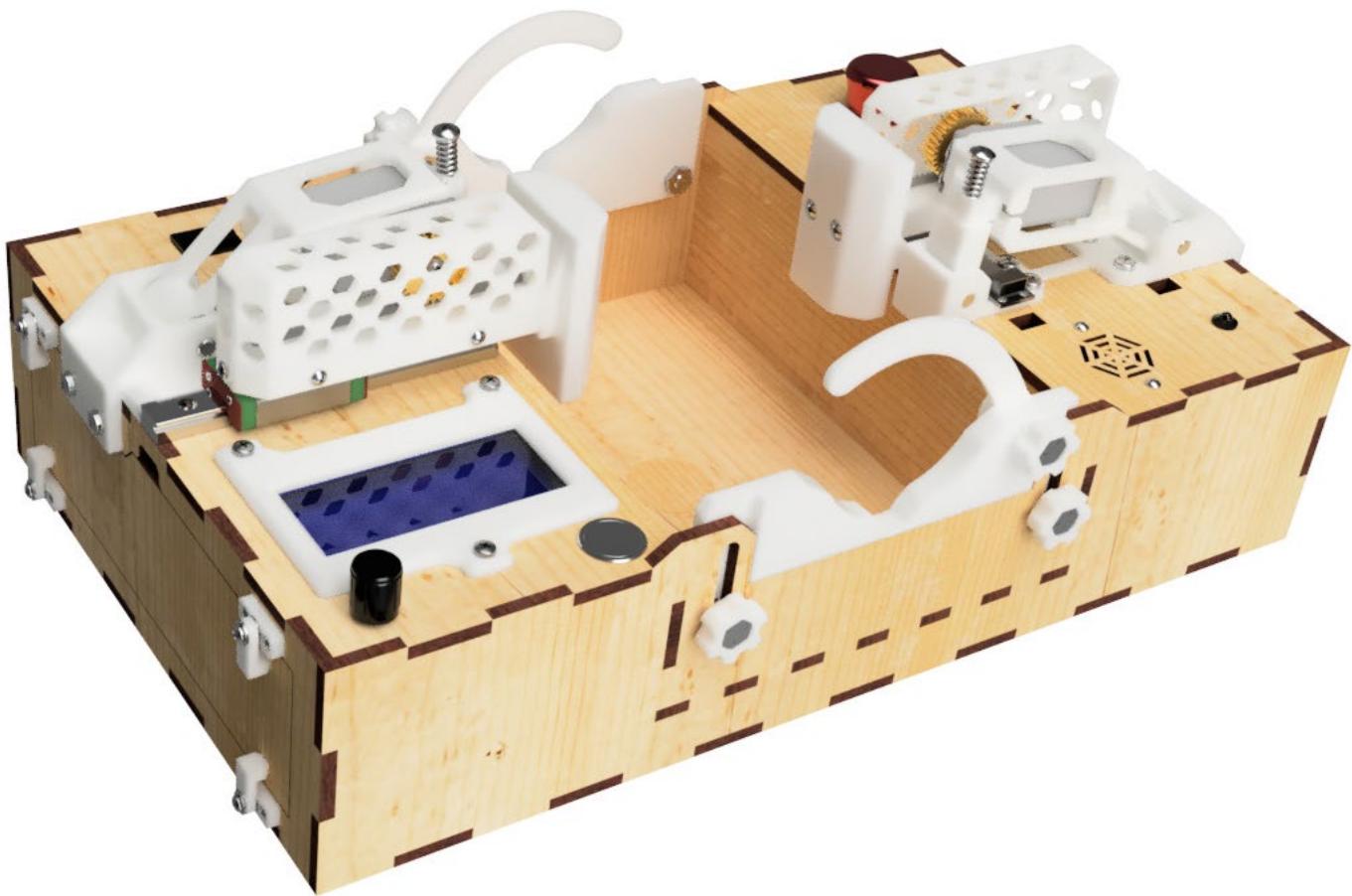




RICE | OEDK
Oshman Engineering Design Kitchen

ApolloBVM

ApolloBVM - Emergency Use Ventilator
Automated Bag Valve Mask



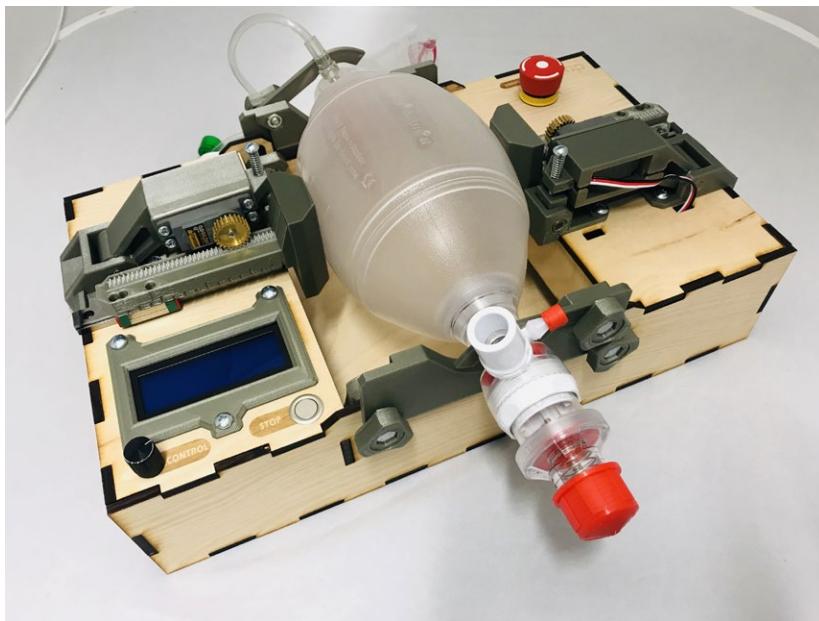
Mechanical Build Assembly Instructions

Revision: 1
Release Date: 6/10/2020

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OVERVIEW OF ApolloBVM



range of high-acuity limited-operability (HALO) ventilator solutions with an a priori design to produce volume and pressure cycled ventilation that includes positive end-expiratory pressure (PEEP) and enriched oxygen sources.

Controls of the ApolloBVM are familiar and clinician-designed with adult, child, and pediatric settings. They allow for tailored ventilation, adjustable I:E ratios, and variable positive pressure. Please note: This design took inspiration from the 2018-2019 Rice University Senior Design Project from Team Take A Breather.

Advantages of ApolloBVM:

Our solution presents many novel advantages including:

End-to-end clinician-informed design inclusive of all critical engineering touch-points
Control systems that are designed to accommodate ARDS settings with positive pressure
Price target under \$250 and components allow for an entirely disposable unit
Hot-swappable parts and power sourcing, with an easily controllable mechanical junction
Fully constructed from DIY components and readily available parts

The ApolloBVM is an automated bag valve mask (BVM) device utilizing off-the-shelf components to provide safe and continuous hospital-grade mechanical ventilation for COVID-19 patients on an open-source basis.

The ApolloBVM is a controllable, automated add-on solution to the existing and widely available Bag Valve Mask. The device compresses the BVM with a mechanical system that is able to provide consistent and accurate ventilation with positive-pressure. This solution exists within the top

Current version: Revision 1

The current prototype employs a dual rack-and-pinion mechanical design converting rotational motion of motors into translational motion for bag compression. The device is powered by 120V AC with a < 15W power draw.

The device accommodates wall or tank-based oxygen through the low-pressure oxygen intake port that is a standard to the BVM.

Current available settings for the device are the following:

Tidal Volume (TV): 300 - 650 mL (50 mL increments)

Respiratory Rate (RR): 5 - 30 BPM (1 BPM increments)

I:E Ratio: 1:2, 1:3, 1:4, 1:5

The user interface consists of an LCD screen that allows the user to set the operating parameters of the device and start compression in less than one minute. During operation, this display also informs the user of the current TV, RR, and I:E. The user can adjust the settings during usage of the device without shutdown. An emergency shut off button allows for immediate cessation of compression.

Initial tests have shown that the ApolloBVM is capable of delivering physiologically relevant volumes of compression for 24 hours of operation.

Total Cost of all parts <\$300

The total cost of the parts to make the device is expected to be under \$250. This number is a significant decrease from the cost of entry-level ventilators with a starting price of \$5000. For a DIY device, this price is arrived at assuming that equipment related to assembly are readily available and does not need to be purchased.

Components and Assembly

ApolloBVM is assembled from readily available, consumer off-the-shelf parts. The majority of components are intended for use as-is and easily ordered through online retailers or hardware stores. Other parts including casing and gears may be 3D printed or laser cut. Our design files include a Bill of Materials for each of the components, ordered, or fabricated.

