow rectifying area before the testing chamber and 5 mm directly after to prevent the fish from being sucked into the impeller. Furthermore, the diameter of the impeller section is arbitrarily set to three times the hydraulic diameter of the testing chamber, and the thickness of the impeller is set to 15 mm. The angled pipes is estimated to have the same hydraulic diameter as the testing chamber and the radius of the four 90° bends is estimated to 15 mm.

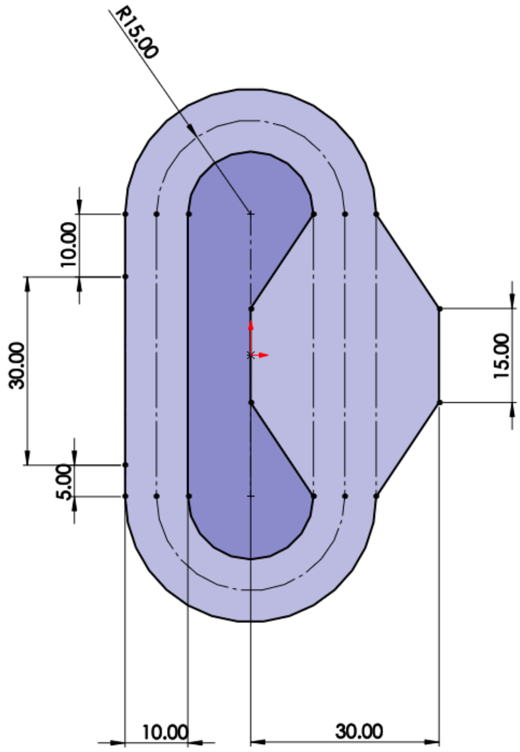

Figure 6.1: Estimated hydraulic system.

Pipe Friction

The pipe length, l, of the estimated system is $\approx 18.4cm$ as shown in Equation 6.1. The surface roughness, ϵ, is estimated to be two times the print layer-height of the resin (see Appendix E.2) which is $2 \cdot 100 \cdot 10^{-6} = 2 \cdot 10^{-4}m$. The fluid velocity is set to $20cm/s = 0.2m/s$ as specified by the product specification (see Chapter 2.1). The kinematic viscosity, υ, is set to that of seawater at $4°C$ which is $\approx 1.6 \cdot 10^{-6}m^2/s$ [11]. The hydraulic diameter of 1cm is held constant through the pump and flow rectifying part of the system to simplify the calculations.

This simplification leads to a higher calculated pipe friction in the pump section and a lower calculated pipe friction in the flow rectifying section as the hydraulic diameter is respectively lower and higher than in the actual system. These differences will cancel each other out to a certain degree, However, the calculations will be repeated once the pump and flow rectifying sections are finalized.

The relative roughness and Reynolds number is calculated as shown in respectively Equation 6.2 and 6.3. According to the Moody Diagram (see Figure 3.1) this is in the laminar flow section and the roughness coefficient, f, is calculated as shown in Equation 6.4.

$$l = 2 \cdot (10 + 30 + 5) + 2 \cdot \pi \cdot 15 \approx 0.184m \tag{6.1}$$

$$\frac{\epsilon}{d} = \frac{2 \cdot 10^{-4}}{0.01} = 0.02 \tag{6.2}$$

$$R = \frac{d \cdot V}{\upsilon} = \frac{0.01 \cdot 0.2}{1.6 \cdot 10^{-6}} = 1250 \tag{6.3}$$

$$f = \frac{64}{R} = \frac{64}{1250} \approx 0.05 \tag{6.4}$$

Finally, the head loss due to friction in the pipes is calculated using the "Darcy-Weisbach" equation (see Equation 3.1, Section 3.1.1) resulting in a head loss of 1.88mm. The calculation can be seen below in Equation 6.5.

$$h_f = f \cdot \frac{l \cdot V^2}{d \cdot 2 \cdot g} = 0.05 \cdot \frac{0.184 \cdot 0.2^2}{0.01 \cdot 2 \cdot 9.81} \approx 1.88mm \tag{6.5}$$

Sudden Enlargement and Contraction

There are six identified areas of enlargement and contraction in the hydraulic system. These six areas are denoted by "E" and "C", respectively representing enlargement and contraction, in Figure 6.2. These areas are created by the change in hydraulic diameter when entering and exiting the pump and flow rectifier sections. The flow rectifier sections are abbreviated as "FR" in the figure.

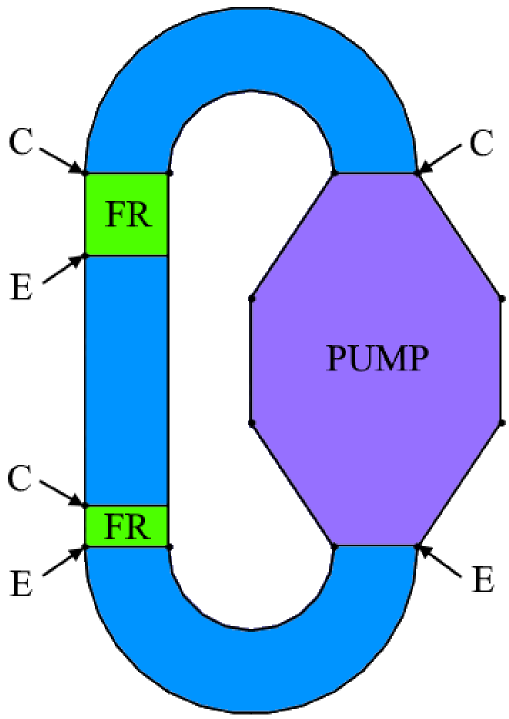

Figure 6.2: Areas of enlargement and contraction denoted by "E" and "C".

The inner diameter of the blue areas in Figure 6.2 is 1cm. The hydraulic diameter of the flow rectifier areas is arbitrarily set to 0.7 times this diameter, giving a hydraulic diameter of 7mm. As mentioned earlier the inner diameter of the pump section is estimated to be 3cm and the fluid velocity in the testing chamber is set to $20cm/s$. For ease of calculation the fluid velocity through the flow rectifier sections are set equal to this value as well, although in reality the average flow velocity in these sections will be higher to account for the increase in volumetric flow velocity due to the decrease in cross-sectional area.

The calculation for the loss of head due to enlargement, as explained in Section 3.1.2, is shown below in Equation 6.6. The values for K_{2_1} and K_{2_2} is retrieved from Figure 3.2 using the relations shown in respectively Equation 6.7 and 6.8.

$$\begin{aligned} h_e = 2 \cdot K_{2_1} \cdot \frac{V_1^2}{2 \cdot g} + K_{2_2} \cdot \frac{V_1^2}{2 \cdot g} &= (2 \cdot K_{2_1} + K_{2_2}) \cdot \frac{V_1^2}{2 \cdot g} \\ &= (2 \cdot 0.26 + 0.84) \cdot \frac{0.2^2}{2 \cdot 9.81} \approx 2.77mm \end{aligned} \tag{6.6}$$

$$\frac{d_2}{d_1} = \frac{1}{0.7} \approx 1.4 \Rightarrow K_{2_1} = 0.26 \tag{6.7}$$

$$\frac{d_2}{d_1} = \frac{3}{1} = 3 \Rightarrow K_{2_2} = 0.84 \tag{6.8}$$

The calculation for the loss of head due to contraction, as explained in Section 3.1.3, is shortened the same way as done in Equation 6.6 and can be seen below in Equation 6.9. The values for K_{3_1} and K_{3_2} is retrieved from Figure 3.3 using the same relations used when calculating enlargement (Equation 6.7 and 6.8), the resulting values can be seen in respectively Equation 6.10 and 6.11.

$$h_c = (2 \cdot K_{3_1} + K_{3_2}) \cdot \frac{V_1^2}{2 \cdot g} = (2 \cdot 0.17 + 0.44) \cdot \frac{0.2^2}{2 \cdot 9.81} \approx 1.59mm \tag{6.9}$$

$$\frac{d_2}{d_1} \approx 1.4 \Rightarrow K_{3_1} = 0.17 \tag{6.10}$$

$$\frac{d_2}{d_1} = 3 \Rightarrow K_{3_2} = 0.44 \tag{6.11}$$

Pipe Bends

The head loss due to the bends in the system is calculated as explained in Section 3.1.4. As mentioned earlier the radius of the four 90° bends is estimated to be 15mm. This gives a ratio $R/d = 15/10 = 1.5$ when compared to the inner diameter of the pipe of 1cm. The bend loss coefficient is retrieved from Figure 3.4 resulting in a K_b of approximately 0.3. The head loss is then calculated as shown in Equation 6.12 below.

$$h_b = K_b \cdot \frac{V^2}{2 \cdot g} = 0.3 \cdot \frac{0.2^2}{2 \cdot 9.81} \approx 0.61mm \tag{6.12}$$

Result

The total head-loss of the system is found by adding the four previously calculated head losses together as shown in Equation 6.13. The total head loss, h_{tot}, for the estimated system is 6.85mm. As this calculated value is based on an estimated system it is not a fully accurate representation of the finished product. Acknowledging this, a safety factor of 1.5 is added to help prevent a redesign in the event of the estimation being lower than the final design. The updated total head loss, $h_{tot_{sf}}$, for the estimated system is 6.85mm as shown in Equation 6.14.

$$h_{tot} = h_f + h_e + h_c + h_b = 1.88 + 2.77 + 1.59 + 0.61 = 6.85mm \tag{6.13}$$

$$h_{tot_{sf}} = h_{tot} \cdot 1.5 = 6.85 \cdot 1.5 \approx 10.28mm \tag{6.14}$$

6.1.2 Pump Design

This subsection covers the calculation and modeling of the impeller based pump of the system. Both selected motors, see Section 5.2, will be considered for use. The impeller will be designed to deliver the 20 cm/s flow requirement of the system, as specified by the product specification in Section 2.1, at 2/3 of the load speed of the "800RPM" motor, and at half of the no-load speed of the "10kRPM" motor. The documentation of the "10kRPM" motor (Appendix D.5) does not specify a load speed and is the cause of this discrepancy. The velocity margins were arbitrarily set to provide additional safety for the system due to the uncertainty of the torque necessary to overcome the friction of the shaft seal (See Section 5.3).

Choice of Impeller Type

There are three main types of impellers: axial-, mixed-, and centrifugal-flow [5]. The axial flow impeller design offers a high-flow-low-pressure characteristic, while the centrifugal flow design offers a low-flow-high-pressure characteristic [5]. The mixed flow impeller sits somewhere between the two. As the system has a low-head high-speed requirement the axial design is chosen.

Calculations

The impeller dimensions are calculated following the theory explained in Section 3.2. The calculations are carried out through a MATLAB script and can be viewed in Appendix C.1. The values used in the calculations, and the resulting dimensions necessary for construction are respectively shown in Table 6.1 and 6.2 below. See Appendix C.1.1 for the complete results with all calculated values.

The rotational velocity, N, of the two motors are calculated as stated earlier in this section resulting in a velocity of $\approx$ 427 RPM for the "800RPM" motor and 5000 RPM for the "10kRPM" motor. Furthermore, the pump head, H, of the "10kRPM" motor calculation is increased from the 10.28 mm calculated in Section 6.1.1 to 10 cm as otherwise the resulting specific speed is a factor of ten higher than the highest value in Table 3.6 (Section 3.2.1). The clearance, δ, between the outer diameter of the impeller and the surrounding pipe is also increased from 0.001 times the outer diameter to 0.01 times it to add some extra tolerance for ease of production and to allow for some vibration of the impeller during operation. The hydraulic efficiency of the system is set to 0.85.

As the size of the calculated impeller for the "10kRPM" motor is significantly smaller than that of the "800RPM" motor, along with its superior pump head, the "10kRPM" impeller was chosen for further development. As the "800RPM" motor impeller was not further developed the resulting calculations are not included in the results below. A left arrow in the tables below signify that the same value was used for both motor calculations.

Table 6.1: Values used in the impeller calculations.

Symbol	"800RPM" Motor	"10kRPM" Motor	[Unit]
H	10.28	100	$[mm]$
v	0.2	$\leftarrow$	$[m/s]$
η_{hyd}	0.85	$\leftarrow$	$[-]$
D_d	0.4	$\leftarrow$	$[m]$
z	2	$\leftarrow$	$[-]$
D_o	-	32.2	$[mm]$
l_1/t_1	-	0.6	$[-]$
l_2/t_2	-	0.6	$[-]$
l_3/t_3	-	0.6	$[-]$
l_4/t_4	-	0.5	$[-]$
l_5/t_5	-	0.4	$[-]$

Table 6.2: Relevant impeller calculation results.

Symbol	"800RPM" Motor	"10kRPM" Motor	[Unit]
Q	0.002	$\leftarrow$	$[m^3/s]$
N_s	≈ 2159	≈ 4589	$[-]$
$D_{o_{allowable}}$	$72.8 \sim 84.1$	$32.1 \sim 37.0$	$[mm]$
$D_{o_{optimal}}$	$73.0 \sim 84.0$	$32.2 \sim 37.0$	$[mm]$
D_h	-	12.9	$[mm]$
δ	-	≈ 0.3	$[mm]$
D_1	-	13.4	$[mm]$
D_2	-	18.2	$[mm]$
D_3	-	23.1	$[mm]$
D_4	-	27.0	$[mm]$
D_5	-	30.9	$[mm]$
l_h	-	2.2	$[mm]$
l_1	-	12.6	$[mm]$
l_2	-	17.2	$[mm]$
l_3	-	21.7	$[mm]$
l_4	-	21.2	$[mm]$
l_5	-	19.4	$[mm]$
l_o	-	4.2	$[mm]$
$\beta_{hub_{inlet}}$	-	≈ 40.93	$[degrees]$
$\beta_{hub_{outlet}}$	-	≈ 43.98	$[degrees]$
$\beta_{1_{inlet}}$	-	≈ 39.82	$[degrees]$
$\beta_{1_{outlet}}$	-	≈ 42.62	$[degrees]$
$\beta_{2_{inlet}}$	-	≈ 31.49	$[degrees]$
$\beta_{2_{outlet}}$	-	≈ 32.84	$[degrees]$
$\beta_{3_{inlet}}$	-	≈ 25.84	$[degrees]$
$\beta_{3_{outlet}}$	-	≈ 26.57	$[degrees]$
$\beta_{4_{inlet}}$	-	≈ 22.48	$[degrees]$
$\beta_{4_{outlet}}$	-	≈ 22.96	$[degrees]$
$\beta_{5_{inlet}}$	-	≈ 19.86	$[degrees]$
$\beta_{5_{outlet}}$	-	≈ 20.19	$[degrees]$
$\beta_{outer_{inlet}}$	-	≈ 19.13	$[degrees]$
$\beta_{outer_{outlet}}$	-	≈ 19.42	$[degrees]$

6.1.3 Impeller Construction

This subsection covers the 3D modeling of the impeller. First a sketch with all diameters is created as shown in Figure 6.3 to the right. Individual sketches for each section of the impeller runner vane are then created tangential to the diameters along the horizontal line as shown in Figure 6.4. The sketches are constructed as shown in Figure 6.4. Furthermore, the sketches are oriented so that a clockwise turn of the motor shaft pushes water away from the motor side. This was done so that a threaded insert could be used to attach the motor shaft to the impeller, as the impeller would tighten itself down onto the motor shaft during operation instead of potentially unscrewing itself.

A spline is created between the intersection of the inlet/outlet angle lines and the lines perpendicular to the ends of the chord length. An arbitrarily decided offset of 1 mm is created from the spline, resulting in a runner vane thickness of 2 mm.

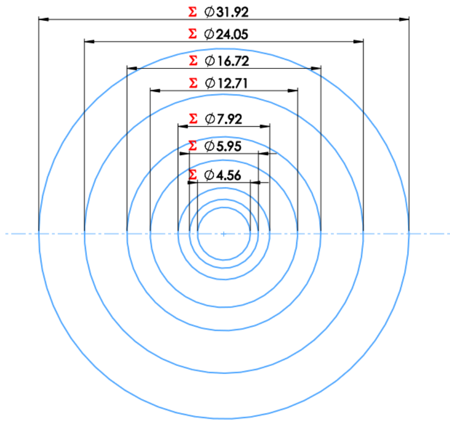

Figure 6.3: Impeller diameter reference sketch.

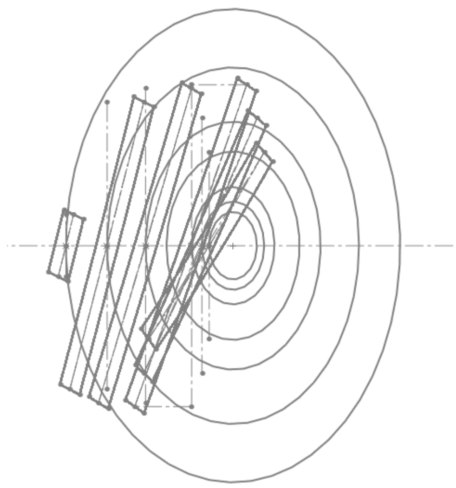

Figure 6.4: Runner vane sketch placements.

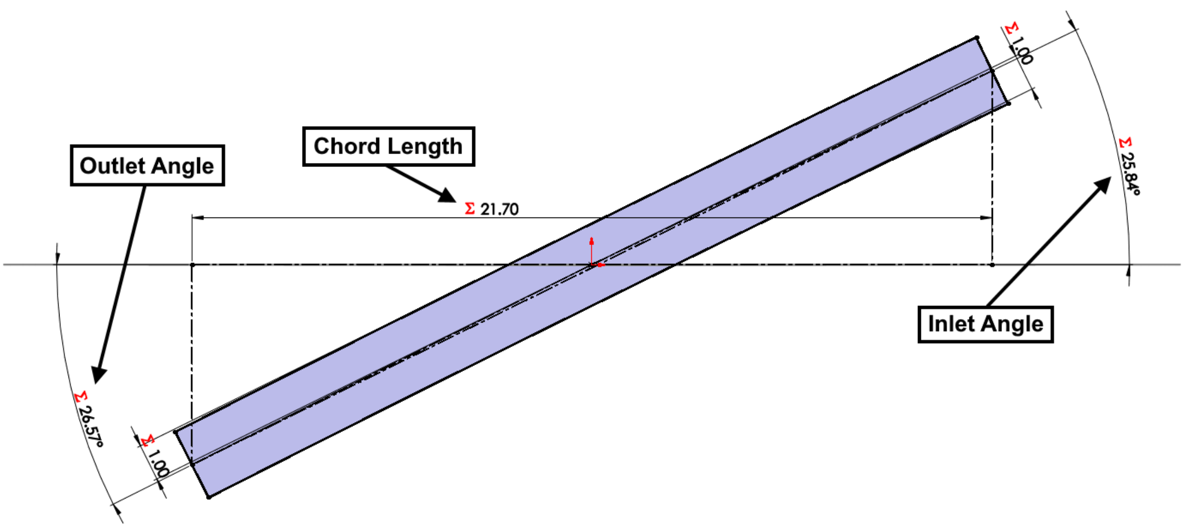

Figure 6.5: Runner Vane Section Sketch (Section 3 pictured).

A loft feature is created between the runner vane sketches, see Figure 6.6, creating one of the two runner vanes. The hub diameter is then extruded to the edges of the runner vane as shown in Figure 6.7, resulting in a hub length of 12.55 mm. The second runner vane is then added via a circular pattern of the first runner vane, a 3 mm motor shaft hole is added to the inlet side of the hub, and fillets are added to remove sharp corners of the impeller. The motor shaft hole is cut extruded 7.55 mm into the hub ensuring that the motor shaft goes past the mass center of the impeller for added stability while still leaving 5 mm of spacing between the front face of the impeller and the motor shaft. The finished impeller is pictured in Figure 6.8.

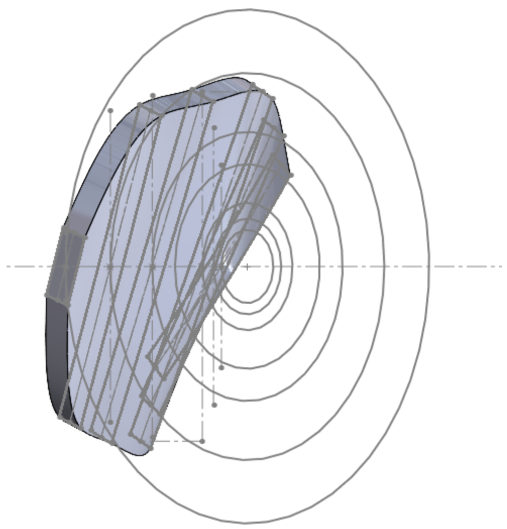

Figure 6.6: Runner vane loft feature.

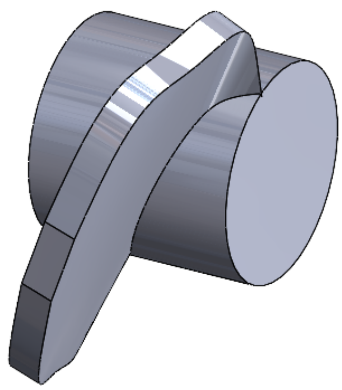

Figure 6.7: Impeller hub feature.

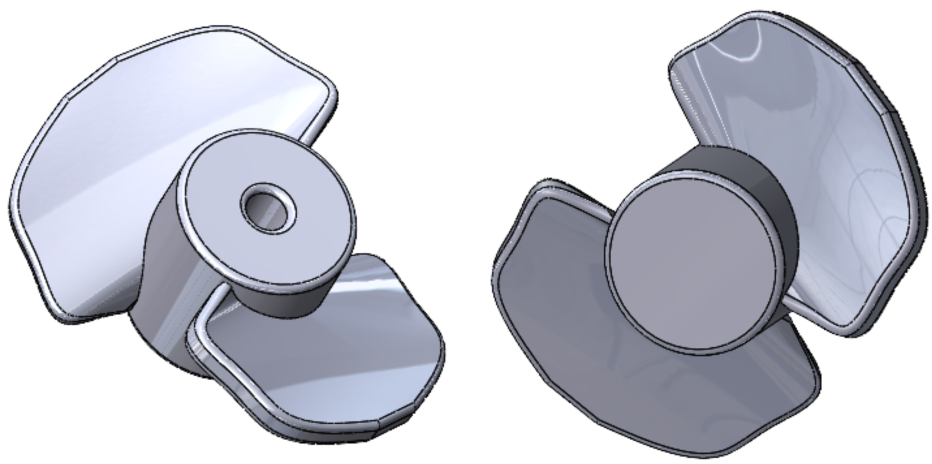

Figure 6.8: Finished impeller.

6.2 Water Tunnel

This section covers the design of the water tunnel of the respirometry system. The main body of the water tunnel can be seen in Figure 6.9 below.

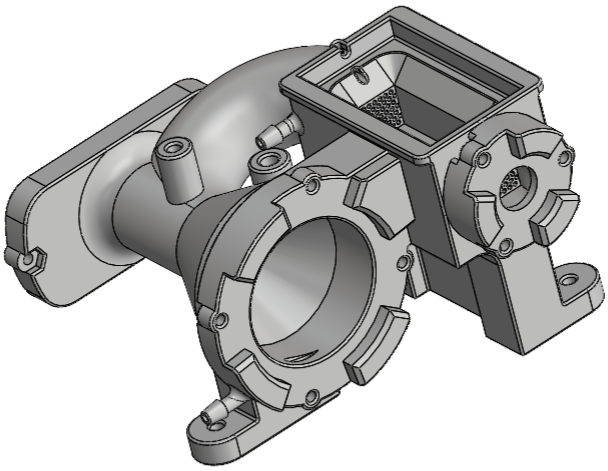

Figure 6.9: Complete view of the main body of the water tunnel.

6.2.1 Testing Chamber

The "testing chamber" of the system comprises of the de-pressurized zone of the water loop where the fish is located. Following the product specification, Section 2.1, the testing chamber is designed to be 1x1x3 cm. The testing chamber is pictured in Figure 6.10.

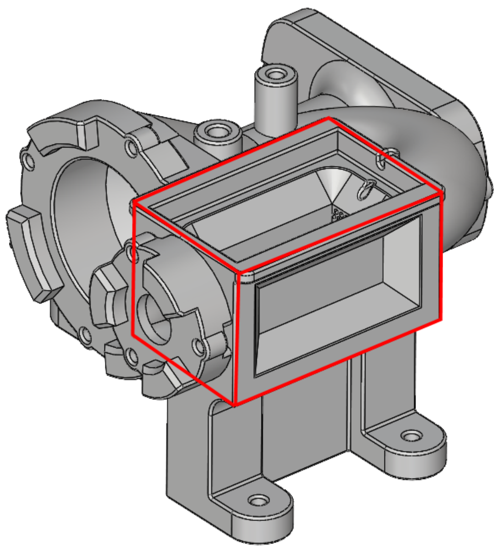

Figure 6.10: The testing chamber of the respirometry system (highlighted in red).

Air-Lock

The testing chamber is designed so that the water level of the system is 2.5 mm above the top of the testing chamber. This serves two functions: Firstly, it reduces the chance of air being sucked into the pump section of the system when running at high flow velocities. Secondly, when the lid is placed in place the water is displaced around it. This acts as a type of air-lock with the intention of preventing air from coming in contact with the water inside the system. An alternative method of designing the testing chamber to be air-tight was also explored, but as this could lead to a change of pressure in the testing chamber during operation which could negatively affect the fish the idea was scrapped in favor of the air-lock design.

Windows

As stated in Section 5.17, there are uncertainties regarding the bio-compatibility and long term stability of the available clear resin; Two versions of the testing chamber are proposed. The first using transparent resin so that the sides of the chamber is see-through, and the second using glass panes in order to allow for the usage of opaque resin for the rest of the system. In order to simplify the design process the transparent resin version uses the same design as the glass pane version with the only difference being that the glass panes are made of solid resin and is built in to the water tunnel.

The glass panes and resin structure are arranged as shown in Figure 6.11, where the purple sections are part of the lid structure while the yellow sections are part of the water tunnel. This design allows for securing the glass panes all around their perimeter while also allowing for a removable lid. The system is arbitrarily designed to accept 5 mm thick glass. However, any thickness could be used provided the glass windows are glued flush to respectively the testing chamber, and bottom of the lid.

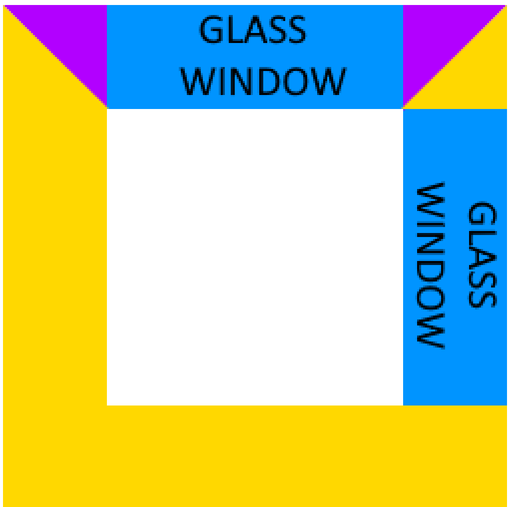

Figure 6.11: Cross section of testing chamber showing the window mounting design. The purple sections are part of the lid while the yellow sections are part of the water tunnel.

Lid

The lid design can be seen in Figure 6.12 to the right. The notches on the side of the lip are there to allow for airflow to the outlet of the system which will be explored further down this chapter.

A lip is designed around the lid-interface of the testing chamber in order to reduce the chance of water spillage along with accepting the water displacement caused by the previously mentioned air-lock design (See Section 6.2). Furthermore, the long edge of the lip has a 2.5x2.5 mm edge added to it to allow a sliding lock to be used to lock the lid in place if desired. The lid also extends to cover the entire top of the lip. The lip and locking edge can be seen highlighted in Figure 6.13 below.

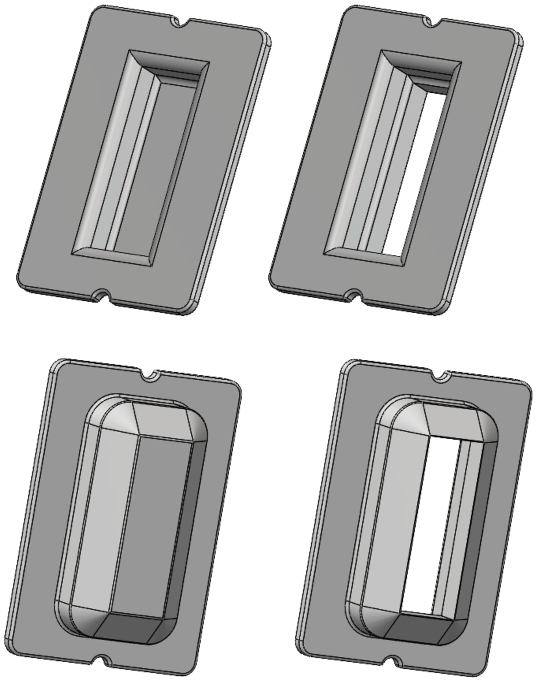

Figure 6.12: The lid of the testing chamber. Both full resin and glass-cutout versions are pictured.

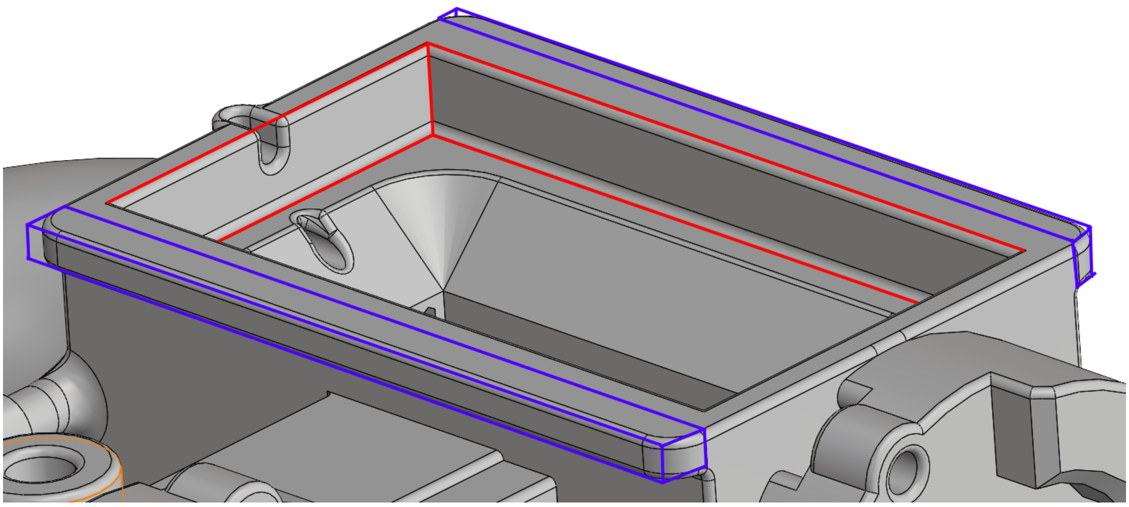

Figure 6.13: Close-up of the top part of the testing chamber. The lip is highlighted in red and the locking edge is highlighted in purple.

The sliding lock can be seen in Figure 6.14 to the right. The lid slides onto the lid-water tunnel assembly, securely locking the lid to the test chamber without blocking the top view as shown in Figure 6.15. The sliding lock is designed with wide indentations on both the top and bottom to allow for easy gripping during placement and removal. A 0.5 mm gap between the inner wall of the sliding lock and the locking edge is added to allow for some print variability without preventing the necessary sliding action.

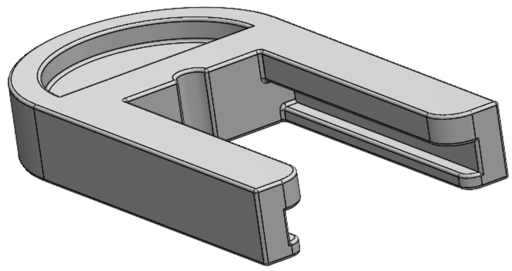

Figure 6.14: The sliding lock used to securely lock the lid to the testing chamber.

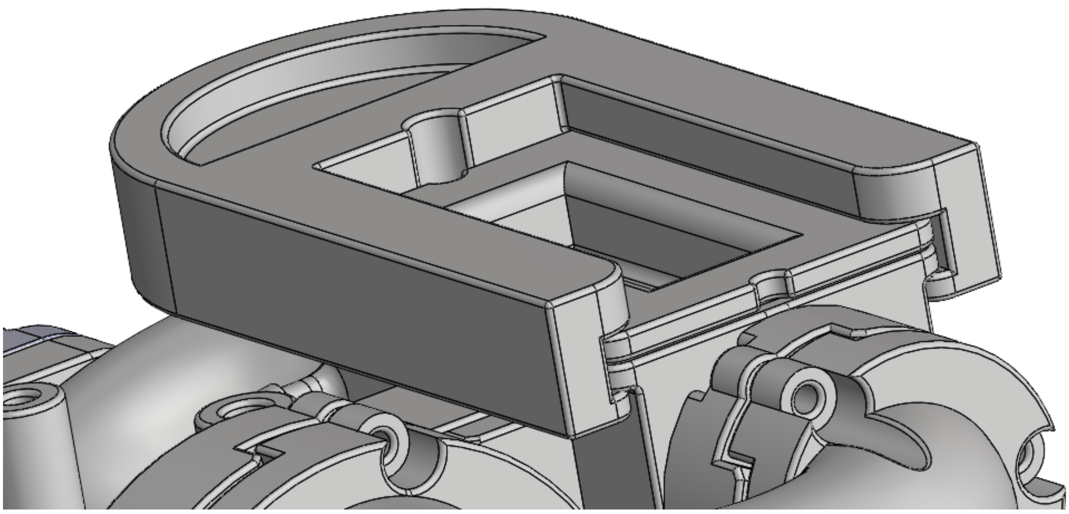

Figure 6.15: The lid lock fully slid in place locking the lid to the testing chamber.

Flow Rectifier

The flow rectifier grid, highlighted in Figure 6.16, serves two main functions. It both counteracts the spinning motion of the water induced by the impeller, and it prevents the fish from swimming into or being sucked into the pump area (and consequently the high velocity impeller). The flow rectifier grid consists of 1 mm wide hexagonal tubes spaced so that the wall between them has a thickness of 0.5 mm. As the fish larvae available for testing have a height of around 2 mm [14] the width of the hexagon tubes are set to 1 mm (diagonal width 1.15 mm) so that the fish is unable to pass through. The wall thickness between the tubes are set 0.1 mm above the minimum wall thickness printable by the "Form 2" resin printer [8] (only resin printer available for students at UiA at the time of this report), to keep the cross sectional area lost to a minimum while lowering the chance of print failure.

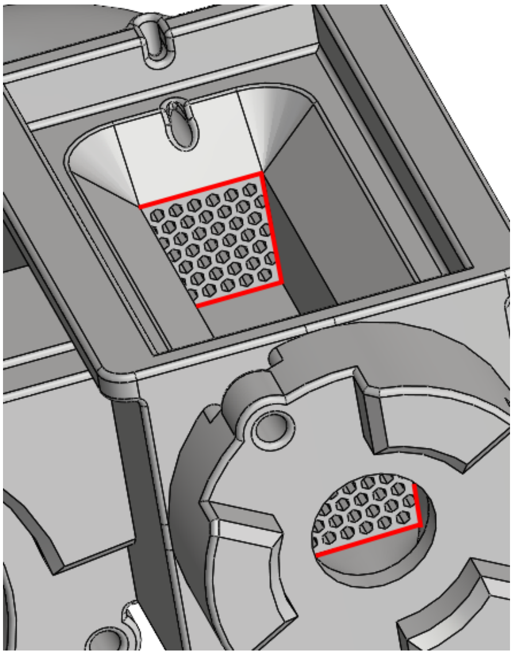

Figure 6.16: The flow rectifier grid (highlighted in red).

A lofted cut over 5 mm changes the square grid to a 10 mm diameter circle for interfacing with pipe of the same diameter. The front lofted cut is pictured in Figure 6.17.

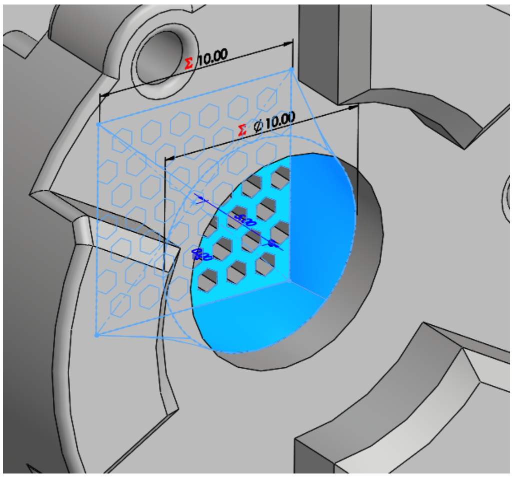

Figure 6.17: Rectifier loft connection.

6.2.2 Pump Section

The pump section of the water tunnel, pictured in Figure 6.18 to the left, houses the impeller and is responsible for the water flow of the system.

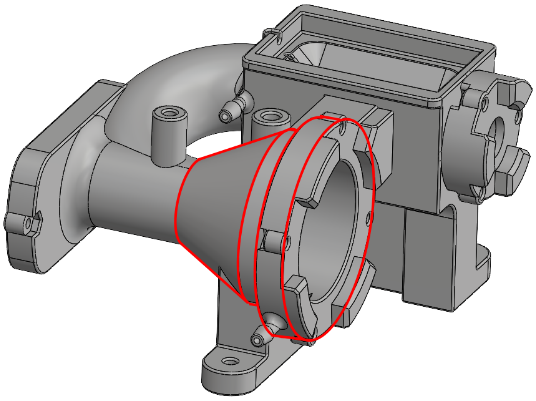

Figure 6.18: The pump section of the water tunnel (highlighted in red).

Impeller Subsection

The radius of the impeller subsection, see Figure 6.19, is equal to the impeller outer radius D_o summed with the clearance $/delta$, while the depth is equal to the length of the impeller hub.

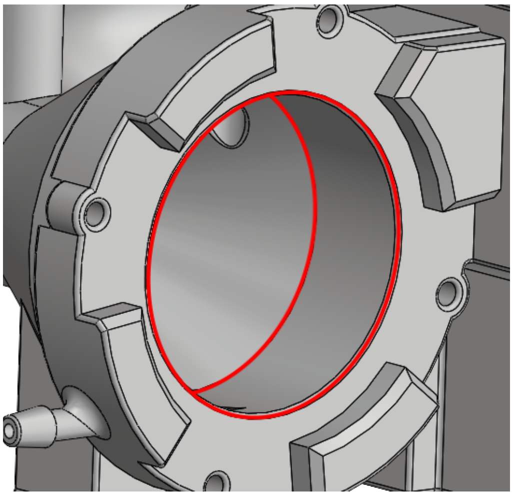

Figure 6.19: The impeller subsection of the pump section (highlighted in red).

