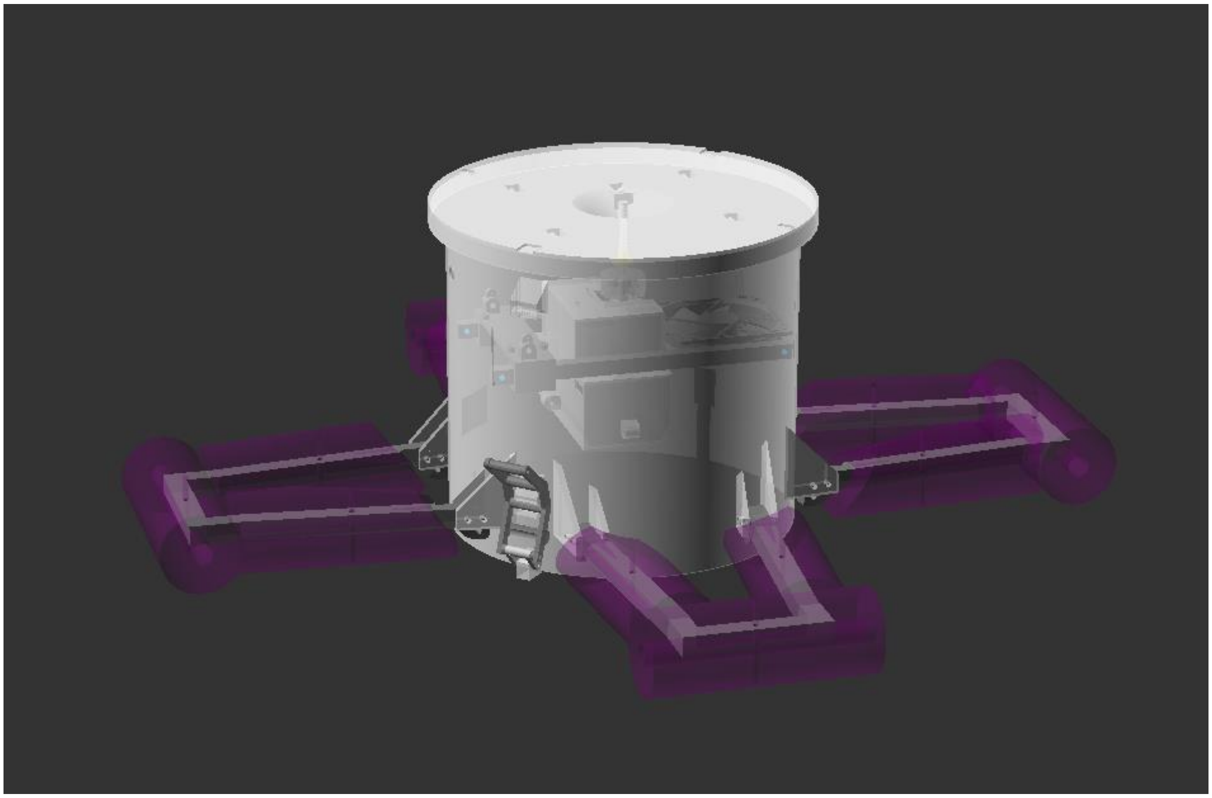
openCHAMBER

Building an open-source community around the development and application of automatically ventilating floating greenhouse gas flux chambers



Chamber.1 Build Guide

Version 1.0

Benjamin Archer 2022

Disclaimer

This build guide details the construction of "Chamber.1", the first 3D printed opensource floating chamber, designed to measure greenhouse gas (GHG) fluxes over an extended temporal resolution, through the automation of chamber headspace ventilation. This document has been created for educational and instructional purposes only. All and any resemblance to any other openCHAMBER company or automatically ventilating chamber product on the market is purely coincidental and not intentional.

Readers are free to use this resource by following its guidance to create their own Chamber.1 ventilating device. In the event that Chamber.1 devices are used to produced data for publication, please respect and observe the authors intellectual property rights by correctly citing the project and or its accompanying scientific publications.

All non-cited images in this handbook have been created by the author.

All inquiries regarding this build guide should be addressed to the author following the most up to date email address given on the openChamber github page. Currently this is at Benjamin.archer@igb-berlin.de.

Contents

List of Figures (LOF)

List of Tables (LOT)

Introduction

Objective

The aim of this document is to provide the reader with the relevant information required to construct the “Chamber.1” automatically ventilating floating chamber design. The document is aimed at being a build guide rather than a detailed explanation into how the chamber works and the justification behind its design. A more detailed explanation about the Chamber.1 design will be available in accompanying scientific paper format publication, to be made available on the openChamber page after publication (Archer, 2022). This document will cover:

- Parts lists
- 3D printing instruction
- Physical assembly instruction (illustrated through action diagrams and GIF animation)
- Software upload and testing
- Proper storage and transport

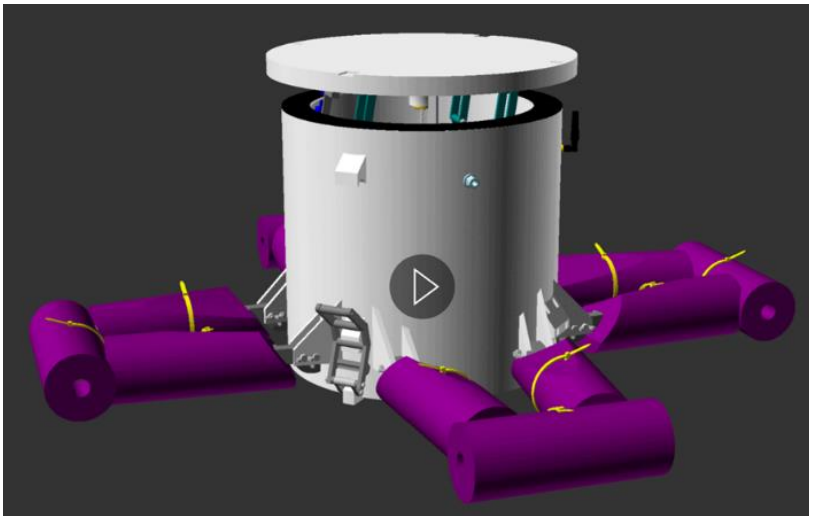
Structure

Part 1 of this guide details the construction of the “Chamber Module” i.e. the automatically ventilating chamber unit, the headspace of which is sampled to determine gas flux with time (Figure 1).

Part 2 of this guide details the construction of the “Valve Changer Module” i.e. the unit that controls air flow between chambers when multiple chambers are used simultaneously (figure …).

Part 1 | Chamber Module

a.)



b.

Figure 1 - Illustration of the chamber module for the Chamber.1 system. Image a illustrates the CAD model of Chamber.1, while image b shows a group deployment of Chamber.1s in the Littoral zone of Lake Stechlinsee Germany. GIF animation available in file "step_6_2_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 6_Construction_Manual_Animations/".

1.1 Parts List

3D Printed Parts

The following parts are 3D printed. The names of the parts refer to the files that are available for download on the openCHAMBER github page under the project Chamber.1 in the 3D files folder (Archer B. , 2022). These 3D files are available as STLs, in addition to gcode sliced for the Anycubic Chiron FDM printer (Anycubic, 2022), which was the printer used throughout the development of this project.

Table 1 lists the parts that must be 3D printed to proceed with the build process. 3D renders of the parts are available in section 1.2 and online in the github project page at: openChamber/Chamber_1/3D_Modelled_Parts/3D_Files/.

Table 1 3D printed parts list

Part Number	Part Name (.stl or .gcode)	Replicates	Single replicate price exc VAT 2022 (€) *
1	Chamber Body	1	18.1 → 23.4
1.b	Chamber Body Tall	1	22.6 → 29.3
2	Chamber lid	1	9.5 → 12.3
3	Chamber Float Arms	4	8.8 → 11.4
3.b	Chamber Float arms Tall	4	11.3 → 14,6
4	Chamber float cutting template - left	1	1.7 → 2.2
5	Chamber float cutting template - right	1	1.7 → 2.2
6a	Fan bracket left	1	0.14 → 0.19
6b	Fan bracket right	1	
7	Lid arm curved	2	0.23 → 0.30
8	Sensor Bracket V1	0-1	1.33 → 1.71
8b	Sensor Bracket V2	0-1	1.10 → 1.42
8c	Sensor Bracket V3	0-1	
9	Motor case	1	7.3 → 9.5
9b	Pawl Guide attachment	1	
10	Motor case lid	1	1.9 → 2.5
11	Motor case latch - small	4	0.23 → 0.3
12	Motor case latch - large	4	0.69 → 0.89
13	Motor case optical switch	1	0.11 → 0.15
14	Aluminium bracket cut guide	1	0.34 → 0.44
15	Bottom pawl	1	0.09 → 0.11
16	Middle Pawl	2	0.09 → 0.11
17	Top Pawl	1	0.09 → 0.11
18	Ratchet	1	0.24 → 0.31
19	Servo Arm	1	0.03 → 0.04

20	Lid optical interrupter bar - template	1	0.14 → 0.19
21	Lid arm spacer	3	0.26 → 0.33
22	Lid arm straight	7	0.5 → 0.65
23	Lid arm servo side 1	1	0.11 → 0.15
24	Lid arm servo side 2	1	0.11 → 0.15
25	Lid arm servo side 3	1	0.13 → 0.17
26	Lid arm servo side 4	1	0.11 → 0.15
27	Chamber stacking clip – small	2	0.11 → 0.15
28	Chamber stacking clip – large	2	0.89 → 1.14
29	Chamber bottom cap	1	12.17 → 15.73
30	Chamber carrying handle	1	3.03 → 3.92
31	Chamber carrying handle clip	1	0.03 → 0.04
104	JST puller size 2	1	
105	JST puller size 3	1	
106	JST puller size 4	1	
107	JST puller size 5	1	
108	JST puller size 6	1	

*Pricing based on PLA printing. Prices represent a range (→) from a low price PLA to a regular price PLA .

Non-Printed Parts

Table 2 lists the parts in the chamber module that have not been 3D-printed and are not electronic hardware. Some of these parts must be cut from larger consumable pieces, for instance parts 48, 51, 52, 56, 61 and 62. The parts that these are made from are listed in the consumable materials part list, and the process of preparing these parts is covered in the build section of this document. Example links are available in the bibliography. As this is an openSource project, these are not affiliate links.

Table 2 Non printed, non-electrical parts list

Part Number	Part Name	Replicates	Single replicate inc VAT 2022 (€)	Reference link
32	M5 hex bolt 45mm	16	0.11	 (*M5 x 45 Mm - Amazon Link*, n.d.)
32.b	M5 butterfly bolt 45mm	8	1.63	 (*M5 Butterfly Bolt - Amazon Link*, n.d.)
33	M5 hex bolt 40mm	13	0.10	 (*M5 x 40 Mm - Amazon Link*, n.d.)

33.b	M5 hex bolt 25mm or 30mm	4	0.09	 (*M5 x 25 Mm - Amazon Link*, n.d.)
34	M5 lock nut	32	0.19	 (*M5 Lock Nuts - Amazon Link*, n.d.)
34.b	M5 butterfly nut	8	0.32	 (*M5 Wing Nut - Amazon Link*, n.d.)
34.c	M5 nut normal	4	0.05	 (*M5 Regular Nuts - Amazon Link*, n.d.)
35	M5 washers	35	0.05	 (*Washers DIN 125 M5 - Amazon Link*, n.d.)

35b	M5 Penny Washer	1	0.08	 (*M5 Penny Washer - Amazon Link* , n.d.)
36	M4 hex bolt 45mm	0	0.26	na
37	M4 hex bolt 40mm	11	0.11	 (*M4 Bolt 40mm - Amazon Link*, n.d.)
37a	M4 hex bolt 35mm	2	0.10	 (*M4 Bolt 35mm - Amazon Link*, n.d.)
38	M4 hex bolt 20mm	4	0.08	 (*M4 20mm Bolt - Amazon Link*, n.d.)
38b	M4 hex bolt 16mm	2	0.07	 (*M4 16mm Bolt - Amazon Link*, n.d.)

39	M4 lock nut	23	0.06	 (*M4 Locking Nuts - Amazon Link*, n.d.)
40	M4 washer	11	0.07	 (*M4 Washer - Amazon Link*, n.d.)
41	M3 bolt 50mm	8	0.4	 (*M3 50mm - Amazon Link*, n.d.)
42	M3 hex bolt 30 to 35mm	10	0.3	 (*M3 35mm Bolt - Amazon Link*, n.d.)
43	M3 hex bolt 20mm	4	0.14	 (*M3 Bolt 20mm - Amazon Link*, n.d.)

44	M3 lock nut	20	0.1	 (*M3 Lock Nuts - Amazon Link*, n.d.)
44.b	M3 hex nut standard	4	0.04	 (*M3 Standard Nut - Amazon Link*, n.d.)
45	M3 washer	2	0.05	 (*M3 Washers - Amazon Link*, n.d.)
46	8mm Pillow Block Bearing (e.g. KFL08)	1	2.00	 (*KFL08 Pillow Block Bearing - Amazon Link*, n.d.)
47	5mm/6mm (motor drive shaft diameter) to 8mm flexible coupling	1	1.44	

				(*Flexible Coupler 6mm to 8mm - Amazon Link*, n.d.)
48	8mm diameter lead screw rod (13cm length)	1	1.25	 (*Lead Screw and T8 Nut - Amazon Link*, n.d.)
49	T8 leadscrew nut (best bought with matching leadscrew)	1	1.00	 (*Lead Screw and T8 Nut - Amazon Link*, n.d.)
50	Pan head M3 self-tapping wood screw	2 to 4	0.05	 (*M3 20mm Pan Head Screws - Amazon Link*, n.d.)
50.b	Servomotor arm bolt	1	na	na
51	Aluminium bracket (Built from consumables aluminium square tube)	2	2.33	na
52	Neoprene gasket (Built from consumables neoprene film)	1	4.99 → 21.00	na

53	Hex female to male standoff (M3 x 13/15)	2	0.06	 (*M3 Standoff - Amazon Link*, n.d.)
54	M3 5mm bolt for standoff	2	0.06	 (*M3 Standoff - Amazon Link*, n.d.)
56	Lid optical interrupter bar (Built from consumables aluminium flat bar)	1	1.20	na
57	Spacer cylinder (21mm x 12mm x 1mm) (Built from consumables aluminium tube)	1	1.20	na
58	Ratchet spring (EXT 5.5 x 25.5mm)	4	0.23	 (*Springs Set- Amazon Link*, n.d.)
59	Chamber carrying handle springs (dimensions)	2	0.23	 (*Springs Set- Amazon Link*, n.d.)

60	Lid to bracket tension spring	4	0.23	 (*Springs Set- Amazon Link*, n.d.)
61	Metal push-fit connectors 1/4" or 6mm internal diameter	2	1.95	 (*6mm Push Fit Connectors - Amazon Link*, n.d.)
61.b	Push fit connector panel mount nut	4	na	na
62	O-ring nitrile rubber cord - 2mm diameter 60mm length	1	1.25	 (*Nitrile Rubber Cord - Amazon Link*, n.d.)
63	Foam float right	4	0.5	na
64	Foam float left	4	0.5	na
64.b	Foam float top	4	0.5	na
	(Optional) wooden board for stacking base (dimensions)	1	na	na

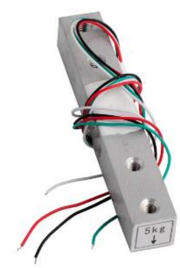
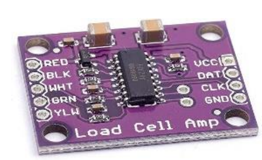
Electrical Parts

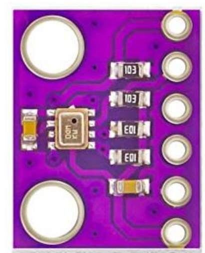
Table 3 lists the electronic parts used in this project. Parts 77 and 78 must currently be constructed from the consumables list (described in section 1.4), but may be supplied in the future along with parts 67b, 75b and 76. Example links are available in the bibliography. As this is an openSource project, these are not affiliate links.

Note: Part 82, the dip format Arduino uno, is used as an atmega328p programmer. It is not included in the actual chamber once deployed on the water. For more programming information, see section 1.6 Electrical Setup and Chamber Testing.

Table 3 Electrical parts list

Part number	Part name	Replicates	Single replicate inc VAT 2022 (€)	Reference link
65	Nema 17 60mm 70Ncm bipolar stepper motor (ACT 17HS6416D6L2)	1	15.80 →23.00	 (*Nema 17 60mm Stepper Motor - Amazon Link*, n.d.; *Nema 17 60mm Stepper Motor - Reichelt Link*, n.d.)
66	MG996R Servomotor	1	6.00	 (*MG996R Servo Motor - Amazon Link*, n.d.)

67	Optical interrupter diode and transistor	1	0.40	 (*Photo Interrupter - Amazon Link*, n.d.)
67b	Optical interrupter circuit board	1	na	na
68a	5kg straight bar load cell (80mm x 12.7mm x 12.7mm)	0 to 2	3.28 → 9.97	 (*5kg Straight Bar Load Cell - Amazon Link*, n.d.)
68b	10kg straight bar load cell (80mm x 12.7mm x 12.7mm)	0 to 2	3.28 → 9.97	 (10 Kg Straight Bar Load Cell - Amazon Link 2, n.d.)
69	Sparkfun SEN-13879 style HX711 (important not to use low quality HX711 modules)	1 to 2	6.99 →12.00	 (*SEN-13879 Style HX711 - Amazon Link*, n.d.)

70	3v CR2032 battery	1	0.45	 (*CR2032 3v - Amazon Link*, n.d.)
70.b	microSD card	1	6.00	 (*32GB Microsd Card - Amazon Link*, n.d.)
71	Pressure sensor	1 to 2	1.99	 (*BMP280 Sensor - Amazon Link*, n.d.)
72	HC-12 433 MHz transceiver (Cheap clones can have reduced range due to a common (fixable) PCB error. Official boards have HC-12 printed on the back)	1	5.75 → 10.40	 (*HC-12 - Amazon Link*, n.d.; *HC-12 - Banggood Link*, n.d.)
73	433.4 MHz Antenna with female SMA plug (2 to 6 dBi depending on range application)	1	4.50	

				 (*433 MHz Antenna - Amazon Link*, n.d.; *433MHz Antenna 6dBi Aerial - Aliexpress Link*, n.d.; *433MHZ High Gain Antenna - Ebay Link*, n.d.)
74	Male SMA to IPEX connector	1	1.00	 (*SMA to Ipex Cable - Amazon Link*, n.d.)
74.b	Antenna connector washer	1	na	na
74.c	Antenna connector nut	2	na	na
75a	Sensor circuit board version 1	1	na	na
75b	Sensor circuit board version 2	1	5.79 (6.51 postage)	na
76	Main Circuit Board	1	13.51 (6.51 postage)	na
77a	Sensor board cable	1	na	na
77b	Radio cable	1	na	na
78a	Load cell cable 1	1	na	na
78b	Load cell cable 2	1	na	na
79a	120mm 5v pc fan	1	4.75	 (*120mm 5v Fan - Ali Express Link*, n.d.)
79b	Fan cable	1	na	na

80	Power Bank (24800 to 26800 mAh, 1.5 x 15 x 7.4 cm)	2	19.99 →31.95	 (*Power Bank - Amazon Link*, n.d.)
80b	5v to 24v 5 amp step-up converter (e.g. LM2587)	1	4.50 → 9.89	 (*LM2587 Step up Converter - Amazon Link*, n.d.; *LM2587 Step up Converter Low Cost - Amazon Link*, n.d.)
81	atmega328p DIP package	3	2.70	 (*ATMEGA328P-PU - Mouser Link*, n.d.)
82	DIP - Arduino uno	1	5.80 →23.49	 (*DIP Arduino Uno Clone - Amazon Link*, n.d.)
83	Arduino uno ISP / bootloader shield	1	7.00 → 14.99	

				(*Bootloader Shield - Amazon Link*, n.d.)
84	Fast charging USB to microusb cable (<=30cm) Quality is important for electronic stability	3	1.60	  (*Micro USB Cable Short - Amazon Link*, n.d.)
85	Nema stepper motor cable	1	na	na
86	CO2 sensor	1 to 2	45.67	 (*SCD30 - Digikey Euro* , n.d.)
87	CH4 sensor	1 to 4	14.10	 (*TGS 2611-E00 - SOSelectronic Link*, n.d.)

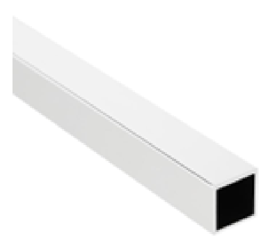
Consumable Materials

Table 4 lists the consumable materials used in the project. These consumables are used throughout the project to build other parts (for example consumable part 94 is used to make part 52 in Table 2), or to process parts before use (for example, treating 3D printed objects (Table 1) with epoxy resin (part 88, Table 4) to make these prints water and gas tight). The processing of these consumable materials is covered in the build process of this document (Section 1.4). Example links are available in the bibliography. As this is an openSource project, these are not affiliate links.

Table 4 List of consumable materials

Part Number	Part Name	Replicates	Price 2022 (€)	Reference link
88	Clear epoxy resin (~300ml)	1	4.00	 (*UV Stabilised Epoxy Resin 3kg - Amazon Link*, n.d.)
89	1kg 3D printing plastic spool (Beginners = White PLA, preferably sustainable eco-pla) (Advanced = White PETG, preferably recycled)	4 to 6	14.3 or 18.5	 (*1kg White PLA 1.75 Mm - Amazon Link*, n.d.)

90	Flexible gel super glue (6 uses throughout)	1	3.42	 (*Flexible and Standard Super Glue Set - Amazon Link*, n.d.)
91	Standard super glue (5 uses throughout)	1	3.42	 (*Flexible and Standard Super Glue Set - Amazon Link*, n.d.)
92	UV resistant polyurethane topcoat (Not needed if using a UV stable epoxy resin) (~100ml)	1	3.19	

				(*Polyurethane Uv Varnish - Amazon Link* , n.d.)
93	Plastic zip ties	14	0.01	 (*Cable Ties - Amazon Link*, n.d.)
94	Neoprene film with adhesive (5mm x 500 x 1000mm)	1	42.00	 (*5 Mm Neoprene Adhesive Film - Amazon Link*, n.d.)
	Polyethylene potential alternative Not tested but theoretically should function as a gasket (5.0 x 400 x 500mm)	1	4.90	 (*Polyethylene Soft Foam - Modulor Link*, n.d.)
95	Aluminium square tube (15mm x 15mm x 1000mm)	1	6.99	

				(*Aluminum Square Tube - Hardware Store Link*, n.d.)
96	Aluminium cylindrical tube (12mm x 1000mm)	1	7.99	 (*Aluminium Round Tube - Hardware Link*, n.d.)
97	Aluminium flat bar (2mm x 30mm x 1000mm)	1	6.99	 (Flat Aluminum Bar - Hardware Store Link, n.d.)
98	Pipe insulation pre-slit (1000mm length x 22mm internal diameter x 13 mm thickness)	4	5.96	 (*Pipe Insulation - Hardware Store Link*, n.d.)
99	Hot glue (5 uses throughout)	2	na	 (*Hotglue Sticks - Amazon Link*, n.d.)

100	Electrical potting compound	1	na	 (*Electronics Potting Compound - Amazon Link*, n.d.)
101	JST type female connectors	15	0.5	 (*JST Connectors - Amazon Link*, n.d.)
102	$0.14mm^2$ gauge wire (~1m)	1	1.58	 (*0.14mm2 Cable - Amazon Link*, n.d.)
103	5kg calibration weight (e.g. Sand, water, weight plate)	1	na	

Pricing estimates

In mid-2022 pricing estimates are difficult to make reliably. Economic instability is resulting in high rates of inflation, in combination with semiconductor shortages and covid disruptions in China, meaning that prices are variable and increasing rapidly. For this reason, I have based the prices of components on prices from more stable and universal platforms, for example Amazon, instead of from the absolute lowest prices available online, for example from Alibaba.com. As a result, it is likely that a chamber could be built for below these prices with a bit of shopping around.

In addition, electronic prices, such as the main circuit board and sensor board, become more inexpensive as larger orders are placed. The current price estimates are from an order of 10 PCBs. By combining group orders together, the prices of components can be reduced. Furthermore, as some institutions may be based outside of Europe, or have limitations upon using suppliers such as Amazon, I have calculated multiple pricing options to try and honestly represent the costs to build the chambers in their current state of development.

The lowest cost for a single chamber calculated in this way is ~300 euro (Table 5).

Table 5 Price estimates for different forms of the chamber in July 2022. Prices are in Euro and exclude VAT. Price quotation sources are listed above in section 1.1.

	Small Chamber Low Cost*	Small Chamber High cost*	Large Chamber low cost*	Large Chamber high cost*	Accessories Low cost*	Accessories High cost*
3D-printed parts	50.94	65.83	57.92	74.84	19.09	24.67
Non-printed parts	59.35	72.80	59.35	72.80	na	na
Electronic parts	157.95	217.85	157.95	217.85	10.76	32.34
Consumables materials	36.89	39.57	36.89	39.57	na	na
Total	305.12	396.04	312.1	405.05	29.85	57.01

***Small chamber low cost** = The regular Chamber V1, printed in budget PLA. Chamber coated in UV resistant epoxy resin. Electronics based on the low estimate with 1 load cell, 1 pressure sensor, 1 CO_2 sensos and 1 CH_4 sensor. This price uses the parts required to make the chamber only i.e. not the construction aids, the programming equipment or transport caps and handles.

***Small chamber high cost** = The regular Chamber V1, printed in premium PLA. Chamber coated in UV resistant epoxy resin with an additional polyurethane topcoat. Electronics based on the high estimate with 1 load cell, 1 pressure sensor, 1 CO_2 sensor and 1 CH_4 sensor. This price uses the parts required to make the chamber only i.e not the construction aids, the programming equipment or transport caps and handles.

***Large chamber low cost** = The tall Chamber V1, printed in budget PLA. Chamber coated in UV resistant epoxy resin. Electronics based on the low estimate with 1 load cell, 1 pressure sensor, 1 CO_2 sensos and 1 CH_4 sensor. This price uses the parts required to make the chamber only i.e. not the construction aids, the programming equipment or transport caps and handles.

***Large chamber high** cost = The tall chamber V1, printed in premium PLA. Chamber coated in UV resistant epoxy resin with an additional polyurethane topcoat. Electronics based on the high estimate with 1 load cell, 1 pressure sensor, 1 CO_2 sensor and 1 CH_4 sensor. This price uses the parts required to make the chamber only i.e. not the construction aids, the programming equipment or transport caps and handles.

***Accessories low cost** = the printed construction aids, the printed chamber handle and chamber bottom protective cap in budget PLA. The Arduino uno and the bootloader shield for programming based on budget clones.

***Accessories high cost** = the printed construction aids, the printed chamber handle and chamber bottom protective cap in premium PLA. The Arduino uno and the bootloader shield for programming based on Arduino branded, high-cost options.

Tools

Access to the following tools is useful when constructing Chamber.1. If inaccessibility to these tools makes constructing an element of the chamber impossible, contact the openChamber community to see if a solution can be found through community outsourcing. The links are provided as examples of suitable equipment, these specific brands/models are not necessary.

- A set of files that includes micro/needle files and larger files.

- Useful in adjusting 3D printed parts and clearing Epoxy where it may have affected tolerances.

- E.g. (Preciva Filing Set, 18 Pieces - Amazon Link)

- Sandpaper

- Useful in adjusting 3D printed parts
  (though for PLA a scraper/ razor often works better), clearing epoxy where it may have affected tolerances and levelling the lid gasket interface surface (part 2).

- E.g. (Professional Sanding Sheets - Amazon Link)

- 3D printer spatula

- Useful in removing 3D printed support material
- E.g. (3D Printer Spatula - Amazon Link)

- 0.4mm and 08.mm 3D printing nozzels
- E.g. (*0.4 Mm Nozzle - Amazon Link*, n.d.)

- Set of pliers
- Useful in pulling 3D printed support material away, cutting wires and for tensioning nuts and bolts.
- E.g. (Set of Pliers - Amazon Link)

Chamber construction tools:

- Spanners / socket wrench set
- Needed to tension nuts and bolts in the chamber body build
- E.g. (HÖGERT Wrench Set - Amazon Link , n.d.)

- Allen keys

- Needed to tension Allen head bolts in the chamber body build.

- E.g. (*Allen Key Set - Amazon Link*, n.d.)

- Angle grinder / Hacksaw

- Needed to cut the lead screws and brackets to length.

- If too difficult this step can be outsourced to the openChamber community.

- E.g. (Bosch Angle Grinder - Amazon Link)
- E.g.(*Junior Hacksaw - Amazon Link*, n.d.)

- Drill / Drill press

- Drill press needed to drill the bracket holes
- Handheld drill needed for redrilling bolt holes after resin coating and for adding bolts/ screws to the chamber.

- E.g. (Scheppach Drill - Amazon Link)
- E.g. (*Bosch Cordless Drill - Amazon Link*, n.d.)

- Screwdriver set

- Needed to insert screws and screw head bolts where the hand held drill is not accessible.

- E.g. (Screwdriver Set - Amazon Link)

- JST Crimping kit

- Not essential, but needed if planning on building or repairing your own cables.

- E.g. (JST Crimping Set - Amazon Link)

- Multimeter

- Useful in trouble shooting

- Needed to set stepper motor vref (unless using pre-set stepper driver provided through openChamber)

- E.g. (*Basic Multimeter - Amazon Link*, n.d.)

- Hot glue gun

- Needed for water tightening elements of to the motor unit.

- E.g. (Hot Glue Gun - Amazon Link)

- Craft knife / razor blade

- Needed to cut the gasket and nitrile o-ring motor unit seal.

- E.g. (*Wedo Craft Knife - Amazon Link*, n.d.)

- Anycubic Chiron

- Needed to 3D print the housing of this project <u>IF NOT</u> purchasing through a 3D printing service such as JLC-PCB, or sourcing with the help of the openChamber community.

- E.g. (*Anycubic Chiron - Anycubic Link*, n.d.)

1.2 3D Printing

1.2.1 Introduction

This 3D printing guide provides information on how the chamber module parts were designed to be printed. The printer used throughout the development of this project, and described in this manual, is the Anycubic Chiron (*Anycubic Chiron – ANYCUBIC*, n.d.). This printer was selected due to its large build volume (400mm x 400mm x 450mm), international availability, extensive online community, and affordability (available for €315 March 2022). Alternatively, 3D printed parts can be printed at your local maker space or ordered from a 3D printing service such as JLCpcb (JLCPCB, 2022). In the future, if there is sufficient community interest, then currently 3D printed parts could be reproduced through injection moulding and distributed to the community. Incidentally, this would also remove the need for the post-print processing steps, such as epoxy coating, described in section 1.3.

Through extensive use of the Anycubic Chiron 3D printer in the development process of this project, there have been commonly occurring issues across the multiple machines in our print farm. This section of the guide provides trouble shooting information for these common problems that you are likely to experience with extended use. Though it must be added that current models of the Chiron (at the time of writing) are already improved over the early forms of the Chiron used throughout this project, and that these problems are easily solved with a bit of guidance.

3D models are available for download in stl form or as pre-sliced gcode for the anycubic chiron (openCHAMBER github page under the project Chamber.1 in the 3D files folder (Archer, 2022)). The 3D models published in this project were all developed using the opensource CAD software openscad 2019.05 (OpenSCAD, 2022). This software was chosen as it is truly open source and free for everybody to use (i.e. not subject to limited contracts and terms of usage that software such as fusion360 are (Autodesk, 2022)), is arguably the most powerful opensource CAD software available at the time of writing (2021), and offers a large online community through which extensive information is available. The openSCAD coding files used to make the 3D models in this project will be made available on the openCHAMBER github page under the project Chamber.1 in the 3D files folder (Archer, 2022), and can be adjusted by the user of this guide if tolerances or parts need adjusting.

The printing of the parts listed in Table 1 is divided into the two nozzle sizes; 0.8mm and 0.4mm. Printing guides assume the use of PLA plastic. Ensure that the PLA is well rolled, packaged and dried (i.e. including desiccant packets, and rolled evenly onto the spool with no tangles or knots which could cause prints to fail).

Printer gcode was generated from 3D models using the opensource slicer software CURA (Ultimaker, 2022).

1.2.2 0.8mm Parts

Printing at a nozzle size of 0.8mm decreases the overall printing time and is optimal for large low detail pieces that serve a structural purpose. This reduces the printing time from days to hours. Print settings must be adjusted to deal with this volume of plastic. The recommended settings are based upon the printers used in this project, however individual printers vary, and may need their own adjustment.

Table 6 details the parts that are printed at 0.8mm, their print times and PLA plastic requirements.

Table 6 0.8mm Part Printing Statistics (for generic pla)

Part Number	Estimated Print Time (Minutes)	Estimated Material Weight (g)	Estimated Filament Length (m)	Support material
1	2070	1267	424.76	YES*
1.a	2570	1583	530.85	YES*
2	1324	666	223.22	NO
3	4 x 232	4 x 154	4 x 51.6	NO
3.b	4 x 304	4 x 197	4 x 65.97	NO
4 and 5	403	236	79.25	YES
6a	15	10	3.3	YES
6b	14	10	3.2	YES
7	2 x 14	2 x 8	2 x 2.64	NO
8c	64	46	15.55	YES
8b	98	77	25.83	YES
9	715	468	156.93	YES
9b	12	10	3.41	NO
10	228	133	44.57	YES
11	4 x 6	4 x 4	4 x 1.46	NO
12	4 x 18	4 x 12	4 x 4.09	NO
21	3 x 12	3 x 6	3 x 2.09	NO
22	7 x 9	7 x 5	7 x 1.71	NO
23	11	8	2.56	NO
24	11	8	2.58	NO
25	13	9	2.93	NO
26	11	8	2.58	NO
27	2 x 6	2 x 4	2 x 1.47	NO
28	2 x 50	2 x 31	2 x 10.46	YES
29	1064	848	284.4	NO
30	294	212	71.25	YES
6a, 6b, 7, 8c, 9, 9b, 10, 11, 12, 21, 22, 23, 24, 25, 26	1348	850	284.93	YES

*The Support material in Part 1 is built into the stl file rather than added later in the slicer.

Using pre-sliced files

If using the pre-sliced models and an Anycubic Chiron printer, then the next steps are straight forward:

1. Install a 0.8mm nozzle to the printer. To change the nozzle, heat up the hotend/heating block to pla printing temperature (190ºC). Hold the heating block in place using a pair of pliers while you remove any existing nozzle using a spanner (Figure 2). Finally insert a 0.8mm nozzle following the reverse of the instructions above.

2. Carry out some pre-print checks

- Ensure that the weight of PLA filament loaded to the machine before printing is greater than that estimated for the print in Table 6. Otherwise, be prepared to change the filament spool at some point during the print, which can cause layer shifts on the Anycubic Chiron and thus a failed print.

- Ensure that the print bed has recently been levelled.

- Ensure that the grub screws on the z-axis motor coupler are tight. Failure to do so can result in catastrophic print failures.

- Inspect the filament and ensure that it has not become brittle in the storage process. Brittle filament can result in print failures as the filament runout sensor will not be triggered.

- Ensure that the filament driver screw is at the correct tension and that the Bowden tube resistance is low (i.e. the Bowden tube is not worn out or blocked by PLA particles, and that filament flows freely through the print Nozzle).

3. Wipe down the print bed with a lint free cloth and isopropyl alcohol, to ensure adhesion of the print layers to the print bed.

4. Transfer the .gcode file of the part that you would like to print from Table 6 to the printer (e.g. Part 1). This is most simply done using an SD card.

5. Once the SD card is inserted into the printer, select the file for printing and select start print.

6. Check intermittently throughout the print to ensure that there has not been a failure and that no action needs to be taken.

7. Once the print is finished, let the printing bed cool to room temperature – the print should release from the print bed by itself. In the case that it is still stuck to the print bed, carefully remove the piece using the spatula/scraper provided with the 3D printer.

8. Store the 3D print safely. Parts with support material (listed in Table 6) will need the support material to be removed. However, this step is covered in section 1.3 (3D printed part post-processing).

9. Repeat steps 1 to 8 until all the parts from Table 6 have been printed.

Figure 2 Demonstrating how to change the extrusion nozzle on an Anycubic Chiron 3D printer.

Slicing models for a different printer

If not using an anycubic chiron printer, or you would like to print groups of specific parts together, then the stl files will need to be sliced before printing. The following is guidance on part orientation and support settings, when preparing your own gcode for the parts in Table 6.

Part 1.

Print settings:

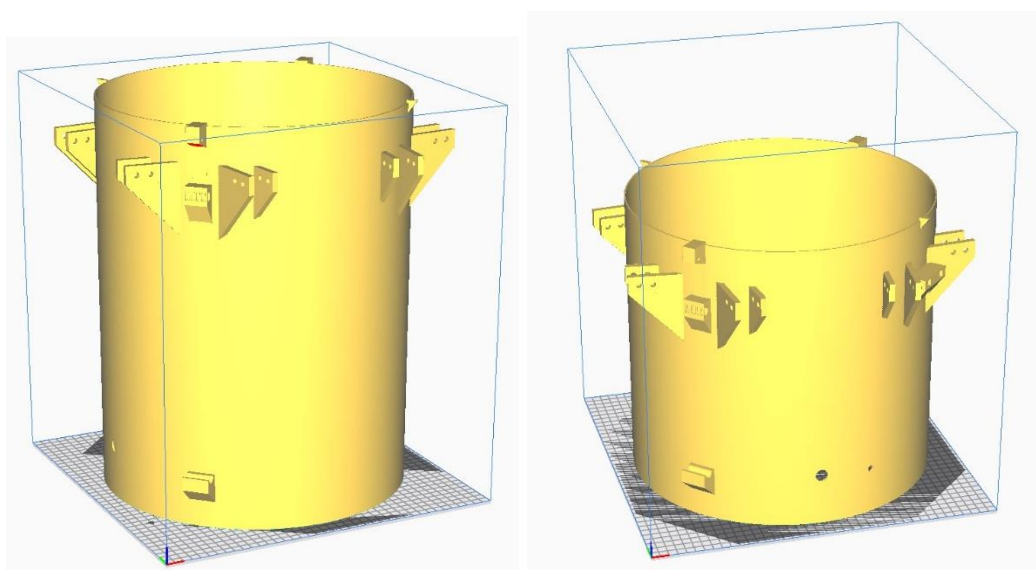


Figure 3 3D render illustrating the optimal printing orientation of Part 1 on the right and part 1.a on the left. The image is taken from the slicing software cura ().

Part 2.

Print settings:

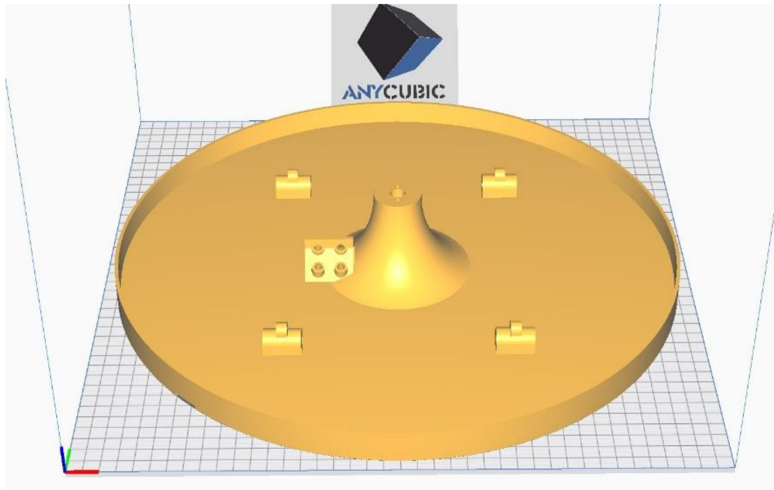


Figure 4 3D render illustrating the optimal printing orientation of Part 2. The image is taken from the slicing software cura ().

Part 3.

Print settings:

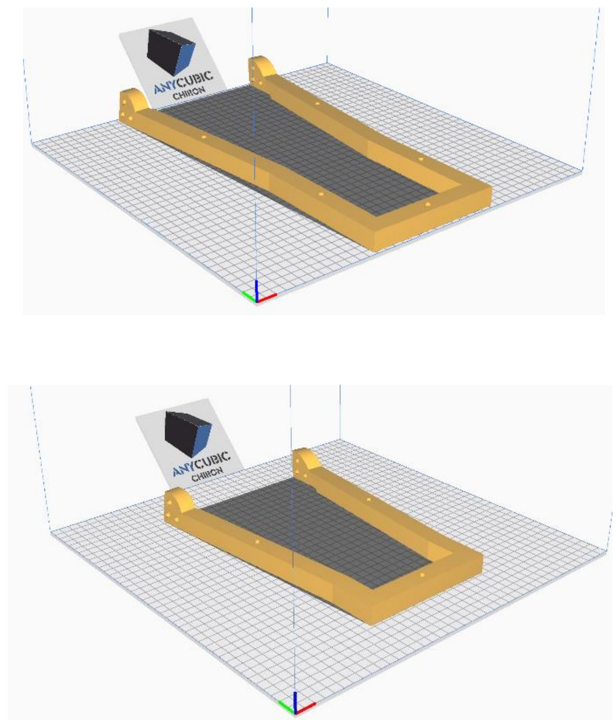


Figure 5 3D render illustrating the optimal printing orientation of part 3 (bottom image) and part 3b (top image). The image is taken from the slicing software cura ().

Part 4 and 5.

Print settings:

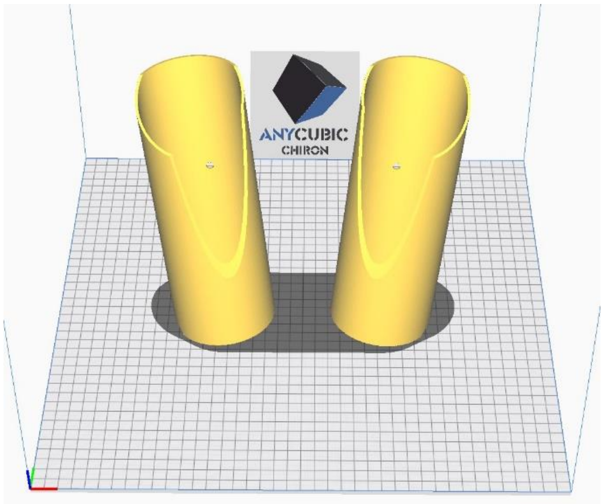


Figure 6 3D render illustrating the optimal printing orientation of parts 4 (left object) and 5 (right object). The image is taken from the slicing software cura ().

Part 6.

Print settings:

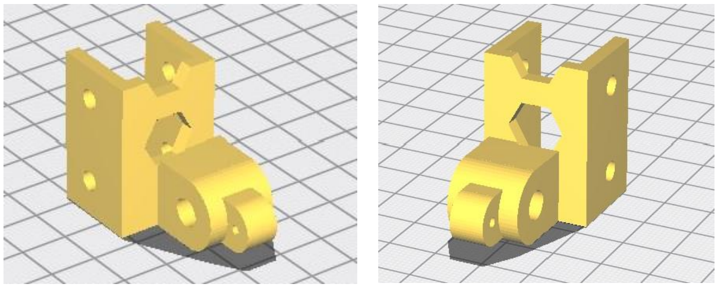


Figure 7 3D render illustrating the optimal printing orientation of parts 6a (left image) and 6b (right image). The image is taken from the slicing software cura ().

Part 7.

Print settings:

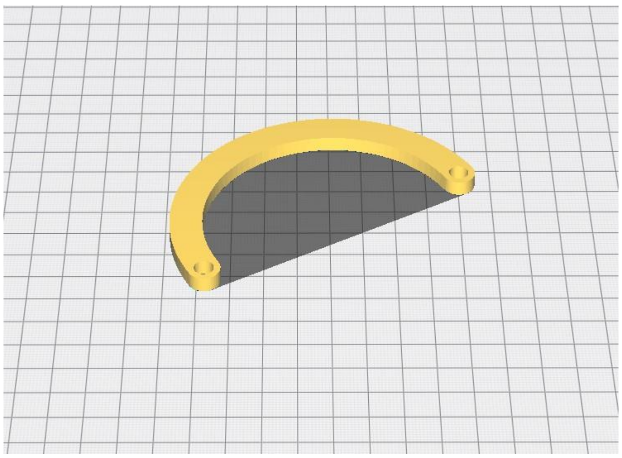


Figure 8 3D render illustrating the optimal printing orientation of part 7. The image is taken from the slicing software cura ().

Part 8.

Print settings:

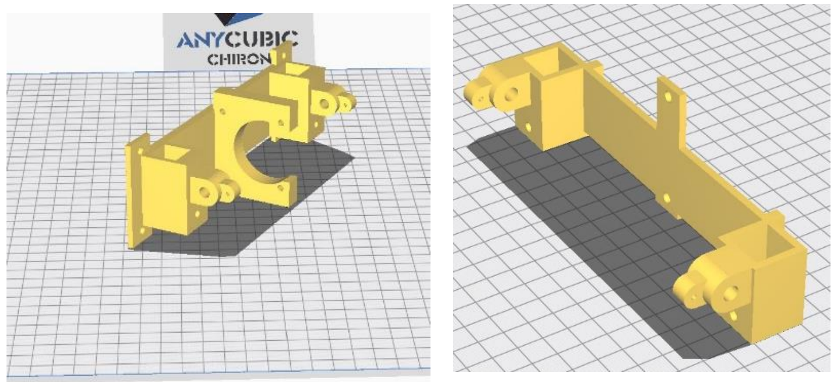


Figure 9 3D render illustrating the optimal printing orientation of parts 8b (left image) and 8c (right image). The image is taken from the slicing software cura ().

Part 9.

Print settings:

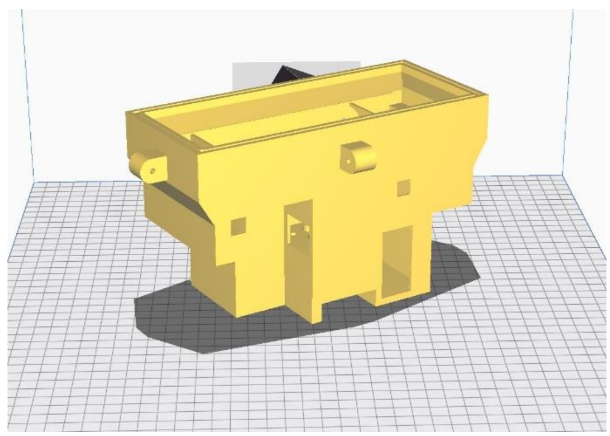


Figure 10 3D render illustrating the optimal printing orientation of part 9. The image is taken from the slicing software cura ().

Part 9b.

Print settings:

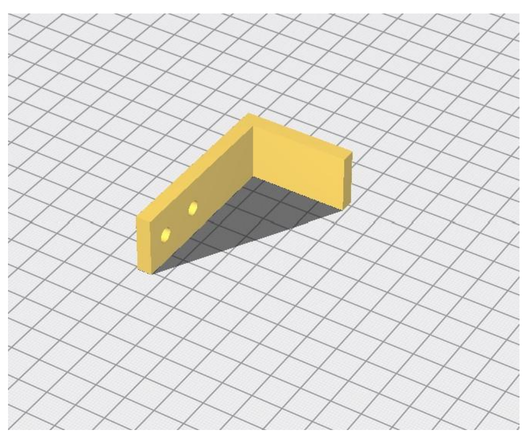


Figure 11 3D render illustrating the optimal printing orientation of parts 4 (left object) and 5 (right object). The image is taken from the slicing software cura ().

Part 10.

Print settings:

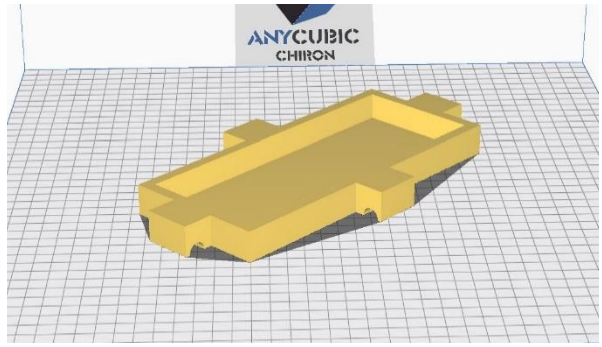


Figure 12 3D render illustrating the optimal printing orientation of part 10 The image is taken from the slicing software cura ().

Part 11.

Print settings:

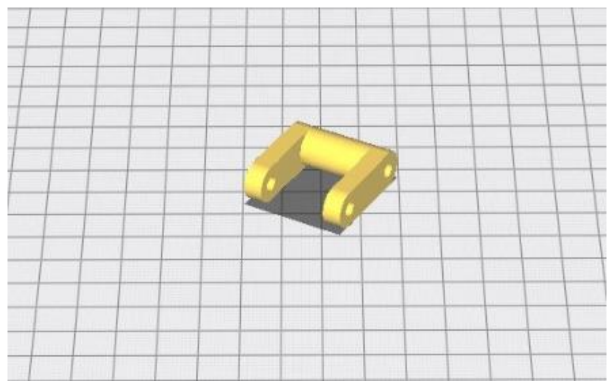


Figure 13 3D render illustrating the optimal printing orientation of part 11. The image is taken from the slicing software cura ().

Part 12.

Print settings:

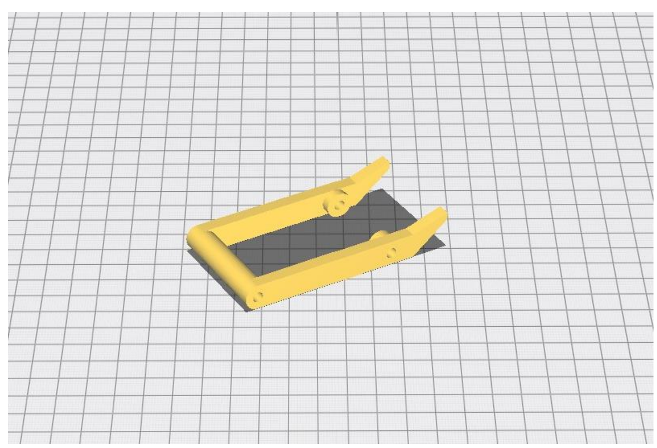


Figure 14 3D render illustrating the optimal printing orientation of part 12. The image is taken from the slicing software cura ().

Part 21.

Print settings:

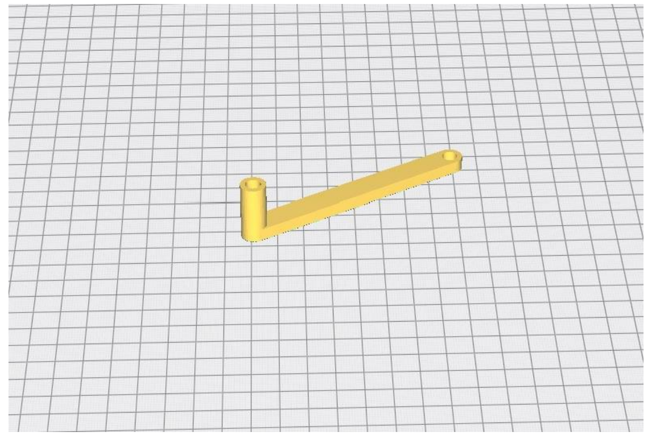


Figure 15 3D render illustrating the optimal printing orientation of part 21. The image is taken from the slicing software cura ().

Part 22.

Print settings:

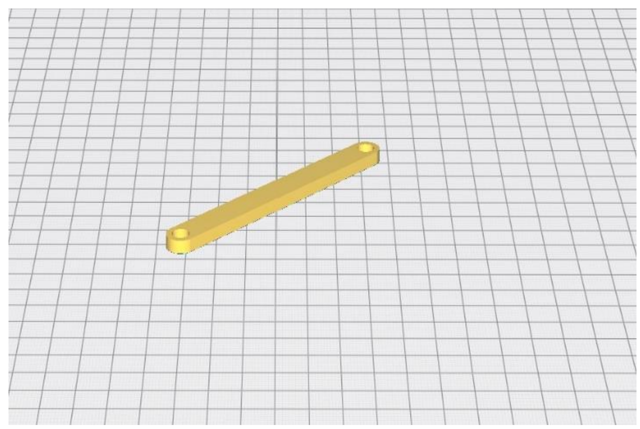


Figure 16 3D render illustrating the optimal printing orientation of part 22. The image is taken from the slicing software cura ().

Part 23.

Print settings:

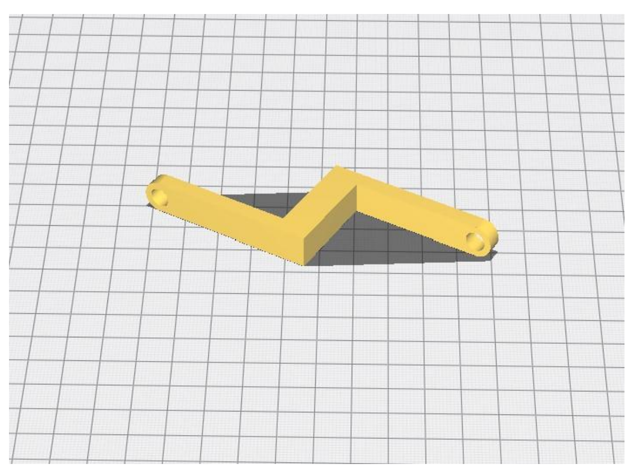


Figure 17 3D render illustrating the optimal printing orientation of part 23. The image is taken from the slicing software cura ().

Part 24.

Print settings:

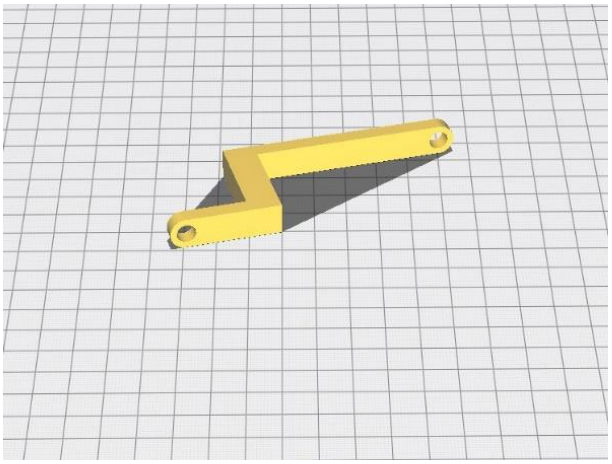


Figure 18 3D render illustrating the optimal printing orientation of part 24. The image is taken from the slicing software cura ().

Part 25.

Print settings:

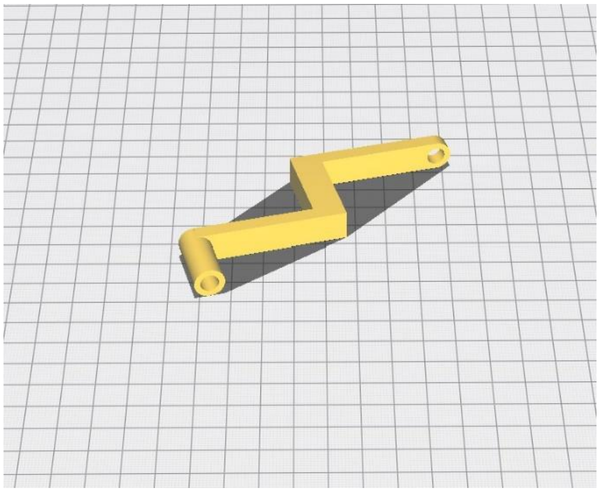


Figure 19 3D render illustrating the optimal printing orientation of part 25. The image is taken from the slicing software cura ().

Part 26.

Print settings:

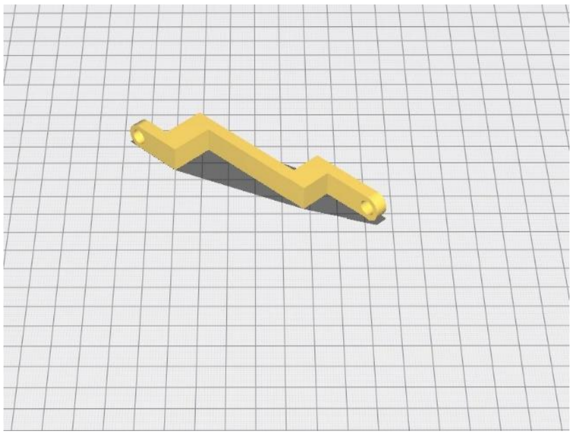


Figure 20 3D render illustrating the optimal printing orientation of part 26. The image is taken from the slicing software cura ().

Part 29.

Print settings:

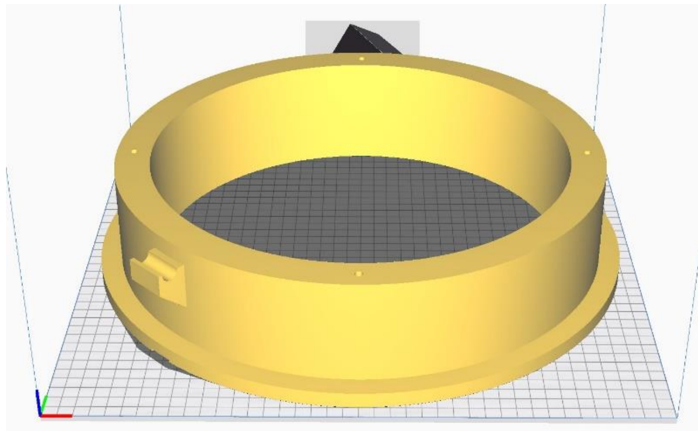


Figure 21 3D render illustrating the optimal printing orientation of part 29. The image is taken from the slicing software cura ().

