1) HARDWARE ASSEMBLY

PARTS:

See "VBA 5.0 hardware bill of materials" spreadsheet

3D printing:

1 **3D printed flag** (see flag_v3.stl in /CAD/ folder of repository on GitHub)

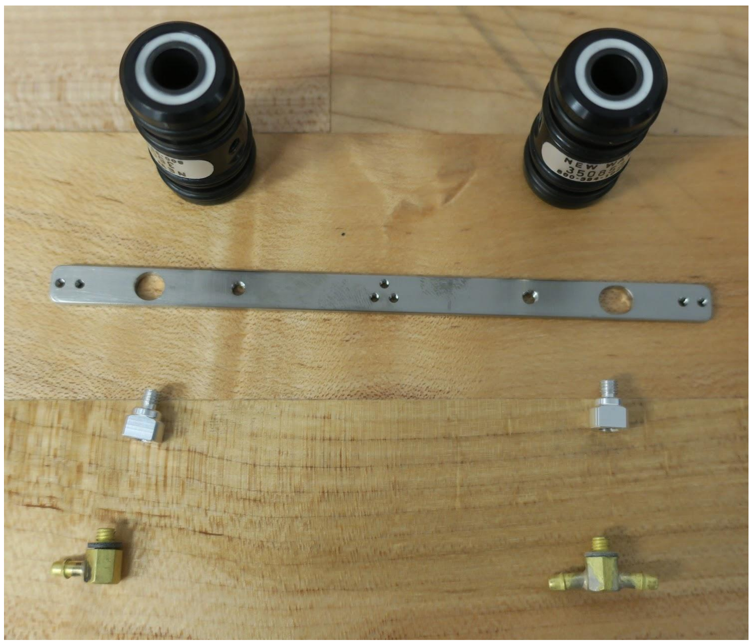
Also needed:

Basic windows PC with VBAcmd software installed
Head fixation solution (anything coming from the front or side of the animal should work)
DAQ solution (software only handles behavior, doesn't stream data to disk), 4 DC channels, 2-10kHz/channel, 0-5V range
PC with DAQmx and VBAcmd software installed (see instructions at **TK**)
3D printer for manufacturing tubes with PLA filament
Absorbent underpads (diaper) for tubes: e.g. Fisher 1420662 ($79.27)
Paw bars for tubes: e.g. Henry Schein 1009175 ($19.95)
Compressed air tank or building air with regulator (max 20 psi needed)
Mice with headplates attached to skull
Something that can generate +5VDC (arduino, DC power supply, etc.) to BNC

(A) BUSHING ASSEMBLY

1. Gather:

    2 **air bushings** (New Way Air Bearings S300601)
    1 **cross bar** (custom machined)
    2 **screw adapters** (custom machined)
    1 **barbed brass fitting, “T” style** (New Way Air Bearings S90F054)
    1 **barbed brass fitting, “elbow” style** (New Way Air Bearings S90F045)
    thick tubing (Cole Parmer EW-96400-13)
    Teflon tape (Amazon B01EZ6MVS8)
    3/16” wrench (Part of McMaster miniature wrench kit 8041A19)



IMG 1797

2. Make sure the bushings, cross bar, and adapter fittings are arranged as shown in the photo (TK photo)

- Triangle of points in the center of the cross bar pointing away from you
- Circular opening in the cross bar to your left
- Elliptical opening in the cross bar to your right
- Elbow fitting to your left
- T fitting to your right

Remove O rings from the air bushings.

2. Wrap a strip of teflon tape around the threads of the **2 screw adapters** and the **2 barbed brass fittings** (one ‘T’ and one ‘elbow’).

IMG 2078

3. Screw **'T' barbed brass fitting** into the screw adapter. Screw **'elbow' barbed brass fitting** into other screw adapter. The brass fittings should not be screwed so tightly into the screw adapters that they cannot be easily turned; they will need to be adjusted later.

IMG 2079

4. Place the **air bushings** on a flat surface with the threaded openings facing up and place the crossbar on top of them. Make sure that the cross bar is sitting flush against the flat area on the air bushings. And ensure that the circular opening on the cross bar is on the left, and the elliptical opening is on the right. The apex of the triangle of three threaded holes in the middle should be facing towards you.

PHOTO OF BUSHING ASSEMBLY

5. Insert the threaded screw adapter connected to the elbow-shaped barb adapter into the bushing on the left, through the circular opening (and not into the bushing on the right and the elliptical opening).

6. Gently screw in both adapters into each of the two bushings. They will be tightened later. At this point, just gently screw them in so that the bushings can still move a bit with respect to the crossbar.

[NOW COMPLETE PART B (rail assembly)]

7. Slide the assembly over the rails with the barbed connectors facing the base plate and put the rails back in place, screwing them into position.

8. Position the assembly in a vertical position and let the bushings slide down. The goal is to ensure that the cross bar is at a 90º with respect to the bushing. It's helpful to take advantage of the large opening on one side of the base plate, so put the bushings on that side. This will permit easier access to the fittings for final adjustments.

TK PHOTO, SHOWING WRENCH TIGHTENING FITTING WITH CIRCLE AND ELBOW

9. Place the rail assembly flat on the table and confirm that the cross bar is flush against the flat part of the bushing.

10. With the cross bar flush against the flat part of the bushing and at a 90º angle with respect to the bushing, for the bushing adjacent the circular hole (i.e. the one with the elbow fitting) *gently* (the fitting can easily break!) tighten the screw adapter into the bushing with a 3/16" wrench. This takes very little force! It needs to be secure but doesn't need to be too tight. Ensure that the 90º angle is maintained and that the cross bar also remains flush against the flat part of the bushing. Continue screwing until the screw is tight, keeping in mind that the adapter can easily break if too much force is exerted by the wrench. The goal is to fix the position of the crossbar at a 90º angle with respect to the bushing.

11. Connect the tubing and turn the air on.

12. To tighten the other screw adapter, rock the bushing back and forth by tilting the rail assembly up and down. This will let the T-bushing (right hand bushing) slide into the elliptical opening. Gradually and gently tighten the screw adapter into that bushing. This screw adapter should never be completely tight. It should remain a little loose to allow "play" about the rail. But it should be as tight as possible to ensure firmness of the crossbar. At some point it will become too tight and motion will no longer be frictionless. A good setting is to loosen it a bit from this point until it is frictionless. This is the tightest possible setting that is frictionless.

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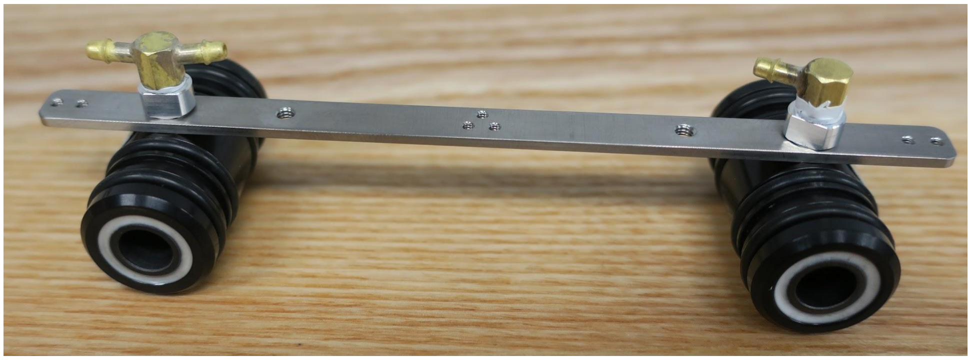
4. Place the **barbed adaptor/screw fitting** assembly through the holes of **crossbar**. The ridge of the screw adapter must fit in the hole. It does not matter which side of the cross bar each assembly is placed into.

IMG 1806

5. Attach a **bushing** to each screw adapter. Do not tighten fully yet. DO NOT use wrench to tighten as the screw adapters are thin and delicate. Make sure the **elbow-shaped fitting** points (approximately) in the direction of the **'T' barbed brass fitting** and 'T' and 'elbow' portions of both are (approximately) in the same axis as the **cross bar**..



IMG 1809

6. Cut 2 lengths of **thick tubing**, approximately 30mm and 75mm

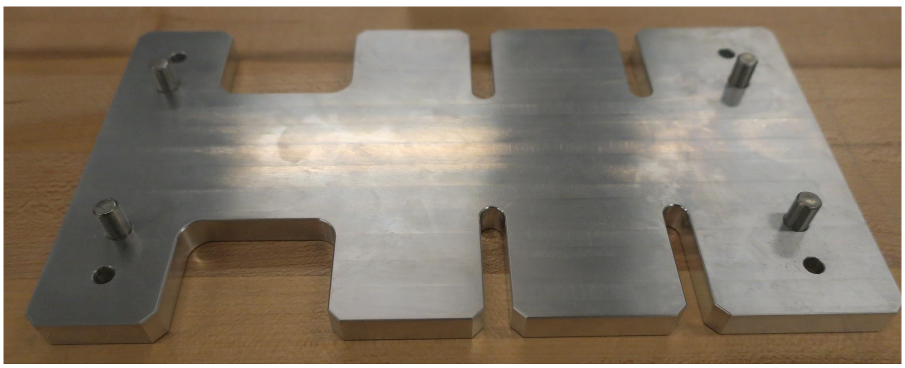
IMG 1819

7. Connect the two inner barbs (between ‘T’ and ‘elbow’ portions) with the **75mm length of thick tubing**. If tubing is so long as to bend, trim slightly until it is approximately straight--but doesn’t need to be perfect, and a gentle curve might actually be a good thing. Connect the **30mm length of thick tubing** to the other side of the **T-shaped barbed brass fitting**.