Placement

The pump placement is based on three main points:

- The center of the impeller is in line with the center of the testing chamber. This is to allow for equal space behind and in front of the pump to channel the water through the testing chamber, minimizing sharp turns.
- The top of the impeller subsection is equal to the top of the testing chamber. This placement makes the water-level highest in the testing chamber as the system is filled to 2.5 mm above it and subsequently above the pump section as well. This prevents air from collecting within the pump section and the air is instead carried to the testing chamber where it escapes the hydraulic system. The drawback to this design is that it adds the radius of the pump section to the overall pump head loss of the system, however the overdimensioned pump head of the impeller design still exceeds this additional requirement.
- The impeller section is placed 10 mm from the outer wall of the testing chamber to allow for ample space for a flange type gasket seal with fasteners (the design of which is explored later in this chapter).

Taper

The back of the pump tapers down to 10 mm over the remaining length of the adjacent testing chamber. This straight taper is necessary as the motor shaft has to have access to the impeller.

6.2.3 Connecting Tube

A 10 mm inner diameter tube connects the back side of the pump to the rear of the testing chamber. The tube follows a half-circle and has a wall thickness of 5 mm.

6.2.4 Shaft Seal Section

A 10 mm inner diameter tube with wall thickness of 5 mm is extruded from the back of the pump taper and a 1.25 mm tall ledge is positioned so that the water proof shaft seal (see Section 5.3) sits flush with the edge of the inner wall of the connecting tube. This is the closest position to the impeller that the shaft seal can be mounted without blocking the water flow to the testing chamber. The shaft seal section can be seen in Figure 6.20. Figure 6.21 shows the shaft seal properly inserted all the way in towards the ledge. The shaft seal should be properly lubricated around its perimeter before insertion to ensure a water-proof seal.

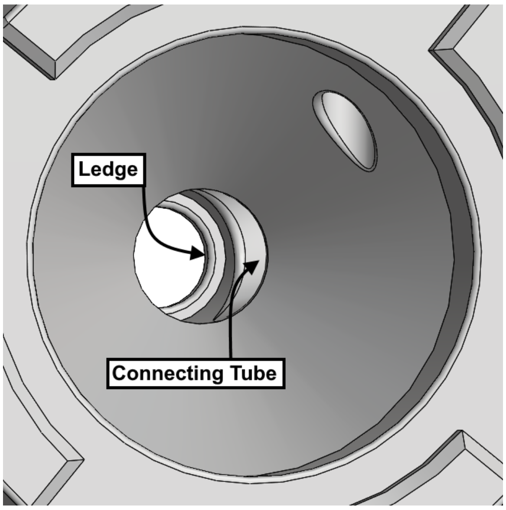

Figure 6.20: Shaft seal section.

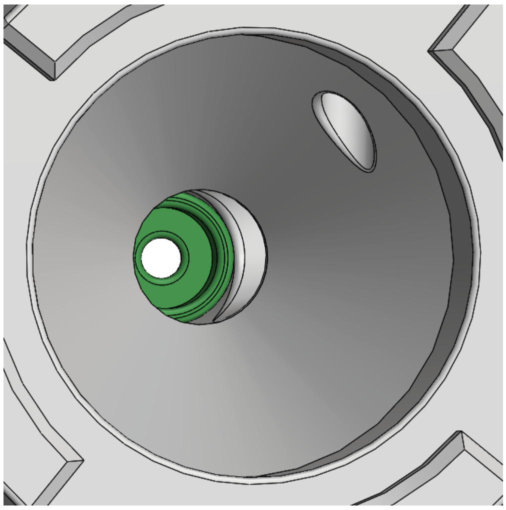

Figure 6.21: Shaft seal inserted all the way towards back ledge.

6.2.5 Ball Bearing Slot

At the opposite side of the previously mentioned ledge, used to properly position and secure the shaft seal, is a slot sized for a motor shaft bearing (see Section 5.8). As the shaft seal is made of rubber it does not provide a secure mounting point for the motor shaft. The ball bearing provides a solid second mounting point for the motor shaft (the first being the internal bearing of the motor itself). This design limits the vibrations of the impeller by reducing the unsupported length of the motor shaft. The slot can be seen in Figure 6.22 and the ball bearing can be seen inserted in Figure 6.23.

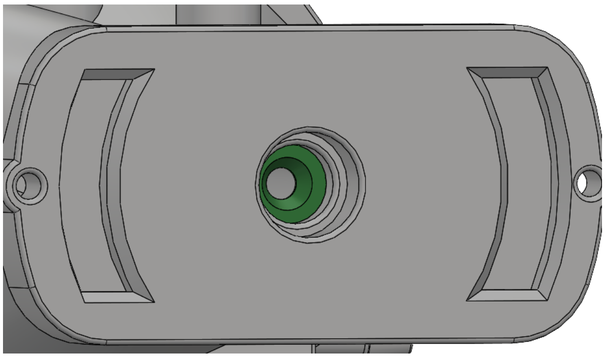

Figure 6.22: Ball bearing slot.

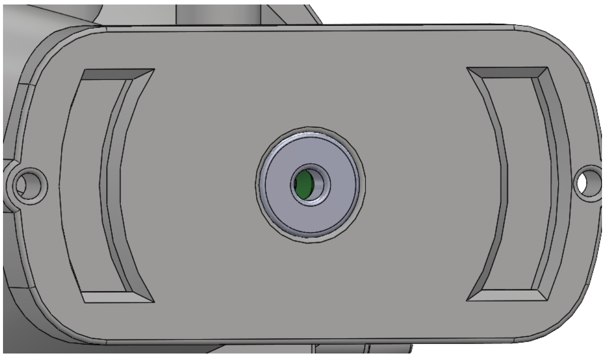

Figure 6.23: Ball bearing properly inserted.

6.2.6 "U-Tube"

The part nicknamed "U-Tube", pictured in Figure 6.25, connects the front side of the pump assembly to the front of the testing chamber as shown in Figure 6.24. This part was designed separate from the main body to enable access to the pump internals for inserting the shaft seal and impeller assembly. Additionally, this design allows easier access to the rectifying grid (Section 6.2) for cleaning purposes as illustrated in Figure 6.26. 6.23.

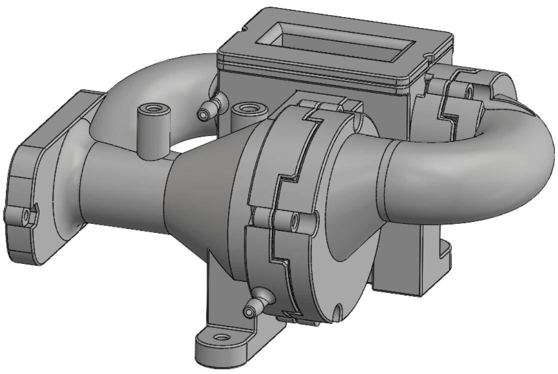

Figure 6.24: The "U-Tube" mounted to the system.

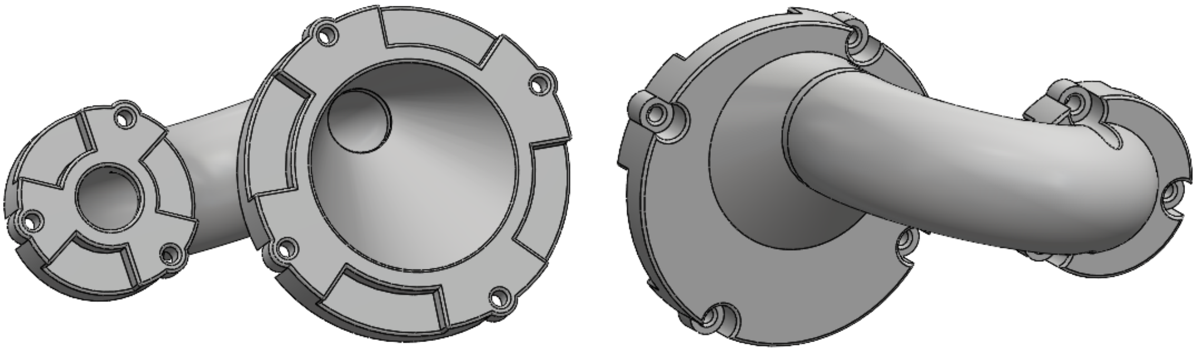

Figure 6.25: Front and rear view of the "U-Tube".

Similar to the connector tube part of the main body (see Section 6.2.3), the "U-Tube" tapers to a 10 mm circle over the remaining length of the adjacent testing chamber. This taper however, follows the top of the inner wall of the pump rather than tapering towards the center. This allows air to flow freely between the pump section and the testing chamber, which greatly eases the process of removing air from the system. The pump section is then connected to the testing chamber through a half-circle shaped 10 mm inner diameter tube. The "U-Tube" is designed so that it compresses in the same direction for both mounting points, this allows for any thickness gasket to be used without fear of misalignment.

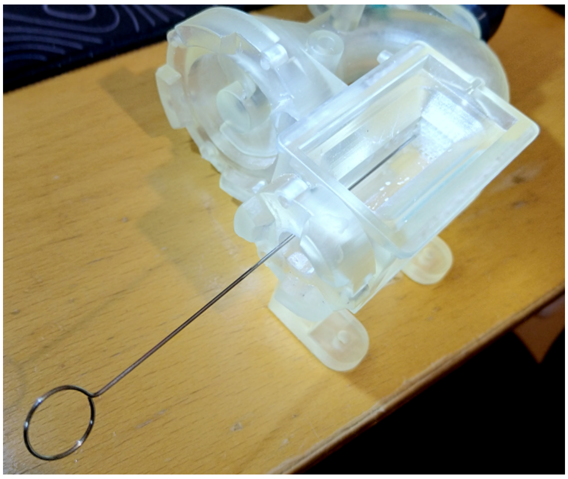

Figure 6.26: Demonstration of dislodging stuck particles from the flow rectifier using a thin rod (demonstration rod is 0.8 mm in diameter).

6.2.7 Flange Design

The "U-Tube" is fastened to the main body with a flange type design. The flange is designed with a male part, Figure 6.28, with guide ridges and a matching female part. Figure 6.30, with slots that fit them for proper alignment and centering of the parts. 0.5 mm spacing is added between the guide ridges and the slots to allow for print variability. A space for a gasket is located in the center of these guides. The gasket should be fully lubricated before inserting to ensure a water-proof seal. The male flange side has integrated slots for M2.5 nuts as pictured in Figure 6.27 and 6.29. The female side has cutouts made for M2.5 washers along with access cuts where necessary to allow for insertion of M2.5 machine screws as shown in Figure 6.31. There are a total of 7 M2.5 machine screws and nuts used to attach the "U-Tube" (Section 6.2.6) to the water tunnel with this design. The screws should be evenly tightened down to ensure even compression of the gasket.

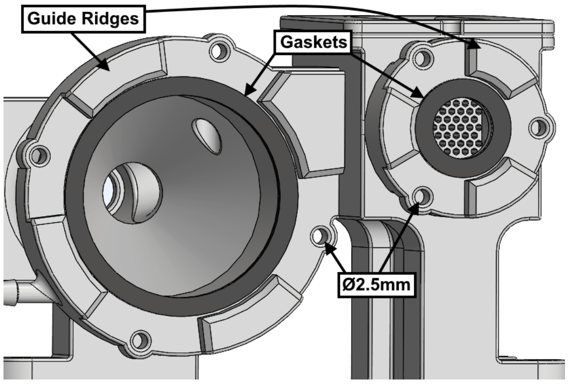

Figure 6.28: Male flange side.

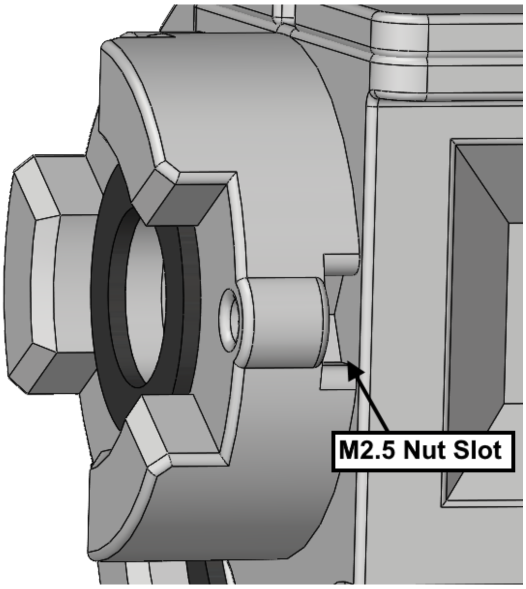

Figure 6.29: M2.5 nut slot design in blocked off areas.

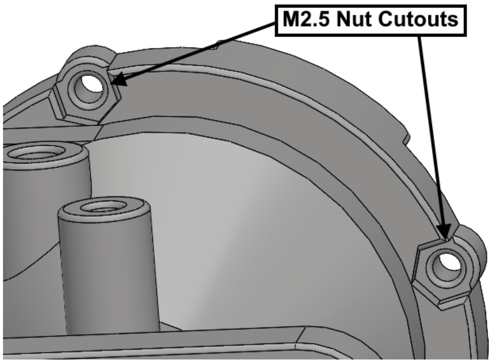

Figure 6.27: M2.5 nut slots.

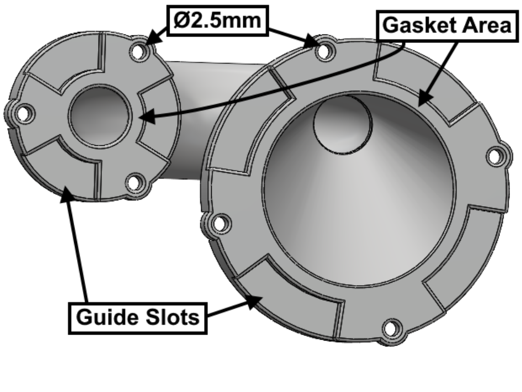

Figure 6.30: Female flange side.

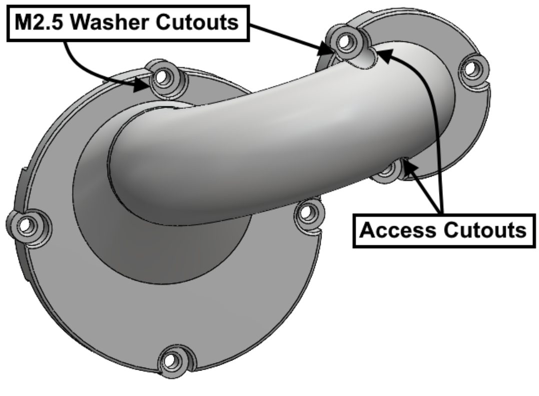

Figure 6.31: Washer cutouts and access cutouts.

6.2.8 Inlet and Outlet

The inlet and outlet of the system can be seen in respectively Figure 6.32 and 6.34. The inlet and outlet uses a connector designed to accept 3 mm inner diameter silicone tubing. The measurements of this connector design is based on the tube connector included with the peristaltic pumps (see Section 5.11) which can be seen pictured in Figure 6.36.

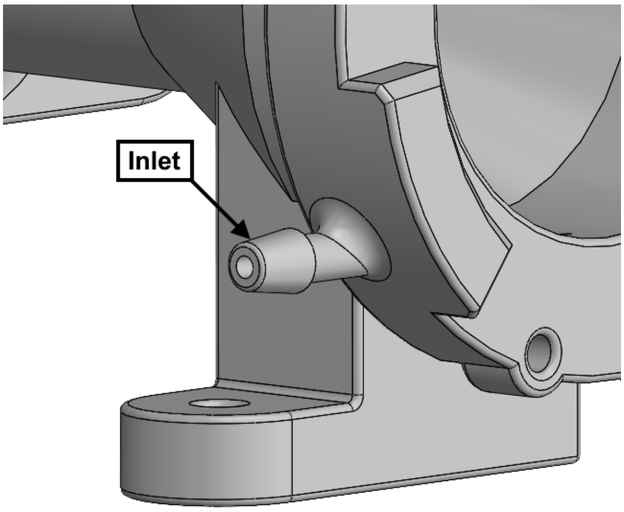

Figure 6.32: System inlet.

The inlet of the system is placed at the lowest point in the hydraulic system (bottom of the impeller subsection of the pump, see Section 6.2.2), allowing it to fully drain the system. The inlet fill/drain opening in the pump section can be seen in Figure 6.33.

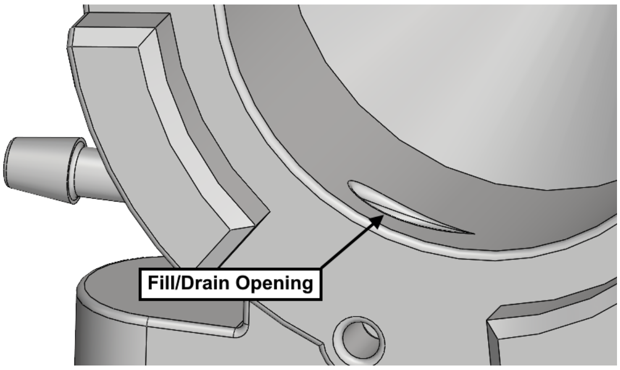

Figure 6.33: Inlet fill/drain opening.

An outlet in the system, see Figure 6.34, is necessary to allow for flushing of the system without having to fully drain and re-fill. The bottom of the internal drain hole of the outlet, see Figure 6.35, is placed 2.5 mm above the testing chamber in the de-pressurized part of the hydraulic system. As the bottom of the drainage hole is placed at the desired water-level height of the system, the drainage pump can run at a higher duty cycle than the fill pump when filling the system which will ensure that the system is not able to overflow due to under-drainage while also not worrying about over-draining the system. This is important as over-drainage would introduce air into the system, while under-drainage would lead to leaks and which could potentially damage electronic equipment.

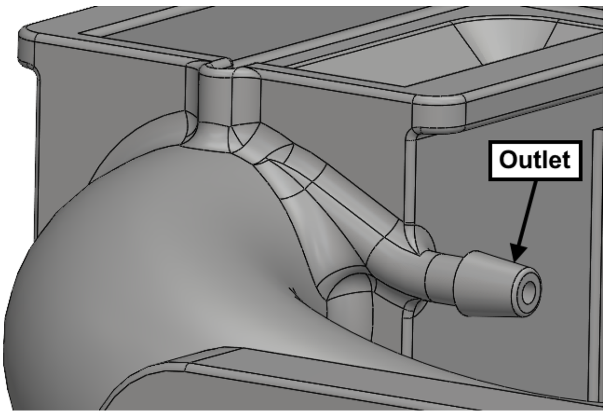

Figure 6.34: System outlet.

This design requires no additional sensor equipment as the water-level is automatically regulated. The top of the drain hole opening extends slightly over the chamfered edge above the testing chamber, allowing for free flow of water to the drain when the lid is placed on the testing chamber as otherwise the drain hole would be blocked by the lid.

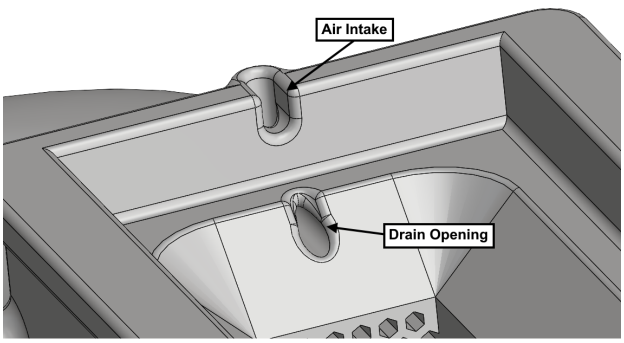

Figure 6.35: Outlet drain opening.

Furthermore, the outlet connector is placed lower than the drainage hole to ensure that air is not introduced into the drainage pump until the water-level is exactly at the ideal height. An air intake is additionally connected to the outlet to prevent depressurizing of the testing chamber when the lid is placed on the testing chamber.

This design also prevents loud noises from occurring from the drain pump attempting to draw in air around the lid edge. A picture of the air intake with the lid fitted can be seen in Figure 6.37. Appropriate cutouts are made in the lid to not obstruct the air flow to the air intake. The cutouts are made on both sides of the lid so this function is maintained regardless of orientation.

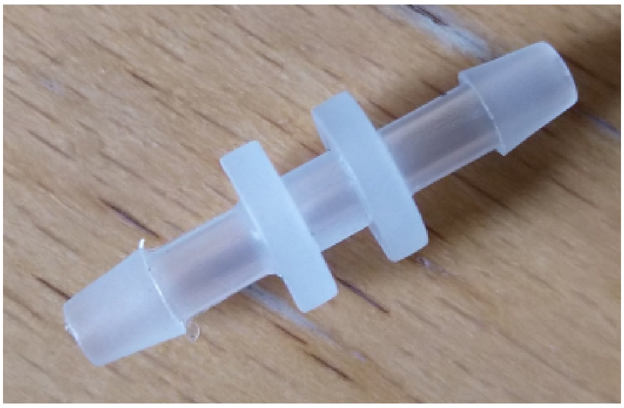

Figure 6.36: Tube connector used for reference.

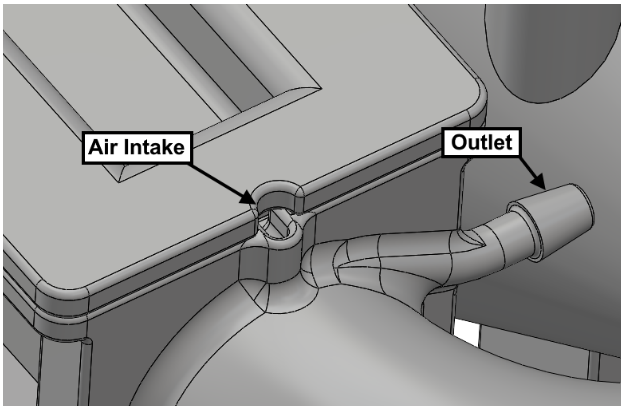

Figure 6.37: Inlet air intake with lid placed onto the testing chamber.

6.2.9 Feet and Surface Mounting

The feet of the water tunnel, see Figure 6.38, supports the system and ensures proper function of the hydraulic design of the system as long as the surface the system is placed on is properly leveled. 5 mm thick brackets extend from the feet with mounting holes for M3 machine screws to securely mount the system.

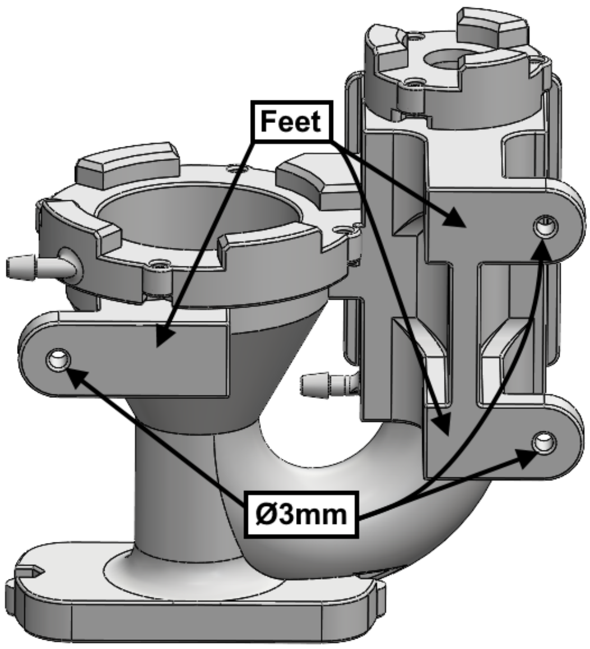

Figure 6.38: Feet of the water tunnel.

6.2.10 Sensor Mounting

Two tubes extend from the top of the water tunnel. These tubes are individually sized to accept the k-type thermocouple, Section 5.13, and the Pyroscience oxygen sensor, Section 5.12, and can be seen pictured in Figure 6.39. The sensors can be seen properly mounted in Figure 6.40 and 6.41. The holes are designed with diameters 0.5 mm wider than that of the sensors to allow for printing variability. The sensor connections are made water-proof by wrapping them with thread-sealing tape (plumber's tape/Teflon tape) or similar before inserting them into their appropriate holes.

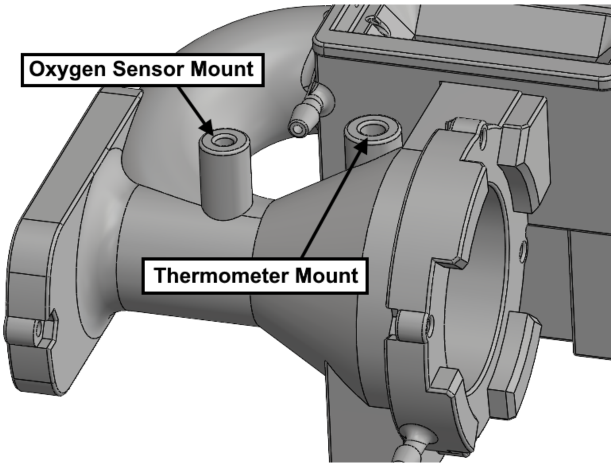

Figure 6.39: Sensor holes.

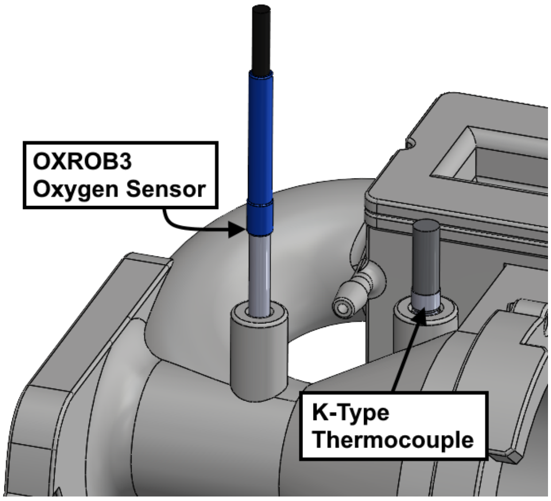

Figure 6.40: Sensors properly mounted.

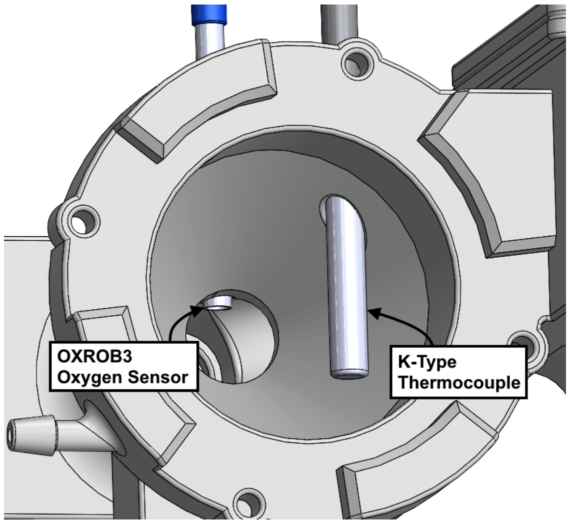

Figure 6.41: Internal view of sensors.

6.2.11 Optional Cooling System

An optional cooling system is designed as a replacement for the "U-Tube", see Section 6.2.6, for fish requiring lower water temperatures than room temperature. As the oxygen saturation of water depends on its temperature it is desirable to keep the temperature in the system as constant as possible. The cooling system can be seen mounted to the system in Figure 6.42. This system requires an additional pump connected to the outside tank to continuously run water through the cooling loop.

The cooling system is made up of a modified version of the "U-Tube" and an accompanying top cover with tube connectors as shown in respectively Figure 6.43 and 6.44. The modified "U-Tube" has four slots for inserting heat-sinks, see Section 5.10. The heat-sinks are epoxy-glued in place flush with the surface of their slots as shown in Figure 6.45. The fins of the heat-sinks are aligned so that they follow the water flow through the tube as shown in Figure 6.46. The heat-sinks are mounted so that the start of the cooling fins are tangent to the top of the internal tube to allow for as much of the fins to be in contact with the internal water as possible. The water inside of the loop conducts heat to the heat-sinks and the constantly running water through the system carries the heat away.

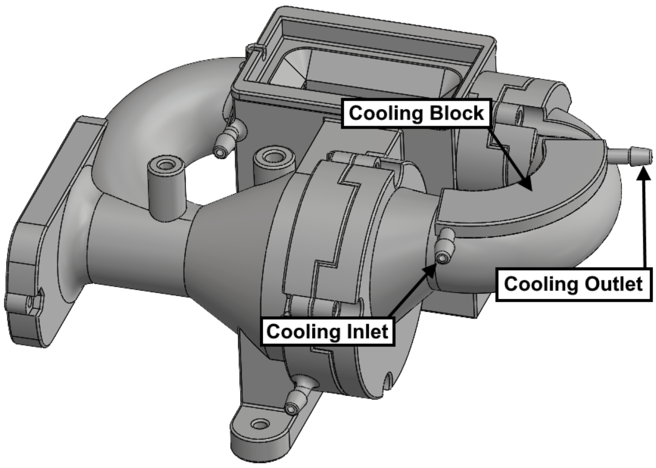

Figure 6.42: The optional cooling system mounted to the system.

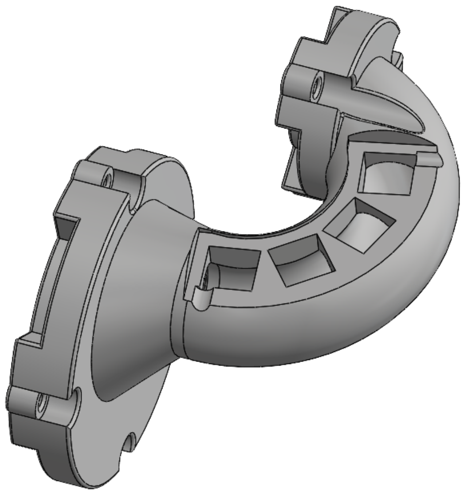

Figure 6.43: Modified version of the "U-Tube" used in the cooling system.

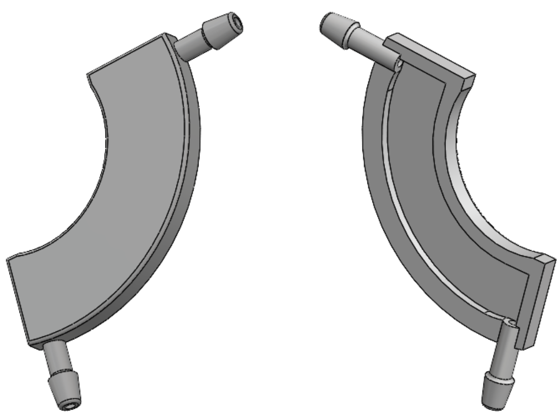

Figure 6.44: Both sides of the top cover of the cooling system.

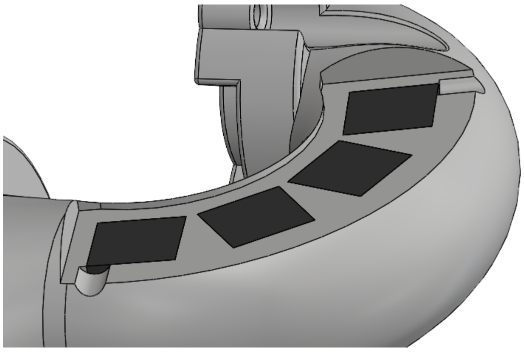

Figure 6.45: The heat-sinks are mounted flush to the surface of the slots.

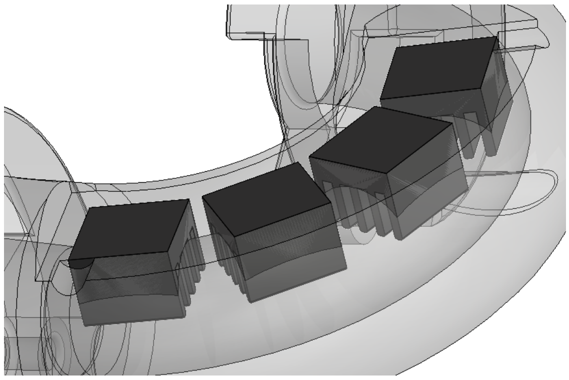

Figure 6.46: The heat-sinks are aligned so that the cooling fins follow the direction of the water flow.

6.3 Motor Assembly

The motor assembly of the system secures the motor in place and connects the motor shaft to the impeller shaft. The motor assembly can be seen fully assembled to the water tunnel in Figure 6.47.

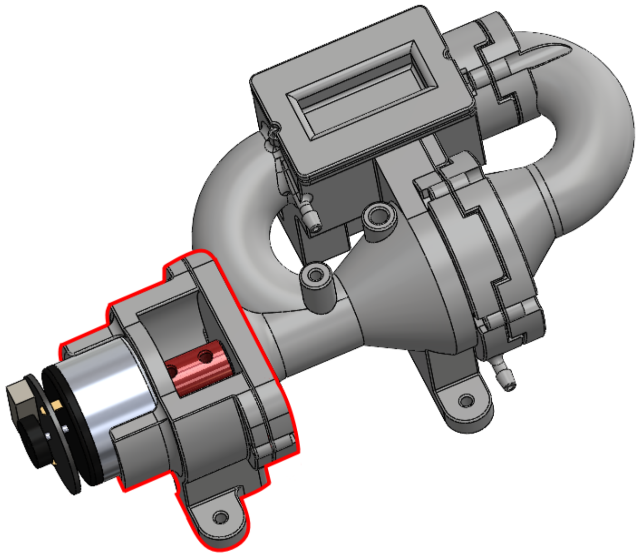

Figure 6.47: The motor assembly (highlighted in red) fully assembled to the water tunnel.

6.3.1 Motor-Connector

The motor-connector, pictured in Figure 6.50 below, securely connects the motor to the water tunnel at an appropriate distance away from it to allow for the fitting of a shaft coupler between the motor shaft and the impeller shaft. Furthermore, it is designed to allow for access to the set-screws of the shaft coupler for assembly purposes.

The motor is secured to the motor-connector using six M2.5 machine screws through accompanying 2.5 mm holes in the motor-connector as shown in Figure 6.48. The motor-connector uses a similar male/female connector design as described in Section 6.2.7 to mount to the water tunnel.

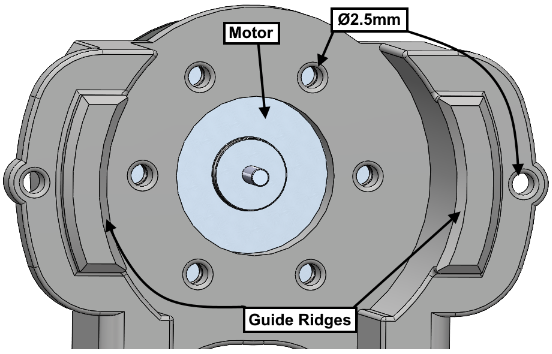

Figure 6.48: 2.5 mm diameter holes for securing the motor using six M2.5 machine screws.

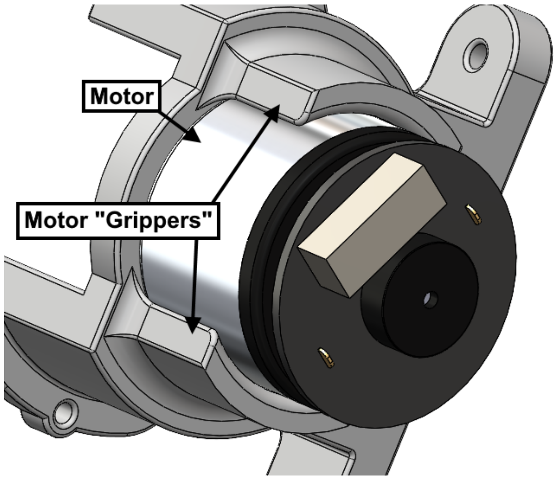

Figure 6.49: The motor is friction fit between two "grippers" which adds extra stability to the system.

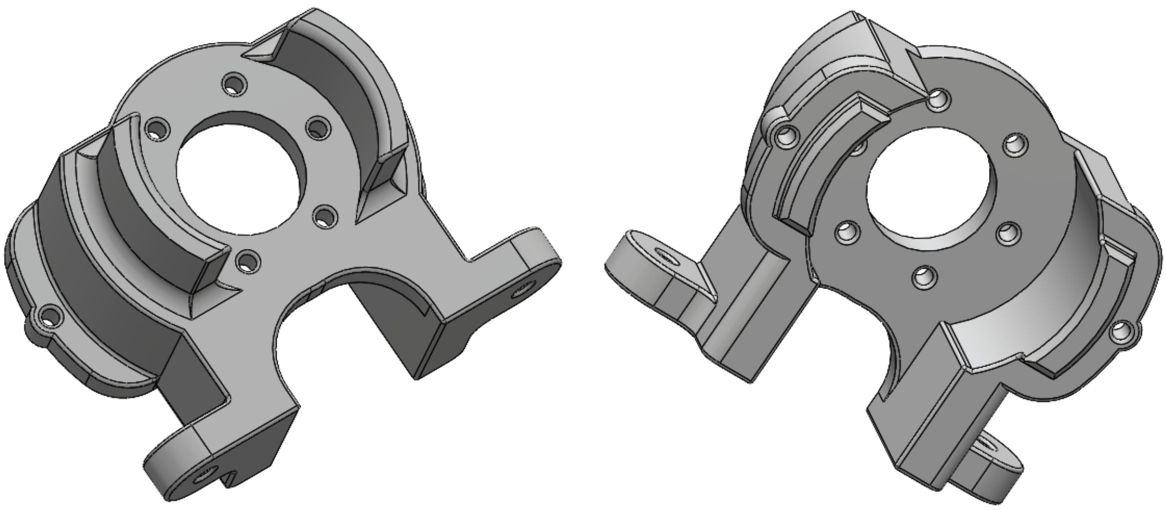

Figure 6.50: Motor connector of the motor assembly.

6.3.2 Impeller Assembly

A 74 mm long 3 mm diameter stainless steel shaft is epoxy glued into the rear hole of the impeller (see Figure 6.8) as shown in Figure 6.51. The impeller assembly is then inserted (through the shaft seal and bearing, see Section 6.2.4 and 6.2.5) into the pump section of the water tunnel so that the top of the impeller sits flush with the end of the impeller section (see Figure 6.19) as shown in Figure 6.52. The shaft should be properly lubricated before inserting through the shaft seal to ensure a water-proof seal along with lowering friction between the two.