Part 30.

Print settings:

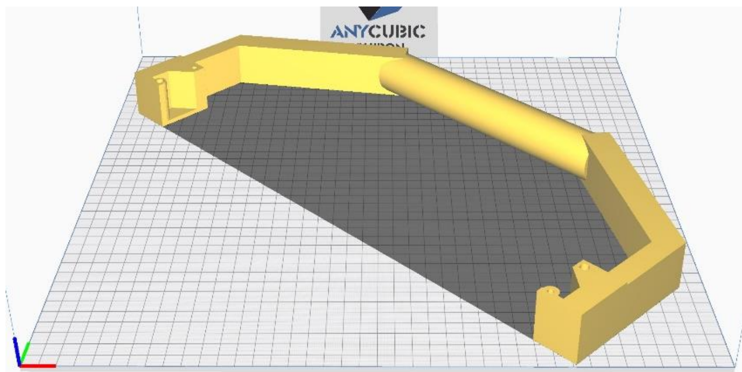


Figure 22 3D render illustrating the optimal printing orientation of part 30. The image is taken from the slicing software cura ().

Parts 6a, 6b, 7, 8c, 9, 9b, 10, 11, 12,

21, 22, 23, 24, 25, 26

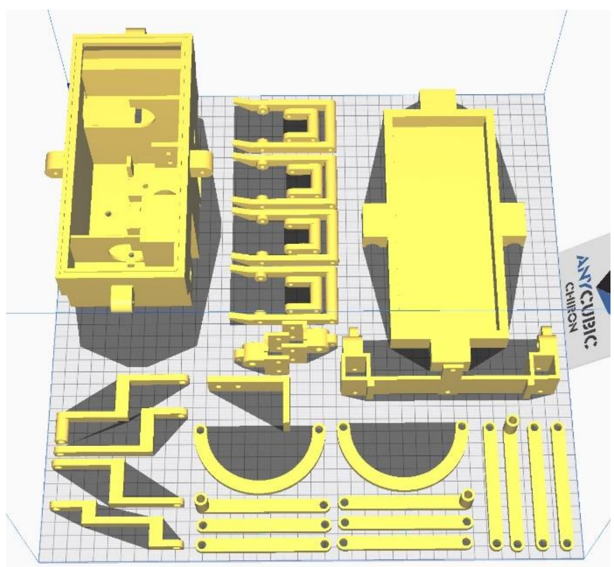


Figure 23 3D render illustrating the optimal printing orientation for batch 0.8mm printing. The image is taken from the slicing software cura ().

1.2.3 0.4mm Parts.

Printing at a nozzle size of 0.4mm increases the detail resolution of an fdm 3D print. This comes at the cost of overall print time, which is increased relative to 0.8mm resolution prints. This allows more intricate parts to be created for the chamber module. Print settings must be adjusted to deal with this lower volume of plastic. The recommended settings are based upon the printers used in this project, however individual printers vary, and may need their own adjustment.

Table 7 details the parts that are printed at 0.4mm, their print times and PLA plastic requirements.

Table 7 0.4mm Part Printing Statistics

Part Number	Estimated Print Time (Minutes)	Estimated Material Weight (g)	Estimated Filament Length (m)	Support material
13	50	8	2.59	NO
14	136	24	8.01	NO
15	40	6	2.12	NO
16	41	6	2.13	YES
17	40	6	2.12	NO
18	91	17	31	NO
19	13	2	0.78	NO
20	75	10	3.33	NO
31	2 x 7	2 x 1	2 x 0.43	NO
104	12	2	0.53	NO
105	15	2	0.69	NO
106	21	3	0.94	NO
107	24	3	1.12	NO
108	29	4	1.31	NO
13, 15, 16, 17, 18, 19, 31	758	116	38.99	YES
14, 20, 104, 105, 106, 107, 108	314	47	15.76	NO

Using pre-sliced files

If using the pre-sliced models and an Anycubic Chiron printer, then the next steps are straight forward:

1. Install a 0.4mm nozzle to the printer. To change the nozzle, heat up the hotend/heating block to pla printing temperature (190ºC). Hold the heating block in place using a pair of pliers while you remove any existing nozzle using a spanner (Figure 2). Finally insert a 0.4mm nozzle following the reverse of the instructions above.

2. Carry out some pre-print checks

- Ensure that the weight of PLA filament loaded to the machine before printing is greater than that estimated for the print in Table 7. Otherwise, be prepared to change the filament spool at some point during the print, which can cause layer shifts on the Anycubic Chiron and thus a failed print.

- Ensure that the print bed has recently been levelled.

- Ensure that the grub screws on the z-axis motor coupler are tight. Failure to do so can result in catastrophic print failures.

- Inspect the filament and ensure that it has not become brittle in the storage process. Brittle filament can result in print failures as the filament runout sensor will not be triggered.

- Ensure that the filament driver screw is at the correct tension and that the Bowden tube resistance is low (i.e. the Bowden tube is not worn out or blocked by PLA particles, and that filament flows freely through the print Nozzle).

1. Wipe down the print bed with a lint free cloth and isopropyl alcohol, to ensure adhesion of the print layers to the print bed.

2. Transfer the .gcode file of the part that you would like to print from Table 7 to the printer (e.g. Part 13). This is most simply done using an SD card.

3. Once the SD card is inserted into the printer, select the file for printing and select start print.

4. Check intermittently throughout the print to ensure that there has not been a failure and that no action needs to be taken.

5. Once the print is finished, let the printing bed cool to room temperature – the print should release from the print bed by itself. In the case that it is still stuck to the print bed, carefully remove the piece using the spatula/scraper provided with the 3D printer.

6. Store the 3D print safely. Parts with support material (listed in Table 7) will need the support material to be removed. However, this step is covered in section 1.3 (3D printed part post-processing).

7. Repeat steps 1 to 8 until all the parts from Table 7 have been printed.

Slicing models for a different printer

If not using an anycubic chiron printer, or you would like to print groups of specific parts together, then the stl files will need to be sliced before printing. The following is guidance on part orientation and support settings, when preparing your own gcode for the parts in Table 7.

Part 13.

Print settings:

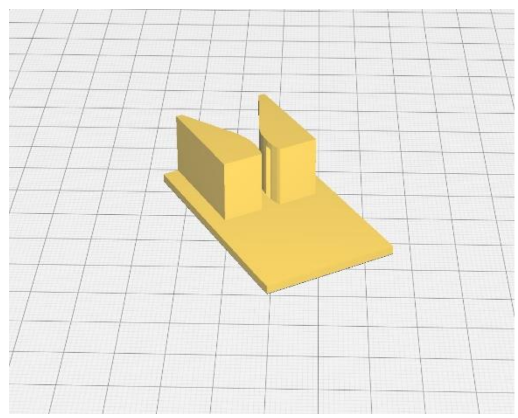


Figure 24 3D render illustrating the optimal printing orientation of part 13. The image is taken from the slicing software cura ().

Part 14.

Print settings:

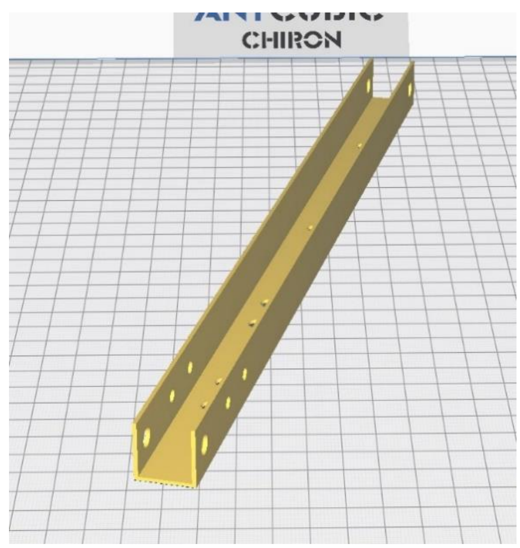


Figure 25 3D render illustrating the optimal printing orientation of part 14. The image is taken from the slicing software cura ().

Part 15.

Print settings:

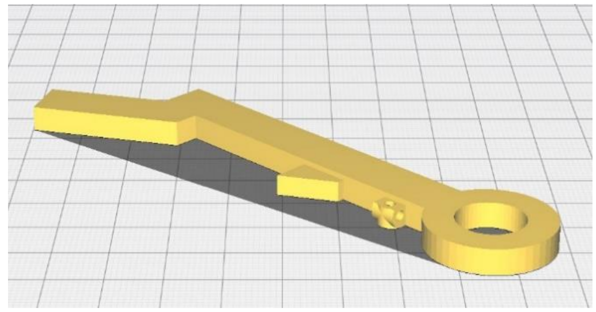


Figure 26 3D render illustrating the optimal printing orientation of part 15. The image is taken from the slicing software cura ().

Part 16.

Print settings:

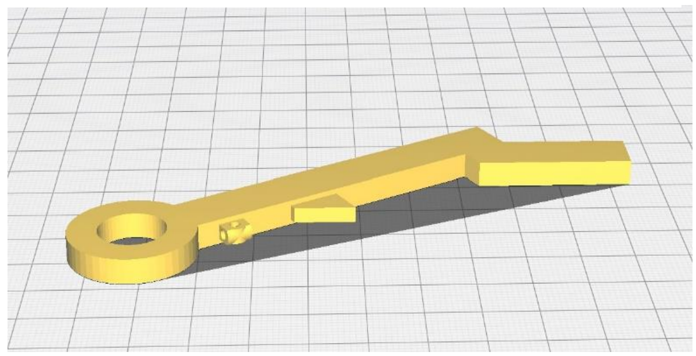


Figure 27 3D render illustrating the optimal printing orientation of part 16. The image is taken from the slicing software cura ().

Part 17.

Print settings:

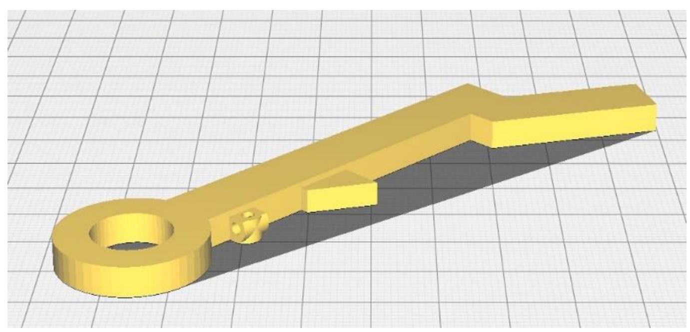


Figure 28 3D render illustrating the optimal printing orientation of part 30. The image is taken from the slicing software cura ().

Part 18.

Print settings:

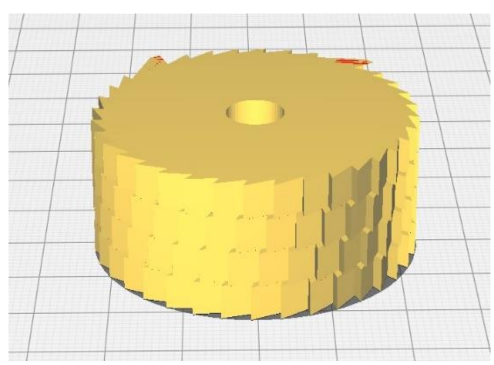


Figure 29 3D render illustrating the optimal printing orientation of part 30. The image is taken from the slicing software cura ().

Part 19.

Print settings:

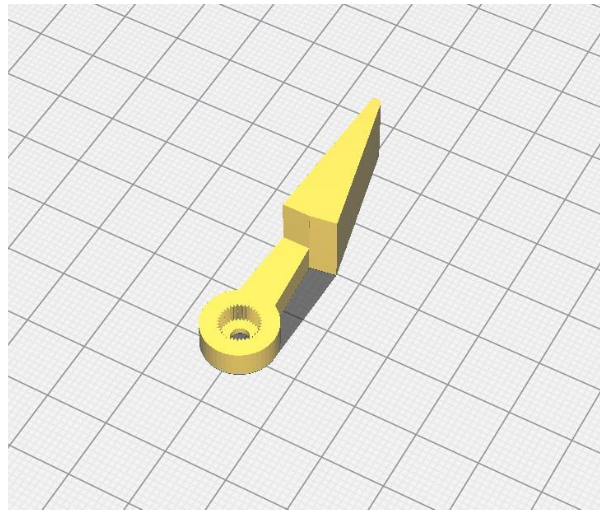


Figure 30 3D render illustrating the optimal printing orientation of part 19. The image is taken from the slicing software cura ().

Part 20.

Print settings:

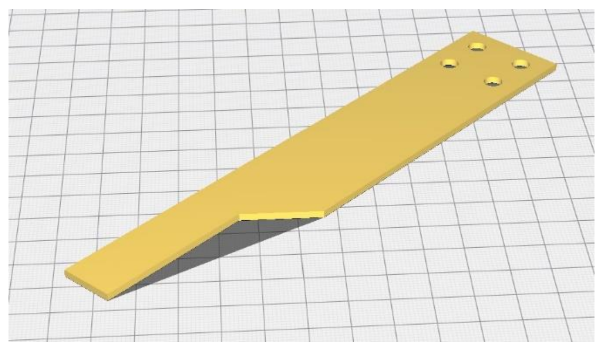


Figure 31 3D render illustrating the optimal printing orientation of part 20. The image is taken from the slicing software cura ().

Part 31.

Print settings:

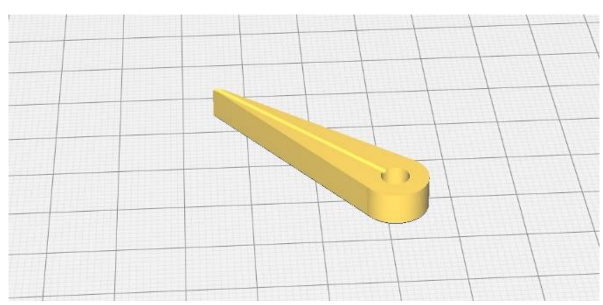


Figure 32 3D render illustrating the optimal printing orientation of part 31. The image is taken from the slicing software cura ().

Part 27.

Print settings:

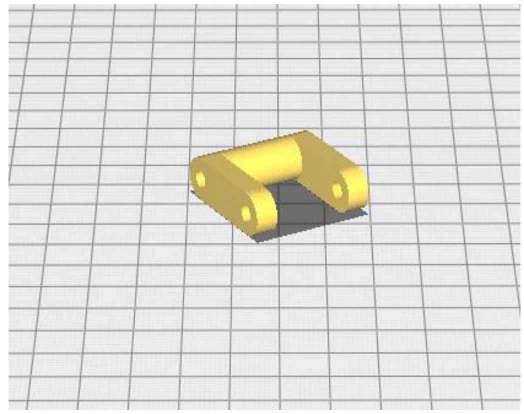


Figure 33 3D render illustrating the optimal printing orientation of part 27. The image is taken from the slicing software cura ().

Part 28.

Print settings:

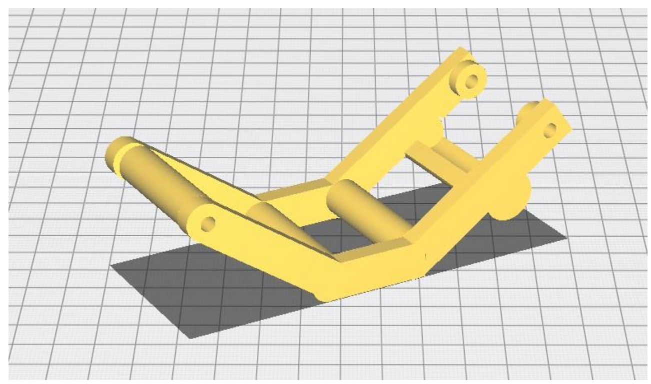


Figure 34 3D render illustrating the optimal printing orientation of part 28. The image is taken from the slicing software cura ().

Part 104.

Print settings:

Image to show orientation

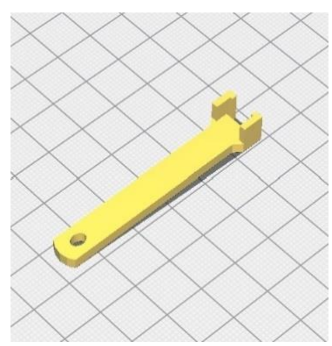


Figure 35 3D render illustrating the optimal printing orientation of part 104. The image is taken from the slicing software cura ().

Part 105.

Print settings:

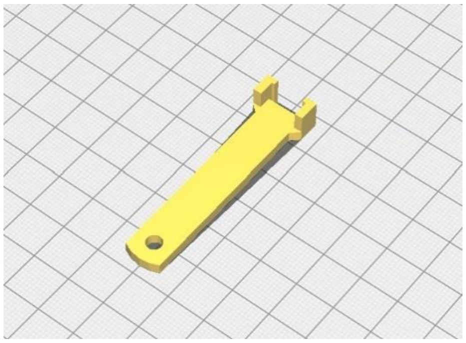


Figure 36 3D render illustrating the optimal printing orientation of part 105. The image is taken from the slicing software cura ().

Part 106.

Print settings:

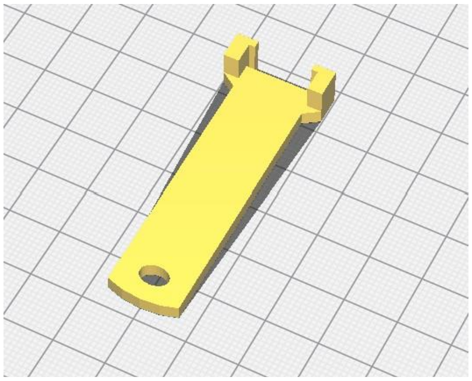


Figure 37 3D render illustrating the optimal printing orientation of part 106. The image is taken from the slicing software cura ().

Part 107.

Print settings:

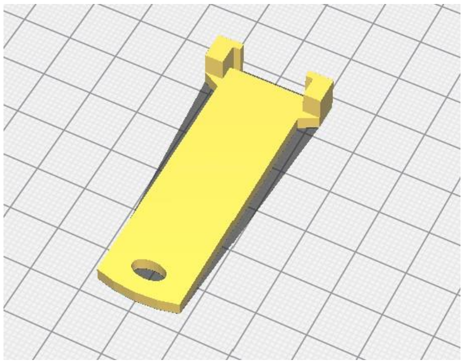


Figure 38 3D render illustrating the optimal printing orientation of part 107. The image is taken from the slicing software cura ().

Part 108.

Print settings:

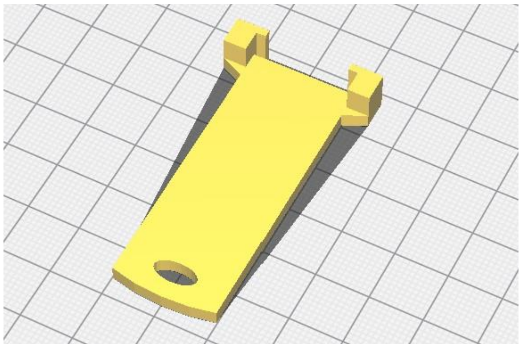


Figure 39 3D render illustrating the optimal printing orientation of part 108. The image is taken from the slicing software cura ().

Parts 13, 15, 16, 17, 18, 19, 31 together.

Print settings:

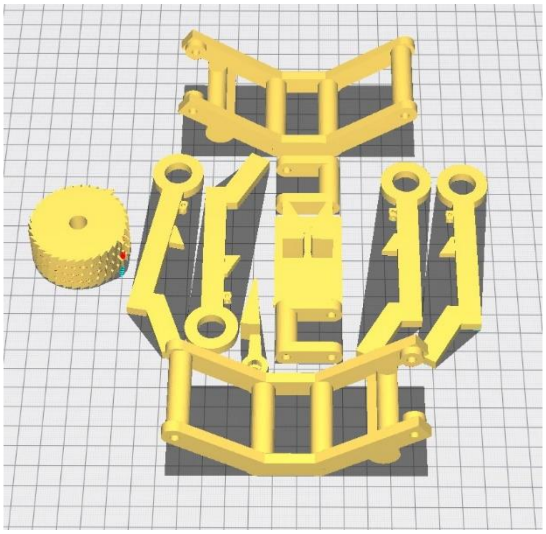


Figure 40 3D render illustrating the optimal printing orientation for batch 0.4mm (chamber parts) printing. The image is taken from the slicing software cura ().

Parts 14, 20, 104, 105, 106, 107, 108 together.

Print settings:

Image to show orientation

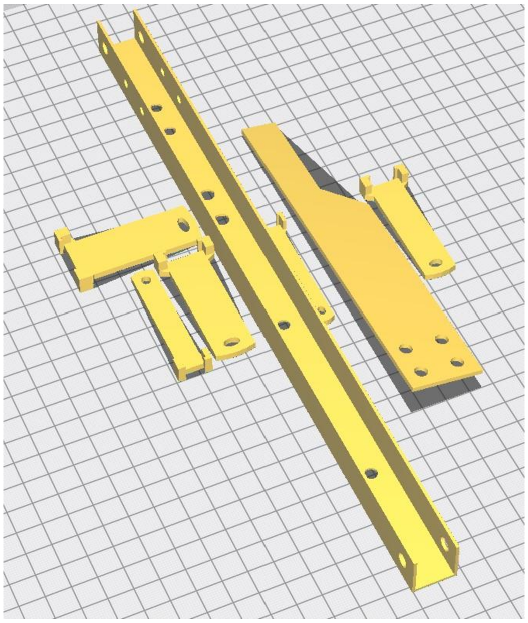


Figure 41 3D render illustrating the optimal printing orientation for batch 0.4mm (construction tools) printing. The image is taken from the slicing software cura ().

1.3 Post-print Processing

Once the 3D printed parts in Table 1 (also listed in Tables 6 and 7) have been printed, a number of processing steps are required before the chamber assembly can begin (section 1.4). These processes are detailed below.

1.3.1 Support removal and clean-up

Firstly, the support material on the parts must be removed. The parts requiring support removal are listed in Tables 6 and 7(section 1.2). Support material removal guidance for each part is given below. For reference, view the 3d renders of the parts on the openChamber Github project page "openChamber/Chamber_1/3d_Modelled_Parts/3d_Files/".

Part 1. Chamber body

Figure 42

Part 4 and Part 5. Chamber float cutting templates

Figure 43

Part 8. Sensor board 1

Figure 44

Part 9. Motor case

Figure 45

Part 10. Motor case lid

Figure 46

Part 16. (middle pawl)

Figure 47

1.3.2 Print sealing and protection

The FDM printing method yields a part which is in essence a stack of mechanically bonded layers of plastic. As the layers are not chemically bonded (like in SLA resin printing), post processing is required to make these prints water and gas tight. For this purpose, we use epoxy resin (part 88 in Table 4) – a resin typically used for waterproofing and sealing due to its very low gas permeability and water vapor transmission properties.

To protect the epoxy resin from UV degradation (visualised as a yellowing of the chamber), a final coat of UV resistant varnish (part 92 in Table 4) is applied over the chamber surfaces that will be exposed to sunlight. This also helps to maintain the structural integrity of the PLA plastic, which is less stable under UV exposure than other printing plastics, such as ASA or PETG.

Table 8 Parts requiring sealing and UV protection

Part Number	Epoxy resin coating	UV protective coating
1	YES	YES
2	YES	YES
3	YES	NO
9	YES	NO
10	YES	NO
13	YES*	NO
63	NO	YES
64	NO	YES
64.b	NO	YES

* Part 13 is a complicated part, requiring optical elements to be added.

Epoxy resin coating

It is advised that a longer cure time epoxy is used, a marine grade epoxy is ideal. This gives stronger results and plenty of time for application. Be careful to follow the safety guidance for the brand of epoxy you are using, however there are some basic principles to follow when working with epoxy:

- Avoid direct contact with the skin! In 10% of people contact between epoxy and skin can cause an allergic reaction called Contact Dermatitis (Westsystem, 2022). To prevent contact with the skin, it is advised that people working with the resin wear a HASMAT suit and tough use nitrile gloves designed for engineers (i.e. thick and not easily torn). Nitrile gloves are recommended as other types of rubber gloves can melt when in contact with epoxy, while Nitrile does not. Tough gloves are recommended as 3Dprinted parts can be quite sharp, causing tears in thin glove material.

- Ensure that the temperature of the workshop area is relatively warm. Epoxy is an exothermic reaction, and in very cold temperatures curing can be inhibited causing a sticky mess!

- Ensure that the working environment is well ventilated. Although epoxy resin off gassing is not obvious by smell, the chemicals can cause respiratory irritation when carried out in poorly ventilated areas or from prolonged exposure.

The working schedule for the epoxy process is as follows:

1. Tie and hang the part to be covered in a way that allows easy epoxy application. For this, fishing line is a good material, as regular string can become brittle after epoxy coating. Examples of how to tie the parts in Table 8 are given below.

2. Prepare your working space, ensuring that you have all the things you will need to mix and apply the epoxy. A small foam roller is an efficient way to apply epoxy, though a brush can also be used to a less aesthetic effect. Typical methods to measure the ratio of hardener to resin include using weighing scales or volumetric syringes.

3. The first layer: apply epoxy until it stops being absorbed by the 3D printed part. As a 3D printed part is in effect a mesh structure, a lot of epoxy will be absorbed in the first coating. When it appears that the print is saturated, wait 5 to 10 minutes before returning. If the print appears to be saturated then continue to the next step, otherwise apply more epoxy and repeat this step.

4. Wait until the epoxy becomes tacky/sticky – i.e. not completely cured. A tacky surface texture will chemically bond with the 2nd layer of epoxy applied. If the epoxy has completely cured then sand the surface to provide a rough texture for the second layer of epoxy to bond to.

5. Additional layers: Apply the next layer of epoxy. Less epoxy will be required for this step, as now the part is not porous. Apply like you would a layer of paint to a wall.

6. Now repeat steps 4 and 5 until the number of desired layers has been achieved. The recommended minimum number of layers is 2 to 3, however as different people apply the resin differently, 3 coats is often a safer option.

7. The last coat should be left to fully cure before removing from its hanging position, as epoxy remains soft after it is touch dry for up to 72 hours.

8. Remove all the parts from the fishing wire and check the areas that must be kept free for proper functioning (described individually for each part below). If these areas are blocked then use tools such as sandpaper, small files or a rotary tool to remove excess varnish. A common brand of rotary tool is the “Dremel”.

9. Store parts safely until you are ready to proceed with the next step in the build guide (UV protective coating).

UV protective Coating

After the necessary parts have been epoxy coated and allowed time to cure fully, it is time to UV coat the parts indicated in Table 8.

Ensure to follow the safety, preparation and application steps described on the UV protection coating that you use, for example polyurethane varnish (part 92 in Table 4). It is unlikely that the varnish will be cause the same irritation described in the Epoxy resin coating section above, however the same safety procedures are recommended. Similarly, temperatures can affect the varnish curing process, so excessively cold workspaces are not recommended.

The working schedule:

1. Tie and hang the part to be varnished in the manner described in the “Epoxy resin coating” section above.

2. Prepare your working space, ensuring that you have all the things you will need to mix and apply the varnish. A small foam roller is an efficient way to apply varnish, though a brush can also be used.

3. Prepare the surface to be varnished I.e., the **outside** of the part only. In most cases this will mean lightly sanding the area to be varnished. This allows a surface texture for the varnish to bind with. However, be sure to follow the specific brands advice.

4. Remove the durst with a damp cloth.

5. Apply the first layer of varnish to the **outside** of the part only, i.e. the area that will be exposed to the sun. Apply thinly like painting a wall. Take special care around areas that are likely to collect varnish and inhibit later construction processes (described in the “Epoxy resin coating” section above).

6. Wait until the varnish becomes tacky/sticky – i.e. not completely cured. A tacky surface texture will chemically bond with the 2nd layer of varnish applied. If the varnish has completely cured, repeat steps 3 and 4.

7. Apply a final coat to the part following step 5. As the purpose of this varnish is for UV protection and not aesthetics, it is likely that 2 coats will achieve this. However, is the manufacturer of your varnish suggests more coats, then follow that advise for best results.

8. Leave the parts to fully cure, following the advice of the given by the manufacturer. This is often 48 to 72 hours.

9. Remove the parts from the fishing wire and check the areas that must be kept free for proper functioning (described in the “Epoxy resin coating” section above). If these are blocked then use tools such as sandpaper, small files or a rotary tool to remove excess varnish. A common brand of rotary tool is the “Dremel”.

10. Store parts safely until you are ready to proceed with the next step in the build guide (Parts assembly).

1.4 Parts Assembly

This chapter details the construction of the chamber module, beginning with a group of individual parts, and ending with the constructed chamber. The assembly process is divided into a subassembly hierarchy, using the principle of 1 significant part to multiple insignificant parts such as fasteners. A combination of action diagrams, supplemented with written text and links to online animations describe this assembly process.

The main sub assembly modules are as follows:

1. Preparation
2. Chamber body subunit
3. Chamber lid subunit
4. Motor unit subunit
5. Chamber bracket subunit
6. Subunit unification

Figure 48 GIF animation depicting the explosion of the chamber parts from their initial constructed form. Print copy will just show one frame from this animation. View online pdf for the animation. Parts and animation carried out in openSCAD.

Step 1: Preparation

Before beginning assembly, check that the parts listed in section 1.1 (Tables 1 to 4) have been collected, **excluding** parts 88, 89, 92 from Table 4 (only required in sections 1.2 and 1.3), **excluding** parts 48, 51, 52, 56, 61 and 62 from Table 2 and **excluding** parts 77 and 78 from Table 3, which will themselves be constructed from parts in Table 4 throughout this assembly section.

Familiarise yourself with the construction steps you are about to undertake, and make sure you have all the required tools to complete construction.

Preparing part 57 – spacer cylinder

Parts required for this section = 1 x part 96.

Cut a 21mm length of part 96 using a hacksaw, an angle grinder, or asking someone to do it for you.

This is now part 57 is ready for chamber installation.

Preparing part 48 – lead screw

Parts required for this section = 1 x part 48.

If you cannot source leadscrew pre-cut to 130mm in length, you will have to cut this to size.

As lead screw is made from hardened steel, this must be done with a motor driven metal cutting saw, for example an angle grinder. If you are not experienced with metal work, and cannot find someone else to do this for you, contact the openChamber project for help in sourcing pre-cut parts.

Once cut, the end must be filed so that the thread is still capable of taking a T8 nut (part 49).

Part 48 is now ready for chamber installation.

Preparing part 51 – chamber brackets

a.) b.) c.)

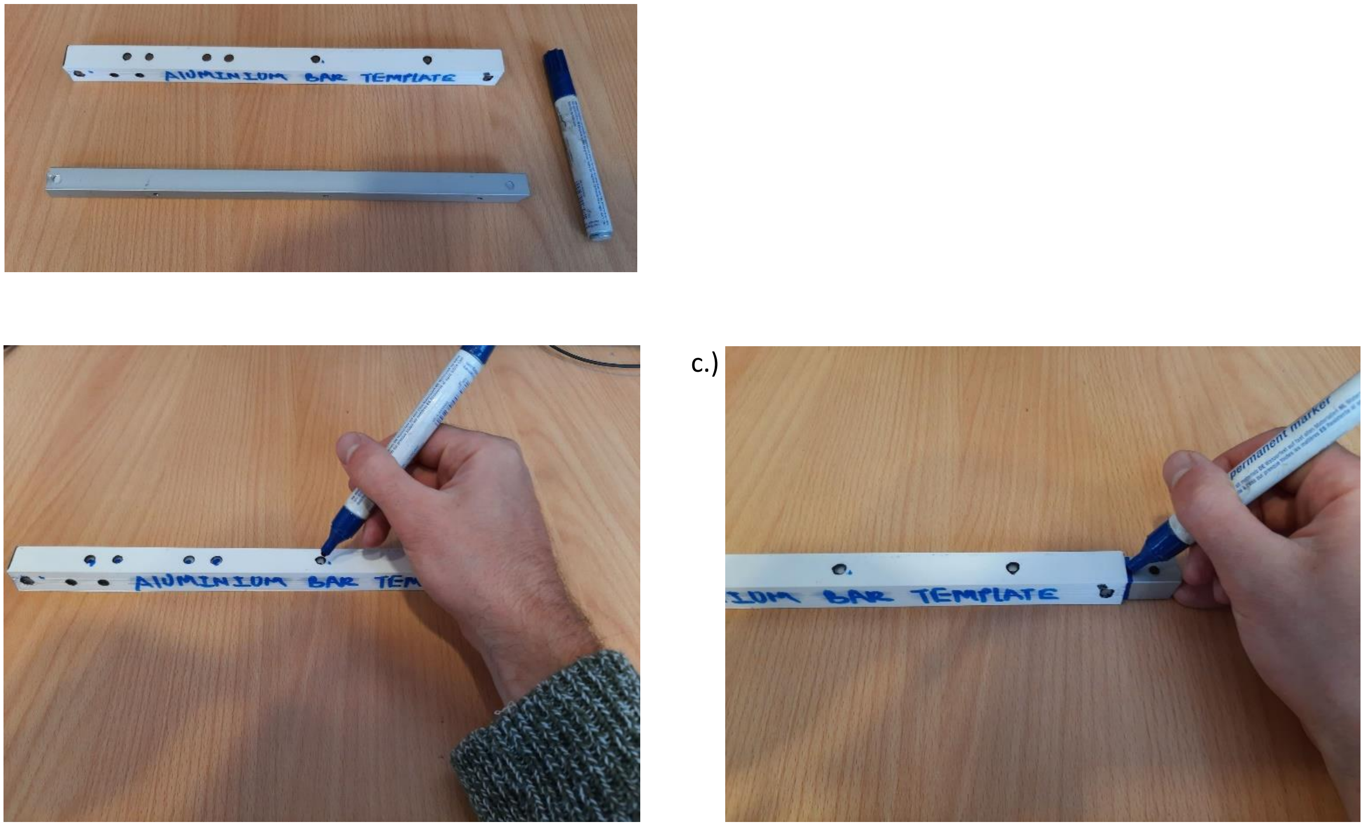


Figure 49 Photographic guide images detailing the construction of part 51 the chamber brackets.

Notes:

Parts required for this section = 1 x part 95, 1 x part 14

Figure 49 a illustrates a section of aluminium bar (the lower bar in the image) that will but cut to become part 51 using part 14 the bracket template (the upper part of the image).

Fit the section of part 95 inside the bracket template (part 14). Mark the drill points onto part 95 using a pen through the template holes (Figure 49 a).

Mark the length of the bar on each side as illustrated in Figure 49c.

Cut part 95 to length following the marked lines, for example using an angle grinder or hacksaw or by asking someone to cut it for you.

Use the holes in the template as a size guide when selecting the correct drill bit diameter.

When not using a drill press, drill the holes from one side, and then the other so ensure that the holes are in the correct alignment.

Repeat this for a second bracket and then your part 51 will be ready for chamber installation.

Preparing part 56 - lid optical interrupter bar

a.) b.) c.)

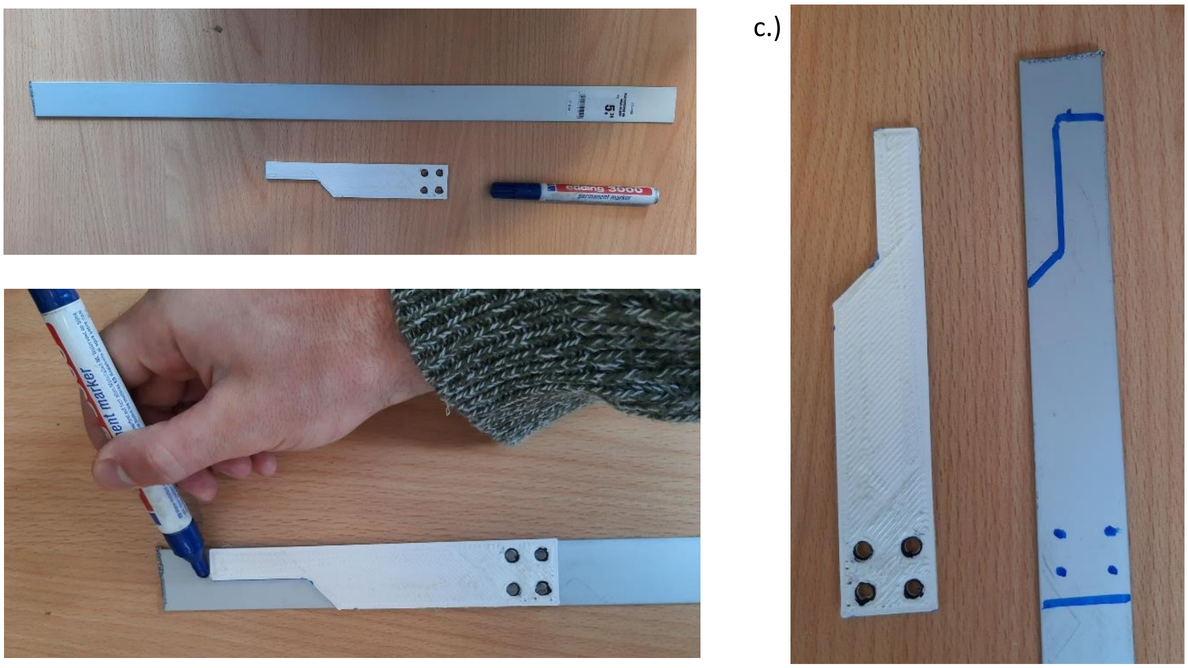


Figure 50 Photographic guide images detailing the construction of part 51 the lid optical interrupter bar.

Notes:

Parts required for this section = 1 x part 20, 1 x part 97

Figure 50a illustrates a section of aluminium flat bar (the upper bar in the image) that will but cut to become part 56 using part 20 the interrupter bar template (the lower part of the image).

Lay the template (part 20) onto the section of part 97. Mark the drill points onto part 97 using a pen through the template holes (Figure 49 b).

Mark the external shape of the template onto part 97 as illustrated in Figure 49 b and c.

Cut the shape of part 95 following the marked lines, for example using an angle grinder or hacksaw or by asking someone to cut it for you.

Use the holes in the template as a size guide when selecting the correct drill bit diameter and drill the holes.

Chamfer and round the edges of the narrow end of the cut out interrupter bar.

With this part 56 is ready for installation.

Preparing parts 63, 64 and 64b – foam floats

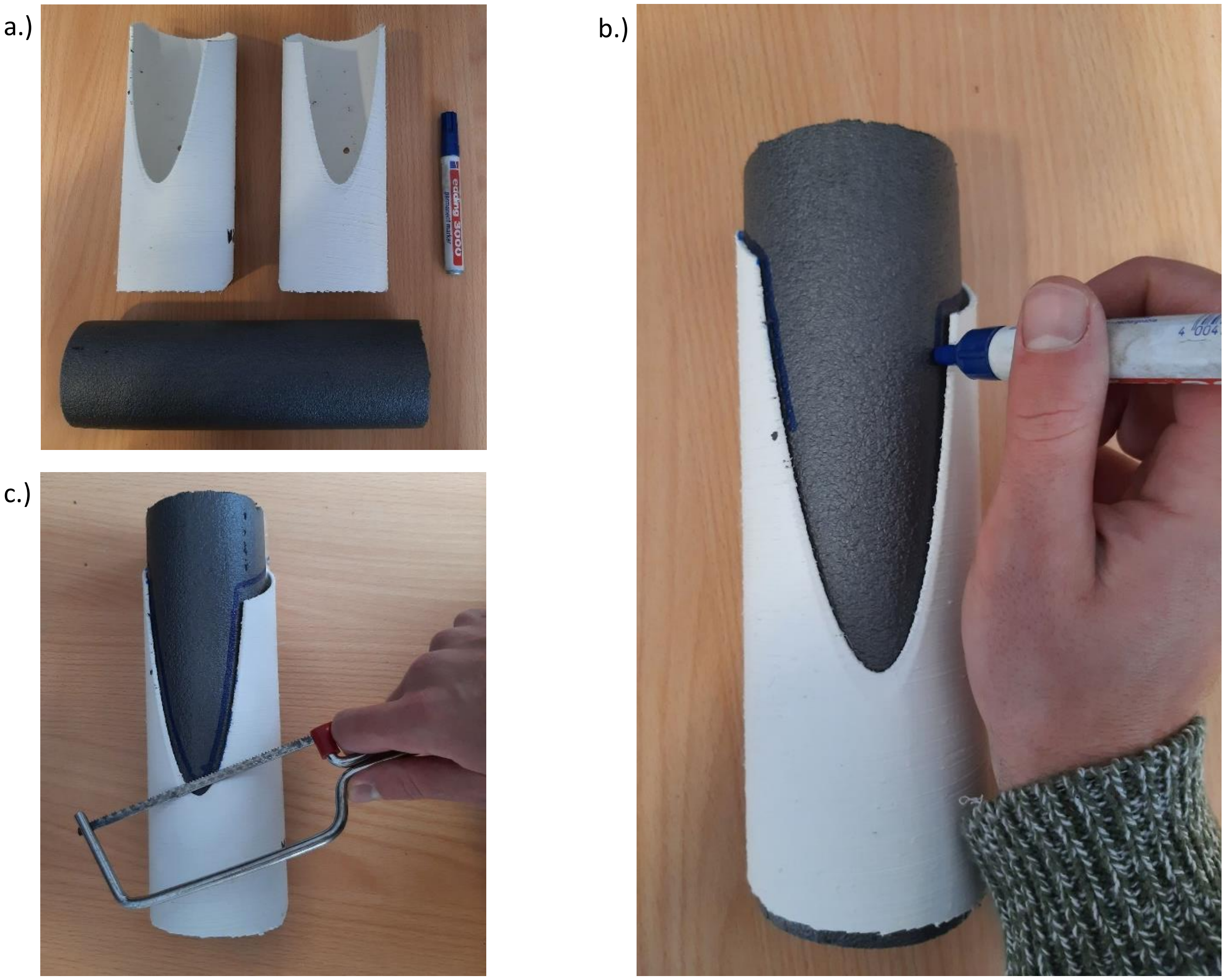


Figure 51 Photographic guide images detailing the construction of part 51 the lid optical interrupter bar.

Notes:

Parts required for this section = 4 x part 98, 1 x part 4, 1x part 5.

This step cuts and shapes the foam floats. The bottom of parts 63 and 64 are shaped to fit against the chamber when the chamber float arms (part 3 or 3b) are stored in the vertical position (Figure 55a Section 1.4.2.4). The top of parts 63 and 64 are shaped to form a neat butt joint with part 64b.

For short chambers (part 1), cut one length of foam tube (part 98) to 200mm. This is part 64b.

For part 63 (foam float right), insert part 98 into part 5 (foam cutting guide right). Following part 5, match the foam tube to the shape either by marking the shape to be cut with a pen (Figure 51b), or by cutting directly in part 5 with the junior hacksaw (Figure 51c). Remember to follow the guides top and bottom.

Repeat this for part 64 (foam float left), inserting part 98 into part 4 (foam cutting guide left).

For tall chambers (part 1.b), cut one length of part 98 to 200mm. This is part 64b. Cut an additional 2 lengths pf part 98 to 300mm. These are the blanks for part 63 and 64.

Shape the bottom of part 63 by inserting the blank part 63 into part 5 (foam cutting guide right) and ensuring that the bottom of part 63 aligns with the bottom of part 5. Following part 5, match the foam tube to the shape either by marking the shape to be cut with a pen (Figure 51b), or by cutting directly in part 5 with the junior hacksaw (Figure 51c). Once this is done, push part 5 to the top of part 63, and repeat the foam cutting process with the top of part 5.

Repeat this for of part 64 by inserting the blank part 63 into part 4 (foam cutting guide left).

Once this is done, parts 63, 64 and 64b are ready for chamber installation.

Step 2: Chamber body

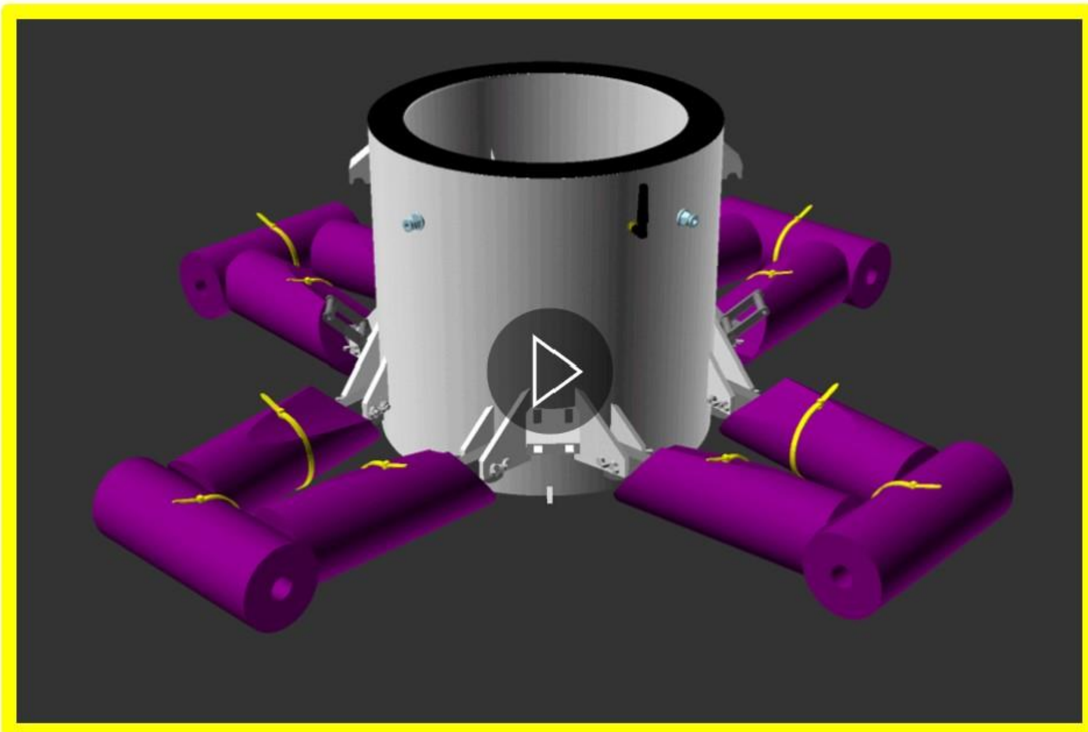
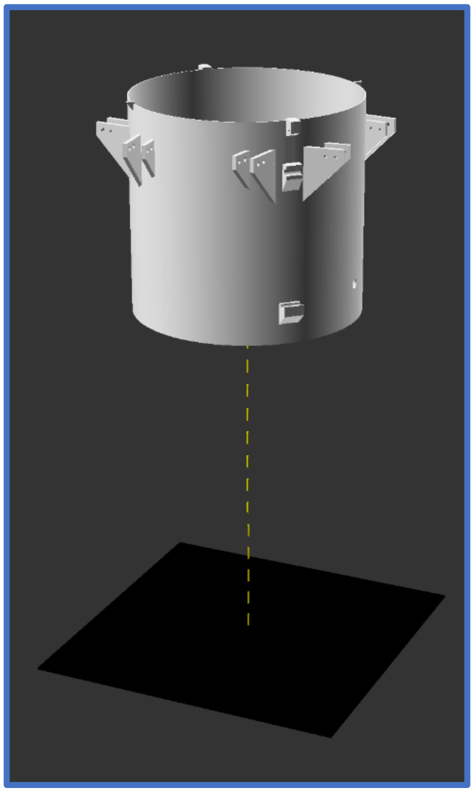


Figure 52 3d model illustrating the product of step 2. Before moving to step 3, your assembled piece should look like this. Print copy will just show one frame from this animation. View online pdf for the GIF animation modelled in openscad.

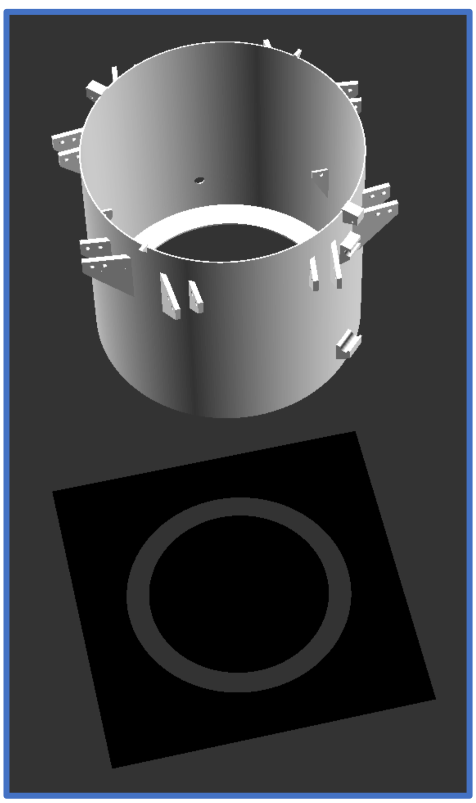
Step 2 focuses upon the subassembly piece “Chamber body”. The end product of this step is an open chamber, with float arms, tube connections, antenna mount, stacking chamber clips and gasket installed (illustrated by Figure 52).

2.1 Gasket installation

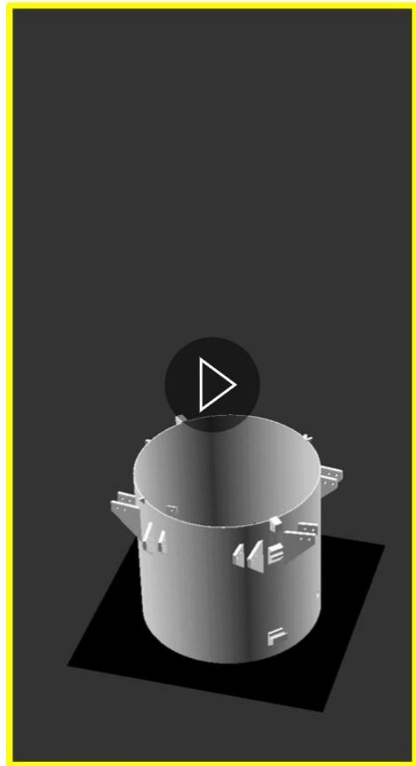
a.)



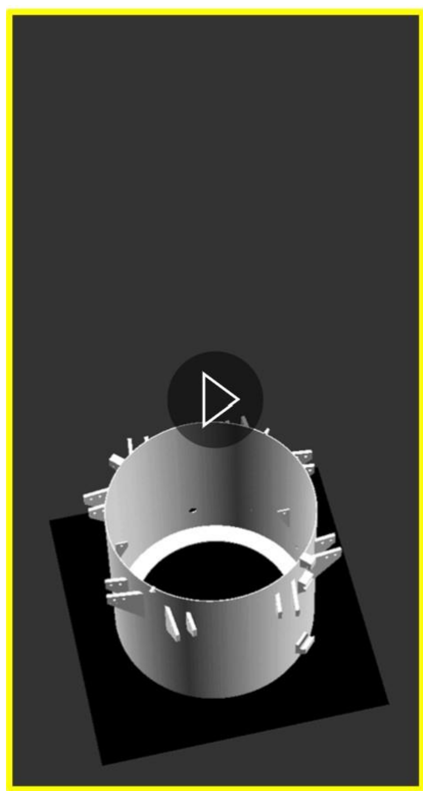
b.)



d.)



e.)



c.)

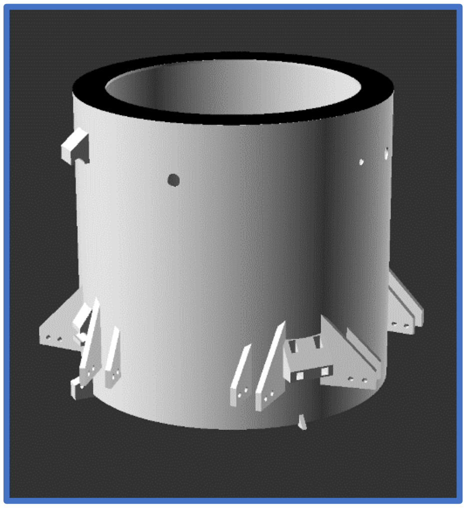


Figure 53 Action diagrams (a, b and c) and animated gifs (d and e) illustrating step 2.1 gasket installation in the chamber body subassembly.

Notes:

Parts required for this section = Part 1 and Part 94 (part 94 will become part 52 after cutting).

Remove the paper protecting the glue surface of Part 94. If this is not supplied with a glued surface, then apply glue to the rubber surface now.

Lightly score the top rim of part 1 that will be face down on the glued surface of part 94. Do this in a cross-hatch pattern using a craft knife. This gives a textured surface for the glue to bind with.

Push part one (cross-hatch pattern down towards the glue) onto the glued surface of part 94 (illustrated in still Figure 53a and animated Figure 53d). Apply weight to part 1 for the curing time of the glue (usually 10 minutes).

Using a craft knife cut part 94 carefully around the outside and the inside of part 1 (this forms the rubber gasket referred to as part 52 from here on). Lift the building unit (part 1 and 52) away to leave part 94 resembling still Figure 53b or animated Figure 53e.

Flip over the building unit so that the gasket (part 52) is not in contact with the floor. Try to keep the gasket clean and damage free throughout the build process. The end product should resemble Figure 53c.

2.2 Float arm axle installation

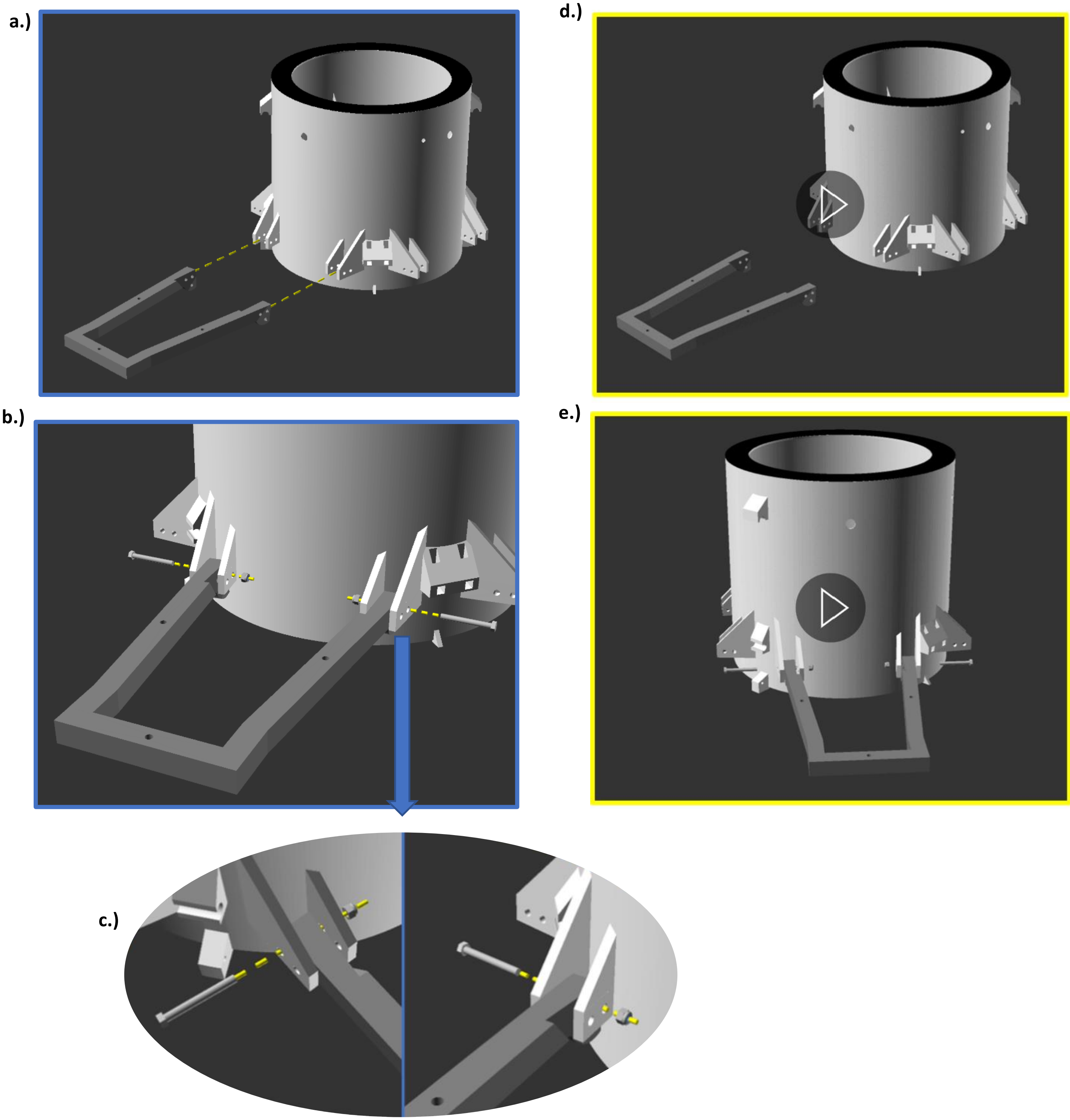


Figure 54 Action diagrams (a, b and c) and animated gifs (d and e) illustrating step 2.2 float arm axle installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.1 (Figure 53c), 4 x part 3, 8 x part 32 and 8 x part 34.

Orient part 3 as illustrated in Figure 54a and d, positioning between the shoulders of part 1 (now the subassembly unit), so that the holes in each part are lined up.

Following Insert part 32 through the outer shoulder hole closest to the chamber body, through the matching hole in part 3 and then out through the inner shoulder hole. Repeat this for both of the 2 shoulders (illustrated in Figure 54b, c and e).

Now screw on parts 34 to parts 32 (illustrated in Figure 54b, c and e) using an 8mm spanner/ wrench. Ideally a ratcheting spanner/wrench is used on the hex bolt outside of the shoulder to do the tightening/ rotation of part 32, while a standard spanner/wrench or pair of pliers are used to hold part 34 in place.