Size

The ApolloBVM device cradles and secures the BVM with a design that balances a small footprint with limited play during and between breath cycles. The current version INCLUDING an adult BVM would be approximately, 14" by 16" by 7".

Weight

The goal is for the device to be placed next to the patient on a side table or using a portable bedside table. The device is light-weight so it can be portable. The device currently weighs less than 10lbs.

Time from beginning of setup to first compression cycle

The time from the machine being turned on to delivering the first breath is less than 1 minute.

Design Specifications/Goals (Reported for Revision 1)

Specification	Value
Total cost of device	<\$250
Time device can run without human intervention	Tested to 24 hours
Time from beginning of setup to first compression cycle	Less than 1 minute
Size (with adult Ambu bag)	Device footprint < 16"x14"x7"
Weight	Device (including bag) weighs < 6lbs
Power usage	<15W

ApolloBVM Design team

Danny Blacker - Lead Designer

Dr. Maria Oden - Faculty Mentor

Dr. Matthew Wettergreen - Faculty Mentor

Thomas Herring - Controls Lead

Amy Kavalewitz - Project Manager

Dr. Rohith Malya - Clinical Lead

Fernando Cruz - Engineering Design Technician

All design work on the ApolloBVM was done at the **Oshman Engineering Design Kitchen** at Rice University

Inspired by the 2018-2019 senior design project **Team Take A Breather**

Parts List

Purchased Parts

Fasteners

1. 1/4"-20 x 1" Bolt (x2)
2. 1/4"-20 Nut (x6)
3. 1/4"-20 x 3/4" Bolt (x4)
4. #4 x 1/2" Screw (x38)
5. #6 x 1/2" Screw (x8)
6. 1/4" Washer (x4)
7. 1/4" x 1-1/2" Steel Dowel (x2)
8. #10-32 Nut (x2)
9. 1/4" x 1" Steel Dowel (x2)
10. #2 x 1/4" Screw (x14)
11. #8 x 1/2" Screw (x17)
12. M3 x 0.5 x 8mm (x8)
13. #8 x 1" (x4)
14. #10-32 x 1-1/2" Socket Screw (x2)
15. #4-40 x 3/4" Screw (x8)
16. #4-40 Lock Nut (x8)
17. #4 Washer (x16)

Purchased Parts

Components

- 1a. MGN12 x 120mm Linear Rail (x2)
- 1b. MGN12 (or MGN12H) Block (x2)
2. goBILDA Torque Servo (x2)
3. 32 Tooth 32 Pitch H23T Spline Gear (x2)
4. 20° Pressure Angle - 32 Pitch Gear Rack (*cut to 4"*) (x2)
5. 1" Compression Spring (x2)
6. Speaker - PSR-29F08S02-JQ
7. RGB LED - 5mm
8. 5mm LED Housing
9. Emergency Stop Button - 22mm
10. New Haven 20x4 LCD Display
11. Power Switch
12. 2.1 mm DC Power Jack
13. Arduino Uno R3
14. Breadboard - 400 Tie-Points
15. Limit Switch
16. Rotary Encoder - KY-040
17. Pushbutton - 16mm
18. Power Supply - 7.5V 2A - 2.1mm



3D Printed Parts

PLA

0.2mm Layer Height
75-100% infill

1. BVM Support (x2)
2. BVM Clasp (x2)
3. Knob (x6)
4. 2mm Servo Shim (x2)
5. Servo Mount (x2)
6. Servo Mount Base (x2)
7. Servo Spring Base (x2)
8. Gear Rack Base (x2)
9. Bumper (x2)
10. Speaker Mount
11. Display Mount
12. Hatch Latch (x8)
13. Hatch Front Plate (x8)
14. Hatch Back Plate (x8)
15. Arduino Mount (x2)
16. Bread Board Mount
17. Servo Guard (x2)



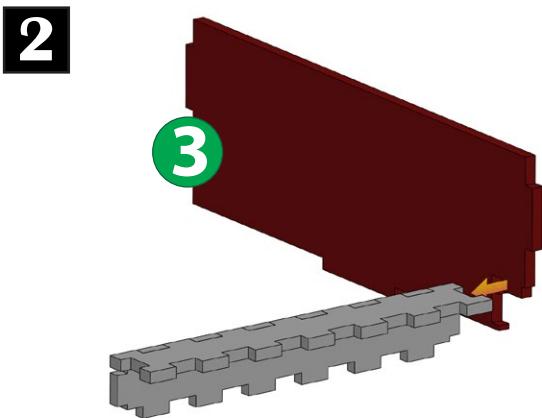
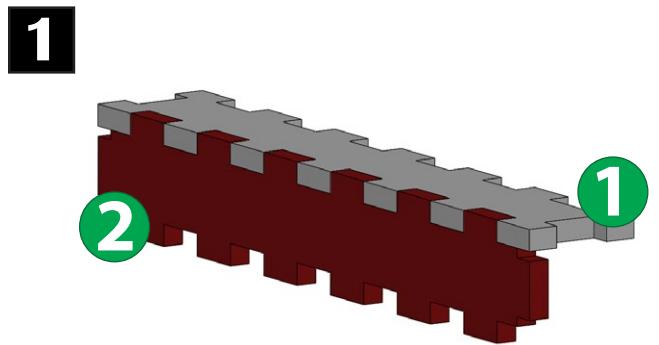
Laser Cut Wood

1/4" or 5mm Birch Ply

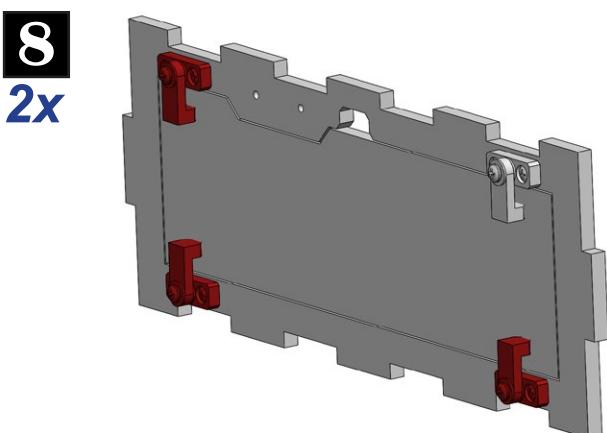
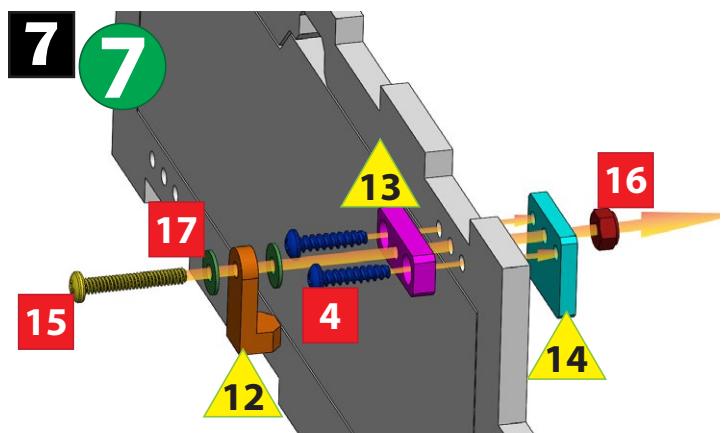
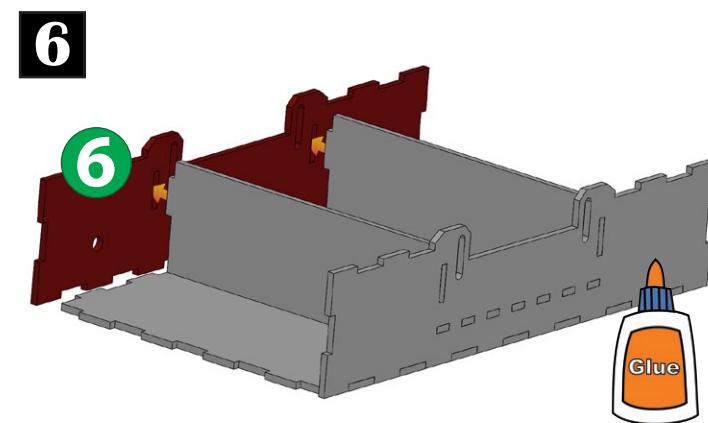
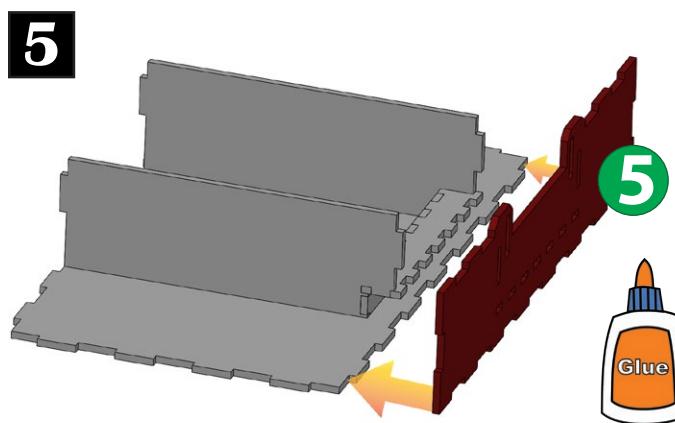
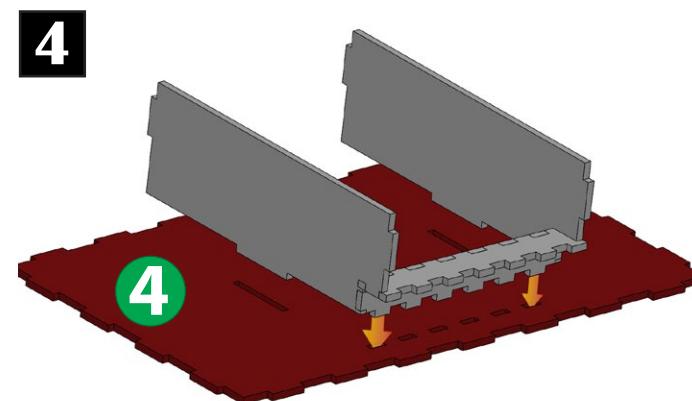
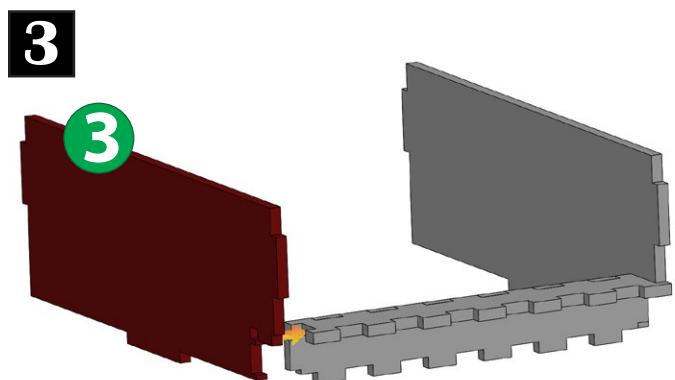
1. Pass-thru - Top
2. Pass-thru - Side
3. Brace (x2)
4. Bottom
5. Front
6. Back
7. Side (x2)
8. Top - Left
9. Top - Right