IMG 2188

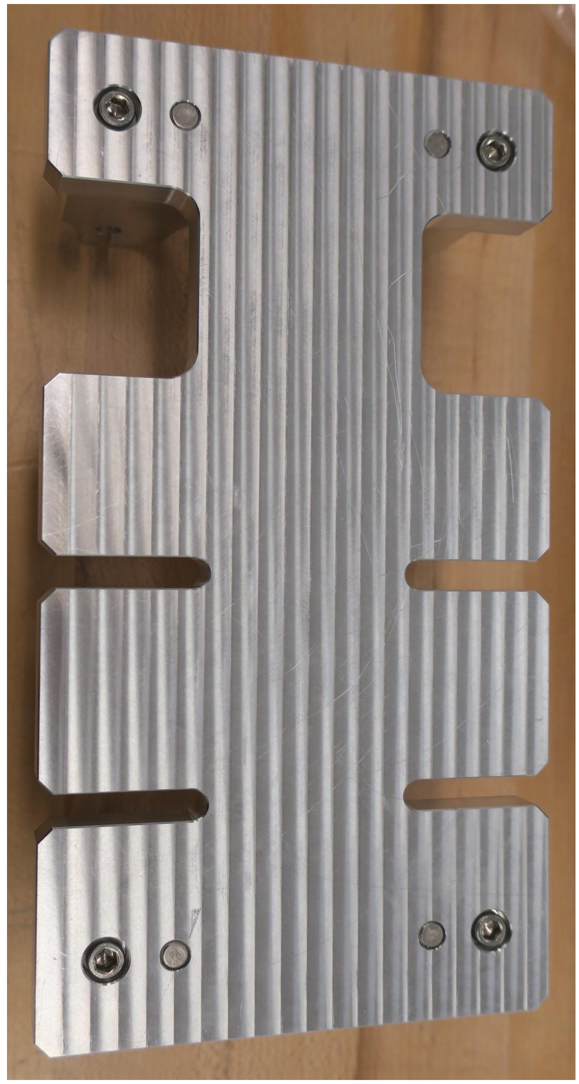
(B) RAIL ASSEMBLY

1. If not already cut to the right dimensions, machine 2 **Thomson shafts** to 200mm length.
2. Gather:
   - 1 **base plate** (custom machined)
   - 2 **end plates** (custom machined)
   - 2 **200mm Thomson shafts (**Amazon B002E7LKLA, trimmed to 200mm each)
   - 8 **4-40 screws** (McMaster 92196A112)
   - 4 **10-32 screws** (McMaster 92196A271)
   - 4 **0.25” dowel pins** (Mcmaster 90145A537)
   - 2 **M2.5x10mm** screws (McMaster 91292A014)
   - 2 **M1.6x5mm screws** (McMaster 91292A262)
   - 1 **3D printed flag** (see flag_v3.stl in /CAD/ folder of repository on GitHub)
   - 4 **6mm ID, 2mm wide O-rings** (McMaster 9262K166 also available in kit 9443K36)
3. Insert 4 **dowel pins** into **base plate**, ridged end into base. Optional: use a vise. If having trouble, talk to a machinist. If still having trouble, get in touch.



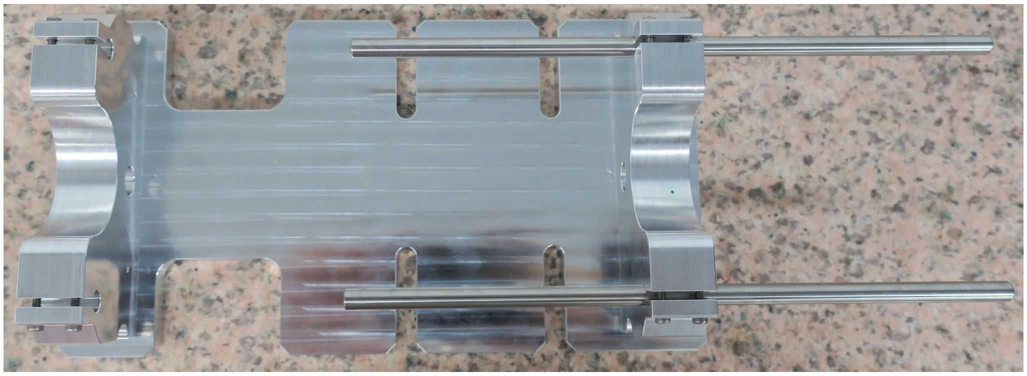
IMG 2075

4. Screw each **end plate** into **base plate** using the **dowel pins** as guide with **10-32 screws**.

IMG 2076, IMG 2077

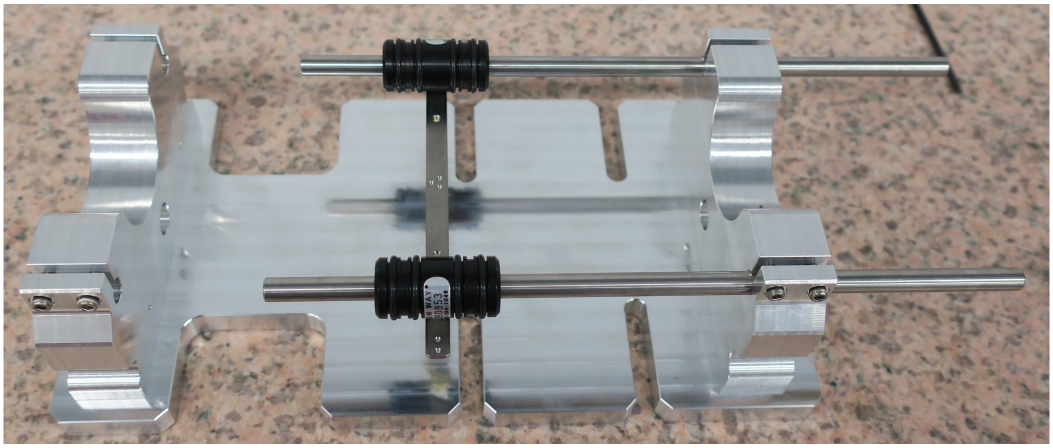
5. Clean the 2 **Thomson shafts** vigorously with isopropanol then slide them through one of the end plates but not all the way through the other **end plate**. **Future: don't cut THomson shafts ourselves, rather have New Way cut and clean them. It's a nightmare to clean ourselves; if we do, attach rails to the base in order get more force during the vigorous clean. Alt. call New Way to figure out how they clean them.**



IMG 1811

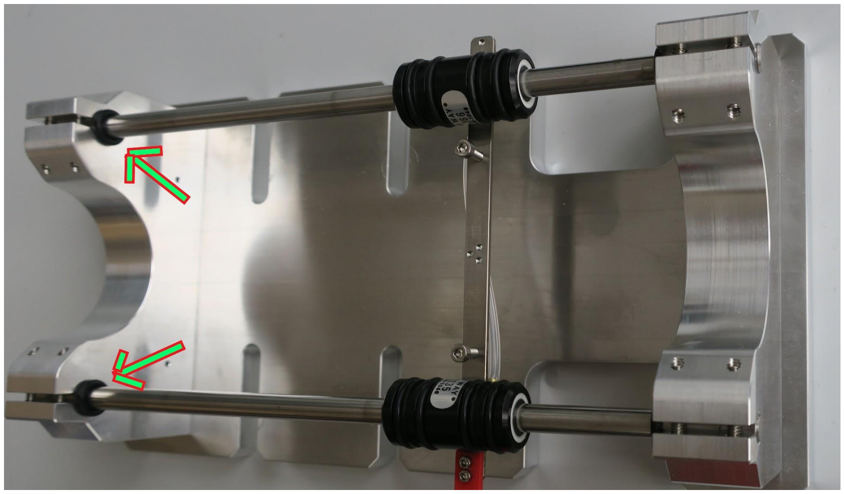
6. Slide the **bushing assembly** onto the rails. CRITICAL:

- The **cross bar** must be below the **Thomson shafts**, i.e. in between the base plate and the **bushings**.
- Orient the **base plate** as shown below (pair of large notches on the left). The **bushing** with the **'T' barbed brass fitting** screwed into it (and the **30mm of thick tubing** sticking out) should be in the lower portion of the picture; the **bushing** with the **'elbow' barbed brass fitting** screwed into it should be in the top portion of the picture. If not, rotate the **bushing assembly** 180 degrees before the next step.



IMG 1812

7. Place 4 **O-rings** at the four ends of rails. O-rings should be flush with the **end plates** to serve as bumpers for **bushings**.



IMG 2172

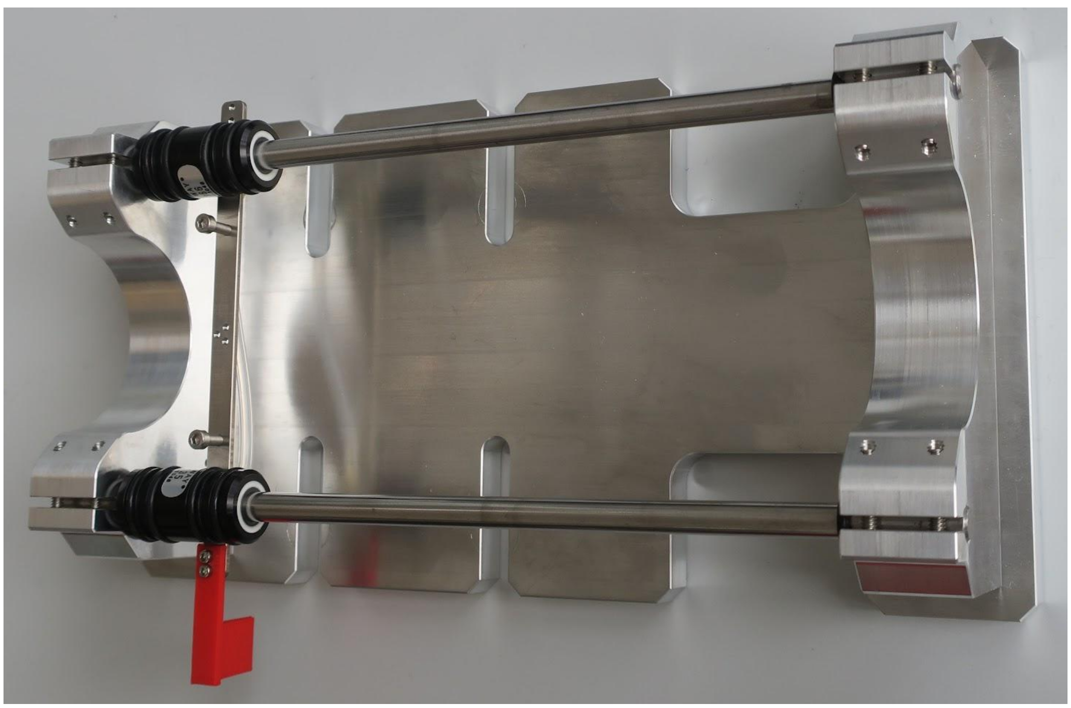
8. Make sure **Thomson Shafts** span both end plates and screw in the **4-40 screws** *lightly*.