The bolt should be tensioned so that it and part 3 can still move freely. Its function is to act as an axle. Do not overtighten.

2.3 Float arm lock pin installation

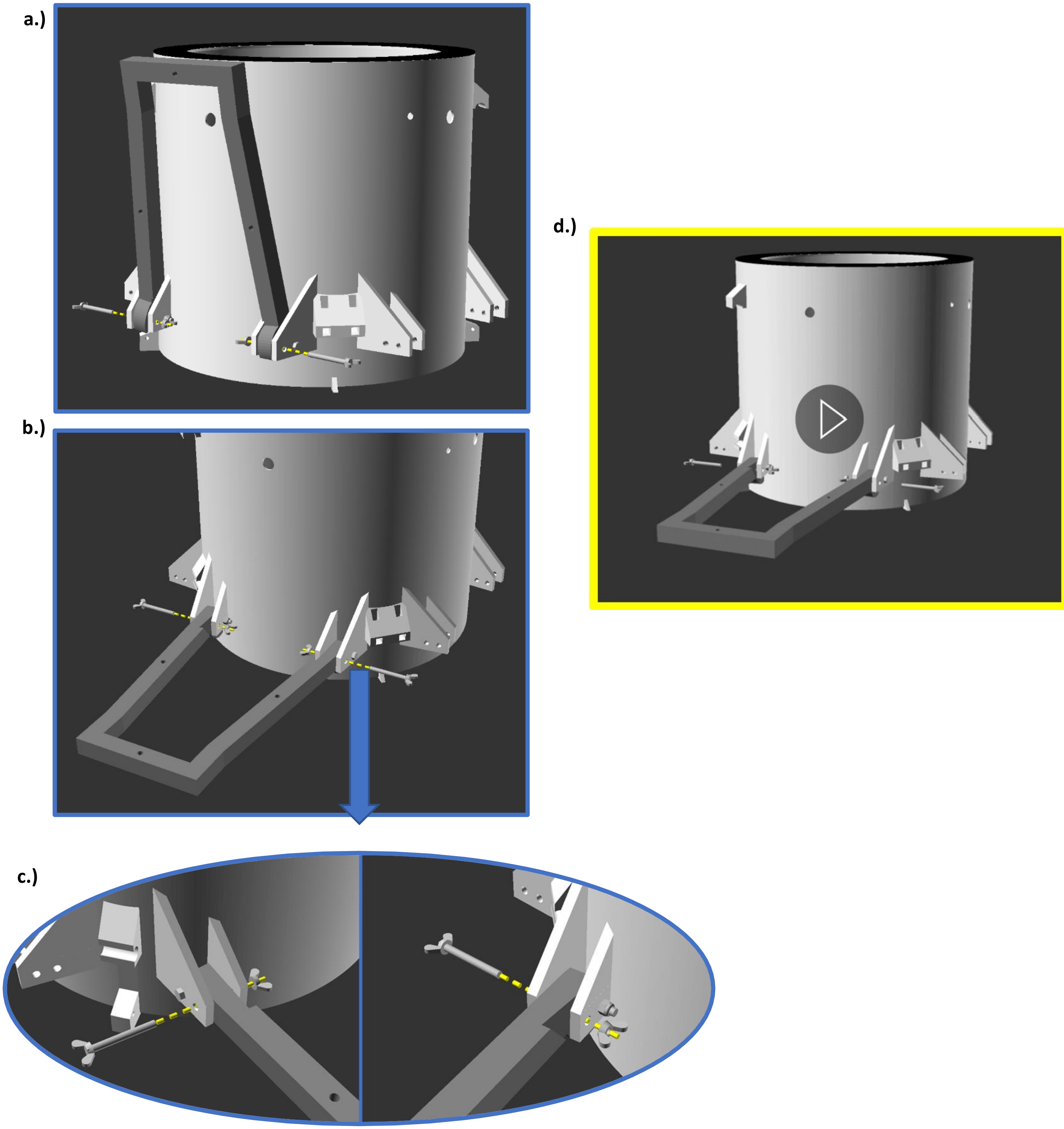


Figure 55 Action diagrams (a, b and c) and animated gifs (d) illustrating step 2.3 float arm lock pin installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.2 (Figure 54b and e), 8 x part 32.b and 8 x part 34b.

This step locks the float arm (part 3) into 2 positions: vertical position for storage and transport (Figure 55a), or horizontal position for use on the water (Figure 55b). The position that we will work with for the next steps is the horizontal position.

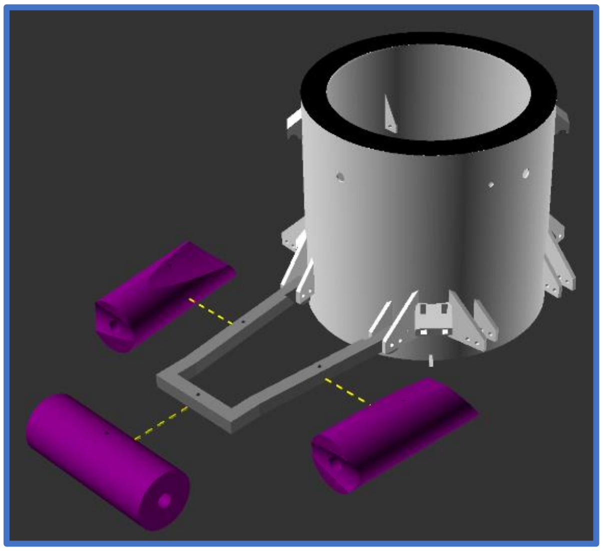
Ensure the hole alignment for subsequent steps using a drill with a drill bit diameter matching the m5 bolt diameter. Insert the drill bit from the outside of the chamber shoulder (part 1 shoulder) inwards, through the hole in part 3, and out through the internal chamber shoulder.

Inset part 32.b through the outside of the chamber shoulder (part 1 shoulder) inwards, through the hole in part 3, and out through the internal chamber shoulder. Next thread part 34b onto part 32.b (illustrated in Figure 55b, c and d).

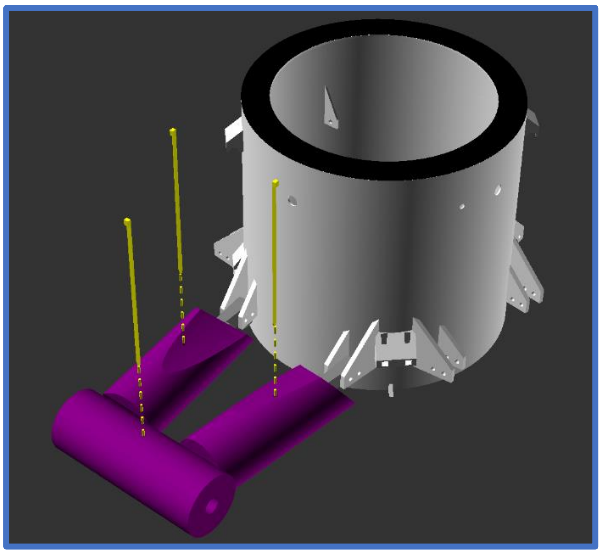
The role of this part is to lock the chamber arm in its position. The bolt and arm should not move. Tighten the bolt using your hands with only moderate force, so as not to break the 3D printed parts. Never use pliers or other tools to gain added leverage as this can result in overtightening and breaking of 3D parts.

2.4 Floats installation

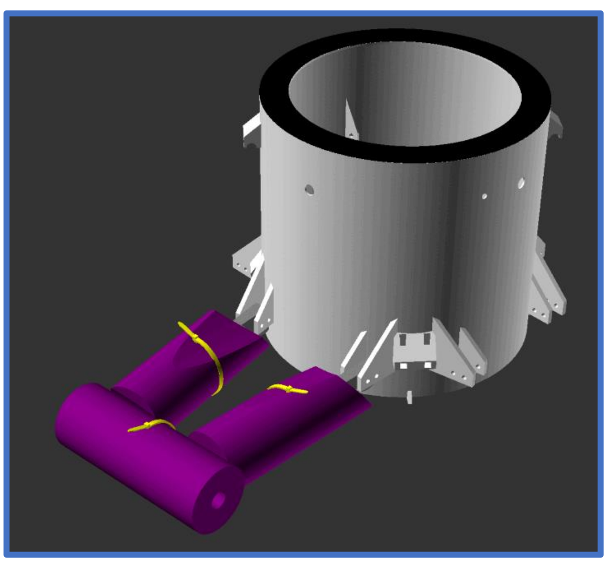
a.)



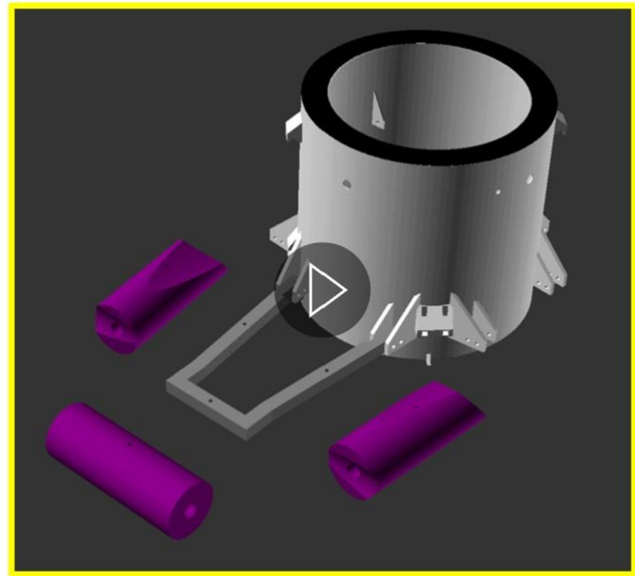
b.)



c.)



d.)



e.)

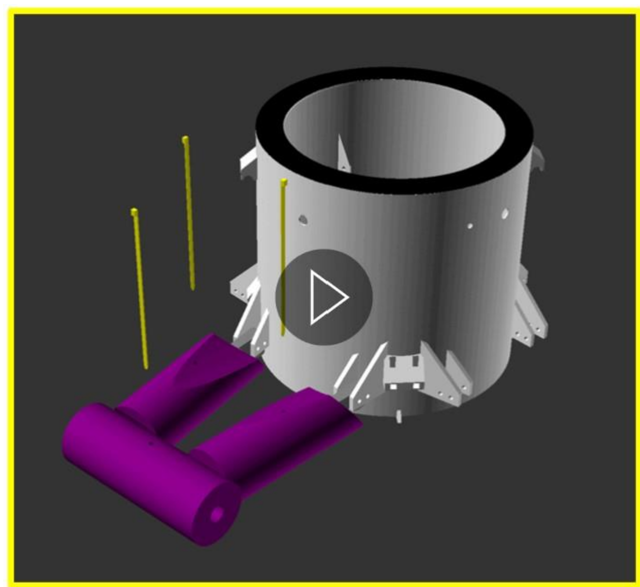


Figure 56 Action diagrams (a, b and c) and animated gifs (d and e) illustrating step 2.4 float installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.3 (Figure 55b and d), 4 x part 63, 4 x part 64, 4x part 64.b and 12x part 93 .

The foam floats (parts 63, 64, and 64.b) must be slipped onto part 3 of the subassembly through the open side of the foam pipe. The drilled holes in the floats should align with the holes in part 3. Parts 63 and 64 should be oriented such that the side cuts are on the chamber side and the end grove is pointing away from the chamber. This process is illustrated in Figure 56a and d, with part 63 being the left most float and part 64 being the right float in the image.

Push the cable/zip ties (part 93) through the top hole in the foam floats, then through the hole in part 3 and out through the bottom hole in the float again (Figure 56b and d). This is sometimes more easily done by peeling back the float around part 3 to see clearly what the cable tie is doing.

Connect the cable tie to its head and tighten to hold the foam in place (Figure 56c and d).

2.5 Complete arm installation

a.) b.)

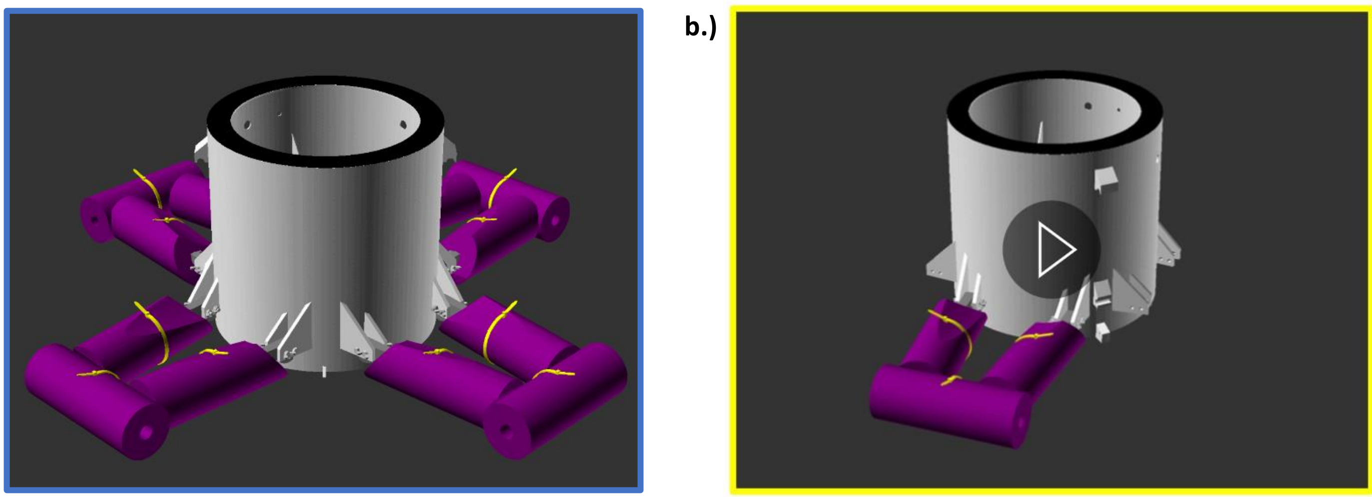


Figure 57 Action diagrams (a) and animated gif (b) illustrating step 2.5 complete arm installation to the chamber body subassembly.

Notes:

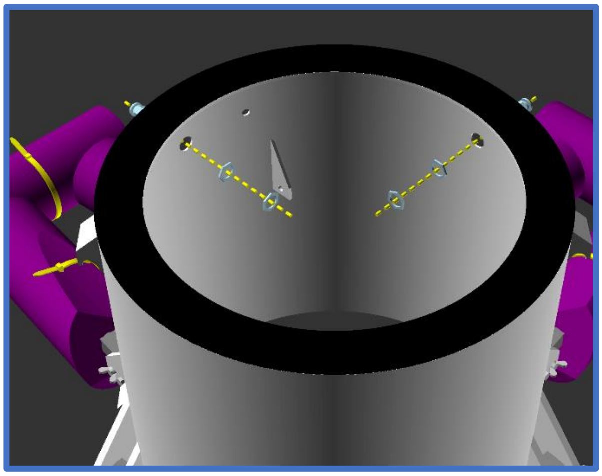
Repeat steps 2.2 to 2.4 until all 4 of the chamber arms have been installed (Figure 57b).

The product of this step should resemble Figure 57a.

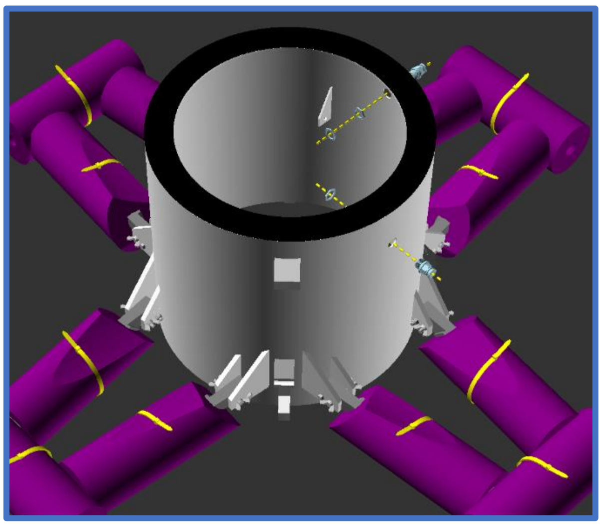
Once in place, the foam floats (parts 63, 64, and 64.b) can be sealed with a UV coating (part 92) to prevent foam degradation and resulting microplastic pollution.

2.6 Push fit tube connector installation

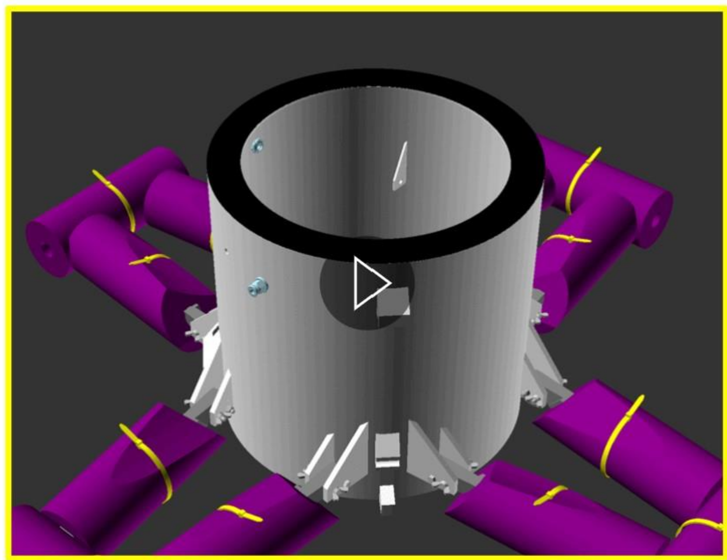
a.)



b.)



d.)



c.)

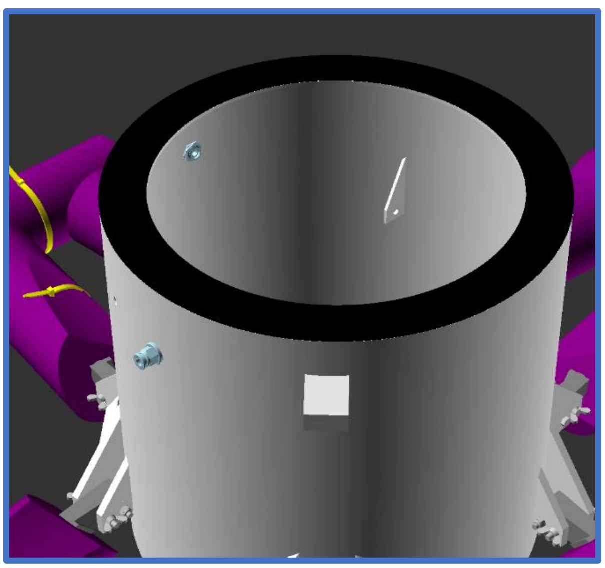


Figure 58 Action diagrams (a, b, c) and animated gif (d) illustrating step 2.6 Push fit tube connector installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.5 (Figure 57b), 2 x part 61, 4 x part 61.b.

Dry fit part 61 into the hole illustrated in Figure 58a, b and d. These are the two larger diameter holes (the smaller diameter hole in between is required for step 2.7).

Dry thread first 1 part 61.b onto the rear thread of part 61, tightening either with 2 pairs of pliers (one on the outside on part 61 and one on the inside on part 61.b) or by using wrenches/spanners. Next dry thread the second part 61.b to lock the first nut in place.

When happy that this assembly is correct and resembling Figure 58c, reverse the process and proceed to the wet fit.

Cover the threaded portion of part 61 with thickened epoxy (part 88) or gel superglue (part 90). Wearing gloves, insert part 61 into the hole again and follow the dry fit steps described above.

After the glue has cured, ensure that there are no leaks around part 61 by testing with water around the glued joint. If a water is leak is spotted, dry thoroughly, apply more glue and repeat until no leak is seen.

Repeat this step for the second push fit connector on the chamber.

2.7 Antenna installation

a.) **b.)** **c.)**

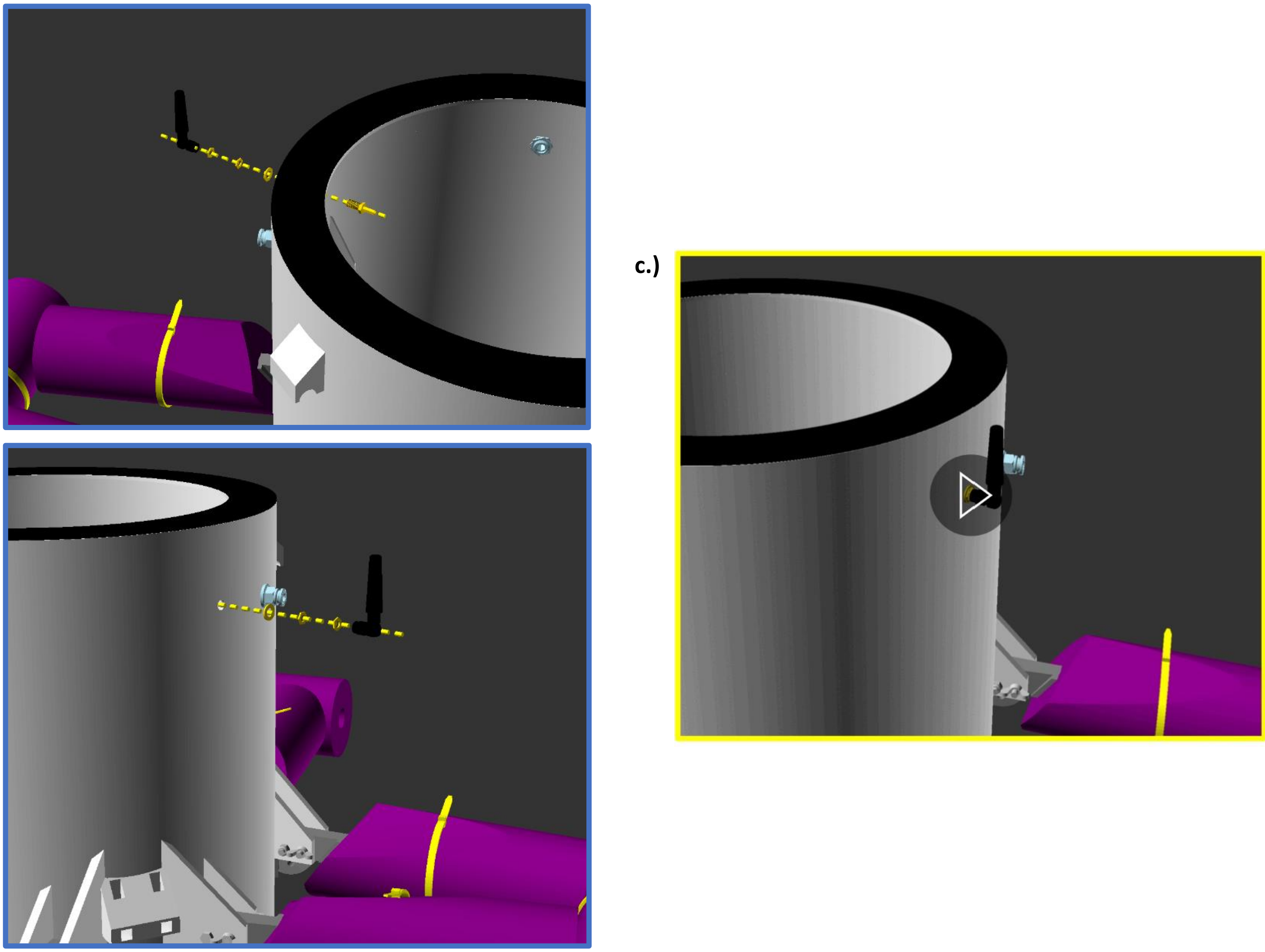


Figure 59 Action diagrams (a, b) and animated gif (c) illustrating step 2.7 Antenna installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.6 (Figure 58c), parts 73, 74, 74.b and 2 x part 74.c.

Dry fit part 74 into the the smaller diameter hole between the 2 push fit connectors (part 61), from the inside of the chamber (part 1) out (illustrated in Figure 59a, b and c).

On the outer side of the chamber apply first part 74.b then the two parts 74c to the threaded connector of part 74. Tighten carefully with 2 pairs of pliers (one on the outside on part 61 and one on the inside on part 61.b) or by using wrenches/spanners.

When happy that this assembly is correct and resembling Figure 59c, reverse the process and proceed to the wet fit.

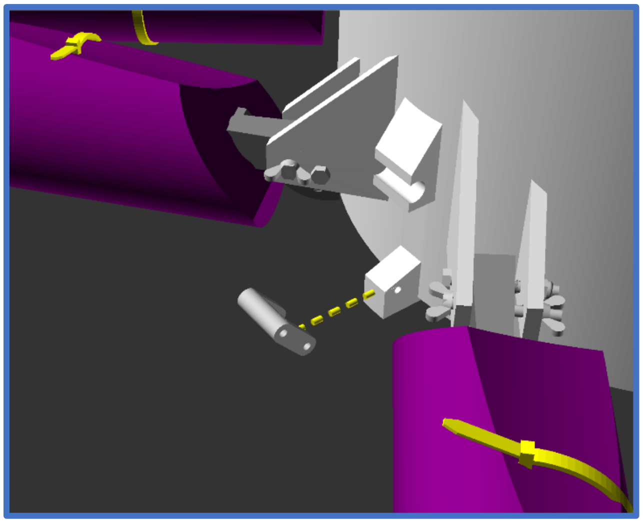
Cover the threaded portion of part 74 with thickened epoxy (part 88) or gel superglue (part 90). Wearing gloves, insert part 74 into the hole again and follow the dry fit steps described above.

After the glue has cured, ensure that there are no leaks around part 74 by testing with water around the glued joint. If a water is leak is detected, dry the area thoroughly, apply more glue and repeat until no leak is seen.

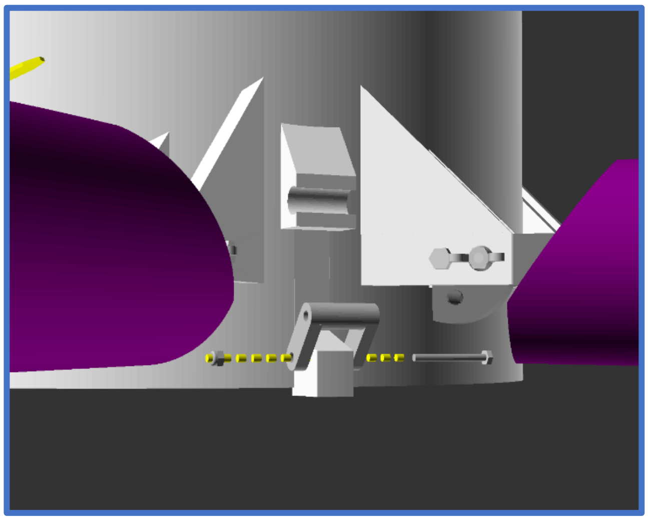
Once complete, screw on part 73, with the antenna pointing upwards.

2.8a Stacking clip installation

a.)



b.)



c.)

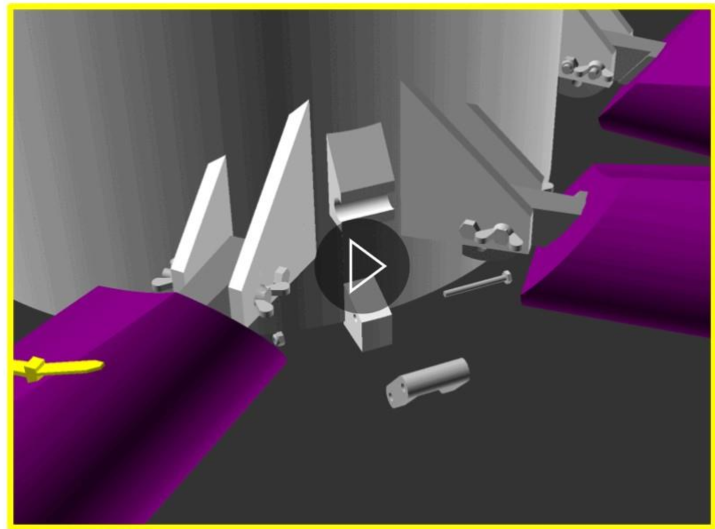


Figure 60 Action diagrams (a and b) and animated gif (c) illustrating step 2.8a stacking clip installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.7, 2x parts 27, 2 x part 42, 2x part 44 (or 2x part 44b combined with part 90 if spacing is an issue).

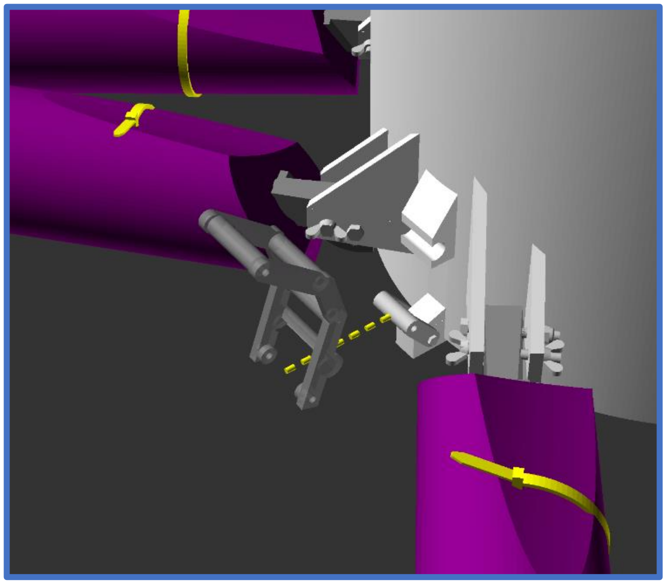
Position part 27 over the chamber body (part one), as illustrated in Figure 60a and c, lining up the holes in each part.

Following Figure 60b and c, insert part 42 through part 27, then through the hole in part 1, and out through part 27 again. Thread part 44 onto the exposed thread of part 42. Tighten with a 5mm spanner/ wrench, so that part 27 can rotate easily, while being confidently that it will not fall off.

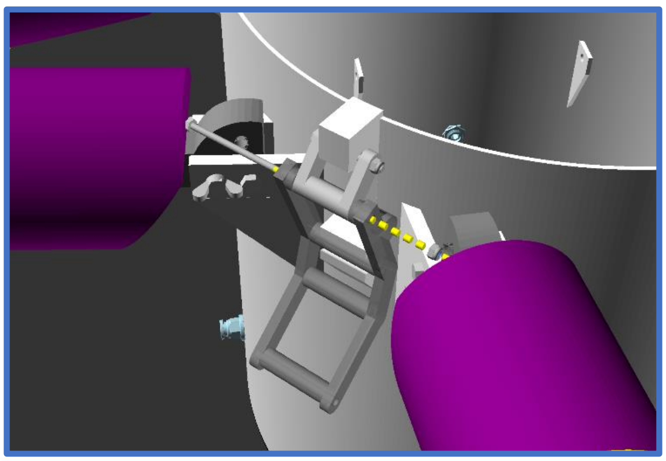
In the case that part 44 blocks the movement of the latch, it can be replaced with a single part 44b and held in place with superglue (part 90). The result is shallower than part 44, though less durable.

2.8b Stacking clip installation

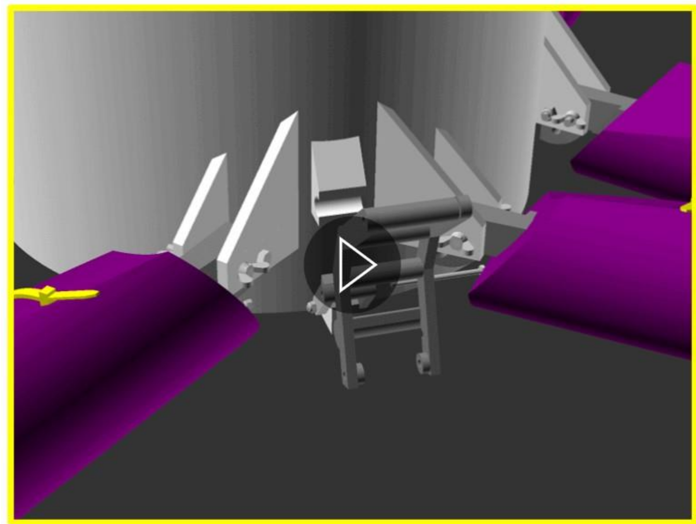
a.)



b.)



c.)



d.)

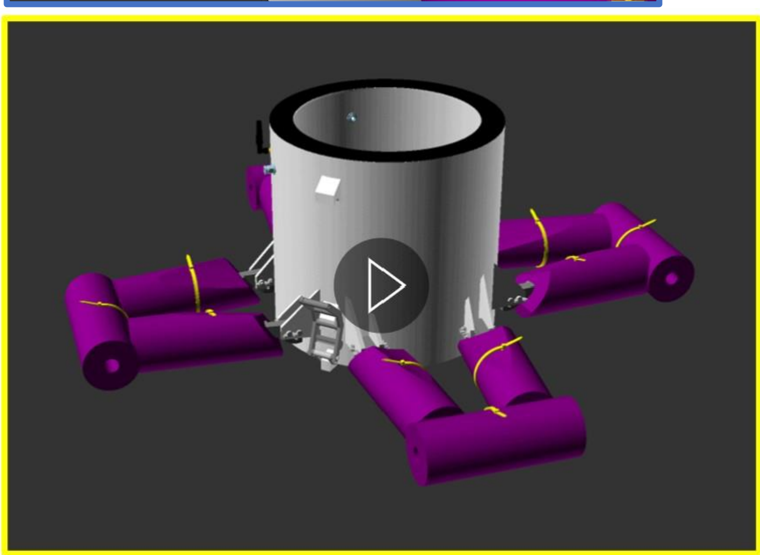


Figure 61 Action diagrams (a and b) and animated gifs (c and d) illustrating step 2.8b Stacking clip installation to the chamber body subassembly.

Notes:

Parts required for this section = Subassembly unit resulting from step 2.8a, 2x parts 28, 2 x part 41, 2x part 44.

Position part 28 over the top hole of part 27 as illustrated in Figure 61a and c, lining up the holes in each part.

Following Figure 61b and c, insert part 41 through part 28, then through the hole in part 27, and out through part 28 again. Thread part 44 onto the exposed thread of part 41. Tighten with a 5mm spanner/ wrench, so that part 28 can rotate easily, while being confidently that it will not fall off.

Repeat steps 2.8a and b on both sides of the chamber. Figure 61d shows the position of both sets of stacking clips.

With this, step 2 and the chamber body subunit are completed, and should look like Figure 52 and Figure 61.

Step 3: Chamber Lid

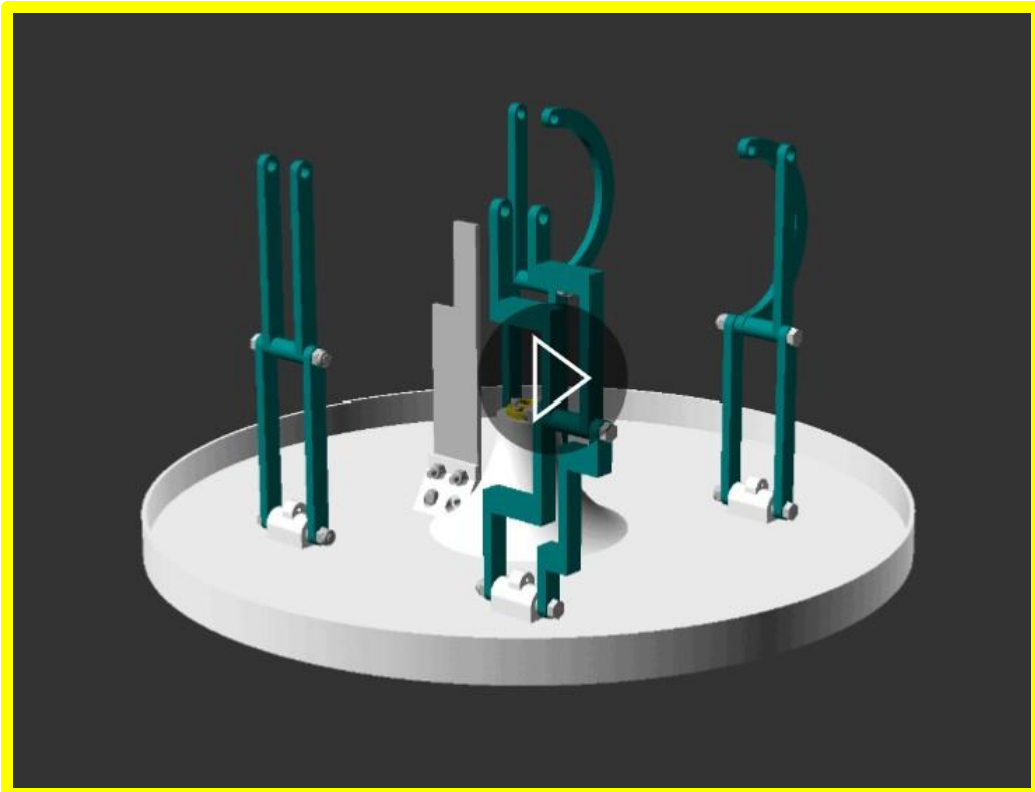


Figure 62 3d model illustrating the product of step 3. Before moving to step 4, your assembled piece should look like this. Print copy will just show one frame from this animation. View the GIF animation online at the openChamber project page.

Step 3 focuses upon the subassembly piece “Chamber lid”. The end product of this step is the chamber lid with its guide arms, bracket mounts (in the form of fan mounts and sensor board mount), lead screw nut and optical end stop installed (Figure 62).

Updates:

Part 7 and part 26 were later additions to the design, therefore are excluded from the GIF animations and construction diagrams. Please take care in steps 3.3 to 3.6.

3.1 Lead screw nut assembly

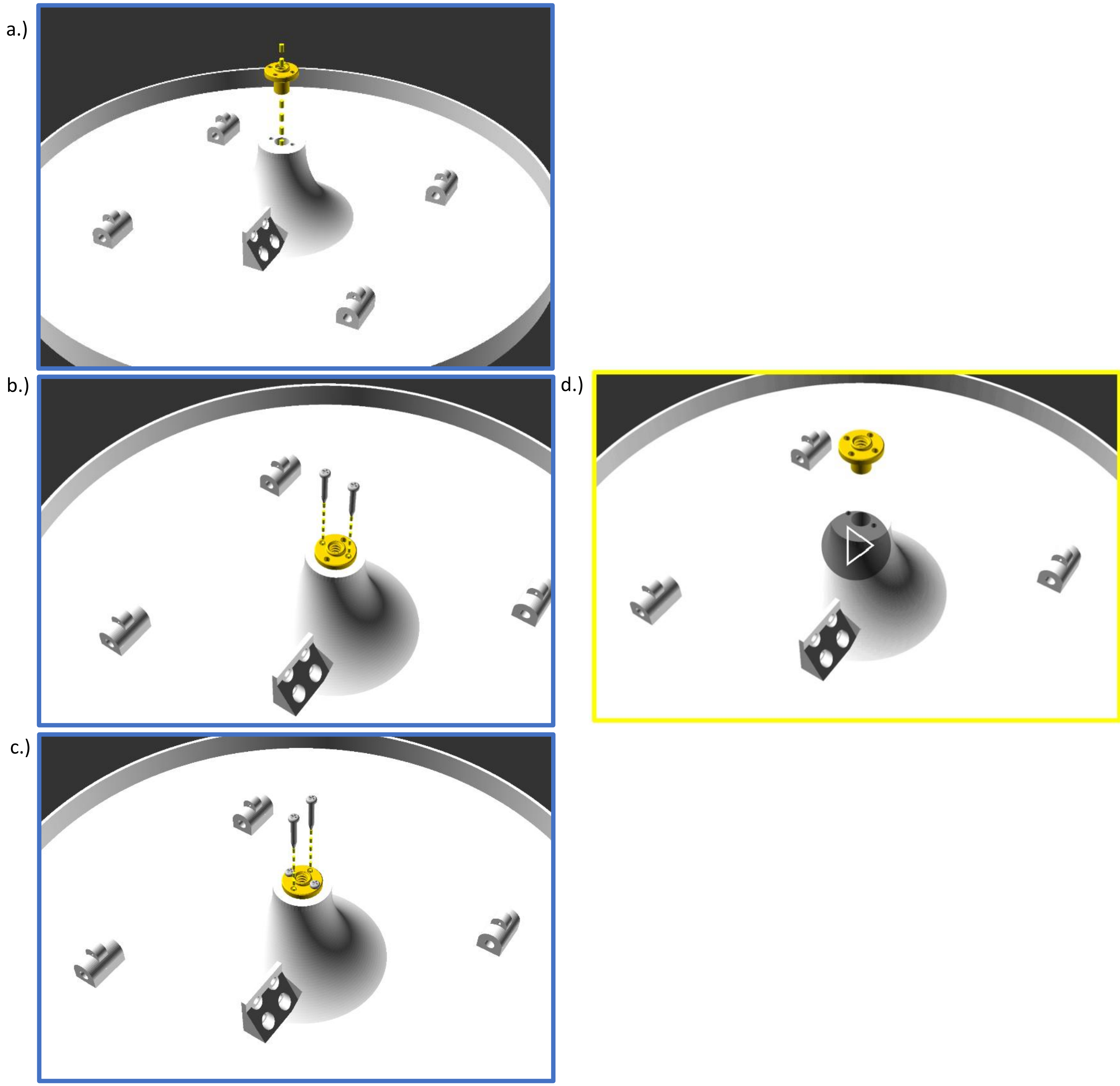


Figure 63 Action diagrams (a, b and c) and animated gif (d) illustrating step 3.1, installing the lead screw nut to the chamber lid subassembly.

Notes:

Parts required for this section = 1 x part 2, 1x part 49, 2 to 4 x part 50.

Insert part 49, long side down, into the hole in the column section of part 2. Ensure that the screw holes in part 49 align with the indents/ holes of part 2, as illustrated in Figure 63a and d.

Next screw 2 x part 50 in from the holes in part 49 that align with the indents / holes in part 2, through the plastic of the chamber lid, as shown in Figure 63b and d.

Now unscrew the 2x part 50 that were just inserted. This will leave a guide hole.

Apply superglue (part 90 or 91) to the guide hole in part 2 left by part 50, and to the threaded portion of part 50. Re-install the 2x part 50s, working quickly to ensure the glue does not dry before they are in place. Now the parts are secured in place.

In the case that part 49 has 4 screw holes available, insert the second set of part 50 into the remaining 2 holes of part 49 (illustrated by figures 51 c and d). Repeat the gluing step and the stage 3.1 is complete.

3.2 Optical limit switch interrupter installation

a.)

b.)

c.)

d.)

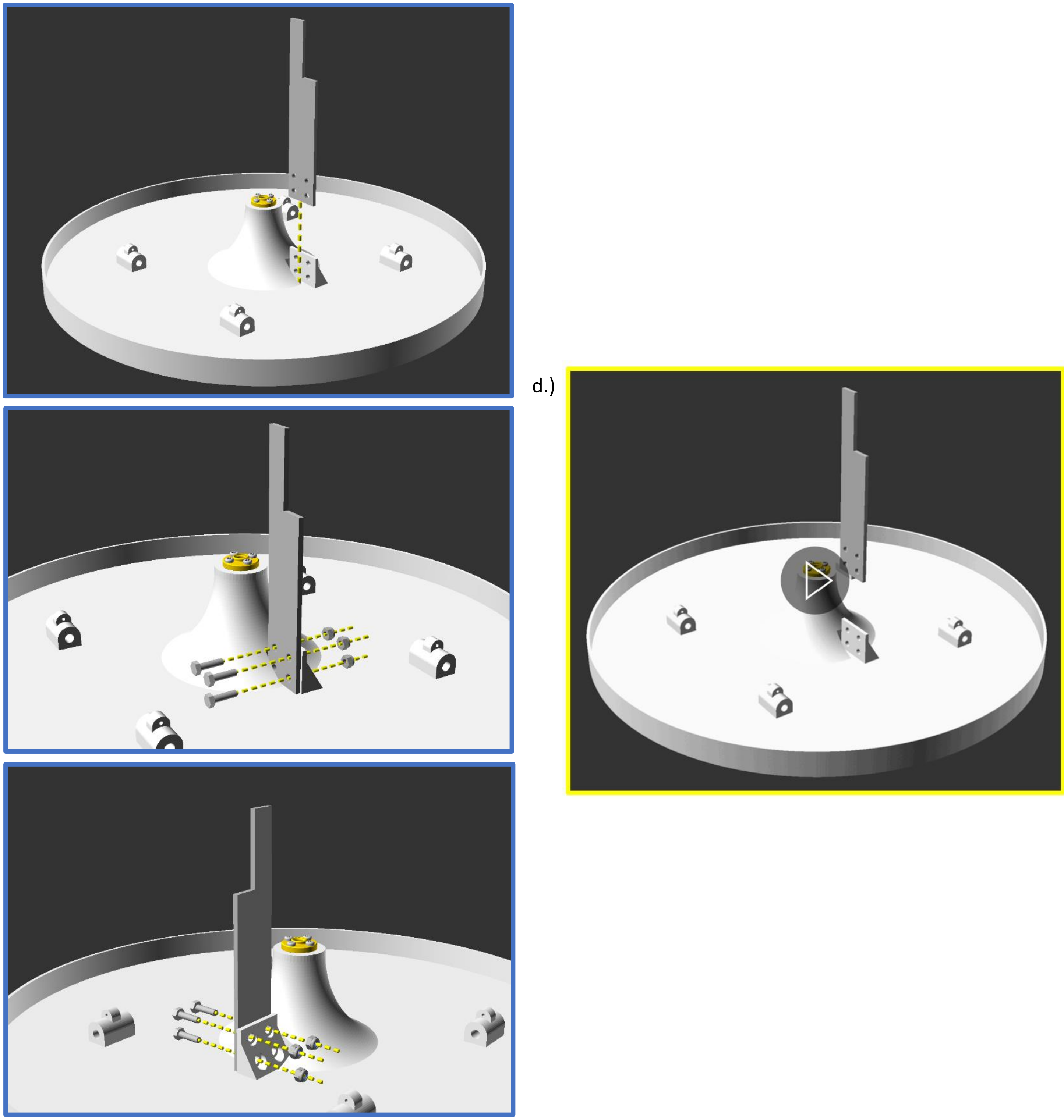


Figure 64 Action diagrams (a, b and c) and animated gif (d) illustrating step 3.2, installing the optical limit switch interrupter to the chamber lid subassembly. This blocks the light beam across the optical limit switch to indicate the lid position.

Notes:

Parts required for this section = Subassembly unit resulting from step 3.1, part 56, 3 to 4 x part 38, 3 to 4 x part 39.

Place part 56 into the receiving slot of part 2. The longest side of part 56 is oriented towards the middle of the lid (part 2), and the holes in each piece should be aligned, as illustrated in Figure 64a and d.

Insert the part 38 (bolts) first through part 56, then through part 2. Fix parts 38 in place using parts 39 (lock nuts) as illustrated in Figure 64a, b and c. This is best done with a size 7mm spanner/ wrench.

These parts should be firmly in place, so that the aluminium bar (part 56) cannot move from side to side when moderate force is applied. This is important for the functioning of the chamber.

Ideally 4 of parts 38 and 39 are used here, however flaws in the current design only allows for 3 of the parts to be inserted (as shown in Figure 64).

3.3 Lid arm 1 assembly: lower

a.)

b.)

c.)

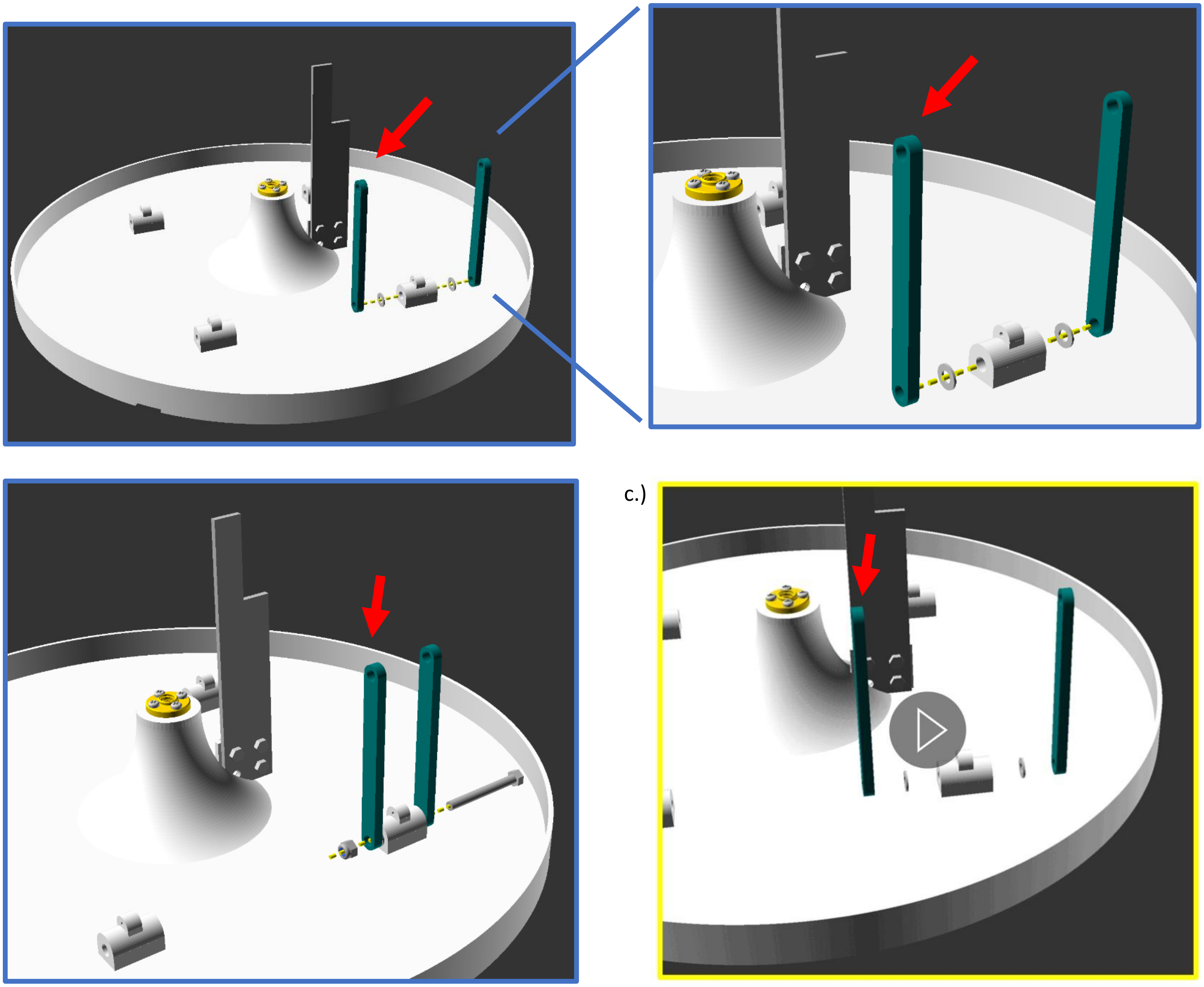


Figure 65 Action diagrams (a and b) and animated gif (c) illustrating step 3.3, installing the bottom portion of lid arm 1 to the chamber lid subassembly.

Notes:

UPDATE – please note that the part indicated by the red arrow has now been replaced with part 7.

Parts required for this section - Subassembly unit resulting from step 3.2, 2x part 35, 1 x 32, 1 x part 34, 2x 22.

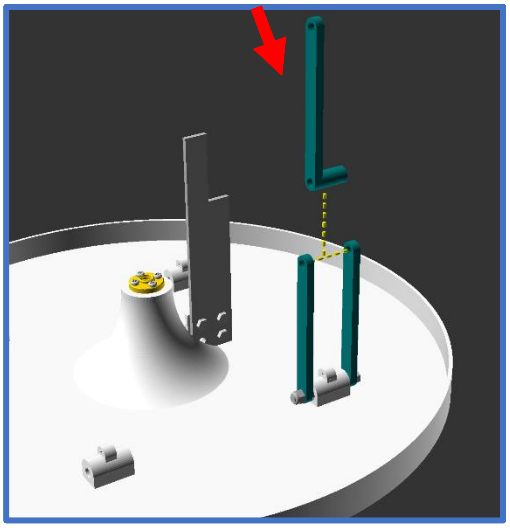
Following Figure 65a and c, orient the 2 washers (part 35) on either side of the mounting point on part 2 located behind the aluminium bar (part 56), followed by the 2x part 22.

Ensuring that the holes in each of the parts are aligned, insert part 32 through part 22 and the rest of the parts as they are placed in the description above. It is **important** that the bolt (part 32) is inserted towards the middle of part 2 (shown in Figure 65). Failure to do so will prevent the lid from sealing.

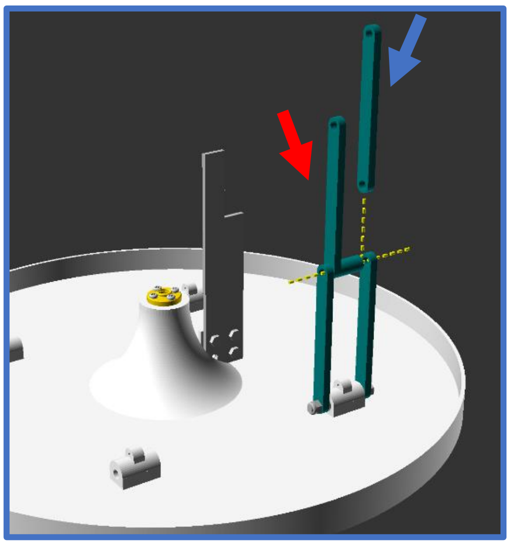
Finally, fix the lock nut (part 34) in place using either 2 size 8 spanner/ wrenches, or holding one side with a pair of pliers and using a spanner on the other side. Tighten gently until resistance is met, then back off 1 turn in the loosening direction, to ensure that the pieces rotate freely without resistance.

3.4 Lid arm 1 assembly: upper

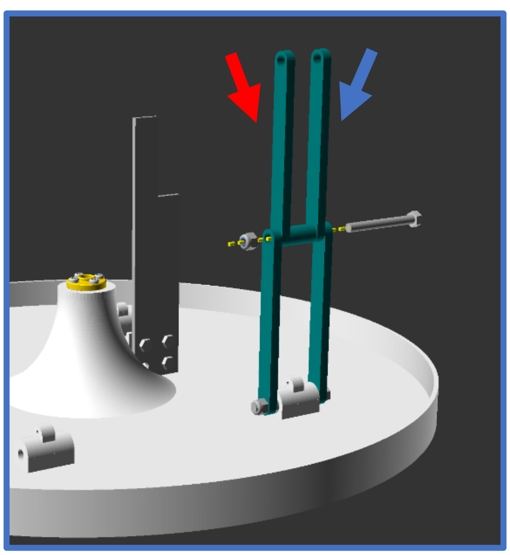
a.)



b.)



c.)



d.)

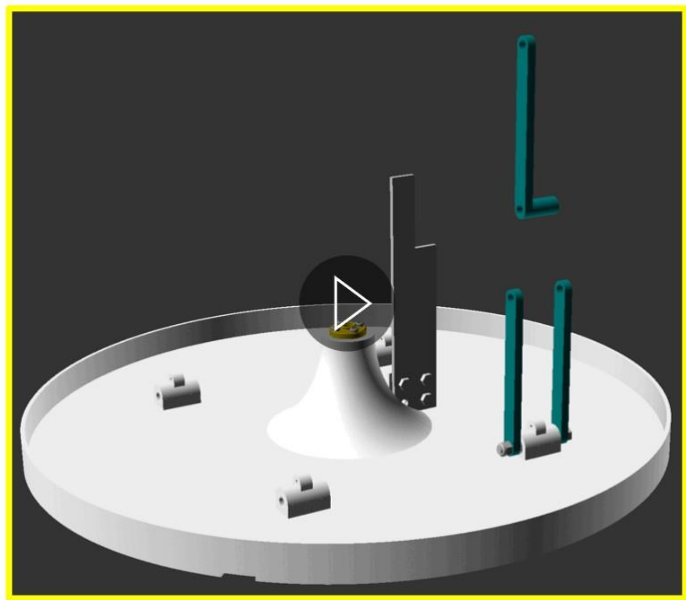


Figure 66 Action diagrams (a, b and c) and animated gif (d) illustrating step 3.4, installing top portion of lid arm 1 to the chamber lid subassembly.

Notes:

UPDATE – Please note that part 7 is now located in the position of the red arrow, part 21 is now located in the position of the blue arrow (Figure 66). The up-to-date lid structure is given below in Figure 67a.

Parts required for this section - Subassembly unit resulting from step 3.3, 1x part 21, 1 x part 32, 1 x part 34, 1x part 7.

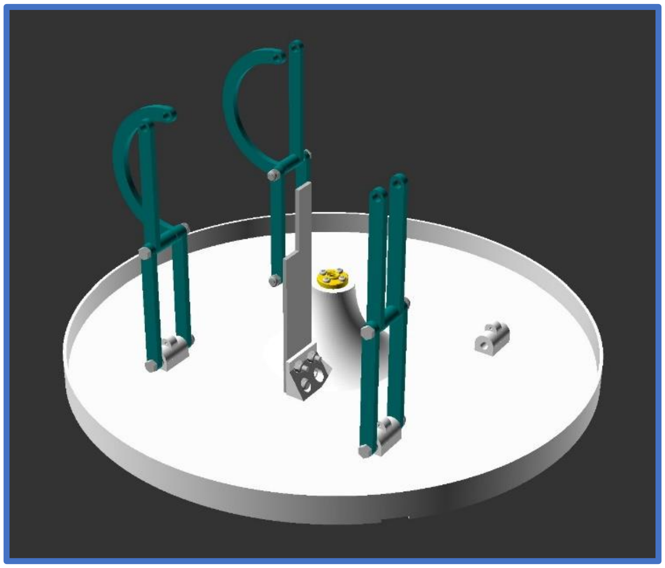
Insert part 21 and 22 in-between parts 22 from step 3.3, ensuring that the holes for each part are in alignment, as shown in Figure 66a, b and d.