Assembly Instructions

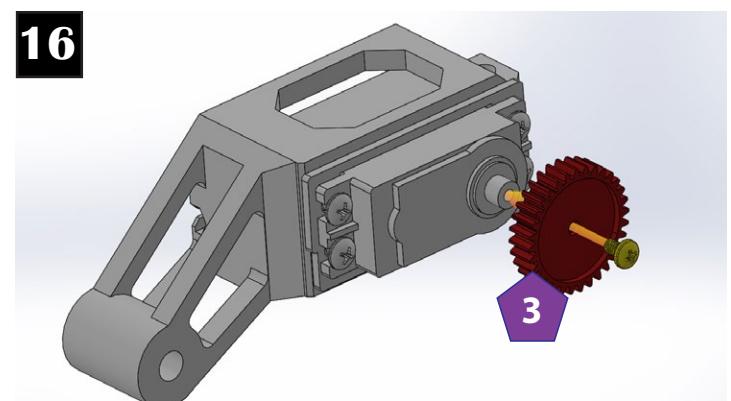
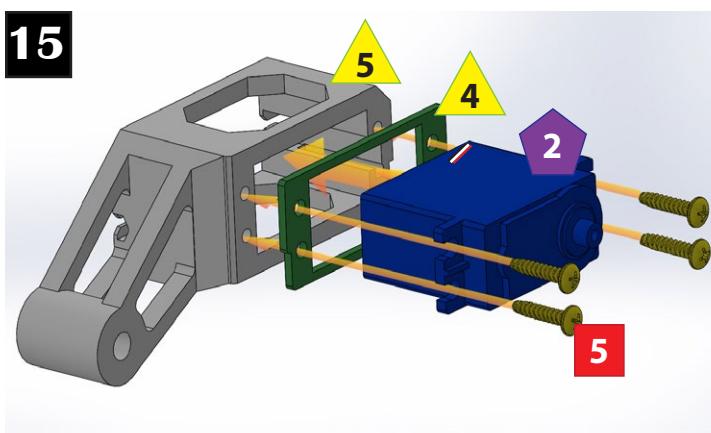
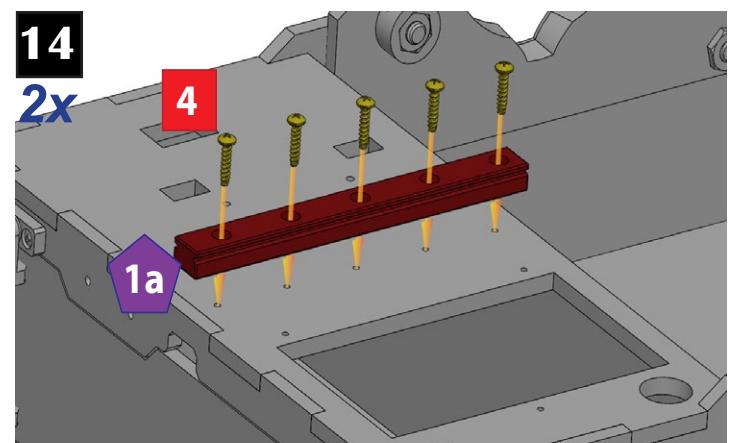
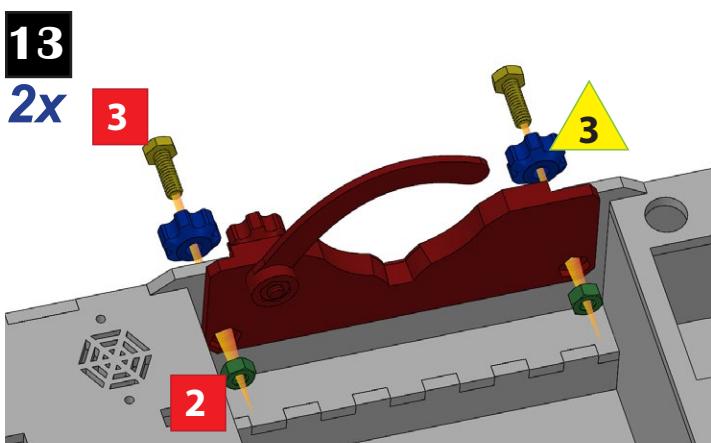
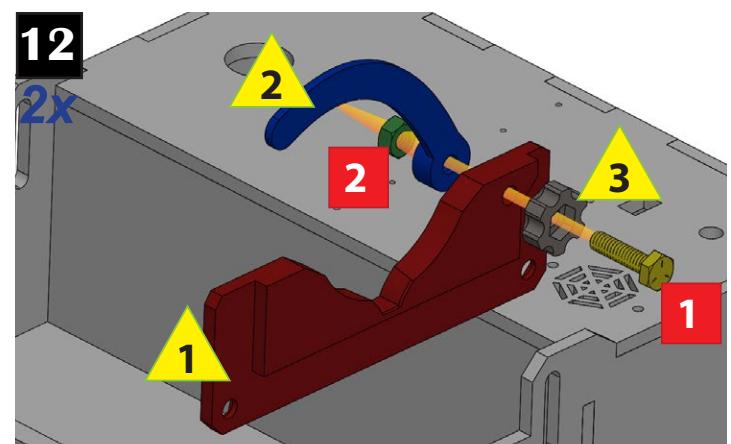
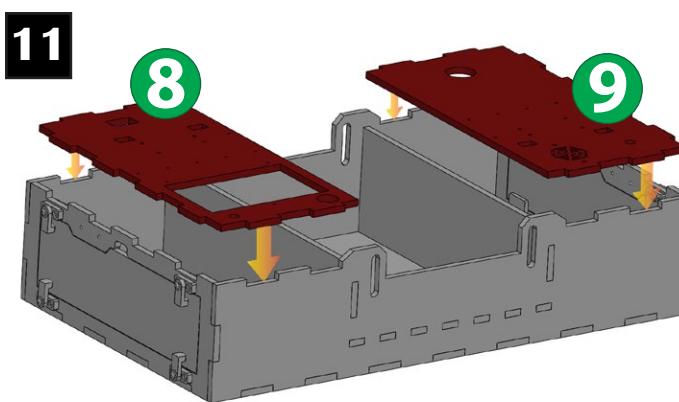
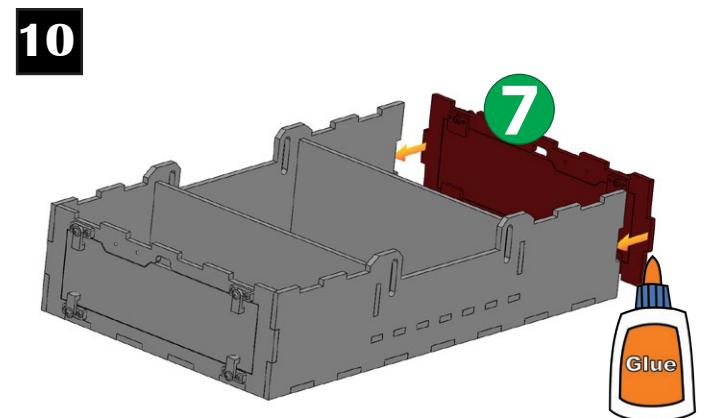
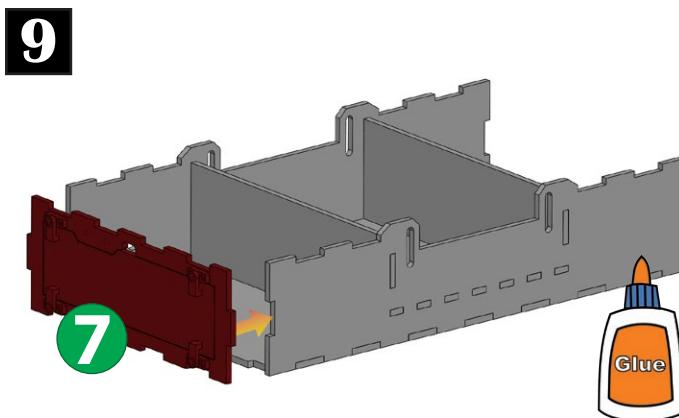


