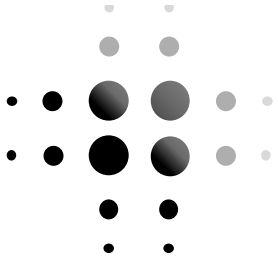


OpenBOS

Hardware Manual

The Open-Source Background-Oriented Schlieren Imaging System

Table of Contents

1.0 BOM

Off-the-shelf item (linked)	Unit	Qty	Cost/Unit ($CAD)	Cost ($CAD)
Plexiglass (16"x16")	Item	1	38.99	38.99
Socket Head Cap Screws (M5-0.8 x 10mm)	pack	1	18.79	18.79
2020 Series T-Slot Nuts (M5)	pack	1	14.99	14.99
Photography Light	item	1	49.99	49.99
2020 Series Aluminum (400mm)	pack	1	59.99	59.99
2040 Series Aluminum (1220mm)	pack	1	115.99	115.99
2020 Series 500mm	pack	1	48.99	48.99
304SS Tubing Dowel (10mm OD)	item	1	13.99	13.99
Camera Mount	item	1	17.99	17.99
Heat-Set Inserts (M5xD7xL7)	item	1	14.99	14.99
Background Paper (16”x16”, 32#)	item	1	[1]13.97	13.97
Non-Slip Furniture Pads Self Adhesive (3/4” square 128 pcs)	item	1	16.99	16.99
Small Measuring Tape	item	1	5.49	5.49
Double-Sided Tape	item	1	6.09	6.09
3D Printer Filament	kg	0.41	[2]25.99	10.66
Total cost				**$447.90 CAD**

Although not included in the budget, the user is expected to have a DSLR camera to conduct BOS experiments. Camera and lens specifications for optimal results are discussed in Section 4.0.

[1] Background printing costs dependent on method used. In this case, University of Waterloo print services were used.

[2] 3D printer filament costs dependent on printer and material used. In this case, matte black PLA is used.

2.0 Manufacturing Steps

1. **Procure:** acquire all parts listed in the BOM in Section 1.0
2. **Generate Background & Print:**
    - See Software Manual for instructions to generate the optimal background and scaling to 16”x16” before printing
3. **Cut:**
    - One of the 400mm 2020 series extrusions cut into two 200mm pieces
    - Two of the 400mm 2020 series extrusions cut down to 395mm
    - One of the 500mm 2020 series extrusions cut down to 435mm
4. **3D-print:** convert all STEP files to STL before printing
    - TriangleConnectionBracket.STEP (x14)
    - LightMountBracket.STEP (x1)
    - LightMountWedge.STEP (x1)
    - Endcap.STEP (x6)
    - LBracket.STEP (x4)
    - RailBracketLeft.STEP (x1)
    - RailBracketRight.STEP (x1)
    - Ski.STEP (x4)
    - BaseSled.STEP (x2)
    - LockingFoot.STEP (x2)
    - StackingRiser.STEP (x2 min, print more as needed)
5. **Prepare:**
    - Install heat-set inserts into two base sleds with soldering iron according to the locations displayed in Figure 1.

Figure 1: Heat-set insert locations for base sleds.

- Similarly, install heat-set inserts into stacking plates according to Figure 2. Repeat as many times as needed.

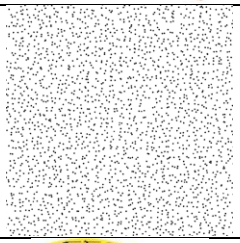
Figure 2: Heat-set insert locations for stacking plates.

3.0 Assembly Steps

3.1 Background Assembly

Set aside the following materials and components (post-cutting and printing) for this assembly, as outlined in the below table.

Item	Qty	Image
400mm 2020 series aluminum pieces	4	
395mm 2020 series aluminum pieces	2	
435mm 2020 series aluminum piece	1	
Triangle connection brackets	10	
165mm 10mm OD metal dowel	1	
Dowel mounting bracket	1	
Dowel mounting wedge	1	
M5 10mm socket head cap screws	56	

M5 T-Slot nuts	56	
End Caps	6	
L-brackets	4	
Photography light	1	
Plexiglass	1	
Background	1	
Double-sided tape	1	
Main rail-attach brackets (left and right)	2	

Helpful Tip: Prepare all of the connection brackets by lightly fastening the screws and t-slot nuts to the brackets, as in Figure 3.