Insert part 32 through the aligned parts, towards the centre of part 2, as illustrated in Figure 66c and d.

Fix the lock nut (part 34) in place using either 2 size 8 spanners/ wrenches or holding one side with a pair of pliers and using a spanner on the other side. Tighten gently until resistance is met, then back off 1 turn in the loosening direction, to ensure that the pieces rotate freely without resistance.

3.5 Lid arm 2 and 3 assembly: repeat

a.)



b.)

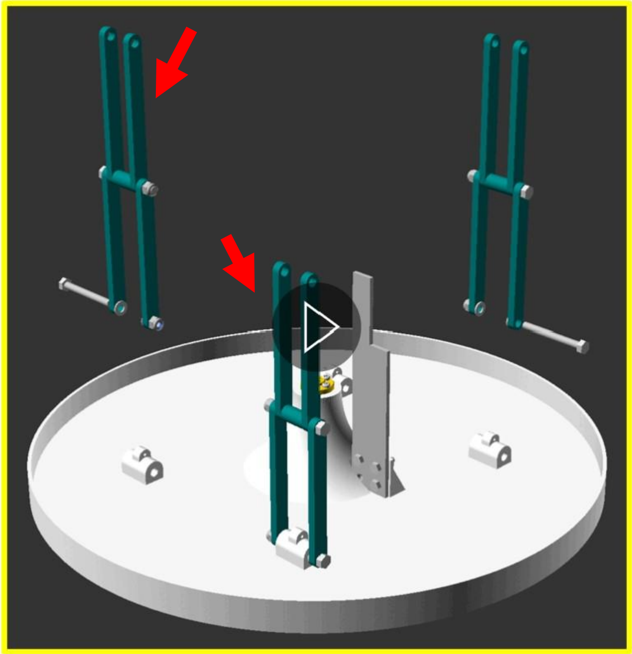


Figure 67 Action diagrams (a) and animated gif (b) illustrating step 3.5, installing lid arms 2 and 3 to the chamber lid subassembly

Notes:

UPDATE – please note that the parts indicated by the red arrows in Figure 67b have now been replaced by part 7.

Parts required for this section - Subassembly unit resulting from step 3.4, 5x part 22, 2x part 21, 4 x part 32, 4 x part 34, 4x part 35, 1x part 7.

Repeat steps 3.3 and 3.4 on the 2 adjacent lid mounting points (part 2), however using a part 22 in place of the part 7in the opposite upper inner arm, as shown in Figure 67a.

3.6 Lid arm 4 assembly: lower

a.)
b.)
c.)

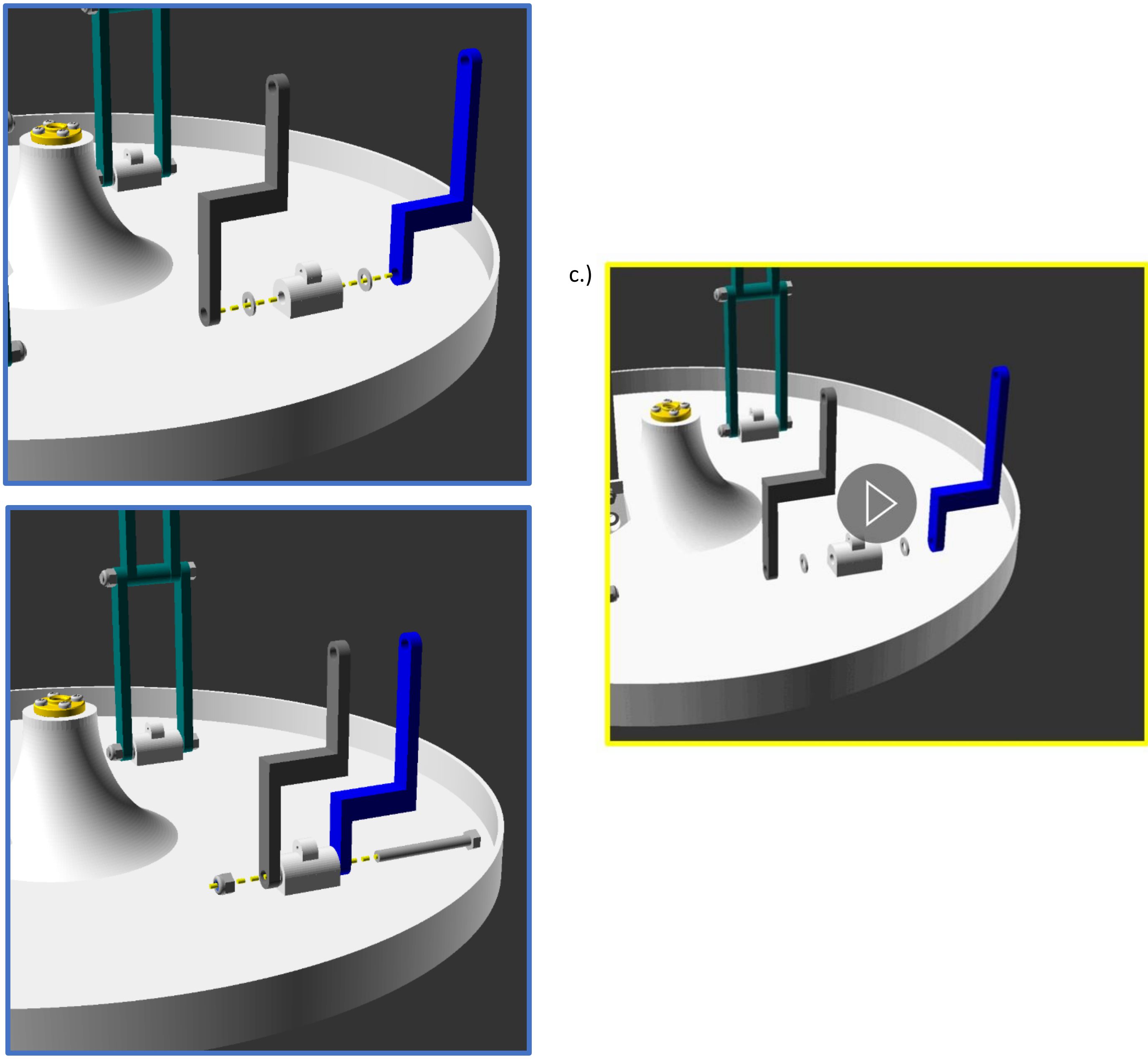


Figure 68 Action diagrams (a and b) and animated gif (c) illustrating step 3.6, installing the bottom portion of lid arm 4 (pawl side lid arm) to the chamber lid subassembly.

Notes:

UPDATE – Please note that part coloured blue (previously part 24) has now been replaced by part 26. The correct part orientation is illustrated in below in Figure 69e.

Parts required for this section - Subassembly unit resulting from step 3.5, 1 x part 32, 1 x part 34, 2x part 35, 1x 23, 1x 26.

Following Figure 68a and c, orient the 2 washers (part 35) on either side of the remaining mounting point on part 2.

Arrange part 23 and 26 on either side of the part 35 washers. Part 23 (Figure 68– part colour grey) **must** be on the side closer to the centre of the lid (part 2) and part 26 **must** be on the side closer to the outside of the lid (part 2). The orientation of these parts is illustrated in Figure 68 and Figure 69e.

Ensuring that the holes in each of the parts are aligned, insert part 32 through part 26 and the rest of the parts as they are placed in the description above. It is **important** that the bolt (part 32) is inserted towards the middle of part 2 (shown in Figure 68). Failure to do so will prevent the lid from sealing.

Finally, fix the lock nut (part 34) in place using either 2 size 8 spanner/ wrenches, or holding one side with a pair of pliers and using a spanner on the other side. Tighten gently until resistance is met, then back off 1 turn in the loosening direction, to ensure that the pieces rotate freely without resistance.

3.7 Lid arm 4 assembly: upper

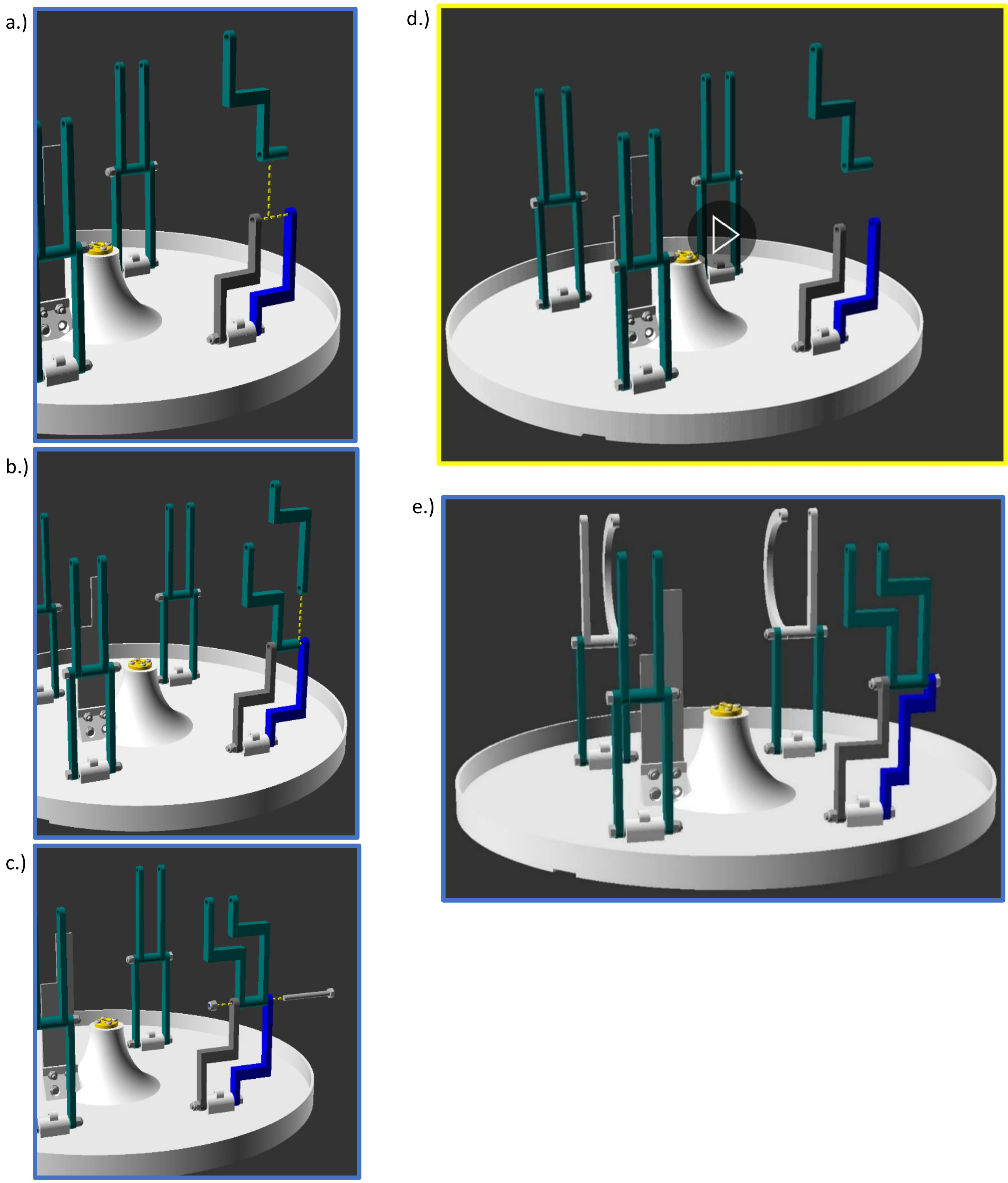


Figure 69 Action diagrams (a, b, c and e) and animated gif (d) illustrating step 3.6, installing the upper portion of lid arm 4 (pawl side lid arm) to the chamber lid subassembly.

Notes:

Parts required for this section - Subassembly unit resulting from step 3.6, 1 x part 32, 1 x part 34, 1x 25, 1x 24.

Insert part 25 and 24 in-between parts 26 and 23 from step 3.6, ensuring that the holes for each part are in alignment, Part 25 **must** be on the side closer to the centre of the lid (part 2) and part 24 **must** be on the side closer to the outside of the lid (part 2), as illustrated by Figure 69a, b and d.

Insert part 32 through the aligned parts, towards the centre of part 2, as illustrated in Figure 69c and d.

Fix the lock nut (part 34) in place using either 2 size 8 spanners/ wrenches or holding one side with a pair of pliers and using a spanner on the other side. Tighten gently until resistance is met, then back off 1 turn in the loosening direction, to ensure that the pieces rotate freely without resistance.

With this, step 3 and the chamber lid subunit are completed, and should look like Figure 62 and Figure 69d.

Step 4: Motor Unit

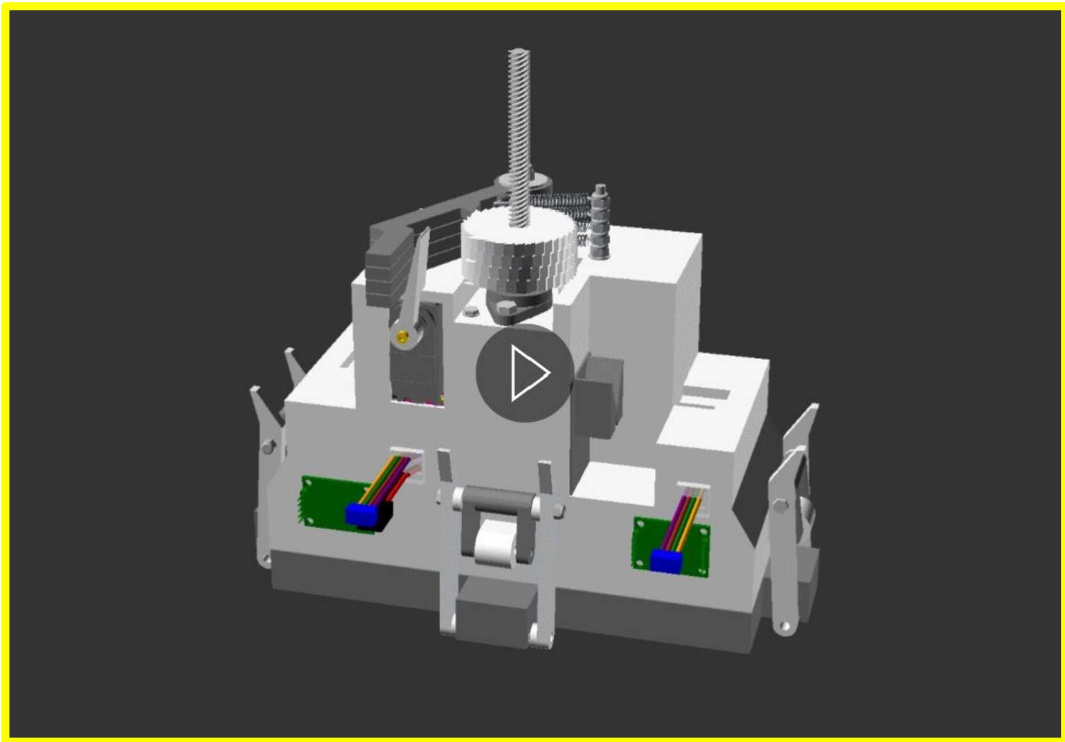


Figure 70 3D model illustrating the product of step 4. Before moving to step 5, your assembled piece should look like this. View this animation in file “step_4_end_product_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Step 4 focuses upon the subassembly piece “Motor Unit”. The end product of this step is the motor unit with the steppers motor drive chain, servomotor and pawl system, optical interrupt, internal circuitry and wiring and water-tight lid installed (Figure 70).

4a.1 Optical limit switch assembly

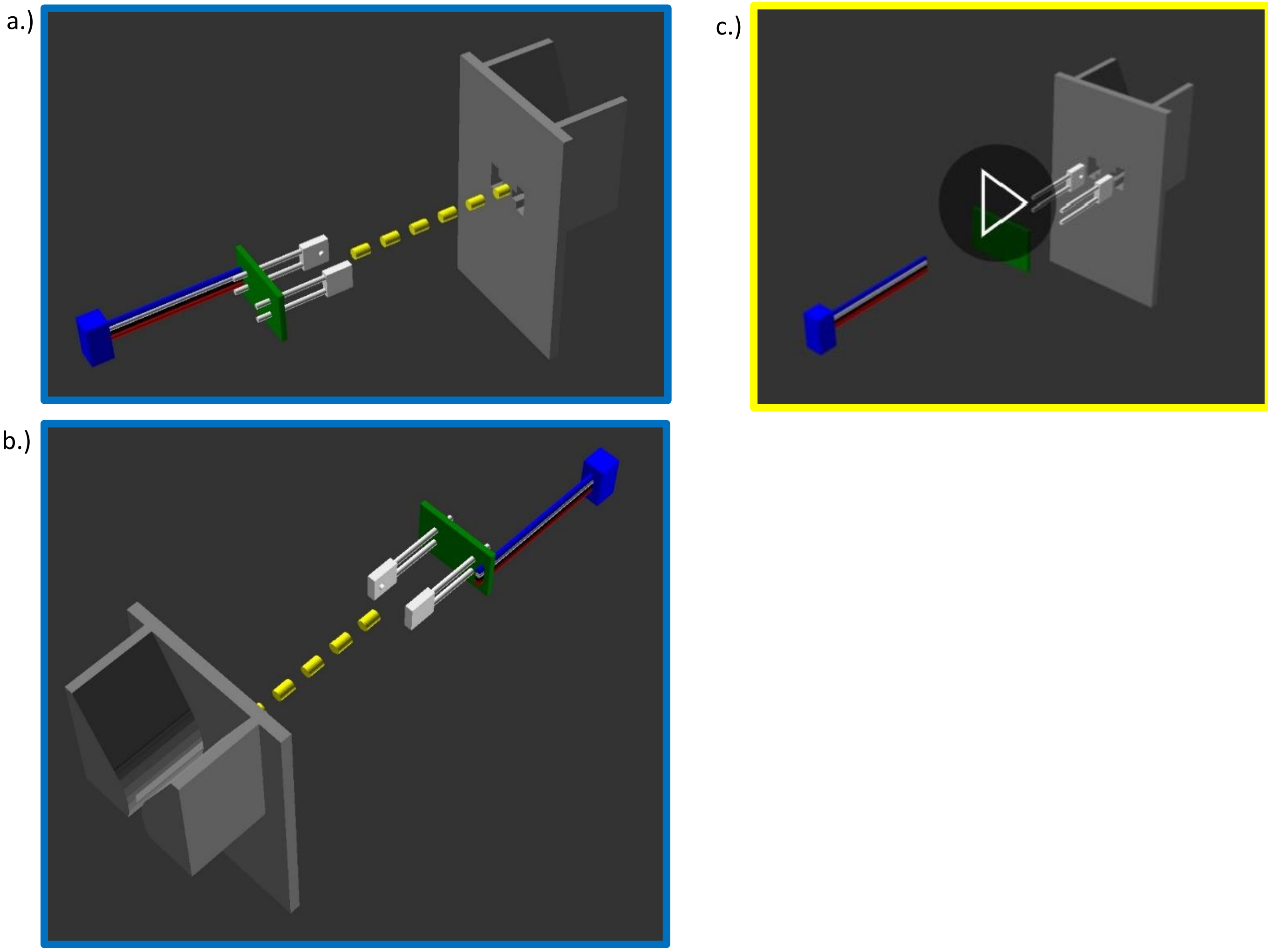


Figure 71 Action diagrams (a and b) and animated gif (c) illustrating step 4a.1, mating of optical limit switch circuitry with 3D printed housing. View animation (c) in file “Step_4a_1 animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - 1 x part 13, 1 x part 67b, part 1x 90 or 91.

First dry fit the parts to ensure that you understand how the pieces fit together, before fitting with glue (part 90 or 91).

Insert part 67b into part 13. As illustrated in Figure 71, part 67b must be inserted from the flat side of part 13 (the back). The circuit board cable connection must be to the left-hand side of part 13, when viewed from the back, with the wide portion of part 13's "V" or funnel pointing upwards.

It is critical that the raised bumps on the diode and transistor of 67b (the white cuboids with legs in Figure 71) are in the open groves of part 13. This grove ensures that the pieces are directly opposite each other, as light must be emitted from the diode cuboid (the light bulb) and be detected by the transistor cuboid (the light switch). When these parts are miss aligned, there is a risk that the light will not be blocked / interrupted when the chamber lid is in the closed position. The light is blocked by the Optical limit switch interrupter in chapter 1.4.3.2, which passes between the "V" or funnel of part 13. This causes issues with chamber functionality; I.e the lid will never be acknowledged as closed even if it is.

Next, separate parts 67b and 13. Add a clear super glue (part 90 or 91) to the cuboids and surfaces that will touch part 13 when in the assembled position. If non-transparent glue is used, light may not be able to pass freely to the transistor cuboid and cause problems in functionality.

Carefully repeat the dry fit steps, but now with glue.

Leave the part for 24 hours, or the full cure time indicated by your glue instructions.

4a.2 Optical Limit Switch Assembly Installation

a.) c.)

b.) d.)

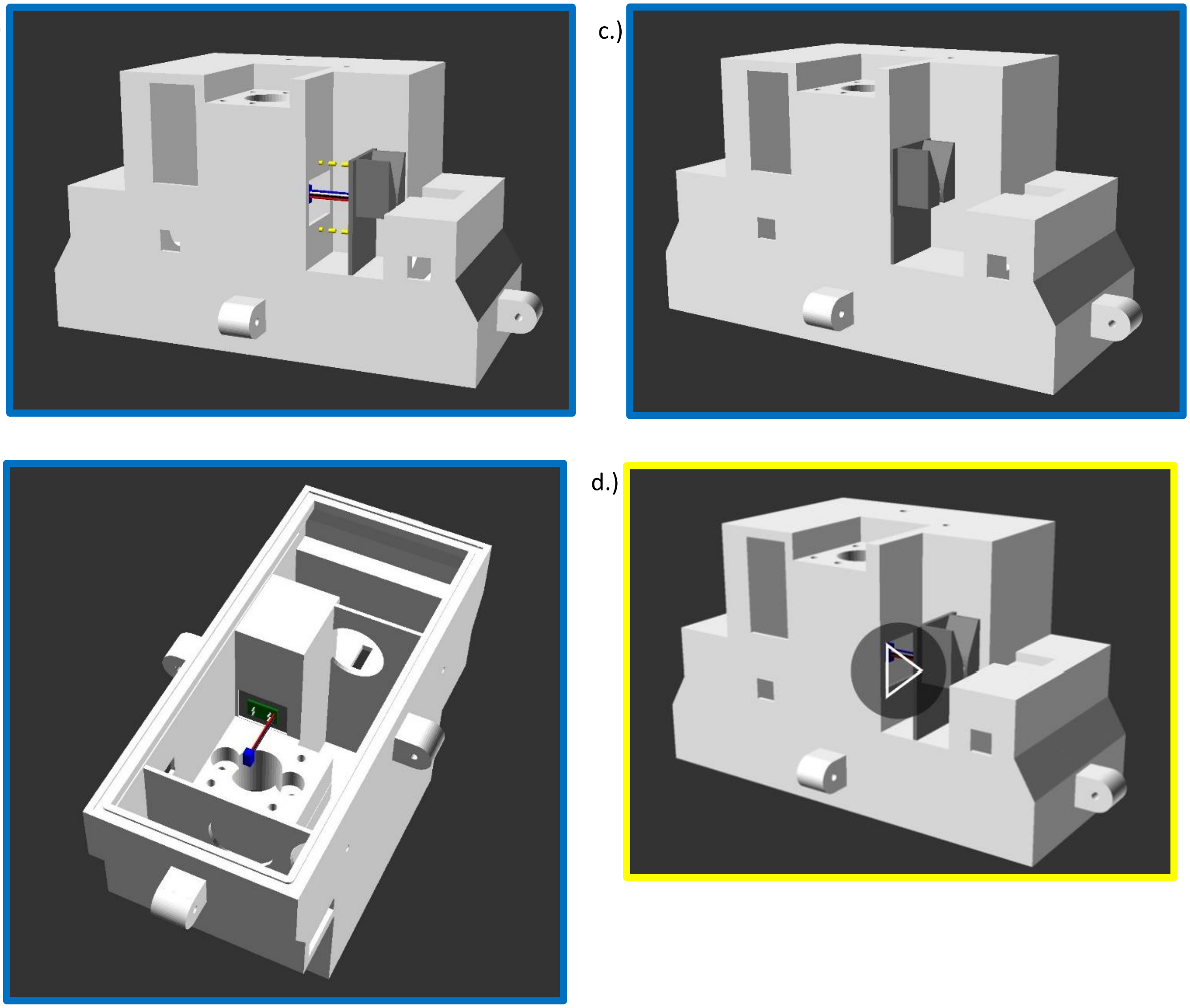


Figure 72 Action diagrams (a, b and c) and animated gif (d) illustrating step 4a.2, mating of the optical limit switch subassembly with main motor unit body. View animation (d) in file “step_4a_2_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.1, 1 x part 9, 1 x part 90 or 91.

Place part 9 with its open portion on the table, as illustrated in Figure 72a and d.

As this step required the gluing of parts, initially dry fit the parts together before committing repeating with glue (part 90 or 91).

Orient the subassembly unit resulting from step 4a.1 with the “v” or funnel in the upwards position. Position this with the bottom edge of the subassembly unit resulting from step 4a.1 touching the shelf surface of part 9, as illustrated in Figure 72a and d.

Next push this subassembly unit until it meets the wall of part 9 (Figure 72c), so that the circuitry and cable pass through the rectangular hole of part 9 and into the motor unit’s internal space (Figure 72b). The flat back side of the subassembly unit resulting from step 4a.1 and the wall of part 9 should meet flush as a “plastic on plastic” joint.

Next, remove subassembly unit resulting from step 4a.1. Using a knife, score/ scratch the 2 surfaces that touch in the “plastic on plastic” joint in a cross-hatch pattern (like a “#” symbol). This provides a strong binding surface for glue adhesion.

Apply superglue (part 90 or 91) to the “plastic on plastic” joint of both part 9 and the subassembly unit resulting from step 4a.1. Repeat the initial steps but now with glue.

Clamp or wedge the piece together and leave for 24 hours, or the full cure time indicated by your glue instructions.

4a.3 Pillow Bushing Assembly

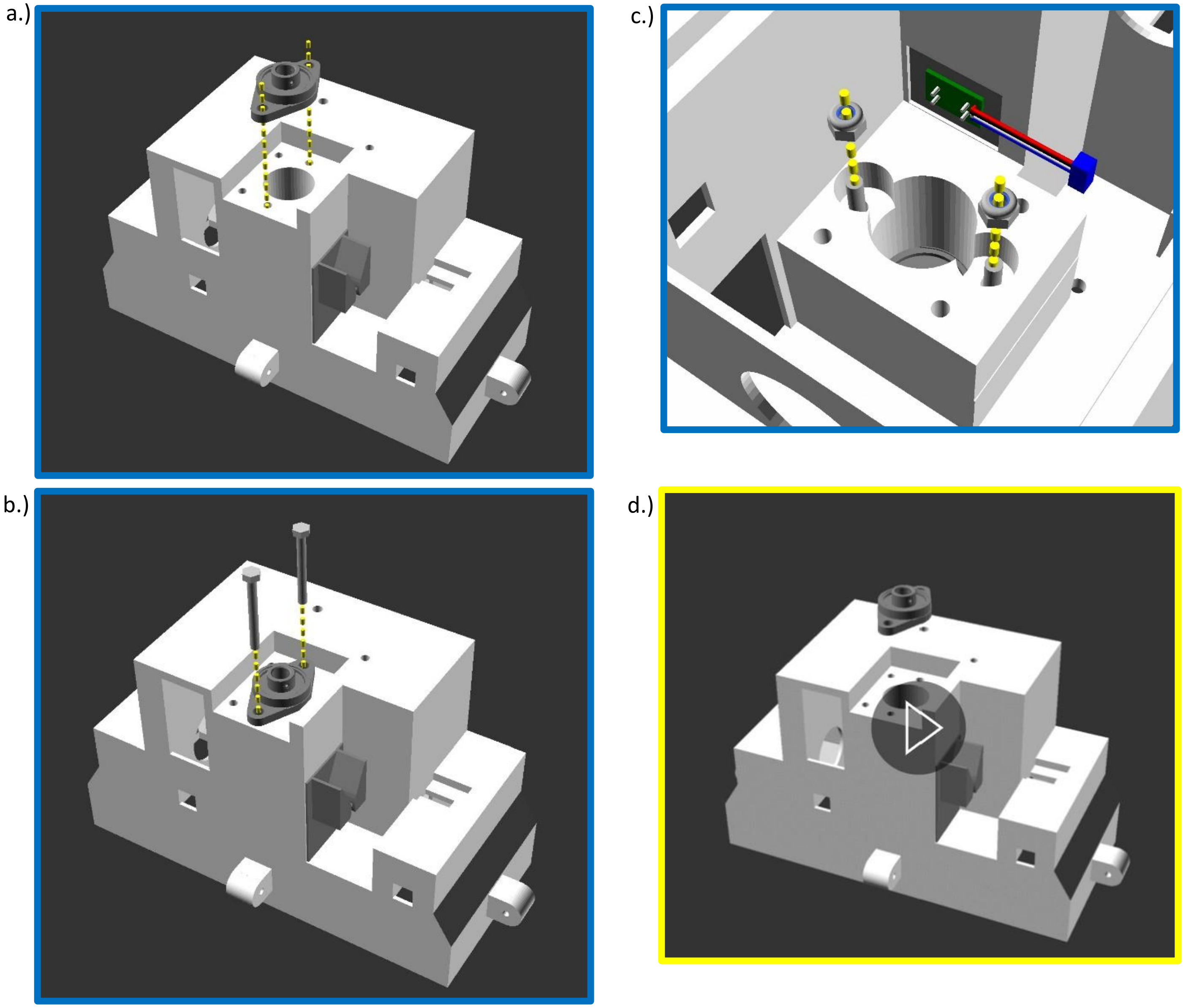


Figure 73 Action diagrams (a, b and c) and animated gif (d) illustrating step 4a.3, installing the pillow bushing to the motor unit subassembly. View animation (d) in file “step_4a_3_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.2, 1 x part 46, 2 x part 37 or 37a, 2 x part 39, 1x part 99.

Position part 46 so that its bolt holes align with the bolt holes in part 9 (the subassembly unit resulting from step 4a.2), as illustrated in Figure 73a and d. This should leave the central 8mm bearing of part 46 in a centralised position over the large cylindrical hole of part 9.

Insert the 2 x part 37 initially through the bolt holes of part 46, following down through the bolt holes of part 9 (Figure 73b and d).

Fix these bolts (part 37) in place using 2 x part 39, from the inside of part 9 (the subassembly unit). The tension of these bolts should tight enough to hold part 46 firmly in place (Figure 73c and d).

Appy hot glue (part 99) around the edges of part 46 to prevent water ingress into the centre of the motor unit. Alternatively, create a waterproof seal by uninstalling part 46, applying hotglue to its base and re-installing again.

4a.4 Servomotor Installation

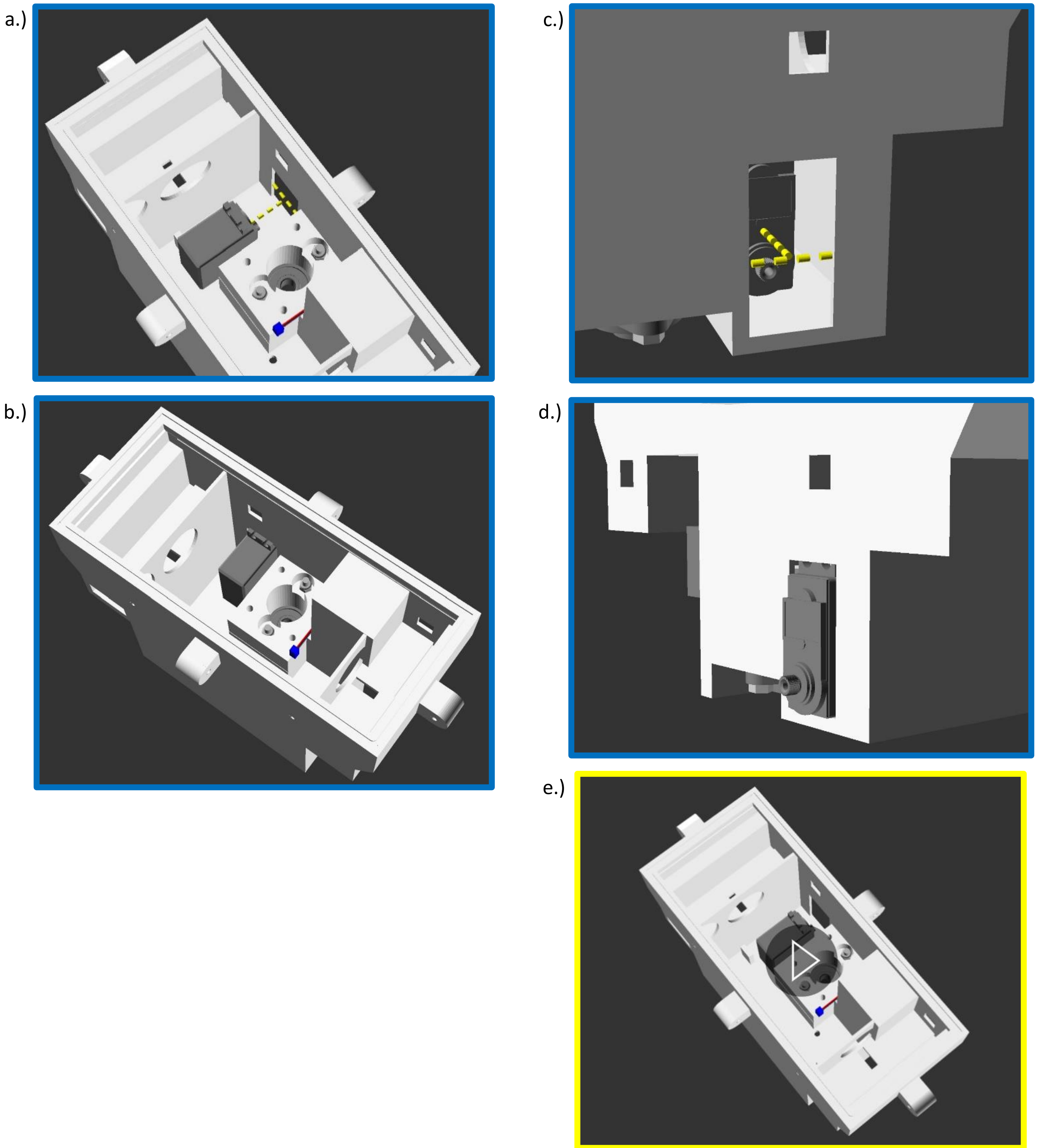


Figure 74 Action diagrams (a, b, c and d) and animated gif (e) illustrating step 4a.4, installing the servomotor to the motor unit subassembly. View animation (e) in file “step_4a_4_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.3, 1 x part 66, 1 x part 99.

With part 66 (the servomotor) oriented so that the motor output shaft is on the bottom, remove any bottom bolt connections that prevent the servo motor from sitting flush on the bottom of the 3D printed motor case (part 9). The top bolt connections must not be removed.

Following Figure 74, place part 66 into the motor case so that the bottom of part 66 is flat and level on the bottom of the motor case. Push part 66 into the hole in the side of the motor case until the top bolt connectors of push up against the inside wall of the motor case. The motor output shaft of part 66 should protrude through the hole in the wall of the motor case.

UPDATE – The following instructions describe the gluing of the part in place. However, step 4c.4 requires nuts to be inserted behind the servo motor (Figure 90). While this is possible, it is simpler to glue in part 66 after step 4c.4.

Once confident with how part 66 should be installed, remove part 66. Apply hot glue (part 99) liberally to the areas of part 66 that will contact the motor case, i.e. the bottom surface and the upper bolt connectors.

Repeat the installation of part 66 described above.

Once the glue has set, apply hot glue (part 99) liberally around the edges of the servo motor, to fill any spaces between the part 66 and the motor case. Stop applying glue when the part 66 has a waterproof seal in the motor case.

In the future this step may be changed to allow for a mechanical binding of part 66 to the motor case (part 9). But for the scope of this project as a part of my PhD, I do not have time to adjust this step at present.

4a.5 O-ring/Gasket Installation

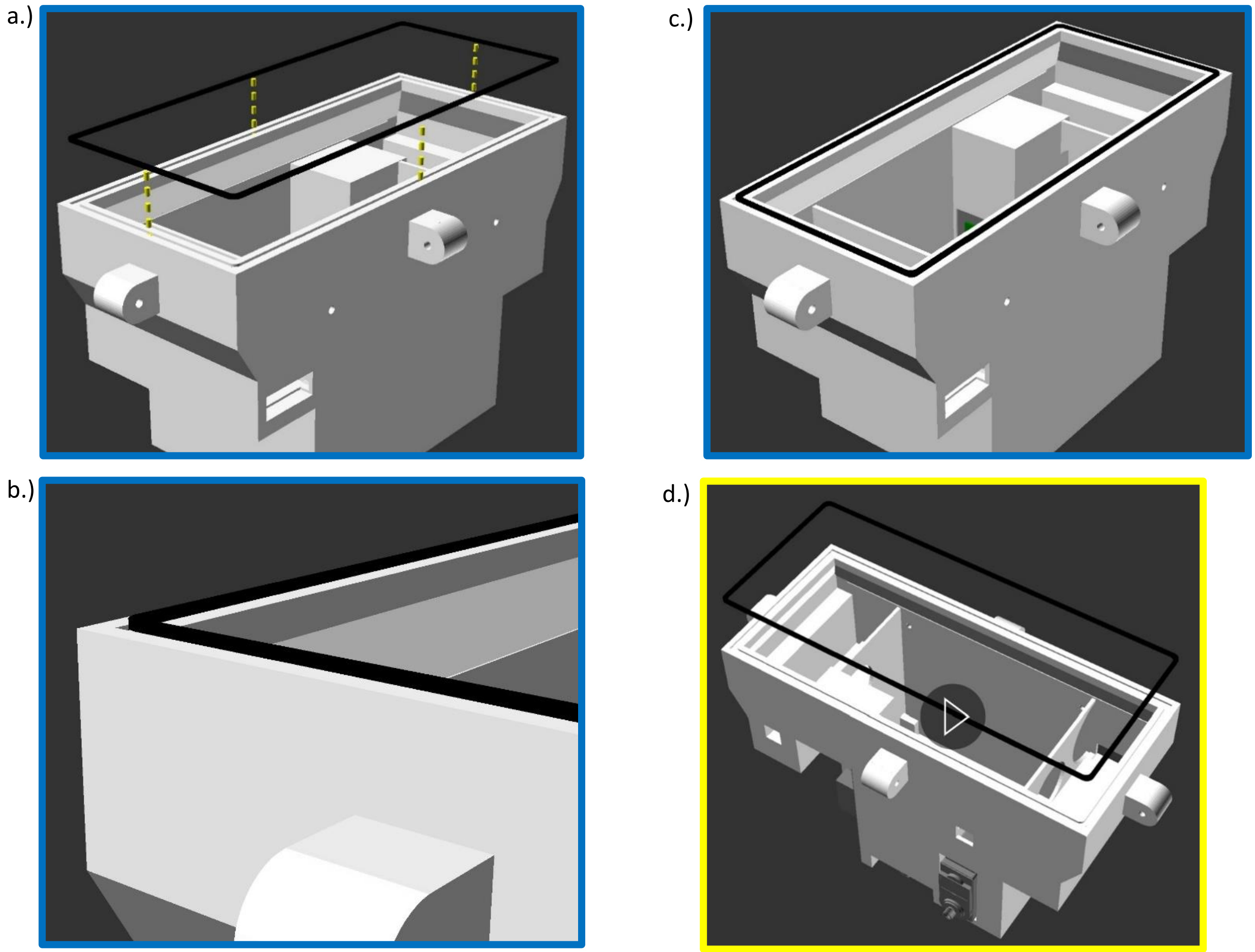


Figure 75 Action diagrams (a, b and c) and animated gif (d) illustrating step 4a.5, installing the O-ring/ Gasket to the motor unit subassembly. View animation (e) in file “step_4a_5_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.4, 1 x part 62, 1 x part 90.

Cut the end of the spooled nitrile rubber cord (part 62) so that it is as vertical as possible. This will have to be glued to the other edge cut edge of the nitrile rubber cord and a clean joint is important.

Apply flexible superglue (part 90) to the grove in the top of part 9 (the motor case), illustrated in Figure 75a and d. When this glue is tacky / sticky (as opposed to wet), insert the nitrile rubber cord into the grove so that it binds into the grove and protrudes above the surface, as illustrated in Figure 75b and d.

Failiure to wait until the glue has become tacky can result in glue spreading and hardening across the nitrile rubber cord. This results in a compromised water seal with the Motor case lid (part 10), which is pressure sealed to the nitrile rubber gasket (illustrated in section 1.4.4c.1).

Better results can sometimes be achieved by working along progressive sections of the grove, waiting until the cord is bound to one section before moving on to the next section of the grove.

Once the cord reaches the starting point of the nitrile rubber cord, carefully cut the end of the cord with a razor blade, so that a tight clean joint is formed, butting up to the starting point. Apply a drop of glue sparingly to the two surfaces that are to meet. Press them together and wait for them to dry.

The result is a flexible gasket ring that should look similar to Figure 75c and d.

4a.6 Small Latch Arm Installation

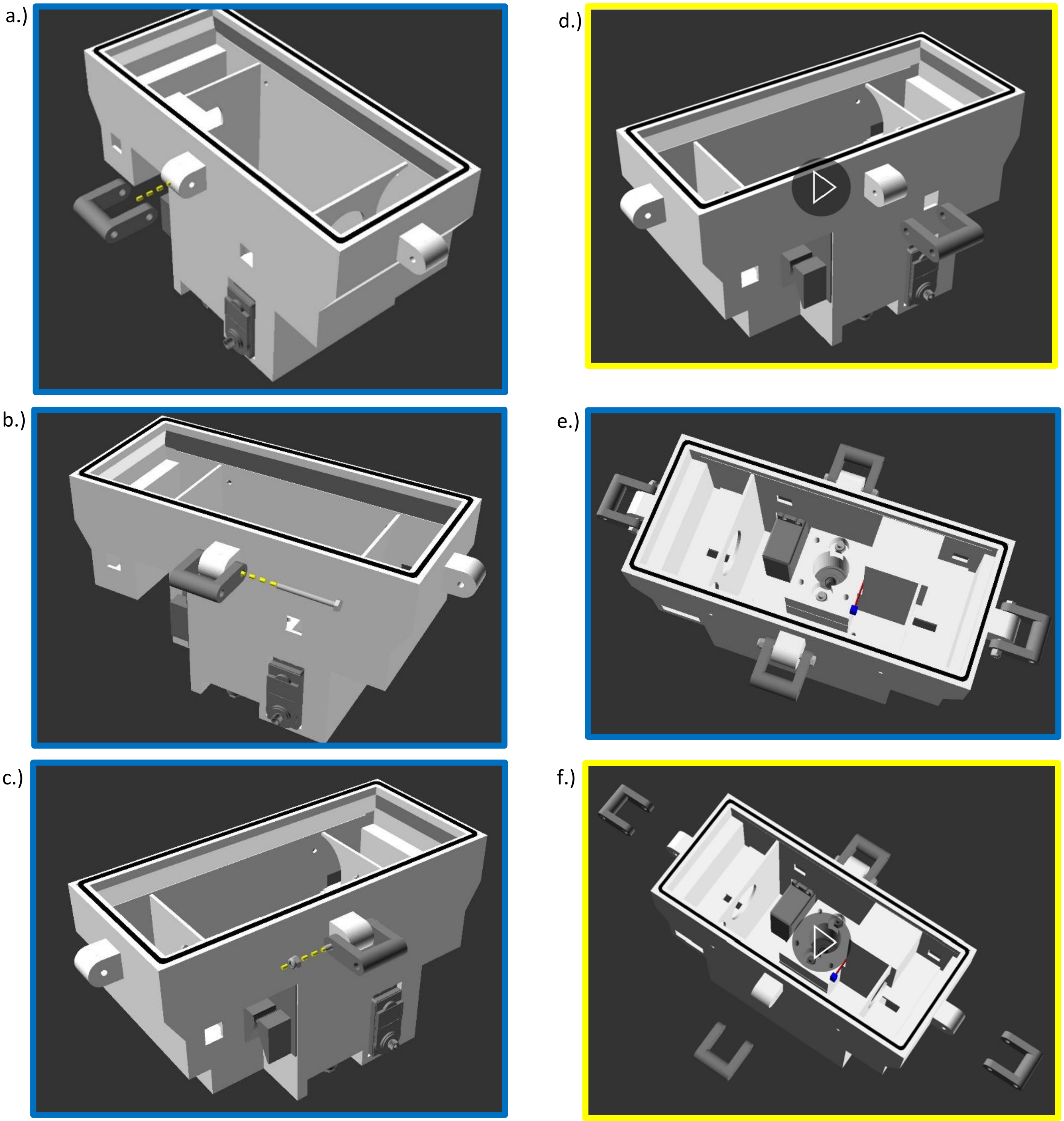


Figure 76 Action diagrams (a, b, c and e) and animated gifs (d and f) illustrating step 4a.6, installing the small latch pieces to the motor unit subassembly. View animation (d) in file "step_4a_6a_animated.gif" and animation (f) in file "step_4a_6b_animated.gif", available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.5, 4 x part 11, 4 x part 44, 4x 42.

Line up part 11 (the small latch arm), open end first, onto the motor case (part 9), ensuring the bolt holes are aligned (Figure 76a and d).

Insert 1x part 42 (the bolt) from outside part 11, through the bolt hole in part 9 (the motor case), and out through part 11 again (Figure 76b and d).

Screw part 44 onto the threaded end of part 42 that protrudes out of part 11 (Figure 76c and d). Tension this nut (part 44) so that the small latch arm (part 11) can rotate freely, but that the bolt (part 42) is not at risk of excessive movement laterally.

Repeat this process a further 3 times for the remaining small latch arm connections (Figure 76e and f).

4a.7 Large Latch Arm Installation

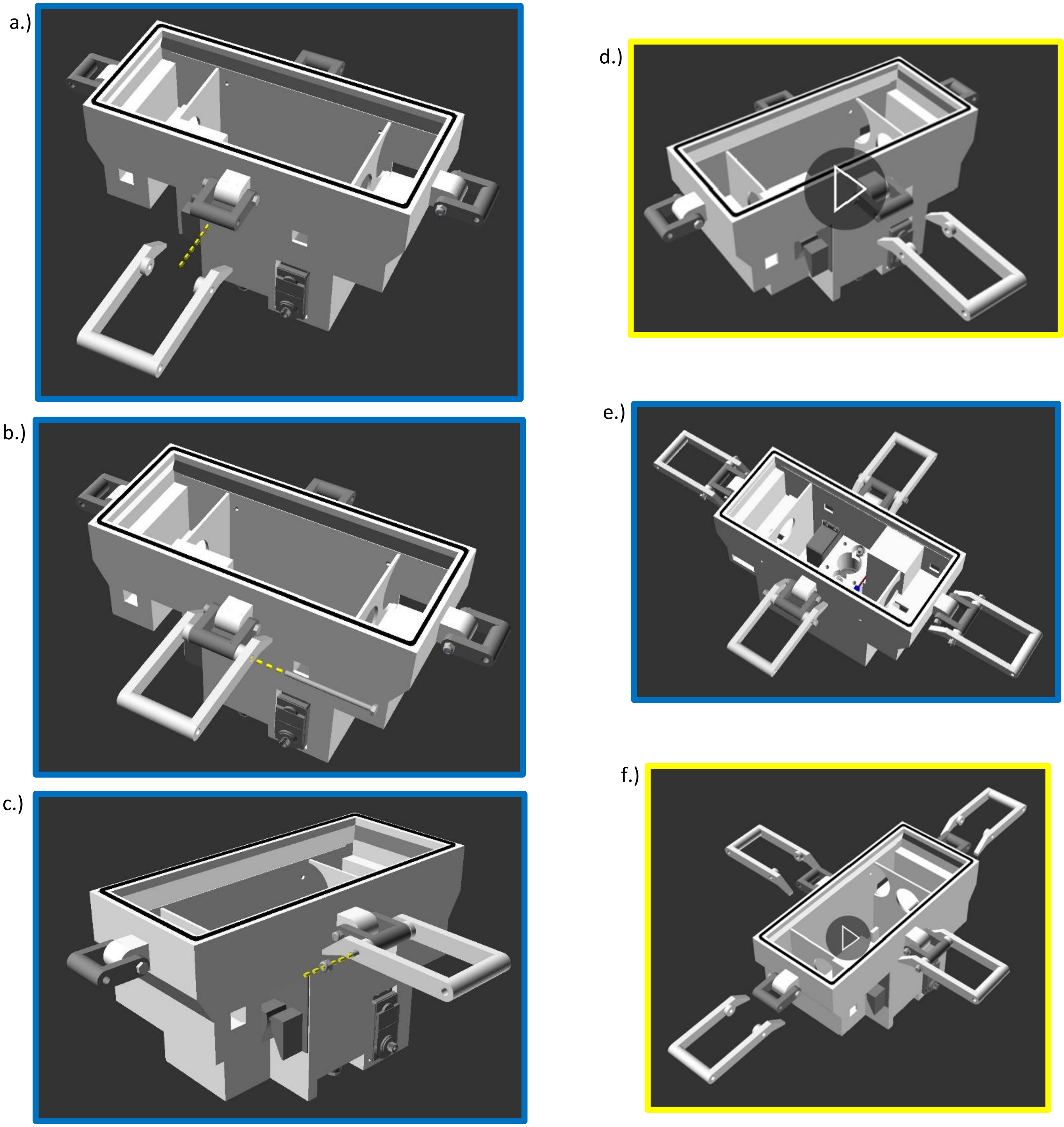


Figure 77 Action diagrams (a, b, c and e) and animated gifs (d and f) illustrating step 4a.7, installing the large latch pieces to the motor unit subassembly. View animation (d) in file “step_4a_7a_animated.gif” and animation (f) in file “step_4a_7b_animated.gif”, available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.6, 4 x part 12, 4 x part 44, 4x 41.

Line up part 12 (the large latch arm), open end first, onto the small latch arm (part 11), ensuring the bolt holes are aligned (Figure 77a and d).

Insert 1x part 41 (the bolt) from outside part 12, through the bolt hole in part 11 (small latch arm), and out through part 12 again (Figure 77b and d).

Screw part 44 onto the threaded end of part 41 that protrudes out of part 12 (Figure 77c and d). Tension this nut (part 44) so that the large latch arm (part 12) can rotate freely, but that the bolt (part 41) is not at risk of excessive movement laterally.

Repeat this process a further 3 times for the remaining large latch arm connections (Figure 77e and f).

4a.8 Pawl Arm Installation

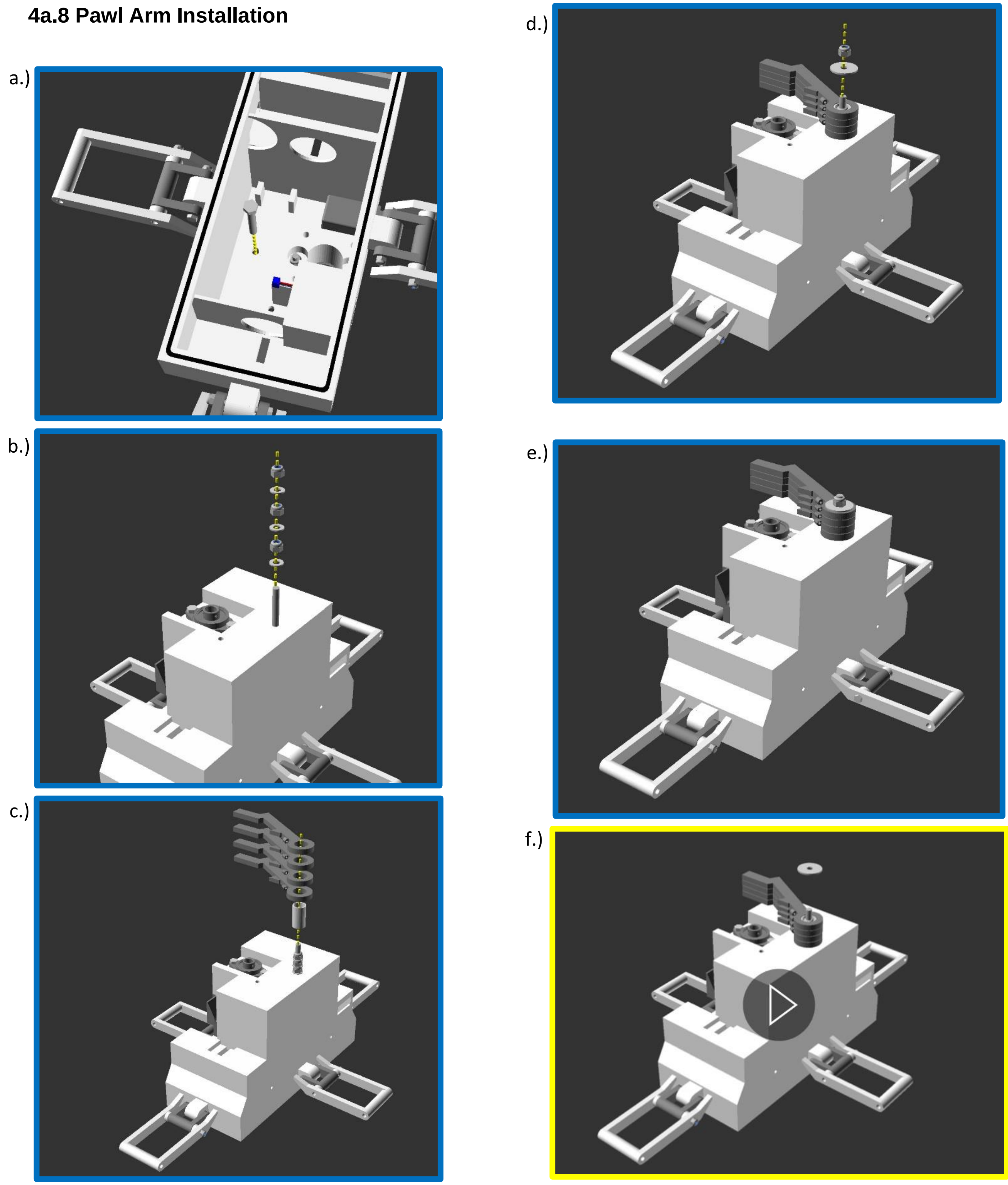


Figure 78 Action diagrams (a, b, c, d and e) and animated gifs (f) illustrating step 4a.8, installing the pawl arms to the motor unit subassembly. View animation (f) in file "step_4a_8_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.8, 1 x part 33, 4 x part 34, 3x part 35, 1x part 35b, 1x part 57, 1x part 15, 2x part 16, 1x part 17.

Insert part 33 (M5 40mm bolt) from the inside of part 9 (the motor case), in the bolt hole closest to the servomotor (part 66), illustrated in Figure 78a, b and f.

On the outside of part 9, place 1x part 35 (standard M5 washer) over part 33, followed by 1x part 34 (M5 lock nut). Tension so that part 35 is held firmly in place.

Next place a second part 35 onto the bolt (part 33), followed by a second part 34. However, this time tension the nut (part 34) so that the washer (part 35) can still spin freely on the shaft of the bolt. The nut is in place to maintain a space between this and subsequent washers.

Repeat this step once more so that there are 3 washers (part 35) and 3 nuts (part 34) on the shaft of the bolt (part 33). This is illustrated in Figure 78b, c and f.

Next place part 57 over this set up, like a sleeve, illustrated in Figure 78c and f. This sleeve rotates around the bolt (part 33) setup described above.

Next place part 15 onto part 57, followed by the 2x part 16 and finally the part 17, as shown in Figure 78c, d and f.

Place part 35b (the M5 penny washer, or M5 wide washer) over the portion of part 33 that is still protruding from the top of the setup. Lock this in place using the final part 34, tensioning so that the parts 15, 16, 17 and 57 are free to spin around the axis of part 33, but are held tightly enough that they are not at risk of slipping from the top of the part 33 assembly. This is shown in Figure 78d, e and f.