*Note: A loose fit between the two pieces is OK.

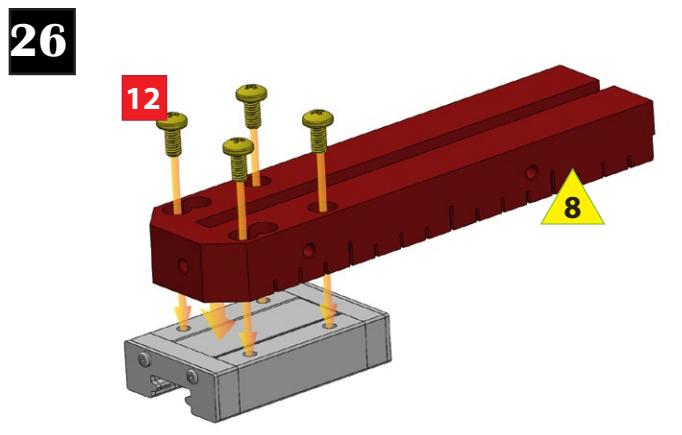
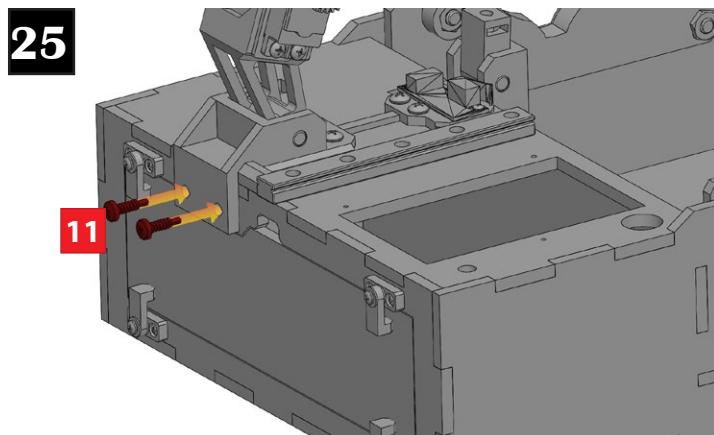
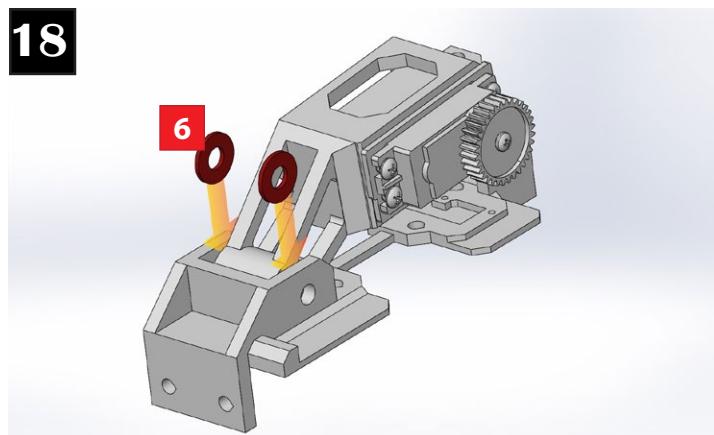
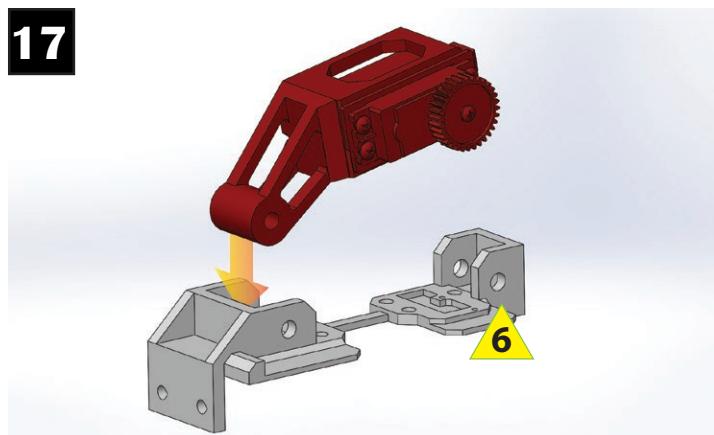


Insert locking nut (16) curved side out into backing (14) for an easier assembly.