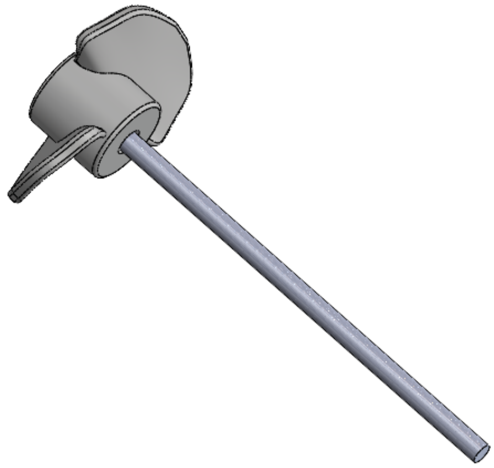

Figure 6.51: The motor shaft mounted to the impeller.

6.3.3 Shaft Coupler

The shaft coupler, see Section 5.5, is inserted as far as it can go onto the impeller shaft as shown in Figure 6.53. The two screws securing the impeller shaft end to the shaft coupler can then be screwed in to lock it in place. There is a 1 mm clearing between the shaft coupler and the water tunnel/bearing, allowing for free rotation of the shaft coupler.

6.3.4 Mounting to the Water Tunnel

The motor-connector with the motor attached to it can then be attached to the water tunnel, as shown in Figure 6.47, using two M2.5 machine screws and nuts.

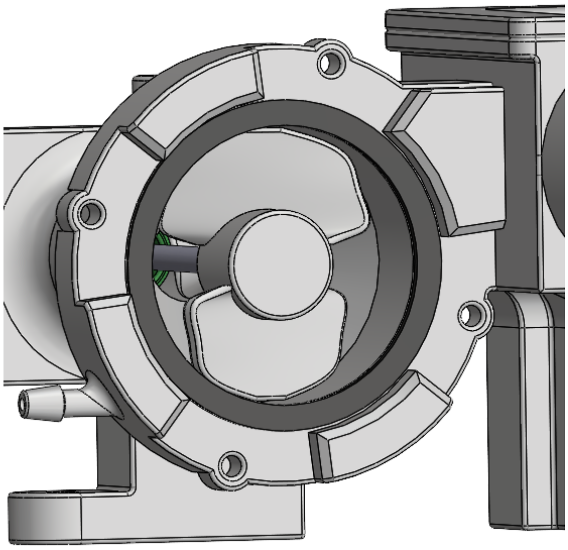

Figure 6.52: The impeller assembly inserted into the pump section of the water tunnel.

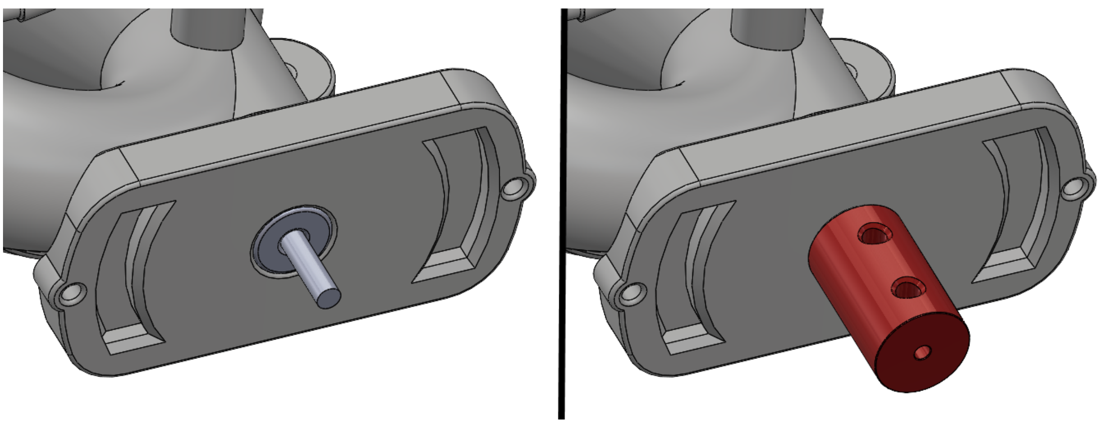

Figure 6.53: Before and after mounting the shaft coupler to the impeller shaft.

6.4 Electrical

This section covers all the electronics, excluding the motor and pumps, of the system. The electrical part of the system comprises all electronics that are necessary for the system. All custom components from this point onward are designed with FDM, Fused Deposition Modeling, printing in mind.

6.4.1 Electrical Enclosure

The electrical components and the wiring needs an enclosure which serves multiple functions.

- It lowers the chance of water coming in contact with the electrical connections.
- It prevents foreign objects from entering the system which could potentially bridge contacts.
- It keeps the components and wiring organized and easy to work with.

The enclosure is designed to contain the power delivery of the system along with three modular breadboards (Section 5.14) to hold the Teensy 4.0 (Section 5.1.3), the two motor drivers (Section 5.9, and the thermometer amplifier (Section 5.13.1). The enclosure can be seen pictured in Figure 6.54 below. The enclosure is designed to be printed using

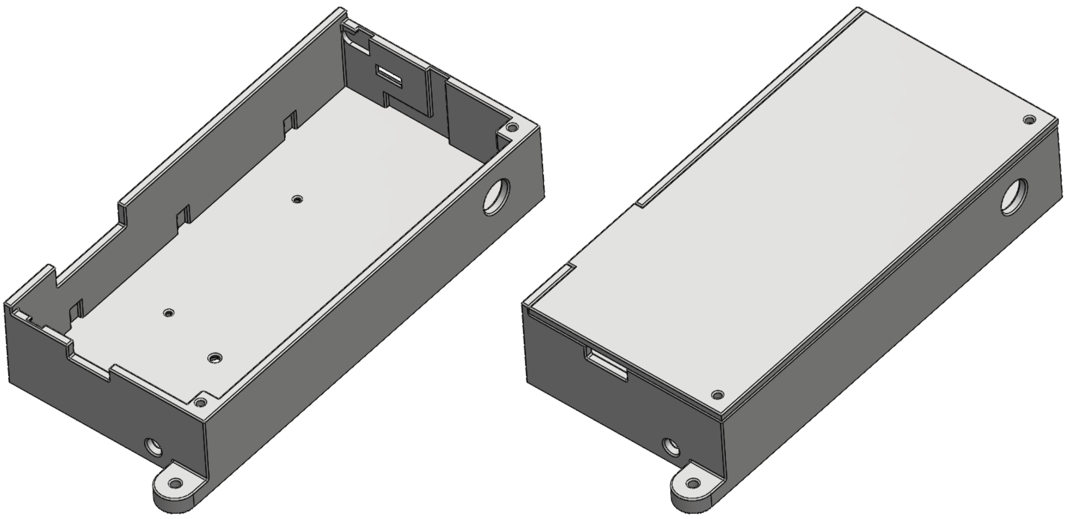

Figure 6.54: Electrical enclosure.

Machine Nut Cutouts

The underside of the electrical enclosure has several mounting slots for machine nuts as shown in Figure 6.55. Two M2, two M2.5, and two M3 nuts are inserted into their relevant holes. In the case of the nuts not fitting into their holes, a soldering iron should be used to head the nuts in order to slide them in place. This will keep the nuts semi-permanently attached to the bottom which is convenient when assembling the rest of the electrical enclosure.

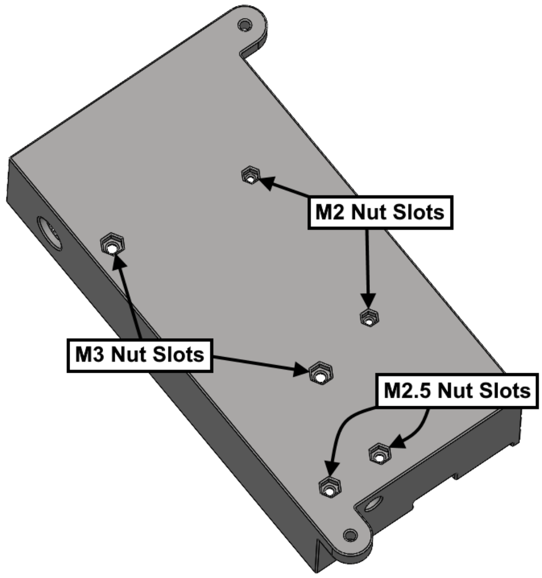

Figure 6.55: Machine screw nut cutouts.

Breadboard Mounting

The three modular breadboards, see Section 5.14, are first connected lengthwise, as shown in Figure 6.56, before being inserted into the electrical enclosure. Cutouts are made in the walls of the enclosure which should be lined up with the connector nubs of the breadboard for proper mounting as shown in Figure 6.57. The breadboards are first inserting directly down, following the slot on the wall, before being pushed all the way into the wall to align it with the 2 mm holes underneath. There is a 0.5 mm gap around the breadboards and the enclosure walls to allow for print variability. Two M2 machine screws, along with accompanying nuts on the underside of the enclosure, are used to securely fasten the breadboard to the enclosure.

Figure 6.56: Three modular breadboards connected together.

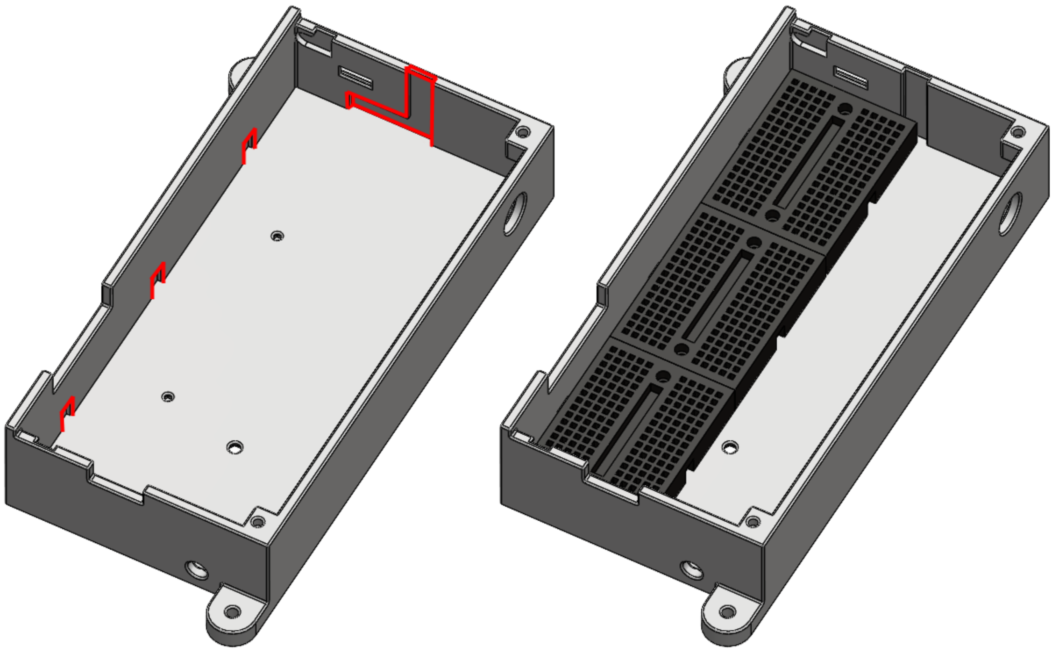

Figure 6.57: Breadboard inserted into the electrical enclosure.

Power Delivery

The 5 V DC/DC regulator (see Section 5.16.1) is mounted as shown in Figure 6.58 using two M3 machine screws through the accompanying hole and M3 nut in the bottom of the enclosure. The regulator is mounted with the regulated 5 V side facing the small hole in the left wall of the enclosure. The left hole is appropriately sized to accept the power cable (see Section 5.16.3) used for carrying power to the Jetson Nano. A cable lock, pictured in Figure 6.60, is designed and implemented to provide extra rigidity to the aforementioned power cable. The cable lock is tightened onto the cable using two M2.5 machine screws with accompanying nuts on the underside of the enclosure.

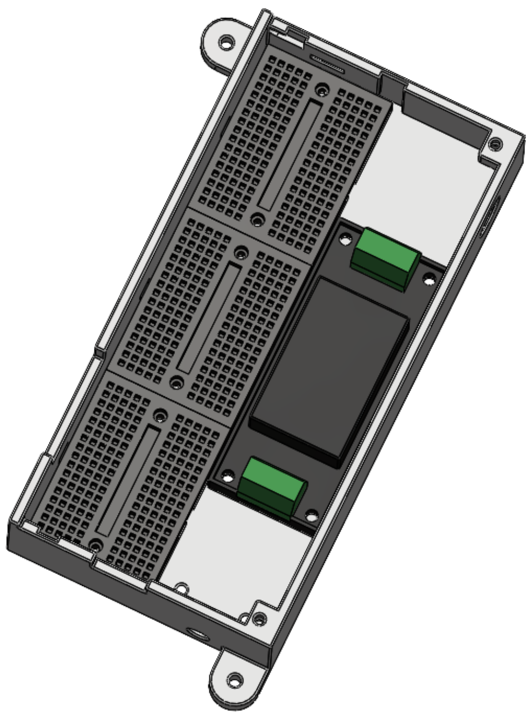

Figure 6.58: 5 V regulator mounted in the Electrical Enclosure.

An 11 mm mounting hole in the enclosure is located next to the input side of 5 V regulator to accept the 12 V power jack (see Section 5.16) providing power to the system when the 12 V power supply is connected. A second 6.5 mm sized hole is used for mounting the power switch (see Section 5.16.2). These aforementioned mounting holes, along with a cutout providing access to the Teensy 4.0 (Section 5.1.3) micro USB connector, can be seen in Figure 6.61. The 12 V power jack is mounted using the included washer and nut and can be seen mounted in Figure 6.59 below.

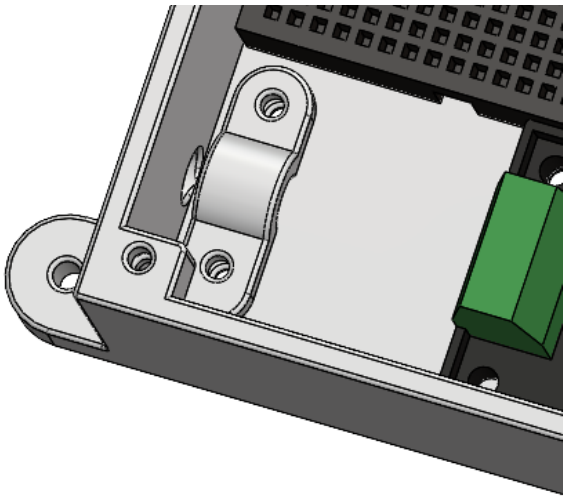

Figure 6.60: Cable lock used to secure the power cable connected to the Jetson Nano.

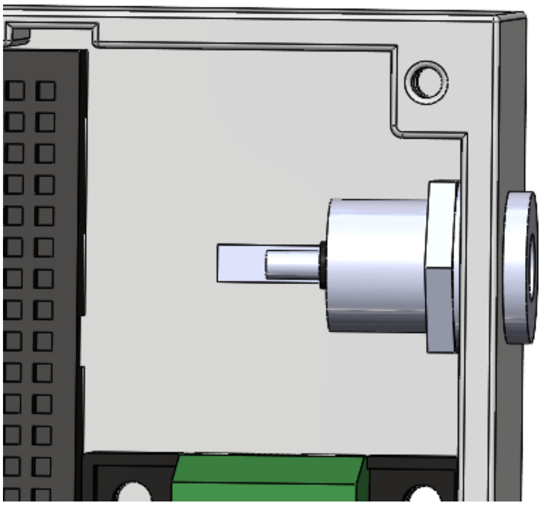

Figure 6.59: 12 V jack mounted to the enclosure.

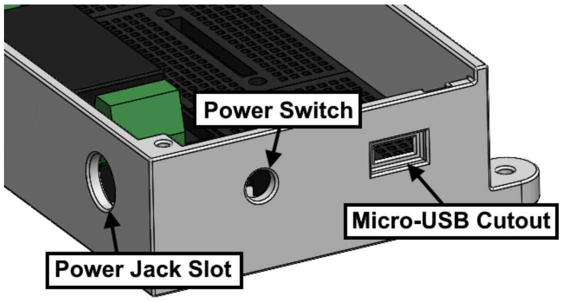

Figure 6.61: Cutout for 12 V power jack and access to the Teensy 4.0 micro USB.

Enclosure Lid

The lid of the enclosure is designed with a rear locking mechanism, see Figure 6.62, to fasten the lid onto the enclosure along with two 2.5 mm holes for securing it in place with M2.5 machine screws. The locking mechanism is located underneath the lid and slides into guide slots in the enclosure that prevents the rear side of the lift from lifting off the enclosure once the screws are in place.

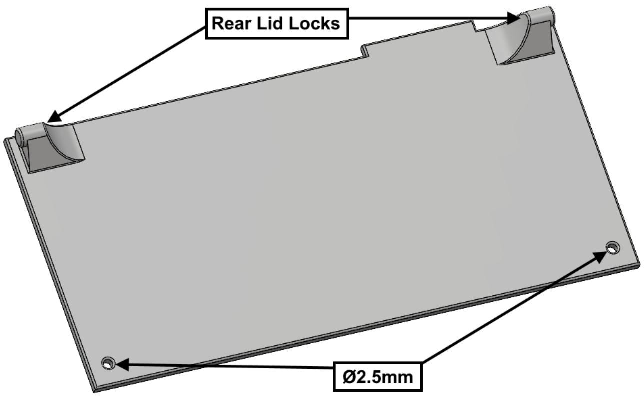

Figure 6.62: Bottom side of enclosure lid.

The guides for the locking mechanism can be seen in Figure 6.63. The M2.5 machine screws locks onto two M2.5 nuts that are inserted into slots in the enclosure that can be seen pictured in Figure 6.64. The slots are designed to tightly fit the machine nuts, and a soldering iron should be used when assembling to heat and push the nuts into their respective slots. This permanently locks the nuts into the enclosure for easy operation of the lid.

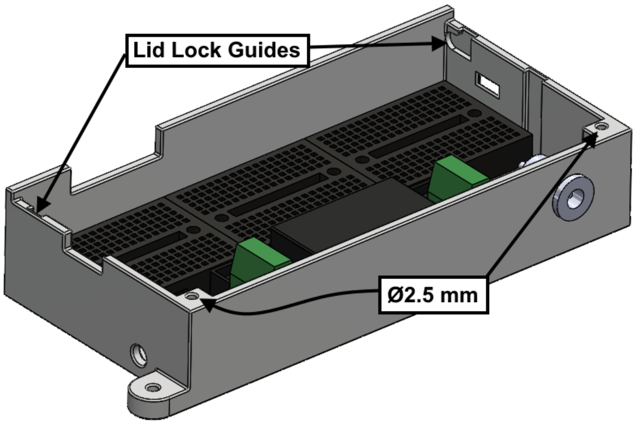

Figure 6.63: Lid lock guides and screw holes.

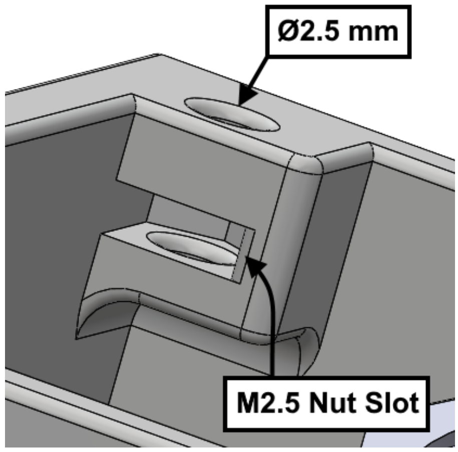

Figure 6.64: M2.5 machine nut slot for fastening lid.

Signal Cable Cutouts

There are two cutouts to allow for the routing of signal cables to the external components that the electronics within the enclosure controls or communicates with. These cutouts can be seen in Figure 6.65.

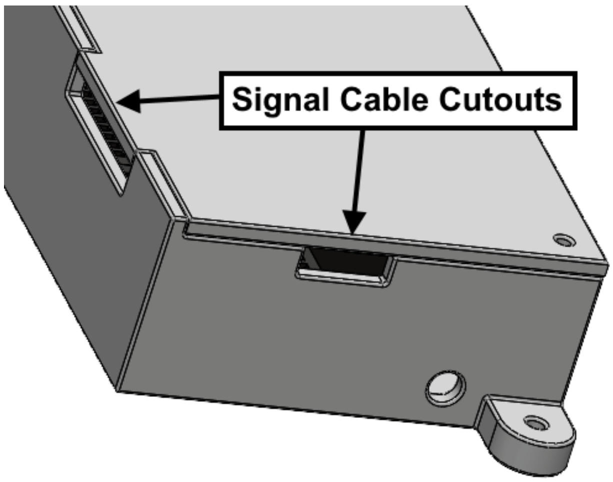

Figure 6.65: Cutouts for routing of signal cables.

6.4.2 Electrical Enclosure Schematic

The electrical schematic of the components of the enclosure can be seen in Figure 6.66. As the thermocouple amplifier (see Section 5.13.1) acts as an SPI slave to communicate the sensed temperature to the Jetson Nano, the Teensy 4.0 (see Section 5.1.3) is connected as a second slave on the SPI connection. This allows for only one extra cable (chip select to the Teensy 4.0) to be used to add communication between the Teensy 4.0 and the Jetson Nano. The components in the schematic is arranged as they should be placed in the electric enclosure itself. The connector labeled "SPI Communication" connects to the Jetson Nano through the right opening shown in Figure 6.65, whereas the motor and pump connections exit through the left opening. The connections to the Jetson Nano will be detailed later in this chapter.

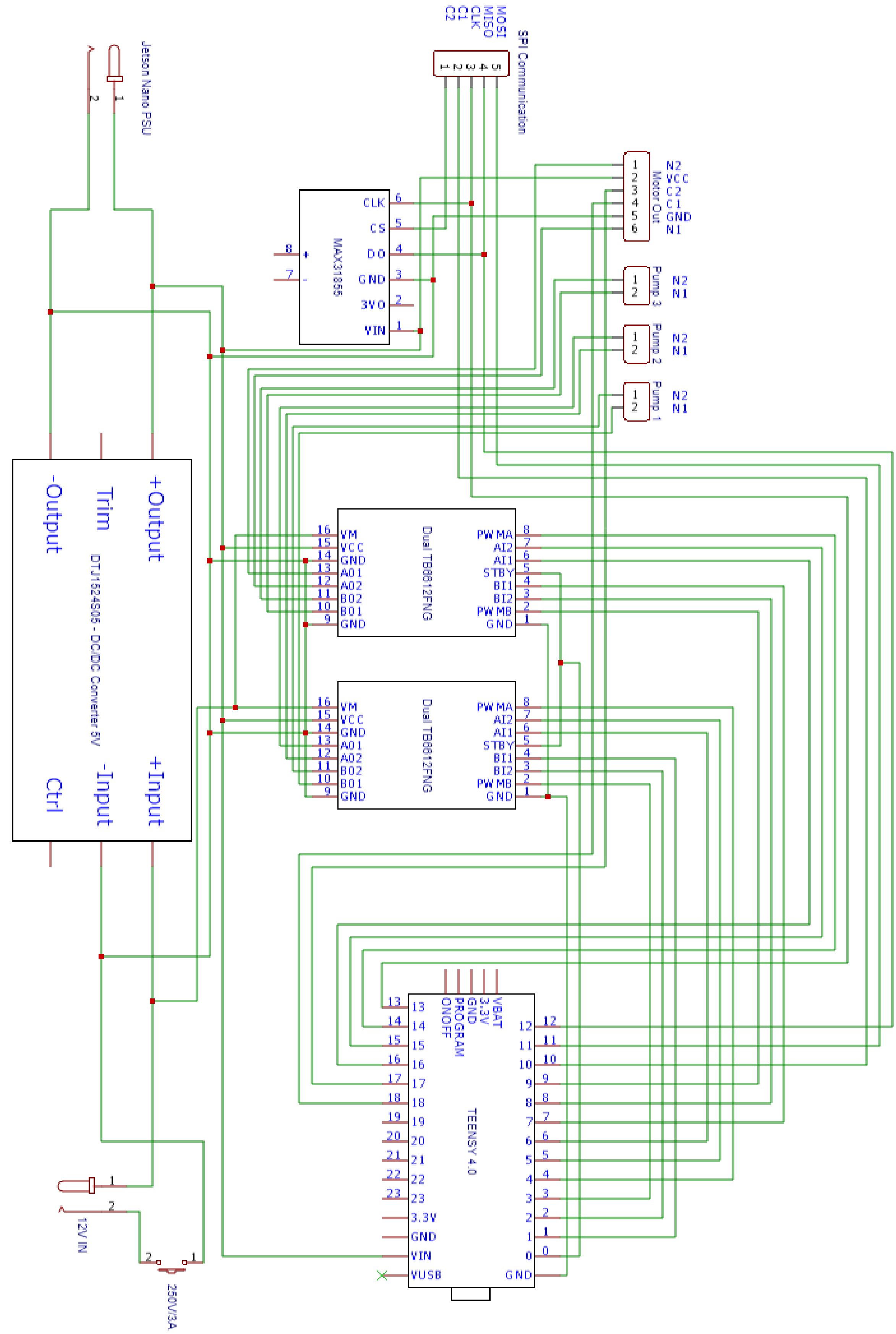

Figure 6.66: Electrical schematic of the electrical enclosure.

6.4.3 Camera Tower

The "camera tower" holds the two cameras (see Section 5.15) at exactly 5 cm away from the start of the inside side of the windows of the testing chamber (see Section 6.2.1). For reasons detailed in Section 5.15, this is the closest possible distance that the cameras can be mounted while still being able to focus on objects throughout the testing chamber. The camera tower also holds four 5 mm white LED lights to evenly illuminate the testing chamber. The camera tower with cameras and LEDs mounted can be seen in Figure 6.67 to the right. The camera tower is designed so that its mass center is located approximately above the center of its foot. This makes the system very stable even when not secured to a surface.

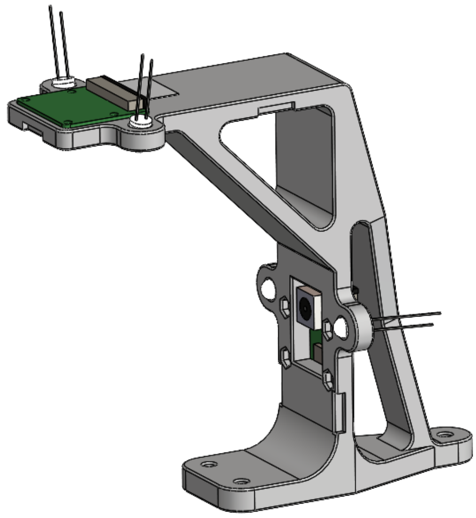

Figure 6.67: The "camera tower" assembly with lighting system.

The two cameras are mounted to the camera tower using 4 M2 machine screws through the PCB of the camera module and relevant hole in the camera tower and secures them using accompanying M2 nuts on the opposite side of the face that they are placed on.

There is a square cut where the camera modules are mounted to provide clearance for the components and the camera assembly on the lens side of the camera module. The LEDs are friction mounted into angled 5 mm cutouts adjacent to the camera module. The aforementioned M2 holes, camera clearance, and LED mounting holes can be seen in Figure 6.68. The cutouts for the M2 nuts can be seen in Figure 6.69.

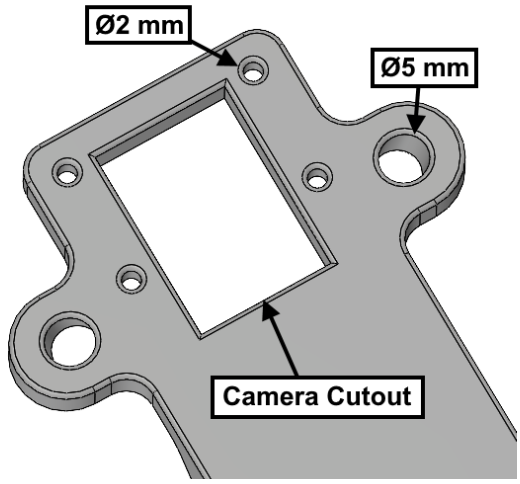

Figure 6.68: The cutouts used for mounting the camera and LEDs.

The CSI ribbon cable of the vertically mounted camera exits the camera tower through an 18 mm wide cutout picture in Figure 6.70.

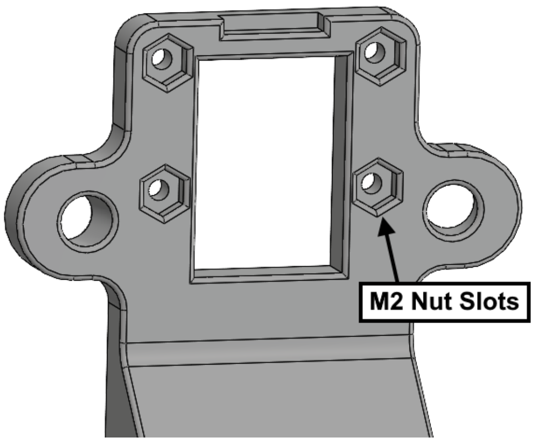

Figure 6.69: Cutouts for M2 nuts used for mounting the camera modules.

Clip Mounting Slots

Several sections of cutout slots can be seen around the edges of the camera tower. These are designed to accept a clip style connector for mounting a cover to conceal the PCBs of the camera modules and wiring to the LEDs. This cover has not been developed as of the writing of this report so these cutouts serve no functional purpose at this point.

Camera FoV

The camera field of view, FoV, is modeled for a visual representation of the camera's view and is shown in Figure 6.71. This model was also used to position the camera with the testing chamber in the center of the view. As the camera records in widescreen, the camera is positioned so that the long edge of the camera view is parallel to the long side of the testing chamber window. The FoV is modeled based on the following parameters [1]:

- Horizontal FoV of 65°
- Vertical FoV of 51°
- Focus range of 5 *sim* 30 cm

Realized Resolution

The height and width of the camera view at the closest focus range of 5 cm is respectively equal to 47.7 mm and 63.71 mm retrieved from the closest surface of the previously detailed FoV representation model. The height and width of the testing chamber window is 10 mm and 30 mm. This means that with a resolution of 1920x1080 pixels (1080p), the total resolution that the testing chamber occupies in the camera view is only ≈ 902x227 pixels as calculated in Equation 6.15 and 6.16. The resolution at 1280x720 pixels (720p) would be ≈ 602x151 pixels.

$$\frac{30mm}{63.71mm} \approx 0.47 \rightarrow 1920pixels \cdot 0.47 \approx 902pixels \tag{6.15}$$

$$\frac{10mm}{47.7mm} \approx 0.21 \rightarrow 1080pixels \cdot 0.21 \approx 227pixels \tag{6.16}$$

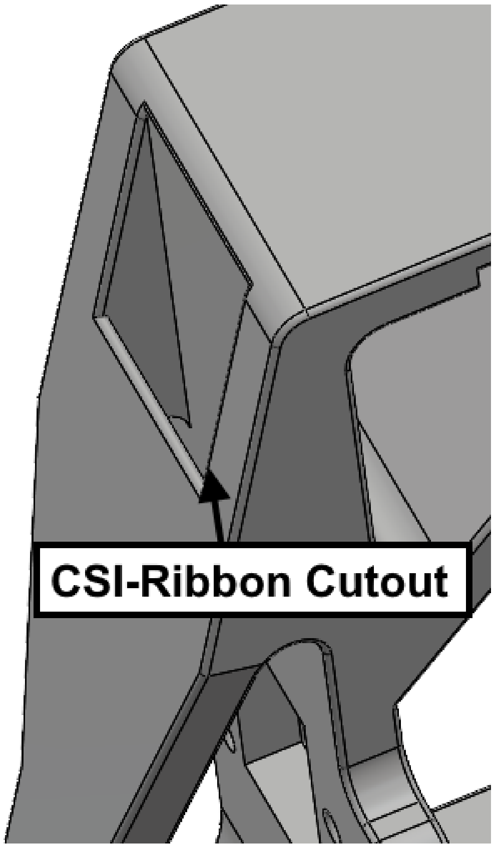

Figure 6.70: Cutout for the CSI-ribbon cable of the vertically mounted camera.

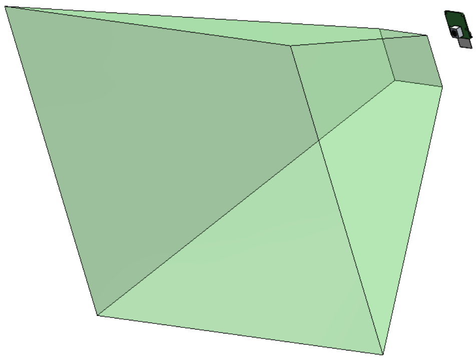

Figure 6.71: Model of the camera module with FoV representation.

LED Lighting Positioning

The LEDs are mounted so that the center axis, i.e. the lighting beam direction, of the left LED (relative to the camera module) passes through the middle of the left half of the testing chamber, while the right LED's axis does the same to the right half. This ensures an even lighting distribution in the testing chamber. The center axis of the LEDs can be seen in Figure 6.72.

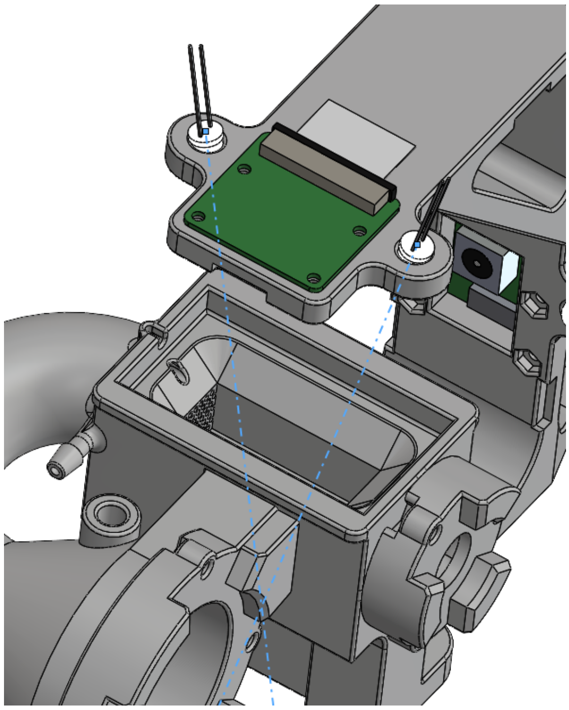

Figure 6.72: Illustration of the beam direction of the LED Lighting.

6.4.4 Camera Lighting Schematic

The four LED's are connected in parallel and require a resistor to limit the current flowing through them. The resistor is calculated using Ohms law as shown in Equation 6.17 where $V_C C$ is the supply voltage, and V_F and I_F are respectively the forward voltage and forward current of the LED's. The base resistance of the transistor is calculated as shown in Equation 6.18 [18]. The h_{FE} is retrieved from the datasheet of the transistor included in Appendix D.2. The schematic of the LED Circuitry is displayed below in Figure 6.73.

$$R_L = \frac{V_C C - V_F}{I_F} = \frac{5V - 3.2V}{20mA \cdot 4} = 22.5\Omega \tag{6.17}$$

$$R_B = 0.2 \cdot R_L \cdot h_{FE} = 0.2 \cdot 22.5 \cdot 100 = 450\Omega \tag{6.18}$$

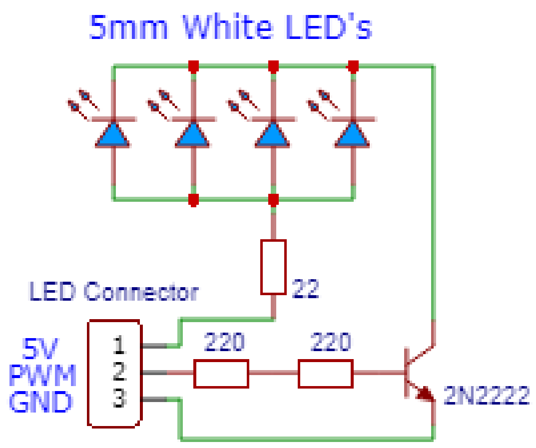

Figure 6.73: Electrical schematic of the camera lighting system.

6.4.5 Jetson Assembly

A modified version of the "NanoBoxABS for B01"[21] enclosure is used to house the Jetson Nano developer kit (see Section 5.1). The version is modified to include two surface fasteners that allows the enclosure to be fixed to a surface using two M3 machine screws. The modified case can be seen pictured in Figure 6.74. The rear of the case has two 6.6 mm holes, see Figure 6.75, for mounting the antennas of the wireless card (see Section 5.1.2) used for the Jetson Nano in this project.

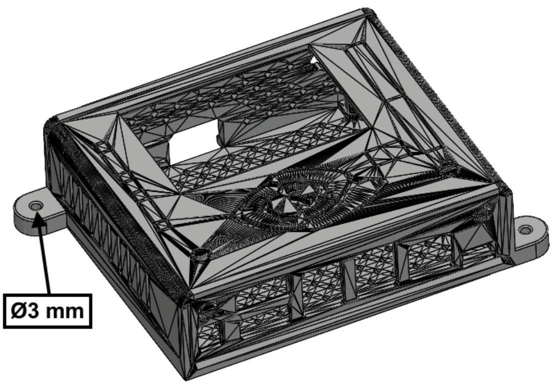

Figure 6.74: Modified "NanoBoxABS for B01"[21] case.

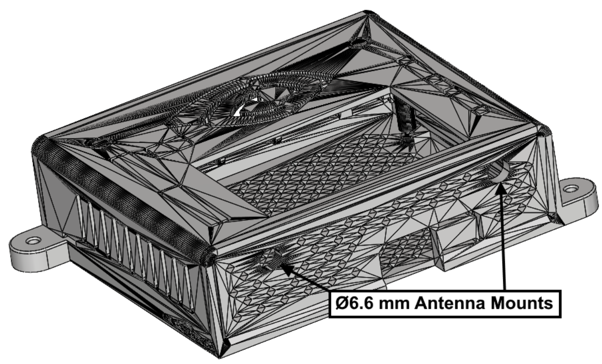

Figure 6.75: Antenna mounting holes in the rear of the "NanoBoxABS for B01"[21] case.

Electrical Connections

The electrical connections made to the Jetson Nano developer kit can be seen in Figure 6.76 below. There are five connections made to the Jetson Nano which are described below.

- "SPI Communication" connects to the electrical enclosure in order to communicate with the Teensy 4.0 and Thermocouple Amplifier as described in Section 6.4.2.
- The "Pyroscience" connection refers to the UART connection to the "FireSting-PRO" (see Section 5.12) meter for oxygen and tank temperature data.
- The "LED Connector" connects to the camera lighting system as described in Section 6.4.4.
- "Camera 1" and "Camera 2" refers to the SPI-connection to the two cameras (see Section 5.15) of the system.