4a.9 Pawl Arm Installation

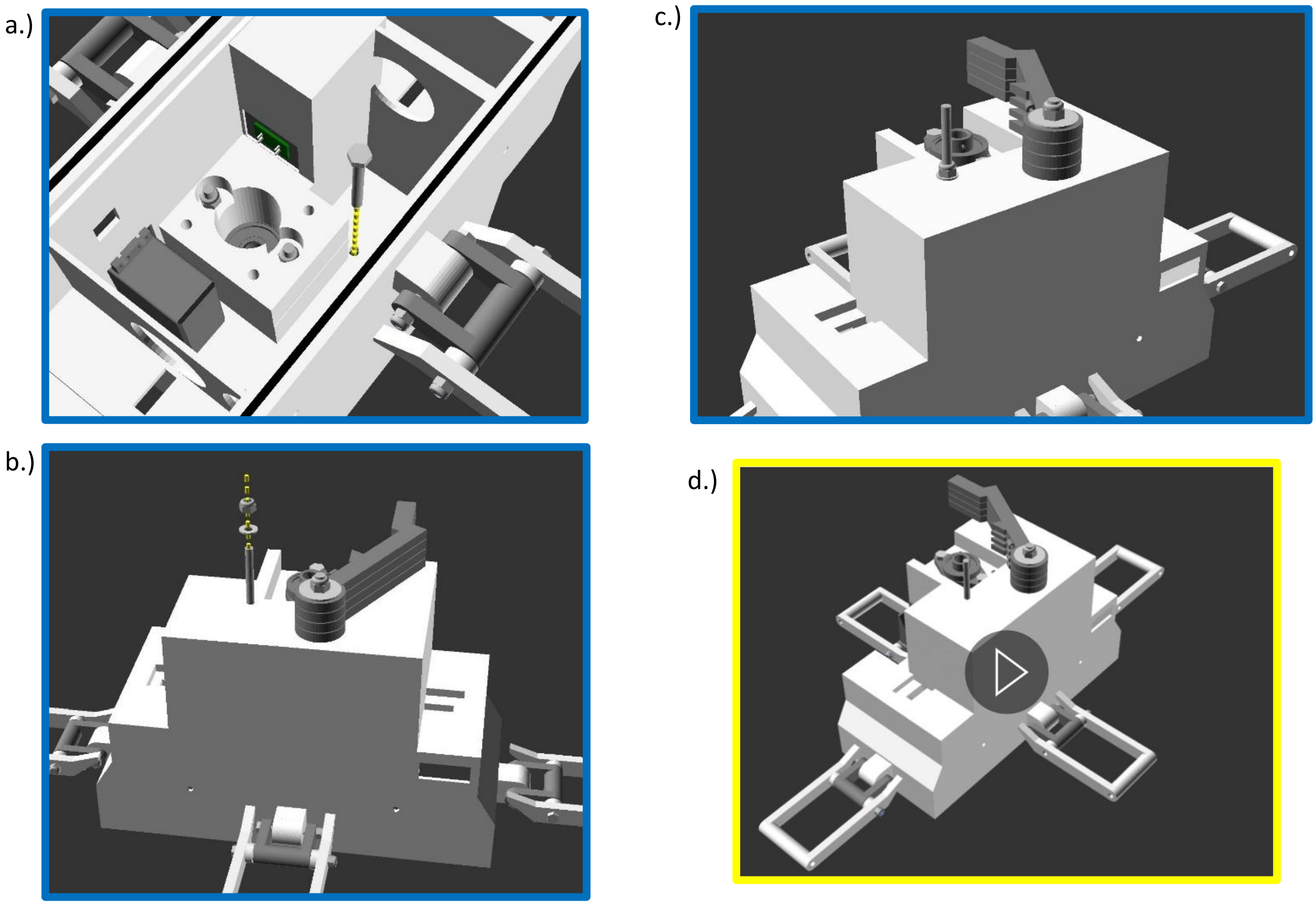


Figure 79 Action diagrams (a, b, and c) and animated gifs (d) illustrating step 4a.9, installing the pawl spring bolt to the motor unit subassembly. View animation (d) in file “step_4a_9_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.8, 1 x part 37, 1 x part 40, 1x39.

Insert part 37 (M4 40mm bolt) from the inside of part 9 (the motor case), in the bolt hole closest to the Optical Limit Switch Assembly, illustrated in Figure 79a, b and d.

(Note - the optical limit switch assembly cable is not rendered for the purpose of illustration simplification).

On the outside of part 9, place 1x part 40 (standard M4 washer) over part 37, followed by 1x part 39 (M4 lock nut). Tension so that part 37 is held firmly in place.

4b.1 Leadscrew Assembly

a.) b.) c.) d.)

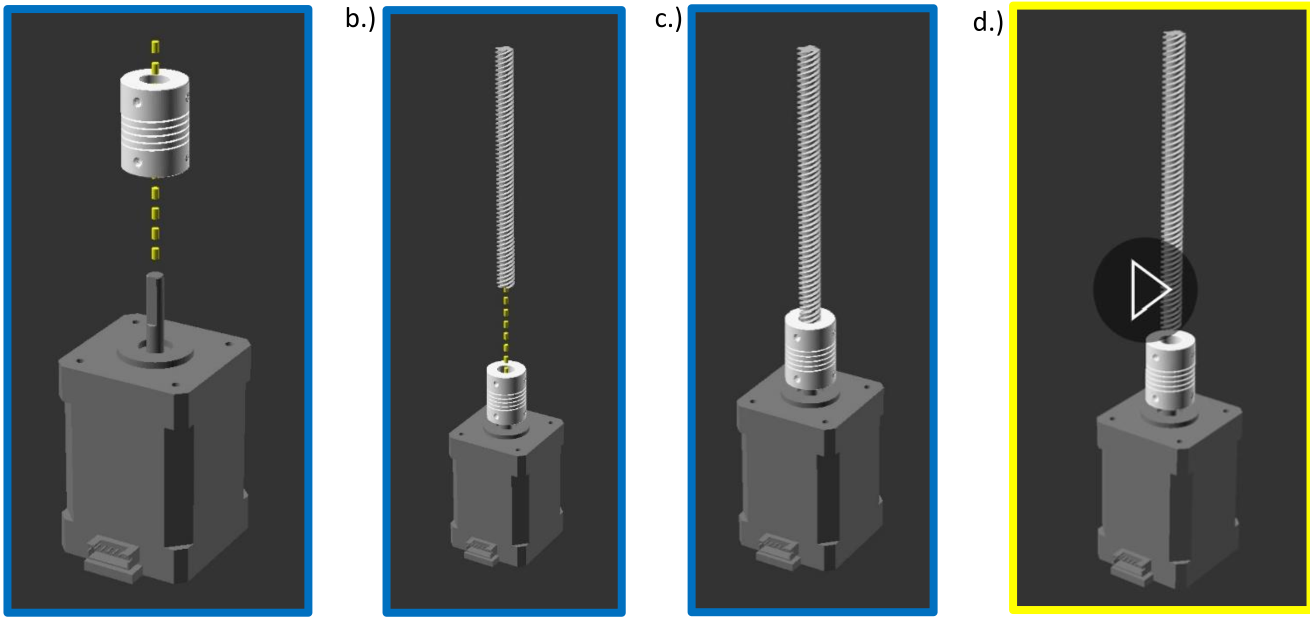


Figure 80 Action diagrams (a, b, and c) and animated gifs (d) illustrating step 4b.1, assembling the leadscrew subassembly in preparation for subsequent installation into the motor unit subassembly. View animation (d) in file “step_4b_1_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - 1 x part 65, 1 x part 47, 1x part 48.

Place part 47 (flexible coupling) 5mm diameter side first (the smaller of the 2 end holes) onto the drive/output shaft of part 65 (nema stepper motor). Align so that the top of the drive shaft ends at the middle point of part 47. Once in the correct position, lock the coupling in place by tightening the bottom 2 grub screws firmly, located on the outside of part 47 (illustrated in Figure 80a, b and d).

Next place part 48 (the leadscrew) into the 8mm side (the larger of the 2 end holes) of part 47, ideally leaving the non-cut end pointing upwards. This should fill the top half of part 47 and rest upon the drive shaft of part 65. Lock the coupling onto part 48 by tightening the top 2 grub screws firmly, located on the outside of part 47 (illustrated in Figure 80 b, c and d).

4b.2 Leadscrew Assembly Installation

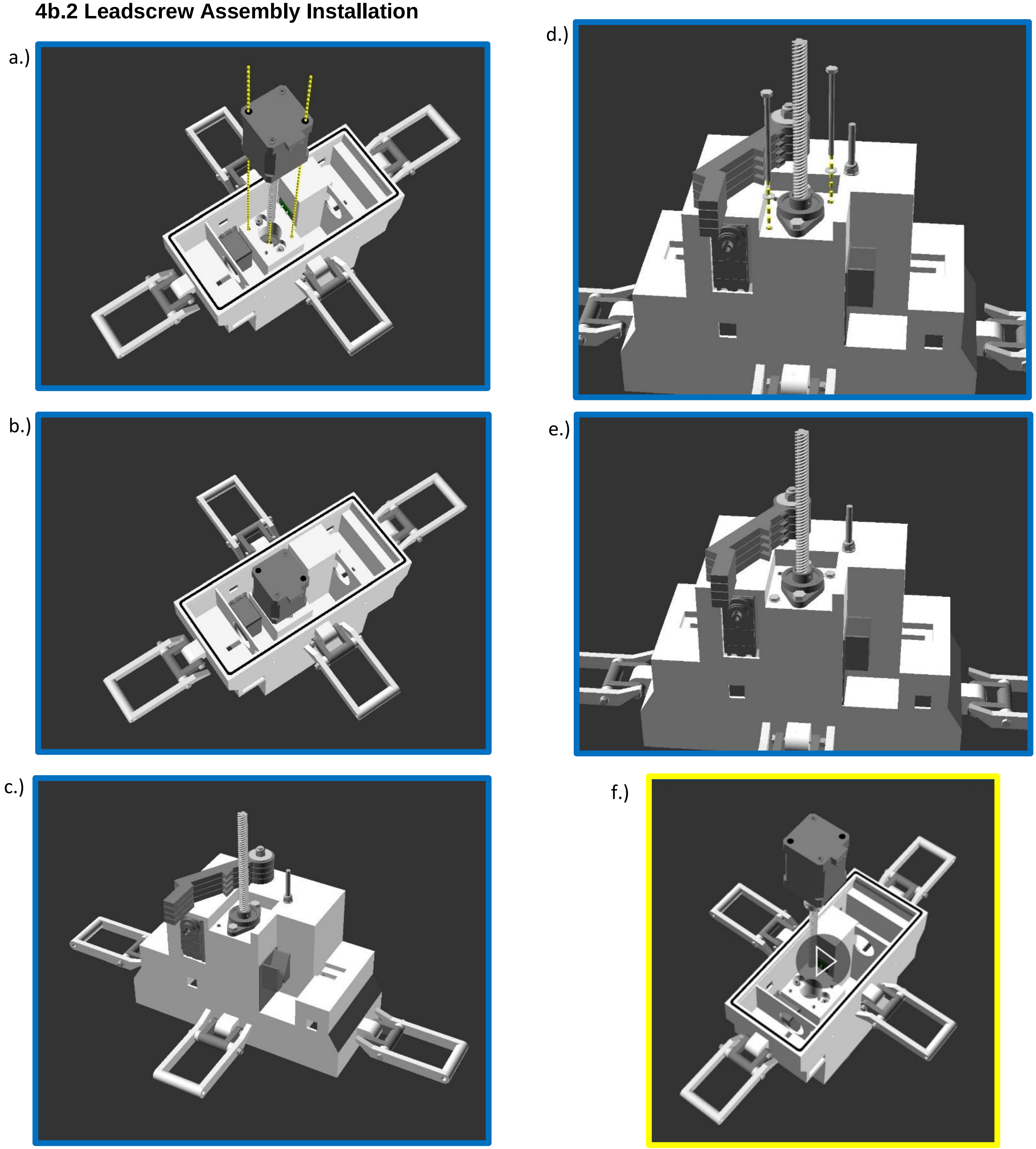


Figure 81 Action diagrams (a, b, c, d and e) and animated gif (f) illustrating step 4b.2, installing the leadscrew assembly into the motor unit subassembly. View animation (f) in file “step_4b_2_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4a.9, subassembly unit resulting from step 4b.1, 2 x part 41, 2x 45, 1x part 99, 1x part 90/91.

Remove the 2x bolts from the stepper motor (part 65) indicated as black dots on the bottom of the stepper motor in Figure 81.

Orient the subassembly unit resulting from step 4b.1 so that the lead screw (part 48) passes through the middle of the pillow block (part 46), and the top surface of the stepper motor (part 65) meets the motor case (part 9). The stepper motor female cable connector should face the inside of the motor case. Ensure that the bolt holes in the motor case (part 9), align with the open bolt holes of the stepper motor, which were previously removed (as shown in Figure 81a, b, c and f).

From the outside of the motor case (part 9), insert the 2 x part 41 (50mm M3 bolts), each through a single part 45 (m3 washer) and into the motor case bolt holes illustrated in Figure 81d, e and f. These bolts then bind with the thread in the stepper motor (part 65).

Tension these bolts so that the hold the stepper motor firmly in place.

After test fitting the subassembly unit resulting from step 4b.1 to the motor unit subassembly, ensure that the top of part 47 does not rub against bottom of part 46 or inhibit the movement of the nema stepper motor driveshaft (part 65). If this does occur, repeat step 4b.1, but adjust the height of part 47 to be lower on the driveshaft of part 65.

Once confident that the Leadscrew assembly is correct, finalise step 4b.1 by applying superglue to the grub screws of part 47, locking the assembly together. Superglue should also be applied to the bottom of part 48, and to the drive shaft of part 65. This binds the flexible coupling to the lead screw assembly.

Failure to glue the grubscrews will result in the leadscrew assembly becoming loose during chamber operation and the failiure of the chamber to function.

Re-install the finalised subassembly unit resulting from step 4b.1 to the subassembly unit resulting from step 4a.9 as describe above.

Finally, apply hot glue around/ on the bolt heads on the outside of part 9 (i.e. the side illustrated in Figure 81 e) to waterproof the joints.

4b.3 Ratchet Installation

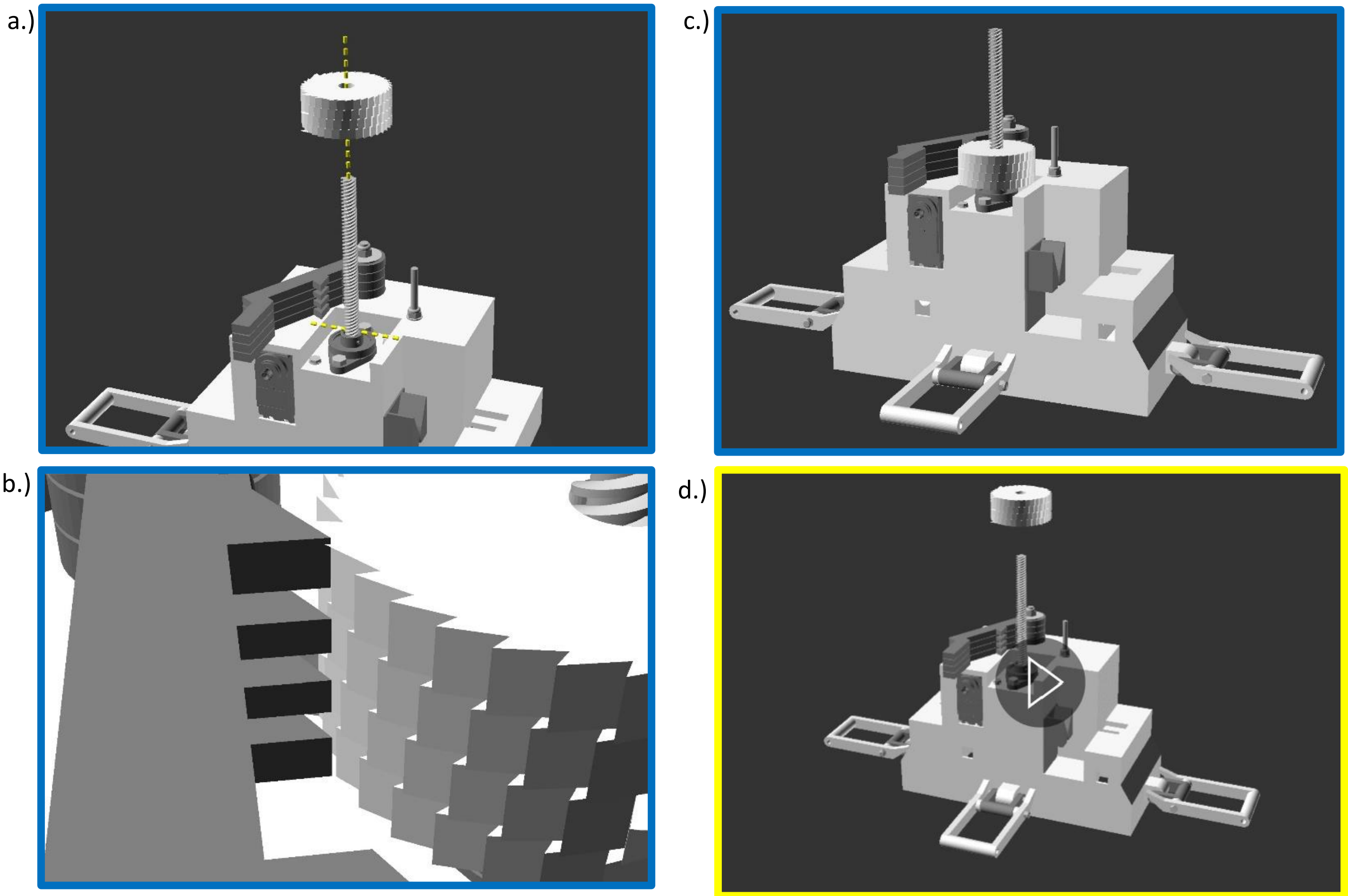


Figure 82 Action diagrams (a, b, and c) and animated gif (d) illustrating step 4b.3, installing the ratchet onto the motor unit subassembly. View animation (d) in file “step_4b_3_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4b.3, 1 x part 18, 1 x 90/91.

Orient part 18 (the ratchet) so that the locking portion of the ratchets (the overhang) face towards the pawls as illustrated in Figure 82b.

Place part 18 over the leadscrew (part 48), so that it passes through the hole in the middle of the part 18.

Part 18 must not rub against the top surface of the motor case (part 9). The goal is to have it ~2mm above the surface of the motor case, and still engage with the pawl arms as illustrated in Figure 82.

Once confident about how part 18 fits to the subassembly unit resulting from step 46.3, remove part 18. Apply super glue (part 90 or 91) to the area on the leadscrew (part 48) where the ratchet to be installed. Replace the ratchet into position over the glue, adding extra glue if necessary to the top of the ratchet when in place.

Be careful to not get glue on the leadscrew above the ratchet, as this is important for later chamber functionality.

Wait for the glue to dry following the instructions indicated on your glue.

4b.4a Circuit Board Standoff Bolts Installation

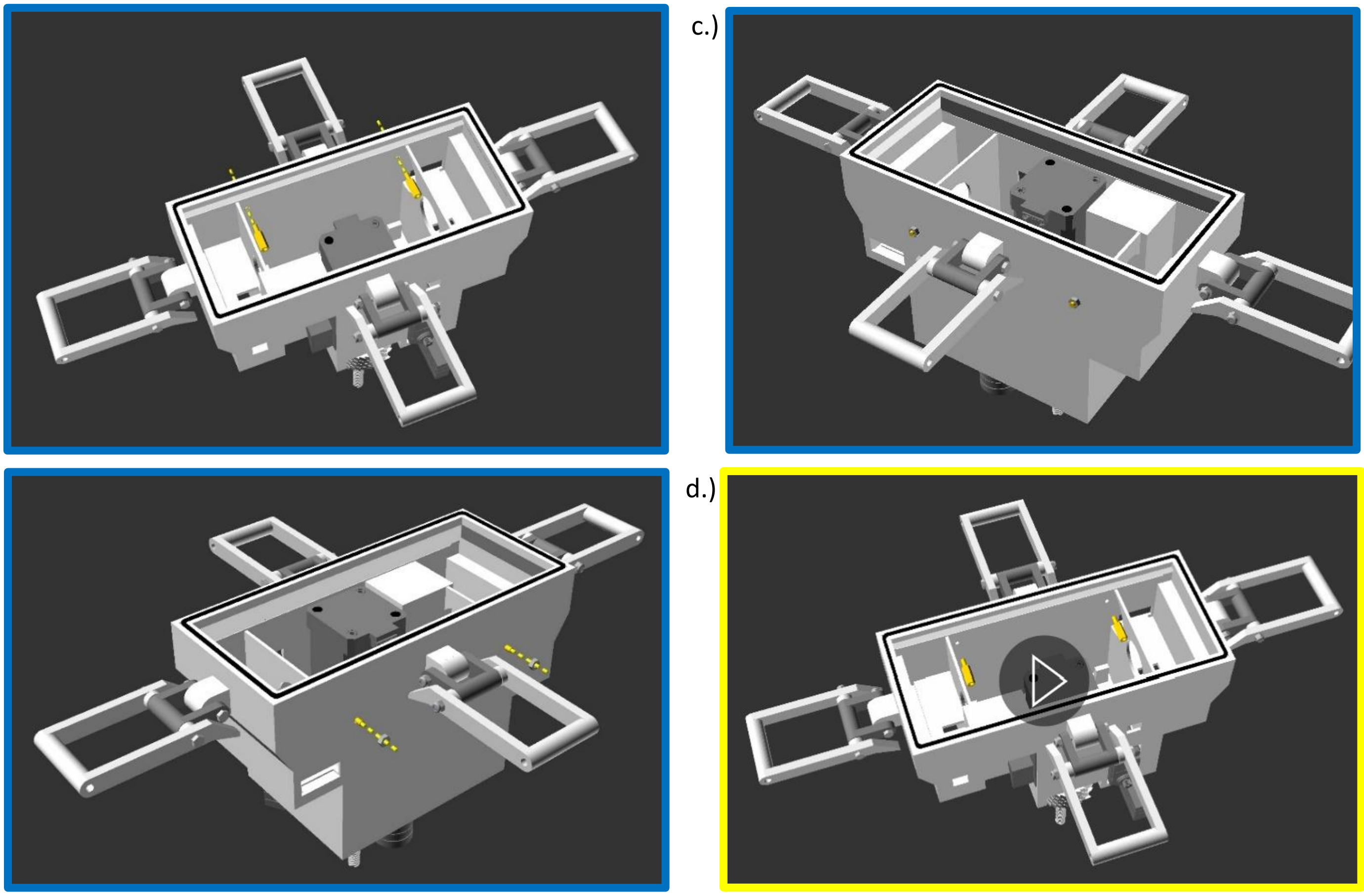


Figure 83 Action diagrams (a, b, and c) and animated gif (d) illustrating step 4b.4a, installing the circuit board standoff bolts onto the motor unit subassembly. View animation (d) in file "step_4b_4_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4b.3, 2 x part 53, 2 x part 44b, 1x part 90 or 91.

Insert the threaded portion of standoff bolts (parts 53), through the holes in the wall of the motor case (part 9), opposite the stepper motor (part 65), as illustrated in Figure 83a and d.

Fix the standoff bolts in place using 1x part 44b on each standoff bolt, from the outside of the motor case (illustrated in Figure 83b, c and d). Tension so that the bolts are held firmly in place.

Apply super glue (part 90 or 91) to the outside facing nuts (Figure 83c). This is to fix them in place and prevent loosening, in addition to waterproofing the joint.

4b.4b Circuit Board Installation

a.) c.) b.) d.)

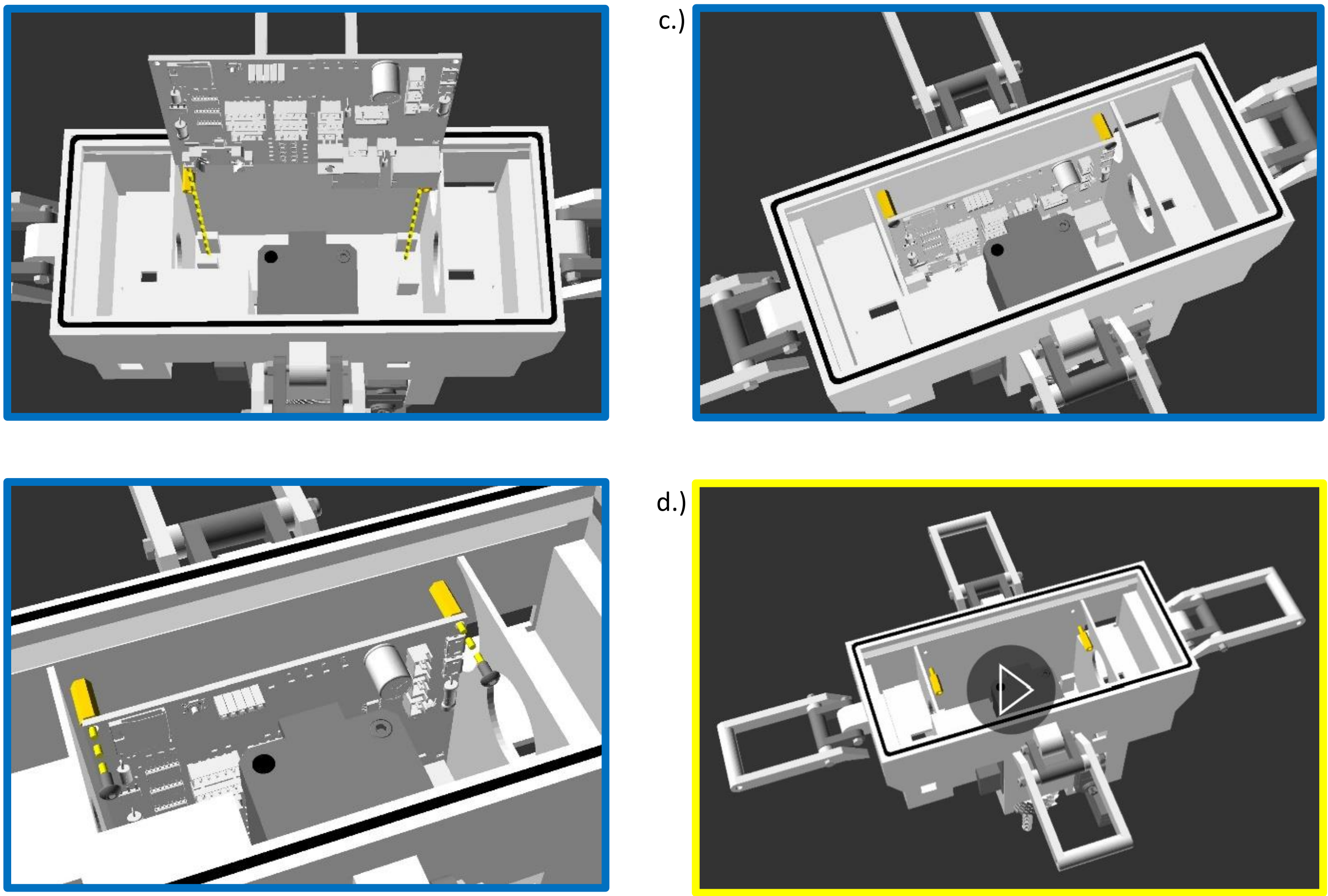


Figure 84 Action diagrams (a, b, and c) and animated gif (d) illustrating step 4b.4b, installing the main circuit board onto the motor unit subassembly. View animation (d) in file "step_4b_4_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4b.4a, 2 x part 54, 1 x part 76.

Orient the main circuit board (part 76) so that the corner bolt holes are at the top of the board. The coin cell battery should be at the bottom left, when facing the standoff bolts (part 53).

The bottom of the circuit board slots into brackets printed into the motor case (part 9), illustrated in Figure 84a and d.

The bolt holes in the top corners of the circuit board (part 76) should now align with the standoff bolts (part 53). Insert one part 54 into each of the bolt holes of the circuit board and into the standoff bolts. Gently tension the bolts so that the circuit board is held in place, but that the surface is not damaged.

This step is important for general usage of the chambers.

4b.5 Glue-on Accessory Circuits Installation

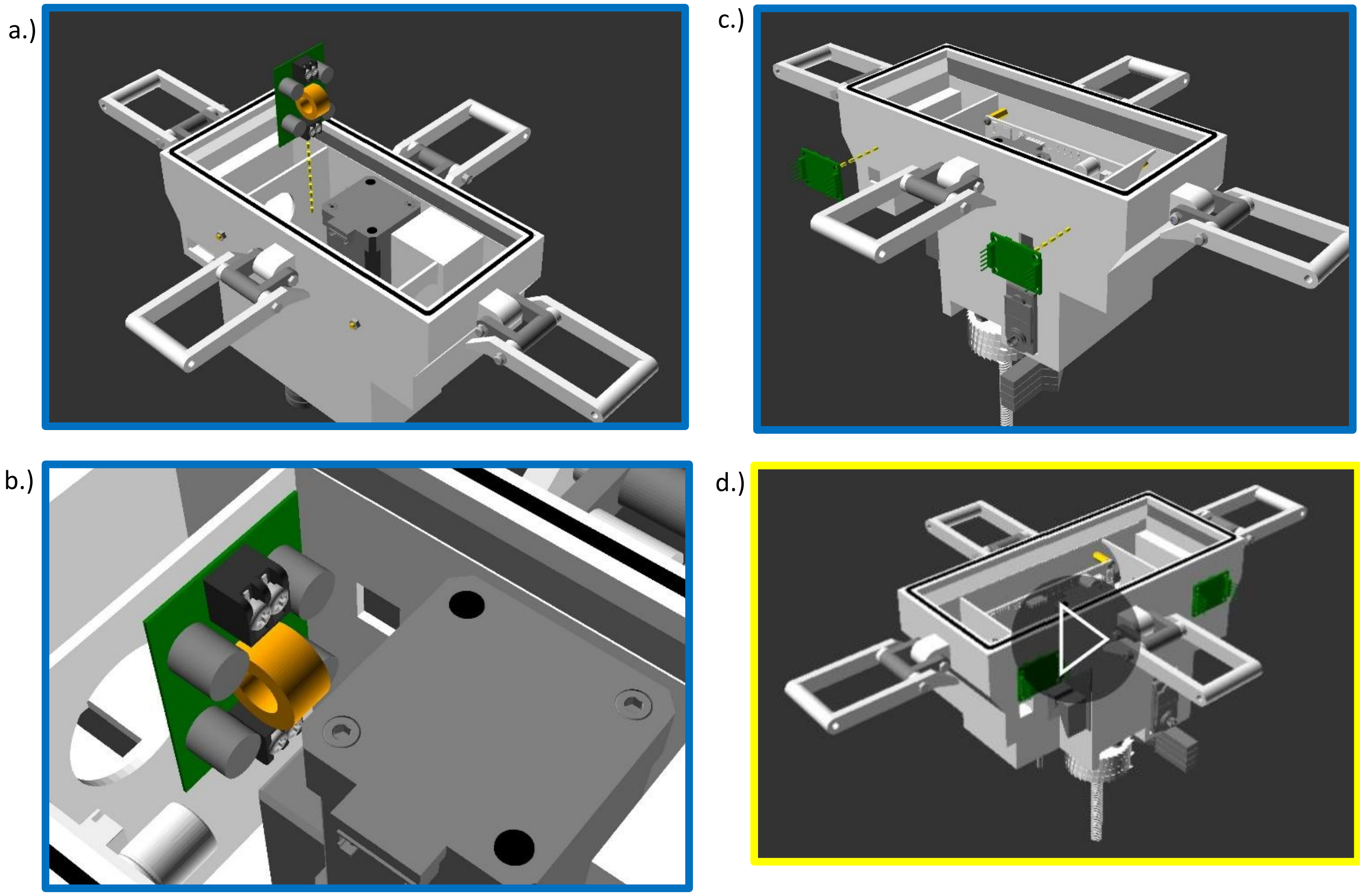


Figure 85 Action diagrams (a, b, and c) and animated gif (d) illustrating step 4b.5, gluing the accessory circuit boards onto the motor unit subassembly. View animation (d) in file "step_4b_5_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4b.5, 1 or 2 x part 69, 1 x part 80b, 1x part 99.

Dry fit part 80b into the motor case as illustrated in Figure 85a, b and d. It is important that the top of part 80b does not protrude over the plastic printed bracket of the motor case that it rests against, as illustrated in Figure 85b. This is because the power banks are positioned upon this bracket, described in step 1.4.4c.1.

UPDATE – The following instructions describe the gluing of the part in place. However, step 4c.4 requires nuts to be inserted behind the part 80b (Figure 90). Therefore, repeat the following instructions after step 4c.4.

Once happy with the fit, apply hot glue to the back of the circuit board and replace in its position.

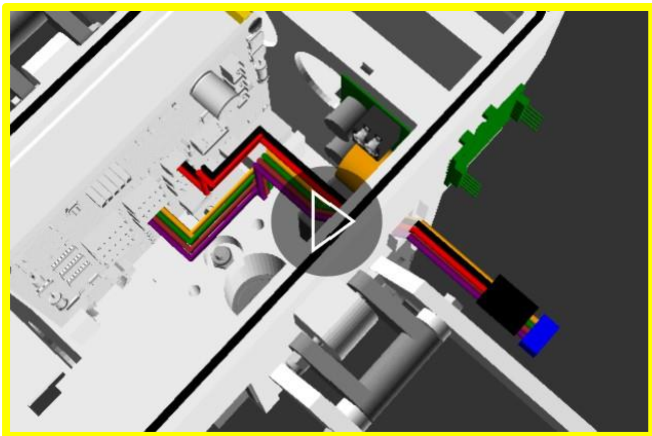
Dry fit parts 69 onto the outside motor case as illustrated in Figure 85 c and d. This should be, with the cable connectors facing away from the motor case (part 9). If only using one load cell in your build, just fit the part 69 to the left in Figure 85c.

Once happy with the fit, apply hot glue to the back of the circuit boards and replace in their positions.

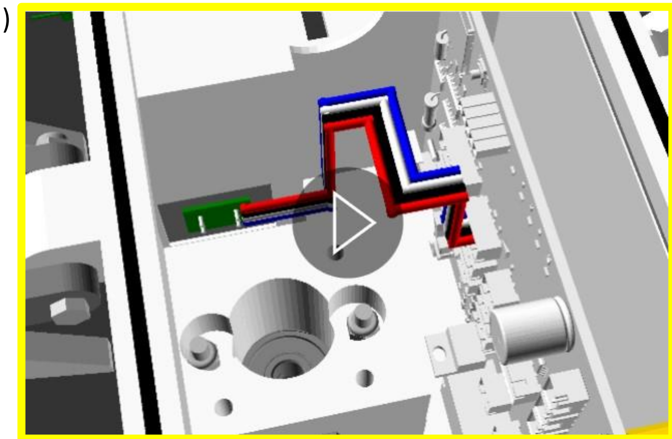
In the future this step may be changed to allow for a mechanical binding of part 73b and parts 69 to the motor case (part 9). But for the scope of this project as a part of my PhD, I do not have time to adjust this step at present.

4b.6, 7, 8 and 9 Motor Unit Wiring

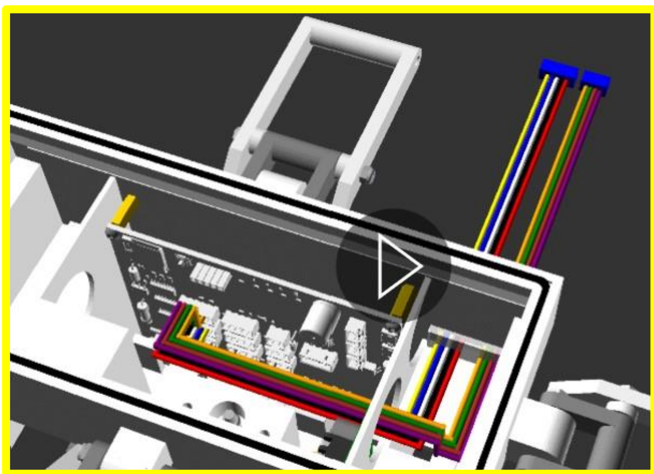
a.)



c.)



b.)



d.)

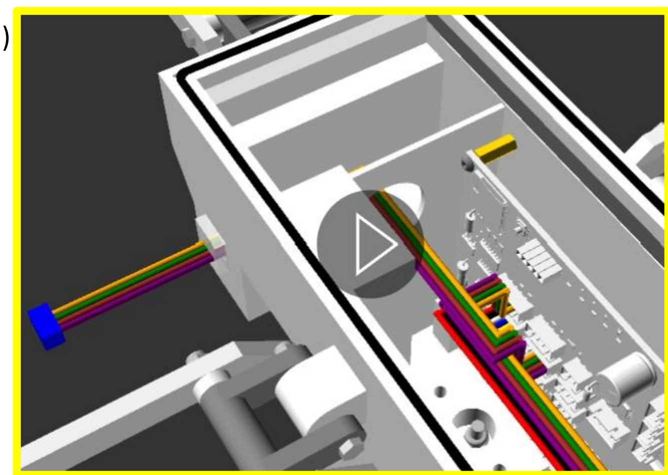


Figure 86 Animated gifs (a, b, c and d) illustrating step 4b.6 to 9, installing and gluing in motor unit subassembly wiring. View animation (a) in file “step_4b_8_animated.gif”, animation (b) in file “step_4b_6_animated.gif”, animation (c) in file “step_4b_9_animated.gif” and animation (d) in file “step_4b_7_animated.gif”, available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4b.5, 1 x part 77a, 1 x part 77b, 1 x part 78a, 1 x part 78b, 1 x part 79b, 1x part 99,

This step installs cables that pass from inside the motor unit into the chamber body cavity, sealing them in place. The leadscrew assembly described in step 4b.1 is absent in Figure 86 to make illustration of the cable installation clearer.

Uninstall the main circuit board (part 76) from the motor unit subassembly, following step 4b.4b. Keep the circuit board as close as you can to its fitted position, while having easy access to all of the cable connectors on the circuit board. This is done as it is easier to install cables onto the main circuit board outside of the motor case, rather than attempting it when the main circuit board is installed.

Insert parts 77a and 77b (the sensor board cable and radio cable) from the outside of the motor case (part 9) to the inside of the motor case, as illustrated in Figure 86b.

Connect the cables to the main circuit board (part 76) in the appropriate male connectors (part 77a to labelled connector “Sensors”, part 77b to labelled connector “HC-12”). *

When confident that the cables (parts 77a and 77b) have enough length on the inside, fix in place by applying part 99 (hot glue) to the hole in the motor case (part 9) that they are routed through. This holds the cables in place and waterproofs the joint. **

Insert part 79b (the fan cable) and if using the second load cell, part 78b (load cell cable 2) from the outside of the motor case (part 9) to the inside of the motor case, as illustrated in Figure 86a.

Connect the cables to the main circuit board (part 76) in the appropriate male connectors (part 78b to labelled connector “Strain 2”, part 79b to labelled connector “Fan”). *

When confident that the cables (parts 79b and 78b) have enough length on the inside, fix in place by applying part 99 (hot glue) to the hole in the motor case (part 9) that they are routed through. This holds the cables in place and waterproofs the joint. **

Insert part 78a (the load cell cable 1) from the outside of the motor case (part 9) to the inside of the motor case, as illustrated in Figure 86d.

Connect the cable to the main circuit board (part 76) in the appropriate male connectors (part 78a to labelled connector “Strain 1”). *

When confident that the cable (parts 78a) has enough length on the inside, fix in place by applying part 99 (hot glue) to the hole in the motor case (part 9) that it is routed through. This holds the cable in place and waterproofs the joint. **

Figure 86c illustrates how cable the Optical Limit Switch cable (step 4a.2) is routed to the main circuit board (part 76). This travels around the leadscrew assembly described in step 4b.1 and connects to the male connector (labelled end stop 1).

Re-install the main circuit board with the connected cables to the motor unit subassembly, following step 4b.4b.

*Ensure that the cables have enough length on the inside of the motor case to connect to the main circuit board. Cables that are too short will be very difficult to work with in subsequent steps, for example when trouble shooting hardware.

**In the future this step may be changed to include cabinet fit cable connectors from the outside of the motor case (part 9), instead of a hot glue permanent joint. This would give more simple chamber body cavity cable length adjustment. But for the scope of this project as a part of my PhD, I do not have time to adjust this step at present.

4c.1 Power-Bank and Lid Installation

a.) b.)

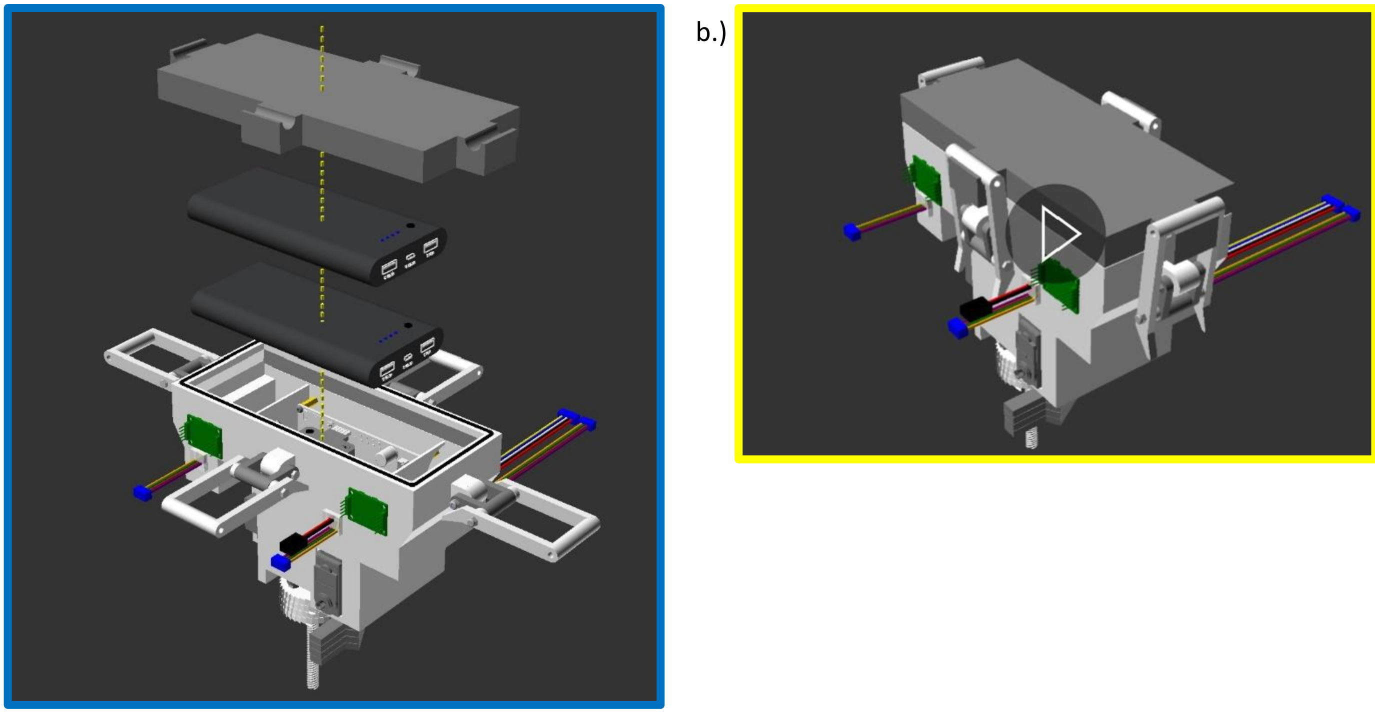


Figure 87 Action diagrams (a) and animated gif (b) illustrating step 4c.1, installing the 2 power banks and lid to the motor unit subassembly. View animation (b) in file “step_4c_1_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4b.6, 7, 8 and 9, 2 x part 80, 1 x part 10.

This step illustrates how the power banks are installed into the motor unit, and how the lid is attached. We will not provide power to the main circuit board (part 76) at this stage, so will not connect the power banks to the main circuit board.

Place the first Power bank (part 80) onto the cross brackets of the motor case (part 9). The LEDs and power button of part 80 (the front surface of the Power bank) should face upwards. The female USB connectors (the top surface of the power bank) should face to the servomotor side of the motor unit subassembly. The opposite side to the female USB connectors (the bottom surface of the power bank) should butt up against the load cell 1 end of the motor case.

Ensure that no cables are trapped between the power bank and the cross brackets of the motor case. Trapped cables can prevent the power bank from lying flat on the brackets or result in damage to the cables.

Place the second Power bank (part 80) onto top of the first power bank, in the same location and orientation described above.

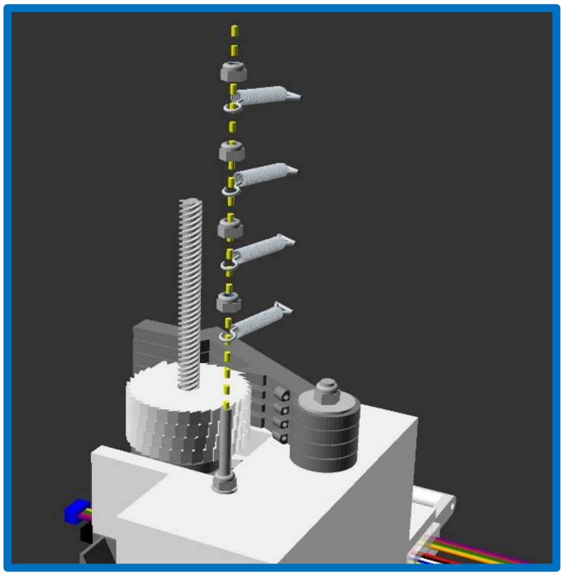
Place the motor case lid (part 10) on top of the 2 power banks. The bottom edge of the motor case lid should press against the O-ring/Gasket of the motor unit subassembly, installed in step 4a.5.

Clamp the motor case lid in place by engaging the motor unit latches with the motor case lid. This and the previous steps are illustrated more clearly in Figure 87.

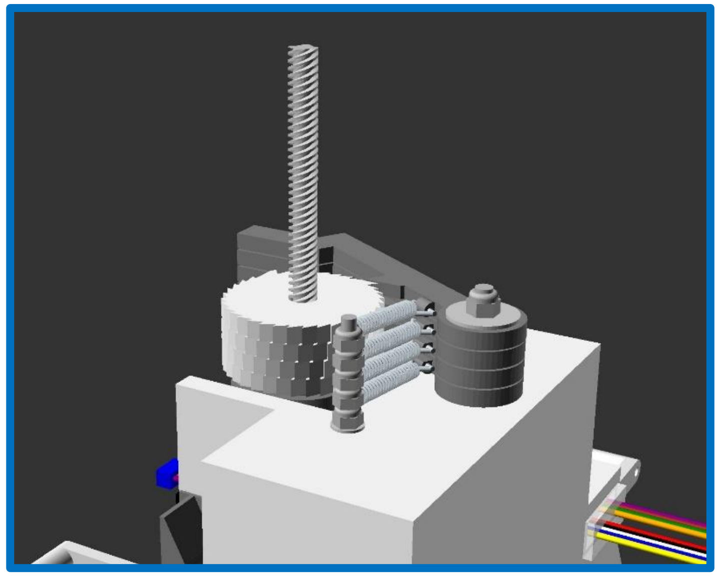
Clamping the motor case lid (part 10) to the gasket of the motor unit subassembly provides a waterproof seal.

4c.2 Pawl Spring Installation

a.)



b.)



c.)

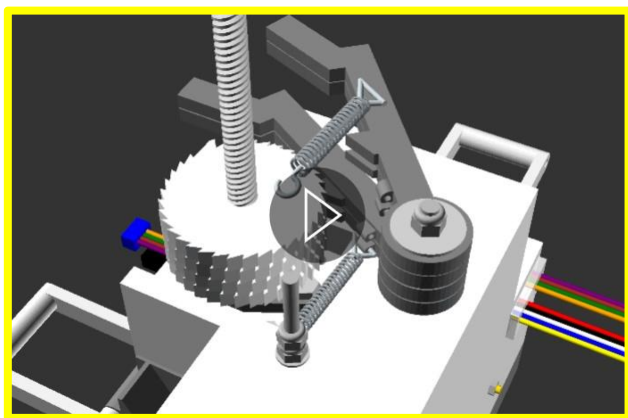


Figure 88 Action diagrams (a and b) and animated gif (c) illustrating step 4c.2, installing the pawl springs onto the motor unit subassembly. View animation (c) in file “step_4c_2_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4c.1, 4 x part 58, 4 x part 39.

Insert the round end of the first part 58 (the “helical extension spring” or “tension spring”) onto the shaft of part 37 (M4 bolt installed in step 4a.9) as illustrated in Figure 88.

Thread the loop of the other end of the tension spring through the bottom pawl arm (part 15) and fold the spring end back on itself to lock the tension spring onto the pawl arm (as illustrated in Figure 88).

Next insert 1 part 39 (M4 locking nut) onto part 37. Screw this locking nut onto part 37 until just above the first tension spring.

Insert the round end of the second part 58 (the “helical extension spring” or “tension spring”) onto the shaft of part 37, as illustrated in Figure 88.

Thread the loop of the other end of the tension spring through the first middle pawl arm (part 16) and fold the spring end back on itself to lock the tension spring onto the pawl arm (as illustrated in Figure 88).

Next insert 1 part 39 (M4 locking nut) onto part 37. Screw this locking nut onto part 37 until just above the second tension spring. *

Insert the round end of the third part 58 (the “helical extension spring” or “tension spring”) onto the shaft of part 37, as illustrated in Figure 88.

Thread the loop of the other end of the tension spring through the second middle pawl arm (part 16) and fold the spring end back on itself to lock the tension spring onto the pawl arm (as illustrated in Figure 88).

Next insert 1 part 39 (M4 locking nut) onto part 37. Screw this locking nut onto part 37 until just above the third tension spring. *

Insert the round end of the fourth part 58 (the “helical extension spring” or “tension spring”) onto the shaft of part 37, as illustrated in Figure 88.

Thread the loop of the other end of the tension spring through the top pawl arm (part 17) and fold the spring end back on itself to lock the tension spring onto the pawl arm (as illustrated in Figure 88).

Next insert 1 part 39 (M4 locking nut) onto part 37. Screw this locking nut onto part 37 until just above the fourth tension spring. *

Figure 88b and c illustrate the end product: a unidirectional locking ratchet, which allows rotation in one direction but not the other.

*This nut acts as a spacer between the tension springs, preventing the tension springs from contacting each other, therefore maintaining the independent movement of each of the pawl arms (parts 15, 16 and 17) as they engage with the rotating ratchet (part 18). These lock nuts (parts 39) can also be adjusted after installation to ensure spring independence.

4c.3 Servo Arm Installation

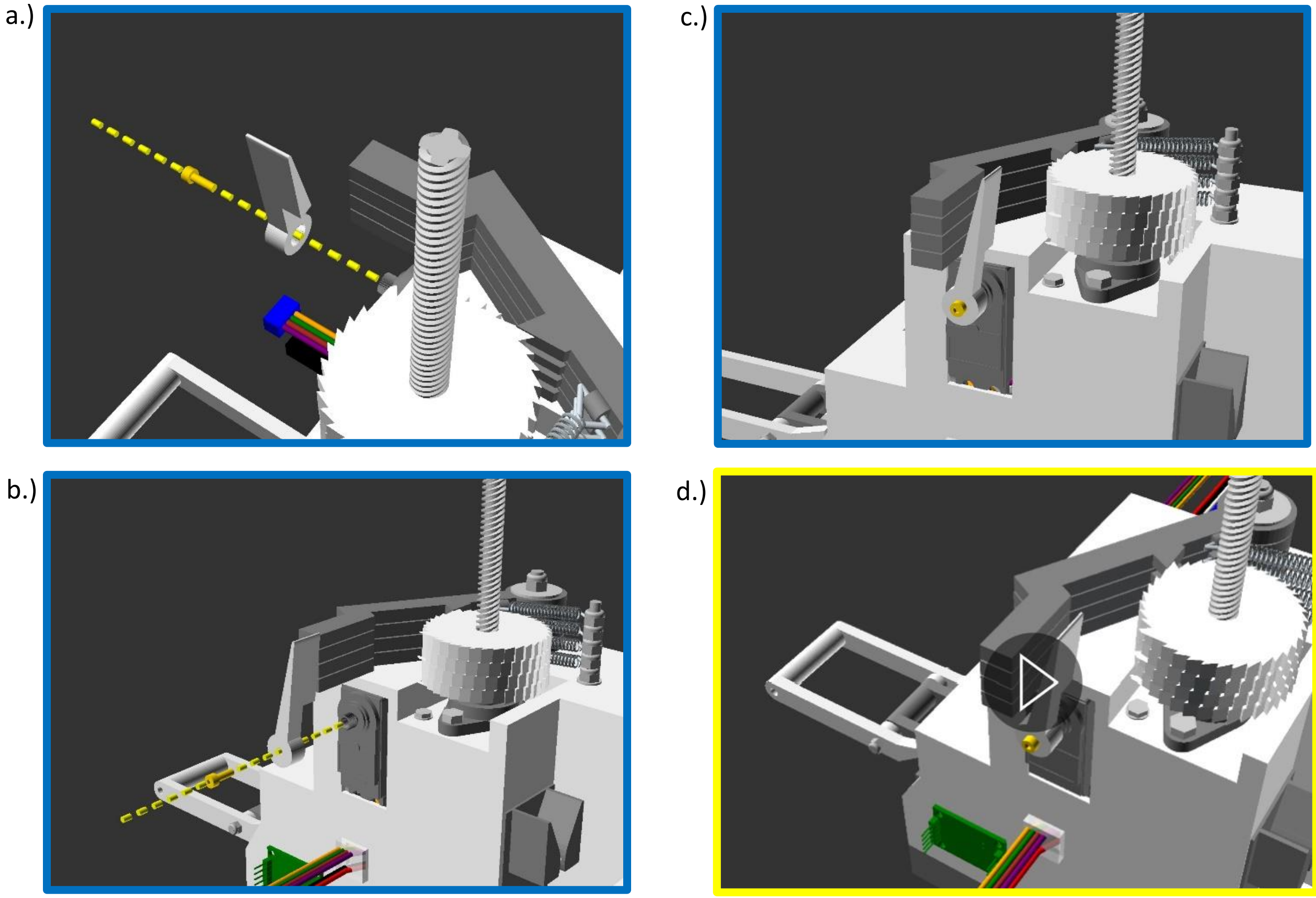


Figure 89 Action diagrams (a, b and c) and animated gif (d) illustrating step 4c.3, installing the pawl springs onto the motor unit subassembly. View animation (d) in file “step_4c_3_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 4_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 4c.2, 1 x part 19, 1 x part 50.b.

This step describes the installation of the servomotor arm (part 19). This step may need to be repeated during servomotor calibration, to ensure that the servomotor arm engages with the pawl arms (parts 15, 16 and 17) correctly.

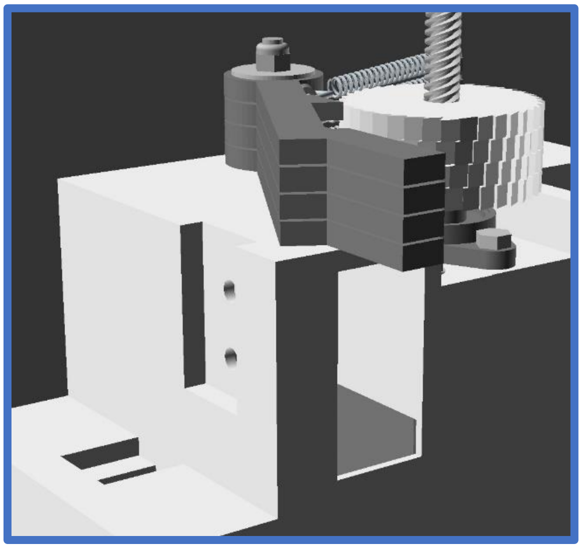
Push part 19 (the servomotor arm) onto the servomotor output shaft (part 66), so that the paddle of the of part 19 is ~1mm away from the pawl arms (parts 15, 16 and 17). This is illustrated in Figure 89.

Next lock the servomotor arm in place by inserting the servomotor arm bolt (part 50.b) through the hole in the middle of the servomotor arm (part 19), threading into the servomotor output shaft (illustrated in Figure 89).

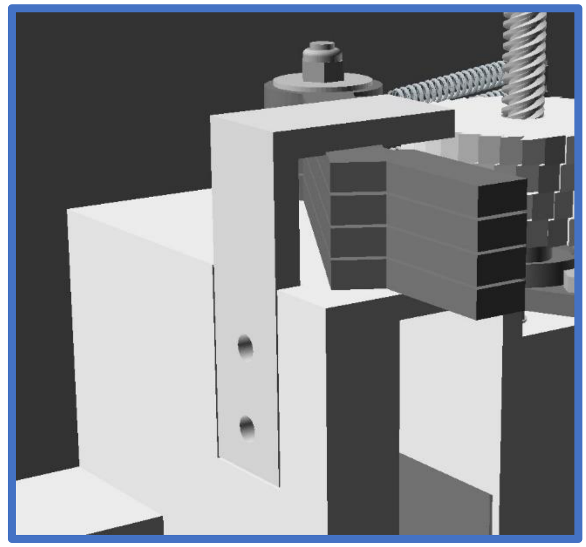
Tension the servomotor arm bolt (part 50.b) so that the arm is held firmly onto the servomotor output shaft, without impeding the internal mechanical movement of the output shaft.

Step 4c.4 – Pawl Guide Installation

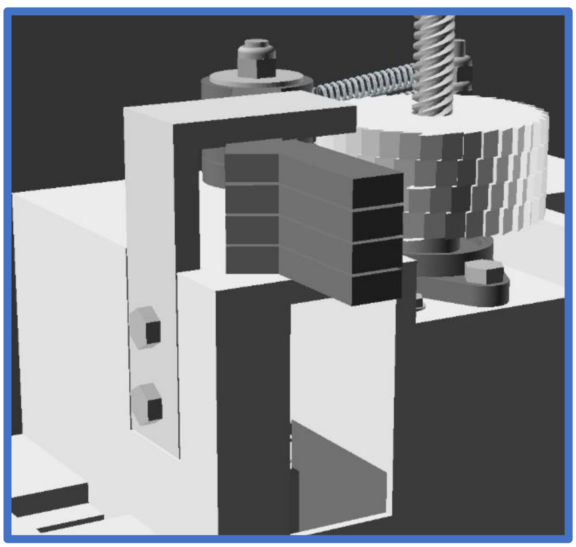
a.)