IMG 1814 (Note that in photo above screws are screwed in too tightly)

9. Clean rails vigorously with isopropyl alcohol.
10. Slide **bushing assembly** back and forth along the entirety of the the **Thomson shafts**. If they are in the correct position, you should feel comparable friction along the entire extent of the Thomson shafts.
11.Tighten all **4-40 screws**.
12. Partially screw in 2 **M2.5x10mm** screws into the taps on the **cross bar**. These will hold the 3d-printed tubes (‘burrows’).

IMG 2172

13. Orient the base plate as in the image below (large notches on the right side) and attach the **3D printed flag** to the **cross bar** using the 2 **M1.6x5mm** screws.



IMG 2173

14. Apply scotch tape over the top of the rail holders on the back side to prevent the fishing line from getting snagged.

(C) TUBING ASSEMBLY

1. Gather:

    thin tubing (Cole Parmer EW-95920-13)

    1 **polypropylene elbow-shaped barbed fitting** (Harvard 72-1508. Also in kit 72-1410)

    1 **polypropylene barbed luer connector** (Harvard 72-1443. Also in kit 72-1407)

2. Cut 1 length of **thin tubing** to 750mm.
3. Connect the open side of the **30mm length of thick tubing** (currently attached to the **'T' barbed brass fitting** on the **bushing assembly**) to the **thin tubing** using the **polypropylene elbow-shaped barbed fitting**.

IMG 1823

4. Connect the open side of the **thin tubing** to the **polypropylene barbed luer connector**,
5. Connect the luer to a compressed air source; slowly ramp from 0 to 15-20psi; this should pass enough air through the **bushings** to permit near-frictionless translation.
6. Test that translation is near-frictionless. For this:
    - Push **bushing assembly** using finger placed in center of **cross bar**. It should feel like magic. If not, see below.
    - Apply gentle tension across the thin tubing using by holding it in one place without moving hands; this should result in oscillation that takes several seconds to decay SEE EXAMPLE MOVIE HERE (*BUSHING_ASSEMBLY_OSCILLATION.mp4 in VBAcmd/Assembly/ folder*). Comparable oscillation should be observed at all positions along the **rail assembly** (i.e. try this not only in the middle of the rail as shown in movie, but at the ends of the rail, close to both of the end plates). If no such oscillation is observed, or if it is only observed at some but not all position of the **rail assembly** see below.

Most of the time near-frictionless translation is not achieved for one of three reasons:

- Either rail alignment is improper; this is unlikely in VBA versions 5+ so long as instructions above were followed.
- Or the **bushing assembly** is too rigid; for this, very slightly loosen the **screw adapters** that connect the **bushings** to the **cross bar**.

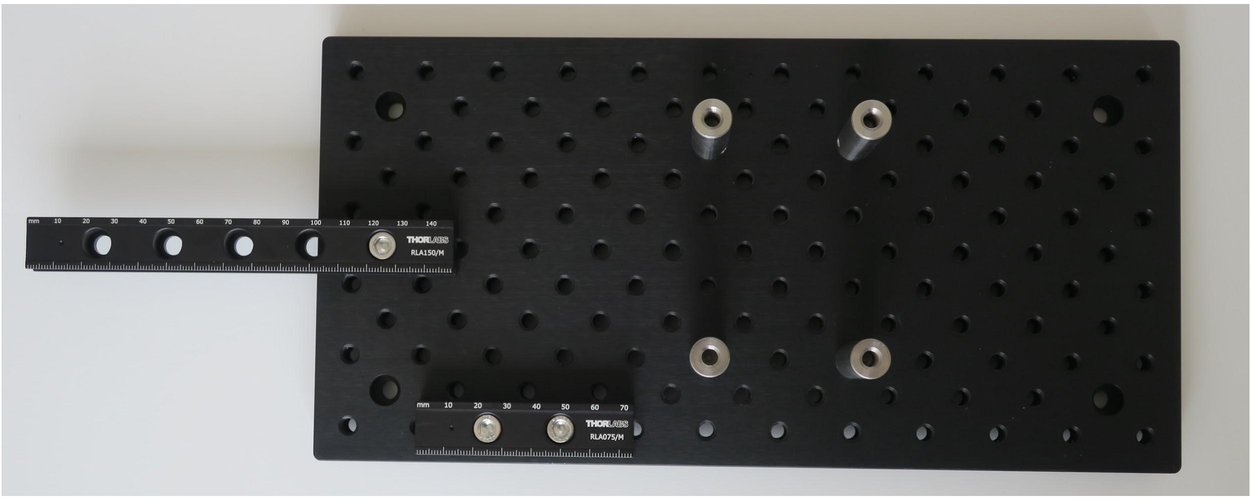
- Or the **Thomson shafts** are dirty; this is almost always the issue. To fix, give them a vigorous isopropyl alcohol cleaning, especially at the ends of the **shafts**.

(D) SENSOR ASSEMBLY

1. If not already done, solder free hanging XLRs to cables of **laser**, **force meter**, and **actuator** as explained in **XLR Cable Assembly**.
2. Gather:

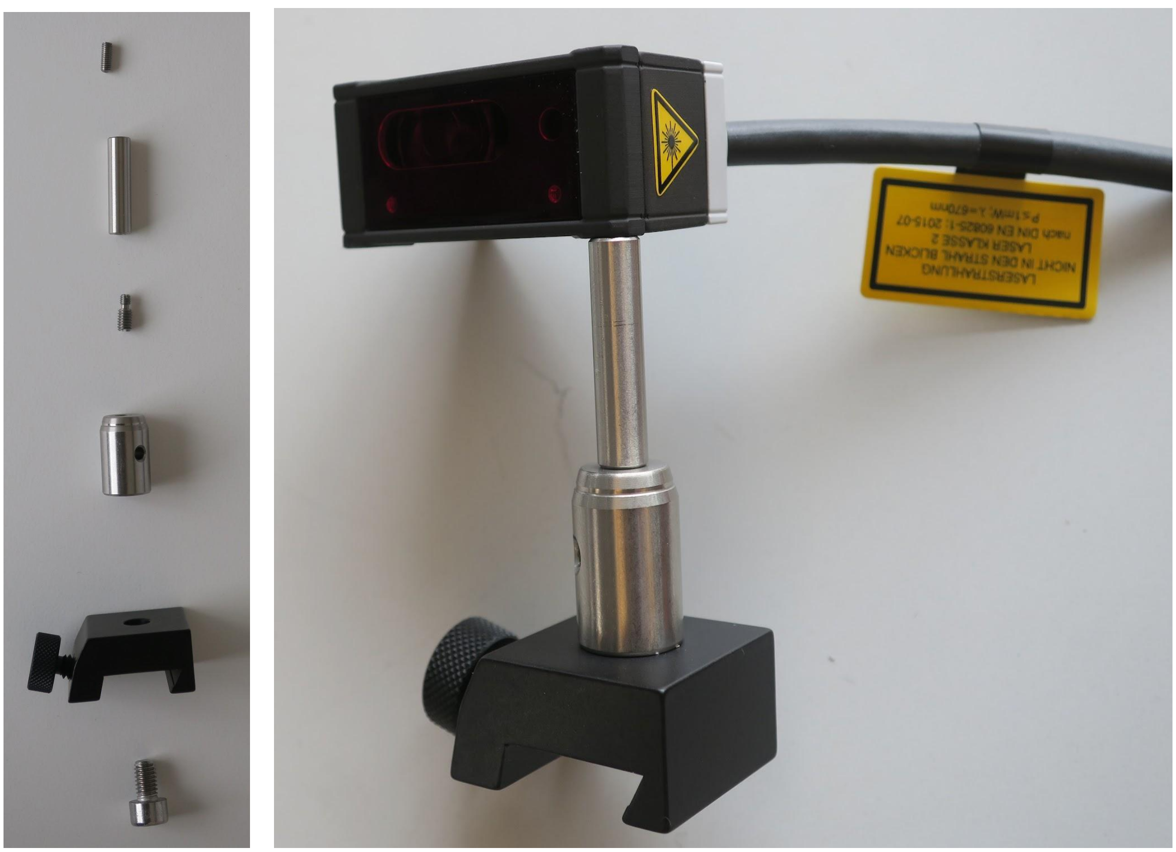
   1 **laser displacement sensor** (Micro-Epsilon ILD1320-100, use analog *not USB*)
   1 **force meter** (Futek LSB200, 250g; Cat no. FSH03871)
   1 **linear actuator** (Firgelli L12-50-50-12-I)
   1 **breadboard** (ThorLabs MB1530/M)
   5 **Ø12.4mm 50mm optical posts** (ThorLabs TR50/M)
   1 **Ø12.4mm 150mm optical post** (ThorLabs TR150/M)
   1 **Ø12.4mm 20mm optical post** (ThorLabs TR20/M)
   1 **Ø6mm 13 mini series optical post** (ThorLabs MS05R/M)
   1 **Ø6mm 25mm mini series optical optical** (ThorLabs MS1R/M)
   4 **M4/M6 adapters** (ThorLabs AP6M4M)
   1 **M3x3mm screw** (McMaster 91292A021)
   1 **Ø12.7mm 30mm optical post** (ThorLabs TR30/M-P5) [forgotten, added feb 2020]
   2 **dovetail rail carriers** (ThorLabs RC1)
   1 **150mm dovetail rail** (ThorLabs RLA150/M)
   1 **75mm dovetail rail** (ThorLabs RLA075/M)
   1 **Ø12.7 mm Post Holder L=40 mm** (ThorLabs PH40/M)
   3 **M3/M4 adaptors** (Thorlabs AP4M3M)
   1 **M4/M8 adaptor** (Grainger 4ZE39)
   1 **4.75 pound test nylon fishing line** (Amazon.com B004KCSD7G)
   1 **M4x6mm screw and washer** (in ThorLabs kit HW-KIT1/M)
   1 **M3 set screw** (in ThorLabs kit HW-KIT3)
   1 **M3 x 12mm button head screw** (McMaster 91239A117) **+ 3 M3 washers from the Thorlabs M3 kit. Alt, try 8mm and 10mm which should work without the washers.**
   M6 screws, **washers**, and 1 **set screw** (in ThorLabs kit HW-KIT2/M)