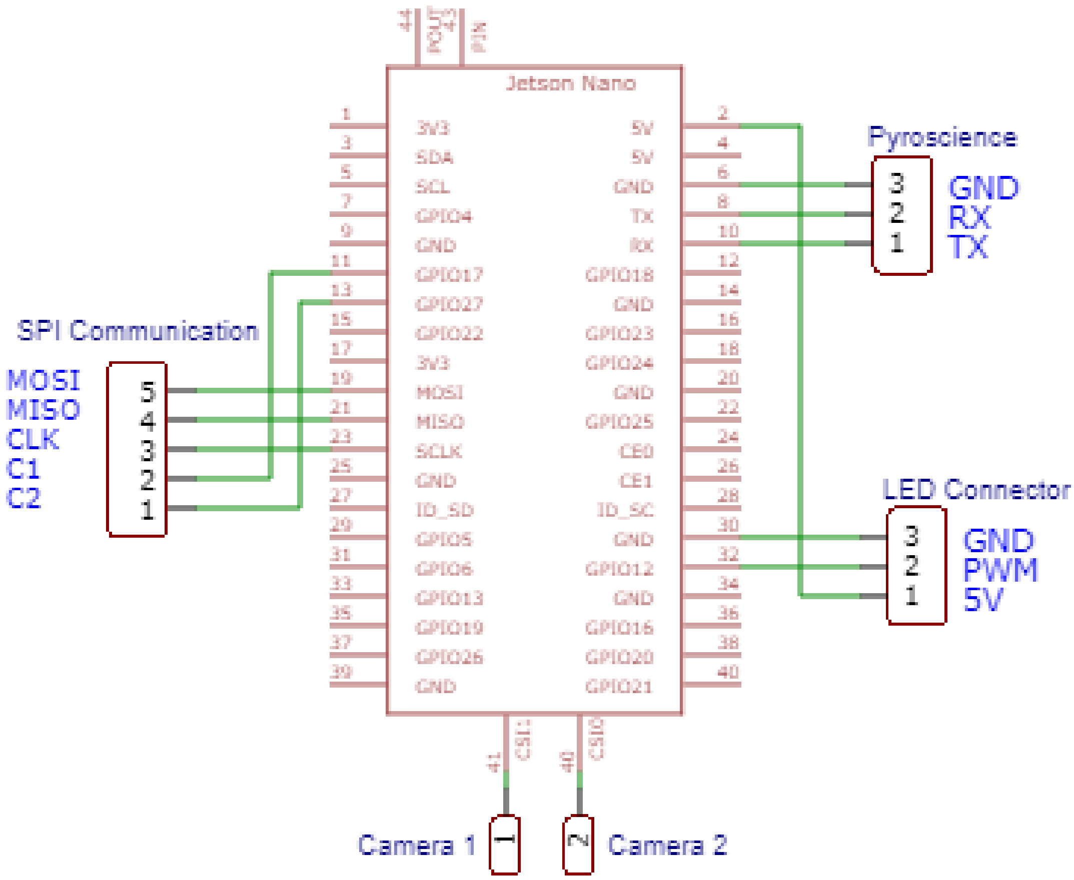

Figure 6.76: Electrical schematic of the connections made to the Jetson Nano.

6.5 Mounting

This section covers mounting solutions developed for all the previously detailed assemblies along with the pumps. These mounting solution are designed to both organize the individual assemblies along with properly positioning them in relation to each other.

6.5.1 Pump Rack

The pump rack secures the inlet and outlet pump of the water tunnel (refer to Section 6.2.8 and 5.11) in place. The rack with the two pumps mounted can be seen in Figure 6.77. Four M3 machine nuts are inserted into slots, shown in Figure 6.79, that are located in the rear side of the pump rack. A version of this pump rack with three pumps should be implemented in order to use the optional cooling system detailed in Section 6.2.11.

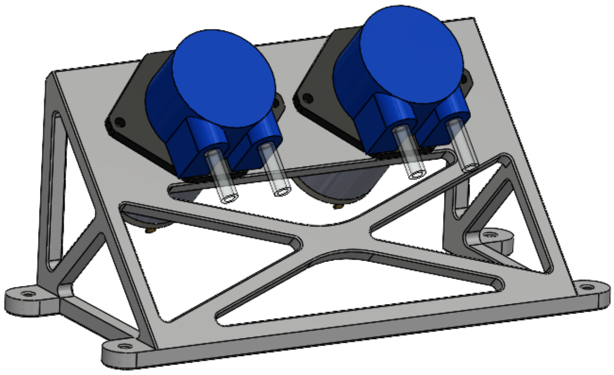

Figure 6.77: Pump rack assembly.

The motor side of the pumps are then inserted through 30 mm holes (0.5 mm gap between the perimeter of the hole and the motor) and then secured using four M3 machine screws into the rear nuts through holes shown in Figure 6.78.

The rack has four holes for secure surface mounting using M3 machine screws. The rack is designed to be FDM printed with the front face flush to the build platform and support structure added to the surface mounting points. The pump rack is designed with several support beams to allow for less printing filament to be used while still maintaining structural integrity.

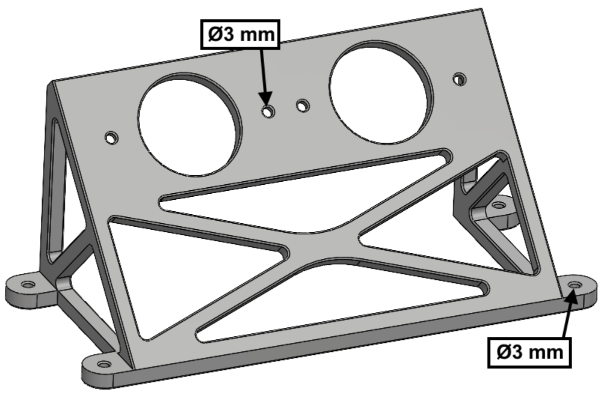

Figure 6.78: Front of the pump rack.

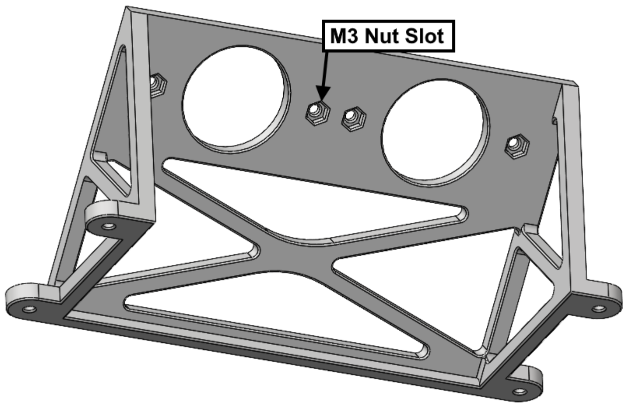

Figure 6.79: Rear side of the pump rack.

6.5.2 Main Mounting Plate

The "main mounting plate" is a 5 mm thick plate that connects the water tunnel assembly (Section 6.2, motor assembly (Section 6.3, electrical enclosure (Section 6.4.1), and pump rack assembly (Section 6.5.1) together as shown in Figure 6.80. The parts are connected using M3 machine screws connected through their surface mounting points and main plate which is tightened to M3 nuts in slots in the bottom side of the main plate. The mounting holes and bottom side nut slots can be seen in Figure 6.81 below.

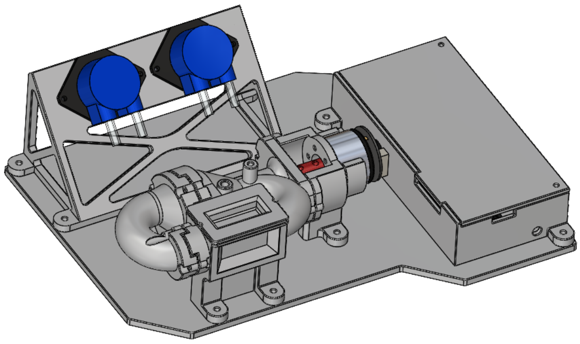

Figure 6.80: Main mounting plate with all associated sub-assemblies mounted to it.

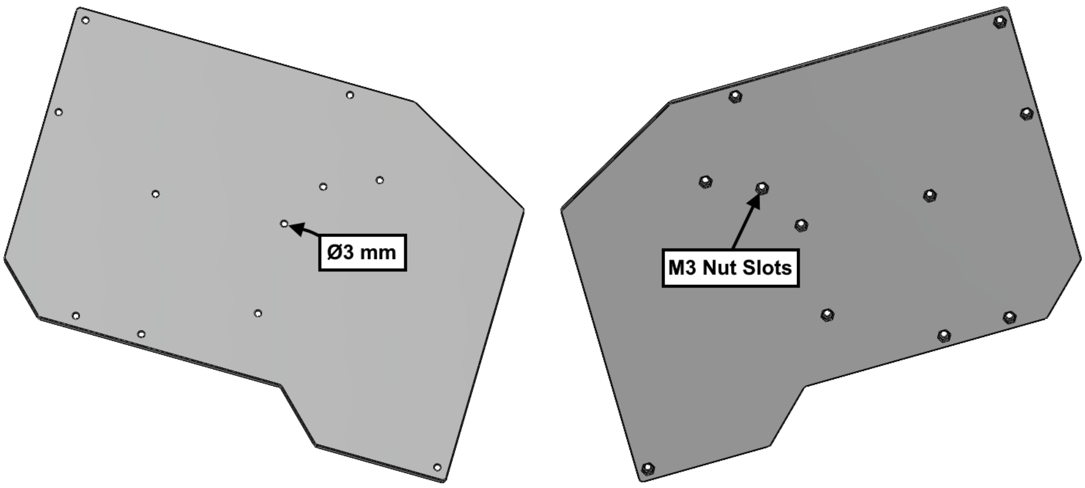

Figure 6.81: Top and bottom side of the main mounting plate.

6.5.3 Camera Tower and Jetson Mount

The mounting system detailed in this subsection can be seen pictured in Figure 6.82 to the right and consists of a mounting plate and a rack that positions the Jetson Nano in a way that allows the included 15 cm long CSI cables that comes pre-installed on the cameras (see Section 5.15) to reach the CSI camera-ports on the Jetson Nano developer kit.

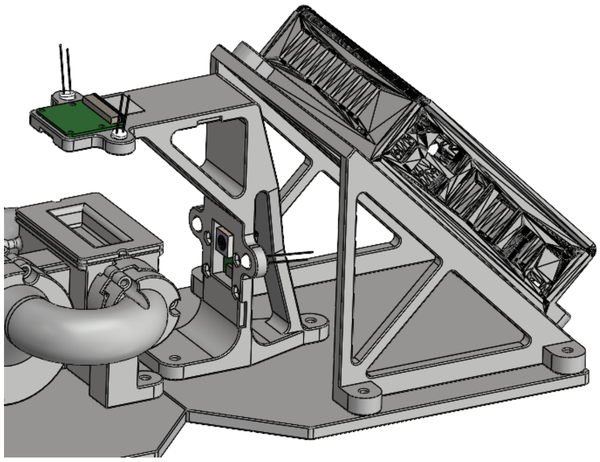

Figure 6.82: "Camera Tower and Jetson Mount" assembly.

The mounting plate is designed the same way as the main mounting plate as described in Section 6.5.2. The chamfered edge on the side of mounting plate is used for alignment and aligns with the identical edge of the main mounting plate.

The rack used to mount the case of the Jetson Nano developer kit (see Section 6.4.5) can be seen pictured in Figure 6.83 and 6.84 below. The Jetson Nano is fixed to the rack using two M3 machine screws that connect through the surface fasteners of its case and the related holes on the rack. The screws are fastened with two M3 nuts in slots located at the opposite side of the rack.

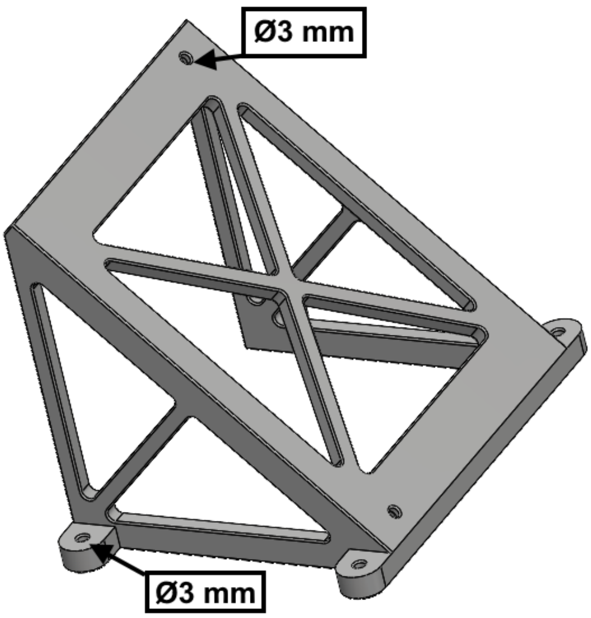

Figure 6.83: Rack used for mounting the Jetson Nano.

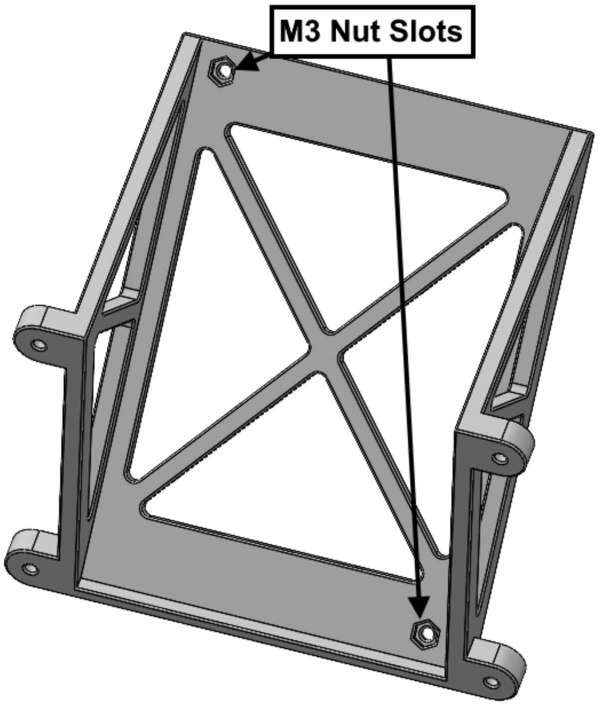

Figure 6.84: Back side of the rack used for mounting the Jetson Nano.

Chapter 7

Prototyping

A prototype of the developed system was manufactured in order to verify design elements and manufacturability. Several design flaws were identified and revised for the final version of the developed system described in Chapter 6. As such, some parts of the prototype detailed in this chapter does not reflect the latest revision of the system and will have to be re-manufactured at a later point to achieve full function of the system. The prototype system can be seen pictured in Figure 7.1.

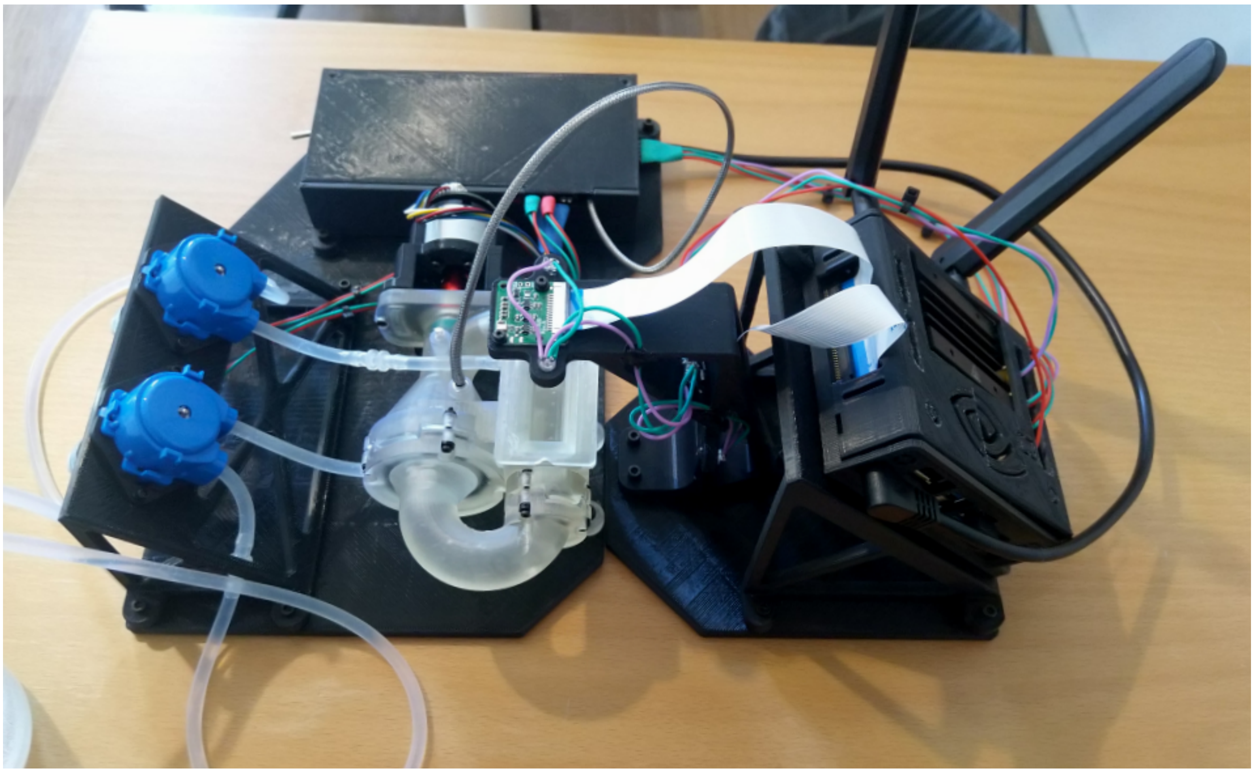

Figure 7.1: Complete prototype.

7.1 Resin Shrinkage and Warping

The prototype resin print of the water tunnel was both warped and smaller than the designed dimensions. Some measurements in comparison to the modeled dimension are shown in the list below.

- Modeled diameter of surface mount hole was 3mm, actual diameter of the prototype is 2.8mm
- Modeled thickness of feet was 6mm, actual thickness is 6.3 mm.
- Modeled diameter of M2.5 nut guides was 5mm, actual diameter is 4.5 4.8 varying between locations.

Due to the shrinkage and warping significant time had to be spent filing the parts with power tools and hand tools to fit them together. The M2.5 nuts were sanded down to decrease their diameter to allow them to fit into the shrunken guides. All screw holes were drilled out using appropriate drill sizes.

7.1.1 Calibrating the Printer

A test print using a cube of equal sides could be printed and then measured to check for shrinking and warping in the different printing axes of the printer. The resin printer could then be calibrated or the model scaled to limit or entirely remove the shrinkage and warping issues.

7.2 Electronic Enclosure

The finished implementation of the schematic shown detailed in Section 6.4.2 can be seen implemented in Figure 7.3 below. Some routing of cables were done underneath the motor drivers and can be seen in Figure 7.2.

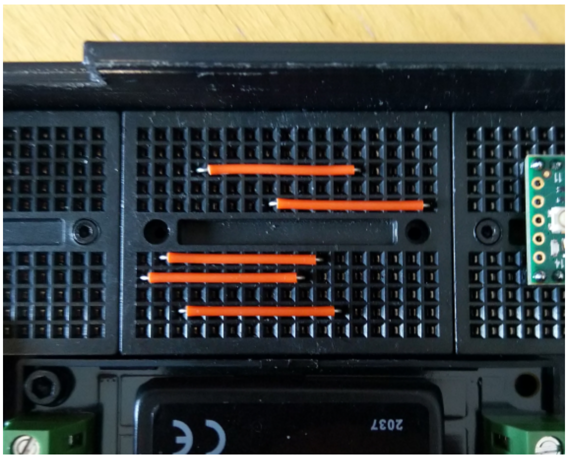

Figure 7.2: Connections made under the motor drivers in the electrical enclosure prototype.

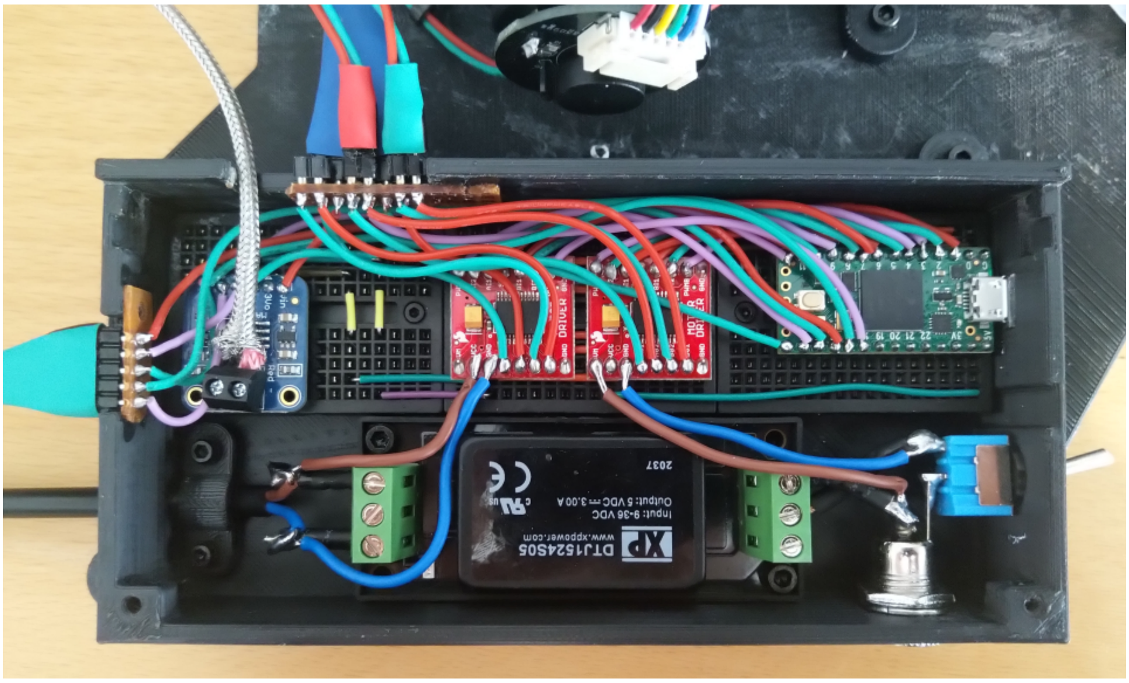

Figure 7.3: Finished electrical enclosure prototype.

7.3 Cables

The cables of the system uses the connector style pictured in Figure 7.4 to connect to the electrical enclosure and camera lighting. The cables are marked with a black permanent marker to show the correct orientation of the connector.

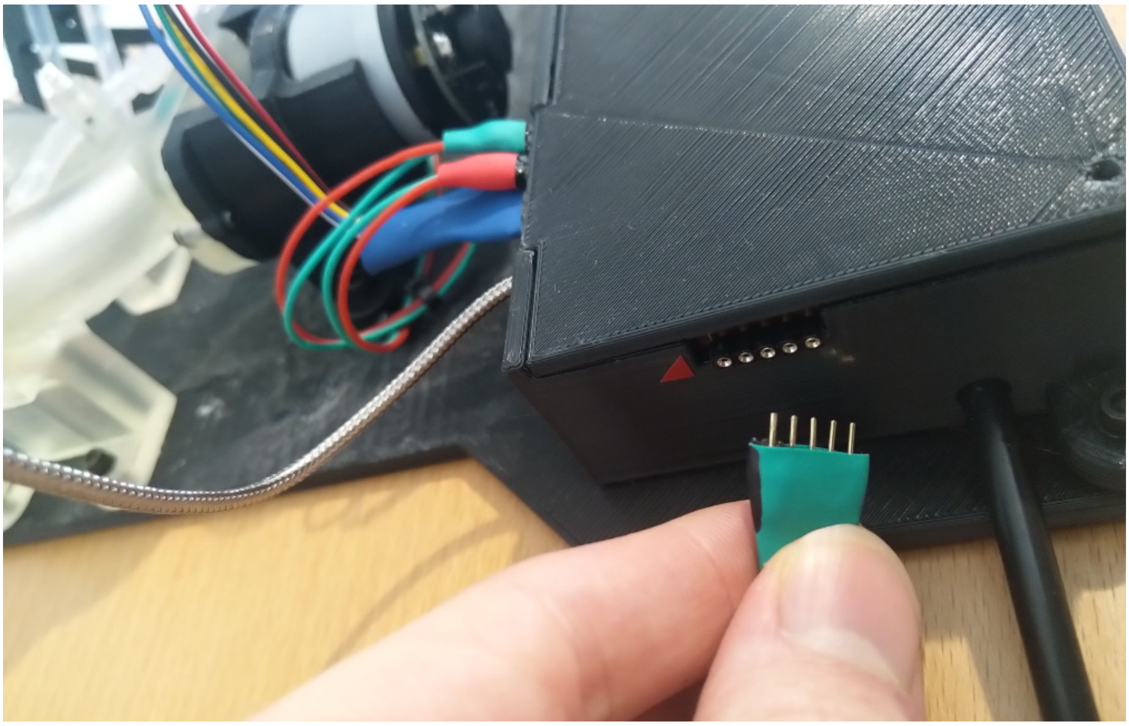

Figure 7.4: Connector style used between external components.

7.4 Camera Lighting

The camera lighting schematic detailed in section 6.4.4 can be seen implemented in Figure 7.5.

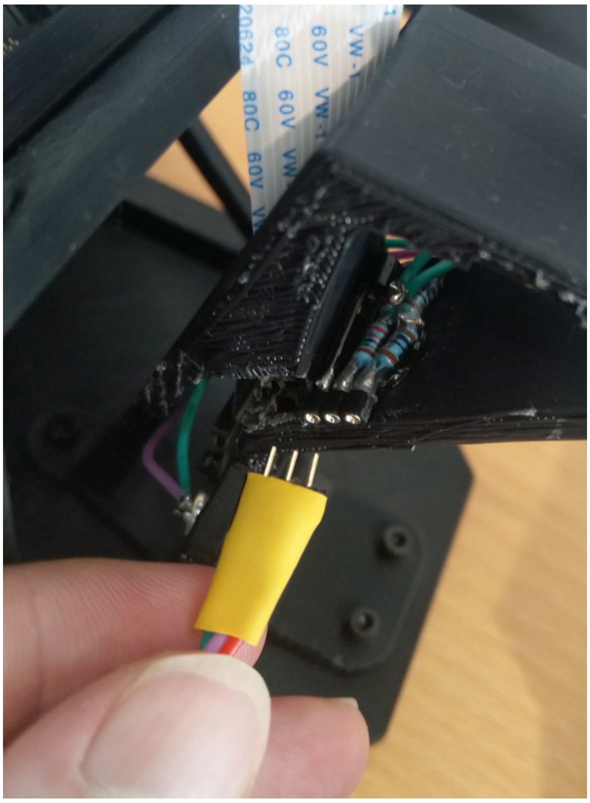

Figure 7.5: Camera lighting circuit and connector.

7.5 Prototype Volume

The internal volume of the hydraulic system of the prototype is ≈ 40.9 ml and was determined by the following method:

1. Place a glass of water of a scale.
2. Insert the inlet tube into the glass.
3. Zero the scale.
4. Completely fill the system by running the inlet pump.
5. Read the negative weight displayed on the scale and convert to milliliters.

The setup and result can be seen in Figure 7.6 to the right. This volume does not necessarily accurately represent the actual developed system due to the shrinkage and warping of the resin print described in Section 7.1.

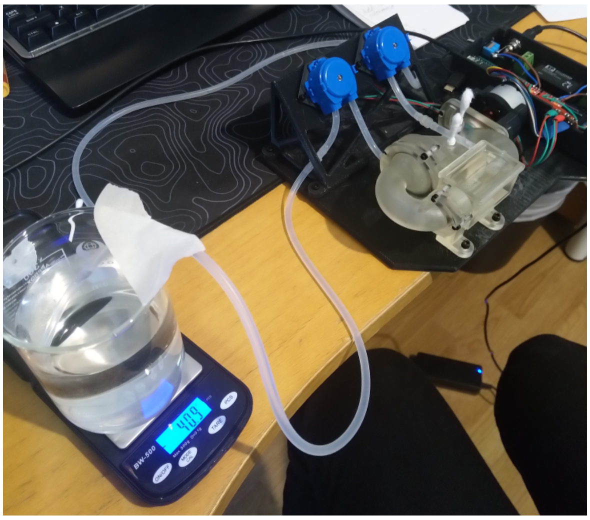

Figure 7.6: Internal volume of the prototype respirometry system.

Chapter 8

Software

This chapter covers the conceptualized and partly implemented control software of the system.

8.1 Impeller Regulation and Pump Control

The impeller RPM is regulated using a PI controller with the motor encoder data as input and the motor duty cycle as output. The PI controller uses the Arduino PID library and uses the "proportional on measurement" [4] selection for the proportional part of the regulation. This is done as the duty cycle of the motor is directly proportional to the RPM of the impeller. The PI controller was tuned to a proportional gain of 0.000001 and a integral gain of 0.1. Using this regulation the motor is able to almost instantly reach the target RPM assuming it is within the range of the motor. Velocities lower than ≈ 500 RPM are unstable as the motor is not able to reliably rotate against the friction of the system. The developed code handling this regulation along with the pump control of the system can be seen in Appendix B.1.

The direction and duty cycle of the motor and pumps are controlled using the following developed library code:

```
    /*
  MotorControl, a simple library to control basic
  functions of the TB6612FNG motor driver.
*/

#include "Arduino.h"
#include "MotorControl.h"

MotorControl::MotorControl(int I1, int I2, int PWMpin)
{
  pinMode(I1, OUTPUT);
  pinMode(I2, OUTPUT);
  pinMode(PWMpin, OUTPUT);
  _I1 = I1;
  _I2 = I2;
  _PWMpin = PWMpin;
}

void MotorControl::CW()
{
  digitalWrite(_I1, HIGH);
  digitalWrite(_I2, LOW);
}
```

```
void MotorControl::CCW()
{
  digitalWrite(_I1, LOW);
  digitalWrite(_I2, HIGH);
}

void MotorControl::BRAKE()
{
  digitalWrite(_I1, HIGH);
  digitalWrite(_I2, HIGH);
}

void MotorControl::COAST()
{
  digitalWrite(_I1, LOW);
  digitalWrite(_I2, LOW);
}

void MotorControl::DRIVE(int PWMvalue)
{
  analogWrite(_PWMpin, PWMvalue); //PWMvalue between 0 and 255
}
```

This code handles the relevant output pins of the TB6612FNG motor driver (see Section 5.9) and allows for easy direction turning using the CCW() and CW() functions standing for counter-clockwise and clockwise, relating to the rotation of the motor. And the duty cycle is easily controlled using the DRIVE() function.

8.2 Flow Control

The "OpenPIV" python software that uses particle image velocimetry to determine flow velocity could be used alongside suitable particles introduced into the hydraulic system to determine the flow velocity at different RPM values of the impeller. A script could be made to alternate the RPM until specific target flow velocities are determined. These flow velocities could then be specified later based on the recorded equivalent RPM value. Alternatively the data of the flow rates at different RPM values could be mapped together to be able to approximate the target flow rate using a the testing data.

8.3 Camera Lighting

The camera lighting can be controlled by setting the duty cycle of PWM pin 32 on the Jetson Nano developer kit. This pin has to be configured in the "Jetson-IO" program on the Jetson Nano in order to configure it as a PWM pin. The "CircuitPython" libraray can then be used to set the duty cycle value.

8.4 Temperature Reading

Temperature can be read from the thermocouple amplifier using the "Adafruit CircuitPython MAX31855" library.

8.5 Integrated Oxygen Logging

The oxygen and temperature data from the oxygen sensor can be read from the oxygen meter over UART as described in Section 5.12.1.

8.6 Fish Respirometry Calculations

If a ROS system was implemented to control the system the fish respirometry calculations could be integrated by using the "rosR" library to add R-code support to the system. The test data from the system could then be loaded into the R-package of the respirometry software "FishResp".

8.7 Configuration File

A configuration file is created at first launch of the system using the python code below. This code uses the functionality given by the "configparser" library.

```
# -----CONFIG FILE-----
config = configparser.ConfigParser()

if os.path.exists('config.ini') == False:
    config['Procedure Settings'] = {
        'start_flow_velocity_[cm/s]': '0.5',
        'end_flow_velocity_[cm/s]': '20',
        'flow_velocity_stepsize_[cm/s]': '0.5',
        'test_time_[min]': '20',
        'flush_time_[min]': '10',
        'flush_pump_strength_[0-255]': '100'
        }

    config['Maintenance'] = {
        'fill_time_[min]': '2',
        'flush_time_[min]': '5',
        'clean_time_[min]': '15',
        'drain_time_[min]': '3',
        'pump_strength_[0-255]': '100'
        }

    config['System Values'] = {
        'min_flow_velocity_[cm/s]': '0.5',
        'max_flow_velocity_[cm/s]': '20',
        'total_volume_[ml]': '40.8'
        }

    with open('config.ini', 'w') as configfile:
        config.write(configfile)
else:
    config.read('config.ini')
```

8.8 Miscellaneous Functions

8.8.1 Increment Value

The “increment” function shown below increments the first value in a given list object by one. This function takes advantage of the fact that list objects in python are “mutable”, which in effect means that if the list is passed into a function and then changed it will also be changed in the script that called it. This differs from an “immutable” object, such as an int, which would only be changed locally within the function.

```
def increment(value):
value[0] += 1
return value[0]
```

8.9 System Class

The “RespSystem” class, short for "Respirometry System" documented in this section contains several values and functions related to the operation of the respirometry system.
The values underneath the “states” comment refer to the different states of the respirometry system. The list “b” is used along with the “increment” function, explained in Section 8.8.1, in order to assign the different states to unique values.
The state machine reads the configuration file detailed in Section 8.7.

```
class RespSystem(config):
    def __init__(self):
        # Read values from configuration file
        maintenance = config['Maintenance']
        self.flush_time = maintenance['flush_time_[min]']
        self.clean_time = maintenance['clean_time_[min]']
        self.drain_time = maintenance['drain_time_[min]']
        self.maintenance_pump_PWM = maintenance['pump_strength_[0-255]']

        systemValues = config['System Values']
        self.min_flow_velocity = systemValues['min_flow_velocity_[cm/s]']
        self.max_flow_velocity = systemValues['max_flow_velocity_[cm/s]']
        self.total_volume = systemValues['total_volume_[ml]']

        # Initiate system variables
        self.inletPumpPWM = 0
        self.inletPumpDirection = 1 # 0 drains while 1 fills the system

        self.outletPumpPWM = 0
        self.outletPumpDirection = 0 # 0 drains while 1 fills the system

        self.impellerRPM = 0

        b = [0] #Counter used to assign unique values to states

        # states
        self.state_idle = increment(b) # idle mode of the system
        self.state_stop = increment(b) # fully stops the system

        # initial state
        self.state = self.state_idle

    def drain(self):
        self.inletPumpPWM = self.maintenance_pump_PWM
        self.inletPumpDirection = 0

        self.outletPumpPWM = self.maintenance_pump_PWM
        self.outletPumpDirection = 0

        self.impellerRPM = 0
```

8.10 AI Concepts

This section contains conceptualized AI solutions for the system.

8.10.1 3D Mapping of the Fish

Mapping the 3D position of the fish within the tank would allow one to look at the relative velocity of the fish in regards to oxygen expenditure rather than just the flow velocity itself.

The position of the fish could be obtained using simple image operations (with software such as OpenCV) following the directions below:

1. Make an image-filter that finds the boundaries of the fish.
2. Center of mass 2D operation on the two images.
3. Translate the pixel locations to their respective xy- and xz- planes.
4. Add the z to the xy-position or the y to the xz-postion to get the 3D xyz-position of the fish.

The following could be done to further find the direction vector of the fish:

1. Make an image-filter that finds the boundaries of the fish's eye(s) which are usually noticeably darker than the rest of the fish [15].
2. Center of mass 2D operation on the two images
3. Make a line through the x position of the mass-center of the eyes and find the two points that intersects with the previously established boundaries of the fish.
4. Find the center of the two points along the line.
5. Draw a vector from the center of the fish to the center of the two points to find the direction of the fish in the xy- and xz- plane.
6. Add the z to the xy-vecor or the y to the xz-vector to get the 3D xyz-vector of the fish.

The velocity of the fish could be found by sampling the direction vectors and dividing the position difference with the sampling time. Care should be taken to use a sampling frequency high enough to capture as much movement of the fish as possible.

8.10.2 Fish Exhaustion

If the fish is pushed to the back of the testing for a specified time the tests could be automatically ended or the flow velocity kept constant or lowered to prevent fully exhausting the fish. This could allow for a "set it and forget it" approach for determining the maximum flow rates that the fish can handle without fear of over-exhausting the fish.

8.11 Maintenance Operations

This section contains conceptualized instructions on how to properly operate maintenance functions of the system. These functions are not fully implemented into the system at the time of writing this report.

Note: Any of the processes described below can be manually stopped by left-clicking the "Stop" button in the GUI.

8.12 Filling Procedure

The filling procedure explained below is used to fill the system and make it ready for the main test operation.

1. Insert the intake and outtake tubes into the holding tank of the fish.

2. Open the "Maintenance" menu by left-clicking the "Maintenance" button in the main menu.
3. Left-click the "Fill" button in the "Maintenance" menu.
4. → The system will now begin filling for 2 minutes before automatically stopping.

As some air is usually left within the system after filling the following procedure should be followed to fully evacuate the remaining bubbles:

1. Left-click the "Air Removal" button in the "Maintenance" menu.
2. → The impeller will now start alternating the flow back and forward while the system will continue the filling operation.
3. Manually tilt the system approximately 20 degrees, raising the U-Tube side of the water tunnel.
4. → The remaining bubbles will be pushed into the testing chamber and escape the system,
5. Once the system is free of air bubbles, left-click the "Stop" button in the "Maintenance" menu.

The system is now ready for operation.

8.13 Cleaning Procedure

This section covers the cleaning procedure that should be carried out after testing has been concluded. Make sure the fish is not in the testing chamber before following the instructions below.

8.13.1 Flush

First the unclean water in the system is flushed out and replaced by clean water as detailed below.

1. Insert the intake tube into a container of clean water.
2. Insert the outtake tube into an empty container.
3. Open the "Maintenance" menu by left-clicking the "Maintenance" button in the main menu.
4. Left-click the "Flush" button in the "Maintenance" menu.
5. → The system will now begin flushing the system for 5 minutes before automatically stopping. The impeller will run during this process to ensure all the unclean water is washed out throughout the system.
6.