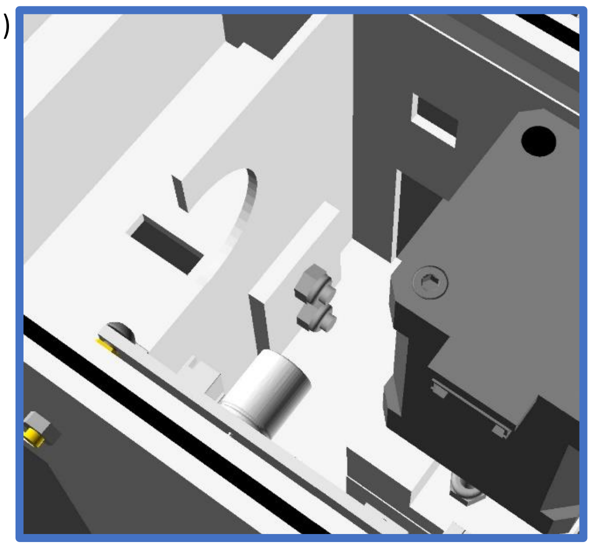
b.)



c.)



d.)



e.)

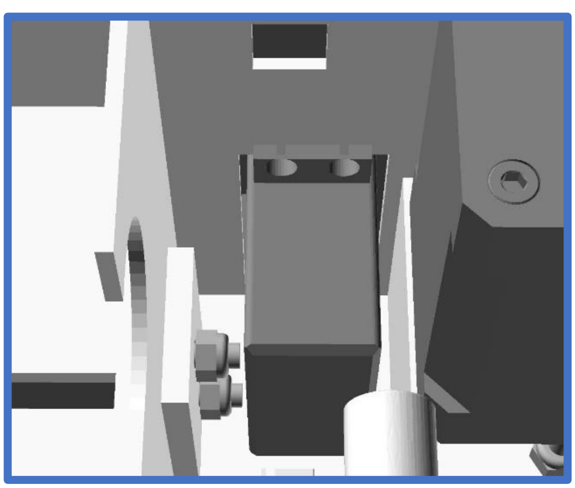


Figure 90 Action diagrams (a to e) illustrating step 4c.4, installing the pawl guide onto the motor unit subassembly. Image e illustrates the final product with the servo motor in place, while images a to d illustrate construction without the servo motor in place.

Notes:

UPDATE – This step is a later addition, therefore may be more suited between steps 4b.5 and 4a.4, or at least before they are installed permanently

Parts required for this section - Subassembly unit resulting from step 4c.3, 2 x part 38b, 2 x part 39, 1 x part 9b

This step describes the installation of the pawl arm guide (part 9b).

Insert part 9b into the socket in part 9 (the motor case) so that the bolt holes in each part are aligned, and the pawl arms (parts 15, 16 and 17) underneath the pawl guid can still move freely. This is illustrated in Figure 90a and b.

Next insert the 2x part 38b (16mm m4 bolts) from the outside of part 9b to the inside of part 9b, as illustrated in figure 77.1 c. Lock the bolts in place using the 2 x part 39 (M4 lock nut) as illustrated in Figure 90d.

Repeat steps 4b.5 and 4a.4

With this, step 4 and the Motor Unit subunit are completed, and should look like Figure 70.

Step 5: Chamber brackets

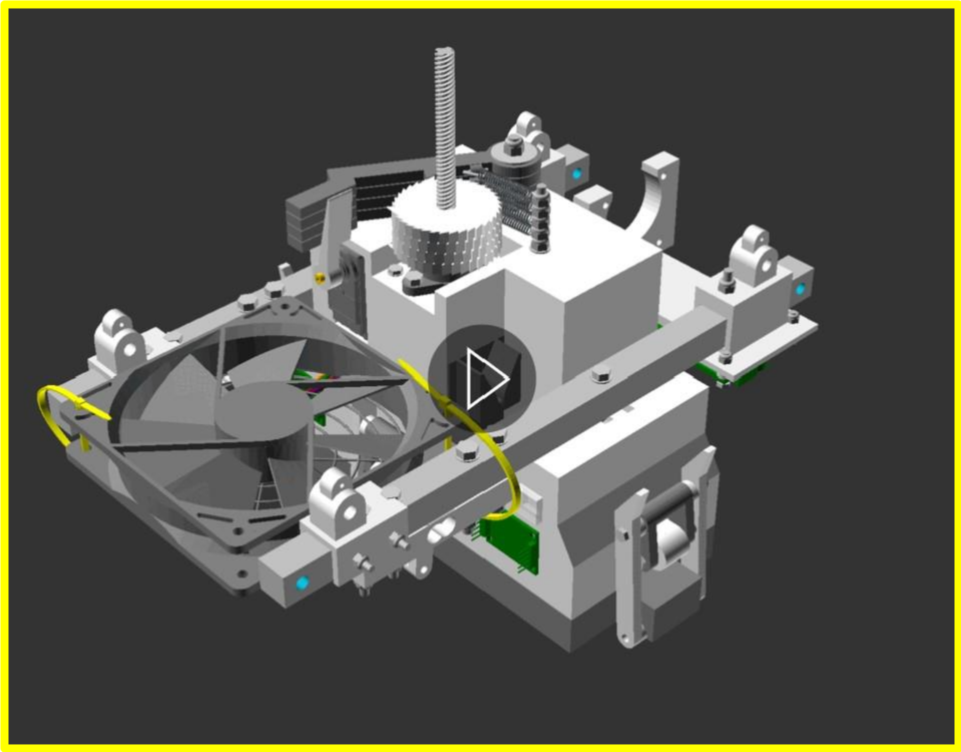
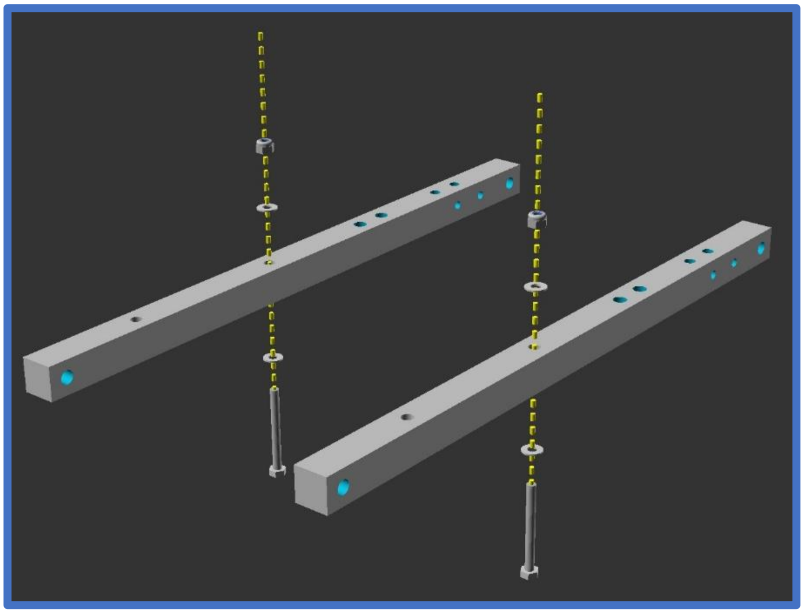


Figure 91 3D model illustrating the product of step 5. Before moving to step 6, your assembled piece should look like this. View this animation in file "step_5_end_product_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 5_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

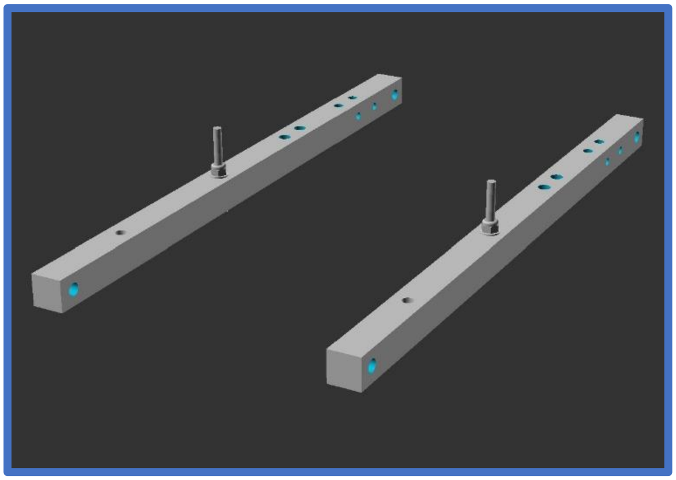
Step 5 focuses upon the subassembly piece "Chamber Brackets". The end product of this step is the chamber brackets with the Motor Unit, sensor bracket, sensor board, load cells/strain gauges, fan brackets, and fan installed (Figure 91).

5.1 Bracket “mounting bolt” installation

a.)



b.)



c.)

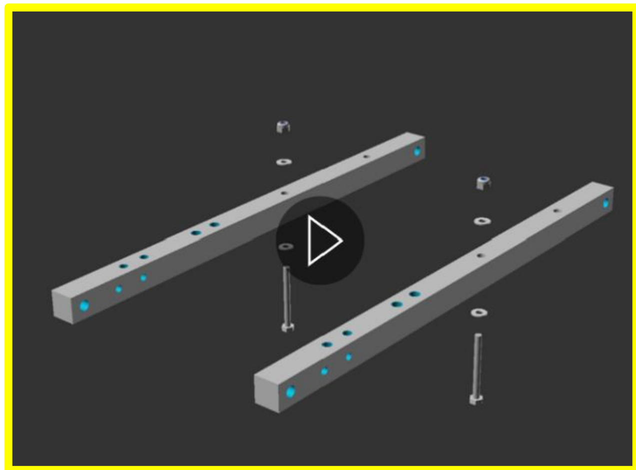


Figure 92 Action diagrams (a and b) and animated gif (c) illustrating step 5.1, installing the bracket “mounting bolt”. View animation (c) in file “step_5_1_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 5_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - 2 x part 51, 2 x part 37, 2 x part 39, 4 x part 40.

Insert part 37 (M4 bolt) through a single part 40 (m4 washer), then through the central hole in part 51 (the bracket), followed by a second part 40 and finally a single part 39 (lock nut). This step is illustrated in Figure 92a, b and c.

Tension part 39 until the bolt is held firmly in place, without damaging part 51 (aluminium bracket) through crushing force.

Repeat this for a second bracket. At the end you should have 2 brackets as illustrated in Figure 92b and c.

5.2 Motor Unit Installation

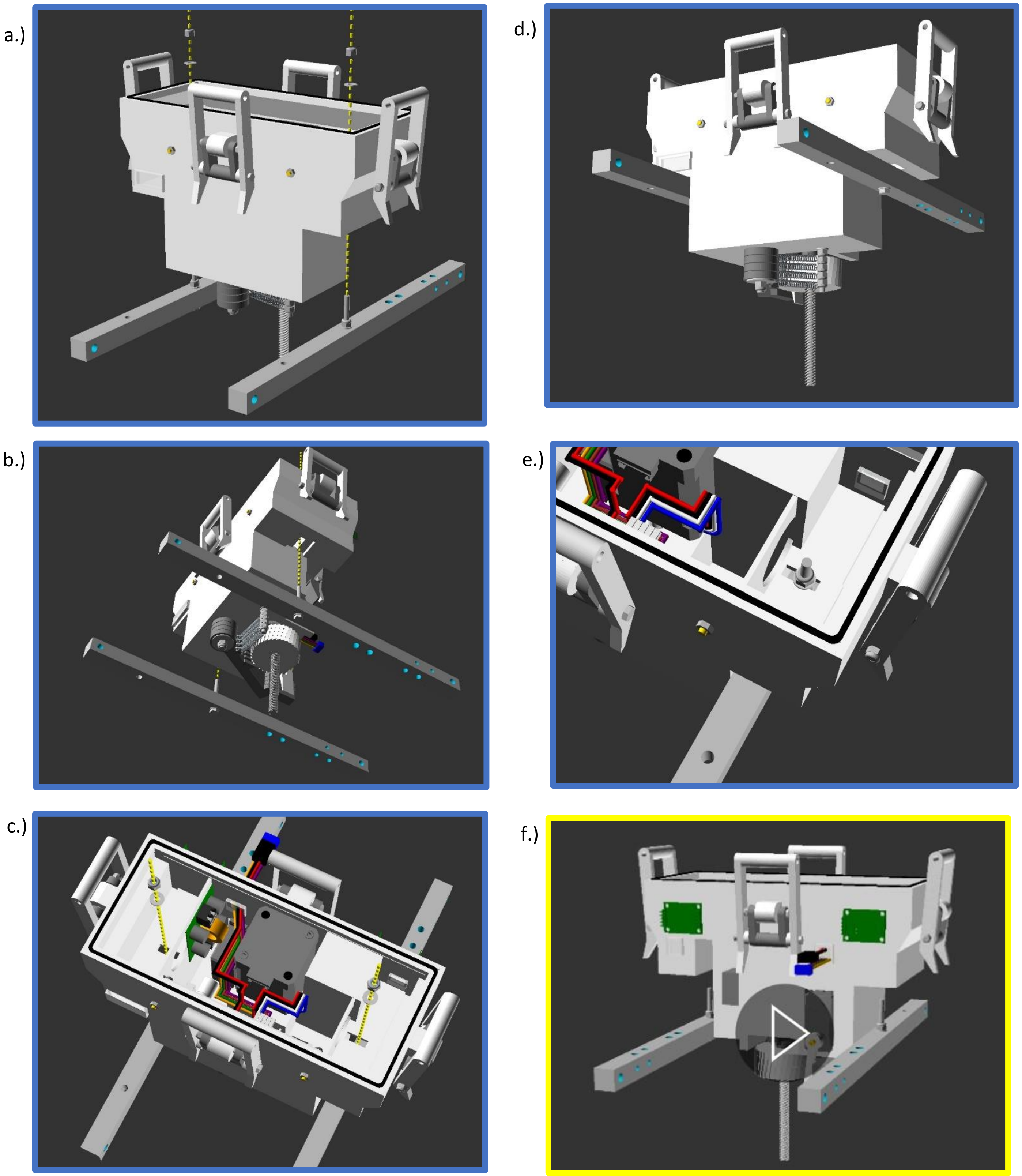


Figure 93 Action diagrams (a, b, c, d and e) and animated gif (f) illustrating step 5.2, installing the motor unit onto the chamber brackets. View animation (f) in file “step_5_2_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 5_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 5.1, Motor Unit resulting from step 4c.3, 2 x part 39, 2 x part 40.

This step fixes the motor unit to the chamber brackets.

With the servomotor (part 66) and load-cell circuit boards (part 69) side of the motor unit facing towards the side of the brackets with 4 vertical holes (per bracket), guide the threaded end of the bolt from step 5.1 through the hole in the motor unit, as illustrated in Figure 93 a, b, c and f.

Next place a single part 40 (washer) over each bracket bolt, followed by a single part 39 (lock nut) over each bolt. Tension these lock nuts so that the brackets are clamped firmly to the motor unit, but not so tightly that the motor unit plastic is damaged through crushing.

In subsequent steps, you may find it necessary to adjust the bracket positioning from side to side. For this reason, the motor unit bolt holes are rectangular, allowing for this later adjustment to be made.

Please also note that this bolt hole will require sealing with hot glue before deployment onto the water, to ensure that the inside of the motor unit remains dry. This should be done later however, as the motor case will need to be removed and refitted in Step 6.

5.3 Loadcell / strain gauge installation

a.) b.)

c.) d.)

e.)

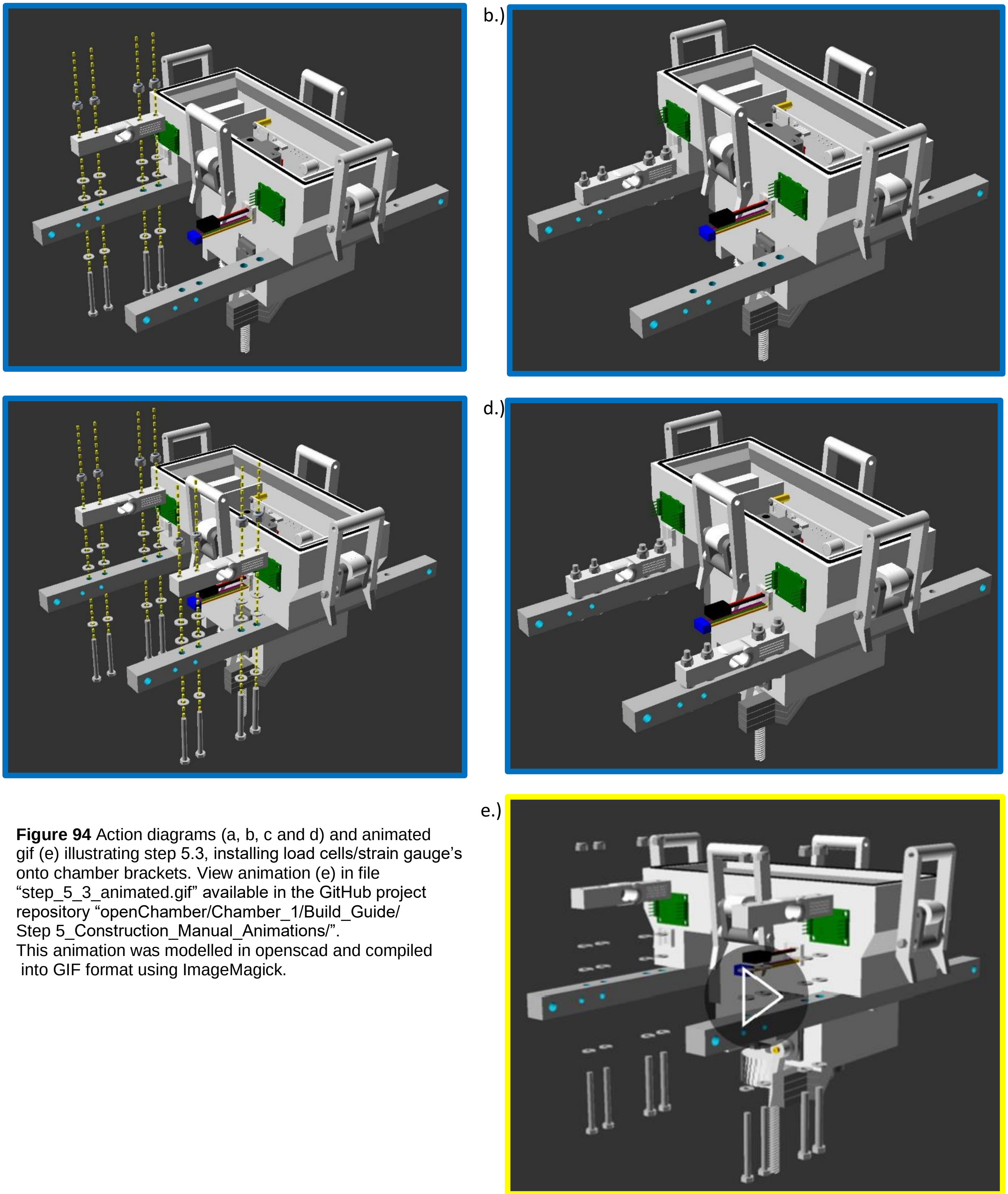


Figure 94 Action diagrams (a, b, c and d) and animated gif (e) illustrating step 5.3, installing load cells/strain gauge's onto chamber brackets. View animation (e) in file "step_5_3_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/ Step 5_Construction_Manual_Animations/".
This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 5.2, 1 or 2 x part 68a or 68b (loadcells - in the beginning I recommend using 1 x 68b). 2 or 4 x part 33 (M5 x 40mm bolt), 2 or 4 x part 34 (M5 lock nut), 2 or 4 x part 37 (M4 x 40mm bolts), 2 or 4 x part 39 (m4 lock nuts), 2 or 4 x part 40 (M4 washers), 8 or 16 x part 35 (M5 washers).

Beginning with the chamber bracket illustrated in Figure 94a, orient part 68a / 68b so that the larger M5 holes are closer to the motor unit and the smaller M4 holes are close to the end of the chamber bracket. This orientation allows the shortest load cell to load cell circuit board (part 69) wires and the. Longer wires result in less reliable lid closing force readings.

Secondly, orient the arrow on the end of the load cell towards the lid of the motor unit. The arrow indicates whether a negative or positive force will be measured upon the lid closing and opening.

Guide 2 x part 33 each into a single part 35, then through the 2 chamber bracket holes closer to the motor unit, then through 2 x part 35s each, then through the loadcell holes and finally through a single part 34 each. This is illustrated in Figure 94 a, b and e. Do not fully tighten the nuts (part 34) or bolts (part 33) yet.

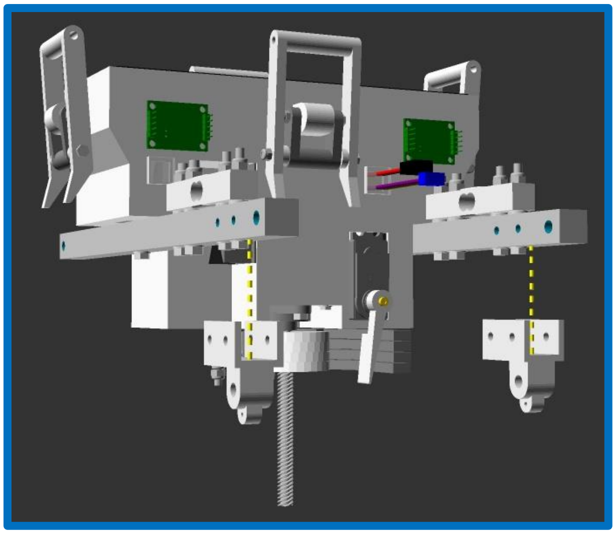
Guide 2 x part 37 each into a single part 40, then through the 2 chamber bracket holes closer to the end of the chamber bracket, then through 2 x part 35s each, then through the loadcell holes and finally through a single part 39 each. This is illustrated in Figure 94a, b and e.

Gently bring the bolts and nuts together so that the load cell is clamped onto the chamber bracket; first fixing the 2 outer bolts, and then the 2 inner bolts. It is essential that excessive load cell bending in this clamping process is avoided, to prevent negatively impacting the load cells accuracy/performance. The load cell should be firmly in place with no freedom to move.

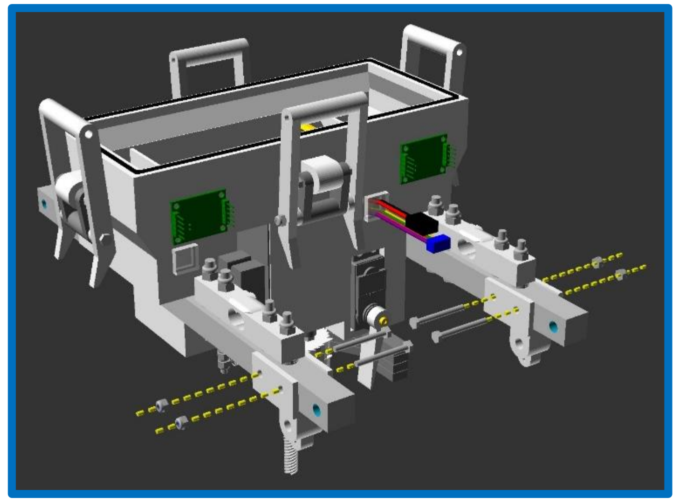
If using 2 load cells, repeat this process for the second load cell on the servomotor (part 66) side bracket, illustrated in Figure 94c, d and e.

5.4 Fan-side lid-arm connection point installation

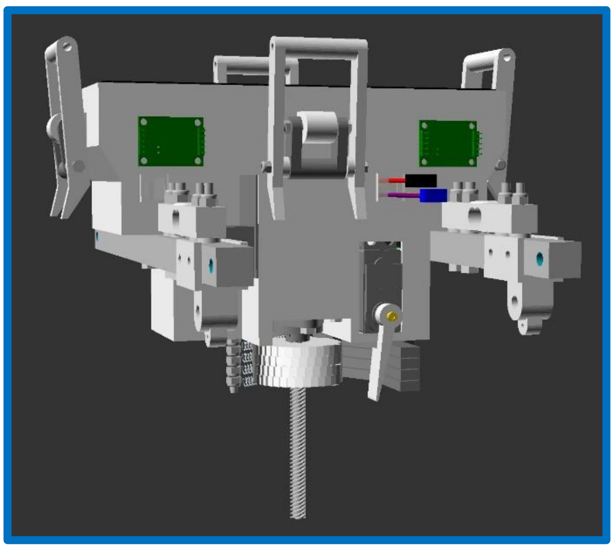
a.)



c.)



b.)



d.)

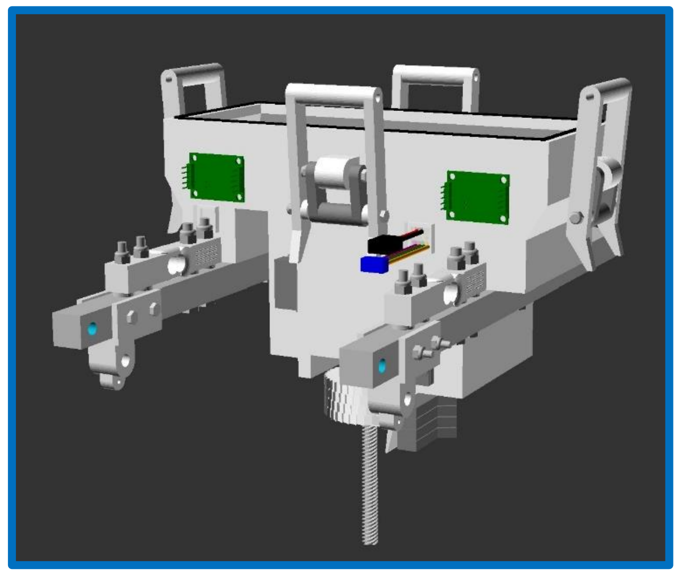
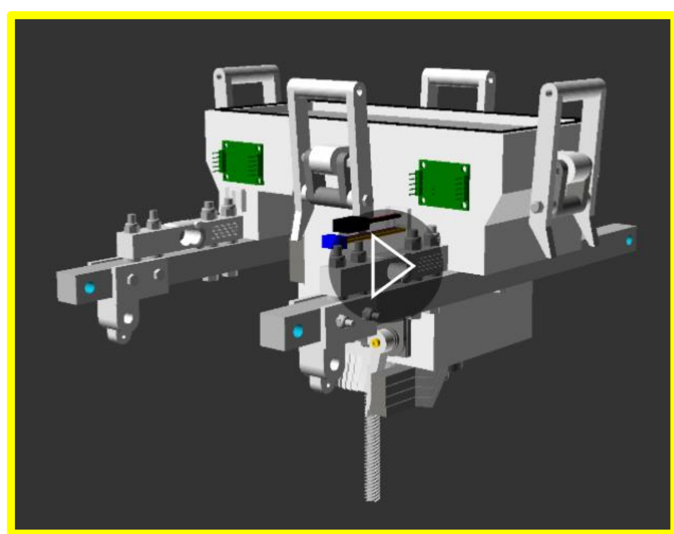


Figure 95 Action diagrams (a, b, c and d) and animated gif (e) illustrating step 5.4, installing Fan-side lid-arm connection point onto chamber brackets. View animation (e) in file “step_5_4_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/ Step 5_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

e.)



Notes:

Parts required for this section - Subassembly unit resulting from step 5.3, 1 x part 6a, 1x 6b (the fan side brackets), 4 x part 42 (M3 x 30mm bolt), 4 x part 44 (M3 lock nut).

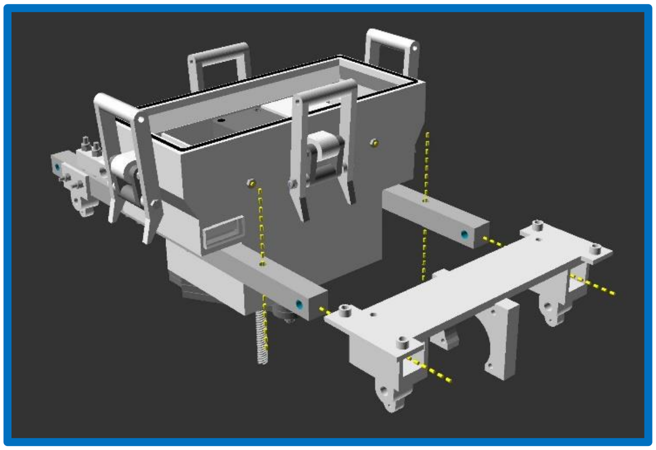
Position part 6a on the left and part 6b on the right when looking at figure 82.a, so that the tall faces point towards the lid of the motor unit its longer portions face towards the motor unit servomotor (part 66) side.

Bring part 6 to meet the chamber bracket (part 51), matching the side holes in the chamber bracket with the side holes in part 6 (Figure 95a, b and e).

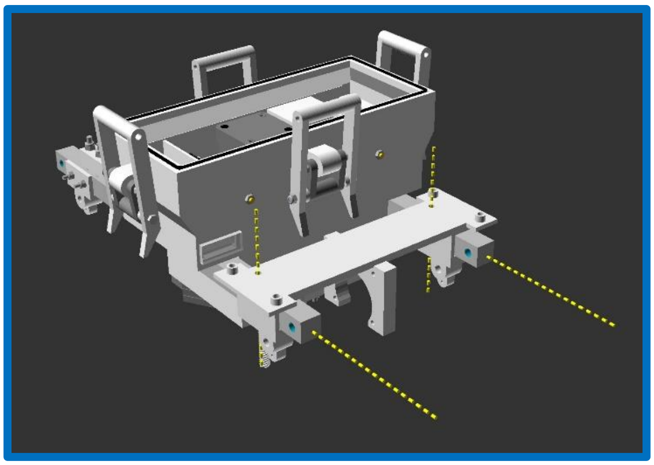
Insert parts 42 through part 6 (fan side bracket) and part 51 (the chamber bracket), from the inside to the outside. Lock the bolts in place using the 4x part 44, tensioning until tight without damaging the 3D printed parts. This is illustrated in Figure 95 c, d and e.

5.5 Sensor platform V2 installation

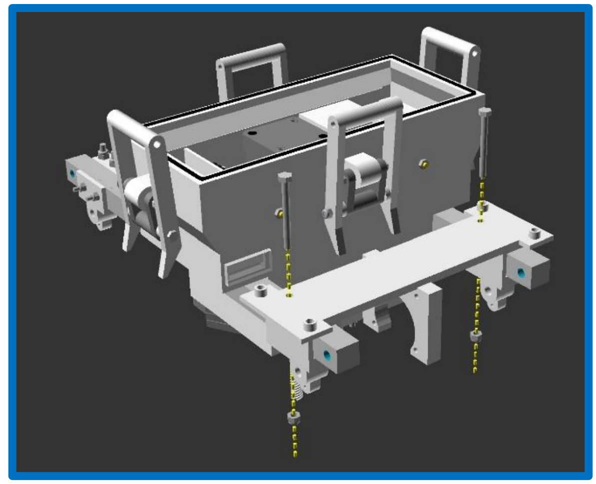
a.)



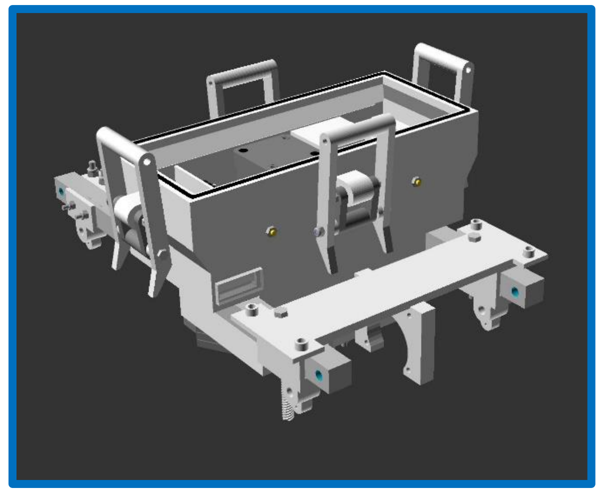
b.)



c.)



d.)



e.)

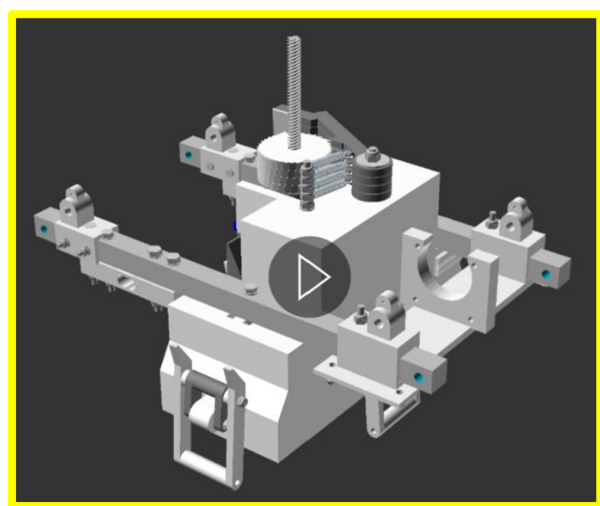


Figure 96 Action diagrams (a, b, c and d) and animated gif (e) illustrating step 5.5, installing Sensor platform V2 onto chamber brackets. View animation (e) in file “step_5_5_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/ Step 5_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 5.4, 1 x part 8c (the sensor bracket), 2 x part 37 (M4 x 40mm bolt), 2 x part 39 (M4 lock nut).

Please note, although the shape of the sensor bracket (part 8) varies between versions, the attachment principles for each is the same.

Position part 8 so that the flat portion faces towards the lid of the motor unit and the coupling (the arch with a hole in it) faces the opposite direction. The coupling is closer to one side of part 8, with a hole in the top of the other side. Position the side with the hole towards the motor unit side. This is Illustrated in Figure 96a and e.

Slide part 8 onto the side of the chamber brackets (part 51), aligning the hole in part 8 with the hole in part 51 (Figure 96 b and e).

Insert the 2x part 37 through parts 8 and 51. Lock these in place with the 2x part 39, tensioning so that the parts are held firmly in place on the chamber bracket, but not so tightly that the 3D parts are damaged. This is illustrated in Figure 96c, d and e.

5.6 Sensor pcb V2 installation to part 8b

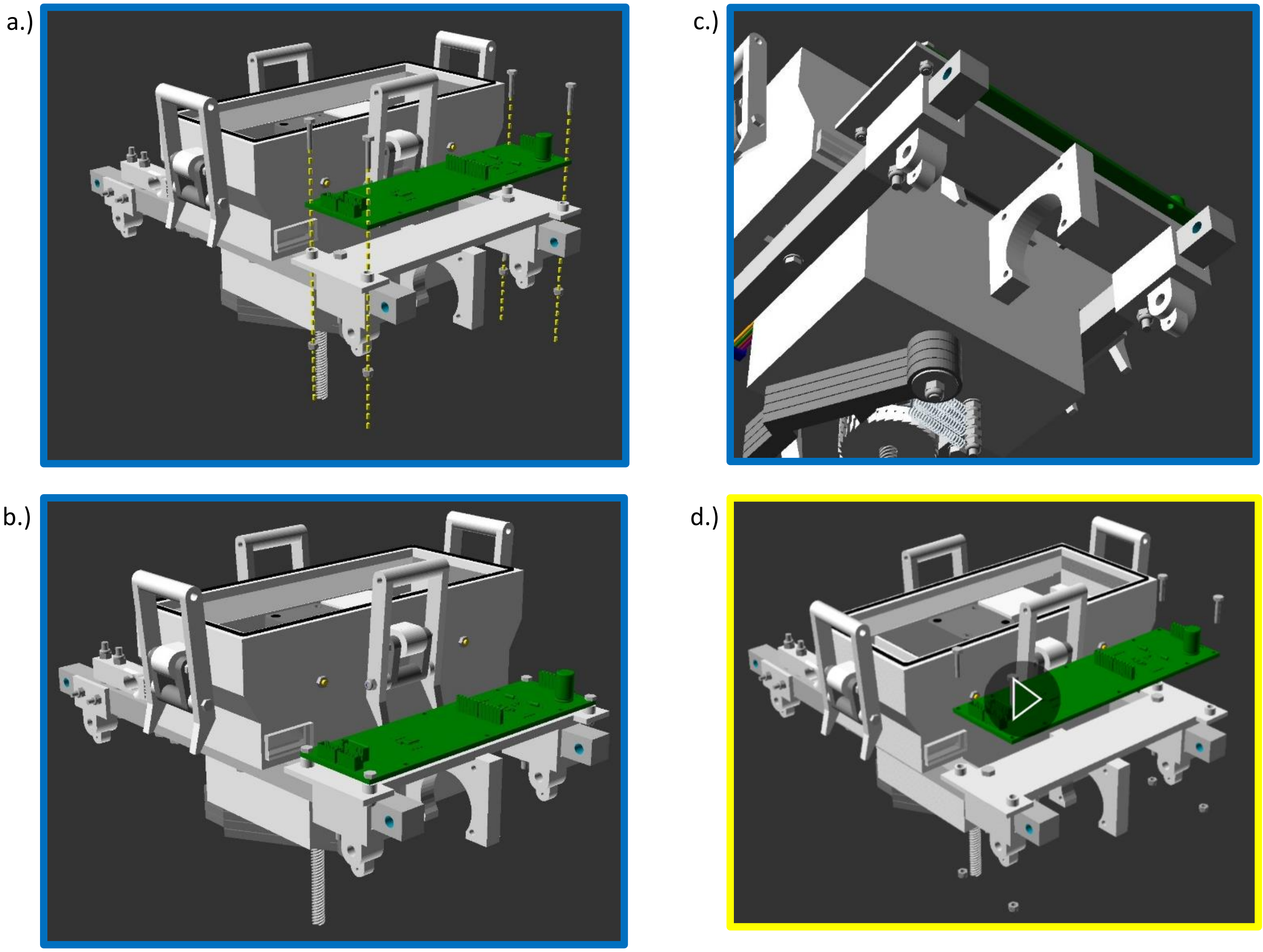


Figure 97 Action diagrams (a, b, and c) and animated gif (d) illustrating step 5.6, installing the Sensor pcb V2 onto the chamber brackets. View animation (d) in file “step_5_6_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 5_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Update – this step is only required when using part 8b with a dry chamber over the sensors and a peristaltic pump underneath. This is not the recommended method for the normal chamber use, but I have left it in to show how the chamber could be used.

Parts required for this section - Subassembly unit resulting from step 5.5, 1 x part 75 b (the sensor circuit board, 4 x part 43 (M3 x 20mm bolt), 4 x part 44 (M3 lock nut).

Please note, although the shape of the sensor circuit board (part 75) varies between versions, the attachment principles for each is the same when paired with the sensor bracket of the same version (i.e. Sensor bracket V1 with Sensor circuit board V1).

Position part 75 so that the JST cable connectors are on the same side as the cable hole of the motor unit. The HC-12 circuit should point in the opposite direction. The sensors should be facing the lid of the motor unit. This is illustrated in Figure 97.

Line up the holes in the sensor circuit board (part 75) with the holes in the sensor bracket (part 8). Insert the 4x part 43 through the holes in part 75 and fix gently in place with the 4x part 44 (Figure 97). It is critical that these nuts and bolts are tensioned gently, so as not to damage the circuitry of part 75.

Additionally, rubber washers could be used between the circuit board and the nuts/ bolts for an added layer of protection. Though I have not found this necessary.

5.6b Sensor pcb V2 installation to part 8c

a.) b.) c.) d.)

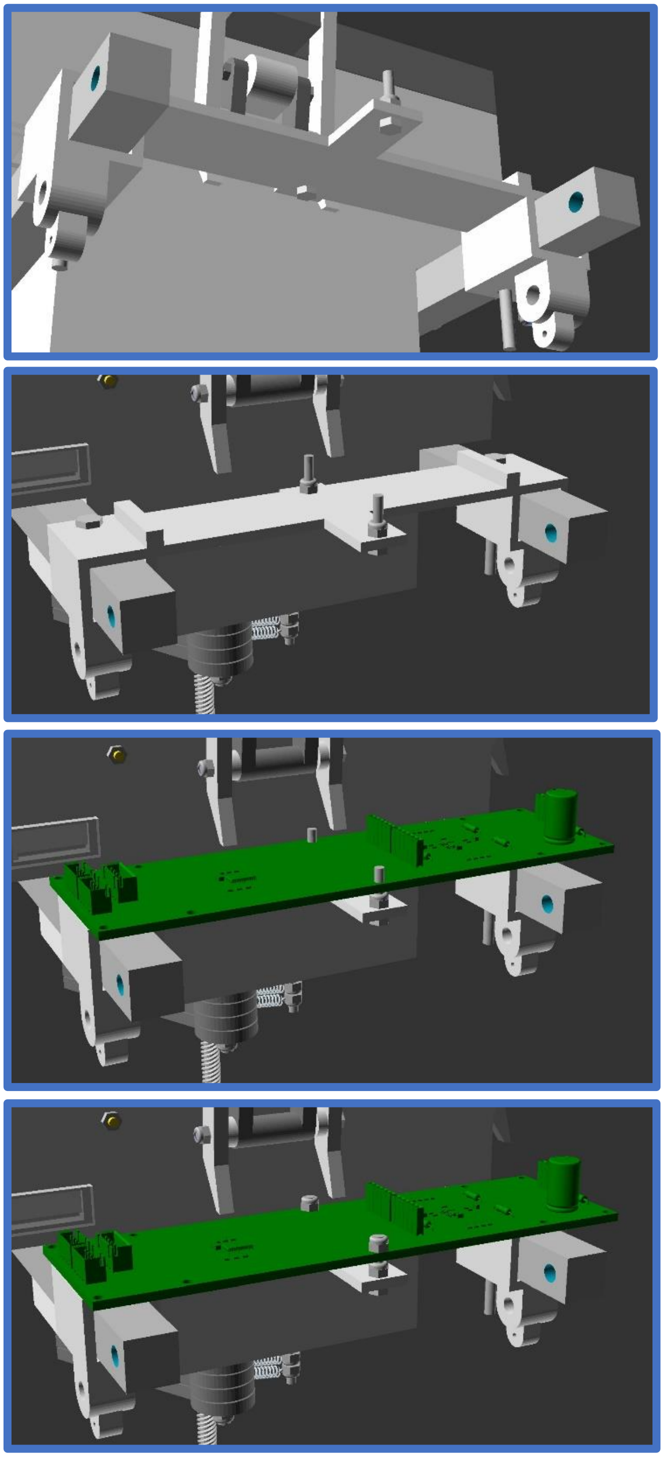


Figure 98 Action diagrams (a, b, c and d) illustrating step 5.6b, installing the Sensor pcb V2 onto the chamber brackets part 8c.

Notes:

Parts required for this section - Subassembly unit resulting from step 5.5, 1 x part 75b (the sensor circuit board, 2 x part 43 (M3 x 20mm bolt), 4 x part 44 (M3 lock nut).

UPDATE – A later addition, therefore action diagrams are simpler, and no gif is included.

Position part 75 so that the JST cable connectors are on the same side as the cable hole of the motor unit. The HC-12 circuit should point in the opposite direction. The sensors should be facing the lid of the motor unit. This is illustrated in Figure 98.

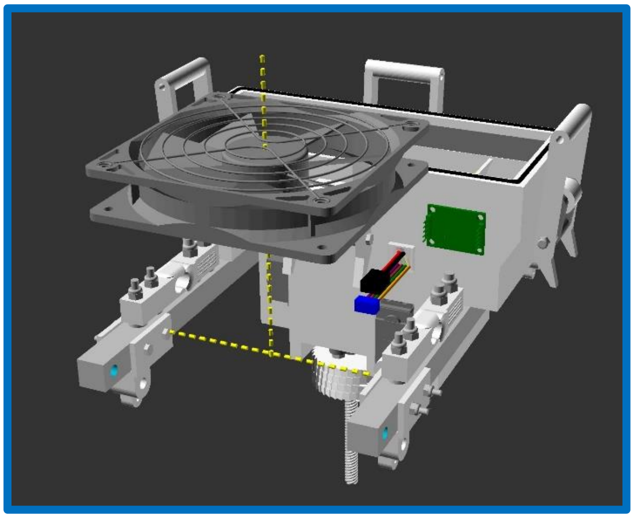
Insert 2x part 43 through the holes in part 8c towards the lid of the motor unit. Fix in place with 2x part 44, as illustrated by Figure 98a and b.

Line up the holes in the sensor circuit board (part 75b) with the bolts in the sensor bracket (part 8c) as illustrated in Figure 98c. Fix gently in place with the 2x part 44 (Figure 98d). It is critical that these nuts and bolts are tensioned gently, so as not to damage the circuitry of part 75.

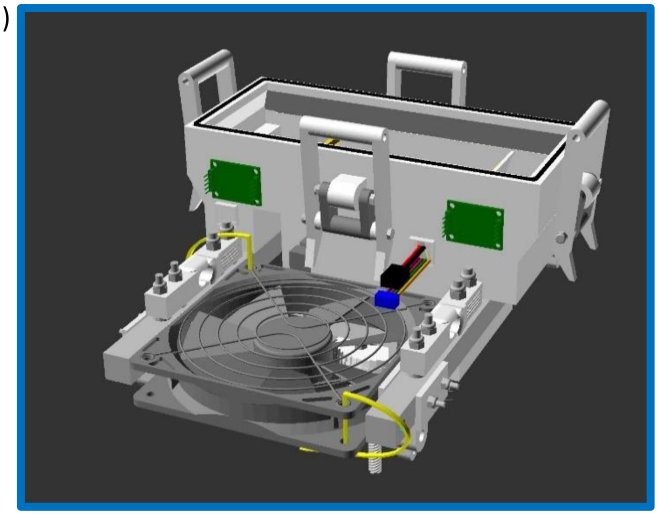
Additionally, rubber washers could be used between the circuit board and the nuts/ bolts for an added layer of protection. Though I have not found this necessary.

5.6 Fan installation

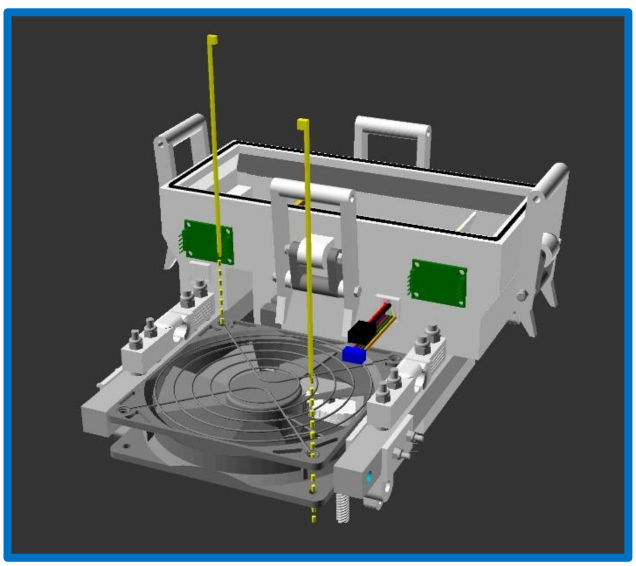
a.)



c.)



b.)



d.)

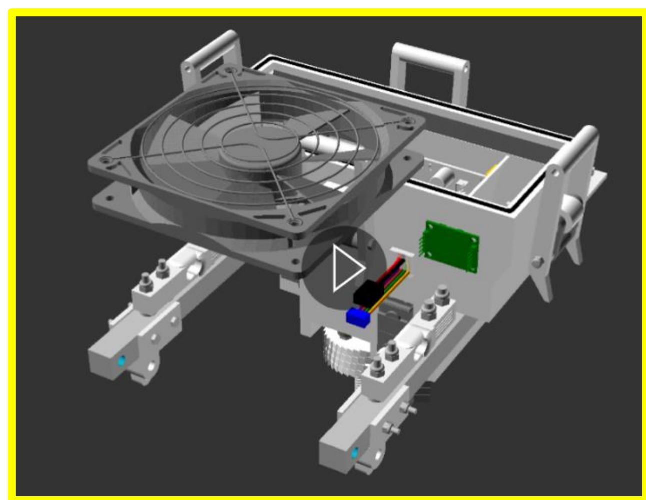


Figure 99 Action diagrams (a, b, and c) and animated gif (d) illustrating step 5.7, installing the fan onto the chamber brackets. View animation (d) in file “step_5_7_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 5_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section - Subassembly unit resulting from step 5.6, 1 x part 79a (the pc fan), 2 x part 93 (zip ties)

Position part 79a (the fan) so that it blows air in the opposite direction to the motor unit lid (i.e. towards the chamber lid (part 2) and away from the water when all the chamber subunits are unified (step 6)). The cable of the fan should be close to the motor unit, to allow short and tidy cable connections.

In this orientation, move the fan between the 2 fan side brackets (part 6) as illustrated in Figure 99.

Fix the fan onto the brackets using 2x part 93 (zip ties). Guide the zip ties through the bolt holes of the fan casing and around the chamber brackets (part 51), as illustrate in Figure 99. Tension the zip ties so that the fan is held in place without fan case distortion, which can prevent the fan blades from moving.

Please note, that the fan must be removed inorder to mate the chamber brackets subunit with the other subunits in step 6.

In the future this step may be changed to allow for a mechanical binding of part 79a to the chamber brackets (part 51), without the need for single use cable ties (for example using nuts and bolts). But for the scope of this project as a part of my PhD, I do not have time to adjust this step at present.

With this, step 5 and the Chamber brackets subunit are completed. The Chamber brackets should look like Figure 91.

Step 6: Subunit unification

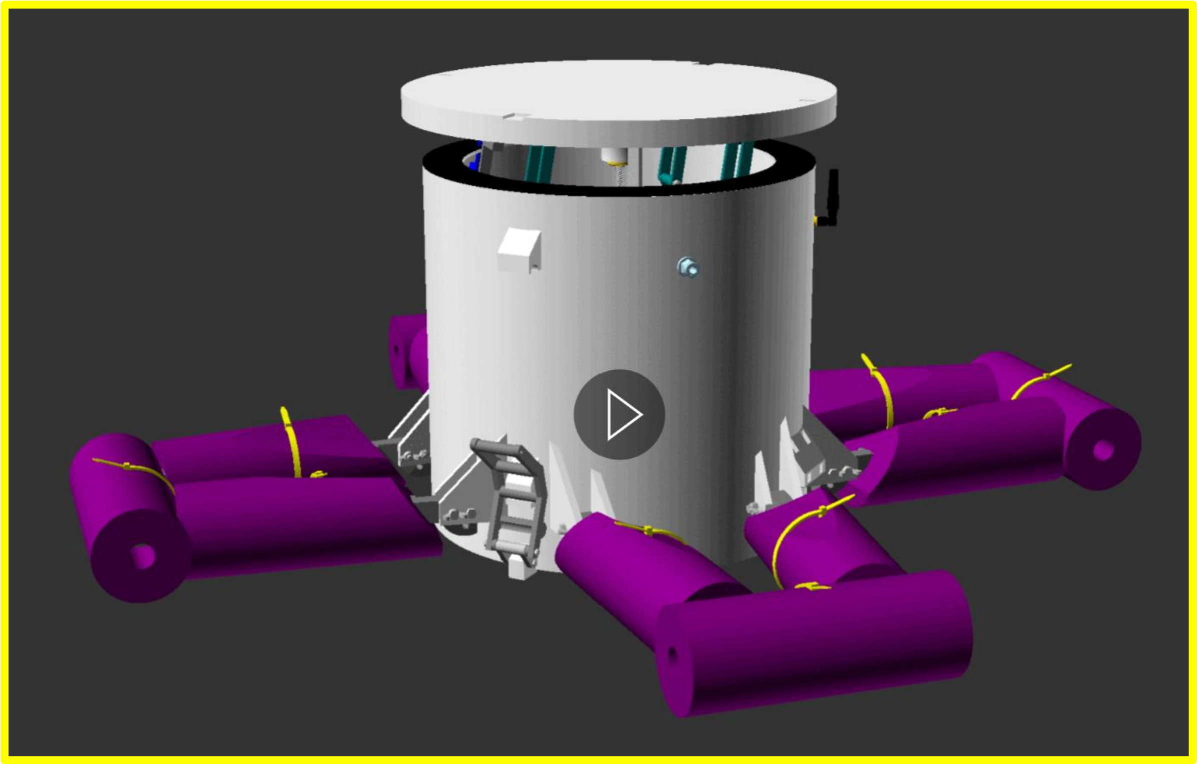
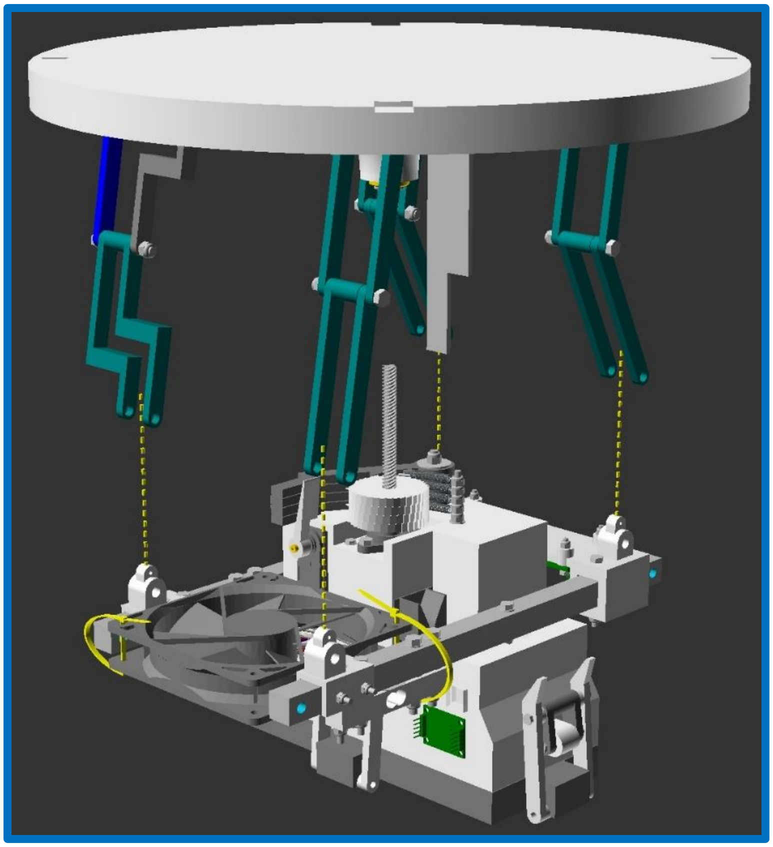


Figure 100 3D model illustrating the product of step 6. View this animation in file "step_6_end_product_animated.gif" available in the GitHub project repository "openChamber/Chamber_1/Build_Guide/Step 6_Construction_Manual_Animations/". This animation was modelled in openscad and compiled into GIF format using ImageMagick.

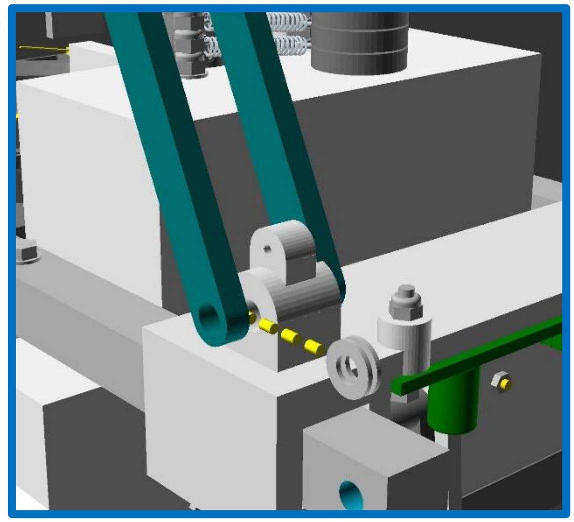
Step 6 focuses upon the unification of the subunit assemblies. The end product of this step is the fully constructed chamber (Figure 100).

6.1 Bracket subunit to lid subunit unification

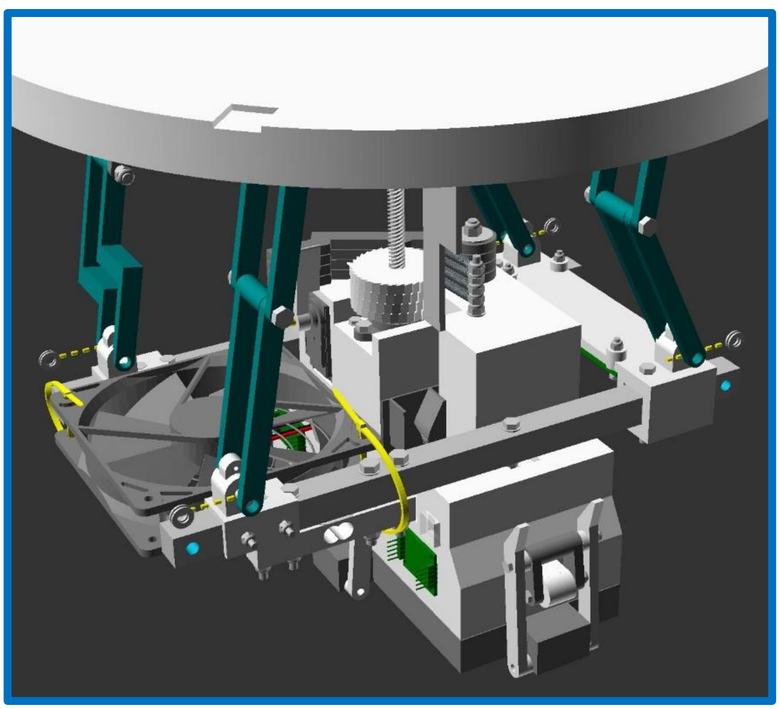
a.)