3. Screw (4) **M4M6 adapters** into the M4 side of (4) **50mm optical posts**. Screw each into appropriate position on breadboard as shown below. Also attach the **150mm dovetail rail** and **75mm dovetail rail** using **M6 screws**.



IMG 2112. ***NOTE: josh took photo of block for alignment***

4. **Laser assembly:** attach **laser** to **25mm mini-series post** using an **M3 set screw** (attach post to the side of the laser that cable is attached; for orientation see *IMG 2174*); attach **mini series post** to **20mm optical post** with **M3/M4** adapter; attach optical post to **dovetail rail carrier** with an **M6 screw**.



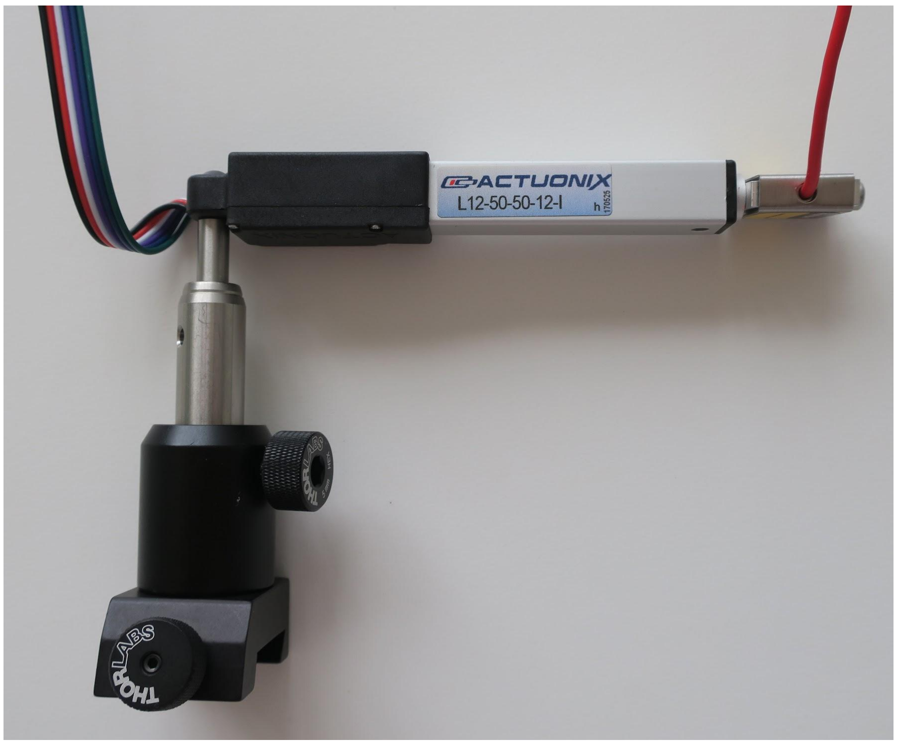
IMG 2111, 2174

5. **Force/actuator assembly:** attach **M3x3mm screw** to **force meter**; **remove the screw that comes with the actuator,** attach the other side of **force meter** to **linear actuator** via a **M4/M8 adapter** and a **M3/M4 adaptor**; attach the linear actuator to the **Ø6mm 12.5 mini-optical post**

via the **M3x12mm button head screw**; attach the **mini-optical post** to the **Ø12.4mm 50mm optical post** via a **M3/M4 adaptor**; attach to a **optical post holder** that is screwed into a **dovetail rail carrier** with an **M6 screw**.

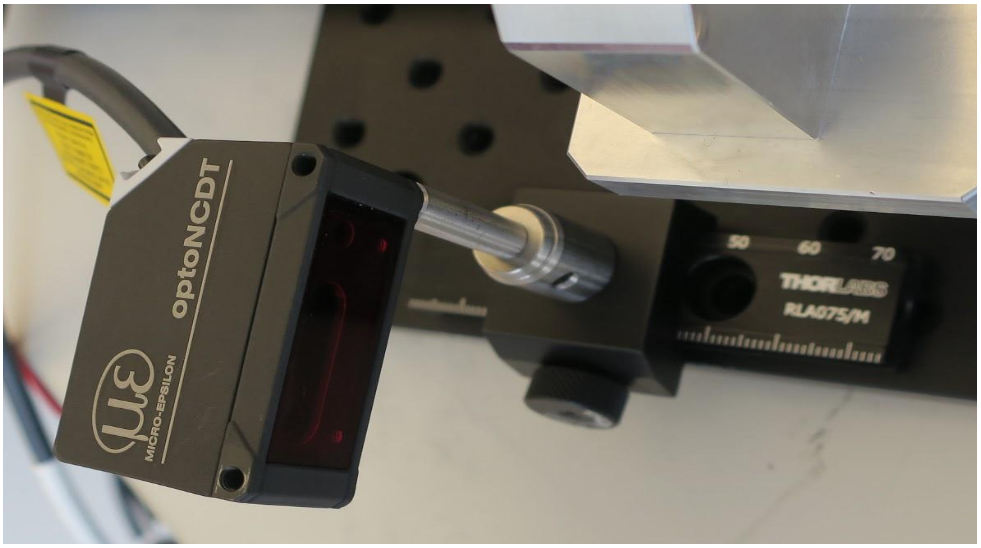
IMG 2114

IMG 2115 ***(note in this photo the post holder is too short, now replaced with 40mm one TK)***



IMG 2127

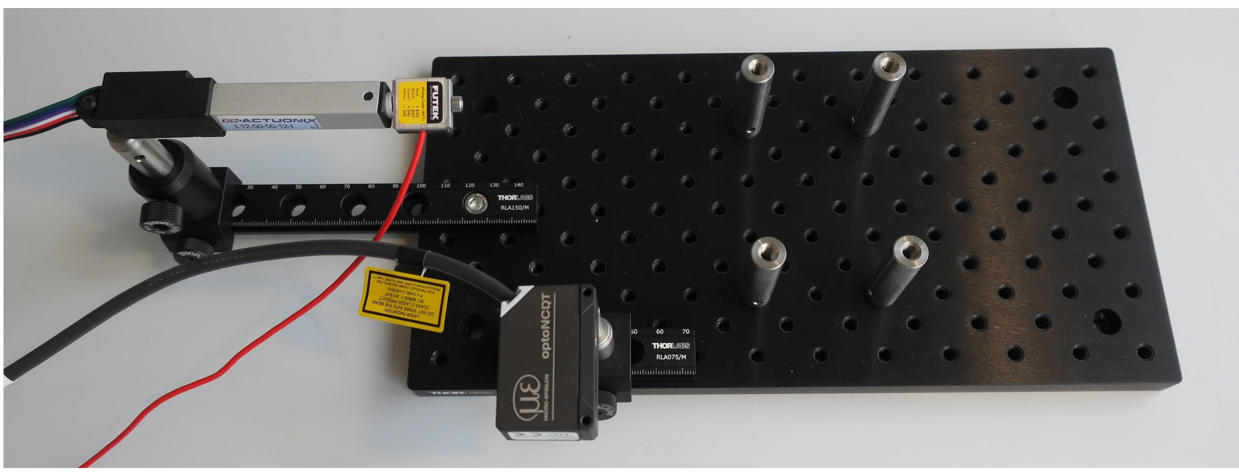
6. Mount the **laser assembly** onto the **75mm rail**



IMG 2175

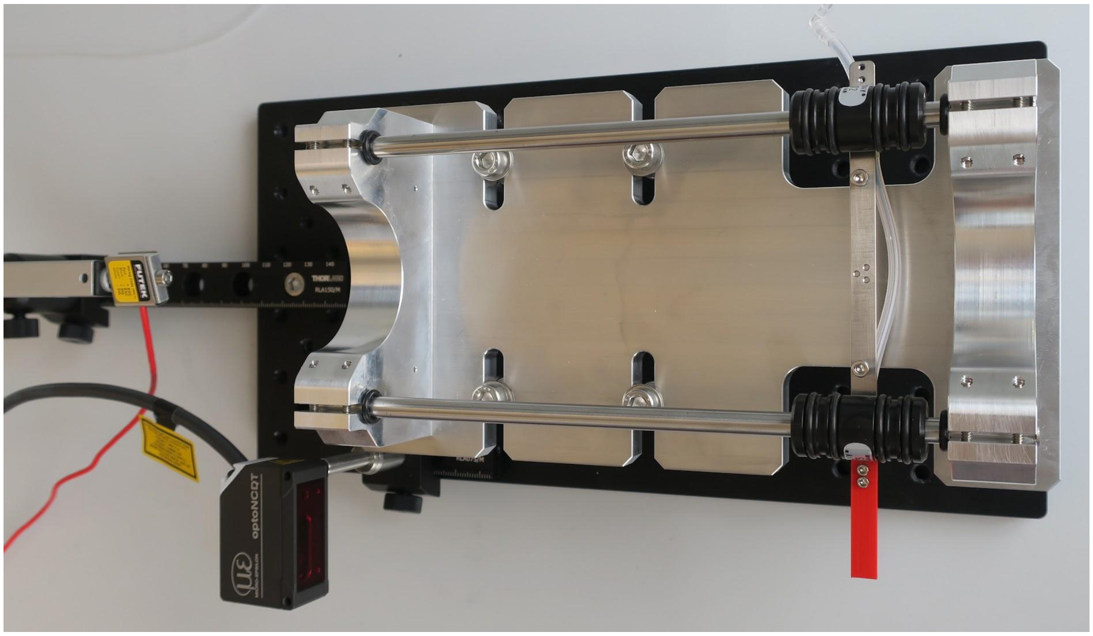
7. Mount the **Force/actuator assembly** onto the **150mm rail**.