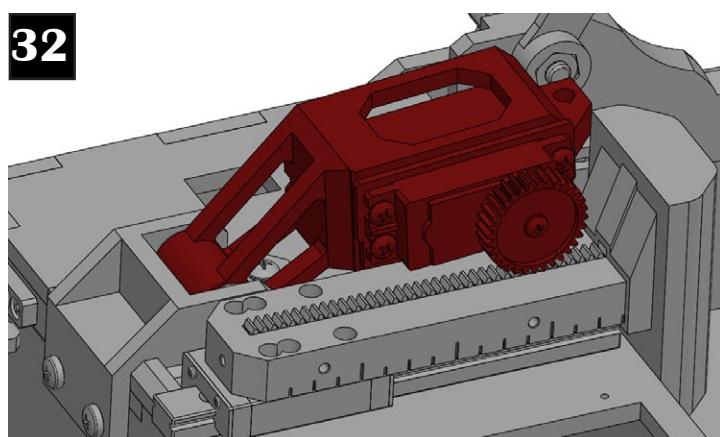
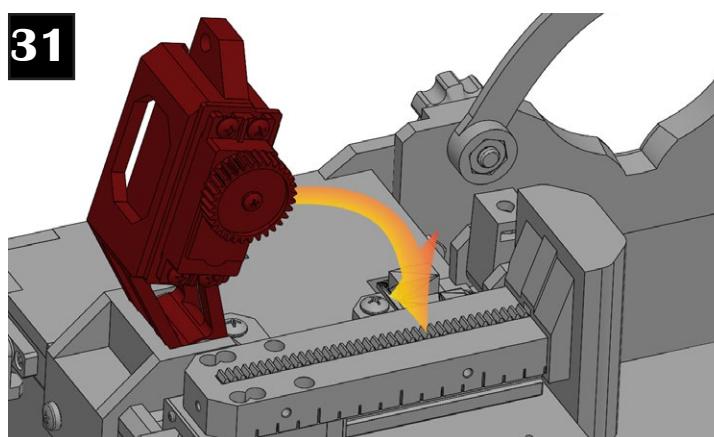
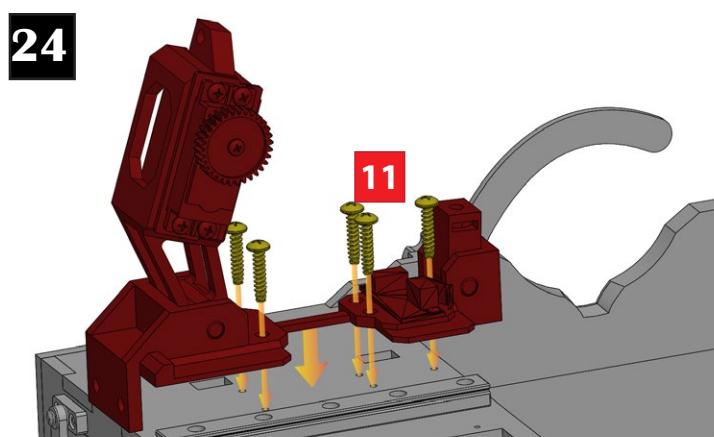
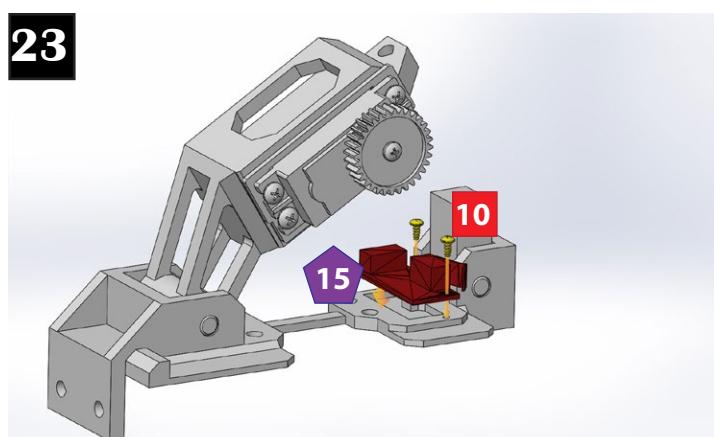
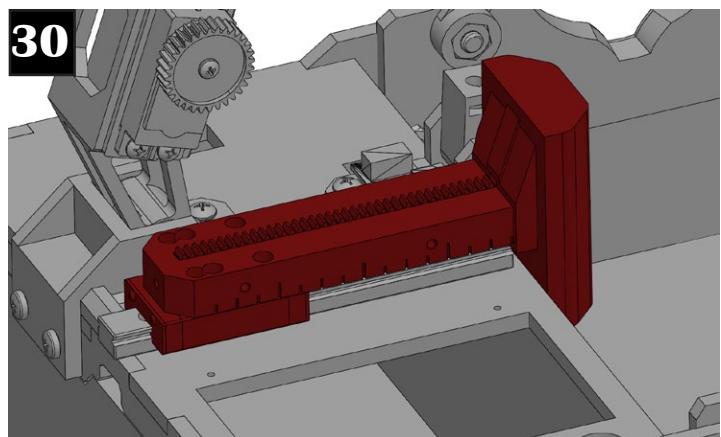
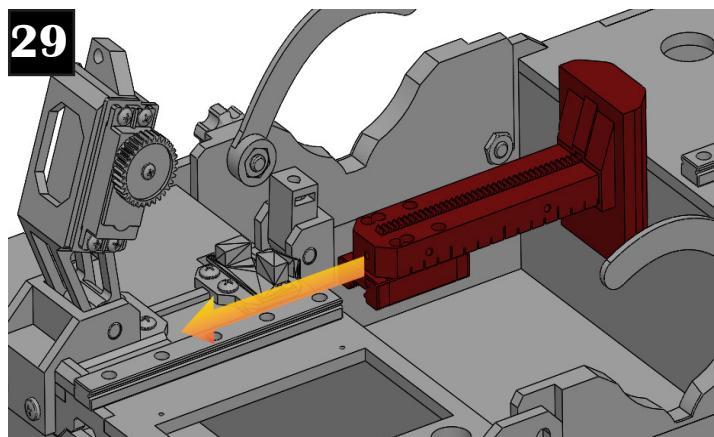
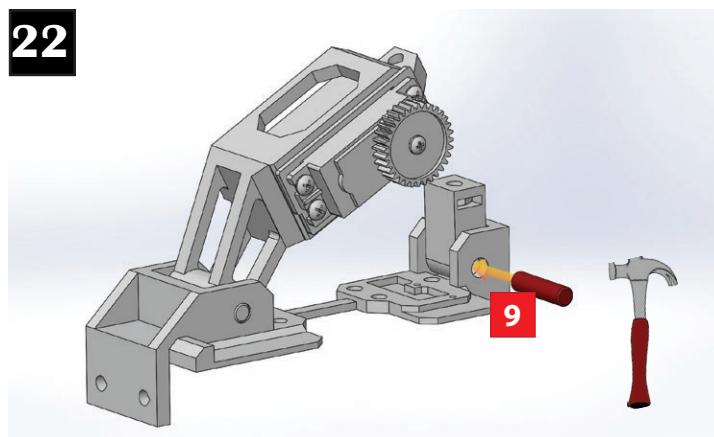
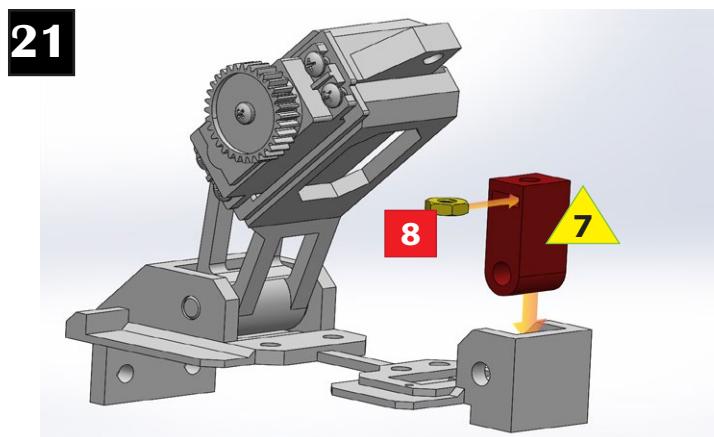
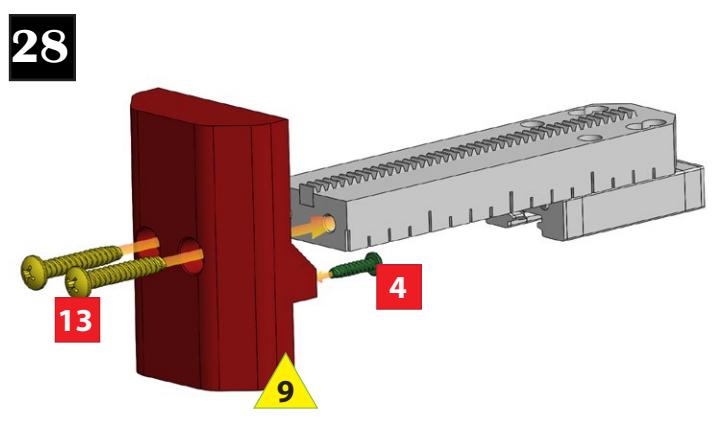
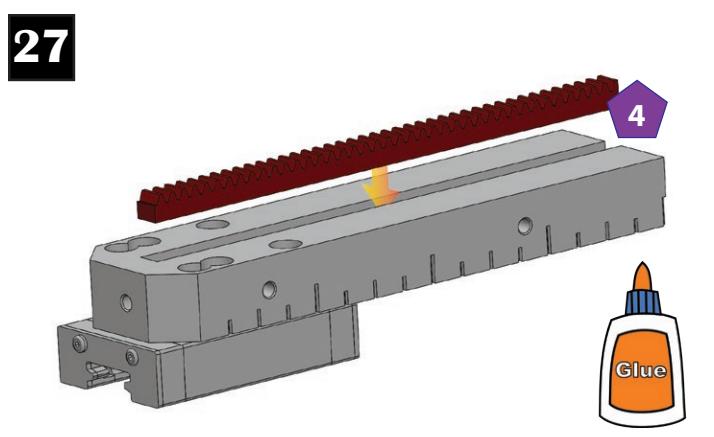
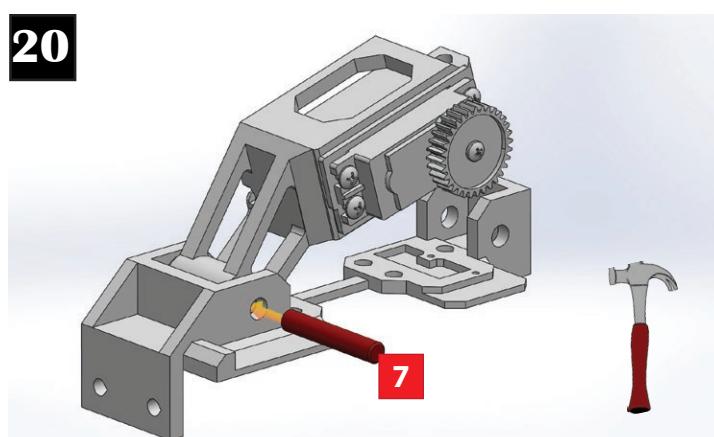
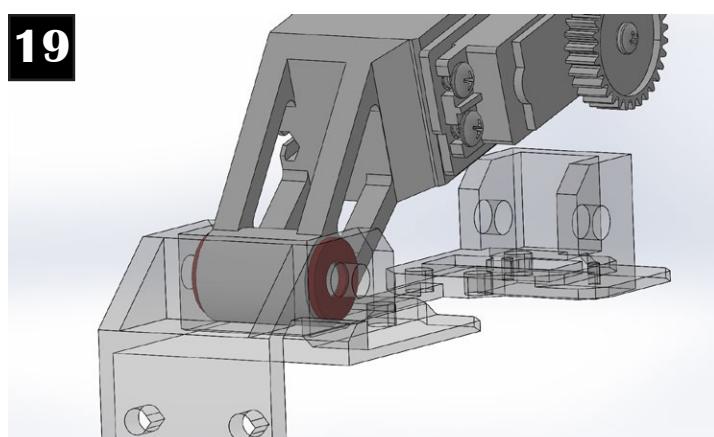
Repeat Step 7 three more times