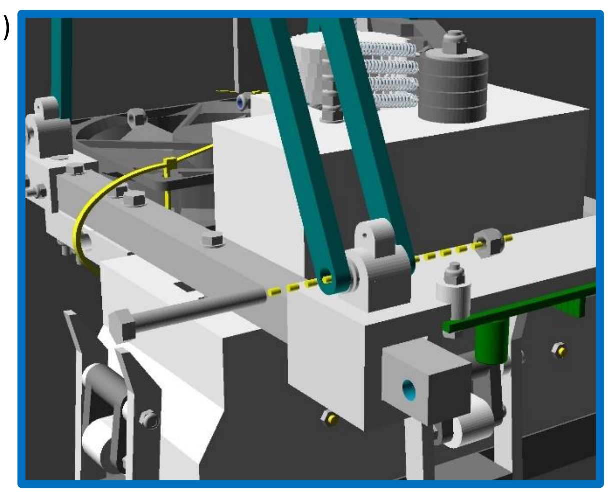
b.)



c.)



d.)



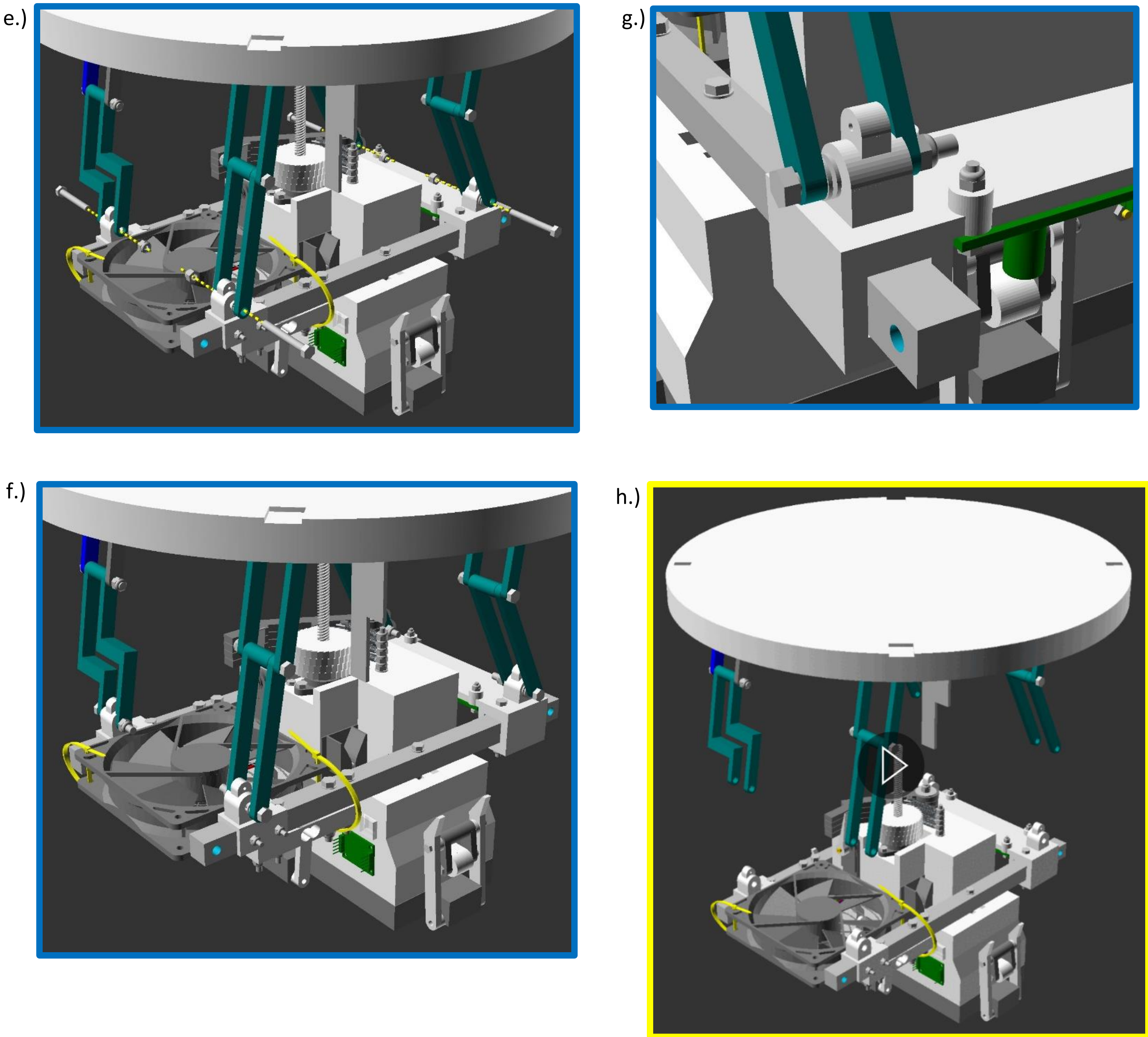


Figure 101 Action diagrams (a, b, c, d, e, f and g) and animated gif (h) illustrating step 6.1 unification of the chamber brackets subunit to the chamber lid subunit. View animation (h) in file “step_6_1_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 6_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

UPDATE – Later design changes mean that the arms now fit more evenly to the couplings. Therefore you may find that instead of placing 2 washers on one side of the coupling, as illustrated in Figure 101b and c, one washer on either side of the coupling works better.

Parts required for this section – Chamber lid subassembly unit resulting from step 3.7, Chamber brackets subassembly unit resulting from step 5.6, 8 x part 35 (M5 washer), 4 x part 33 (M5 x 40mm bolts), 4 x part 34 (M5 lock nuts).

Position the chamber lid subassembly so that the chamber arms fit on either side of the bracket couplings, illustrated in Figure 101a and h. Part 56 (described in step 3.2) should be positioned between the guides of part 13 (described in step 4a.1 and 4a.2).

Between the outside chamber arm and the outside of the chamber couplings, insert 2 x part 35 (Figure 101 b, c and h).

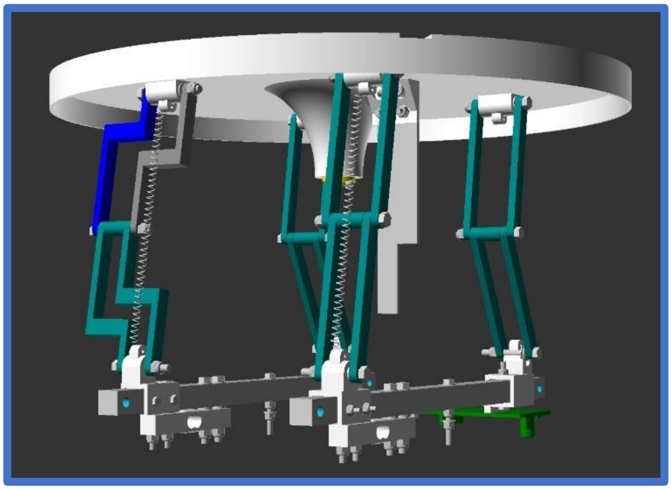
Next insert part 33 from the outside arm, through the bracket coupling, and through the inside arm. Fix this bolt in place with 1 x part 34. This should be repeated for each set of chamber arms / couplings (Figure 101d, e, f, g and h).

Fix the lock nuts (part 34) in place by tightening gently until resistance is met, then backing off by 1 turn in the loosening direction, to ensure that the pieces rotate freely without resistance. *

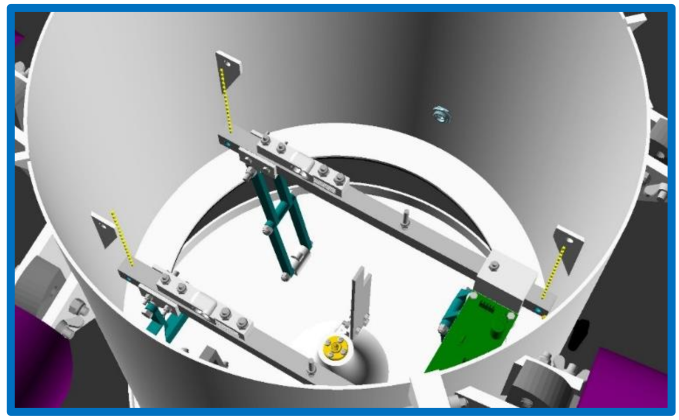
* Tip: This can be done using 2 size 8 spanners/ wrenches or holding one side with a pair of pliers and using a spanner on the other side.

6.2 Bracket-Lid subunit to Chamber subunit unification

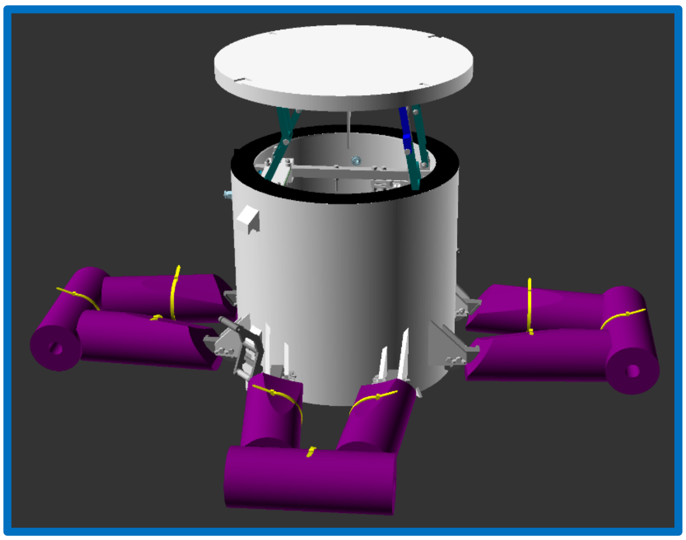
j.)



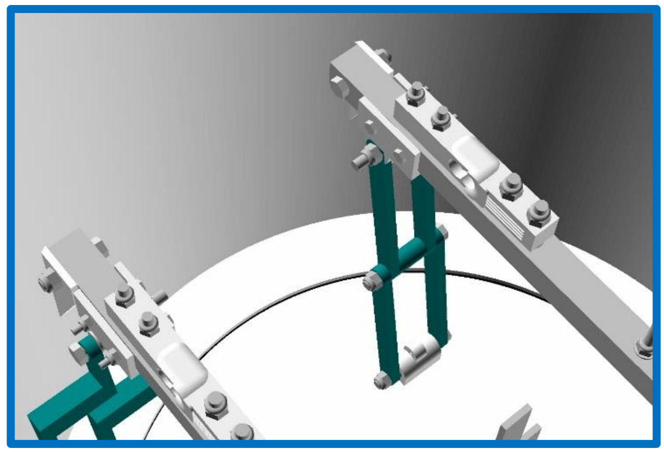
b.)



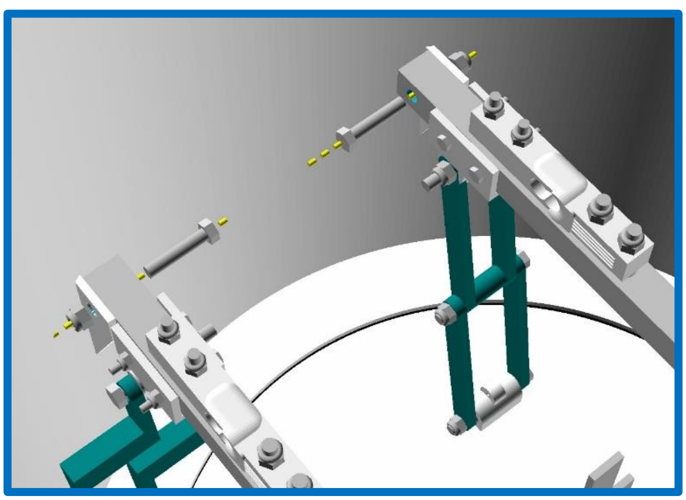
a.)



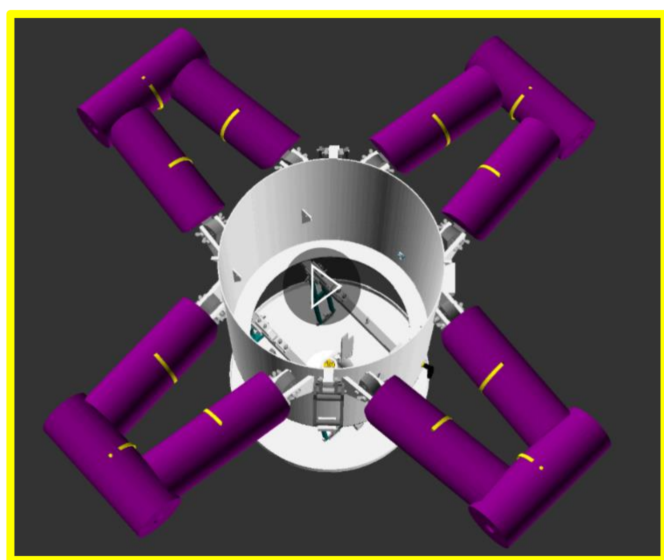
d.)



c.)



e.)



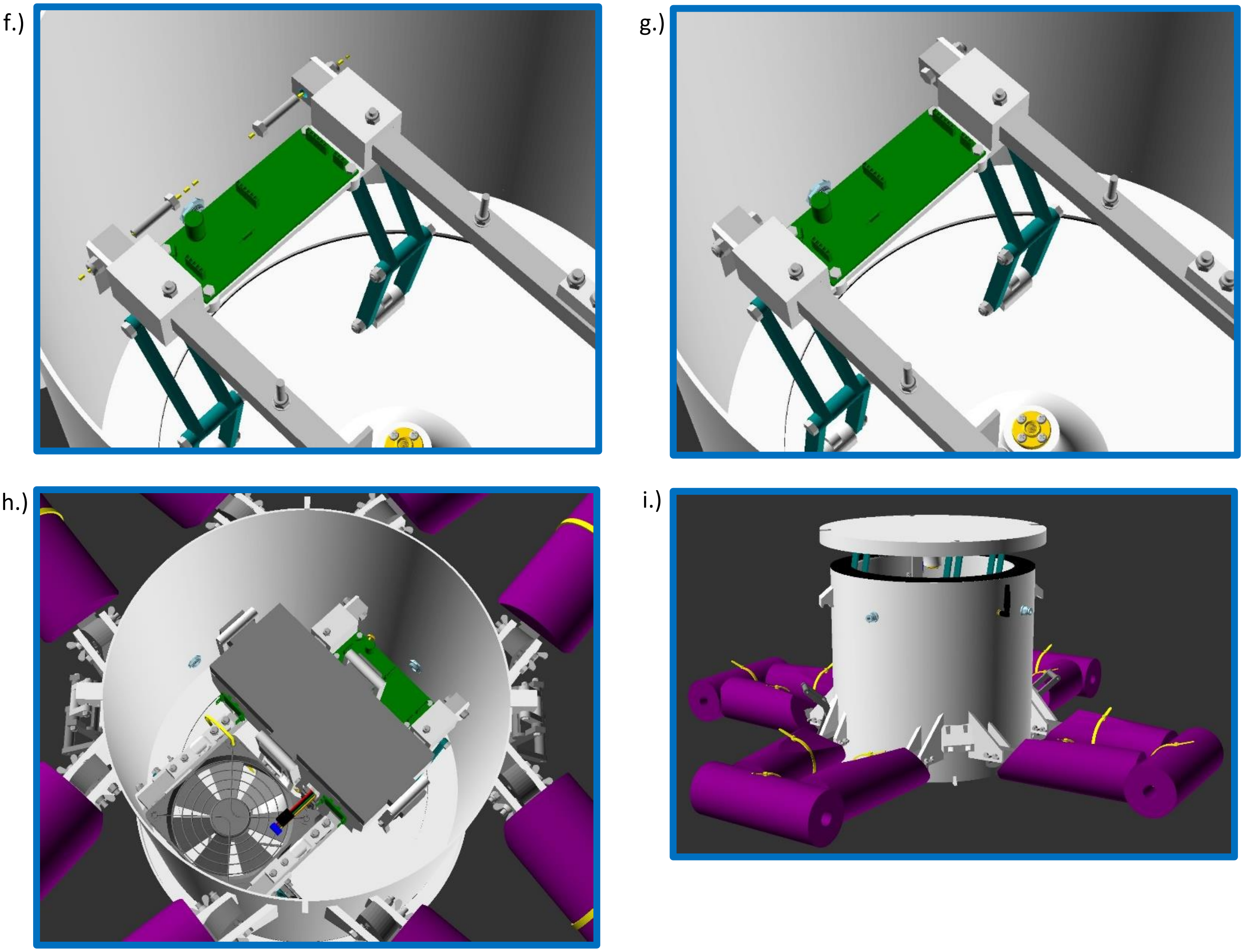


Figure 102 Action diagrams (a, b, c, d, f, g, h, I and j) and animated gif (e) illustrating step 6.2 unification of the chamber subunit to the chamber bracket-id subunit. View animation (e) in file “step_6_2_animated.gif” available in the GitHub project repository “openChamber/Chamber_1/Build_Guide/Step 6_Construction_Manual_Animations/”. This animation was modelled in openscad and compiled into GIF format using ImageMagick.

Notes:

Parts required for this section – Lid-bracket subassembly unit resulting from step 6.1, Chamber body subassembly unit resulting from step 2.8a, 4 x part 33 or 33.b (M5 x 25 or 30mm bolts), 4 x part 34 or 34.c (M5 lock nuts or regular nuts), 4x part 60.

For lid tension, install part 60 between the bracket coupling and the lid coupling on each of the 4 arms as illustrated by Figure 102j. Thread the spring through the small hole at the top of the couplings. Once in place, apply a drop of superglue (part 91) at the spring coupling hole to ensure the spring is secure. Note that this step can be skipped but the lid will appear to wobble in highly turbulent conditions.

Remove the motor unit and fan from the Chamber brackets subassembly, following the instructions described in step 5.2 and 5.6. Although the Lid-bracket subassembly can be installed without removing these items, it is easier to achieve safely by removing these parts.

Brush the chamber gasket (part 52) to ensure there is no debris that could affect the seal of the lid to the chamber body.

Position the lid-bracket subassembly so that the sensor board (part 75b) side is closest to the antenna (part 73 described in step 2.7) and the chamber brackets fit between the chamber body couplings (Figure 102 a and b).

From the top of the chamber body subassembly, insert the lid-bracket subassembly into the chamber body subassembly.

Beginning with the side further away from the sensor board, line up the holes in the chamber brackets with the holes in the chamber body couplings. Following this, insert part 33 or part 33.b (whichever is a better fit) first through the chamber bracket hole and then through the chamber body coupling hole. Fix the bolt in place using part 34.c (however for deployment of the chamber on the water, using part 34 (locking nuts) is more likely to prevent problems associated with loosening). Do not tension the nuts/ bolts tightly at this point. This step is illustrated in Figure 102c, d and e.

Line up the sensor board side holes in the chamber brackets with the holes in the chamber body couplings. Following this, insert part 33 or part 33.b (whichever is a better fit) first through the chamber bracket hole and then through the chamber body coupling hole. Fix the bolt in place using part 34.c (however for deployment of the chamber on the water, using part 34 (locking nuts) is more likely to prevent problems associated with loosening). This step is illustrated in Figure 102e, f and g.

Now tension the 4 nut/bolts until the chamber brackets are held firmly in place, without damaging the 3D printed parts through over tightening.

Re-install the motor unit following the instructions described in step 5.2. With the pawls (parts 15, 16 and 17) disengaged from the ratchet (part 18 - the engaged position is illustrated in Figure 82 b), thread the leadscrew of the motor case (part 48) into the lead screw nut of the chamber lid (part 49 installed in step 3.1). As you do this, ensure that the chamber arms fold towards the middles of the chamber and not outwards.

Once the chamber lid is flat against the chamber body gasket (part 52), re-install the fan to the chamber brackets subassembly (instructions described in step 5.6) as illustrated by Figure 102e and h.

With this, step 6 and the Chamber construction is completed. The chamber should look like Figure 100 and is ready for electrical setup and chamber testing (section 1.6) or chamber storage (section 1.7).

1.6 Electrical Setup and Chamber Testing

1. Uploading a programme

Uploading a programme or a “sketch” to the atmega328p microcontroller chip (part 81) tells the main circuit board (part 76) what do during a chamber deployment. Programming the chambers main circuit board can be done in 3 ways: By removing the the microcontroller chip and programming it with a standard Arduino uno (section 1.6.1 Chip removal programming method), by connecting the serial port of the chamber main circuit board to a USB to serial interface (section 1.6.1 Serial programming method) or by removing the microcontroller chip and programming it with an ISP programmer (section 1.6.1 ISP programming method). The suitable programming method will be written at the top of the programme to be uploaded.

Note: Direct programming of the main circuit board by USB to computer was deliberately not included into the design. This was to save power and the additional parts/ complexity that the ATMEGA16U2-MU(R) “bridge” requires.

Chip removal programming method

Introduction

On the main circuit board there is a ZIF (Zero insertion force) socket (Figure 104). This socket allows DIP (Dual In-line Package) atmega328p chips to be inserted and removed repeatedly without damage. The ZIF socket allows separate chamber programmes to be stored on individual atmega328p chips and quickly changed without computer reprogramming or the memory stability issues associated with storing multiple programmes on a single chip. This is particularly useful when repeatedly switching the code on the chamber. For example, during a field campaign, chambers may be deployed for long periods of time with a low power/ low frequency sampling rate. However, once per month sensor calibration with CRDS may be required, for which a high power/ high frequency sampling rate is more effective. By changing the atmega328p chip, the low power/ low frequency programme can be changed easily to the calibration mode programme in-situ from the boat.

Atmega328p chip exchange is also useful in field-based chamber maintenance. For example, in cases where errors are observed due to atmega328p corruption, having a fresh atmega328p chip at hand is very useful in bringing chambers back online without experiencing delays to sampling campaigns. Similarly, the systems clock can be reset to a known date and time in the case that an emergency clock reset is required in the field. For instance, if the clock battery needs replacing.

Instructions

First ensure that the power banks to main circuit board cables are removed. I.e. there is no power supplied to the board. Remove the chip by lifting the handle of the ZIF socket (Figure 104) into the open (vertical) position.

Ensure that your ATMEGA328p chip has had the bootloader burned onto it. If not, follow the "Burning a bootloader" subsection below to prepare your chip for the next steps. **

Place the removed chip into a donor DIP style Arduino UNO so that the pin 1 indicator of the ATMEGA328p chip (Figure 103) aligns with the pin 1 indicator of the Arduino uno. Ideally you should use an Arduino uno with a ZIP socket, for example by fixing a ZIF socket to an existing Arduino uno (Figure 105a) or by using a ZIF socket shield such as the ZIF socket shield v2 by canaduino (CANADUINO, n.d.) shown in Figure 105.b.

Open the Arduino IDE with the required sketch. Check that the serial port for the Arduino is detected, by selecting the "Tools" tab and then the "Port" sub tab (Figure 106). ***

In the "Tools" tab, select the "Board" subtab and select "Arduino Uno" (Figure 107).

In the "Tools" tab, select the "Programmer" subtab "AVRISP mkII" (Figure 108).

Check that the computer has the required libraries downloaded from the openChamber Github page (https://github.com/BArcherResearch/openChamber/tree/main/Chamber_1/Arduino_Programs/Libraries) and loaded into your Arduino IDE.

If not uploaded, select the select the "Sketch" tab. In the drop down menu select the "include library" sub tab. In the subsequent dropdown menu, select the "Add .ZIP Library..." subtab (Figure 109).

In the pop-up window, select the libraries from your downloads that you wish to import into the arduio IDE and select "Open" (Figure 110). The libraries should now be accessible when uploading your programme to the ATMEGA328p chip.

Next select the "Upload" tab (the arrow button, Figure 111).

If the upload was successful, the message "Done uploading." will appear in the console (Figure 112).

Unplug the ATMEGA328p from the programmer Arduino uno. Place the programmed chip back into the Main circuit board ZIF socket, ensuring that the pin 1 indicator of the ATMEGA328p chip is aligned with the pin 1 indicator on the Main circuit board.

Insert the main circuit board power cable into the power banks and the programme will begin.

**Unless the "Read Me" file associated with the code that you would like to run says that your code does not need the bootloader. This is currently not the case but could be the case for future programmes where more static memory is asked of the microcontroller.

***If nothing is detected, then try plugging the Arduino in again, or in a new USB port. If still no Arduino is detected, check the cable used, the Arduino board, and finally try a new chip. Failing this, reload the Arduino IDE and try again.

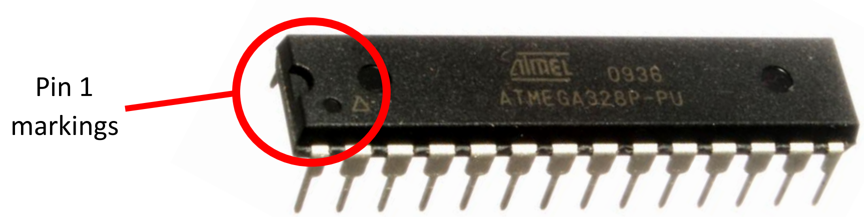


Figure 103 Photograph of the DIP format ATMEGA328p (part 81), illustrating the Pin 1 or "Top" end of the polarised chip. Ensure that this end is always inserted into the Pin 1 end of the main circuit board or programmer.

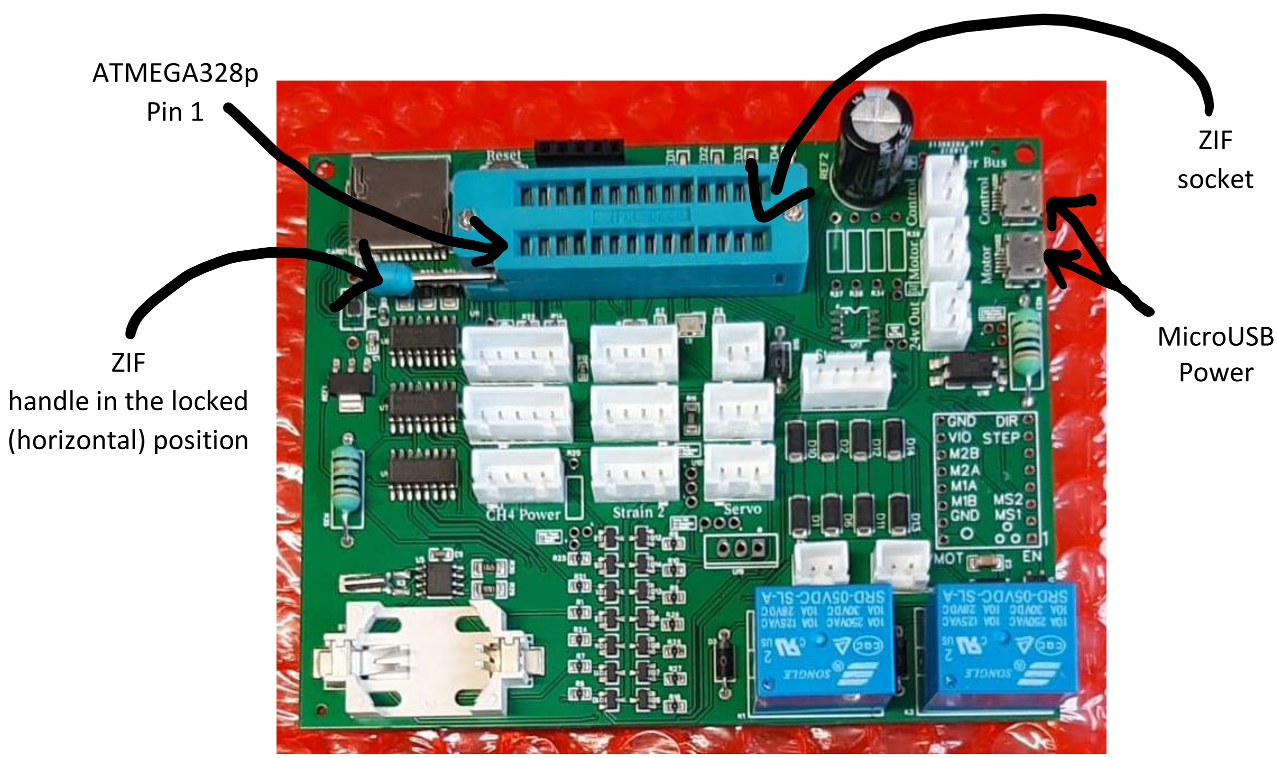


Figure 104 Photograph of the main circuit board (part 76), illustrating the ZIF (zero insertion force) socket for the ATMEGA328p microcontroller (part 81) as well as microusb power sockets.

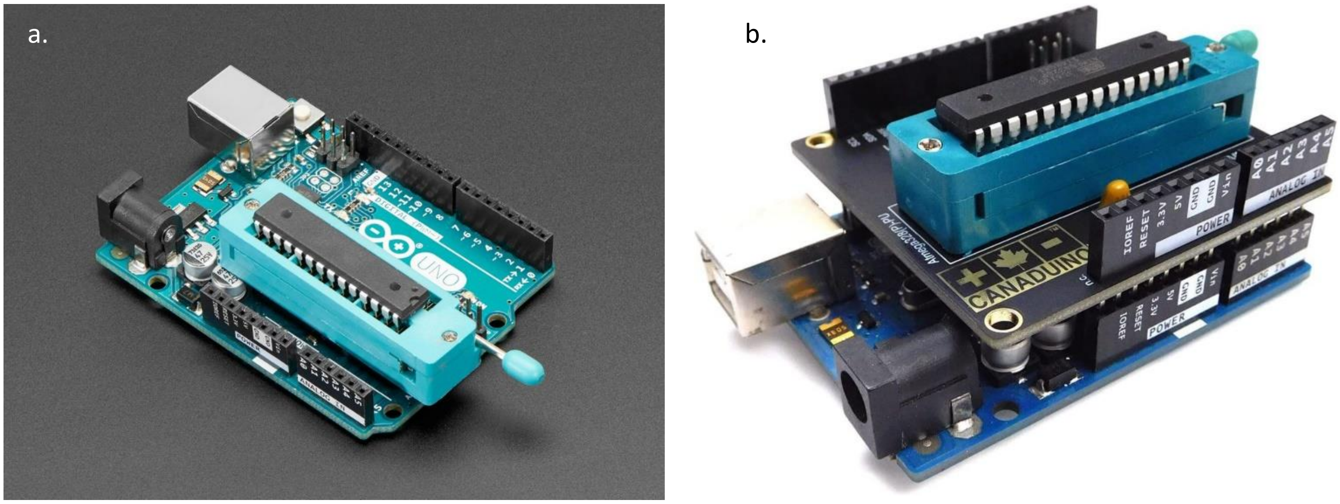


Figure 105 Photograph of an Arduino uno amended to take a ZIF socket (a.) (image taken from (Adafruit Industries, n.d.)) and the commercial ZIF socket shield V2 by canaduino (CANADUINO, n.d.). Both options convert a standard DIP package Arduino uno into an efficient ATMEGA328p programmer

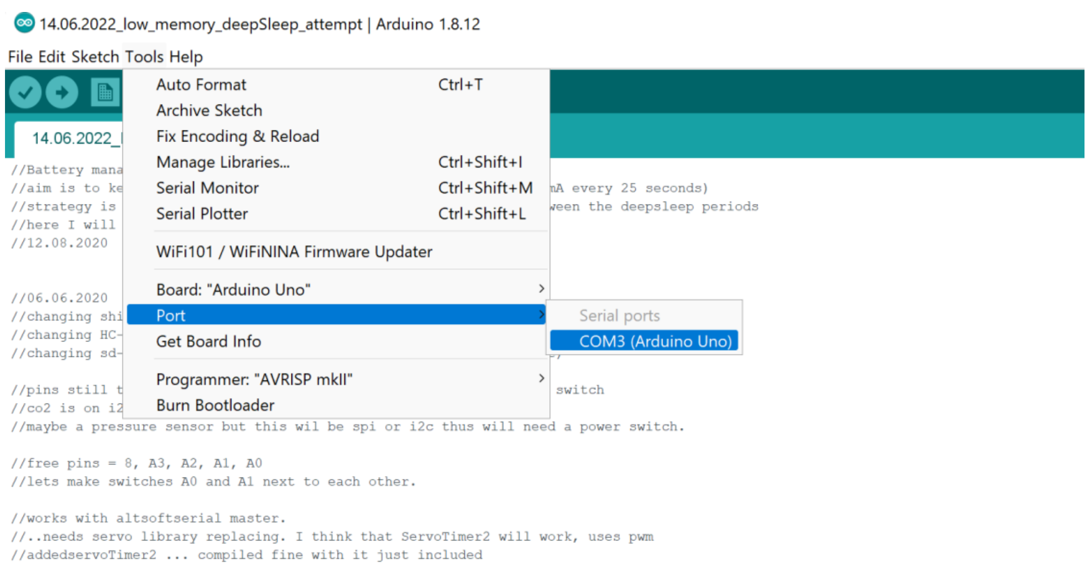


Figure 106 Screen shot illustrating the process of selecting the serial port during ATMEGA328p programming.

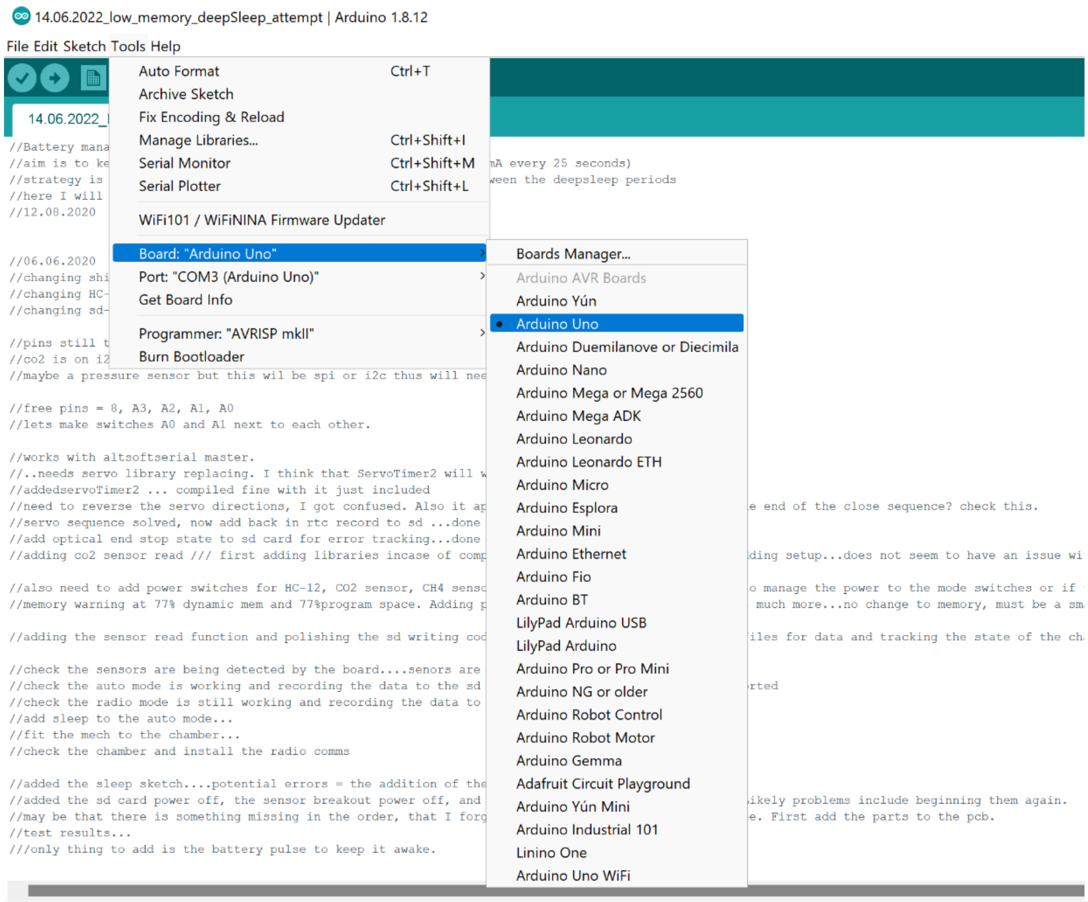


Figure 107 Screen shot illustrating the process of selecting the board during ATMEGA328p programming.

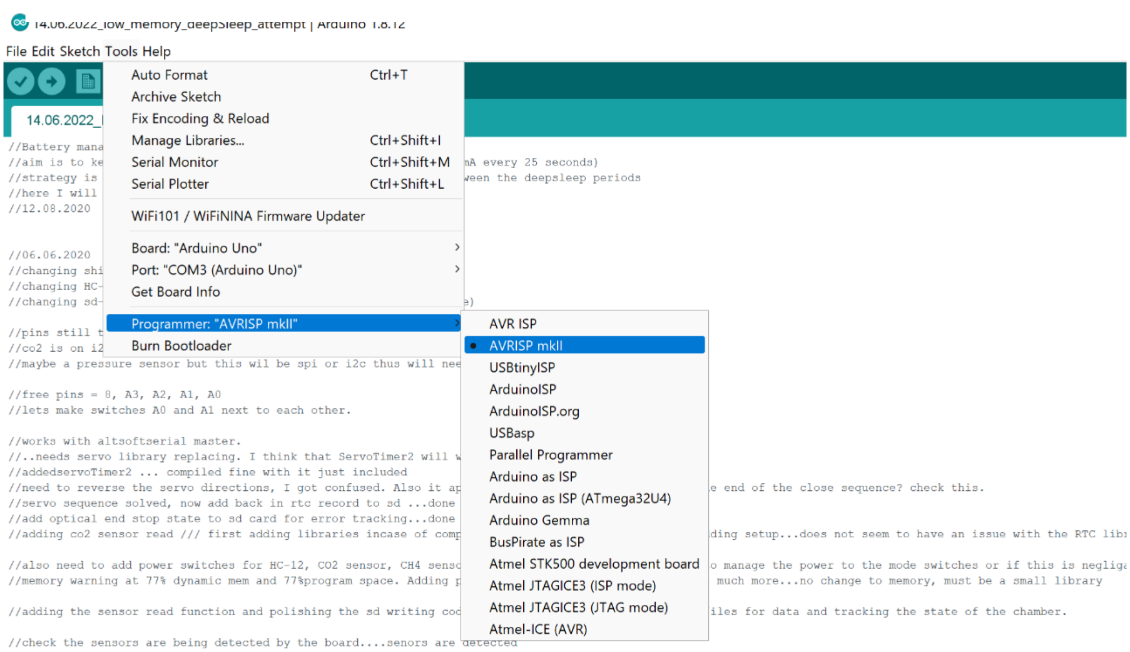


Figure 108 Screen shot illustrating the process of selecting the appropriate programmer for Arduino uno style programming methods.

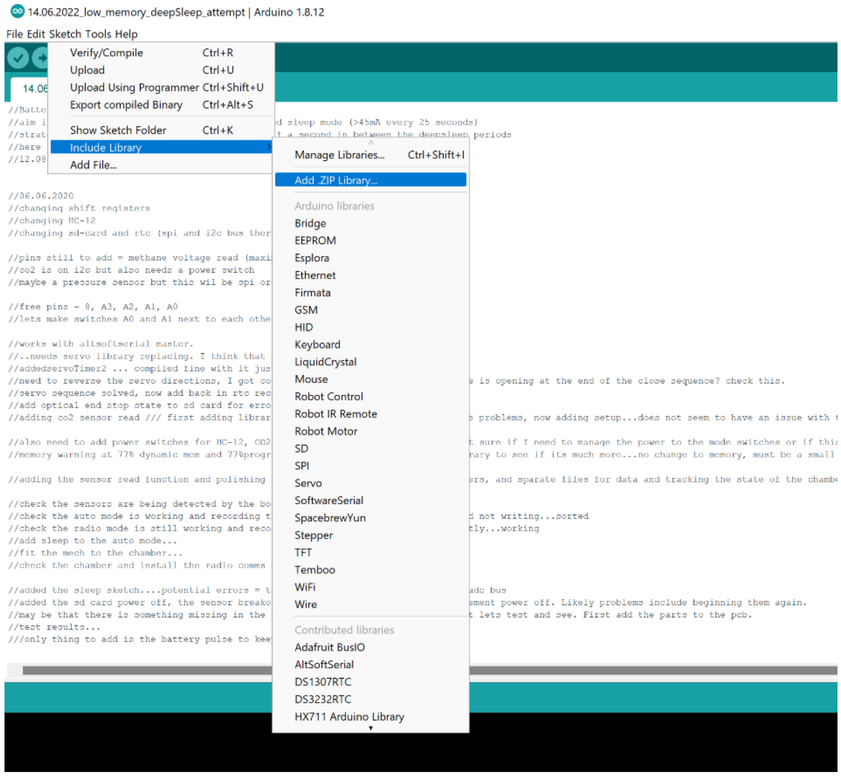


Figure 109 Screen shot 1 illustrating the process of importing libraries during ATMEGA328p programming.

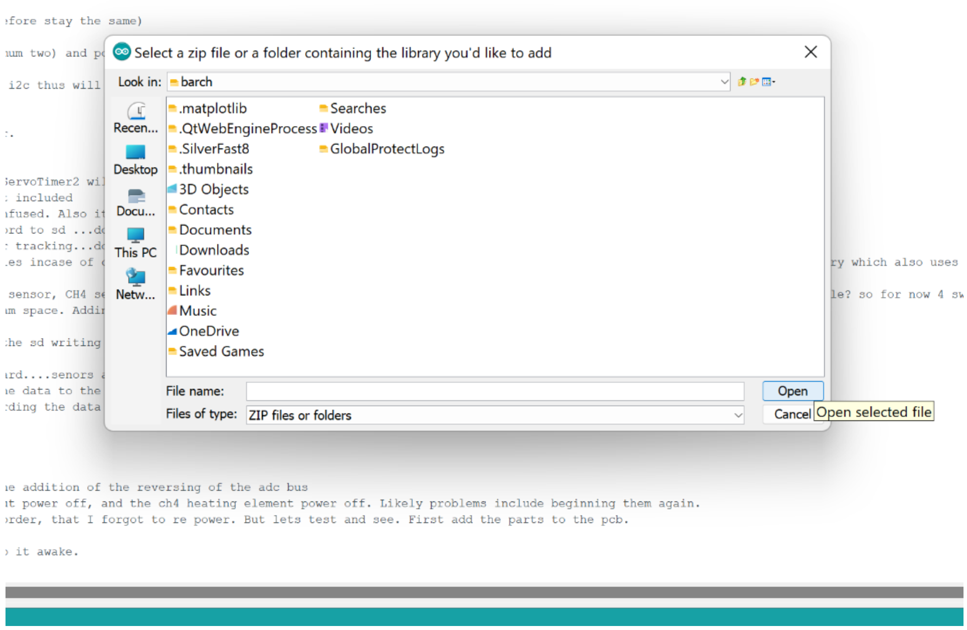


Figure 110 Screen shot 2 illustrating the process of importing libraries during ATMEGA328p programming.

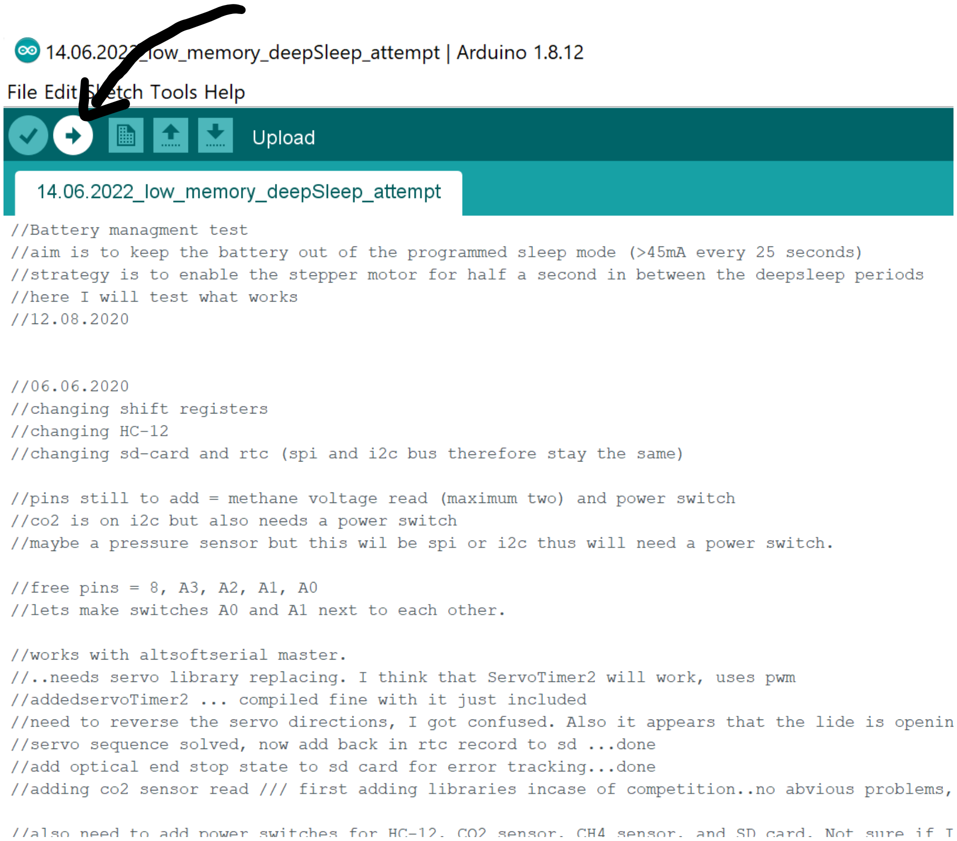


Figure 111 Screen shot illustrating the upload button, during ATMEGA328p programming.

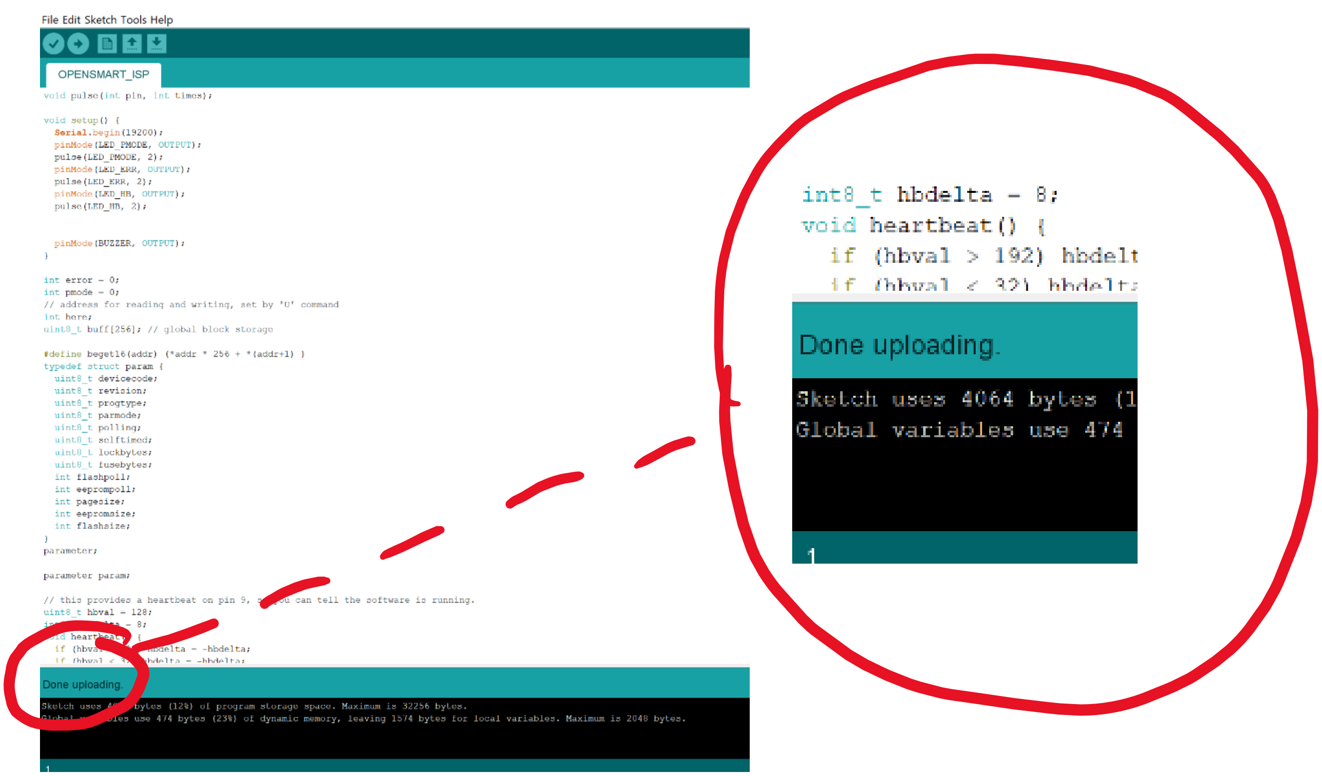


Figure 112 Screen shot illustrating a successful programming attempt to the ATMEGA328p.

Serial programming method

Instructions

This method requires a USB to serial adapter. This adapter can be an Arduino uno with the ATMEGA328p chip removed or a dedicated serial adapter board such as the FTDI FT232RL (**Error! Reference source not found.**).

First ensure that the power banks to main circuit board cables are removed. I.e. there is no power to the board. *

Ensure that your ATMEGA328p chip has had the bootloader burned onto it. If not, follow the "Burning a bootloader" subsection below to prepare your chip for the next steps. **

Connect the Main circuit board "Serial Port" pins to the corresponding serial adapter pins. I.e. Main circuit board → serial adapter: Vcc → Vcc, GND → GND, TXD→ RXD, RXD →TXD, RST → DTR or RTS or RST or RESET. ***

Open the Arduino IDE with the required sketch. Check that the serial port for the Arduino is detected, by selecting the "Tools" tab and then the "Port" sub tab (Figure 106). ****

In the "Tools" tab, select the "Board" subtab and select "Arduino Uno" (Figure 107).

In the "Tools" tab, select the "Programmer" subtab "AVRISP mkII" (Figure 108).

Check that the computer has the required libraries downloaded from the openChamber Github page (https://github.com/BArcherResearch/openChamber/tree/main/Chamber_1/Arduino_Programs/Libraries) and loaded into your Arduino IDE.

If not uploaded, select the select the "Sketch" tab. In the drop-down menu select the "include library" sub tab. In the subsequent dropdown menu, select the "Add .ZIP Library..." subtab (Figure 109).

In the pop-up window, select the libraries from your downloads that you wish to import into the Arduino IDE and select "Open" (Figure 110). The libraries should now be accessible when uploading your programme to the ATMEGA328p chip.

Next select the "Upload" tab (the arrow button, Figure 111).

If the upload was successful, the message "Done uploading." will appear in the console (Figure 112).

Disconnect the Main circuit board "Serial Port" from the serial adapter.

Insert the main circuit board power cable into the power banks and the programme will begin.

*In some cases, you may need to plug in the control circuit power bank. For example, if your computers usb port is not able to provide enough power to run the board while programming the ATMEGA328p chip.

**Unless the "Read Me" file associated with the code that you would like to run says that your code does not need the bootloader. This is currently not the case but could be the case for future programmes where more static memory is asked of the microcontroller.

***Sometimes the RX and TX pins can be mislabelled. Try them in the reverse if at first this does not work.

****If nothing is detected in this Port, check that you have the correct drivers installed for your FTDI programmer, try plugging in again or in a new USB port. Failing this, check the cable used and reload the Arduino IDE.

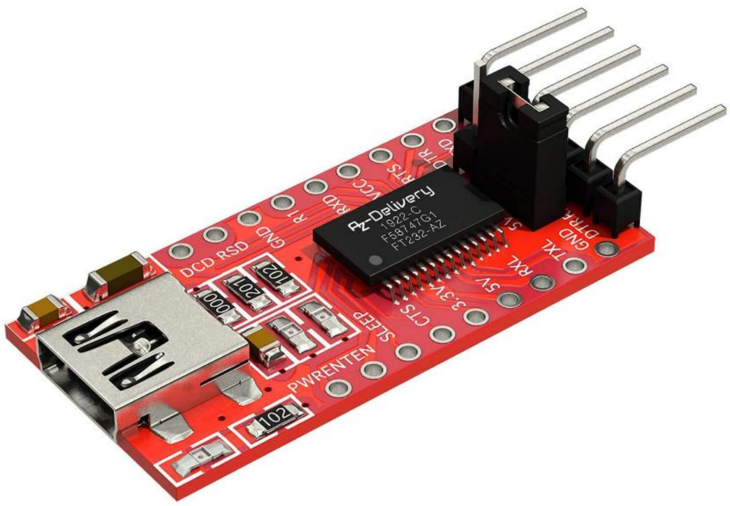


Figure 113 FTDI FT232RL Serial programmer / adapter board produced by EZDELIVERY (AZDelivery, n.d.)**.**

ISP programming method

Introduction

The ISP programming method is used for final chamber deployment because it removes the bootloader programme, freeing up memory space and the initial start-up delay experienced with the conventional Arduino programming methods described above. Because the ATMEGA328p has limited memory, it is susceptible to programme stability issues, therefore any memory that can be saved is beneficial when considering long chamber deployments.

Instructions

First, if no bootloader has already been burnt to the ATMEGA328p, burn the bootloader following step 1.6.1 (this sets the internal fuses of the chip).

Keeping the chip in the AVR ISP programmer, open the Arduino IDE with the required sketch. Check that the serial port for the Arduino is detected, by selecting the “Tools” tab and then the “Port” sub tab (Figure 106).

In the “Tools” tab, select the “Board” subtab and select “Arduino Uno” (Figure 107).

In the “Tools” tab, select the “Programmer” subtab “Arduino as ISP” (Figure 114).

Check that the computer has the required libraries downloaded from the openChamber Github page (https://github.com/BArcherResearch/openChamber/tree/main/Chamber_1/Arduino_Programs/Libraries) and loaded into your Arduino IDE.

If not uploaded, select the select the "Sketch" tab. In the drop-down menu select the "include library" sub tab. In the subsequent dropdown menu, select the "Add .ZIP Library..." subtab (Figure 109).

In the pop-up window, select the libraries from your downloads that you wish to import into the Arduino IDE and select “Open” (Figure 110). The libraries should now be accessible when uploading your programme to the ATMEGA328p chip.

Next, in the Sketch tab select the select the “Upload Using Programmer” tab, this may take a few minutes (Figure 115).

If the upload was successful, the message “Done uploading.” will appear in the console (Figure 112), and the buzzer on the AVR ISP shield will sound briefly.

Unplug the ATMEGA328p from the programmer Arduino uno. Place the programmed chip back into the Main circuit board ZIF socket, ensuring that the pin 1 indicator of the ATMEGA328p chip is aligned with the pin 1 indicator on the Main circuit board.

Insert the main circuit board power cable into the power banks and the programme will begin.

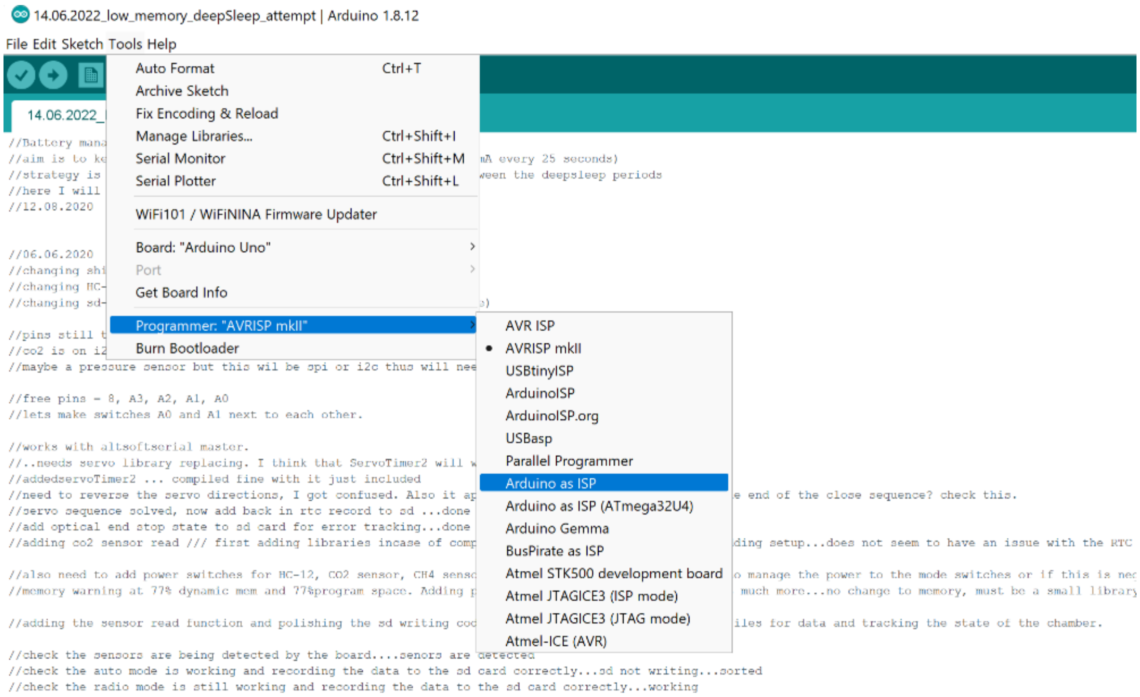


Figure 114 Screen shot illustrating the process of selecting the appropriate programmer for ISP style programming methods.