8. Mount the 150 mm rail to breadboard using the forwardmost screw position on rail (see photo).



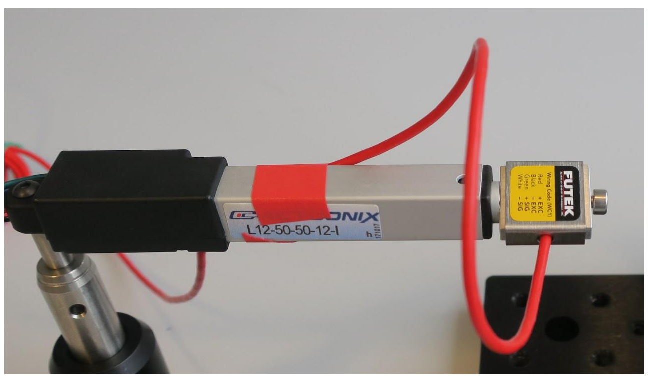
IMG 2176

9. Mount the **rail assembly** onto the 4 **50mm optical posts** using **M6 screws** and **washers**.



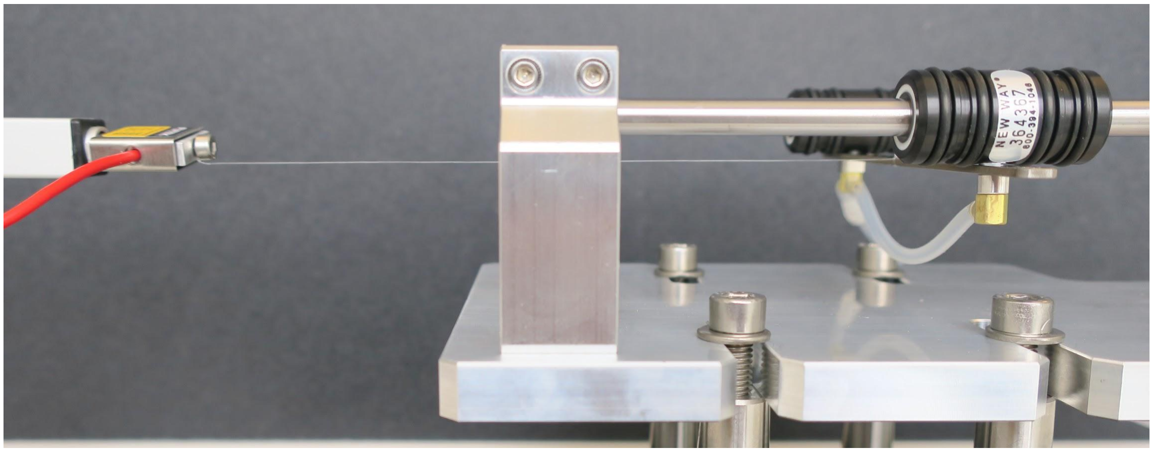
IMG 2178

10. Tape the **force meter** cable to the top of the **actuator** to reduce strain on **force meter**. Tape the cable in such a way as to force it to avoid the (black) **laser** cable in case it is nearby.



IMG 2186

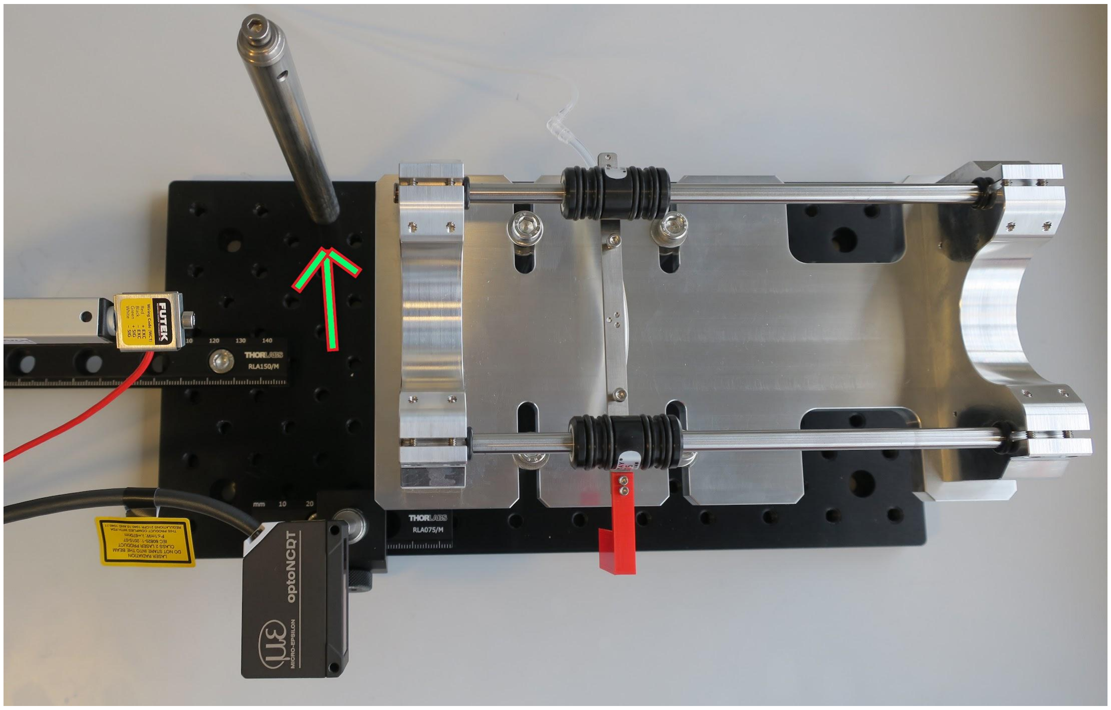
11. Attach **fishing line** between the **M3 screw** at the end of the **force meter** and the center hole in the **cross bar**. Final length of **fishing line** should be approximately 15cm. Note that it is easier to tie knot on the **cap screw** before **cross bar**. Fisherman's knots are recommended. (See photos below in instruction 11.)
12. Rotate the **linear actuator** so that **fishing line** axis is parallel to the **rail assembly** axis, and adjust the vertical position of the **linear actuator** so that the **fishing line** is horizontal with respect to the plane of the **breadboard**.



IMG 2139

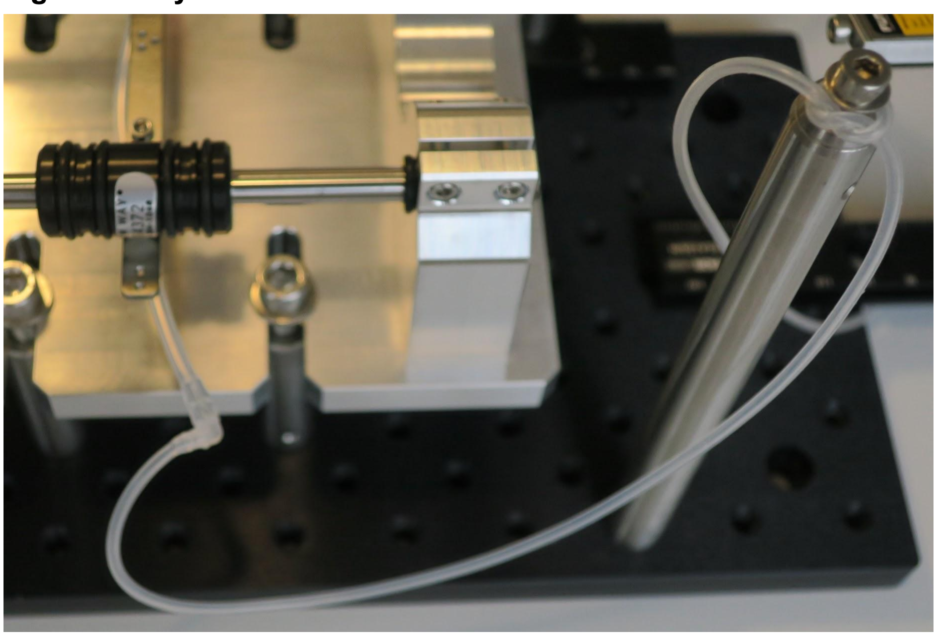
IMG 2138

13. Screw in **150mm optical post** to breadboard (for position see photo) using an **M6 set screw**.



IMG 2183

14. Tie a loose knot 25 cm from end of **thin tubing** on side of bushing. Using an **M4x6mm screw** and washer, tightly secure the knot to the **optical post**. The purpose is to reduce strain on the **bushing assembly**.