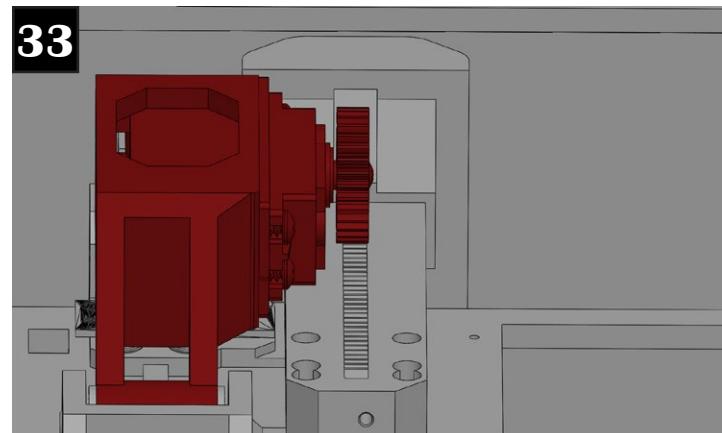


Screw supplied with servo

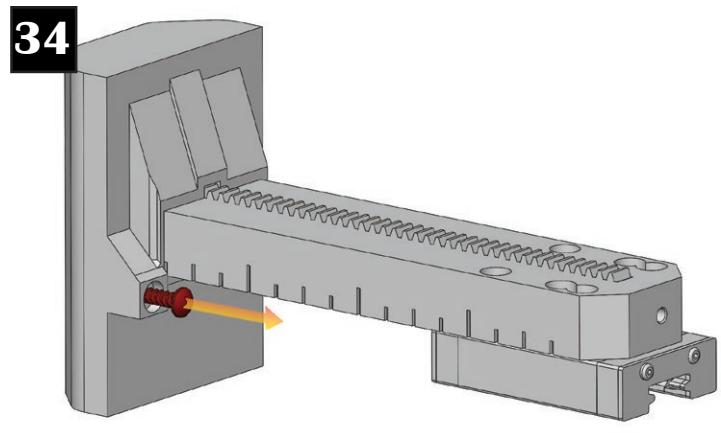


*Hole spacing may differ from picture

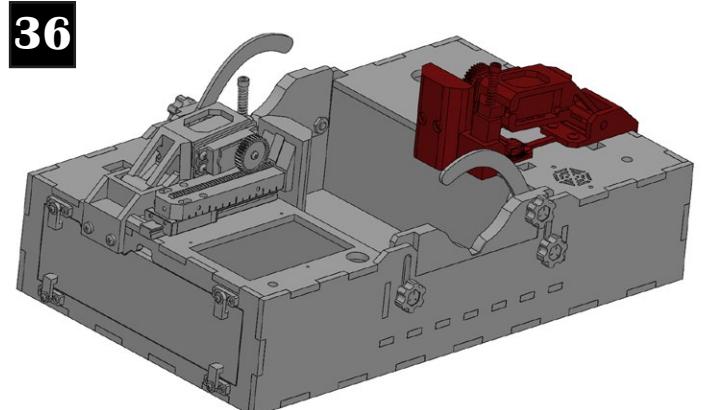
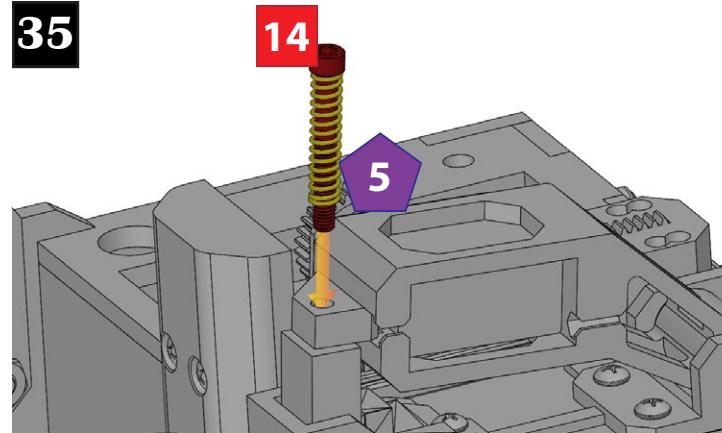




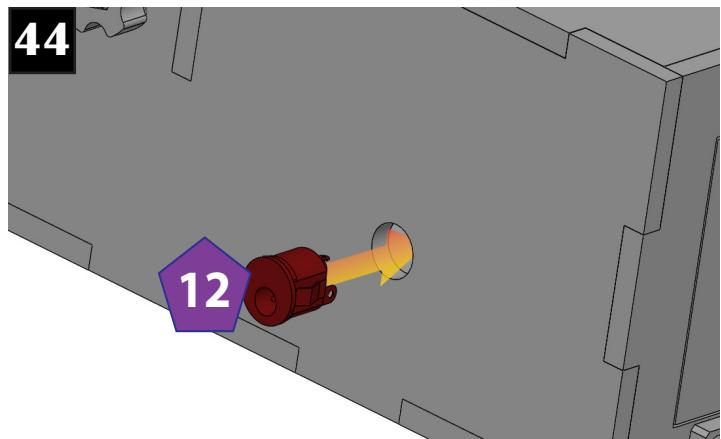
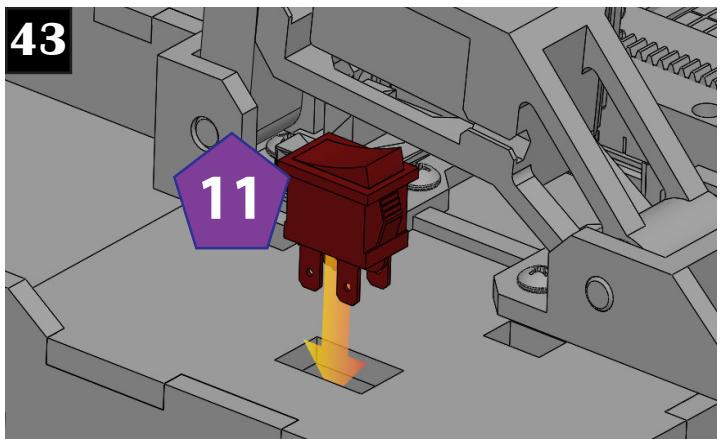
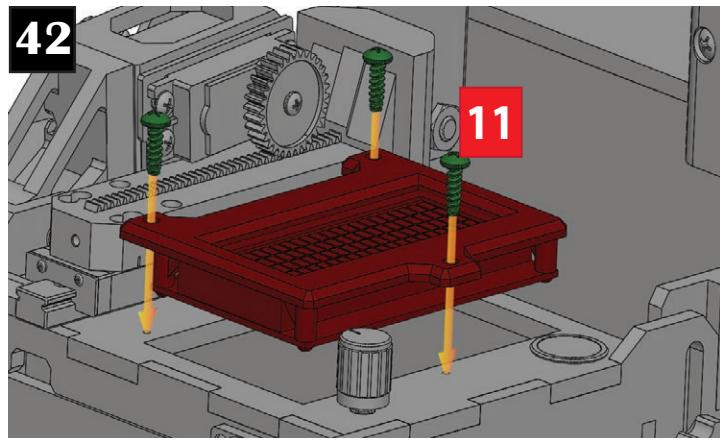
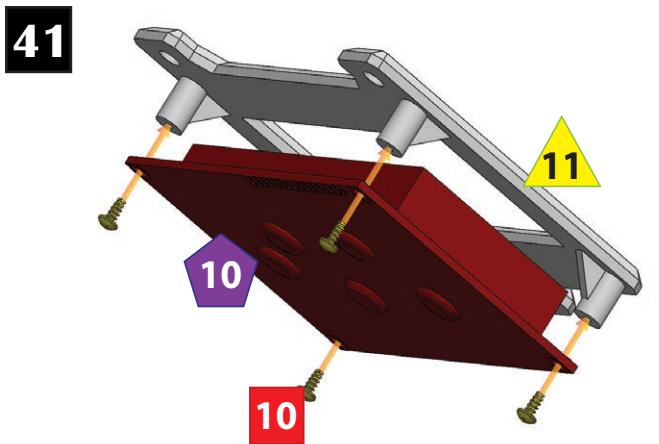
Use different size shims if gear is not properly aligned with gear rack.