The system is now flushed and the cleaning process can be started.

8.13.2 Clean

Secondly, a cleaning solution is filled into the system as described below. If a solution that is not residue-free is used, and additional flush should be performed using clean water should be used as described in Section 8.13.1.

1. Insert the intake tube into a container of cleaning solution.
2. Make sure that the outtake tube is still in an empty container.
3. Left-click the "Clean" button in the "Maintenance" menu.
4. → The system will now begin cleaning the system for 15 minutes before automatically stopping. The impeller will run during this process to agitate the solution throughout the system.

8.13.3 Drain

Lastly the system is fully drained as described below.

1. Make sure that the outtake tube is still in an empty container.
2. Left-click the "Drain" button in the "Maintenance" menu.
3. → The system will now fully drain the system for 3 minutes before automatically stopping.

8.13.4 Suggested Procedure

Suggested cleaning procedure after testing is as follows:

1. Flush with water.
2. Clean with warm soapy water.
3. Flush with warm water.
4. Clean with an alcohol solution.

The "Flush" and "Clean" in the instructions above refers to the system operations described in Section 8.13.1 and 8.13.2. This suggested procedure will first clean away fat soluble contaminants using the soapy water followed by sterilization of the system with the alcohol solution.

8.13.5 Configuration

The fill, flush, clean, and drain time can be manually adjusted under the "Maintenance" section of the "config.ini" file (automatically created by the system at first launch) located in the main folder of the system. Note that a system restart is necessary for any changes made to the configuration file to come into effect.

Chapter 9

Conclusion

The conclusions made in this chapter are based of the "needs" and "wants" specified by the product description in Section 2.1.

9.1 Needs

3 cm long 1x1 cm testing chamber.

The testing chamber of the system is equal to this as detailed in Section 6.2.1.

See through walls on the top and side of the testing chamber

The water tunnel has see through walls as detailed in Section 6.2.

Temperature Control

An optional cooling loop has been developed for maintaining tank temperature in the internal water as detailed in Section 6.2.11.

Salt water compatible components

All components in direct contact with the internal hydraulic system are compatible with salt water.

Max internal volume of system under 100 ml.

The prototype version of the system had an internal volume of 40.9 ml as determined in Section 7.5.

Max flow rate of 20 cm/s

The pump of the respirometry system has been designed to deliver a flow rate of 20 cm/s as detailed in section 6.1.2. However, this rate has not been confirmed by real-world measurements.

Min flow rate of 0.5 cm/s.

The prototype system is able to deliver a minimum of 500 RPM (as mentioned in Section 8.1) to the impeller which is ten times lower than the rotational velocity that the impeller is designed to deliver 20 cm/s at. The actual flow speed at 500 RPM has not been measured or calculated.

Adjustable flow rate in 0.2 cm/s steps.

A method for potentially achieving this has been conceptualized as detailed in section 8.2. However no system has been implemented.

Material selection for the system to prevent oxygen storage.

This point has not been explored in this report.

9.2 Wants

AI monitoring

AI monitoring of the fish to determine position and direction has been conceptualized as detailed in Section 8.10.1, but no system has been implemented.

AI control

AI control of the system based on the exhaustion of the fish has been loosely conceptualized as described in Section 8.10.2, but no system has been implemented.

Chapter 10

Discussion

Due to there only being one resin printer available at school that had high demand during the prototyping process, the printed parts was delayed a full week, making it approx one and a half week upon requesting the print to actually having it ready. This made it difficult to receive iterations in a timely manner which in turn resulted in only one iteration of the system being produced during this thesis.

10.1 Pressure Differential

The oxygen sensor is currently placed in the pump section of the system instead of the testing chamber itself. This means that the pressure where the oxygen is measured differs from where the fish itself is (lower pressure as it is placed behind the impeller). This could potentially have an effect on the accuracy of the measurements taken.

10.2 Flow Rectifying Grid Structure

An hexagonal grid was chosen for the flow rectifying parts of the system as it is the grid structure with the highest open area to perimeter area ratio. However, as the testing chamber cross-section is square in shape the grid structure is unable to cover the entire area. Therefore a different grid structure that is able to fully cover the cross sectional area might be superior.

10.3 Possibility of Connecting Wrong Voltage

The power jack of the Jetson Nano developer kit has the same plug dimensions as the 12 V power supply of the system. If the power cable used for carrying 12 V to the system is accidentally connected into the Jetson Nano it may be irreparably damaged as it does not have an on-board 5 V power regulator. This potential problem was identified when the 12 V power supply was selected, but as other available power supplies (from the vendor at the time of purchase) with different sized connectors had a lower wattage than the one selected they were not considered due to uncertainties regarding the total power usage of the system.

If a power supply with a different sized connector is sourced and implemented, this potential user-problem could be avoided all together.

Chapter 11

For the Future

11.1 Custom PCB

A custom PCB for connections made in the electronic enclosure (see Section 6.4.1) could be developed to greatly reduce assembly time.

11.2 Remote Control

Set up a rosbridge server with HMI allowing for remote control of the system through browsers on remote devices such as phones or laptops. This could allow for full control of the system without the necessity of connecting a mouse and monitor to the Jetson Nano.

11.3 Regulated Cooling

A controller could be programmed to regulate the cooling of the system when using the optional cooling tube (Section 6.2.11). This would allow the usage of a cooling liquid with a lower temperature than the tank itself, which could provide more effective cooling than what achieved with the tank water alone.

11.4 Fully Develop the Control Software

Due to the time limitation of the project, the control software of the system was only partly implemented. For full functionality of the system, the conceptualized software described in Chapter 8 will need to be developed.

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Appendix A

Project Description

"Metabolism in small fish"

"Bachelor/Master"

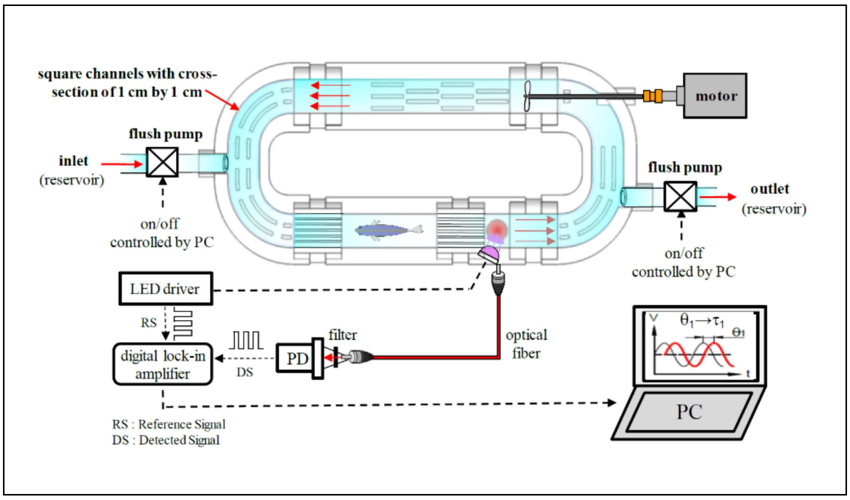
Short Introduction

The first months in the life of a fish are tough and critical for survival. These baby fish are more vulnerable to extreme changes in environmental factors like temperature or salinity, as they are not yet equipped with the well-developed physiological machinery they have as adults. They are also not great swimmers and initially cannot swim against currents. Understanding how environmental parameters influence larval physiology and swimming behavior is essential for making predictions about future impacts of climate-driven changes (e.g. we need to estimate the highest temperatures larvae can withstand in order to assess the impact of heatwaves). Unfortunately, there is a big lack in equipment available to make this kind of studies in small fish. We need to work with relatively small volumes of water (e.g. 2-100 mL), low flow rates and with materials that are compatible with living animals. Therefore, this project aims to design and test a device to measure oxygen consumption in larval fish while they swim (i.e. swimming respirometer), based on commercially available designs for larger fish.

Dr Marta Moyano, Assoc Prof at the Department of Natural Sciences UiA, will co-supervise this project together with other faculty at UiA Grimstad. She has extensive experience in experimental work with larval fish and also in collaborating with engineers to design prototypes for research (e.g. video systems for long-term recording or swimming chambers).

Keywords

- Mechanical engineering
- Electrical engineering
- Fluid dynamics
- Control Theory



UiA Faculty of Engineering and Science

Project Description

So far there is only one type of swimming respirometer available in the market, and that is for big fish (i.e. https://vimeopro.com/loligosystems/loligo-systems-videos/video/72805729). The issues with downscaling this to larval size (which may be 10 to 30 mm in size) mainly group on two aspects:

- difficulty of building a system in which one can get a signal in oxygen consumption (i.e. volume needs to be small enough so that we can get a decreasing signal in oxygen due to larval consumption),
- building this device with controlled laminar flow rates that can be fine-tuned (e.g. starting at 0.5 cm/s and increasing in 0.2 cm/s steps).
- type of material selection to prevent oxygen storage, something that would interfere with the measurements.

Recently one paper has been published in which they proposed a very reduced version of this swimming respirometer for zebrafish larvae (Huang et al. 2020, https://doi.org/10.3390/s20185088) using a 3D printer. So this will be a great starting point for this project!

This project will have two objectives, which build on each other:

1. Design and build a swimming chamber for fish larvae. This apparatus will likely have a donut shape as that on the image. A propeller connected to a motor will create a water flow that will be then straightened to enter the chamber where the fish will be. This chamber could be around 10-50 mL. Ideally this system (or at least the chamber where the fish is) should be transparent so that one can make video recording if needed. Once the prototype is up and running, testing with fish will be done always together with Marta.
2. Design and implement oxygen measurements within the swimming chamber. The design will need to be carefully done taking into consideration size of the chamber, and oxygen consumption rates at different temperatures (already available). Marta has a respiration system from Pyroscience (https://www.pyroscience.com/en/), which could be coupled to this system. Once the design is advanced, testing with fish will be done always together with Marta. T

The results from this project will be highly relevant for a large number of fish researcher. Therefore, the student is encouraged to publish the results of this project in a scientific journal, should this project successfully accomplish all objectives

Contact information:

Full name	E-mail address	Phone number
Marta Moyano	marta.moyano@uia.no	38142394

Appendix B

Code

B.1 Impeller Regulation and Pump Control

```
#define ENCODER_OPTIMIZE_INTERRUPTS
// The above line forces the encoder library to default to using interrupt ...
   pins rather than using attachInterrupt leading to a more optimized code
#include <Encoder.h>
#include <MotorControl.h>
#include <PID_v1.h>

// ----PINS----
// Pump 1
int pump1_I1 = 1;
int pump1_I2 = 2;
int pump1_PWM = 3;

// Pump 2
int pump2_I1 = 6;
int pump2_I2 = 5;
int pump2_PWM = 4;

// Pump 3
int pump3_I1 = 7;
int pump3_I2 = 8;
int pump3_PWM = 9;

// Impeller Motor
int impeller_I1 = 16;
int impeller_I2 = 15;
int impeller_PWM = 14;

// Impeller Encoder
int impellerEnc_C2 = 17;
int impellerEnc_C1 = 18;

// SPI Communication
int chipSelect = 10;
int MOSIpin = 11;
int MISOpin = 12;
int CLKpin = 13;

// Other
int standbyPin = 0;

// ----CONSTANTS----
int encoderTicks = 45; //Number of ticks per rotation of the motor shaft
```

```
int revsPerCalc = 1; //Number of revolutions before RPM calculation is made
double impeller_Kp = 0.000001;
double impeller_Ki = 0.1;
double impeller_Kd = 0;

// ----INITIATE----
long impellerPos = -999;
long oldImpellerPos = 0;
double impellerRPM = 0;
double oldImpellerRPM = 0;
unsigned long timeCurrent = 0;
unsigned long timeElapsed = 0;
unsigned long timeOld = millis();
double impellerPWM = 0;
double impellerRPM_setpoint = 0;
int inletPumpPWM = 0;
int outletPumpPWM = 0;

Encoder impellerEnc(impellerEnc_C1,impellerEnc_C2);
MotorControl impeller(impeller_I1, impeller_I2, impeller_PWM);
PID impellerPID(&impellerRPM, &impellerPWM, &impellerRPM_setpoint, ...
    impeller_Kp, impeller_Ki, impeller_Kd, P_ON_M, DIRECT);
MotorControl outletPump(pump1_I1, pump1_I2, pump1_PWM);
MotorControl inletPump(pump2_I1, pump2_I2, pump2_PWM);


void setup() {
  Serial.begin(9600);
  impellerEnc.write(0);
  digitalWrite(standbyPin, HIGH);

  impeller.CW(); //CW is positive
  impellerRPM_setpoint = 0;

  impellerPID.SetMode(AUTOMATIC);

  inletPumpPWM = 100; //0 to 255, 100 is nice and slow
  inletPump.CCW(); //CW = pump out, CCW = pump in
  inletPump.DRIVE(inletPumpPWM);

  outletPumpPWM = 120;
  outletPump.CW(); //CW = pump out, CCW = pump in
  outletPump.DRIVE(outletPumpPWM);


}

void loop() {

  // ----PID----
  impellerPID.Compute();
  impellerPWM = constrain(impellerPWM, 0, 255);
  impeller.DRIVE(impellerPWM);

  impellerPos = impellerEnc.read();
  if (abs(impellerPos) >= (encoderTicks*revsPerCalc))
  {
    impellerEnc.write(0);
    timeCurrent = millis();
    timeElapsed = timeCurrent - timeOld;
    impellerRPM = (1000*60*revsPerCalc)/(timeElapsed);
```

```
    timeOld = timeCurrent;


  }

  if (impellerRPM != oldImpellerRPM) {
    Serial.print("Impeller RPM = ");
    Serial.print(impellerRPM);
    Serial.println();
    Serial.print("Impeller PWM = ");
    Serial.print(impellerPWM);
    Serial.println();
    oldImpellerRPM = impellerRPM;
  }

}
```

Appendix C

Calculations

C.1 Impeller Calculations

```
clc; clear;

%% System Values
N = 5000; %RPM, safety added
%N = 427;
%H = 10.28e-3; %m, Pump head
H = 0.1; %m, Pump head
v = 0.2; %m/s, fluid velocity
eta = 0.85; %Hydraulic efficiency
g = 9.81; %m/s^2, gravitational acceleration

%% Hub Ratio and Number of Blades
Q = v*0.01; %m^3/s
N_s = (3.65*N*sqrt(Q))/(H^(3/4))

%Resulting values after referring to relevant table
D_d = 0.4;
z = 2;


%% Diameter
%Outer Diameter Checks
%D_o_allowable = sqrt(Q*60)*[0.08, 0.1] %m
D_o_optimal = sqrt(1/(1-D_d^2))*nthroot((Q/N), 3)*[4, 4.6] %m

D_o_allowable = [2*sqrt(Q/(pi*0.08*nthroot((Q*N^2), 3)*(1-D_d^2))), ...
    2*sqrt(Q/(pi*0.06*nthroot((Q*N^2), 3)*(1-D_d^2)))] %m

%Chosen Diameter
D_o = 0.0322;

%Hub Diameter and Clearance
D_h = D_d*D_o %m
%delta = 0.001*D_o %m
delta = 0.01*D_o %m %increased tolerance to allow for easier manufacturing
D_imp = D_o + 2*delta; %m, internal diameter of the tube the impeller sits in

%Section Diameters
%D_1 = D_h + [0.03, 0.05]*D_h
D_1 = D_h + 0.04*D_h %0.4 chosen
D_3 = D_o*sqrt(((1+D_h)^2)/2)
D_2 = D_1 + (D_3-D_1)/2
D_5 = D_o - 0.04*D_o
```

```
D_4 = D_3 + (D_5-D_3)/2



%% Chord Length
K_H = H/(D_o^2*(N/60)^2);

t_h = D_h*pi/z; %m
t_1 = D_1*pi/z; %m
t_2 = D_2*pi/z; %m
t_3 = D_3*pi/z; %m
t_4 = D_4*pi/z; %m
t_5 = D_5*pi/z; %m
t_o = D_o*pi/z; %m


ratio_o = 5.95*K_H;
%ratio_h = ratio_o*[1.25, 1.30];
ratio_h = ratio_o*1.30; %1.30 chosen
ratio_1 = 0.6;
ratio_2 = 0.6;
ratio_3 = 0.6;
ratio_4 = 0.5;
ratio_5 = 0.4;

chord_h = ratio_h*t_h;
chord_1 = ratio_1*t_1;
chord_2 = ratio_2*t_2;
chord_3 = ratio_3*t_3;
chord_4 = ratio_4*t_4;
chord_5 = ratio_5*t_5;
chord_o = ratio_o*t_o;


%% Vane Angle
v_z = 4*Q/(pi*(D_o^2-D_h^2)); %m/s
omega = 2*pi*N/60; %rad/s

%Hub Diameter
u_h = pi*D_h*N/60; %m/s
v_u_h = 2*g*H/(omega*eta*D_h); %m/s

beta_hub_inlet = atand(v_z/u_h) %degrees
beta_hub_outlet = atand(v_z/(u_h-v_u_h)) %degrees

%Section 1 Diameter
u_1 = pi*D_1*N/60; %m/s
v_u_1 = 2*g*H/(omega*eta*D_1); %m/s

beta_1_inlet = atand(v_z/u_1) %degrees
beta_1_outlet = atand(v_z/(u_1-v_u_1)) %degrees

%Section 2 Diameter
u_2 = pi*D_2*N/60; %m/s
v_u_2 = 2*g*H/(omega*eta*D_2); %m/s

beta_2_inlet = atand(v_z/u_2) %degrees
beta_2_outlet = atand(v_z/(u_2-v_u_2)) %degrees

%Section 3 Diameter
u_3 = pi*D_3*N/60; %m/s
```

```
v_u_3 = 2*g*H/(omega*eta*D_3); %m/s

beta_3_inlet = atand(v_z/u_3) %degrees
beta_3_outlet = atand(v_z/(u_3-v_u_3)) %degrees

%Section 4 Diameter
u_4 = pi*D_4*N/60; %m/s
v_u_4 = 2*g*H/(omega*eta*D_4); %m/s

beta_4_inlet = atand(v_z/u_4) %degrees
beta_4_outlet = atand(v_z/(u_4-v_u_4)) %degrees

%Section 5 Diameter
u_5 = pi*D_5*N/60; %m/s
v_u_5 = 2*g*H/(omega*eta*D_5); %m/s

beta_5_inlet = atand(v_z/u_5) %degrees
beta_5_outlet = atand(v_z/(u_5-v_u_5)) %degrees


%Outer Diameter
u_o = pi*D_o*N/60; %m/s
v_u_o = 2*g*H/(omega*eta*D_o); %m/s

beta_outer_inlet = atand(v_z/u_o) %degrees
beta_outer_outlet = atand(v_z/(u_o-v_u_o)) %degrees
```

C.1.1 Results

The resulting values from the calculations above can be seen in Table C.1 and C.2 below.

Table C.1: Impeller calculation results (PART 1/2).

Symbol	"800RPM" Motor	"10kRPM" Motor	[Unit]
Q	0.002	$\leftarrow$	$[m^3/s]$
N_s	≈ 2159	≈ 4589	$[-]$
$D_{o_{allowable}}$	$72.8 \sim 84.1$	$32.1 \sim 37.0$	$[mm]$
$D_{o_{optimal}}$	$73.0 \sim 84.0$	$32.2 \sim 37.0$	$[mm]$
D_h	-	12.9	$[mm]$
δ	-	≈ 0.3	$[mm]$
D_1	-	13.4	$[mm]$
D_2	-	18.2	$[mm]$
D_3	-	23.1	$[mm]$
D_4	-	27.0	$[mm]$
D_5	-	30.9	$[mm]$
K_H	-	0.0139	$[-]$
t_h	-	20.2	$[mm]$
t_1	-	21.0	$[mm]$
t_2	-	28.6	$[mm]$
t_3	-	36.2	$[mm]$
t_4	-	42.4	$[mm]$
t_5	-	48.6	$[mm]$
t_o	-	50.6	$[mm]$
l_o/t_o	-	0.0826	$[-]$
l_h/t_h	-	0.1074	$[-]$
l_h	-	2.2	$[mm]$
l_1	-	12.6	$[mm]$
l_2	-	17.2	$[mm]$
l_3	-	21.7	$[mm]$
l_4	-	21.2	$[mm]$
l_5	-	19.4	$[mm]$
l_o	-	4.2	$[mm]$
v_z	-	≈ 2.92	$[m/s]$
ω	-	≈ 523.60	$[rad/s]$

Table C.2: Impeller calculation results (PART 2/2).

Symbol	"800RPM" Motor	"10kRPM" Motor	[Unit]
u_{hub}	-	≈ 3.37	$[m/s]$
$v_{u_{hub}}$	-	≈ 0.34	$[m/s]$
$\beta_{hub_{inlet}}$	-	≈ 40.93	$[degrees]$
$\beta_{hub_{outlet}}$	-	≈ 43.98	$[degrees]$
u_1	-	≈ 3.51	$[m/s]$
v_{u_1}	-	≈ 0.33	$[m/s]$
$\beta_{1_{inlet}}$	-	≈ 39.82	$[degrees]$
$\beta_{1_{outlet}}$	-	≈ 42.62	$[degrees]$
u_2	-	≈ 4.77	$[m/s]$
v_{u_2}	-	≈ 0.24	$[m/s]$
$\beta_{2_{inlet}}$	-	≈ 31.49	$[degrees]$
$\beta_{2_{outlet}}$	-	≈ 32.84	$[degrees]$
u_3	-	≈ 6.04	$[m/s]$
v_{u_3}	-	≈ 0.19	$[m/s]$
$\beta_{3_{inlet}}$	-	≈ 25.84	$[degrees]$
$\beta_{3_{outlet}}$	-	≈ 26.57	$[degrees]$
u_4	-	≈ 7.07	$[m/s]$
v_{u_4}	-	≈ 0.16	$[m/s]$
$\beta_{4_{inlet}}$	-	≈ 22.48	$[degrees]$
$\beta_{4_{outlet}}$	-	≈ 22.96	$[degrees]$
u_5	-	≈ 8.09	$[m/s]$
v_{u_5}	-	≈ 0.14	$[m/s]$
$\beta_{5_{inlet}}$	-	≈ 19.86	$[degrees]$
$\beta_{5_{outlet}}$	-	≈ 20.19	$[degrees]$
u_{outer}	-	≈ 8.43	$[m/s]$
$v_{u_{outer}}$	-	≈ 0.14	$[m/s]$
$\beta_{outer_{inlet}}$	-	≈ 19.13	$[degrees]$
$\beta_{outer_{outlet}}$	-	≈ 19.42	$[degrees]$

Appendix D

Data Sheets and Component Data

D.1 Project Description

JETSON NANO DEVELOPER KIT

DA_09402_004 | January 15, 2020

User Guide

DOCUMENT CHANGE HISTORY

DA_09402_004

Version	Date	Authors	Description of Change
1.0	March 18, 2019	plawrence	Initial release
1.1	July 8, 2019	plawrence	Updates concurrent with Jetson Linux Driver Package release 32.2. Added and corrected carrier board information; added information about NVIDIA Container Runtime; added information about first boot configuration process.
1.2	January 7, 2020	ssheshadri	Updates concurrent with Jetson Linux Driver Package release 32.3.1. Added references to VPI.
1.3	January 15, 2020	ssheshadri	Documentation added for rev B01.

NOTE

Welcome to the NVIDIA Jetson platform! There two key things you should do right away:

1. Sign up for the NVIDIA Developer Program – this enables you to ask questions and contribute on the NVIDIA Jetson Forums, gives access to all documentation and collateral on the Jetson Download Center, and more.
2. Read this User Guide! After that, check out these important links:
   - Jetson FAQ – Please read the FAQ.
   - Support Resources – This web page links to important resources, including the Jetson Forum and the Jetson Ecosystem page.
   - NVIDIA Jetson Linux Driver Package Developer Guide – Jetson Linux Driver Package is a key component of the Jetson platform, and provides the sample filesystem for your developer kit. Comprehensive documentation may be found in the *Developer Guide*.

Thanks,

The NVIDIA Jetson team

TABLE OF CONTENTS

DEVELOPER KIT SETUP AND HARDWARE

The NVIDIA® Jetson Nano™ Developer Kit is an AI computer for makers, learners, and developers that brings the power of modern artificial intelligence to a low-power, easy-to-use platform. Get started quickly with out-of-the-box support for many popular peripherals, add-ons, and ready-to-use projects.

A Jetson Nano Developer Kit includes a non-production specification Jetson module (P3448-0000) attached to a reference carrier board (P3449-0000). This user guide covers two revisions of the developer kit:

- The latest Jetson Nano Developer Kit (part number 945-13450-0000-100), which includes carrier board revision B01.
- The original Jetson Nano Developer Kit (part number 945-13450-0000-000), which includes carrier board revision A02.

Your carrier board revision is the last three characters of the 180-level part number, which is printed the underside of the carrier board. Your Jetson Nano Developer Kit part number is printed on the developer kit box.

Note	**The B01 revision carrier board is compatible with the production specification Jetson Nano module. The A02 revision carrier board is not.** **Both revisions of the carrier board are described in this user guide.**

Jetson Nano is supported by the comprehensive NVIDIA® JetPack™ SDK, and has the performance and capabilities needed to run modern AI workloads. JetPack includes:

- Full desktop Linux with NVIDIA drivers
- AI and Computer Vision libraries and APIs
- Developer tools
- Documentation and sample code

INCLUDED IN THE BOX

- A Jetson non-production Jetson Nano module (P3448-0000) with heatsink
- A reference carrier board (P3449-0000)
- A small paper card with quick start and support information
- A folded paper stand for the developer kit

DEVELOPER KIT SETUP

Before using your developer kit, you need to set up a microSD card with the operating system and JetPack components. The simplest method is to download the microSD card image and follow instructions found in Getting Started with Jetson Nano Developer Kit.

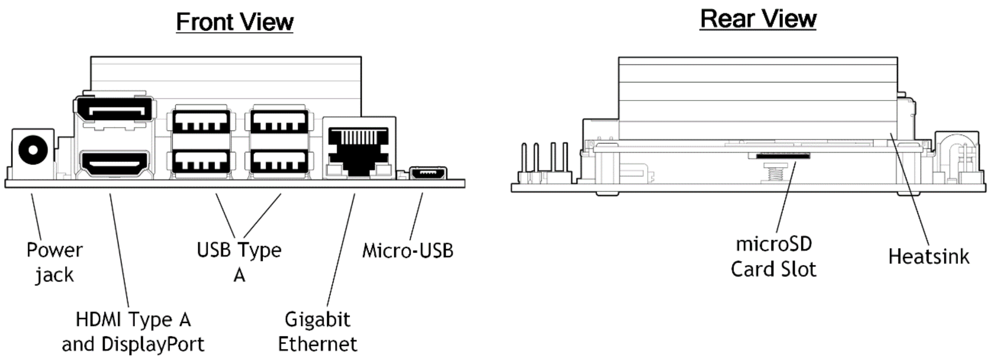
In summary:

- You need a 16 GB or larger UHS-1 microSD card, HDMI or DP monitor, USB keyboard and mouse, and 5V⎓2A Micro-USB power supply.
- Download the image and write it to the microSD card.
- Insert the microSD card into the slot under the Jetson Nano module, then attach the display, keyboard, mouse, and Ethernet cable or wireless networking adapter.
- Connect the Micro-USB power supply. The developer kit powers on automatically.

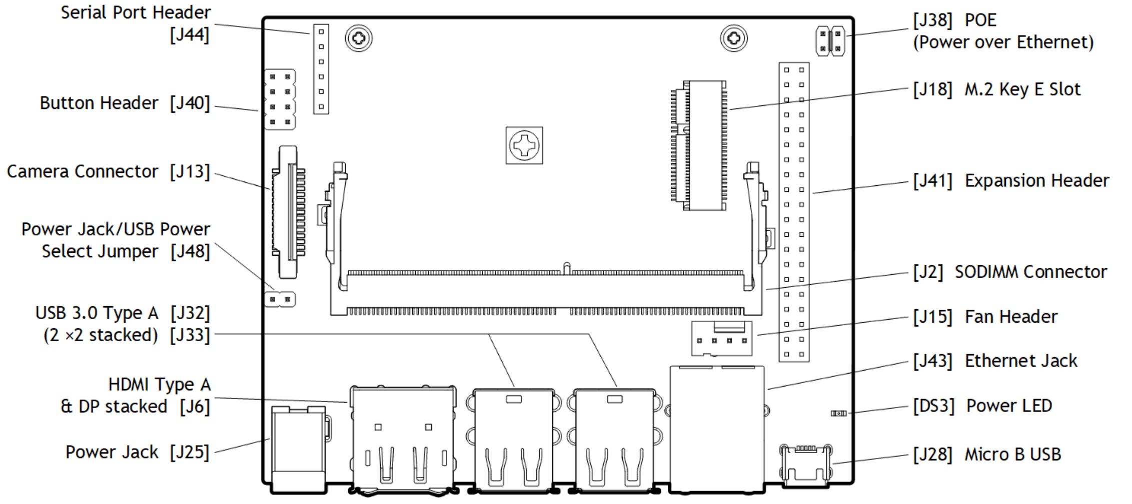
For alternative methods, see How to Install JetPack, below.

DEVELOPER KIT INTERFACES

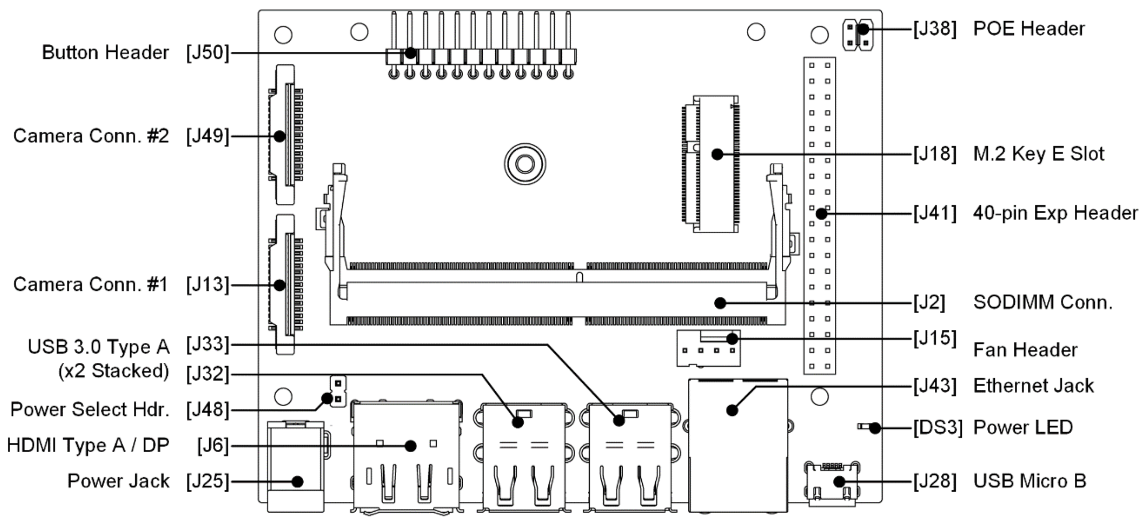
Developer kit module and carrier boards: front and rear views



Developer kit carrier boards: rev A02 top view



Developer kit module and carrier board: rev B01 top view



Interface Details

This section highlights some of the Jetson Nano Developer Kit interfaces. See the *Jetson Nano Developer Kit Carrier Board Specification* for comprehensive information.

Module

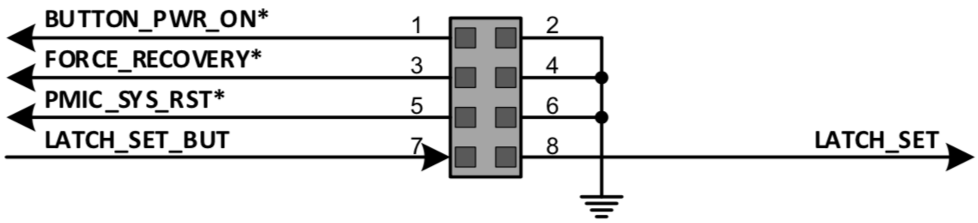
- [J501] Slot for a microSD card.

- The passive heatsink supports 10W module power usage at 25° C ambient temperature. If your use case requires additional cooling, you can configure the module to control a system fan. See the Jetson Nano Supported Component List for fans that have been verified for attachment to the heatsink.

Carrier Board

- [DS3] Power LED; lights when the developer kit is powered on.
- [J2] SO-DIMM connector for Jetson Nano module.
- [J6] HDMI and DP connector stack.
- [J13] Camera connector; enables use of CSI cameras. Jetson Nano Developer Kit works with IMX219 camera modules, including Leopard Imaging LI-IMX219-MIPI-FF-NANO camera module and Raspberry Pi Camera Module V2.
- [J15] 4-pin fan control header. Pulse Width Modulation (PWM) output and tachometer input are supported.
- [J18] M.2 Key E connector can be used for wireless networking cards; includes interfaces for PCIe (x1), USB 2.0, UART, I2S, and I2C.

  To reach J18 you must detach the Jetson Nano module.
- [J25] Power jack for 5V⎓4A power supply. (The maximum supported continuous current is 4.4A.) Accepts a 2.1×5.5×9.5 mm plug with positive polarity.
- [J28] Micro-USB 2.0 connector; can be used in either of two ways:
  - If J48 pins are not connected, you can power the developer kit from a 5V⎓2A Micro-USB power supply.
  - If J48 pins are connected, operates in Device Mode.
- [J32 and J33] are each a stack of two USB 3.0 Type A connectors. Each stack is limited to 1A total power delivery. All four are connected to the Jetson Nano module via a USB 3.0 hub built into the carrier board.
- [J38] The Power over Ethernet (POE) header exposes any DC voltage present on J43 Ethernet jack per IEEE 802.3af.
- [J40] **Carrier board rev A02 only**: 8-pin button header; brings out several system power, reset, and force recovery related signals (see the following diagram).



  - Pins 7 and 8 disable auto power-on.
  - Pins 1 and 2 initiate power-on if auto power-on is disabled.
  - Pins 5 and 6 reset the system.

  - Pins 3 and 4 put the developer kit into Force Recovery Mode if they are connected when it is powered on.
- [J41] 40-pin expansion header includes:
  - Power pins.

    Two 3.3V power pins and two 5V power pins. These are not switchable; power is always available when the developer kit is connected to power.

    Two 5V pins can be used to power the developer kit at 2.5A each.
  - Interface signal pins.

    All signals use 3.3V levels.

    By default, all interface signal pins are configured as GPIOs, except pins 3 and 5 and pins 27 and 28, which are I2C SDA and SCL, and pins 8 and 10, which are UART TX and RX. L4T includes a Python library, `Jetson.GPIO`, for controlling GPIOs. See `/opt/nvidia/jetson-gpio/doc/README.txt` on your Jetson system for details.

    L4T includes the `jetson-io` utility to configure pins for SFIOs. See "Configuring the 40-pin Expansion Header" in the *L4T Development Guide* for more information.
- [J43] RJ45 connector for gigabit Ethernet.
- [J44] **Carrier board rev A02 only**: 3.3V serial port header; provides access to the UART console.
- [J48] Enables either J28 Micro-USB connector or J25 power jack as power source for the developer kit. Without a jumper, the developer kit can be powered by J28 Micro-USB connector. With a jumper, no power is drawn from J28, and the developer kit can be powered via J25 power jack.
- [J49] **Carrier board rev B01 only**: Camera connector; same as [J13].
- [J50] **Carrier Board Rev B01 only**: 12-pin button header; brings out system power, reset, UART console, and force recovery related signals:

  - Pin 1 connects to LED Cathode to indicate System Sleep/Wake (Off when system is in sleep mode).
  - Pin 2 connects to LED Anode.
  - Pins 3 and 4 are respectively UART Receive and Send.
  - Pins 5 and 6 disable auto power-on if connected.
  - Pins 7 and 8 reset the system if connected when the system is running.
  - Pins 9 and 10 put the developer kit into Force Recovery Mode if they are connected when it is powered on.
  - Pins 11 and 12 initiate power-on when connected if auto power-on is disabled.

Power Guide

Jetson Nano Developer Kit requires a 5V power supply capable of supplying 2A current.

Micro-USB Power Supply Options

Out of the box, the developer kit is configured to accept power via the Micro-USB connector. Note that some Micro-USB power supplies are designed to output slightly more than 5V to account for voltage loss across the cable. For example, Adafruit's GEO151UB-6025 Power Supply (validated by NVIDIA for use with the Jetson Nano Developer Kit) is designed to provide 5.25V. The critical point is that the Jetson Nano module requires a minimum of 4.75V to operate. Use a power supply capable of delivering 5V at the J28 Micro-USB connector.

Other Power Supply Options

If the developer kit's total load is expected to exceed 2A, e.g., due to peripherals attached to the carrier board, connect the J48 Power Select Header pins to disable power supply via Micro-USB and enable 5V⎓4A via the J25 power jack. Another option is to supply 5V⎓5A via the J41 expansion header (2.5A per pin).

The J25 power jack is 9.5 mm deep, and accepts positive polarity plugs with 2.1 mm inner diameter and 5.5 mm outer diameter. As an example, NVIDIA has validated Adafruit's GEO241DA-0540 Power Supply for use with Jetson Nano Developer Kit.

Power Budget Considerations

The developer kit's total power usage is the sum of carrier board, module, and peripheral power usage, as determined by your particular use case.

The carrier board consumes between 0.5W (at 2A) and 1.25W (at 4A) with no peripherals attached.

The Jetson Nano module is designed to optimize power efficiency and supports two software-defined power modes. The default mode provides a 10W power budget for the modules, and the other, a 5W budget. These power modes constrain the module to near their 10W or 5W budgets by capping the GPU and CPU frequencies and the number of online CPU cores at a pre-qualified level. See the NVIDIA Jetson Linux Driver Package Developer Guide for details about power modes.

Note that the power mode budgets cover the two major power domains for the Jetson Nano module: GPU (VDD_GPU) and CPU (VDD_CPU). Individual parts of the CORE (VDD_CORE) power domain, such as video encode and video decode, are not covered by these budgets. This is a reason why power modes constrain the module to *near* a power budget, but not to the *exact* power budget. Your particular use case determines the module's actual power consumption. See the *Jetson Nano module Data Sheet* for details about how power domains are used to optimize power consumption.

Attached peripherals are the final component of the developer kit's total power usage. Select a power supply that is capable of delivering sufficient power for your workload.

JETPACK

NVIDIA JetPack SDK is the most comprehensive solution for building AI applications. It includes the latest OS images for Jetson products, along with libraries and APIs, samples, developer tools, and documentation.