IMG 2185

FINAL ASSEMBLY AND TESTING

- Plug in laser, force and servo cables into the appropriate plugs in the enclosure.
- Plug in 24V power supply, switch on and confirm box LED is on and laser LEDs are ib.
- Install software, including NI DAQmx (**see instructions TK**); after restarting computer, plug in USB cable and connect to computer. This should automatically open a window ("Device detected: NI USB-6001"). Record the name of the device on the computer. If it's the first time a NI device has ever been connected to it, it should be named "Dev1". Otherwise, it will be named "DevN", where N is an integer greater than 1.
- Close the "Device detected window", navigate to the `VBAcmd` folder cloned from GitHub, rename `VBAcmdconfig.py.template` to `VBAcmdconfig.py`. Open that file and:
    - Confirm that all of the instances of the NI device name (there should be 4 in total) correspond to the DevN name you just recorded; if not change them. (Default: "dev1".)
    - Uncomment one pair of 'rangeForce' and 'rangeForceVout' lines (if you don't know which pair, uncomment the bottom two, it's much more likely to be that one.) **TKEDIT THIS FOR CLARITY/I think i already wrote this better somewhere**
    - Save and close the file.
- While still in the `VBAcmd` folder, enter `conda activate vba` at the command line. Then enter `python VBAcmd3.pyw` which should launch the software.

CHECK THE OUTPUTS

- Ensure that the servo is flush with the back of the rail. [ces jan 2019 not clear what this is for]
- Test that the linear actuator works by toggling between pulling and slackening (set the pull position to 0 and slack position to 50 for full range of movement) by clicking on the appropriate buttons under "servo state" in the VBA software. Ensure that the red trace (middle channel, servo signal) moves accordingly, for the correct range (about 50 mm). Also make sure that there is no strain on the force sensor when slackening and pulling by observing the force trace on the software. If there is strain, adjust the position of the wire connected to the linear actuator.
- Plug a BNC cable into Servo OUT and connect to an oscilloscope in DC mode to make sure servo OUT is output properly (e.g. try toggling again between pulling and slackening as above → should be from 0V to 3.3V, should move in opposite direction as red trace in VBAcmd). Switch oscilloscope to AC mode to look at peak-to-peak noise, which should be around **TK mV**.
- Next, test force by plugging the oscilloscope/BNC cable into Force OUT; make sure to switch the oscilloscope back to DC mode. Then tug on the tether attached to the force meter and check that both the oscilloscope and the software (bottom panel, black trace) register this. Signal in oscilloscope should vary from 0-4.9V; signal in the software should vary between 0-250g. Switch the oscilloscope to AC mode and measure peak-to-peak noise while the sensor is in range. It should be around **TK mV**. (Note that if no pulling force is applied, the sensor will not be in range, so make sure to apply a bit of constant force before measuring)

- Next, test the laser by plugging the oscilloscope/BNC cable into Laser OUT; make sure to switch the oscilloscope back to DC mode. Adjust the position of the laser such that the sensor face is flush with the back of the end plate. Note that you may need to adjust the position, but this is a good place to start. Make sure that the signal varies on the oscilloscope and check in the software (center panel, blue trace) that it is working. Move the bridge to two different positions, readout the measurement in the blue trace, and compare this to a measurement with a ruler. Move the bridge the whole length of the rails and ensure that the laser light stays relatively centered on the flag. If not, rotate the laser appropriately. Switch the oscilloscope to AC mode and measure the peak-to-peak noise while the sensor is in range; it should be around **TK mV**. (The sensor is not in range if both LEDs on the back of it are red; move an object along the laser beam until one of the LEDs turns green or orange; note that the other LED will always remain red.)
- Test the state OUT by plugging it into the oscilloscope. Toggle between slackening and pulling and the oscilloscope should change between -1 and -2V.
-Test the trig OUT by plugging it into the oscilloscope. Move the bushings as far back as possible towards the laser, so the value is at its minimum. Go to “Control Mode” in the software, and press “automatic”. After a few seconds, the bottom right portion of the software screen should say “Launching” in red. Right when this happens you should see a 5V pulse on the oscilloscope. [5/31/2020 CES: might be 3.3V, check the code].

TEST INPUTS

- Test analog IN. Connect the analog IN to force OUT. Tug on the force meter by pulling on the tether, and ensure that in the top window (black trace) of the software a signal comes in. Note that the scaling of that window is set manually on the left (it does not autoscale).
- Set control mode back to “stick shift”. Plug the BNC into trig IN and pass a +5V current into it (using the +5V pin on an arduino, 5V power supply, 5V DC power supply, etc.). The field under “Manual control” in the bottom right corner of the software should be blank when no current is passed through, and “Stim: pull but manual” when connected.

CALIBRATE!

- The calibrate button offsets the plotting of the servo position (red trace, middle panel), so that it matches approximately the laser position (blue trace, middle panel). It is for ease of visualization only, and does not affect measurement or output.
- In stick shift mode, set servo state to “slacken”. Pull the bridge such that the fishing line is taut. Then click calibrate.

AFTER HEAD PLATE POSITION SET

- The difference between slack and pull position should be approximately 15.
- Make sure tubing for air delivery to bushings does not drag on the table or cause any friction.

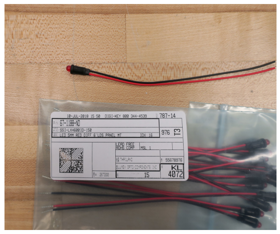
2) ELECTRONICS ASSEMBLY

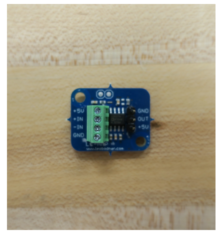
PARTS:

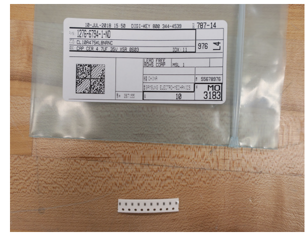
See "VBA 5.0 hardware bill of materials" spreadsheet
Extra on 7:
10 and 100uF
****all resistors and capacitors need to be 24V or greater**

(A) Solder Components

1. Gather:
    - 7 **BNCs** (digikey: ARFX1905-ND)
    - 6 **pairs of 15 cm 22 awg wires (green and black)**
    - 1 **pair 20 cm wires (green and black)**
    - 3 **DIP adaptor** (DIP Adapter, Digikey: 1568-1098-ND)
    - 6 **0.1μF capacitor** (Mouser: 81-RDE5C1H104J2K1H3B)
    - 3 **operational amplifiers** (Mouser: 584-LT1797CS5#TRMPBF)
    - 3 **3cm 30 awg wires**
    - 12 lengths of **20 cm 24awg flexible wire**. Refer to **VBA XLR Table** for colors.
    - 1 **250 Ohm resistor** (Digikey: USR2G-250RX1-ND)
    - 1 **LED**
    - 1 **470 Ohm resistor**
    - 1 **Load cell amplifier**
    - 4 **4.7 uF Capacitors** (Mouser: 81-GRM188R6YA475KE5D)
    - 1 **5V linear regulator** (Digikey: 576-2248-ND)
    - 1 length of **25cm wire**
    - 1 pair of **8cm wire**
    - 3 **Male XLRs** (1 **XLR4**, 1 **XLR5,** and 1 **XLR6)**
    - 1 **heat sink**
    - 1 **8V linear voltage regulator** (Digikey: 497-1446-5-ND)
    - 1 **¼ inch 2-56 pan head screw**
    - 1 **2-56 nut**
    - 1 **#2 washer**







BNCs

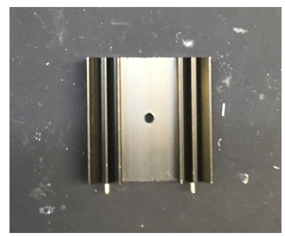
LED

Load Cell Amplifier

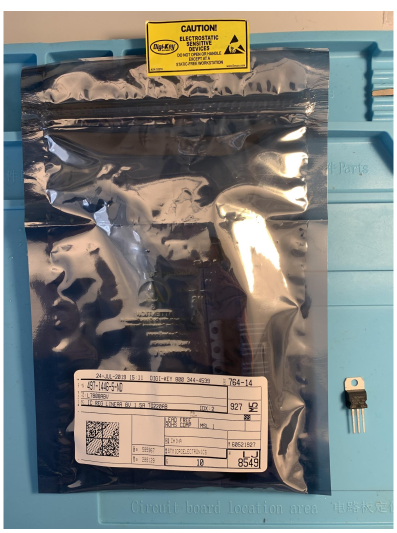
4.7 uF Capacitors

5V Linear Regulator

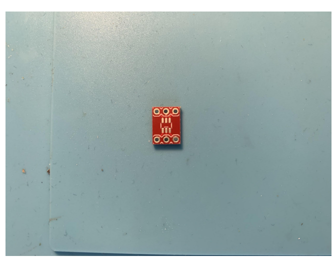
Male XLRs



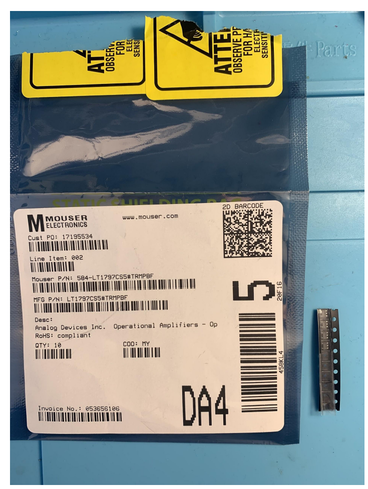
Heat Sink



8V Linear Regulator

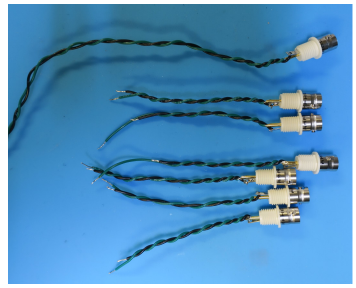


DIP adaptor

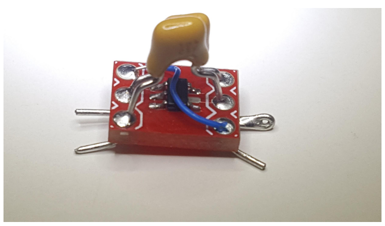
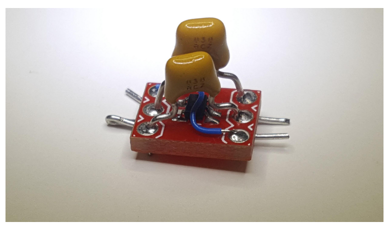
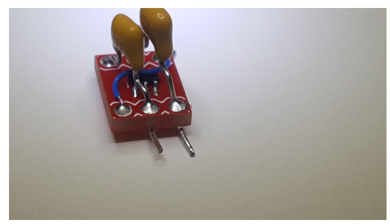