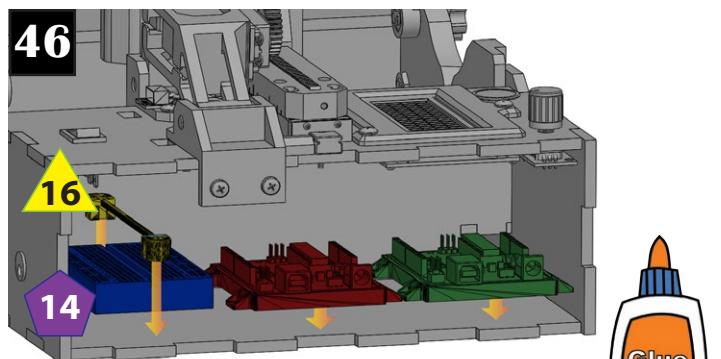
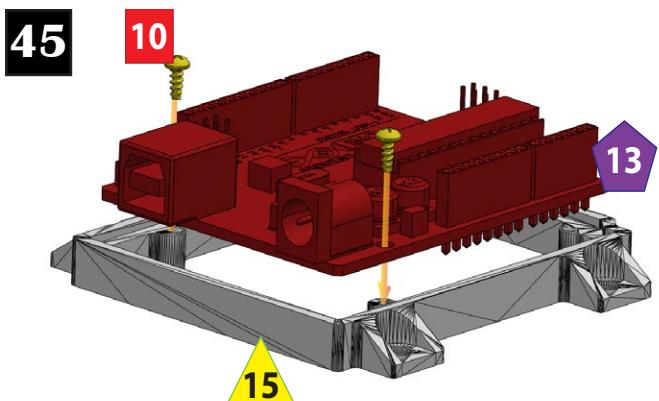
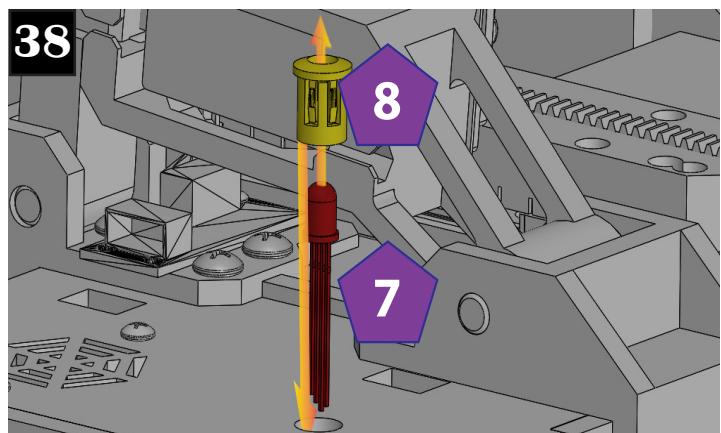
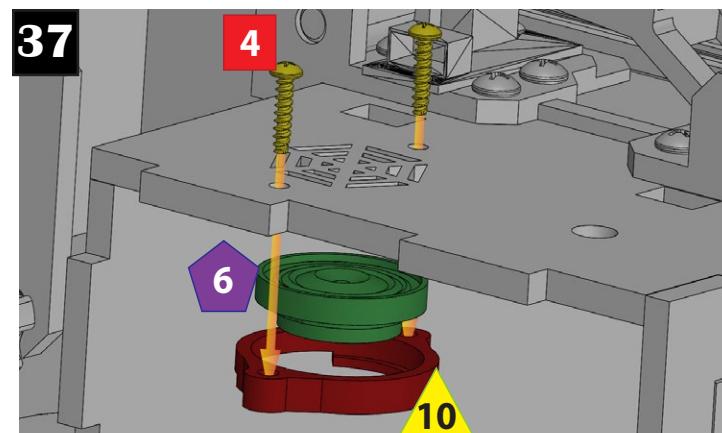
If limit switch doesn't activate with bumper fully retracted, extend limit switch activation extension screw.



Repeat steps 14-35 to complete other side.

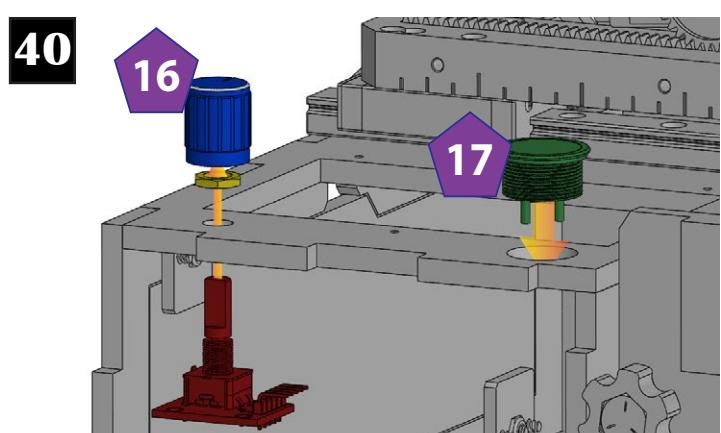


*Your button may have a nut to remove before installation.

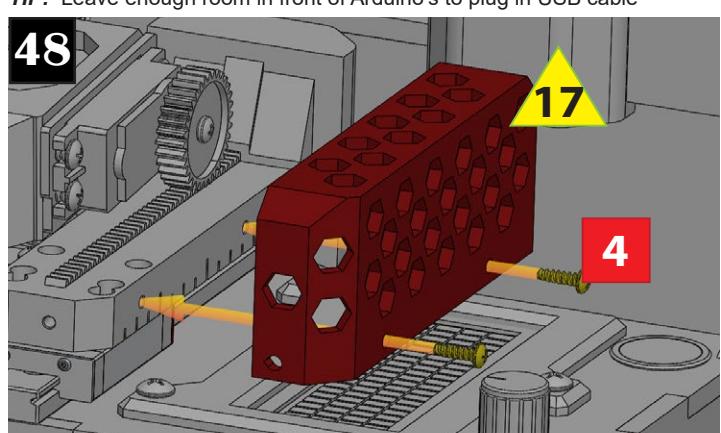
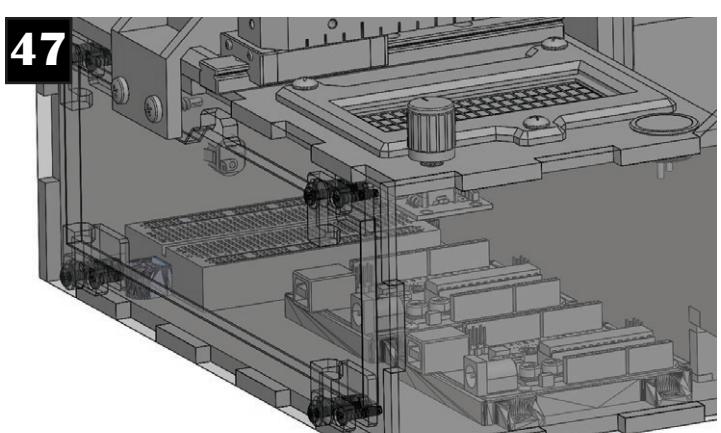


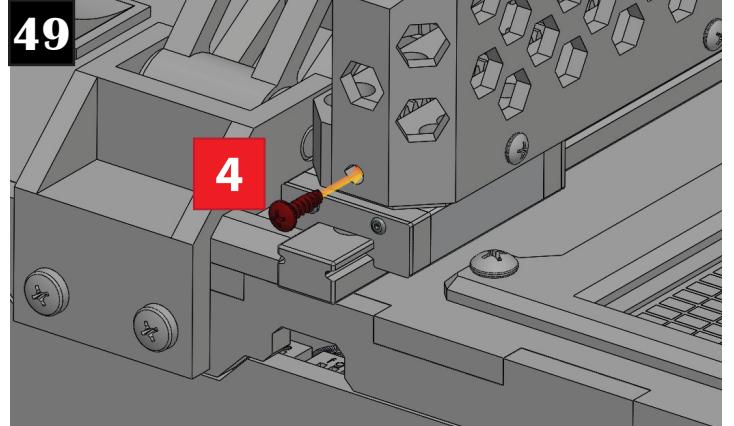
TIP: Flash software code and wire up as much as you can before gluing in place

TIP: Leave enough room in front of Arduino's to plug in USB cable

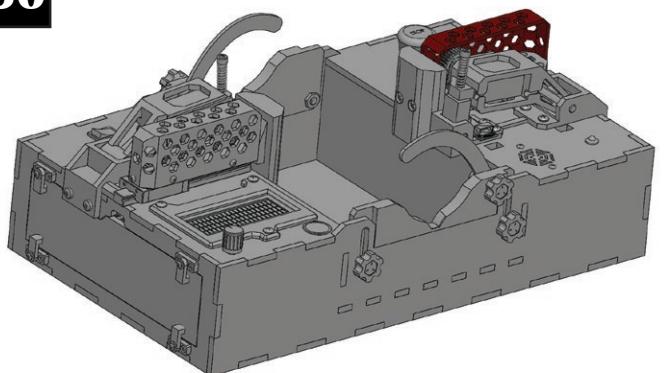


*Your button may have a nut to remove before installation.