SUMMARY OF JETPACK COMPONENTS

This section briefly describes each component of JetPack. For additional details about these components, see the online documentation for JetPack at:

```
https://docs.nvidia.com/jetson/jetpack/index.html
```

OS Image

JetPack includes a reference file system derived from Ubuntu.

Libraries and APIs

JetPack libraries and APIs include:

- TensorRT and cuDNN for high-performance deep learning applications
- CUDA for GPU accelerated applications across multiple domains
- NVIDIA Container Runtime for containerized GPU accelerated applications
- Multimedia API package for camera applications and sensor driver development
- VisionWorks, OpenCV, and VPI (Developer Preview) for visual computing applications
- Sample applications

Sample Applications

JetPack includes several samples which demonstrate the use of JetPack components. These are stored in the reference filesystem and can be compiled on the developer kit.

JetPack component	Sample locations on reference filesystem
TensorRT	/usr/src/tensorrt/samples/
cuDNN	/usr/src/cudnn_samples_<version>/
CUDA	/usr/local/cuda-<version>/samples/
Multimedia API	/usr/src/tegra_multimedia_api/
VisionWorks	/usr/share/visionworks/sources/samples/ /usr/share/visionworks-tracking/sources/samples/ /usr/share/visionworks-sfm/sources/samples/
OpenCV	/usr/share/OpenCV/samples/
VPI	/opt/nvidia/vpi/vpi-0.0/samples

Developer Tools

JetPack includes the following developer tools. Some are used directly on a Jetson system, and others run on a Linux host computer connected to a Jetson system.

- Tools for application development and debugging:
  - Nsight Eclipse Edition for development of GPU accelerated applications: Runs on Linux host computer. Supports all Jetson products.
  - CUDA-GDB for application debugging: Runs on the Jetson system or the Linux host computer. Supports all Jetson products.
  - CUDA-MEMCHECK for debugging application memory errors: Runs on the Jetson system. Supports all Jetson products.
- Tools for application profiling and optimization:
  - Nsight Systems for application profiling across GPU and CPU: Runs on the Linux host computer. Supports all Jetson products.
  - nvprof for application profiling across GPU and CPU: Runs on the Jetson system. Supports all Jetson products.
  - Visual Profiler for application profiling across GPU and CPU: Runs on Linux host computer. Supports all Jetson products.
  - Nsight Graphics for graphics application debugging and profiling: Runs on the Linux host computer. Supports all Jetson products.

Documentation

Documents that are relevant to developers using JetPack include:

- JetPack Documentation
- Multimedia API Reference

- NVIDIA Jetson Linux Driver Package Developer Guide
- Tegra NVIDIA Jetson Linux Driver Package Release Notes
- TensorRT Documentation
- cuDNN Documentation
- CUDA Toolkit
- NVIDIA Container Runtime
- OpenCV Documentation
- VisionWorks Documentation
- Nsight Eclipse Edition Documentation
- CUDA-GDB Documentation
- CUDA-MEMCHECK Documentation
- Nsight Systems
- nvprof
- Visual Profiler
- Nsight GraphicsNsight Compute CLI
- VPI–Vision Programming Interface

HOW TO INSTALL JETPACK

There are two ways to install JetPack on your developer kit:

- Use an SD Card image.

  Follow the steps in Getting Started with Jetson Nano Developer Kit to download the system image and use SD Card writing software to flash it to flash it to a microSD card. Then use the microSD card to boot the developer kit.

- Use NVIDIA SDK Manager.

  You must have a Linux host computer with a working Internet connection to run SDK Manager and flash the developer kit. Supported host operating systems are:

  - Ubuntu Linux x64 Version 18.04 or 16.04

  Follow these instructions to download and install NVIDIA SDK Manager.

Note	**Use of SDK Manager to install JetPack requires that:** • **The developer kit be in Force Recovery mode.** • **The developer kit *not* be powered by a Micro-USB power supply. The Micro-USB port is needed to flash and update the developer kit.**

Before using SDK Manager, follow these steps to power your developer kit and put it into Force Recovery mode:

1. Jumper the Force Recovery pins (3 and 4) on J40 button header
2. Jumper the J48 Power Select Header pins and connect a power supply to J25 power jack. The developer kit automatically powers on in Force Recovery mode.
3. Remove the Force Recovery pins' jumper when the developer kit powers on.

Now use SDK Manager to flash your developer kit with the OS image and install other Jetpack components. SDK Manager can also set up your Linux host computer development environment. For full instructions, see the SDK Manager documentation.

INITIAL CONFIGURATION UPON FIRST BOOT

Whether you use the SD Card image or use SDK Manager to flash your developer kit, upon first boot it will prompt you for initial configuration information like keyboard layout, username and password, etc.

Headless initial configuration

If no display is attached to the developer kit during first boot, the initial configuration process is "headless." That is, you must communicate with the developer kit through a serial application on the host computer (e.g., puTTY) connected via a host serial port and the developer kit's Micro-USB port.

Note	**Headless initial configuration requires that the developer kit *not* be powered by a Micro-USB power supply, since the Micro-USB port is needed to access the initial configuration prompts.**

WORKING WITH JETSON LINUX DRIVER PACKAGE

NVIDIA® Jetson™ Linux Driver Package (L4T) is the operating system component of JetPack, and provides the Linux kernel, Bootloader, Jetson Board Support Package (BSP), and sample filesystem for Jetson developer kits. L4T is included on the Jetson Nano SD Card image. Alternatively, you can use SDK Manager to install L4T along with all the other JetPack components to your developer kit.

L4T is also available for download directly from the main L4T page on the Jetson Developer Site. See the "Quick Start Guide" section of the NVIDIA Jetson Linux Driver Package Developer Guide for flashing instructions.

The "Platform Adaptation and Bring-Up" topic in the *Developer Guide* describes how to port the Jetson BSP and bootloader from your developer kit to a new hardware platform incorporating the Jetson module. Porting L4T to a new device enables use of the other JetPack components on that device, along with the software you've created using the developer kit.

COMPLIANCE INFORMATION

The NVIDIA Jetson Nano Developer Kit is compliant with the regulations listed in this section.

UNITED STATES

Federal Communications Commission (FCC)

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including any interference that may cause undesired operation of the device.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation.

If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

FCC Warning: The FCC requires that you be notified that any changes or modifications to this device not expressly approved by the manufacturer could void the user's authority to operate the equipment.

Underwriters Laboratories (UL)

UL listed Product Logo for Jetson Nano Developer Kit, model name P3450.

UL Recognized Component Logo for Embedded System Module for Jetson Nano, model number P3448

CANADA

Innovation, Science and Economic Development Canada (ISED)

CAN ICES-3(B)/NMB-3(B)

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

EUROPEAN UNION

European Conformity; Conformité Européenne (CE)

This device complies with the following Directives:

- Electromagnetic Compatibility Directive 2014/30/EU
- Low Voltage Directive 2014/35/EU
- RoHS Directive 2011/65/EU

The full text of EU declaration of conformity is available at the following internet address: www.nvidia.com/support

A copy of the Declaration of Conformity to the essential requirements may be obtained directly from NVIDIA GmbH (Floessergasse 2, 81369 Munich, Germany).

AUSTRALIA AND NEW ZEALAND

Australian Communications and Media Authority

This product meets the applicable EMC requirements for Class B, I.T.E equipment and applicable radio equipment requirements

JAPAN

Voluntary Control Council for Interference (VCCI)

この装置は、クラスB情報技術装置です。この装置は、家庭環境で使用することを目的としていますが、この装置がラジオやテレビジョン受信機に近接して使用されると、受信障害を引き起こすことがあります。
取扱説明書に従って正しい取り扱いをして下さい。

ＶＣＣＩ－Ｂ

Japan RoHS Material Content Declaration

日本工業規格JIS C 0950:2008により、2006年7月1日以降に販売される特定分野の電気および電子機器について、製造者による含有物質の表示が義務付けられます。

機器名称: Jetson Nano Developer Kit 開発者コンポーネント

主な分類	特定化学物質記号					
	Pb	Hg	Cd	Cr(VI)	PBB	PBDE
PCBボード	0	0	0	0	0	0
パッシブ電子部品	除外項目	0	0	0	0	0
アクティブ電子部品	除外項目	0	0	0	0	0
コネクター / ケーブル	除外項目	0	0	0	0	0
プロセッサー	0	0	0	0	0	0
メモリ	0	0	0	0	0	0
機械部品	除外項目	0	0	0	0	0
はんだ付け材料	0	0	0	0	0	0
フラックス、クリームはんだ、ラベル、その他消耗品	0	0	0	0	0	0

注:

1.「0」は、特定化学物質の含有率が日本工業規格JIS C 0950:2008に記載されている含有率基準値より低いことを示します。

2.「除外項目」は、特定化学物質が含有マークの除外項目に該当するため、特定化学物質について、日本工業規格JIS C 0950:2008に基づく含有マークの表示が不要であることを示します。

3.「0.1wt%超」または「0.01wt%超」は、特定化学物質の含有率が日本工業規格JIS　C 0950:2008　に記載されている含有率基準値を超えていることを示します。

A Japanese regulatory requirement, defined by specification JIS C 0950: 2008, mandates that manufacturers provide Material Content Declarations for certain categories of electronic products offered for sale after July 1, 2006.

Product Model Number: Jetson Nano Developer Kit

Major Classification	Symbols of Specified Chemical Substance					
	Pb	Hg	Cd	Cr(VI)	PBB	PBDE
PCB	0	0	0	0	0	0
Passive components	Exempt	0	0	0	0	0
Active components	Exempt	0	0	0	0	0
Connectors/Cables	Exempt	0	0	0	0	0
Processor	0	0	0	0	0	0
Memory	0	0	0	0	0	0
Mechanicals	Exempt	0	0	0	0	0
Soldering material	0	0	0	0	0	0
Flux, Solder Paste, label and other consumable materials	0	0	0	0	0	0

Notes:

1. “0” indicates that the level of the specified chemical substance is less than the threshold level specified in the standard, JIS C 0950: 2008.

2. “Exempt” indicates that the specified chemical substance is exempt from marking and it is

not required to display the marking for that specified chemical substance per the standard, JIS C 0950: 2008. 3. “Exceeding 0.1wt%” or “Exceeding 0.01wt%” is entered in the table if the level of the specified chemical substance exceeds the threshold level specified in the standard, JIS C 0950: 2008.

SOUTH KOREA

Radio Research Agency (RRA)

R-R-NVA-P3450 **R-R-NVA-P3448**

B급 기기	이 기기는 가정용(B급) 전자파적합기기로서 주로 가정에서 사용하는 것을 목적으로 하며, 모든 지역에서 사용할 수 있습니다.

Korea RoHS Material Content Declaration

<table>
<tr><td colspan="6">확인 및 평가 양식은 제품에 포함 된 유해 물질의 허용 기준의 준수에 관한</td></tr>
<tr><td rowspan="3">문
준비</td><td>상호 :</td><td>앤비디아홍콩홀딩즈리미티드(영업소)</td><td>법인등록번호</td><td colspan="2">110181-0036373</td></tr>
<tr><td>대표자성명</td><td>카렌테레사번즈</td><td>사업자등록번호:</td><td colspan="2">120-84-06711</td></tr>
<tr><td>주소</td><td colspan="4">서울특별시 강남구 영동대로 511, 2101호 (삼성동, 코엑스무역타워)</td></tr>
<tr><td colspan="6">제품 내용</td></tr>
<tr><td colspan="2">제품의 종류</td><td>해당없음</td><td>제품명(규격)</td><td colspan="2">해당없음</td></tr>
<tr><td colspan="2">세부모델명(번호):</td><td>해당없음</td><td>제품출시일</td><td colspan="2">해당없음</td></tr>
<tr><td colspan="2">제품의 중량</td><td>해당없음</td><td>제조, 수입업자</td><td colspan="2">앤비디아</td></tr>
</table>

엔비디아의 그래픽 카드제품은 전기 전자제품 및 자동차의 자원순환에 관한 법률 시행령 제 11조 제 1항에 의거한 법 시행행규칙 제 3조에에따른 유해물질함유 기준을 확인 및 평가한 결과, 이를 준수하였음을 공표합니다.
구비서류 : 없음 작성방법 ① 제품의 종류는 "전기.전자제품 및 자동차의 자원순환에관한 법률 시행령" 제 8조 제 1항 및 제 2항에 따른 품목별로 구분하여 기재합니다. ② 전기 전자 제품의 경우 모델명 (번호), 자동차의 경우, 제원관리번호를 기재합니다. ③ 해당제품의 제조업자 또는 수입업자를 기재합니다.

Confirmation and Evaluation Form Concerning the Adherence to Acceptable Standards of Hazardous Materials Contained in Products				
Statement Prepared by	Company Name:	Nvidia HongKong Holding Ltd.Korea branch	Corporate Identification Number:	110181-0036373
	Name of Company Representative:	Karen Theresa Burns	Business Registration Number:	120-84-06711
	Address	2788 San Tomas Expressway, Santa Clara, CA 95051		
Product Information				

Product Category:	N/A	Name of Product:	N/A
Detailed Product Model Name (Number):	N/A	Date of first market release:	N/A
Weight of Product:	N/A	Manufacturer and/or Importer:	NVIDIA Corporation
This for is publicly certify That NVIDIA Company has undergone the confirmation and evaluation procedures for the acceptable amounts of hazardous materials contained in graphic card according to the regulations stipulated in Article 3 of the 'Status on the Recycling of Electrical and Electronic Products, and Automobiles' and that company has graphic card adhered to the Enforcement Regulations of Article 11, Item 1 of the statute.			
Attachment: None * Preparing the Form			

① Please indicate the product category according to the categories listed in Article 8, Items 1and 2 of the ' Enforcement Ordinance of the Statute on the Recycling of Electrical, Electronic and Automobile Materials'

② For electrical and electronic products, please indicate the Model Name (and number). For automobiles, please indicate the Vehicle Identification Number.

③ Please indicate the name of manufacturer and/or importer of the product.

RUSSIA/KAZAKHSTAN/BELARUS

Customs Union Technical Regulations (CU TR)

This device complies with the technical regulations of the Customs Union (CU TR)

This device complies with the rules set forth by Federal Agency of Communications and the Ministry of Communications and Mass Media

Federal Security Service notification has been filed.

TAIWAN

Bureau of Standards, Metrology & Inspection (BSMI)

D33088
RoHS

This device complies with CNS 13438 (2006) Class B.

Product Name: Jetson Nano Developer Kit開發者組件

Taiwan RoHS Material Content Declaration

<table>
<tr><td colspan="2">限用物質含有情況標示聲明書
Declaration of the presence condition of the Restricted Substances Marking</td></tr>
<tr><td colspan="2">設備名稱：Jetson Nano Developer Kit
Equipment Name: Jetson Nano Developer Kit</td></tr>
<tr><td>單元
Parts</td><td>限用物質及其化學符號
Restricted substances and its chemical symbols</td></tr>
</table>

	铅 (Pb)	汞 (Hg)	镉 (Cd)	六價铬 (Cr(VI))	多溴聯苯 (PBB)	多溴二苯醚 (PBDE)
印刷電路板 PCB	O	O	O	O	O	O
處理器 Processor	O	O	O	O	O	O
主動電子零件 Active components	-	O	O	O	O	O
被動電子零件 Passive components	-	O	O	O	O	O
存儲設備 Memory	O	O	O	O	O	O
機械部件 Mechanicals	-	O	O	O	O	O
連接器/**線材** Connectors/Cable	-	O	O	O	O	O
焊接金屬 Soldering material	O	O	O	O	O	O
助焊劑，錫膏，標籤及耗材 Flux, Solder Paste, label and other consumable materials	O	O	O	O	O	O

備考1：O：系指該限用物質未超出百分比含量基準值
Note 1： O：indicates that the percentage content of the restricted substance does not exceed the percentage of reference value of presence.
備考2： -：系指該项限用物質为排外項目。
Note 2：-：indicates that the restricted substance corresponds to the exemption.

此表中所有名稱中含 "-" 的部件均符合歐盟 RoHS 立法。
All parts named in this table with an "-" are in compliance with the European Union's RoHS Legislation.

注：環保使用期限的參考標識取决與產品正常工作的温度和濕度等條件
Note: The referenced Environmental Protection Use Period Marking was determined according to normal operating use conditions of the product such as temperature and humidity.

CHINA

China RoHS Material Content Declaration

产品中有害物质的名称及含量
The Table of Hazardous Substances and their Content
根据中国《电器电子产品有害物质限制使用管理办法》
as required by Management Methods for Restricted Use of Hazardous Substances in Electrical and Electronic Products

部件名称 Parts	有害物质 Hazardous Substances					
	铅 (Pb)	汞 (Hg)	镉 (Cd)	六价铬 (Cr(VI))	多溴联苯 (PBB)	多溴二苯醚 (PBDE)
印刷电路板 PCB	O	O	O	O	O	O
处理器 Processor	O	O	O	O	O	O
主动电子零件 Active components	X	O	O	O	O	O
被动电子零件 Passive components	X	O	O	O	O	O
存储设备 Memory	O	O	O	O	O	O
机械部件 Mechanicals	X	O	O	O	O	O
连接器/线材 Connectors / Cable	X	O	O	O	O	O
焊接金属 Soldering material	O	O	O	O	O	O
助焊剂，锡膏，标签及耗材 Flux, Solder Paste, label and other consumable materials	O	O	O	O	O	O

本表格依据SJ/T 11364-2014 的规定编制
The table according to SJ/T 11364-2014

O：表示该有害物质在该部件所有均质材料中的含量均在GB/T 26572-2011 标准规定的限量要求以下。
O: Indicates that this hazardous substance contained in all of the homogeneous materials for this
part is below the limit requirement in GB/T 26572-2011.
X：表示该有害物质至少在该部件的某一均质材料中的含量超出GB/T 26572-2011 标准规定的限量要求。
X: Indicates that this hazardous substance contained in at least one of the homogeneous materials used for this part is above the limit requirement in GB/T 26572-2011.

此表中所有名称中含 "X" 的部件均符合欧盟 RoHS 立法。
All parts named in this table with an “X” are in compliance with the European Union’s RoHS Legislation.

注：环保使用期限的参考标识取决于产品正常工作的温度和湿度等条件
Note: The referenced Environmental Protection Use Period Marking was determined according to normal operating use conditions of the product such as temperature and humidity.

INDIA

India RoHS Compliance Statement

This product, as well as its related consumables and spares, complies with the reduction in hazardous substances provisions of the "India E-waste (Management and Handling) Rule 2016". It does not contain lead, mercury, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers in concentrations exceeding 0.1 weight % and 0.01 weight % for cadmium, except for where allowed pursuant to the exemptions set in Schedule 2 of the Rule.

India RoHS Self-Declaration Form
(as per E-Waste (Management) Rules, 2016)

Sr. No.	**Product Category & Code (as Per Schedule I of E-Waste (M) Rules, 2016**	**Product name**	**Model No.**	**Product Weight (g)**	**Date of placing on market**	**Compliance with RoHS Yes/No**	**RoHS Information provided on product info booklet Yes/No**	**In case Product is imported from other country, name of the country manufactured**
i.	ITEW2	Jetson Nano Developer Kit	P3450	N/A	N/A	Yes	Yes	China

www.nvidia.com

D.2 P2N2222A - Amplifier Transistors NPN Silicon

P2N2222A

Amplifier Transistors

NPN Silicon

Features

- These are Pb−Free Devices*

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Value	Unit
Collector − Emitter Voltage	V_{CEO}	40	Vdc
Collector − Base Voltage	V_{CBO}	75	Vdc
Emitter − Base Voltage	V_{EBO}	6.0	Vdc
Collector Current − Continuous	I_C	600	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	625 5.0	mW mW/°C
Total Device Dissipation @ T_C = 25°C Derate above 25°C	P_D	1.5 12	W mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +150	°C

THERMAL CHARACTERISTICS

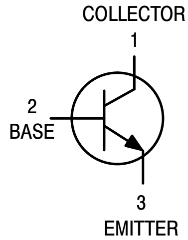
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

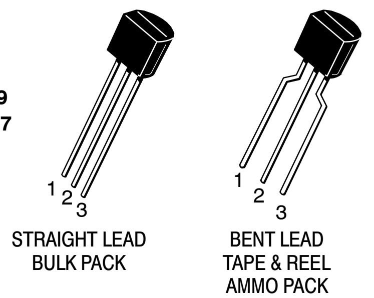
*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

ON Semiconductor®

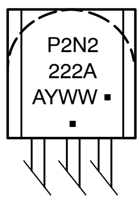
http://onsemi.com



TO−92
CASE 29
STYLE 17



MARKING DIAGRAM



A = Assembly Location
Y = Year
WW = Work Week
▪ = Pb−Free Package
(Note: Microdot may be in either location)

ORDERING INFORMATION

Device	Package	Shipping†
P2N2222AG	TO−92 (Pb−Free)	5000 Units/Bulk
P2N2222ARL1G	TO−92 (Pb−Free)	2000/Tape & Ammo

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specification Brochure, BRD8011/D.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

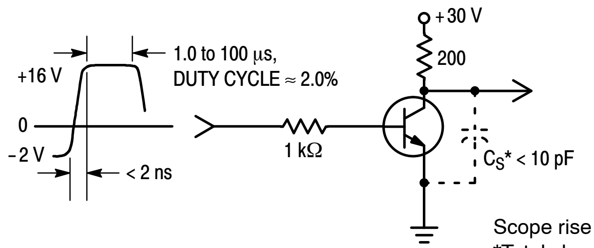
Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector–Emitter Breakdown Voltage (I_C = 10 mAdc, I_B = 0)	$V_{(BR)CEO}$	40	–	Vdc
Collector–Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)	$V_{(BR)CBO}$	75	–	Vdc
Emitter–Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)	$V_{(BR)EBO}$	6.0	–	Vdc
Collector Cutoff Current (V_{CE} = 60 Vdc, $V_{EB(off)}$ = 3.0 Vdc)	I_{CEX}	–	10	nAdc
Collector Cutoff Current (V_{CB} = 60 Vdc, I_E = 0) (V_{CB} = 60 Vdc, I_E = 0, T_A = 150°C)	I_{CBO}	 – –	 0.01 10	μAdc
Emitter Cutoff Current (V_{EB} = 3.0 Vdc, I_C = 0)	I_{EBO}	–	10	nAdc
Collector Cutoff Current (V_{CE} = 10 V)	I_{CEO}	–	10	nAdc
Base Cutoff Current (V_{CE} = 60 Vdc, $V_{EB(off)}$ = 3.0 Vdc)	I_{BEX}	–	20	nAdc
ON CHARACTERISTICS				
DC Current Gain (I_C = 0.1 mAdc, V_{CE} = 10 Vdc) (I_C = 1.0 mAdc, V_{CE} = 10 Vdc) (I_C = 10 mAdc, V_{CE} = 10 Vdc) (I_C = 10 mAdc, V_{CE} = 10 Vdc, T_A = −55°C) (I_C = 150 mAdc, V_{CE} = 10 Vdc) (Note 1) (I_C = 150 mAdc, V_{CE} = 1.0 Vdc) (Note 1) (I_C = 500 mAdc, V_{CE} = 10 Vdc) (Note 1)	h_{FE}	 35 50 75 35 100 50 40	 – – – – 300 – –	–
Collector–Emitter Saturation Voltage (Note 1) (I_C = 150 mAdc, I_B = 15 mAdc) (I_C = 500 mAdc, I_B = 50 mAdc)	$V_{CE(sat)}$	 – –	 0.3 1.0	Vdc
Base–Emitter Saturation Voltage (Note 1) (I_C = 150 mAdc, I_B = 15 mAdc) (I_C = 500 mAdc, I_B = 50 mAdc)	$V_{BE(sat)}$	 0.6 –	 1.2 2.0	Vdc
SMALL–SIGNAL CHARACTERISTICS				
Current–Gain – Bandwidth Product (Note 2) (I_C = 20 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)C	f_T	300	–	MHz
Output Capacitance (V_{CB} = 10 Vdc, I_E = 0, f = 1.0 MHz)	C_{obo}	–	8.0	pF
Input Capacitance (V_{EB} = 0.5 Vdc, I_C = 0, f = 1.0 MHz)	C_{ibo}	–	25	pF
Input Impedance (I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz) (I_C = 10 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{ie}	 2.0 0.25	 8.0 1.25	kΩ
Voltage Feedback Ratio (I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz) (I_C = 10 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{re}	 – –	 8.0 4.0	X 10^{-4}
Small–Signal Current Gain (I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz) (I_C = 10 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{fe}	 50 75	 300 375	–
Output Admittance (I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz) (I_C = 10 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{oe}	 5.0 25	 35 200	μMhos
Collector Base Time Constant (I_E = 20 mAdc, V_{CB} = 20 Vdc, f = 31.8 MHz)	$rb'C_c$	–	150	ps
Noise Figure (I_C = 100 μAdc, V_{CE} = 10 Vdc, R_S = 1.0 kΩ, f = 1.0 kHz)	N_F	–	4.0	dB

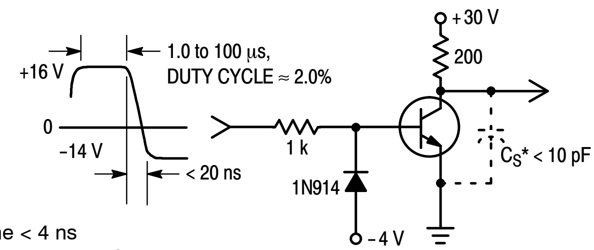
1. Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle ≤ 2.0%.
2. f_T is defined as the frequency at which $|h_{fe}|$ extrapolates to unity.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) (Continued)

Characteristic		Symbol	Min	Max	Unit
SWITCHING CHARACTERISTICS					
Delay Time	(V_{CC} = 30 Vdc, $V_{BE(off)}$ = −2.0 Vdc, I_C = 150 mAdc, I_{B1} = 15 mAdc) (Figure 1)	t_d	–	10	ns
Rise Time		t_r	–	25	ns
Storage Time	(V_{CC} = 30 Vdc, I_C = 150 mAdc, I_{B1} = I_{B2} = 15 mAdc) (Figure 2)	t_s	–	225	ns
Fall Time		t_f	–	60	ns

SWITCHING TIME EQUIVALENT TEST CIRCUITS





Scope rise time < 4 ns
*Total shunt capacitance of test jig, connectors, and oscilloscope.

Figure 1. Turn−On Time

Figure 2. Turn−Off Time

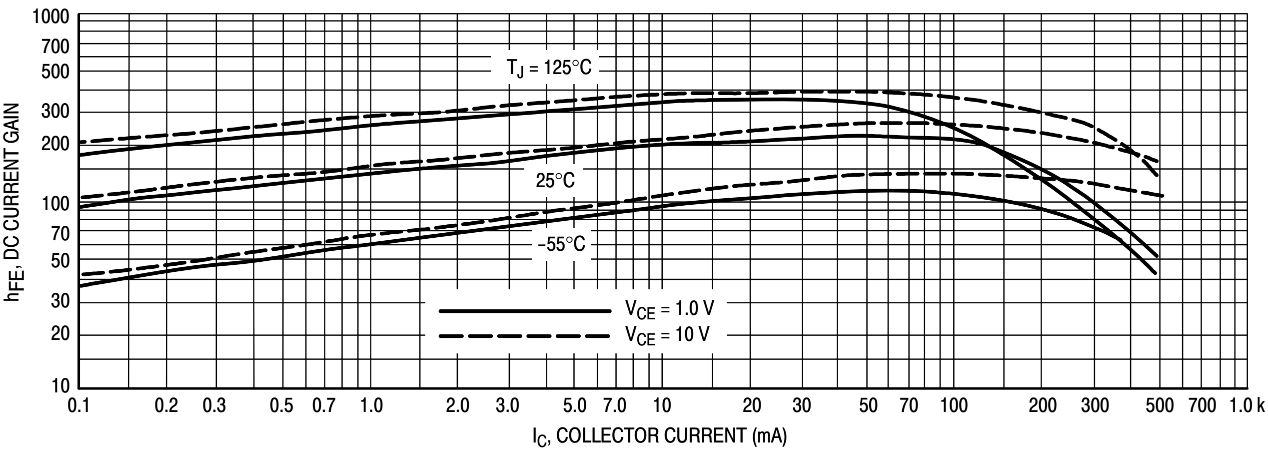


Figure 3. DC Current Gain

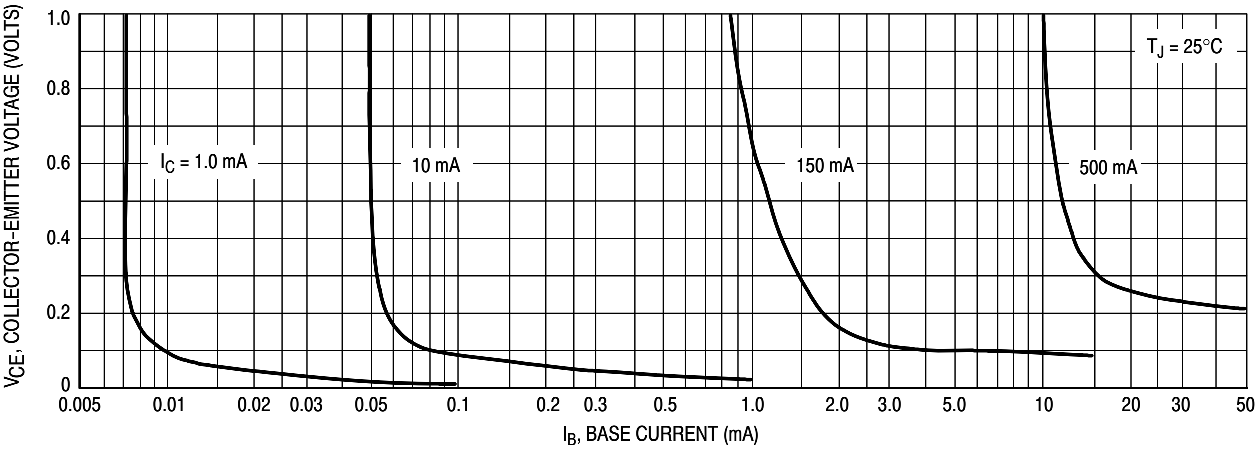


Figure 4. Collector Saturation Region

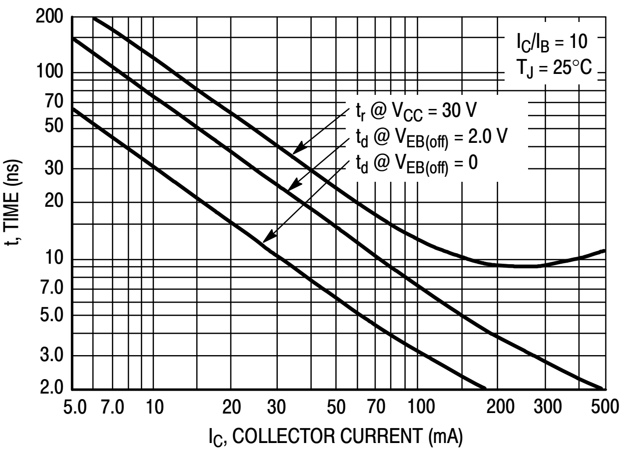


Figure 5. Turn−On Time

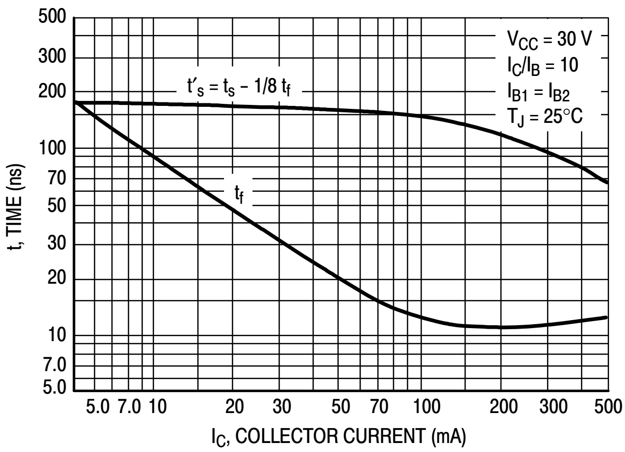


Figure 6. Turn−Off Time

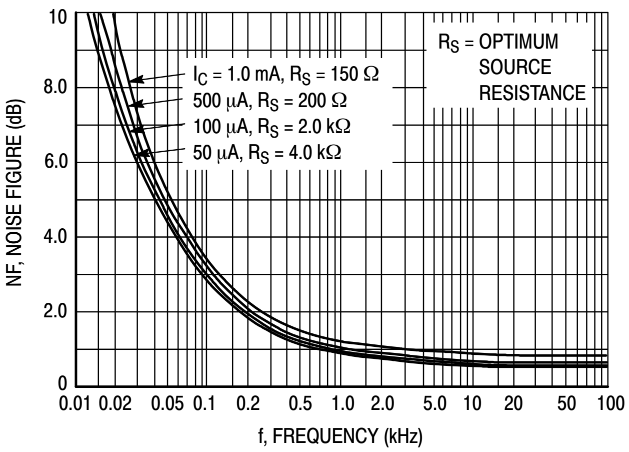


Figure 7. Frequency Effects

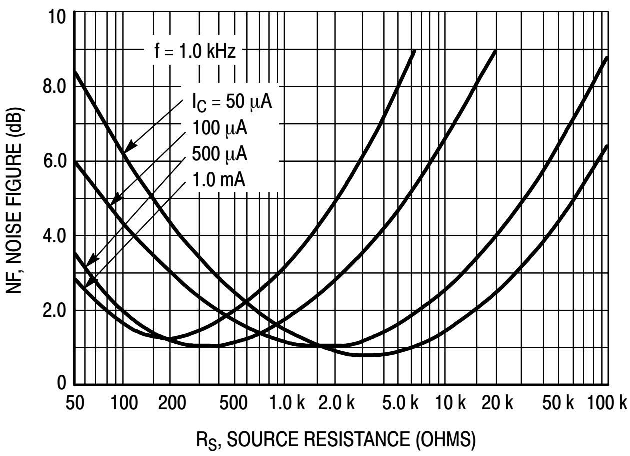


Figure 8. Source Resistance Effects

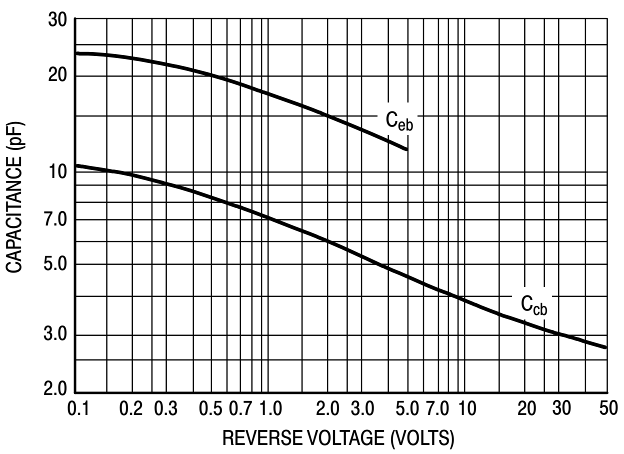


Figure 9. Capacitances

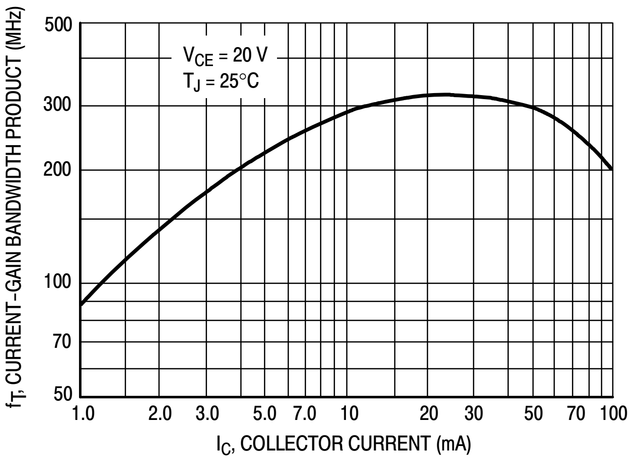


Figure 10. Current−Gain Bandwidth Product

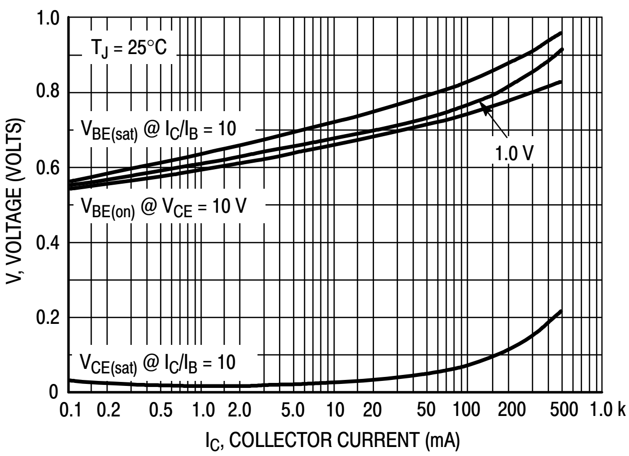


Figure 11. "On" Voltages

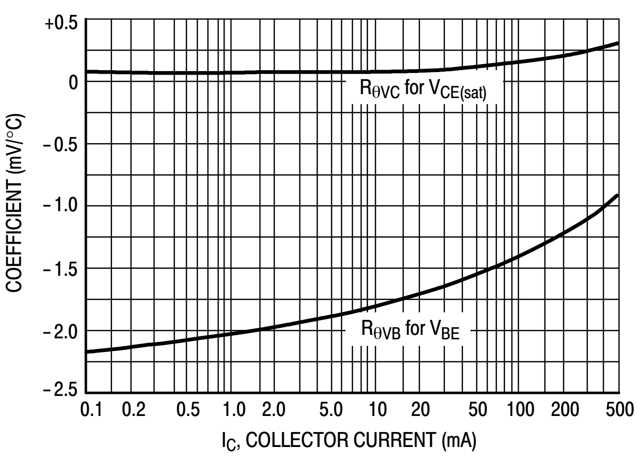
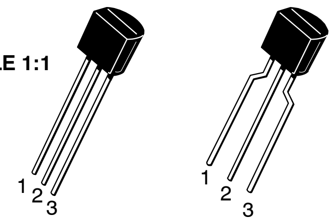


Figure 12. Temperature Coefficients

MECHANICAL CASE OUTLINE
PACKAGE DIMENSIONS

ON Semiconductor®

SCALE 1:1

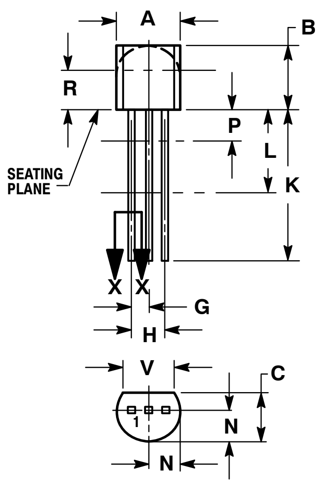


STRAIGHT LEAD BULK PACK

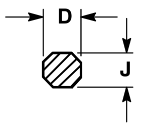
BENT LEAD TAPE & REEL AMMO PACK

TO−92 (TO−226)
CASE 29−11
ISSUE AM

DATE 09 MAR 2007



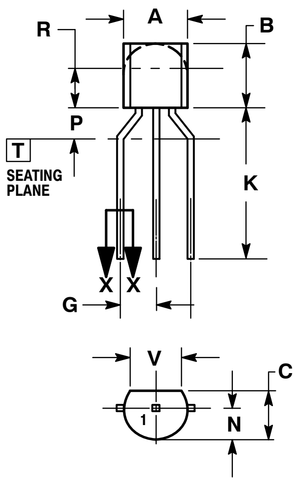
STRAIGHT LEAD
BULK PACK



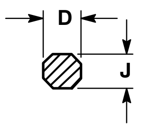
SECTION X−X

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. CONTOUR OF PACKAGE BEYOND DIMENSION R IS UNCONTROLLED.
4. LEAD DIMENSION IS UNCONTROLLED IN P AND BEYOND DIMENSION K MINIMUM.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.175	0.205	4.45	5.20
B	0.170	0.210	4.32	5.33
C	0.125	0.165	3.18	4.19
D	0.016	0.021	0.407	0.533
G	0.045	0.055	1.15	1.39
H	0.095	0.105	2.42	2.66
J	0.015	0.020	0.39	0.50
K	0.500	---	12.70	---
L	0.250	---	6.35	---
N	0.080	0.105	2.04	2.66
P	---	0.100	---	2.54
R	0.115	---	2.93	---
V	0.135	---	3.43	---



BENT LEAD
TAPE & REEL
AMMO PACK



SECTION X−X

NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. CONTOUR OF PACKAGE BEYOND DIMENSION R IS UNCONTROLLED.
4. LEAD DIMENSION IS UNCONTROLLED IN P AND BEYOND DIMENSION K MINIMUM.