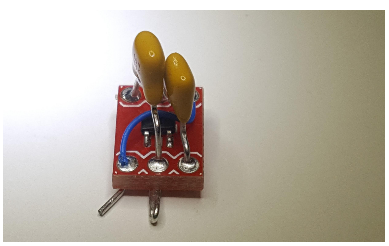
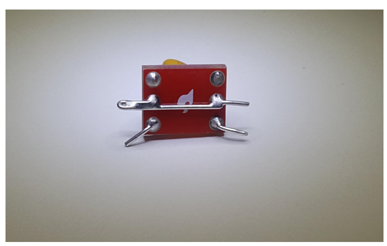
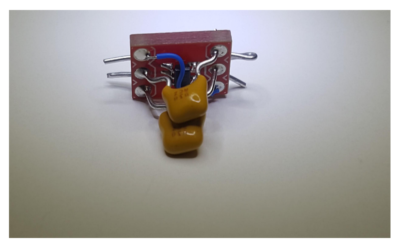
Operational Amplifers

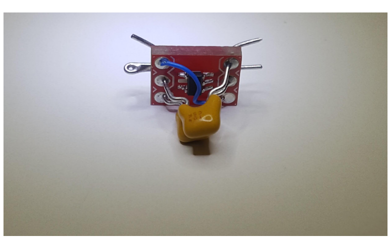
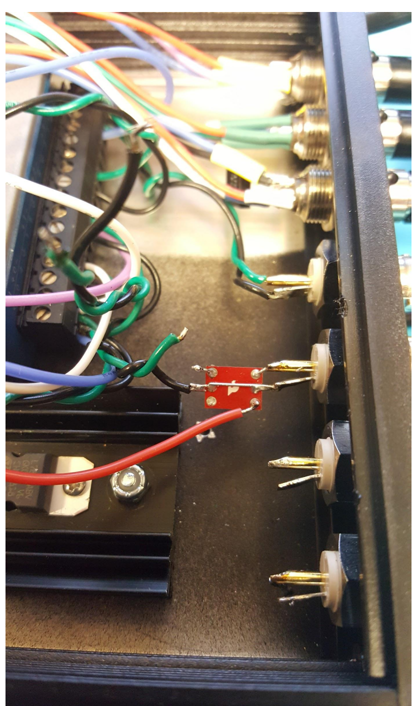
2. **BNCs.** Strip and tin both sides of 6 **pairs of 15 cm wires** and 1 **pair of 20” cm wires**. For **4 BNC**, solder **wire pair** (black to outer pin, green to center solder cup) and twist wires together (3 15cm wire pairs and 1 20 cm wire pairs).

For the other **3 BNCs** (all 15 cm wire pairs), assemble and attach **DIP adaptor** (red boards). NOTE: do not trim wires or capacitor legs after soldering. To assemble board, first solder **operational amplifier** onto **DIP adaptor**. Next, solder **3 cm wire** through opposite corners (as shown in pictures). Lastly, solder **0.1µF capacitors** to boards. Next, solder pairs of **15cm wire** to boards (black to middle pin, green outer pin of capacitor. Layout of all these parts is shown in the photos below. **NOTE: do not attach red boards to BNCs until BNCs are in their place in the panel (Enclosure Assembly Step 2)**

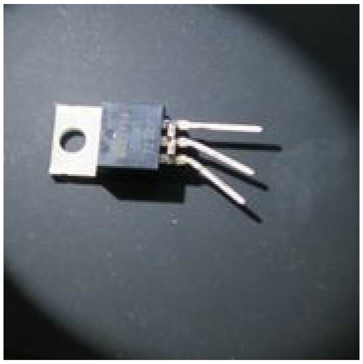
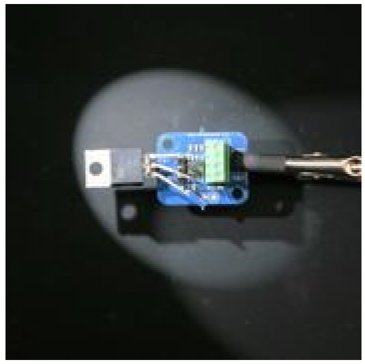
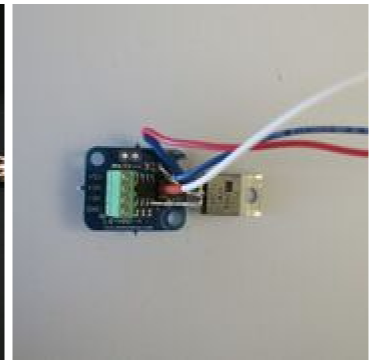
  

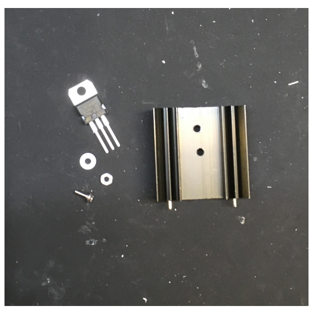
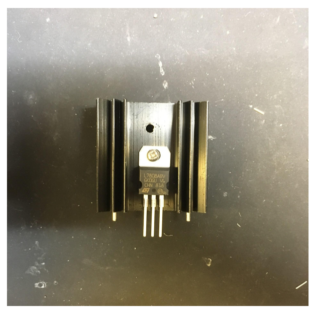
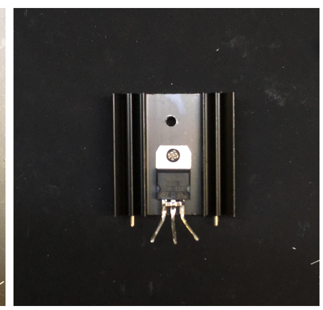
3. **Male XLRs**. Strip **20 cm wires** to the extent of XLR solder cups to prevent an excess of exposed wires from contacting each other. Tin both ends of each wire. Solder wires into cups following **VBA Wiring Diagram**. Note: Laser **XLR** requires a **250 Ohm resistor** between pins 2 and 3.


4. **LED**. Cut anode wire in half. Strip and tin both cut sides. Slide thin heat shrink onto both sides of wire. Solder a **470 Ohm resistor** between the two wires. Heat shrink over the solder joints.

5. **Regulator assembly**. Solder 4.7uF surface mount capacitors between pins of **5V linear regulator** (see **VBA Wiring Diagram** inset). Then solder **5V linear regulator** to appropriate pins on **load cell amplifier**. Note that after this point you should avoid bending the pins, as this can cause mechanical failure of the capacitors. Solder **25 cm wire** onto “Out” pin and solder **8cm wires** onto “GND” and “In” pins.

6. **Linear Voltage Regulator Assembly.** Drill a hole in the **heat sink**, between the existing hole and the back edge. Attach the **8V linear voltage regulator** to the heat sink, using a **1/4 inch 2-56 pan head screw** through the middle hole of the heat sink. Make sure to use a **2-56 nut** and **#2 washer**. Bend the pins away from one another, and tin them. Solder **4.7μF ceramic capacitors** between the pins of the linear regulator (one between each pin, see **VBA Wiring Diagram** inset). Again, after this point you should avoid bending the pins, as this can cause mechanical failure of the capacitors

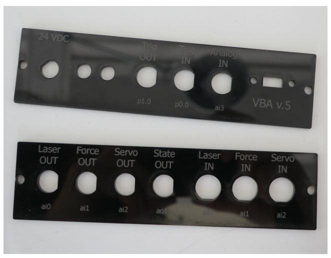
(B) Enclosure Assembly

1. Gather:

   1 **Lansing enclosure + 4 included flathead screws**
   2 **Laser-cut acrylic panels**
   4 Hex **standoffs** 2-56 x 7/16”
   4 **machine screws** 2-56x ¼ Phillips
   1 **5V Regulator assembly** (see previous section)
   1 9.1V **diode**
   7 soldered **BNCs** (see previous section)
   3 soldered male **XLRs** (see previous section)
   1 soldered **LED** (see previous section)
   1 **National Instruments DAQ**
   1 **6 cm piece of Velcro tape**
   1 t**oggle switch**
   1 **power barrel jack**

3 **5 cm** red wire
2 **5 cm** black wire
2 **15cm** black wire
2 **15cm red wire**

1 **panel mount USB connector**
1 **heat sink**
1 **8V regulator assembly** (see previous section)
1 heat sink **mounting screw and nut**
1 **24V wall power adapter**