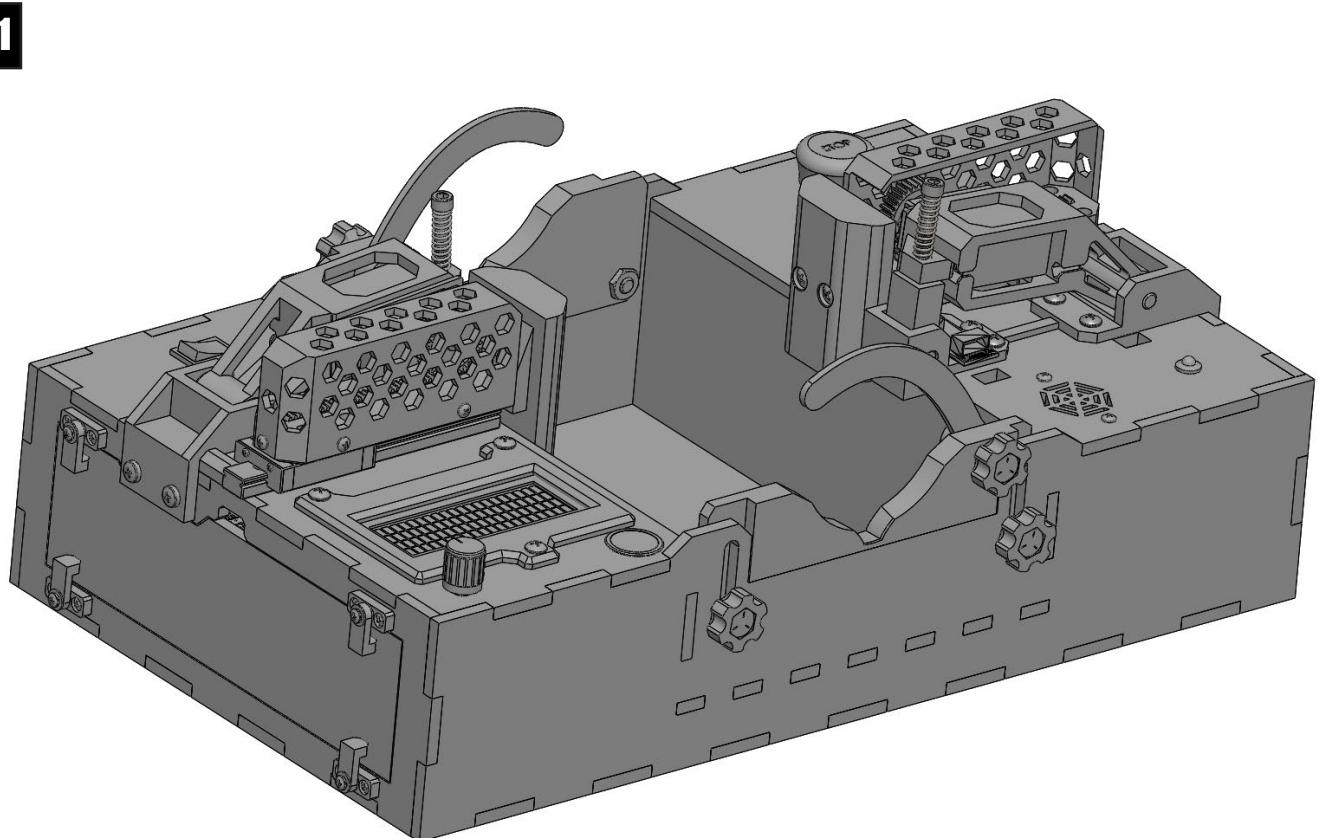




49



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Parts List Links

Purchased Parts

Fasteners

1. 1/4"-20 x 1" Bolt (x2)	https://www.mcmaster.com/92865a542
2. 1/4"-20 Nut (x6)	https://www.mcmaster.com/95462a029
3. 1/4"-20 x 3/4" Bolt (x4)	https://www.mcmaster.com/92865a540
4. #4 x 1/2" Screw (x38)	https://www.mcmaster.com/90380a110
5. #6 x 1/2" Screw (x8)	https://www.mcmaster.com/90380a148
6. 1/4" Washer (x4)	https://www.mcmaster.com/90107a029
7. 1/4" x 1-1/2" Steel Dowel (x2)	https://www.mcmaster.com/98381a546
8. #10-32 Nut (x2)	https://www.mcmaster.com/90480a195
9. 1/4" x 1" Steel Dowel (x2)	https://www.mcmaster.com/98381a542
10. #2 x 1/4" Screw (x14)	https://www.mcmaster.com/90380A005
11. #8 x 1/2" Screw (x17)	https://www.mcmaster.com/90380a194
12. M3 x 0.5 x 8mm (x8)	https://www.mcmaster.com/92000a118
13. #8 x 1" (x4)	https://www.mcmaster.com/90380a202
14. #10-32 x 1-1/2" Socket Screw (x2)	https://www.mcmaster.com/90128a951
15. #4-40 x 3/4" Screw (x8)	https://www.mcmaster.com/91772a113
16. #4-40 Lock Nut (x8)	https://www.mcmaster.com/90631a005
17. #4 Washer (x16)	https://www.mcmaster.com/92141a005

Purchased Parts

Components

1. MGN12 or MGN12H x 120mm Linear Rail (x2)	https://bit.ly/35pTp9n	https://bit.ly/3d83Xwv
2. goBILDA Torque Servo (x2)	https://bit.ly/3aXKMnI	https://bit.ly/2KUdonq
3. 32 Tooth 32 Pitch H23T Spline Gear (x2)	https://bit.ly/3aWF5q7	
4. 20° Pressure Angle - 32 Pitch Gear Rack (cut to 4") (x2)	https://www.mcmaster.com/2662n53	
5. 1" Compression Spring (x2)	https://www.mcmaster.com/9657k149	
6. Speaker - PSR-29F08S02-JQ	https://bit.ly/3aUwlAD	
7. RGB LED - 5mm	https://bit.ly/2KTsbP4	
8. 5mm LED Housing	https://bit.ly/3feDWxB	
9. Emergency Stop Button - 22mm	https://amzn.to/2Yy4CU9	
10. New Haven 20x4 LCD Display	https://bit.ly/2VXL91X	
11. Power Switch	https://bit.ly/3feDUFZ	
12. 2.1 mm DC Power Jack	https://amzn.to/3aYMifM	
13. Arduino Uno R3	https://www.sparkfun.com/products/11021	https://www.adafruit.com/product/2488
14. Breadboard - 400 Tie-Points	https://www.servocity.com/400-point-breadboard	https://bit.ly/2YsCNwc
15. Limit Switch	https://amzn.to/2Whfgf2	
16. Rotary Encoder - KY-040	https://amzn.to/2zUKhy5	https://bit.ly/2WmPEgH
17. Pushbutton - 16mm	https://bit.ly/3fc57ZD	
18. Power Supply - 7.5V 2A - 2.1mm	https://amzn.to/3aW0boB	

Completed assembly!

IMPORTANT!! When applying power for the first time, raise servo gear off of gear rack to allow servo to zero. Once servo has zeroed, you can lower the servo gear and secure with socket screw.

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The ApolloBVM System has not been FDA Approved by the Food and Drug Administration (FDA) or any other governmental or oversight authority.

Several FDA guidance documentation may apply, as well as certain declarations on liability immunity for pandemic countermeasures.

The information is being provided without warranties (expressed and/or implied).

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There is no further obligation of Rice to make available clinical data, modifications, or improvements to the ApolloBVM System.