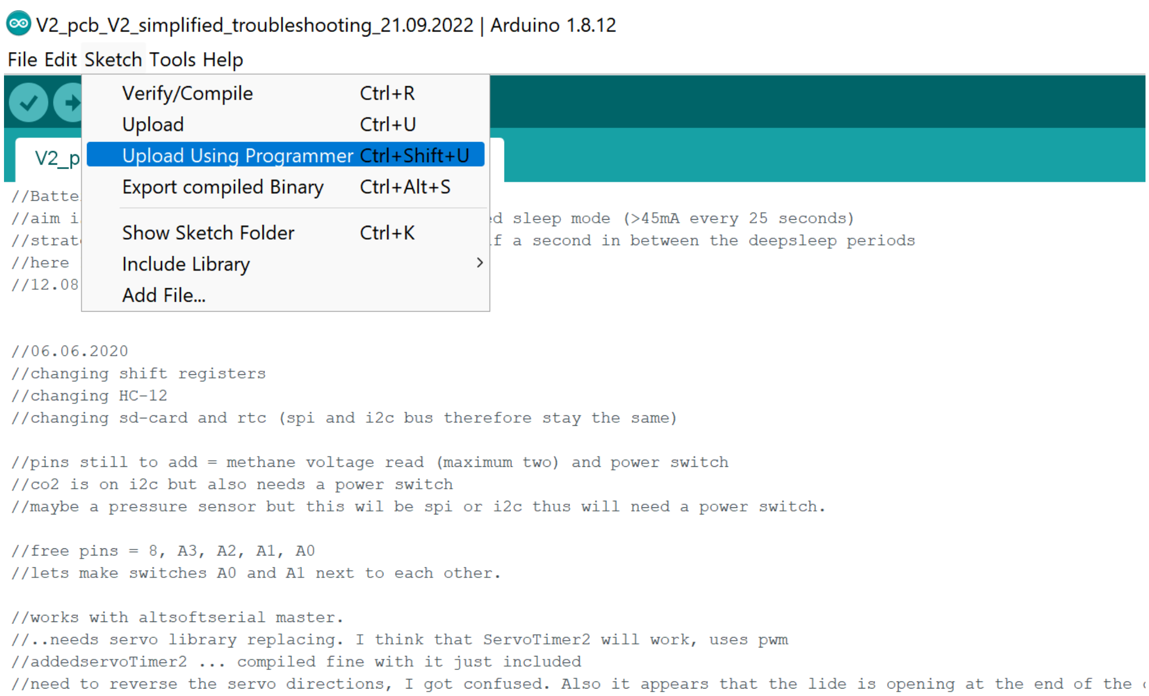


Figure 115 Screen shot illustrating the upload tab for ISP ATMEGA328p programming.

2. Burning a Bootloader

Introduction

Most of the programmes that you will use with the chamber main circuit board will require a bootloader to function. This runs at the beginning of each programme when power is applied to the circuit and is what causes the slight delay before the programme. The bootloader allows a programme to be uploaded to the ATMEGA328p chip easily.

The "read me" file paired with the programme available on the openChamber project page, will state if a bootloader is required on the ATMEGA328p for the sketch. If so, follow the steps below, or buy an ATMEGA328p with a pre-installed bootloader.

Instructions

Insert a bootloader programmer AVR ISP Shield onto your normal Arduino Uno header pins (Figure 116). Connect your Arduino to your computer using the USB cable.

Open the Arduino ISP with the OPENSMART_ISP programme from the openChamber programme folder.

that the serial port for the Arduino is detected, by selecting the "Tools" tab and then the "Port" sub tab (Figure 106). ***

In the "Tools" tab, select the "Board" subtab and select "Arduino Uno" (Figure 107).

In the "Tools" tab, select the "Programmer" subtab "AVRISP mkII"

Next select the "Upload" tab (the arrow button, Figure 111).

If the upload was successful, the message "Done uploading." will appear in the console (Figure 112).

Next insert the blank ATMEGA328p chip to be burnt into the AVR ISP Shield ZIF socket, ensuring that the pin 1 indicator of the ATMEGA328p chip is aligned with the pin 1 indicator on the AVR ISP Shield (Figure 116).

Next, in the "Tools" tab, select the "Programmer" subtab "Arduino as ISP" (Figure 114)

In the "Tools" tab, select the "Burn Bootloader" subtab (Figure 117). You should hear a beep as the burning begins, and a beep as the burning ends.

The bootloader has now been burnt onto the ATMEGA328p chip. This chip is ready for use in your main circuit board and programming through standard methods, as described in section 1.6.1 "Uploading a programme".

***If nothing is detected, then try plugging the Arduino in again, or in a new USB port. If still no Arduino is detected, check the cable used, the Arduino board, and finally try a new chip. Failing this, reload the Arduino IDE and try again.

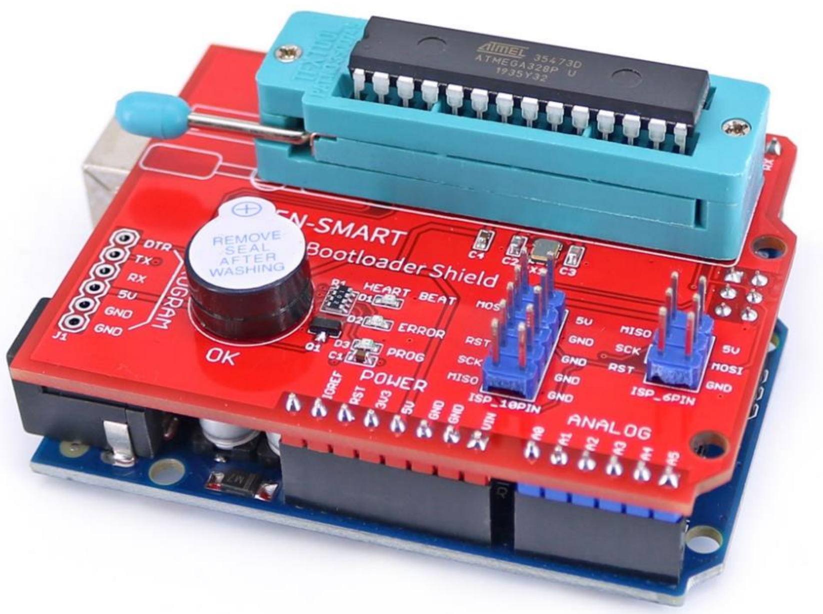


Figure 116 Arduino uno with bootloader ACR ISP shield stacked onto header pins, ready to burn the bootloader onto the ATMEGA328p (AliExpress, n.d.)**.**

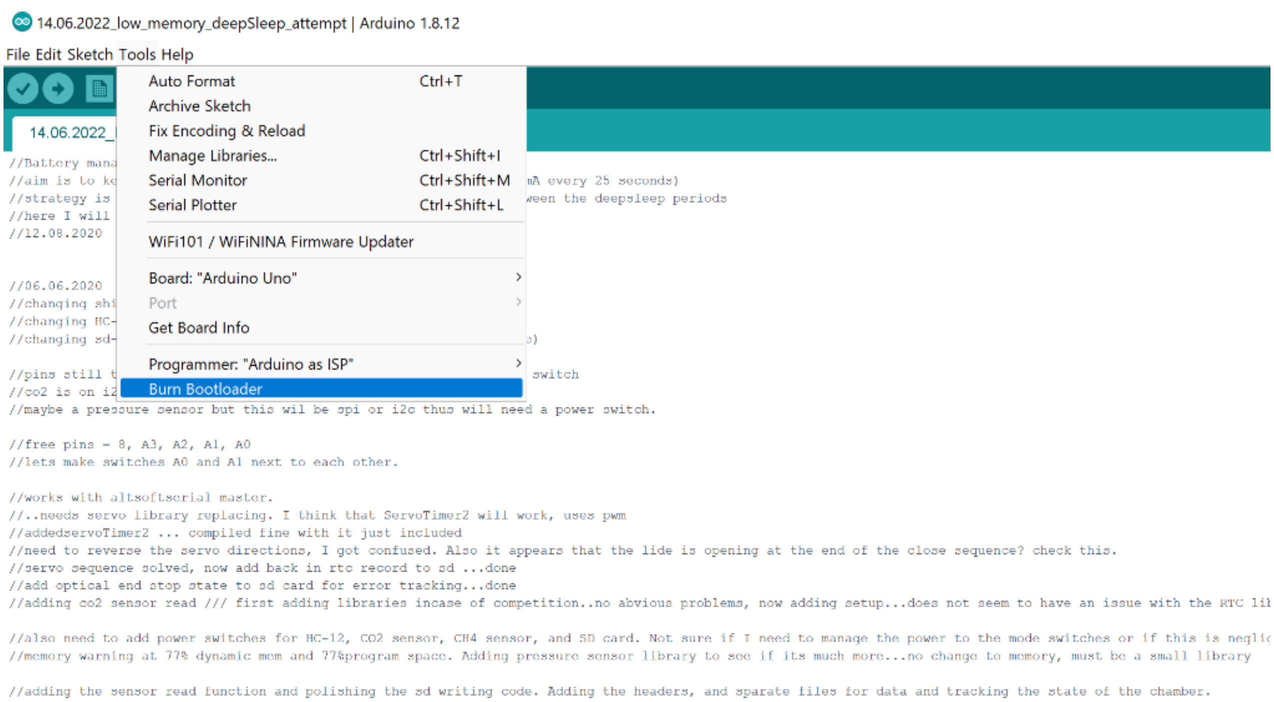


Figure 117 Screen shot illustrating the tab to select inorder to burn the bootloader onto the atmega328p chip.

3. Main circuit board preparation

We are now ready to test the main circuit board and prepare it for use in the chamber. It is best to do these tests before installation (instructions in section 1.4, Step 4b.4b), laying out the individual components on the workbench. It will also help your understanding of the different elements of the board.

LED testing

First test the overall functionality of the board.

Following the instructions in section 1.6.1, upload the "" programme onto the chamber board.

If everything is functioning properly, the LEDs at the top of the chamber board should turn on as shown in figure … , and you can move onto the next step "Setting real time clock".

If nothing happens, check that the pin 1 indicator of the ATMEGA328p chip is aligned with the pin 1 indicator on the Main circuit board.

If still nothing happens, check that your power supply is plugged in correctly or use a new power bank.

If still nothing happens, try a new ATMEGA328p and ensure that the bootloader is burned to the chip, as described in section 1.6.2.

If still nothing happens, there could be an issue with the main circuit board itself. For example, if the reset circuit held low (to ground), then the ATMEGA328p will not run the programme. Try a new circuit board or consult the openChamber github project page for further guidance.

Setting Real Time Clock

The clock of your main circuit board needs to be set from your computer. This is done most accurately with the Serial programming method (section 1.6.1), but if you do not mind being a couple of seconds behind Coordinated Universal Time (UTC) then using the chip removal programming method (section 1.6.1), is fine. The delay is equal to the time it takes to remove the ATMEGA328p chip from the programmer, install it into the main circuit board and turn on the power).

First install a 3.3v CR2032 (part 70) into the main circuit board coin cell clip (figure…).

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

The time has now been set from your computer's time.

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Apply power to the circuit. A green light will flash if the RTC has been successfully set and a red light will flash if there was a problem (figure …). If you have a green light, move onto the next step "Optical endstop/ interrupt testing". If you have a red light, check your ATMEGA328p chip alignment, your 3,3v coin cell and repeat this step from the beginning.

If still you get a red light or no light shines at all, there could be an issue with the main circuit board itself. For example, if the RTC circuit could be corrupted or the I2C line is held low. Try a new circuit board or consult the openChamber github project page for further guidance.

Optical endstop/ interrupt testing

The optical endstop/ interrupt detects the lid position as either “Open” or “Closed”. It is also used in zeroing the lid position as a part of the chamber lid closing and opening protocols. If this does not work, you can have serious problems with your lid movement.

To test this functionality, upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Upon applying power, the green light should be on. Block the space between the optical limit switch (part described in section 1.4 Step 4a.1) with an opaque object (e.g. part 56, described in section 1.4 Step 3.2) as illustrated in figure …. . Now the red light should be on. Repeat to be sure the correct light response is viewed. If this functions properly, move onto the next step “MicroSD card testing”.

If no change in the light colour occurs when the optical limit switch space is blocked, check your optical limit switch wiring.

If still no change in the light colour occurs, try with a new optical limit switch.

If still no change in the light colour occurs there could be an issue with the main circuit board itself. For example, a corrupted power transistor or shift register. Try a new circuit board or consult the openChamber github project page for further guidance.

MicroSD card testing

The MicroSD card (part 70.b) is the most sensitive element of the circuit to power supply stability. Testing before field application is critical if SD card detection issues are to be avoided.

To test this functionality, upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Ensure that the MicroSD card is plugged into the MicroSD card socket (figure …) before applying power to the circuit.

Upon applying power, the green light should flash, indicating that the sd card has been detected successfully. If the red light flashes, the SD card has not successfully been detected.

Ensure that the power to the circuit is removed before removing the MicroSD card. Open the sd card on your computer. If everything has functioned correctly, you should have a file called “TEST”. Your sd card functions properly, move onto the next step “Servo testing”.

If you observed a red light, check that your SD card functions correctly on your computer. Repeat the steps above – sometimes the problem is that the sd card was not correctly installed into the MicroSD card socket.

If the problem persists, follow the steps outlined in section 1.8 “SD-card not detected” .

Servo testing

Servomotor testing is important to ensure that the pawl assembly correctly disengages from the ratchet. If the pawls do not correctly disengage from the ratchet, the chamber lid will not open.

First upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Turn on the power, the servo arm (part …) will move to the “Pawl disengaged” position. This should resemble figure … If the servo arm needs adjusting, remove the servo arm and reinstall it in the correct position, following the steps in section 1.4 Step 4c.3. *

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

This will sweep the servo arm from the “pawl engaged” position to the “pawl disengaged” position repeatedly until the power is removed (fig …). The pawls should now disengage from the ratchet correctly as described in figure… .

To make this servo arm position permanent, remove the servo arm following the steps in section 1.4 Step 4c.3, apply a **very minimal** amount of superglue (part 90 or 91) to the inside of the servo arm where it binds to the servomotor shaft and reinstall it in the correct position. Too much glue can risk sticking the servomotor driveshaft in place i.e. it can no longer move.

Gluing the servo arm in place is important for long deployments, as if the servo arm comes loose, the pawls will not disengage from the ratchet and the chamber lid will no longer open. If your servo is ready, move onto the next step “Setting stepper motor power”.

* If there is no servomotor movement, check the wiring of the servomotor to the main circuit board.

If there is still no servomotor movement, try a new servomotor (the old one may be broken).

If there is still no servomotor movement, ensure that the main circuit powerbank is supplying at least 2.5 amps, if not the servomotor may not have enough power to move.

If there is still no servomotor movement, there could be an issue with the main circuit board itself. For example, a corrupted power MOSFET or shift register. Try a new circuit board or consult the openChamber github project page for further guidance.

Setting stepper motor power

Before connecting the 5v step-up converter (part 80b) to the main circuit board, adjust its output to 24v. To do this, use a multi-meter across the positive and negative connections of the step-up converter and adjust the potentiometer until the voltage output reads 24v (figu….). *

Connect the step-up converter to the main circuit board (fig…).

Now we must set the motor driver (TMC2208) reference voltage (vref) to ~1.5v. Disconnect the stepper motor cable from the main circuit board (i.e. disconnect the load on the motor driver).

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Apply power first to the motor circuit and then after to the control circuit and (fig…).

The vref is measured between the motor power ground (gnd) and the vref pin of the TMC2208 using a multi-meter* (Figure 118). Adjust the motor driver potentiometer until the voltage output reads 1.5v.

Remove power from the circuits. Plugin the stepper motor cable from the main circuit board to the stepper motor.

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Put a piece of tape onto the drive shaft of the stepper motor if you find it easier to visualise the stepper motor drive shaft movement (fig…).

Again, apply power first to the motor circuit and then after to the control circuit. You should see the stepper motor run smoothly in one direction, pause, and then run smoothly in the opposite direction. Once the stepper motor has stopped moving, you can remove power from the circuits. If this behaved as expected, then move onto the next step “Sensors testing”.

*If you do not have access to a multi-meter, pre-set step-up converters may be able to be provided by contacting the author or the openChamber community.

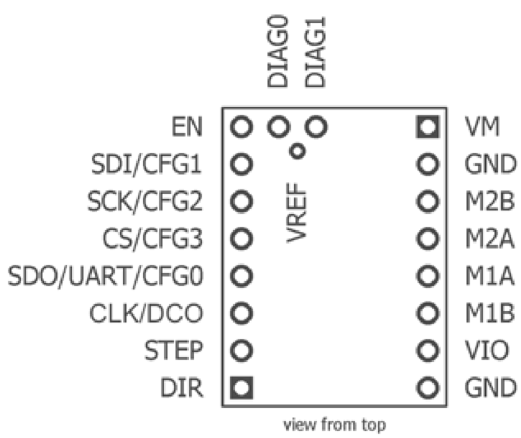


Figure 118 TMC2208 v2 pinout (Watterott, 2022).

Sensors testing

Connect the sensor board to the main circuit board. On sensor board V2, this is the cables labelled "Sensors" and the cable labelled "CH4 power" (fig…). If using sensor board V1, this cable is labelled "H1" (fig…). Connect the strain sensor cable labelled "strain 1" (if using 2 strain sensors/ load cells also connect cable labelled "strain 2") to the main circuit board (fig…).

There are 4 modes of using the sensor boards:

1. Sensor board V1 mode.
2. Sensor board V2 mode with 1 co2 sensor and 1 ch4 sensors using the Arduino internal ADC.
3. Sensor board V2 mode with 1 co2 sensor and 1 - 4 ch4 sensors using the high-resolution external ADC.
4. Sensor board V2 mode with 2 co2 sensors and 1 – 4 ch4 sensors.

Mode 1 and 2:

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Mode 3:

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Mode 4:

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Apply power to the control circuit.

The sensors will be activated one by one. As each sensor begins, the green light will flash to indicate that everything is okay. In between each sensor being tested, all 4 lights will flash on and off in unison 1 time. After all the sensors have been tested, all 4 lights will flash on and off in unison 5 times. If this occurs then your sensors have successfully begun and you can move onto the next step "Radio testing" - unless you are not using a radio in your setup, in which case move one the next step "Load cell calibration".

If there is a problem with the sensors, the red light will flash on its own until the power is turned off or the sensor successfully begins.

If you experience a red flashing light without ever reaching all 4 lights flashing on and off in unison 5 times, check your sensor board to main circuit board wiring.

If still no change in the light flashing, try with a new sensor board - one of the sensors may have been corrupted and need replacing. Also check that you are running the right programme for your sensor board setup

If still no change in the light colour occurs there could be an issue with the main circuit board itself. For example, a corrupted power transistor or shift register. Try a new circuit board or consult the openChamber github project page for further guidance.

Radio testing

Connect the cable labelled HC-12 from the sensor board V2 to the main circuit board (fig…). If using sensor board V1 this cable is labelled "H6" (fig…).

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Apply power to the control circuit. As the radio is activated, the green light will flash to indicate that everything is okay, followed by all 4 lights flashing on and off in unison 5 times(fig…). If this occurs, then the radio has successfully begun and you can move onto the next step "Bench Test".

If there is a problem with the radio, the red light will flash on its own until the power is turned off or the radio successfully begins (fig…).

If you experience a red flashing light without ever reaching all 4 lights flashing on and off in unison 5 times, check your sensor board to main circuit board wiring.

If still no change in the light flashing, try with a new sensor board / radio module - the HC-12 board may have been corrupted and need replacing.

If still no change in the light colour occurs there could be an issue with the main circuit board itself. For example, a corrupted power transistor or shift register. Try a new circuit board or consult the openChamber github project page for further guidance.

4. Chamber mechatronic testing

Bench Test

The “bench test” trials the functionality of chamber mechanics and electronics before integration into the chamber body subunit.

Install the main circuit board back into the motor case following section 1.4 Step 4b.4b, connecting all the elements that were tested in the aforementioned steps: i.e. Microsd card, Optical endstop, servomotor, Stepper motor, sensor, strain sensor and radio cables.

Reverse section 1.4 step 6.2 , so that you are have the end product of section 1.4 Step 6.1.

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Apply power first to the motor circuit and then after to the control circuit. When there are no issues with the elements that we tested above, then the programme will begin. This is shown by the flashing of the white and blue lights together (fig …). If there is an issue, the red light will flash continuously until the problem is solved.

Once these lights have been seen, insert the power banks into the motor case and close the lid, as described in section 1.4. Step 4c.1. An indication that everything is okay is also the flashing light inside the CO_2 sensor and the movement of the fan.

After ~1minute, the “lid close” function will begin. The pawls will disengage from the ratchet, followed by the lid moving down the leadscrew (part 48). Once the optical interrupter bar (part 56) moves into the space between the optical limit switch (part described in section 1.4 Step 4a.1) the lid will perform a “zeroing” manoeuvre (stopping, slowly reversing direction, then moving down across the optical limit switch again more slowly and thus more precisely) then continue to close. Finally, the pawls will engage with the ratchet again, followed by a few audible “clicks” as the lid locks in position. This procedure is demonstrated in figure … .

After the clicks stop, wait ~1 minute for the “lid open” function to begin. The pawls will disengage from the ratchet, followed by the lid moving up the leadscrew (part 48). The lid will move more quickly than the “lid close” function, as no zeroing manoeuvres are required. When the lid reaches its top “closed” position, the pawls will engage with the ratchet again, helping to keep the lid in the “open” position.

Open the chamber motor case following the reverse of section 1.4. Step 4c.1 and remove power from the circuits by unplugging the power banks.

If there were no problems, then move onto the next step “Load cell calibration”.

If an element of the sequence did not function as described, check the setup of the testing steps of section 1.6, consult section 1.8 Trouble shooting and finally if the problem persists consult the openChamber community.

Load Cell Calibration

Reverse Section 1.4 Step 6.1, so that the lid is not attached to the bracket subunits (fig…). Insert the brackets subunit to the chamber body subunit in the same way as described in Section 1.4 Step 6.2 – just without the lid subunit this time.

Upload the … programme onto the main circuit board following the instructions in section 1.6.1.

Upturn the chamber so that the gasket (part 52) is on a (clean) workbench (fig…). Apply power to the control circuit. When there are no issues with the elements that we tested above, then the programme will begin. This is shown by the flashing of the white and blue lights together (fig …). If there is an issue, the red light will flash continuously until the problem is solved.

Insert the power banks into the motor case and close the lid, as described in section 1.4. Step 4c.1.

1 minute after applying power to the control circuit, place your calibration weight (part 103) onto the motor case as directly over the lead screw / motor subunit as possible (fig…).

Wait 10 minutes, then remove the weight, open the motor case lid, take out the power banks (the reverse of section 1.4. Step 4c.1.) and remove power from the circuit.

Remove the MicroSD card. View the SD card file on your computer. If the calibration factor has reached a measurement of 5kg, then note down the calibration factor (fig…). Otherwise repeat the process above but wait longer than before for the calibration to reach 5kg.

Open the programme that you will use in your chamber on the water (i.e. stand-alone).

Edit the programme script, changing the calibration factor to that which you have just calculated and noted down.

(If using 2 load cells/ strain sensors, then you will need to repeat these steps for your seconds load cell/ strain sensor.)

The load cell calibration step is complete. If you had no problems, move onto the next step "Final Test". Otherwise, check the setup of the testing steps of section 1.6, consult section 1.8 Trouble shooting and finally if the problem persists consult the openChamber community.

Final Test

The "final test" trials the functionality of chamber mechanics and electronics in deployment ready state.

Follow section 1.4 Step 6, until all the subunits are unified (i.e. section 1.4 Step 6.2).

Clip on the chamber bottom cap for protection during testing (Section 1.7.1).

Upload the programme that you will use for your chamber deployment (i.e. stand-alone), having already edited the load cell calibration factor calculated in the load cell calibration step, onto the main circuit board following the instructions in section 1.6.1.

Insert MicroSD card.

Position the chamber float arms into their deployment / horizontal position (fig…), following the float arm lock pin instructions in section 1.4 Step 2.3.

Apply power first to the motor circuit and then after to the control circuit. When there are no issues with the elements that we tested above, then the programme will begin. This is shown by the flashing of the white and blue lights together (fig …). If there is an issue, the red light will flash continuously until the problem is solved.

Once these lights have been seen, insert the power banks into the motor case and close the lid, as described in section 1.4. Step 4c.1. An indication that everything is okay is also the flashing light inside the CO_2 sensor and the movement of the fan.

Flip the chamber onto its base (ensuring to lift the chamber from its side clamping point (fig…) and not from the lid). Like in the "Bench test" step above, after ~1min the "lid close" function should occur. At the end of the lid close protocol, the lid should be clamped strongly to the gasket material (part 52) of the chamber body.

Wait for the chamber incubation time (i.e. lid closed time) to be over. This is written in the "read me" file of the associated programme you are using. For example, the ….. programme has an incubation period of 25 mins, while the … programme has an incubation period of 3 hours. After this time has elapsed the "lid open" function should occur. The lid should stay in the open position for ~5 minutes before repeating the "lid close" and incubation functions.

After a few hours, check the chamber. Wait until the lid is in the "lid closed" position, then flip the chamber onto its lid (remembering lift from the side clamping points) to access the motor case.

Open the chamber motor case following the reverse of section 1.4. Step 4c.1 and remove power from the circuits by unplugging the power banks.

Check the MicroSD card on your computer. Open the "Status" file. The chamber writes to this file every time the programme restarts. As the chamber has only been started one time, you should only see 1 data point in this file (e.g. figure…). If there are more points, it suggests that an element of the chamber is not functioning correctly, for example a power supply issue causing the chamber to restart. Check the setup of the testing steps of section 1.6, consult section 1.8 Trouble shooting and finally if the problem persists consult the openChamber community.

Next check the file with your current date (fig). Check that the sensors are all writing values greater than zero (Faulty CO_2 sensors for example can give CO_2 values of zero fig…).

Check that the expected lid status matches the recorded lid status throughout the measurement (figure …). If not, then an error has occurred.

Check that the lid tension measurement is recording positive weight during the lid down measurement and negative values during the lid open measurement. If very small lid tension values are measured, for example less than 1kg, then either not enough force is being applied to the lid in the closed position, or the load cell calibration has not been set accurately.

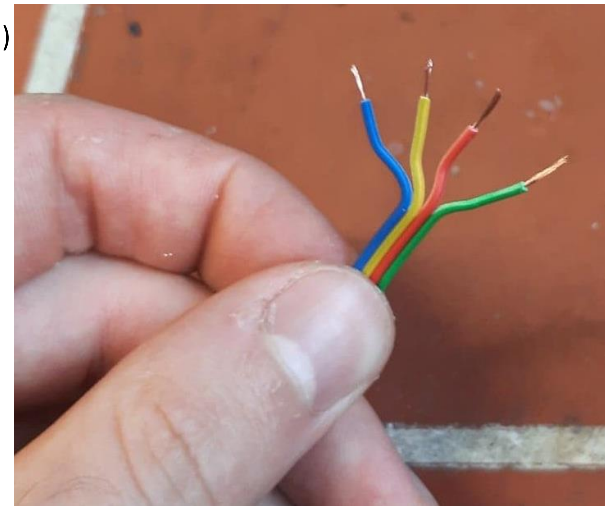
If you had no problems, your chamber is now ready for deployment on the water. Otherwise, check the setup of the testing steps of section 1.6, consult section 1.8 Trouble shooting and finally if the problem persists consult the openChamber community.

5. Cable building

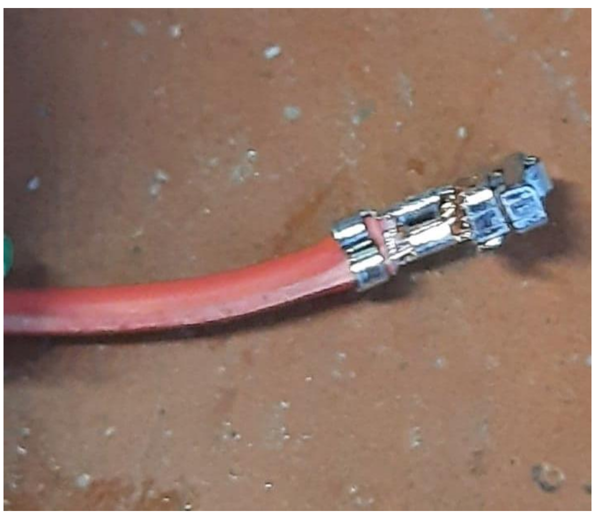
This is a basic introduction into JST cable building. I have included this section because so often when trouble shooting the chambers the problem came down to poor cable connections. In the future, JST cables will be provided as a part of the openChamber electronics kit to remove this skill requirement.

a.)

b.)

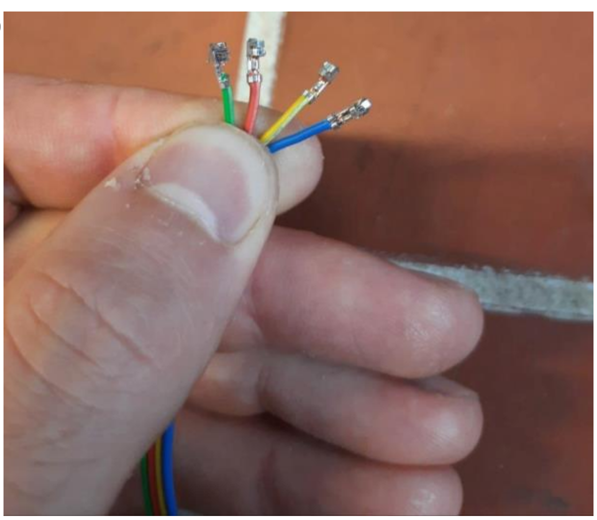


c.)



d.)

e.)



f.)

Figure 119 Photographic illustrations of the JST cable building process.

Notes:

Parts required – part 101, part 102, JST crimping tool, wire cutters/ insulation strippers, tweezers (Figure 119a).

Strip the end of the wire to be inserted into the JST connector so that ~3mm of bare copper are exposed (Figure 119b). Twist the copper ends to keep the strands together.

Insert the metal crimp into the crimping tool, followed by the exposed copper wire. The wire should be inserted deep enough into the crimp that the insulation is grabbed by the base of the crimping tool while the exposed copper is grabbed by the subsequent part of the crimp (Figure 119c). It is important that the insulation is grabbed because this takes the mechanical load of the connection – if it is not gripped properly, then it is likely that the wire will become loose and cause electrical errors during chamber functioning.

Ensure that the barb of the crimp has not been pushed flat, but is sticking up like in Figure 119d.

Repeat for all of the cables (Figure 119e).

Finally insert the crimp into the female JST connector, so that the barb of the crimp locks into the open section of the female connector (Figure 119f).

1.7 Chamber storage and transportation

Introduction

The chamber design has been built around the important principles of safe storage and transportation. This comes from the experiences of using these chambers in an intensive annual field campaign. Under these conditions, many chambers needed to fit into a single vehicle and needed to withstand the general wear and tear that comes with being at different sites every day for weeks at a time. After the seasonal field campaigns, they had to fit into a lab with very minimal storage space and survive the curiosity / lack of caution of people in the lab setting.

An area at risk of damage is the bottom rim of the chamber. For this reason, the chamber is protected by clamping the bottom rim either to another chambers lid (through chamber stacking), or to a protective bottom cap.

A second area at risk of damage is the float arms of the chamber. For this reason, the float arms fold into a vertical position when being transported or stored, keeping them out of harm's way. Additionally, this vertical storage position reduces the footprint of the chambers, meaning they can be fit into a small area in the lab, and more can be fit into a single vehicle during field work.

Moving chambers safely

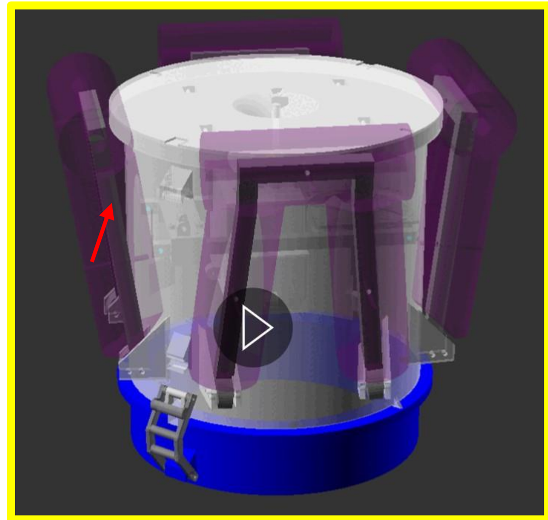
When handling the chambers, it is best to lift them from the clamping points (indicated by the red arrow in Figure 120b and c) rather than by the chamber lid. This avoids unnecessary stain upon the mechanical elements of the chamber. Alternatively, part 30 (chamber carrying handle) can be slotted onto the clamping points to make moving the chambers more comfortable (Figure 120a). To install part 30 onto the chamber, alight the chamber clamping points with the corresponding hole in part 30 (Figure 120c). Pull back the spring-loaded handle clips (part 31) and push the handle onto the chamber clamping points (Figure 120d and e). Release the spring-loaded handle clip so that it locks part 30 onto the chamber clamping point (Figure 120f). To remove part 30, follow these steps in reverse.

Before moving individual chambers, place the chamber feet into the receiving indents of part 29 (chamber bottom cap). Clamp the chamber to part 29 using the clips (illustrated in Figure 120b).

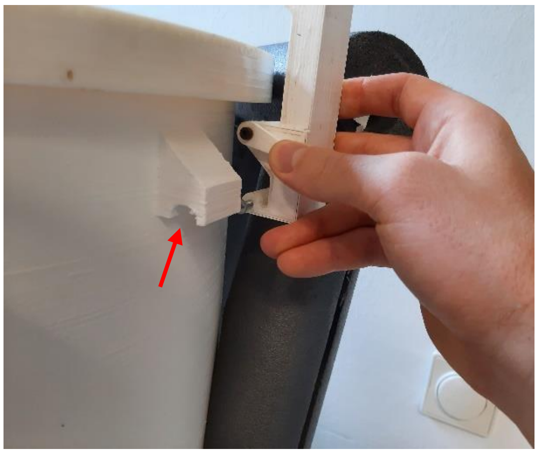
Finally move the chamber arms into the vertical position, following the instructions of section 1.4.2.3.

a.)

b.)



c.)



e.)

d.

f.)

Figure 120 Image “a” photographs a chamber ready for safe transport. Image “b” is a GIF animation illustrating the process of clamping a chamber to its protective bottom base (part 29). GIF available on the openChamber Github project page under “openChamber/Chamber_1/Build_Guide/Chamber_storage_and_transportation”.

Stacking chambers

The bottom chamber must be clamped into part 29 (the chamber bottom cap) as described in the moving chamber safely section above.

Place the chamber feet into the receiving indents of the bottom chambers lid (part 2). Clamp the chamber being stacked to the chamber underneath's clamping points using the clips (Figure 121).

Move the chamber arms into the vertical position, following the instructions of section 1.4.2.3.

Repeat for as many chambers as you would like.

a.) b.)

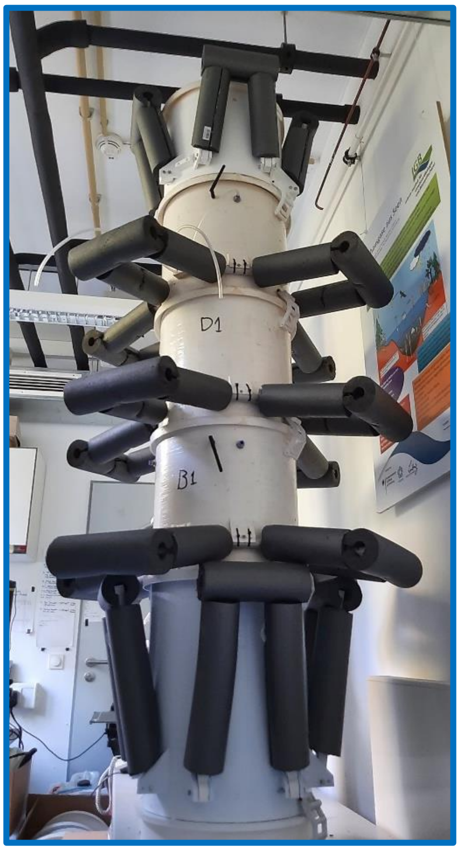


Figure 121 Illustration of the process of clamping chambers on top of one another during the stacking process (part 29). Image "a" is a photographic demonstration of 5 chambers stacked in the lab. The bottom chamber is the tall chamber format (part 1.b) while the other 4 chambers are the short chamber format (part 1). The arms of the top and bottom chambers are in the vertical position while the arms of the middle 3 chambers are in the horizontal position. Image b is a GIF animation of the chamber stacking process, available on the openChamber Github project page under "openChamber/Chamber_1/Build_Guide/Chamber_storage_and_transportation".

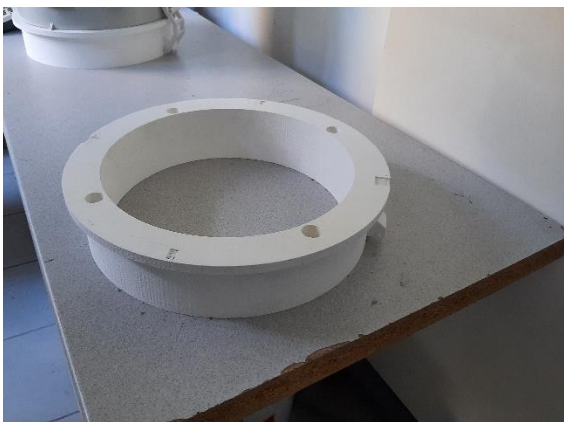
Storing chambers

When storing chambers in one place, it is best to have the bottom cap (part 29) firmly secured to a solid surface (for example a concrete floor or a wide wooden base) for extra stability.

For this reason, part 29 has 4 bolt holes included through which it can be securely fixed to a surface.

Bolt part 29 to your surface (Figure 122a and b). Next follow the “stacking chambers” instructions as described above (Figure 122c).

a.)



b.)

b.)

Figure 122 Series of Photographs illustrating a long-term chamber storage scenario. Images a and b show the chamber bottom cap (part 29) firmly bolted to a wooden tabletop. Image c then shows 2 chambers clamped and stacked onto the secure bottom cap.

1.8 Trouble shooting

SD-card not detected

SD card problems:

Cause 1: The SD card is corrupted therefore will not read.

Solution = Exchange the old sd card to a fresh sd card that you know works on other devices.

Solution = Load the SD card onto a computer. The computer will sometimes fix the sd card. For example, if the power was removed while the SD card was in use, the sd card can get confused. Just like how on a computer you are asked to eject a USB stick before removing from the device, you sd card can be temporarily corrupted!

Power problems:

1. Power cable not a thick enough gauge therefore doesn't allow the required current for the sd card to be detected.

Solution = change the usb cable to a thicker gauge

2. Power cable usb connector is not a high enough quality therefore doesn't get a strong enough connection to the powerbank. This can be visualised as flickering LEDs. This disrupted power supply stops the sd card (which is very power sensitive) from loading up/ being read.

Solution = change the usb cable to one with high quality connectors, and ensure that the powerbank usb connector has not been damaged also.

Solution = Quick fix solution can be to use duct tape to hold the usb connector into the power bank to maintain the quality connection.

3. The power cable has broken somewhere inside the cable. This can sometimes occur through repeated use.

Solution = Change the power cable for a new one!

4. The power bank has broken. This means that the power is not providing a smooth power supply at the correct voltage and current requirements.

Solution = Replace the power bank for one that is fresh, or that you know is functional.

Circuit problems:

1. The ATMEGA328p chip is not seated correctly in the ZIF socket. Sometimes the connection with one of the pins can be loose causing the SD → ATMEGA328p communication to be faulty.

Solution = Remove the ATMEGA328p chip from the ZIF socket and carefully replace it again in the ZIF socket, making sure that the connections are clean and in contact.

2. The ATMEGA328p chip has broken. This can sometimes happen due to a short circuit, or damage to the specific bus of the chip that deals with the sd card.

   Solution = Replace the ATMEGA328p chip for another ATMEGA328p chip that you know is functional on other circuits.

3. The SD card circuitry on the main circuit board has experienced damage and needs to be replaced.

Solution = Replace the circuit board for a new circuit board.

Solution = If you are confident in electronics, consult the circuit Gerber file and schematic. Replace the sd card components.

Real Time Clock (RTC) not detected

Programming problems:

1. The time on the clock need resetting. This can be because of a power supply interruption, or because the RTC was never set in the first place. This is usually the case if the chip is detected, but cannot begin the programme.

   Solution = Run the “set time” programme on the circuit board, to set the time to your computers time.

Circuit Problems:

1. There is a problem with one of the sensors running on the I2C bus of the ATMEGA328p. This can block the I2C line of the ATMEGA328p, for example by holding the data line high or low. This prevents the ATMEGA328p from communicating with the RTC, which also uses the I2C line for communication.

   Solution = Unplug the "Sensors" JST connector. If the clock is now detected on start-up, check your sensor board wiring, or replace the sensor board for a new one.

2. The RTC circuitry on the main circuit board has experienced damage and needs to be replaced.

   Solution = Replace the circuit board for a new circuit board.

   Solution = If you are confident in electronics, consult the circuit Gerber file and schematic. Replace the sd card components.

Stepper motor not running properly

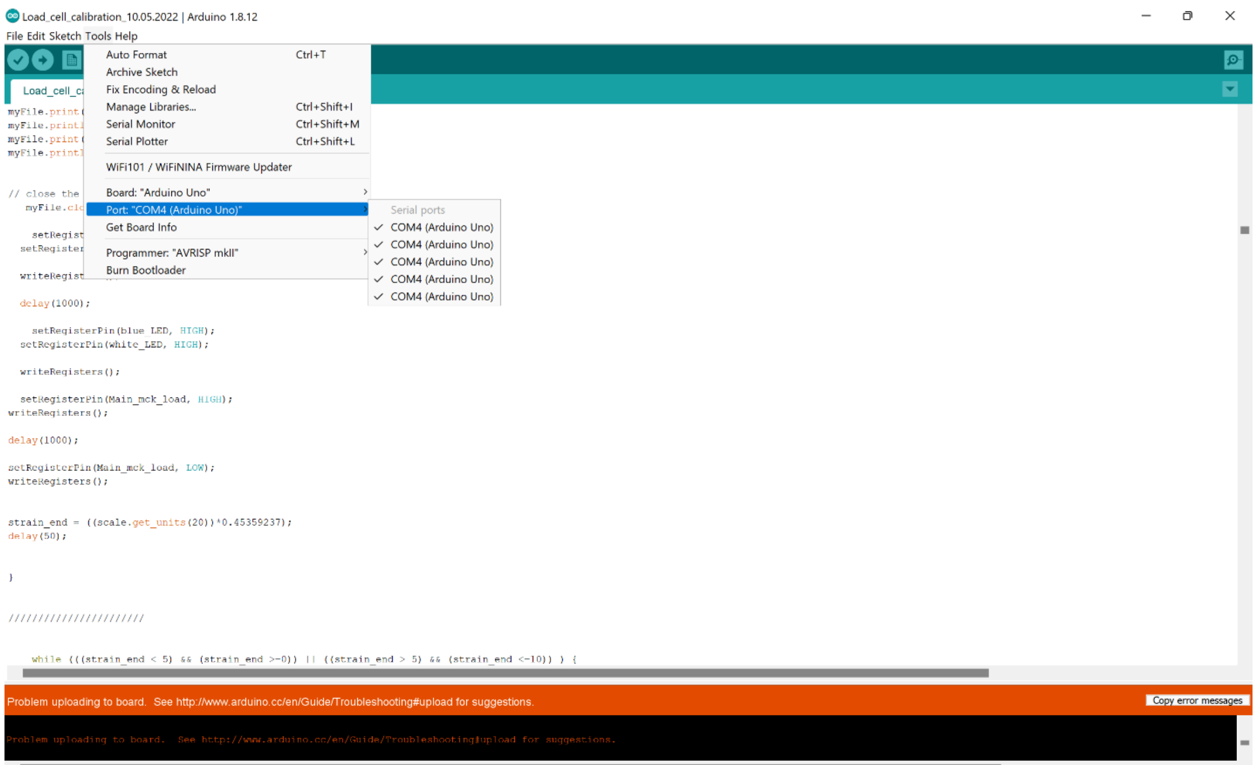
Stepper motor runs in short bursts "on_off_on_off"

1. Check the cables connecting the motor to the boost converter / step-up voltage board. If the cables are not a thick enough gauge, not enough power will be able to pass through to the motor, causing a start-stop motion, as emergency protection circuits do their job.

   Solution = Replace the cable running from the main circuit board to the boost converter/ step-up voltage board for a thicker gauge of cable.

Uploading code to microcontroller

1. Serial port error



2. Wrong USB cable used – make sure USB is not just power but has data cables as well.

   Solution = Use a new USB cable ensuring it has data transfere capabilities.

3. Corrupted ATMEGA328p chip

   Solution = replace the chip for a new one.

4. Damaged DIP / zif socket on Arduino uno programmer

   Solution = replace the DIP / ZIF socket on the Arduino uno, or buy a new Arduino uno using the DIP mount ATMEGA328p .

Chamber lid doesn't open when it should – Drumming noise when lid should be opening – 1, 0, error code.

1. Servo arm failiure - The pawl arms are not disengaging from the ratchet. This means that the stepper motor will try to move which is locked closed. The stalling of the motor causes a drumming noise.

   Solution = Check the servo arm is not loose. If it is, reset the arm position and glue carefully in place. Now the pawls should disengage from the ratchet as intended.

   Solution = If the servo arm is not loose, you may have set its position incorrectly. This would mean that the servo arm position does not match where it should be, to disengage the pawl arm from the ratchet. Reset the arm position or reset the pawl arm end position in the chamber code (only advised if the pawl arm is already glued in place and a quick solution is needed).

   Solution = The servo arm does not respond to any command. Test with the "servo test" Arduino programme. If it still does not respond, check your wiring to the servo motor, and if this doesn't change anything, replace the servo motor with a new one.

2. ATMEGA328p not seated correctly in ZIF socket – E.g. one of the pins on the chip is not making contact with the circuit board.

   Solution = Take out the ATMEGA328p chip, check the pins are not bent or dirty (in which case carefully bend pins back or remove the dirt), check the chip orientation is correct and re-insert the chip.

3. Programming Failiure – Something has caused the ATMEGA328p chip to malfunction.

   Solution = Reprogramme the chip and install back onto the board. This reset of the chip can often solve the issue, particularly if the system has been turned on and off again repeatedly during testing.

Part 2 | Valve Changer Module

a.)

b.)

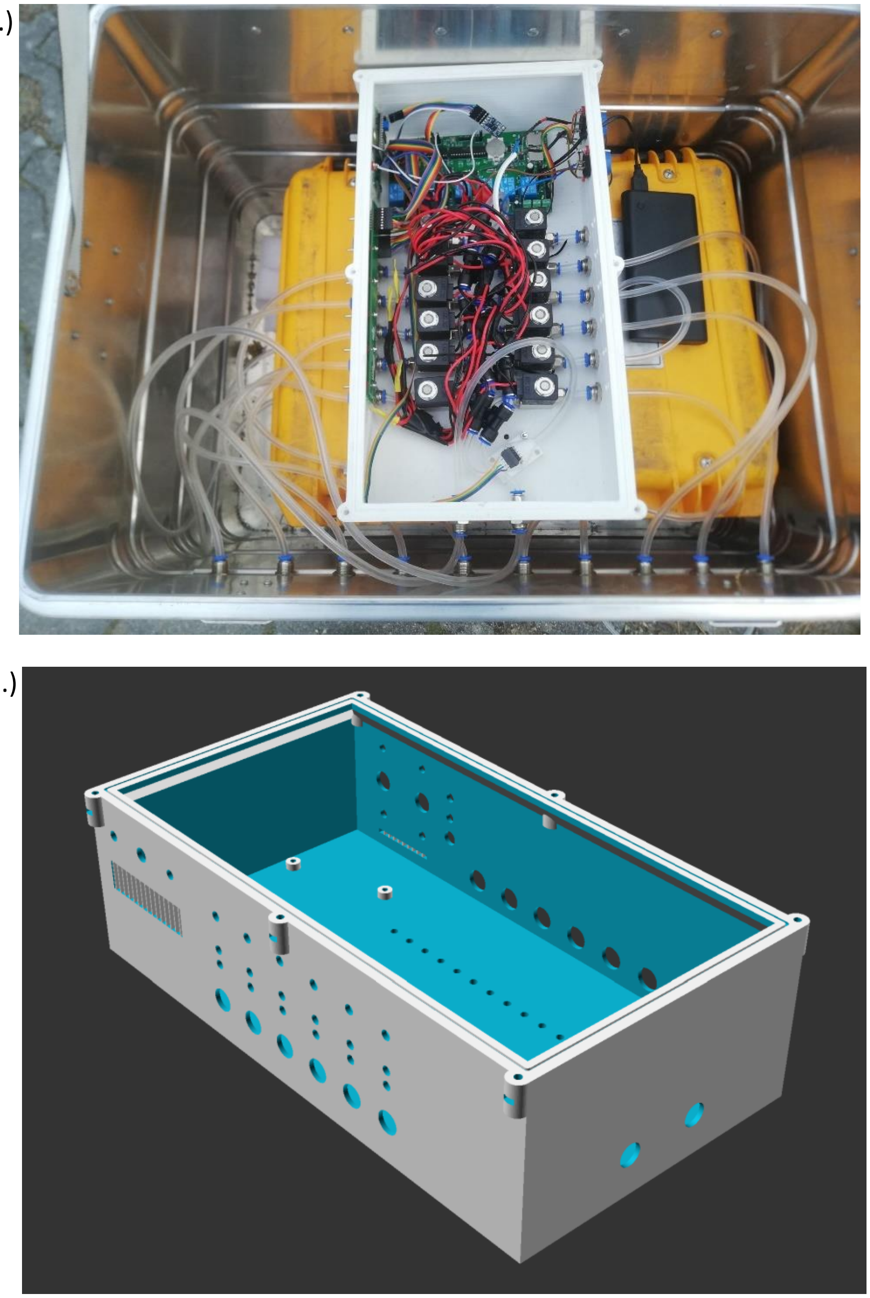


Figure 123 - Illustration of the valve changer module for the Chamber.1 system. Image a shows the module deployed in field conditions, while image b shows the CAD model of the module.

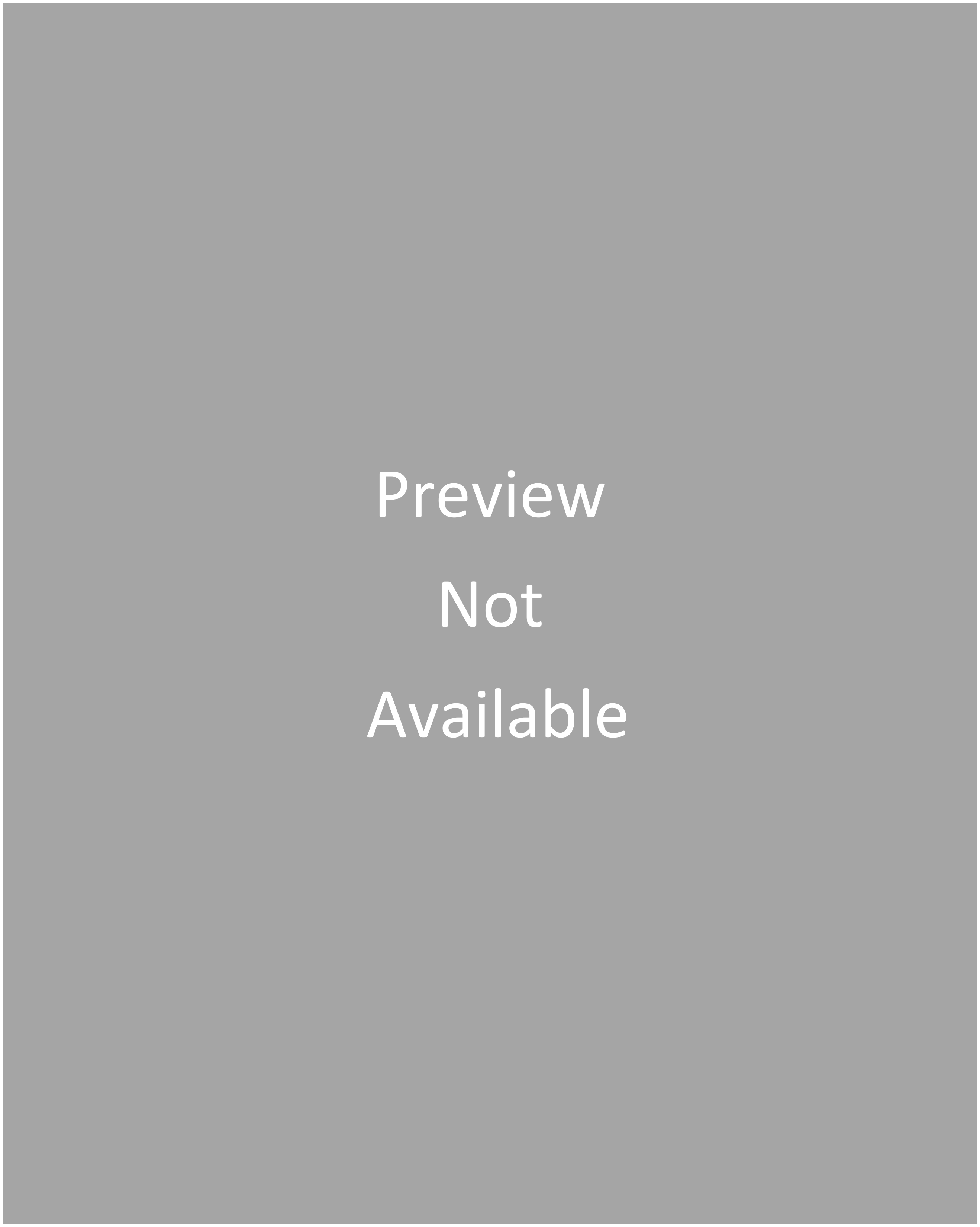
2.1 Parts List

Preview

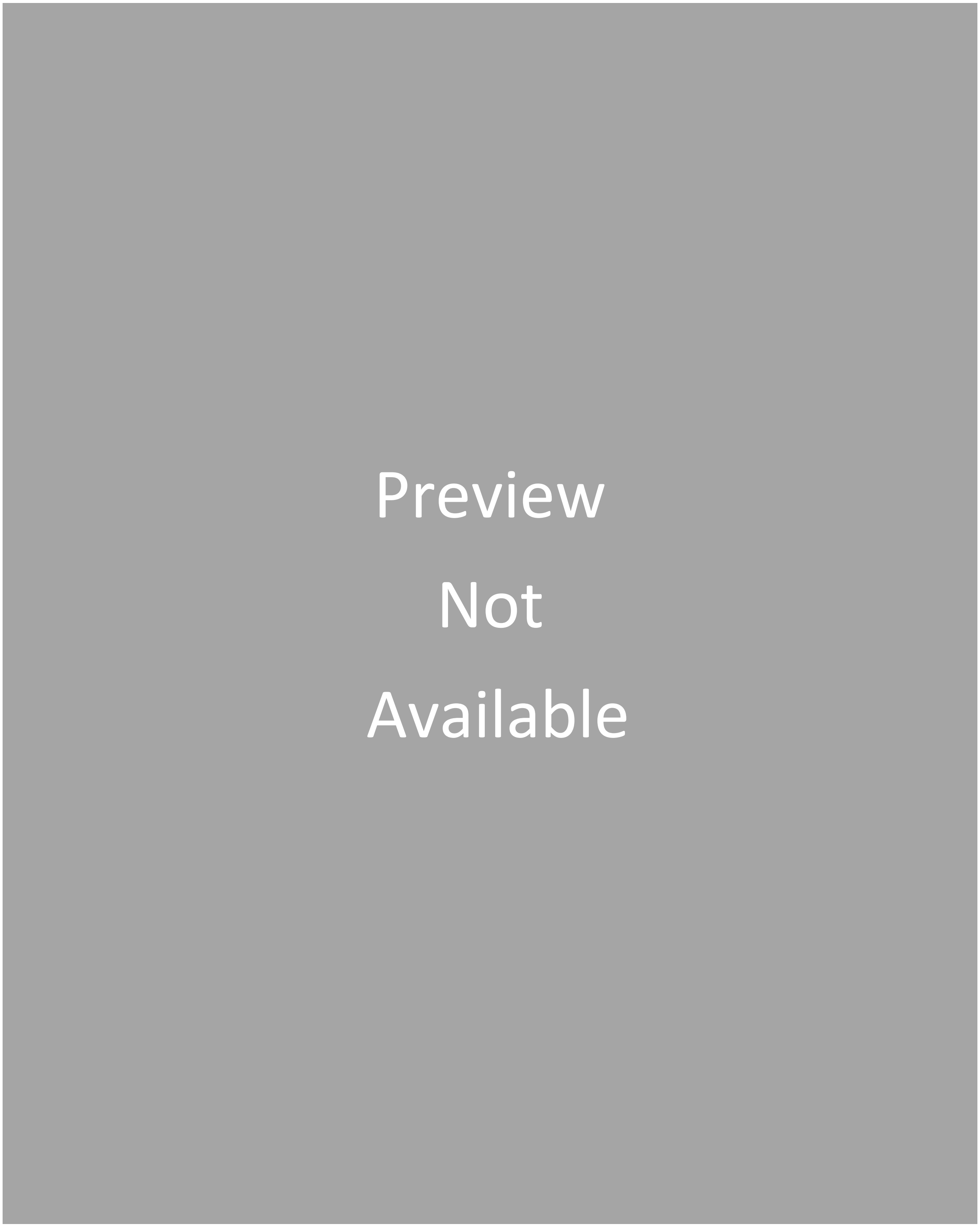
Not

Available

2.2 3D Printing



2.3 3D printing post processing



2.4 Parts assembly

Preview

Not

Available

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