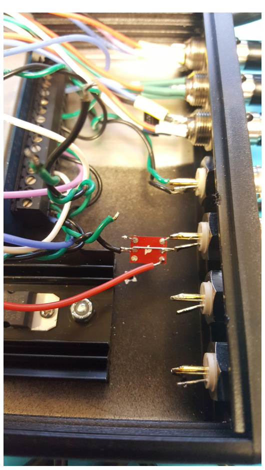
Acrylic panels

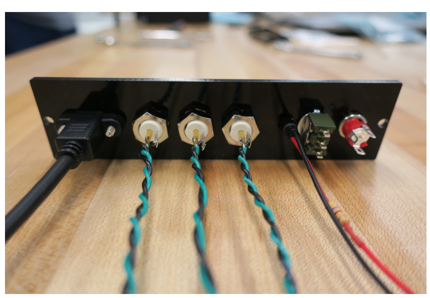
National Instruments DAQ

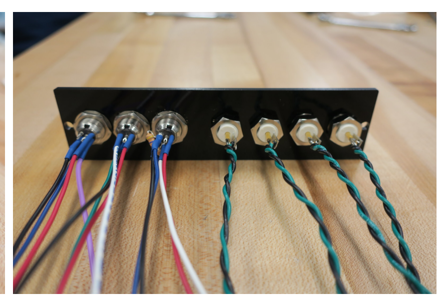
Toggle Switch

Power Barrel Jack

2. Mount components into **acrylic panels** but do not screw panels onto enclosure yet. Note:
   -**LED** is placed in hole closer to the **BNCs**.
   -To mount the **toggle switch**, use washer with single tooth where tooth faces towards the acrylic on back side of panel.
   -20cm wire pair **BNC** is mounted in Analog IN.
   -3 **BNC**s with **DIP adaptor boards** are for the Force OUT, Laser OUT, and Servo OUT (filtering boards not shown in last two images below).
      -first insert BNCs and secure with washer. Then solder red board to BNC pins





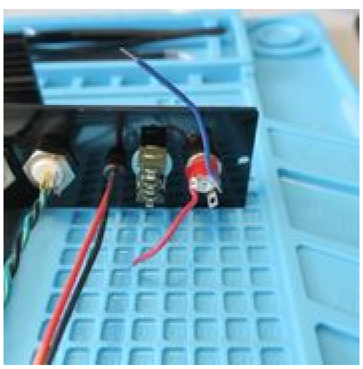
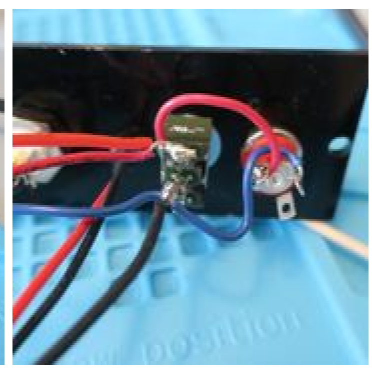


3. Plug in panel mount **USB connector** into **DAQ.**
4. Arrange **DAQ** and **regulator assembly** into box. Make sure **USB connector** clears these components.
5. Drill holes in Lansing enclosure for **heat sink**. Ensure that the heat sink will clear the other panel mounted components. Screw the **heat sink** into the box using the heat sink **mounting screw and nut**.
6. Velcro **DAQ** to **enclosure**.

7. Solder red and black **5cm wires** between the Servo Out BNC red board and Force Out BNC red board.
8. Solder red and black **5cm wires** between the Force Out BNC red board and the Laser Out BNC red board.
9. Cut a **15 cm red wire** in half and solder a 24Ohm resistor to each side.
10. Solder a 9.1V diode on one side of the resistor (see wiring diagram).
11. Strip a section of a 15 cm black wire and solder other end of diode here.
11. Solder red wire (the end with diode) to Laser Out BNC red board.
12. Screw in Back panel and frame using the other 2 of the **flathead screws**.

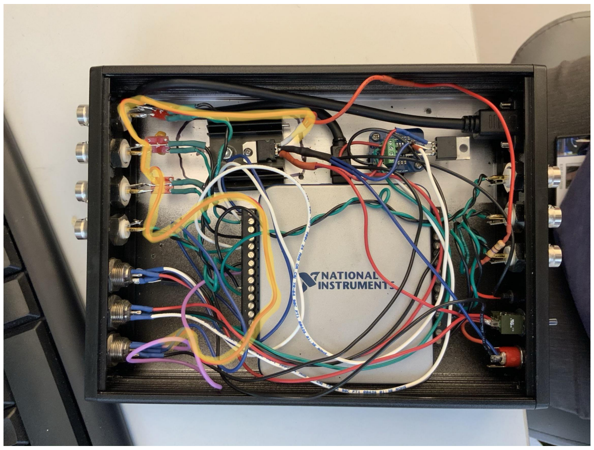
13. Solder **5cm red wire** between bottom pin of toggle to signal pin of **power barrel jack**
14. Screw in Front Panel and frame using 2 of the **flathead screws**.

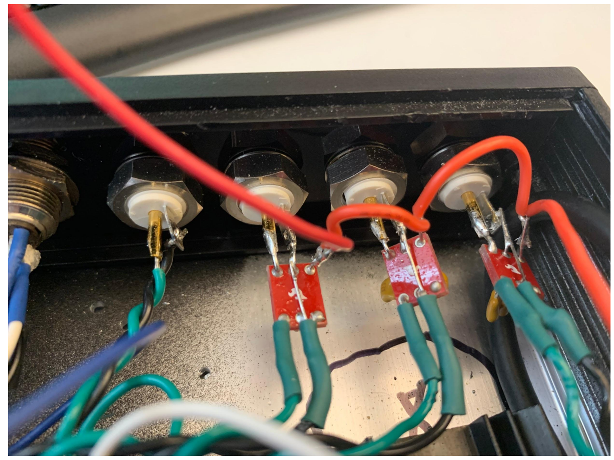
15. Twist together two ground wires (black wire from the **laser XLR** and a black **15cm wire).** Separately, twist together the two signal wire**s** (red wire from the **laser XLR,** and a red **15cm wire)**.
16. Solder the two twisted ground wires to the ground pin on **power barrel jack** switch and the two twisted red wires onto the middle pin of the **toggle switch**.

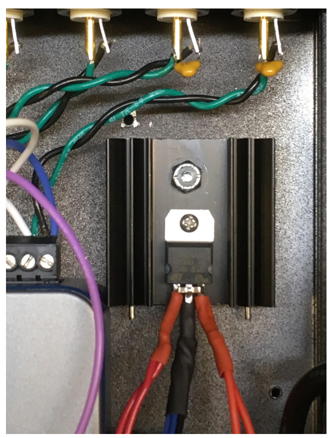
13. Solder two wires to the 24V pin of the **8V regulator assembly**: the red **15 cm wire** (from toggle switch) and the 24V red wire attached to the **5V regulator assembly.**
14. Solder 5 wires to the middle pin of the **8V regulator assembly**: the black **15cm wire** (from power barrel jack), the black G wire from the **5V regulator assembly**, the black **LED wire**, the

black wire from servo XLR, and the **black 15 cm wire** (attached to diode). Make sure to slide heat shrink over the wires before soldering them on, and shrink it over the pins after soldering.





15. Solder three wires to the 8V pin of the **8V linear voltage regulator**: the red **LED** wire, 8V, and the red wire from servo XLR.



15. Wire up DAQ according to **VBA Wiring Diagram**.
16. Test power is being supplied to **LED** by plugging in 2**4V power adaptor** into **power barrel jack** and flipping the **toggle switch**.

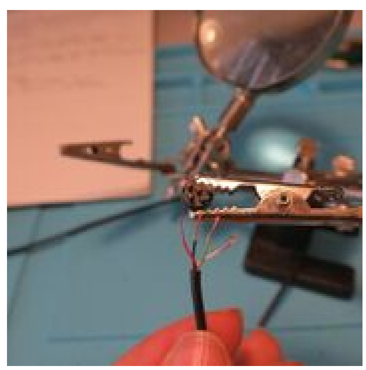
(C) XLR Cable Assembly
Gather:

1 **1.5m length of USB cable**
3 **Female XLRs**(1 **XLR4**, 1 **XLR5,** and 1 **XLR6)** *IMG Female XLRs, IMG Female XLRs Face*
1 **Futek load cell**
1 **Actuonix servo motor**
1 **Microepsilon optoNCDT laser**

For all three components (**Force, Servo and Laser**) refer to **VBA Wiring Diagram** and **VBA XLR Table** for pin positions. Note that pin numbers on the female XLRs are a mirror image of male XLRs. Therefore pins on the female XLR progress numerically in the counterclockwise direction whereas the male XLRs are clockwise. Pin numbers are stamped on the XLR face for reference.


1. Force (XLR5)

a. Load the XLR Boot and crimp connector to cable.
b. Trim fine wires so they will not be crimped (refer to step e). Strip only as much of each of the 4 leads as needed to solder into cups.
c. Solder the 4 leads directly into the XLR solder cups following **VBA Wiring Diagram** and **VBA XLR Table**.

d. Slide up the crimp connector to mate with the soldered XLR.
e. Crimp the metal tabs one at a time lightly then two at a time more tightly. Make sure crimping is onto the cable housing, not to the fine wires.
f. Slide up the boot to connect with crimp connector. XLR face should be flush with housing.

2. Servo (XLR6)

a. Cut off the headers originally on the servo hookup wire.
b. Trim down the white and green hookup wires.

c. Add large heat shrink to the hookup wire but don't shrink.
d. Use the 4-pin USB Cable wire. Cut down the metal braided shield.
e. Splice together USB wires with hookup wires. One by one, first add tiny heat shrink then splice, tin, solder, shrink (*IMG Servo 1*). USB green to hookup blue; USB white to Hookup purple. USB red to hookup red; USB black to Hookup black (*IMG Servo 2*)
f. Heat shrink large heat shrink tubing over these.
g. Repeat steps a-f from Force section using the other end of the USB cable. Follow the wiring diagram for the servo and color code from above.

C. Laser (XLR4)

a. Strip laser cable down about 2 inches, more than what is in photo (*IMG Laser 1*).
b. Separate out red blue white and black wires and cut off extra wires.
c. Unbraid the metal shield and snipping off some to thin it out
d. Strip down blue and black wires and twist both tightly with the metal shield (*IMG Laser 2*).
e. Heat shrink these twisted wires with two layers of thinner shrink (*IMG Laser 3*).
f. Shrink large diameter heat shrink over all the wires and the black cable.
g. Repeat steps a-f from the Force section. Follow the wiring diagram/table for the laser.