	MILLIMETERS	
DIM	MIN	MAX
A	4.45	5.20
B	4.32	5.33
C	3.18	4.19
D	0.40	0.54
G	2.40	2.80
J	0.39	0.50
K	12.70	---
N	2.04	2.66
P	1.50	4.00
R	2.93	---
V	3.43	---

STYLES ON PAGE 2

DOCUMENT NUMBER:	**98ASB42022B**	Electronic versions are uncontrolled except when accessed directly from the Document Repository. Printed versions are uncontrolled except when stamped “CONTROLLED COPY” in red.
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NEW STANDARD:		
DESCRIPTION:	**TO−92 (TO−226)**	**PAGE 1 OF 3**

TO−92 (TO−226)
CASE 29−11
ISSUE AM

DATE 09 MAR 2007

STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

STYLE 2:
PIN 1. BASE
2. EMITTER
3. COLLECTOR

STYLE 3:
PIN 1. ANODE
2. ANODE
3. CATHODE

STYLE 4:
PIN 1. CATHODE
2. CATHODE
3. ANODE

STYLE 5:
PIN 1. DRAIN
2. SOURCE
3. GATE

STYLE 6:
PIN 1. GATE
2. SOURCE & SUBSTRATE
3. DRAIN

STYLE 7:
PIN 1. SOURCE
2. DRAIN
3. GATE

STYLE 8:
PIN 1. DRAIN
2. GATE
3. SOURCE & SUBSTRATE

STYLE 9:
PIN 1. BASE 1
2. EMITTER
3. BASE 2

STYLE 10:
PIN 1. CATHODE
2. GATE
3. ANODE

STYLE 11:
PIN 1. ANODE
2. CATHODE & ANODE
3. CATHODE

STYLE 12:
PIN 1. MAIN TERMINAL 1
2. GATE
3. MAIN TERMINAL 2

STYLE 13:
PIN 1. ANODE 1
2. GATE
3. CATHODE 2

STYLE 14:
PIN 1. EMITTER
2. COLLECTOR
3. BASE

STYLE 15:
PIN 1. ANODE 1
2. CATHODE
3. ANODE 2

STYLE 16:
PIN 1. ANODE
2. GATE
3. CATHODE

STYLE 17:
PIN 1. COLLECTOR
2. BASE
3. EMITTER

STYLE 18:
PIN 1. ANODE
2. CATHODE
3. NOT CONNECTED

STYLE 19:
PIN 1. GATE
2. ANODE
3. CATHODE

STYLE 20:
PIN 1. NOT CONNECTED
2. CATHODE
3. ANODE

STYLE 21:
PIN 1. COLLECTOR
2. EMITTER
3. BASE

STYLE 22:
PIN 1. SOURCE
2. GATE
3. DRAIN

STYLE 23:
PIN 1. GATE
2. SOURCE
3. DRAIN

STYLE 24:
PIN 1. EMITTER
2. COLLECTOR/ANODE
3. CATHODE

STYLE 25:
PIN 1. MT 1
2. GATE
3. MT 2

STYLE 26:
PIN 1. V_{CC}
2. GROUND 2
3. OUTPUT

STYLE 27:
PIN 1. MT
2. SUBSTRATE
3. MT

STYLE 28:
PIN 1. CATHODE
2. ANODE
3. GATE

STYLE 29:
PIN 1. NOT CONNECTED
2. ANODE
3. CATHODE

STYLE 30:
PIN 1. DRAIN
2. GATE
3. SOURCE

STYLE 31:
PIN 1. GATE
2. DRAIN
3. SOURCE

STYLE 32:
PIN 1. BASE
2. COLLECTOR
3. EMITTER

STYLE 33:
PIN 1. RETURN
2. INPUT
3. OUTPUT

STYLE 34:
PIN 1. INPUT
2. GROUND
3. LOGIC

STYLE 35:
PIN 1. GATE
2. COLLECTOR
3. EMITTER

ON Semiconductor®	DOCUMENT NUMBER: 98ASB42022B PAGE 3 OF 3

ISSUE	REVISION	DATE
AM	ADDED BENT−LEAD TAPE & REEL VERSION. REQ. BY J. SUPINA.	09 MAR 2007

PUBLICATION ORDERING INFORMATION

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Email Requests to: orderlit@onsemi.com

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Phone: 011 421 33 790 2910

Europe, Middle East and Africa Technical Support:
Phone: 00421 33 790 2910
For additional information, please contact your local Sales Representative

D.3 RS-775 DC Motor

Banebots RS-775 Motor – 14.4V Specifications

Performance

Operating v	6v - 20v
Nominal v	14.4v
No Load RPM	17350
No Load A	2.6A
Stall Torque	111.18 oz-in / 785.1 mN-m
Stall Current	102A
Kt	1.09 oz-in/A / 7.7 mN-m/A
Kv	1205 rpm/V
Efficiency	70%
RPM - Peak Eff	15047
Current - Peak Eff	17A

Physical

Weight	11.9 oz (337g)
Length - for motor	2.81 in (71.3mm)
Diameter (with flux ring)	1.85 in (47mm)
Diameter (no flux ring)	1.66 in (42.1mm)
Shaft Diameter	0.2 in (5mm)
Shaft Length	0.54 in (13.7mm)
Mounting Screws (2)	M4

D.4 Uxcell Gear Motor with Encoder DC 12V 800RPM

The following information is retrieved from the Amazon listing of the "uxcell Gear Motor with Encoder DC 12V 800RPM Gear Ratio 6.25:1 D Shaft Metal Encoder Gear Motor Silver 37Dx49L mm for Robot RC Model DIY Engine". The listing image is shown in Figure D.1.

Specifications: Material: Metal Color: Silver Rated Voltage: 12V Voltage Range: 6-24V No-load Speed: 800RPM Load Speed: 640RPM No-load Current: 45mA Torque: 0.5kg.cm Reduction Ratio: 6.25:1 Gearbox Size(D*L): 37x19mm/1.46x0.75inch Motor Size(D*L): 34.5x30mm/1.36x1.18inch Shaft Size(D*L): 6x15.5mm/0.24x0.61inch Encoder Cable Length: 20cm/7.87inch Gross Weight: Approx. 190g
Features: The encoder has 6 color-coded, 7.87" (20 cm) leads terminated by a 6 female header with a 0.1" pitch. The A and B outputs of the hall sensor are square waves from 0 V to Vcc approximately 90° out of phase. The face plate has 6 mounting holes evenly spaced around the outer edge threaded for M3 screws; These mounting holes form a regular hexagon and the centers of neighboring holes are 15.5 mm apart.

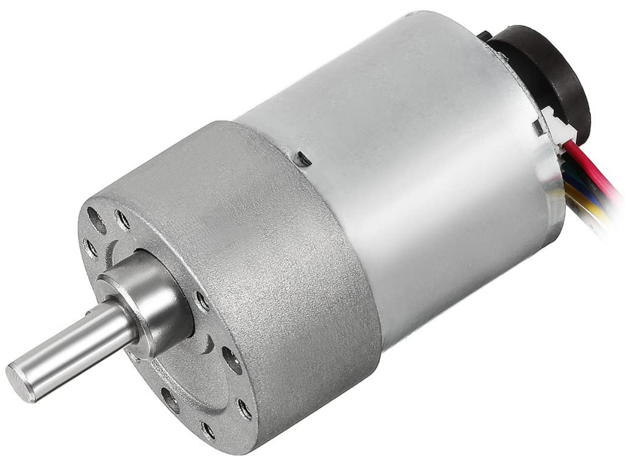


Figure D.1: Uxcell Gear Motor with Encoder DC 12V 800RPM.

D.5 Uxcell Micro Motor DC 12V 10000RPM

The following information is retrieved from the Amazon listing of the "uxcell Micro Motor DC 12V 10000RPM 6 Wire High Speed Encoder Motor for DIY Model Remote Control". The listing image is shown in Figure D.2.

Technical Parameter: Rated Voltage: DC 12V No-load Speed: 10000 RPM Rotation Direction: CW / CCW Output Shaft Diameter: 2mm Length of Output Shaft: 7.1mm Wire Length: 14cm Motor Dimension: 34mm x 33mm (H * Dia) Operational Temperature: -25C +65C Weight: 63g
Feature: Low noise, high speed, high efficiency, low resistance. Widely use for DIY, game device, game controller, cellphone etc. Replacement spare part and give your RC airplane a new life.

Figure D.2: Uxcell Gear Motor with Encoder DC 12V 800RPM.

D.6 SHAFT SEALING RING 3-10-6 FOR SHAFT 3MM

The following information is retrieved from the Alexander Engel KG listing of the "SHAFT SEALING RING 3-10-6 FOR SHAFT 3MM". The listing image can be seen in Figure D.3.

Drive shaft sealing rings provide a very compact and simple solution to sealing rotating shafts. Their use is excellent for low to medium pressure applications such as for model submarines. The shaft sealing ring, also known under the trade name Simmerring®, features a narrow sealing lip pressed on to a shaft by a small coil spring. The spring pressure is adequate to form an effective seal without causing excessive amounts of friction.
The section housing the coil spring (look closely) is the rear of the sealing ring which shoud face towards the prop. The more flat face section is the front of the sealing ring and should be installed facing the inside of the WTC.
Make sure to grease the sealing ring from time to time in order to prevent excessive wearout. Furthermore, sealing rings should only be used in combination with drive shafts made of

stainless steel. Shafts made of brass will wear quite fast around the section of the sealing ring lip.
Shaft diameter 3 mm Outer diamter 10 mm Width 6 mm

Figure D.3: SHAFT SEALING RING 3-10-6 FOR SHAFT 3MM.

D.7 Uxcell 3mm to 6mm Bore Rigid Coupling

The following information is retrieved from the Amazon listing of the "uxcell 3mm to 6mm Bore Rigid Coupling Set Screw L20XD12 Aluminum Alloy,Shaft Coupler Connector,Motor Accessories,Red,2pcs". The listing image is shown in Figure D.4.

Connection Diameter: 3mm to 6mm, Total Length: 20mm /0.78 inch, Outside Diameter : 12mm/ 0.47 inch Widely used in blowers,3D printer,DIY robots,CNC machine,stepper motors,etc. Similar to rigid clamp couplings, shaft couplers are used to hold bearings and sprockets tightly on the shaft, and are used in motor and gearbox assemblies. Top tight type rigid coupling with 2/4 screws to hold the shaft tightly; high torque with rigidity, low inertia and excellent sensitivity. NOTE: The rigid type basically does not allow eccentricity, and it must be fully adjusted during use. Single piece set screw clamp design makes it easy to set up the items on the shaft and control the holding capacity of the coupling.

D.8 Uxcell 2mm to 3mm Bore Rigid Coupling

The following information is retrieved from the Amazon listing of the "uxcell 2mm to 3mm Bore Rigid Coupling Set Screw L20XD12 Aluminum Alloy,Shaft Coupler Connector,Motor Accessories,Dark Red,4pcs". The listing image is shown in Figure D.5.

Connection Bore Diameter: 2mm to 3mm; Total Length: 20mm/0.78 inch, Outside Diameter : 12mm/0.47 inch; with M4 Screws Widely used in blowers,3D printer,DIY robots,CNC machine,stepper motors,etc. Similar to rigid clamp couplings, shaft couplers are used to hold bearings and sprockets tightly on the shaft, and are used in motor and gearbox assemblies. Top tight type rigid coupling with 2/4 screws to hold the shaft tightly; high torque with rigidity, low inertia and excellent sensitivity. NOTE: The rigid type basically does not allow

Figure D.4: Uxcell 3mm to 6mm Bore Rigid Coupling.

eccentricity, and it must be fully adjusted during use. Single piece set screw clamp design makes it easy to set up the items on the shaft and control the holding capacity of the coupling.

Figure D.5: Uxcell 2mm to 3mm Bore Rigid Coupling.

D.9 1 mm Rubber Sheet

The following information is retrieved from the Biltema listing of the "GUMMIDUK 1,0 250X300 MM". The listing information is in Norwegian. The listing image is shown in Figure D.6.

Med høy brennstoff- og oljebestandighet. Klippes/ skjæres til ønsket form. Strekkstyrke: 80 kg/cm^3. Hardhet: 70 ± 0,05 shore. Spesifikk vekt: 1,20 ± 0,05. Temperaturområde: -30 °C til +120 °C.

Figure D.6: 1 mm Rubber Sheet.

D.10 Peristaltic Pump Kamoer NKP 12V DC DIY Liquid dosing Pump

The following information is retrieved from the Amazon listing of the "Peristaltic Pump Kamoer NKP 12V DC DIY Liquid dosing Pump for Aquarium Lab Analytical 3mm ID x 5mm OD". The listing image is shown in Figure D.7. Detailed dimensions of the pump can be seen in Figure D.8.

Features:
FLOWRATE - pump tube size: 3mm ID x 5mm OD
100% brand new and high quality.
Suppprt self-priming and dry-running.
Small, low noise, no pollution, reversible flow is possible.
EASY USE - Simple construction, high percision,easy to install and maintain.
CHANGEABLE FLOW DIRECTION - flow direction can be controlled by the positive and negative connection.
PORTABLE FOR WIDE USE - has been widely used in the field of experimental, biochemical analysis, pharmaceuticals, fine chemicals, biotechnology, pharmaceutical, products, ceramics, water treatment, environmental protection, etc.

Specification:
Main material: engineering plastics
Pump tube material type: Silicone
Color: Blue
Overall length: 65mm
Motor length: 48.5mm
Voltage: DC12V
Flow range: 5.2ml/min 90ml/min

Working temp: 0 40 ℃
Relative humidity: <80%
Pulsation: 3 rolling wheel

Figure D.7: Peristaltic Pump Kamoer NKP 12V DC DIY Liquid dosing Pump.

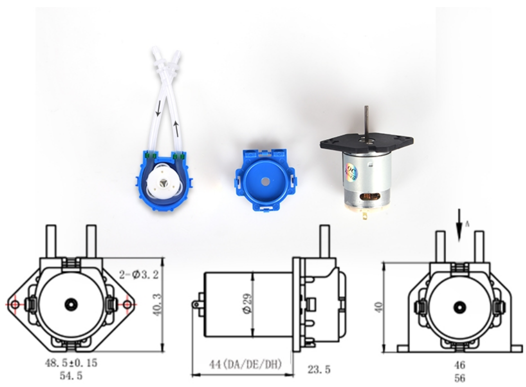


Figure D.8: Peristaltic Pump Dimensions.

D.11 250V3A 6 mm Switch

The following information is retrieved from the AliExpress listing of the "10Pcs MTS-101 2 Pin SPST Switch ON-OFF 2 Position AC125V/6A 250V/3A 6mm Blue Mini Toggle Switches". The listing image is shown in Figure D.9.

D.12 SILICONE DIELECTRIC AND VACUUM GREASE - 91003

TECHNICAL DATA SHEET

SUPER LUBE® SILICONE DIELECTRIC AND VACUUM GREASE

October 2020

PRODUCT DESCRIPTION:

Super Lube® Silicone Dielectric and Vacuum Grease is a specially formulated non-curing silicone compound that exhibits superior performance in both electrical and vacuum applications.

Super Lube® Silicone Dielectric and Vacuum Grease seals, protects, and insulates electrical components and connectors. It is waterproof and provides a barrier against moisture and other contaminants in many types of electrical contact points.

Super Lube® Silicone Dielectric and Vacuum Grease helps reduce the overall leak rate in vacuum applications by filling the spaces of the gland's surfaces and lowering permeation rates of the elastomer. It outperforms in both vacuum and pressure systems.

Super Lube® Silicone Dielectric and Vacuum Grease is an NSF registered Food Grade lubricant, rated H1 for incidental food contact. Meets former USDA (H1) guidelines. It is translucent white, clean and clear in appearance and exhibits high dielectric strength. It is compatible with most plastics and rubbers.

FEATURES:

- High dielectric strength
- Food grade and clean
- Seals out moisture
- Resistant to thermal degradation
- Heavy consistency
- Low vapor pressure
- High resistance to water and chemicals
- Protects electrical components from corrosion
- Prevents electrical arcing
- Wide temperature range
- Low volatility
- Low outgassing
- High resistance to high and low temperatures
- Compatible with majority of rubber and plastic compounds
- Environmentally friendly
- Kosher certified
- NSF Registered (H1), #141973

TECHNICAL DATA SHEET

SUPER LUBE® SILICONE DIELECTRIC AND VACUUM GREASE October 2020

TYPICAL APPLICATIONS:

- Electrical insulation, damping and lubrication of brass components
- Electrical assemblies and terminals
- Rubber gaskets
- Control valves
- Flow Meter Bearings
- Battery cables, spark plugs and distributor caps
- Sealing and insulation
- Light bulbs
- Cable connections
- Terminal strips and disconnects
- Stopcock grease
- Motorized actuators
- Glass to rubber boundaries
- Ceramic plug gaskets
- Sealing of chemical process equipment
- Food processing equipment
- Water treating equipment
- Sealing of vacuum pressure systems
- Plug valves

PACKAGE SIZES:

Part No.	Description	Part No.	Description
91003	3 oz. Tube	**91400**	400 lb. Drum
91015	400 gram Cartridge	**91015/UV***	400 gram Cartridge
91016	400 gram Canister	**91016/UV***	400 gram Canister
91005	5 lb. Pail	**91005/UV***	5 lb. Pail
91030	30 lb. Pail	**91030/UV***	30 lb. Pail
91120	120 lb. Keg		

***UV tracer added validates the existence of the lubricant.**

PROPERTIES:

Test	Test Method	Rating
NLGI Grade:	ASTM D1092	2
Color:		Translucent white
Temperature Range:		-40°F to 500°F (-40°C to 260°C)
Viscosity (Base Oil) cSt @ 25°C:	ASTM D445	5000
Specific Gravity @ 25°C (77°F):	ASTM D1298	1.07
Penetration, Worked 60 strokes:	ASTM D217	265 – 295
Specific Heat (Joules/g,°C)		1.5
Thermal Conductivity (Watts/Meter K):	PLTL-73	0.16
Dielectric Strength		

TECHNICAL DATA SHEET

SUPER LUBE® SILICONE DIELECTRIC AND VACUUM GREASE October 2020

(Volts/mil, 50 mil gap):	CTM 0114	400
Dielectric Loss:	ASTM D924	1.2 x 10^{12}
Dielectric Resistivity @ 25°C (ohm/cm):	ASTM D1169	1 x 10^{15}
Dielectric Constant @25°C between 0.5 and 100 kHz:	ASTM D924	2.8
Oil Separation, 21 hrs. / 100°C:	ASTM D6184	0%
Evaporation Loss 22 hrs. @ 212°F (100°C)	ASTM D972	0.4%
Vapor Pressure @ 25°C:		5 x $10^{(-10)}$ Torr
Bleed:		NIL
Outgassing Characteristics:	ASTM E595	TML < 1.0% CVCM < 0.1%
Flash Point:	ASTM D92	>572°F (300°C)
Melting Point:		No Melt
Water Washout:	ASTM D1264	< 1%

DIRECTIONS:

- Clean mating surfaces.
- Apply evenly to surfaces.

SHELF LIFE / WARRANTY:

Super Lube® products have a five (5) year recommended shelf life when stored in the original container and in reasonable ambient conditions. The warranty period is twenty-four (24) months from the date of purchase. For complete information visit www.super-lube.com/what-is-the-shelf-life-ezp-320.html.

See Safety Data Sheet (SDS) for further details regarding safe use of this product.

Made in USA

The information provided in this Technical Data Sheet including the recommendations for use and application of the product are based on our knowledge and experience of the product as of the date of this bulletin. The product can have a variety of different applications as well as differing application and working conditions in your environment that are beyond our control. Synco Chemical Corporation is, therefore not liable for the suitability of our product for the production processes and conditions in respect for which you use them, as well as the intended applications and results. We strongly recommend that you carry out your own prior trials to confirm such suitability of our product.

24 DaVinci Drive, P.O. Box 405, Bohemia NY, 11716
T: (631) 567-5300 F: (631) 567-5359 E: info@super-lube.com

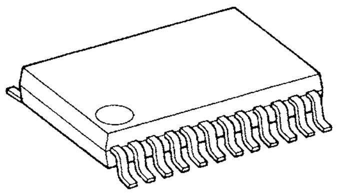
D.13 TB6612FNG Driver IC for Dual DC motor

Toshiba Bi-CD Integrated Circuit Silicon Monolithic

TB6612FNG

Driver IC for Dual DC motor

TB6612FNG is a driver IC for DC motor with output transistor in LD MOS structure with low ON-resistor. Two input signals, IN1 and IN2, can choose one of four modes such as CW, CCW, short brake, and stop mode.



SSOP24-P-300-0.65A

質量: 0.14 g (標準)

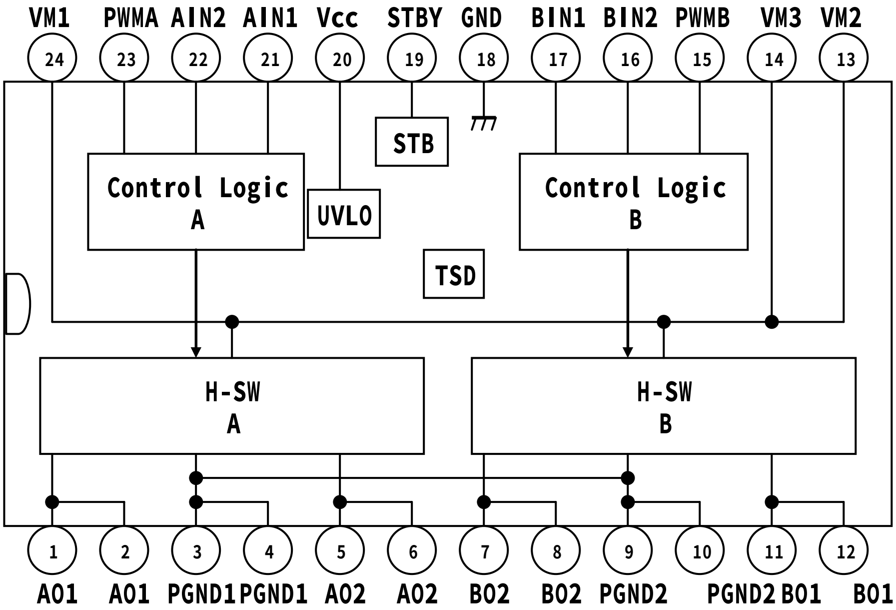
Features

- Power supply voltage ; VM=15V（Max.）
- Output current ; Iout=1.2A(ave) / 3.2A (peak)
- Output low ON resistor ; 0.5Ω (upper＋lower Typ. @VM≧ 5V)
- Standby (Power save) system
- CW/CCW/short brake/stop function modes
- Built-in thermal shutdown circuit and low voltage detecting circuit
- Small faced package（SSOP24：0.65mm Lead pitch）
- Response to Pb free packaging

* This product has a MOS structure and is sensitive to electrostatic discharge. When handling this product, ensure that the environment is protected against electrostatic discharge by using an earth strap, a conductive mat and an ionizer. Ensure also that the ambient temperature and relative humidity are maintained at reasonable levels.

The TB6612FNG is a Pb-free product.
The following conditions apply to solderability:
*Solderability
1. Use of Sn-37Pb solder bath
   *solder bath temperature = 230°C
   *dipping time = 5 seconds
   *number of times = once
   *use of R-type flux
2. Use of Sn-3.0Ag-0.5Cu solder bath
   *solder bath temperature = 245°C
   *dipping time = 5 seconds

Block Diagram



Pin Functions

Pin NO.	Symbol	I/O	Remarks
1	AO1	O	chA output1
2	AO1		
3	PGND1	—	Power GND 1
4	PGND1		
5	AO2	O	chA output2
6	AO2		
7	BO2	O	chB output2
8	BO2		
9	PGND2	—	Power GND 2
10	PGND2		
11	BO1	O	chB output1
12	BO1		
13	VM2	—	Motor supply (2.5V～13.5V)
14	VM3		
15	PWMB	I	chB PWM input / 200kΩ pull-down at internal
16	BIN2	I	chB input2 / 200kΩ pull-down at internal
17	BIN1	I	chB input1 / 200kΩ pull-down at internal
18	GND	—	Small signal GND
19	STBY	I	"L"=standby / 200kΩ pull-down at internal
20	Vcc	—	Small signal supply (2.7V～5.5V)
21	AIN1	I	chA input1 / 200kΩ pull-down at internal
22	AIN2	I	chA input2 / 200kΩ pull-down at internal
23	PWMA	I	chA PWM input / 200kΩ pull-down at internal
24	VM1	—	Motor supply (2.5V～13.5V)

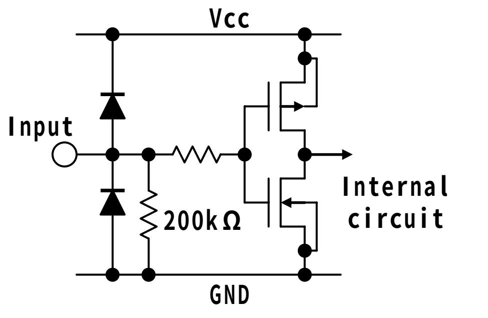
Absolute Maximum Ratings (Ta = 25°C)

Characteristics	Symbol	Rating	Unit	Remarks
Supply voltage	VM	15	V	
	Vcc	6		
Input voltage	VIN	-0.2〜6	V	IN1,IN2,STBY,PWM pins
Output voltage	Vout	15	V	O1,O2 pins
Output current	Iout	1.2	A	Per 1ch
	Iout (peak)	2		tw=20ms Continuous pulse, Duty≦20%
		3.2		tw=10ms Single pulse
Power dissipation	PD	0.78	W	IC only
		0.89		50×50 t=1.6(mm) Cu≧40% in PCB mounting
		1.36		76.2×114.3 t=1.6(mm) Cu≧30% in PCB monting
Operating temperature	Topr	-20〜85	℃	
Storage temperature	Tstg	-55〜150	℃	

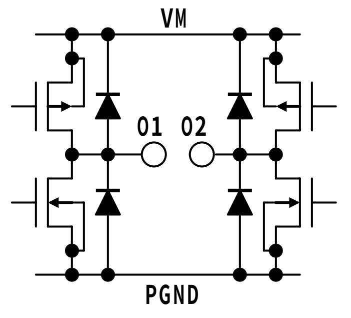
Operating Range (Ta=-20〜85℃)

Characteristics	Symbol	Min	Typ.	Max	Unit	Remarks
Supply voltage	Vcc	2.7	3	5.5	V	
	VM	4.5	5	13.5	V	
Output current (H-SW)	Iout	---	---	1.0	A	VM≧5V
		---	---	0.4		5V>VM≧4.5V
Switching frequency	fPWM	---	---	100	kHz	

Input pin; IN1,IN2,PWM,STBY



Output pin; O1,O2

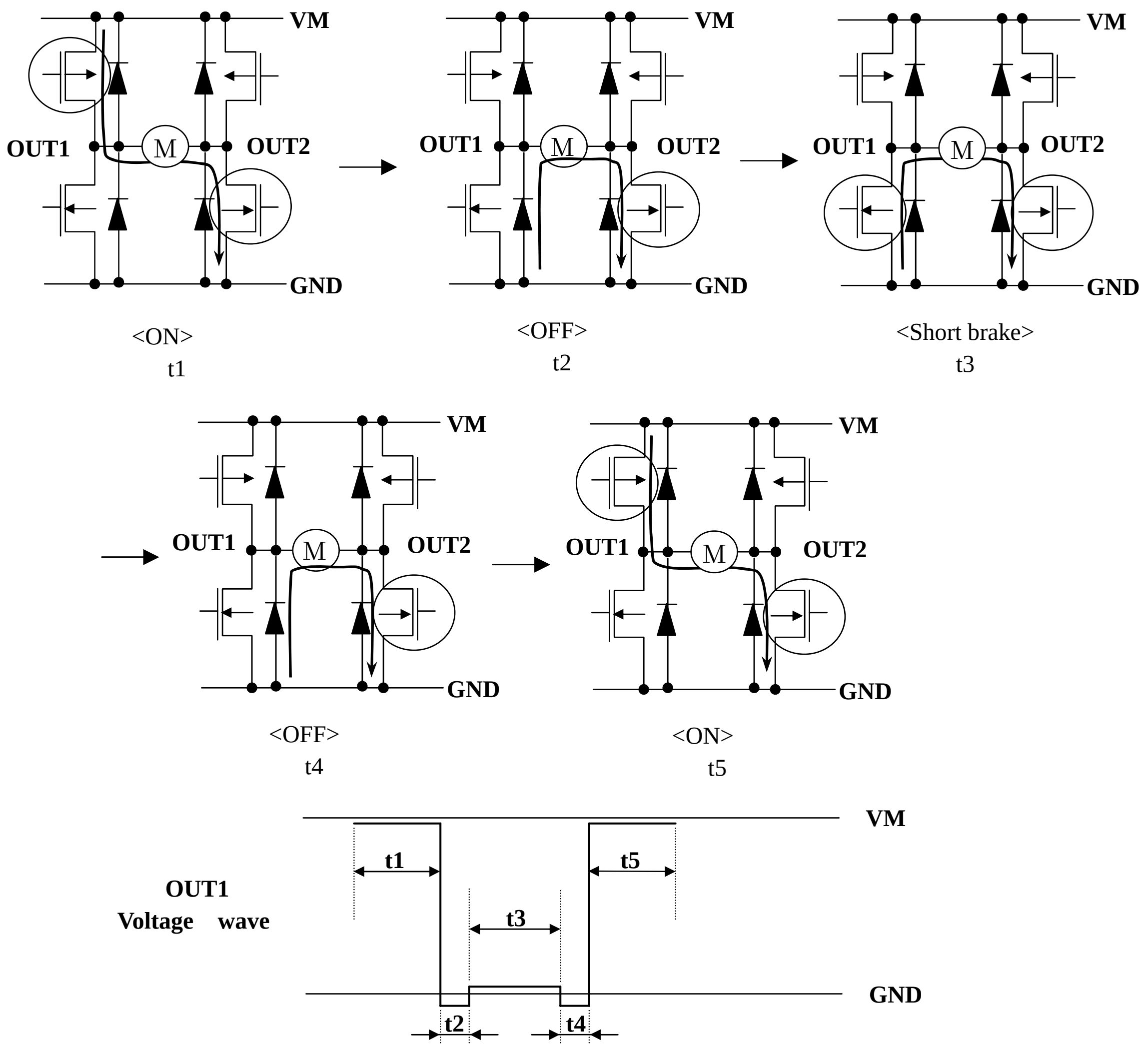


H-SW Control Function

Input				Output		
IN1	IN2	PWM	STBY	OUT1	OUT2	Mode
H	H	H/L	H	L	L	Short brake
L	H	H	H	L	H	CCW
		L	H	L	L	Short brake
H	L	H	H	H	L	CW
		L	H	L	L	Short brake
L	L	H	H	OFF (High impedance)		Stop
H/L	H/L	H/L	L	OFF (High impedance)		Standby

H-SW Operating Description

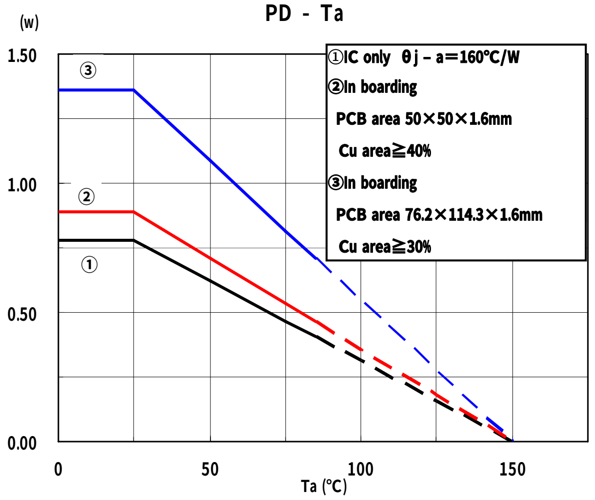
・To prevent penetrating current, dead time t2 and t4 is provided in switching to each mode in the IC.

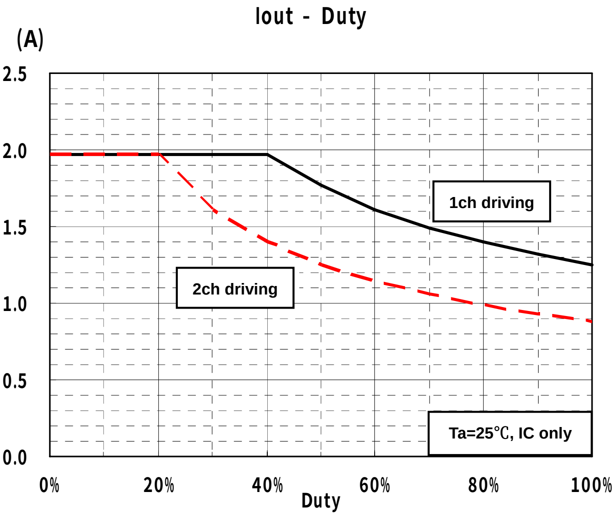


Electrical Characteristics (unless otherwise specified, Ta = 25°C, V_{CC}=3V, VM=5V)

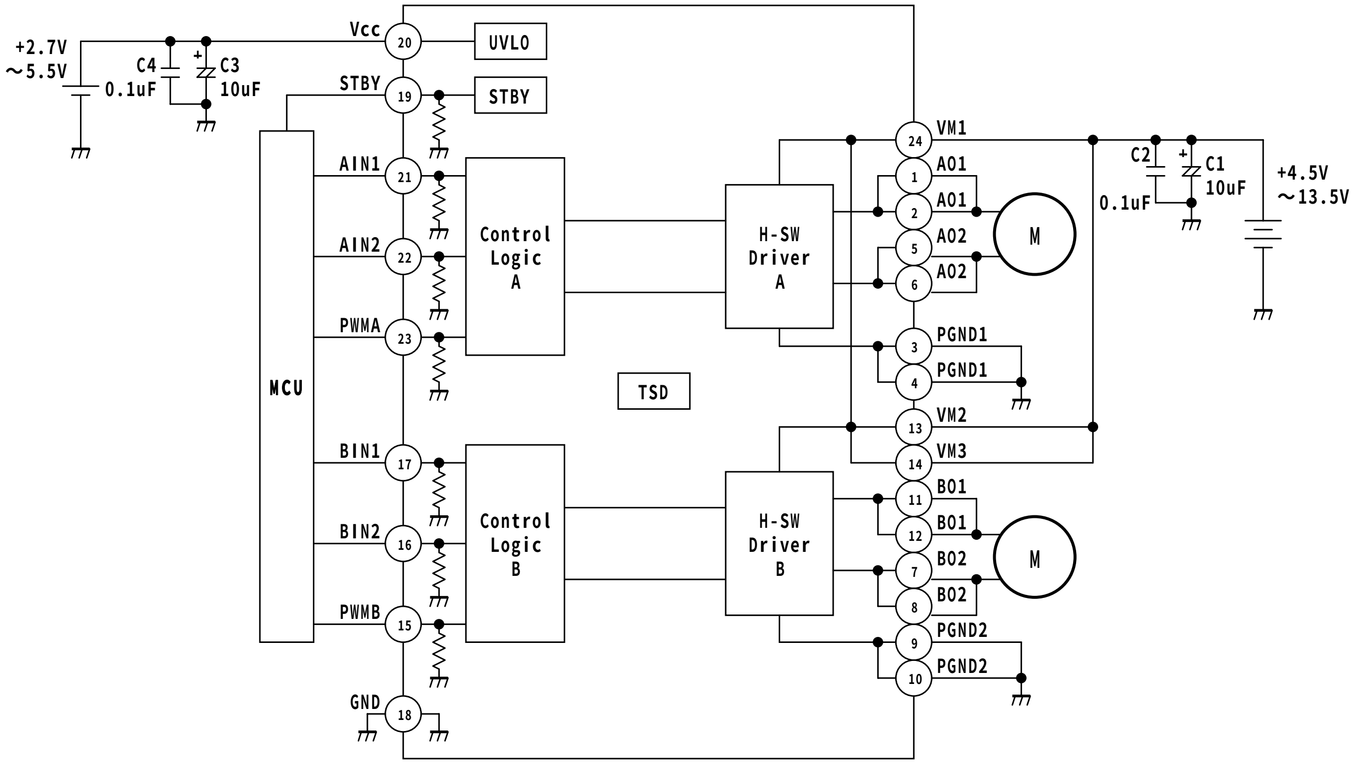
Characteristics	Symbol		Test Condition	Min	Typ.	Max	Unit
Supply current	Icc(3V)		STBY=Vcc=3V, VM=5V	---	1.1	(1.8)	mA
	Icc(5.5V)		STBY=Vcc=5.5V, VM=5V	---	1.5	2.2	
	Icc(STB)		STBY=0V	---	---	1	μA
	IM(STB)			---	---	1	
Control input voltage	VIH			Vcc×0.7	---	Vcc+0.2	V
	VIL			-0.2	---	Vcc×0.3	
Control input current	IIH		VIN=3V	5	15	25	μA
	IIL		VIN=0V	---	---	1	
Standby input voltage	VIH(STB)			Vcc×0.7	---	Vcc+0.2	V
	VIL(STB)			-0.2	---	Vcc×0.3	
Standby input current	IIH(STB)		VIN=3V	5	15	25	μA
	IIL(STB)		VIN=0V	---	---	1	
Output saturating voltage	Vsat(U+L)1		Io=1A,Vcc=VM=5V	---	0.5	(0.7)	V
	Vsat(U+L)2		Io=0.3A,Vcc=VM=5V		0.15	(0.21)	
Output leakage current	IL(U)		VM=Vout=15V	---	---	1	μA
	IL(L)		VM=15V,Vout=0V	-1	---	---	
Regenerative diode VF	VF(U)		IF=1A	---	1	1.1	V
	VF(L)			---	1	1.1	
Low voltage detecting voltage	UVLD		(Designed value)	---	1.9	---	V
Recovering voltage	UVLC			---	2.2	---	
Response speed	tr		(Designed value)	---	24	---	ns
	tf			---	41	---	
	Dead time	H to L	Penetration protect time (Designed value)	---	(50)	---	
		L to H		---	(230)	---	
Thermal shutdown circuit operating temperature	TSD		(Designed value)	---	175	---	°C
Thermal shutdown hysteresis	△ TSD			---	20	---	

Target characteristics



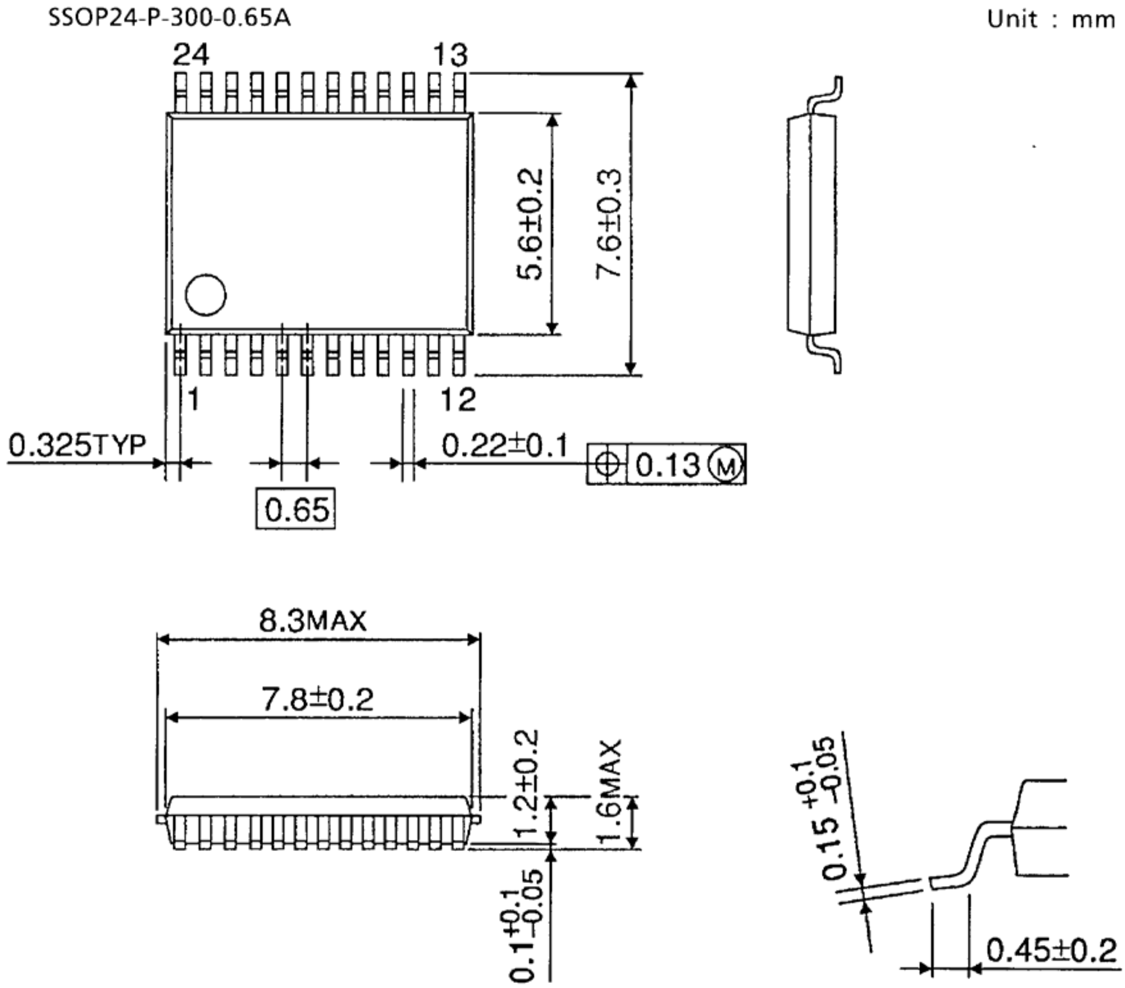


Typical Application Diagram



Note: Condensers for noise absorption (C1, C2, C3, and C4) should be connected as close as possible to the IC.

Package Dimennsions



Weght: 0.14 g (typ)

Notes on Contents

1. Block Diagrams

Some of the functional blocks, circuits, or constants in the block diagram may be omitted or simplified for explanatory purposes.

2. Equivalent Circuits

The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

3. Timing Charts

Timing charts may be simplified for explanatory purposes.

4. Application Circuits

The application circuits shown in this document are provided for reference purposes only. Thorough evaluation is required, especially at the mass production design stage.

Toshiba does not grant any license to any industrial property rights by providing these examples of application circuits.

5. Test Circuits

Components in the test circuits are used only to obtain and confirm the device characteristics. These components and circuits are not guaranteed to prevent malfunction or failure from occurring in the application equipment.

IC Usage Considerations

Notes on handling of ICs

[1] The absolute maximum ratings of a semiconductor device are a set of ratings that must not be exceeded, even for a moment. Do not exceed any of these ratings.
Exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result injury by explosion or combustion.

[2] Use an appropriate power supply fuse to ensure that a large current does not continuously flow in case of over current and/or IC failure. The IC will fully break down when used under conditions that exceed its absolute maximum ratings, when the wiring is routed improperly or when an abnormal pulse noise occurs from the wiring or load, causing a large current to continuously flow and the breakdown can lead smoke or ignition. To minimize the effects of the flow of a large current in case of breakdown, appropriate settings, such as fuse capacity, fusing time and insertion circuit location, are required.

[3] If your design includes an inductive load such as a motor coil, incorporate a protection circuit into the design to prevent device malfunction or breakdown caused by the current resulting from the inrush current at power ON or the negative current resulting from the back electromotive force at power OFF. IC breakdown may cause injury, smoke or ignition.
Use a stable power supply with ICs with built-in protection functions. If the power supply is unstable, the protection function may not operate, causing IC breakdown. IC breakdown may cause injury, smoke or ignition.

[4] Do not insert devices in the wrong orientation or incorrectly.
Make sure that the positive and negative terminals of power supplies are connected properly.
Otherwise, the current or power consumption may exceed the absolute maximum rating, and exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result injury by explosion or combustion.
In addition, do not use any device that is applied the current with inserting in the wrong orientation or incorrectly even just one time.

Points to remember on handling of ICs

(1) Thermal Shutdown Circuit

Thermal shutdown circuits do not necessarily protect ICs under all circumstances. If the thermal shutdown circuits operate against the over temperature, clear the heat generation status immediately.

Depending on the method of use and usage conditions, such as exceeding absolute maximum ratings can cause the thermal shutdown circuit to not operate properly or IC breakdown before operation.

(2) Heat Radiation Design

In using an IC with large current flow such as power amp, regulator or driver, please design the device so that heat is appropriately radiated, not to exceed the specified junction temperature (T_J) at any time and condition. These ICs generate heat even during normal use. An inadequate IC heat radiation design can lead to decrease in IC life, deterioration of IC characteristics or IC breakdown. In addition, please design the device taking into considerate the effect of IC heat radiation with peripheral components.

(3) Back-EMF

When a motor rotates in the reverse direction, stops or slows down abruptly, a current flow back to the motor’s power supply due to the effect of back-EMF. If the current sink capability of the power supply is small, the device’s motor power supply and output pins might be exposed to conditions beyond maximum ratings. To avoid this problem, take the effect of back-EMF into consideration in system design.

RESTRICTIONS ON PRODUCT USE

070122EBA_R6

- The information contained herein is subject to change without notice. 021023_D
- TOSHIBA is continually working to improve the quality and reliability of its products. Nevertheless, semiconductor devices in general can malfunction or fail due to their inherent electrical sensitivity and vulnerability to physical stress. It is the responsibility of the buyer, when utilizing TOSHIBA products, to comply with the standards of safety in making a safe design for the entire system, and to avoid situations in which a malfunction or failure of such TOSHIBA products could cause loss of human life, bodily injury or damage to property.
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- The products described in this document are subject to foreign exchange and foreign trade control laws. 060925_E

D.14 FireSting-PRO Optical Multi-Analyte Meter

pyroscience
sensor technology

FireSting-PRO
Optical Multi-Analyte Meter

USER MANUAL

O_2 pH T

FireSting-PRO

Optical Multi-Analyte Meter

Document Version 1.05

The FireSting-PRO is released by:

PyroScience GmbH
Hubertusstrasse 35
52064 Aachen
Germany

Phone	+49 (0)241 5183 2210
Fax	+49 (0)241 5183 2299
Email	info@pyroscience.com
Web	www.pyroscience.com

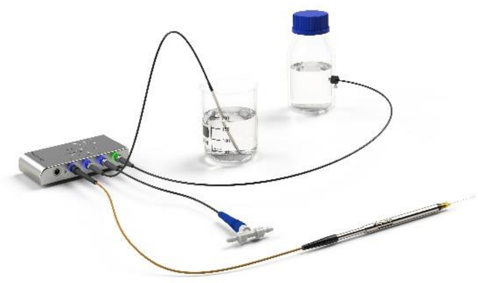
Registered: Aachen HRB 17329, Germany

TABLE OF CONTENT

1 OVERVIEW

The compact USB-powered fiber-optic meter **FireSting-PRO** with 1, 2, or 4 channels for multiple analytes and sensor heads features:

- freely configurable channels for O_2, pH and temperature
- broad optical sensor portfolio (multiple fiber-based and contactless sensor heads for several ranges)
- with (ultra-)high speed sampling
- zero-noise and zero-latency temperature compensation
- improved ambient light suppression and
- smart measuring modes for prolonged sensor lifetime
- pH, oxygen and temperature determination simultaneously in one sample

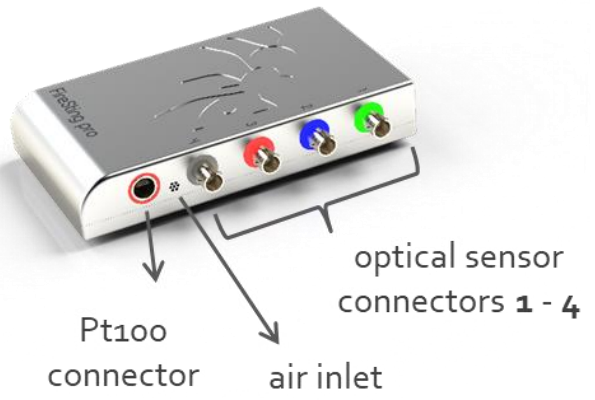


This single-device solution for multi-analyte measurements has integrated atmospheric pressure and humidity sensors for precise and easy oxygen sensor calibration, but also for automatic pressure compensation of the oxygen measurements. Furthermore, the **FireSting-PRO** offers 4 analog outputs and a broadcast-mode.

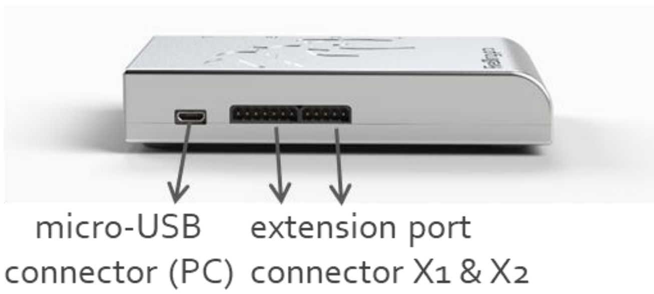
The new innovative and user-friendly **Pyro Workbench** allows operation of several **FireSting-PRO** meters in parallel as a scalable multi-channel system.

2 INTRODUCTION

The **FireSting-PRO** comes with 1, 2, or 4 channels (optical sensor ST-connectors **1** to **4**) for up to 4 fiber-optic sensors and one connector (**T**) for an external Pt100 temperature probe. The optical channel connectors are color coded, indicating the analyte (**oxygen**, **pH** or **temperature**), which is currently measured and can be changed for each channel. The air inlet equilibrates the internal temperature, pressure and humidity sensors with the surrounding. Avoid covering these holes to ensure free air circulation towards the internal sensors.



The micro-USB connector on the left side panel provides energy supply and data exchange with the PC. Right-hand side of it, a connector **X1** for power and digital interface (7-pins) and a connector **X2** for analog output (5 pins) is located.



3 QUICK START

Step 1: Download the correct software and manual from the downloads tab of your purchased device on www.pyroscience.com

Step 2: Connect the **FireSting-PRO** meter with the micro-USB cable to the Windows PC/laptop (Windows 7, 8, 10).

Step 3: Connect appropriate **PyroScience** sensor(s) to the optical sensor connectors **1** to **4** at the device (see 4).

Step 4: Connect an external temperature sensor (item no. **TDIP15** or **TSUB21**) to the Pt100 connector or, alternatively, an optical temperature sensor (see 5) to one of the optical sensor connectors **1** to **4** for automatic temperature compensation.

Step 5: Prepare appropriate calibration standards, as described in the respective sensor manuals (see 8).

Step 6: Start the logger software by clicking on the short-cut "**Pyro Workbench**" on your desktop.

Step 7: Open the **Settings Wizard** by clicking on the **FireSting-PRO** picture**.** Select the **respective analyte** and enter all sensor settings for each sensor, including an appropriate mode of temperature compensation.

Step 8: Open the **Calibration Wizard** and follow the calibration instructions for each sensor. Measurements with the respective sensors will start automatically after all required sensor calibrations have been performed.

Step 9: Configure the **Graphs** according to your preferences.

Step 10: Activate **Data Logging**.

4 CONNECTING SENSORS

The fiber-optic oxygen, pH and temperature sensors, as well as optical fibers needed for read-out of contactless sensors are connected to the ST-connectors of the **FireSting-PRO** (**1** to **4**) with a male fiber plug.

- Remove the black caps from the plug of the sensor / fiber.
- Remove the red caps from the sensor ports at the **FireSting-PRO** (the red caps should be put on again if it is not in use anymore to protect the optics).
- Insert the male fiber plug of the sensor cable into the ST-port (female fiber connector) of the **FireSting-PRO** and turn the bayonet coupling gently clockwise until the plug is locked firmly.

5 OPTICAL SENSORS

The **FireSting-PRO** is compatible with a broad range of optical oxygen, pH and temperature sensors from **PyroScience.** For an overview of available optical sensor types, please see the **PyroScience** website.

5.1 Fiber-optic Sensors

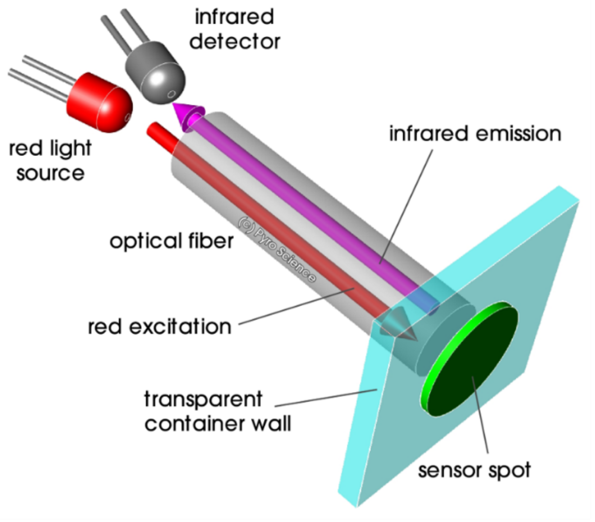
Sensor	Item	Analyte	Application
Miniprobes	**OXROB…**	**O_2**	stirred water, gas
	+PHROB …	**pH**	water & media
Retractable Tip Minisensors	***OXR…**	**O_2**	water, gas & semi-solid samples
	TPR…	**Temp.**	
Fixed Tip Minisensors	***OXF…**	**O_2**	water, gas & semi-solid samples (esp. seawater)
	TPF…	**Temp.**	
	OXF…-PT	**O_2**	gas (puncturing septa/packaging)
Bare Fiber Minisensors	**OXB…**	**O_2**	water, gas & custom
	TPB…	**Temp.**	
Solvent-Resistant Probes	**OXSOLV**	**O_2**	approved polar and non-polar solvents
	OXSOLV-PTS	**O_2**	approved solvent vapours

* also as Microsensor; + different pH ranges; **water**=water, seawater, aqueous solutions

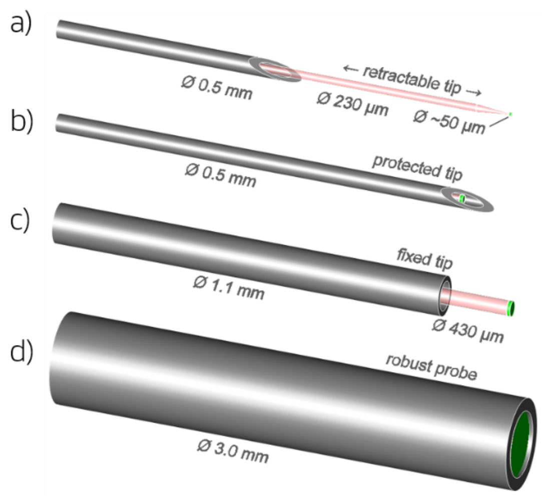
5.2 Contactless Sensors

Sensor	Item	Analyte	Application
Nanoprobes	**OXNANO**	O_2	aqueous solutions & microfluidics
Sensor Spots	**OXSP5**	O_2	water & gas
	TPSP5	**Temp.**	
	***PHSP5…**	**pH**	water & media
Sensor Vials	**OXVIAL…**	O_2	water & gas
	TOVIAL…	**Temp.** & O_2	
	+PHVIAL…	**pH**	water & media
	+PHTVIAL…	**Temp.** & **pH**	
	+PHTOVIAL…	**Temp.** & **pH** & O_2	
Flow-Through Cells	**OXFTC…**	O_2	water & gas
	OXFTCR		
	TPFTC2	**Temp.**	
	TOFTC2	**Temp.** & O_2	
	+PHFTCR…	**pH**	water & media

\+ different pH ranges; **water**=water, seawater, aqueous solutions



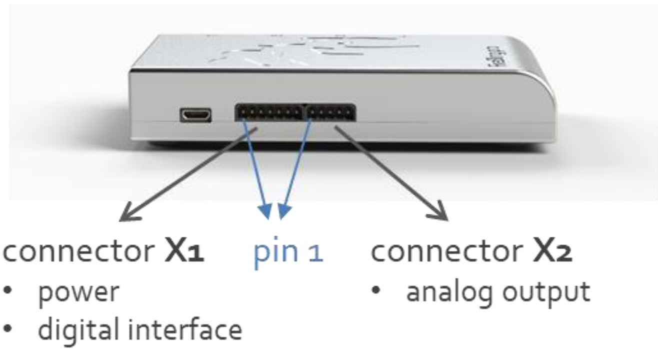
Principle of contactless read-out of sensor spots and sensor vials



Examples of available sensor tips:
a) retractable microsensor **b)** fixed minisensor with protected tip and with **c)** protruding sensor tip, **d)** robust probe

6 EXTENSION PORT

The extension port of the **FireSting-PRO** consists of the two connectors **X1** and **X2** (fitting connector plugs can be obtained from **Phoenix Contact** item **no. 1778887** and **1778861**).



6.1 Connector X1 (Power, Digital Interface, Analog In)

The pin configuration of the connector **X1** is given in the table below. Pins 1-2 (GND and VCC) can be used for providing an external power supply (3.5…5.0 VDC), if the **FireSting-PRO** should not be powered via the USB port. The transmit and receive pins of the UART-interface are given at pins 4 (TXD) and 5 (RXD) (communication protocol on request). When using the UART-interface it is recommended to connect pin 3 (/USB_DISABLE) to pin 1 (GND), which disables the USB interface.

Pin 6 (/PAUSE_BROADCAST) and Pin 7 (/TRIGIN) are related to the so called “broadcast mode” which can be configured in the PC control software (e.g. **Pyro Workbench** or **Pyro Developer Tool**). During broadcast mode, the device triggers itself periodic measurements which can be read out from the analog outputs or from a text message transmitted via the USB/UART interface. For more details refer to the manual of the respective control software are to the communication protocol (available on request).

Pin 7 (/TRIGIN) acts as a trigger input for the broadcast mode. Note, the option “Enable Trigin” must be enabled in the broadcast settings in the control software. Every time this pin is connected to pin 1 (GND) then an additional broadcast measurement is triggered.

Pin 6 (/PAUSE_BROADCAST) acts as a master switch of the broadcast mode. As long this pin is tied to pin 1 (GND), then the broadcast mode is paused. Neither periodic broadcast measurements, nor triggered broadcast measurements are performed.

Pin	Name	Function	Description
1	GND	Power	Ground
2	VCC	Power	Power supply, 3.5V to 5.0V DC max. 70 mA (typ. 40 mA)
3	/USB_DISABLE	Digital Input	Connect to GND for disabling the USB interface
4	TXD	Digital Output (UART TX)	UART interface with 3.3V levels (5V tolerant), baud rate 115200, 8 data bits, 1 stop bit, no parity, no handshake.
5	RXD	Digital Input (UART RX)	Reduce humidity in the environment of the device.
6	/PAUSE_ BROADCAST	Digital Input (0V or 3.3V, internally pulled-up to 3.3V)	Connect to GND for pausing any broadcast-mode operation.
7	/TRIGIN	Digital Input (0V or 3.3V, internally pulled-up to 3.3V)	Triggers a broadcast measurement every time, when this pin is tied to GND.

6.2 Connector X2 (Analog Output)

The connector **X2** provides 4 analog outputs with a range of 0-2.5V DC at a resolution of 14 bits (see table below). Refer to the **Pyro Workbench** manual how to configure the analog outputs.

Pin	Name	Function	Description
1	GND		Ground
2	AO_A	Analog Output (0 – 2.5 V DC) (14-bit resolution)	Analog Output Port A (alternatively digital alarm output)
3	AO_B	Analog Output (0 – 2.5 V DC) (14-bit resolution)	Analog Output Port B (alternatively digital alarm output)
4	AO_C	Analog Output (0 – 2.5 V DC) (14-bit resolution)	Analog Output Port C (alternatively digital alarm output)
5	AO_D	Analog Output (0 – 2.5 V DC) (14-bit resolution)	Analog Output Port D (alternatively digital alarm output)

7 SPECIFICATIONS

Feature	Specification
Dimensions	68 x 120 x 22 mm (housing) 78 x 120 x 24 (total)
Weight	ca. 290 g
Interface	USB 2.0
Power supply	USB-powered (max 50mA at 5V)
Supported operating systems	Windows 7, 8, 10
Operating temperature	0 to 50°C
Max. relative humidity	non-condensing conditions
Optical sensor port	1, 2, or 4 (dependent on model)
Optical sensors	complete **PyroScience** sensor portfolio for O_2, pH & T
Optical sensor connector	fiber-optic ST-plug
Max. sample rate	ca. 10 samples per second (depending on Settings)
External temperature port Range, Resolution, Accuracy*	1 channel for 4-wire Pt100 -30°C to 150°C, 0.02°C, ±0.5°C
Internal temperature sensor Range, Resolution, Accuracy*	-40 to 125°C, 0.01°C, ±0.3°C
Internal pressure sensor Range, Resolution, Accuracy	300 to 1100 mbar, 0.1 mbar, typ. ±3 mbar
Internal humidity sensor Range, Resolution, Accuracy	0 to 100% rel. humidity (RH), 0.04% RH, typ. ±0.2% RH
Digital interface at extension port **X1** (7 pins)	UART with 3.3V levels (5V tolerant), 115 200 baud, 8 data bit, 1 stop bit, no parity, no handshake

Connector plug port **X1**	Phoenix Contact, item no. 1778887
Analog output (4 channels) at extension port **X2** (5 pins)	0 to 2.5 VDC 14-bit resolution
Connector plug port **X2**	Phoenix Contact, item no. 1778861

8 RELATED DOCUMENTS

Detailed instructions for using the **Pyro Workbench** and application of optical oxygen, pH and temperature sensors:

- manual for logger software "**Pyro Workbench**" (Windows)
- manuals for optical sensors from **PyroScience** (oxygen, pH, temperature)

9 WARNINGS & SAFETY GUIDELINES

Before using the FireSting-PRO and its sensors, read carefully the instructions and user manuals.

In case of problems or damage, disconnect the instrument and mark it to prevent any further use! Consult **PyroScience** for advice! There are no serviceable parts inside the device. Please note that opening the housing will void the warranty!

The FireSting-PRO is not watertight, is sensitive to corrosive conditions and to changes in temperature causing condensation. Avoid any condition (e.g. direct sun light) causing a heating of the device above 50°C (122°F) or below 0°C (32°F). Avoid any elevated humidity causing condensing conditions.

Handle the sensors with care especially after removal of the protective cap! Prevent mechanical stress to the fragile sensing tip! Prevent injuries with needle-type sensors!

Calibration and application of the sensors is on the user's authority, as well as data acquisition, treatment & publication!

The optical sensors and meter **FireSting-PRO** are **not** intended for medical, diagnostic, therapeutic, or military purposes or any other safety-critical applications. The sensors must **not** be used for applications in humans and must not be brought in direct contact with foods intended for consumption by humans.

The FireSting-PRO and optical sensors should be used in the laboratory by qualified personnel only, following the user instructions and the safety guidelines of the manual, as well as the appropriate laws and guidelines for safety in the laboratory!

Keep the sensors and the fiber-optic meter **FireSting-PRO** out of reach of children!

CONTACT

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Deutschland

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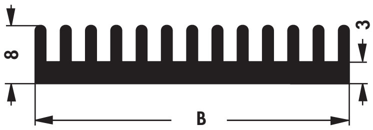
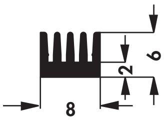
Fax: +49 (0)241 5183 2299
info@pyroscience.com
www.pyroscience.com

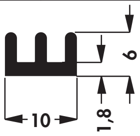
D.15 Fischer Elektronik, Heatsinks for SMD



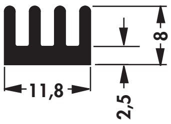
art. no.	↔ [mm]	R_{th} [K/W]	art. no.	↔ [mm]	R_{th} [K/W]
ICK SMD E 15 SA	15.3	27	**ICK SMD E 29 SA**	29.0	18
ICK SMD E 22 SA	22.3	21			



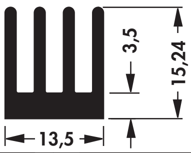
art. no.	↔ [mm]	R_{th} [K/W]	art. no.	↔ [mm]	R_{th} [K/W]
ICK SMD F 8 ...	8	74	**ICK SMD F 19 ...**	19	37
ICK SMD F 10 ...	10	71	**ICK SMD F 21 ...**	21	33
ICK SMD F 17 SA	17	42	**ICK SMD F 26 ...**	26	26



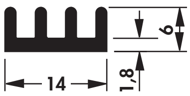
art. no.	↔ [mm]	R_{th} [K/W]	art. no.	↔ [mm]	R_{th} [K/W]
ICK SMD G 8 MI	8	73	**ICK SMD G 17 SA**	17	41
ICK SMD G 10 ...	10	70	**ICK SMD G 19 SA**	19	36
ICK SMD G 13 SA	13	61	**ICK SMD G 21 ...**	21	32



art. no.	↔ [mm]	R_{th} [K/W]	art. no.	↔ [mm]	R_{th} [K/W]
ICK SMD H 8 ...	8	33.0	**ICK SMD H 19 SA**	19	23.0
ICK SMD H 10 ...	10	29.0	**ICK SMD H 25 ...**	25	20.0
ICK SMD H 17 ...	17	24.5			



art. no.	↔ [mm]	R_{th} [K/W]	art. no.	↔ [mm]	R_{th} [K/W]
ICK SMD K 8 ...	8	25.6	**ICK SMD K 17 ...**	17	19.4
ICK SMD K 10 SA	10	23.4	**ICK SMD K 19 ...**	19	18.0
ICK SMD K 13 ...	13	21.5	**ICK SMD K 21 ...**	21	16.5



art. no.	↔ [mm]	R_{th} [K/W]	art. no.	↔ [mm]	R_{th} [K/W]
ICK SMD M 8 SA	8	72	**ICK SMD M 19 SA**	19	35
ICK SMD M 10 SA	10	66	**ICK SMD M 21 SA**	21	31
ICK SMD M 17 MI	17	40			

please indicate: **... surface**
SA = black anodised
MI = solderable surface

Extruded heatsinks → **A 22 – 83**
Pin heatsinks for IC → **B 21 – 27**
Insulting clamping parts → **E 43**
Thermal conductive glue → **E 21 – 22**
Thermally conductive foil → **E 5 – 13**
Thermal conductive paste → **E 19 – 20**
Hole pattern → **A 21**
Technical introduction → **A 2 – 7**

Figure D.9: 250V3A 6 mm Switch.

Appendix E

Formlabs

E.1 Standard Clear Resin

MATERIAL DATA SHEET

Standard

Materials for High-Resolution Rapid Prototyping

High Resolution. For demanding applications, our carefully-engineered resins capture the finest features in your model.

Strength and Precision. Our resins create accurate and robust parts, ideal for rapid prototyping and product development.

Surface Finish. Perfectly smooth right out of the printer, parts printed on the Form 2 printer have the polish and finish of a final product.

CLEAR	WHITE	GREY	BLACK	COLOR
FLGPCL04	FLGPWH04	FLGPGR04	FLGPBL04	FLGPCB01

Prepared 04 . 19 . 2016
Rev 01 04 . 18 . 2017

Material Properties Data

The following material properties are comparable for all Formlabs Standard Resins.

	METRIC[1]		IMPERIAL[1]		METHOD
	Green[2]	Post-Cured[3]	Green[2]	Post-Cured[3]	
Tensile Properties					
Ultimate Tensile Strength	38 MPa	65 MPa	5510 psi	9380 psi	ASTM D 638-10
Tensile Modulus	1.6 GPa	2.8 GPa	234 ksi	402 ksi	ASTM D 638-10
Elongation at Failure	12 %	6.2 %	12 %	6.2 %	ASTM D 638-10
Flexural Properties					
Flexural Modulus	1.25 GPa	2.2 GPa	181 ksi	320 ksi	ASTM C 790-10
Impact Properties					
Notched IZOD	16 J/m	25 J/m	0.3 ft-lbf/in	0.46 ft-lbf/in	ASTM D 256-10
Temperature Properties					
Heat Deflection Temp. @ 264 psi	42.7 °C	58.4 °C	108.9 °F	137.1 °F	ASTM D 648-07
Heat Deflection Temp. @ 66 psi	49.7 °C	73.1 °C	121.5 °F	163.6 °F	ASTM D 648-07

[1] Material properties can vary with part geometry, print orientation, print settings, and temperature.

[2] Data was obtained from green parts, printed using Form 2, 100 µm, Clear settings, washed and air dried without post cure.

[3] Data was obtained from parts printed using Form 2, 100 µm, Clear settings, and post-cured with 1.25 mW/cm^2 of 405 nm LED light for 60 minutes at 60 °C.

Solvent Compatibility

Percent weight gain over 24 hours for a printed and post-cured 1 x 1 x 1 cm cube immersed in respective solvent:

Solvent	24 Hour Weight Gain (%)	Solvent	24 Hour Weight Gain (%)
Acetic Acid, 5 %	< 1	Hydrogen Peroxide (3 %)	< 1
Acetone	sample cracked	Isooctane	< 1
Isopropyl Alcohol	< 1	Mineral Oil, light	< 1
Bleach, ~5 % NaOCl	< 1	Mineral Oil, heavy	< 1
Butyl Acetate	< 1	Salt Water (3.5 % NaCl)	< 1
Diesel	< 1	Sodium hydroxide (0.025 %, pH = 10)	< 1
Diethyl glycol monomethyl ether	1.7	Water	< 1
Hydrolic Oil	< 1	Xylene	< 1
Skydrol 5	1	Strong Acid (HCl Conc)	distorted

HIGH RESOLUTION

For demanding applications, our carefully-engineered resins capture the finest features in your model.

STRENGTH AND PRECISION

Our resins create accurate and robust parts, ideal for our rapid prototyping and product development.

SURFACE FINISH

Perfectly smooth right out of the printer, parts printed on the Form 2 printer have the polish and finish of a final product.

CLEAR

Our Clear Resin polishes to near optical transparency, making it ideal for showcasing internal features.

WHITE

Our White Resin emphasizes fine details and has a matte finish with a warm, slightly ivory color.

GREY

Our Grey Resin has a smooth, matte finish and shows details beautifully without primer.

BLACK

Our Black Resin's opaque matte finish rivals the look of injection-molded plastics, capable of producing incredible looks-like prototypes.

COLOR KIT

Color Kit contains a Color Base cartridge and five Color Pigments. Use Color Kit to mix and print matte, opaque parts in a range of colors without the manual work of finishing and painting.

E.2 BioMed Clear Resin

MEDICAL RESIN

BioMed Clear

Biocompatible Photopolymer Resin for Formlabs SLA Printers

BioMed Clear Resin is a rigid material for biocompatible applications requiring long-term skin or mucosal membrane contact. This USP Class VI certified material is suitable for applications that require wear resistance and low water absorption over time. Parts printed with BioMed Clear Resin are compatible with common sterilization methods. BioMed Clear Resin is manufactured in our ISO 13485 facility and is supported with an FDA Device Master File.

Consider BioMed Clear Resin for:

- Medical devices and device components
- Respirator and ventilator components
- Surgical planning and implant sizing tools
- Research and development
- Masks
- Parts containing breathing gas pathways
- Drug delivery devices
- Bioprocessing equipment
- Jigs and fixtures

V1 **FLBMCL01**

formlabs

Prepared 06 . 12 . 2020
Rev 02 09 . 16 . 2020

BIOMED CLEAR MATERIAL PROPERTIES DATA

	METRIC	IMPERIAL	METHOD
	Post-Cured[1,2]	Post-Cured[1,2]	
Tensile Properties			
Ultimate Tensile Strength	52 MPa	7.5 ksi	ASTM D638-10 (Type IV)
Young's Modulus	2080 MPa	302 ksi	ASTM D638-10 (Type IV)
Elongation	12%	12%	ASTM D638-10 (Type IV)
Flexural Properties			
Flexural Strength	84 MPa	12.2 ksi	ASTM D790-15 (Method B)
Flexural Modulus	2300 MPa	332 ksi	ASTM D790-15 (Method B)
Hardness Properties			
Hardness Shore D	78 D	78 D	ASTM D2240-15 (Type D)
Impact Properties			
Notched IZOD	35 J/m	0.658 ft-lbf/in	ASTM D256-10 (Method A)
Unnotched IZOD	449 J/m	8.41 ft-lbf/in	ASTM D4812-11
Thermal Properties			
Heat Deflection Temp. @ 1.8 MPa	54 °C	129 °F	ASTM D648-18 (Method B)
Heat Deflection Temp. @ 0.45 MPa	67 °C	152 °F	ASTM D648-18 (Method B)
Coefficient of Thermal Expansion	82 µm/m/°C	45 µin/in/°F	ASTM E831-14
Other Properties			
Water Absorption	0.54%	0.54%	ASTM D570-98 (2018)

Sterilization Compatibility	
E-beam	35 kGy E-beam radiation
Ethylene Oxide	100% Ethylene oxide at 55°C for 180 minutes
Gamma	29.4 - 31.2 kGy gamma radiation
Steam Sterilization	Autoclave at 134°C for 20 minutes Autoclave at 121°C for 30 minutes

Disinfection Compatibility	
Chemical Disinfection	70% Isopropyl Alcohol for 5 minutes

For more details on sterilization compatibilities, visit **formlabs.com.**

Samples printed with BioMed Clear Resin has been evaluated in accordance with ISO 10993-1:2018, ISO 7405:2018, ISO 18562-1:2017 and has passed the requirements associated with the following biocompatibility endpoints:

ISO Standard	Test Description[3]
EN ISO 10993-5:2009	Not cytotoxic
ISO 10993-10:2010/(R)2014	Not an irritant
ISO 10993-10:2010/(R)2014	Not a sensitizer
ISO 10993-3:2014	Not mutagenic

ISO Standard	Test Description[3]
ISO 10993-17:2002 ISO 10993-18:2005	Not toxic (subacute/subchronic)
ISO 18562-2:2017	Does not emit particulates
ISO 18562-3:2017	Does not emit VOCs
ISO 18562-4:2017	Does not emit hazardous water-soluble substances

The product was developed and is in compliance with the following ISO Standards:

ISO Standard	Description
EN ISO 13485:2016	Medical Devices – Quality Management Systems – Requirements for Regulatory Purposes
EN ISO 14971:2012	Medical Devices – Application of Risk Management to Medical Devices

[1] Material properties may vary based on part geometry, print orientation, print settings, temperature, and disinfection or sterilization methods used.

[2] Data were measured on post-cured samples printed on a Form 3B printer with 100 µm BioMed Clear Resin settings, washed in a Form Wash for 20 minutes in 99% Isopropyl Alcohol, and post-cured at 60°C for 60 minutes in a Form Cure.

[3] BioMed Clear Resin was tested at NAMSA World Headquarters, OH, USA.