Figure 3: Triangle connection bracket prepared with screws and t-slot nuts.

1. **Build the Aluminum Base**
    - Put one piece of cut 395mm aluminum in the middle of two perpendicular, un-cut 400mm pieces. Use a vertical surface, such as a wall, to align the pieces and connect them using the corner brackets, shown in Figure 4.
    - Once the edges are aligned, tighten the fasteners to secure the brackets.

Figure 4: Aluminum base skeleton step 1.

    - Secure the dowel and the dowel mounting bracket to the center of the back rail and tighten the screws, as seen in Figure 5.

Figure 5: Dowel mounting bracket screwed into back rail.

- Place the other 395mm piece parallel to the first, between the bars, at a distance of approximately 310 mm from outside edge to outside edge. Once the aluminum is in position, use four corner brackets to secure the bar to the assembly, shown in Figures 6a & b.

Figures 6a & b: Aluminum base skeleton step 2.

- Mount two 400mm extrusions vertically to the base skeleton with two corner brackets on each side of the extrusions, as displayed in Figures 7a & b


Figures 7a & b: Vertical extrusions to hold plexiglass.

2. Mount the Light and Background

- Position the light tripod mount on the dowel and secure it with the set screw, as shown in Figure 8.

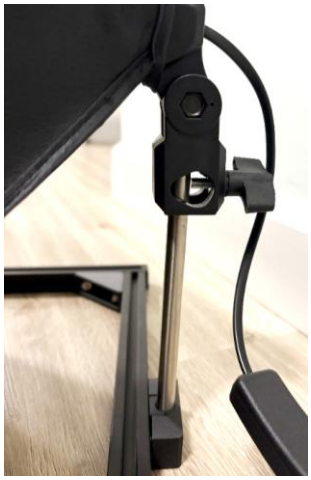


Figure 8: Light mounted to dowel.

- Ensure that the light is angled to be parallel to the frame and tighten the rotating joint screw, so it remains in place. This is pictured in Figure 9.

Figure 9: Light sitting parallel to frame.

- Using the double-sided tape, secure all four corners of the 16”x16” background print. Use as little tape as possible and avoid taping too far into the middle of the background so as much of the pattern as possible can be used for experimentation. This is displayed in Figure 10.

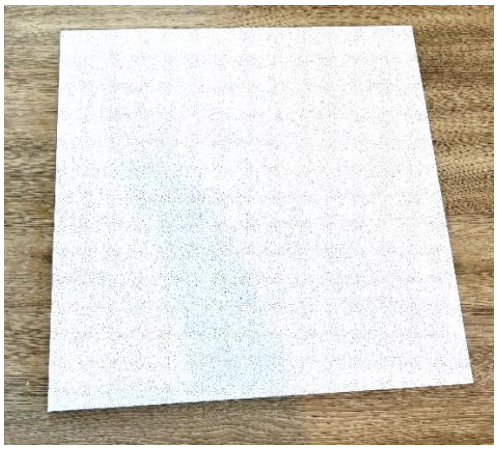


Figure 10: Background print taped to plexiglass.

- Slide the taped background print and plexiglass into the background frame, being cautious of colliding with the light, as displayed in Figure 11.

Figure 11: Plexiglass and background inserted into frame.

- Install the top cut 435mm extrusion to connect the two the frame extrusions with L-brackets sandwiching the front and back on each side. This is displayed in Figures 12a & b

Figures 12a & b: Top frame extrusion installed.

3. Build Main Rail Attachment Receptacle

- Align one of the cut 200mm extrusions in the center of the front background rail to ensure that the main rail-attach brackets are spaced correctly, as shown in Figure 13. Ensure that the endcaps are on the alignment extrusion so that the brackets are placed correctly in the next step.

Figure 13: Main rail alignment with 200mm extrusion piece.

- Place rail-attach brackets over the extrusion alignment piece, ensuring they are snug against it, before screwing the brackets into place. Remove the alignment piece. This is shown in Figures 14a & b.

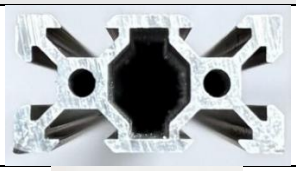
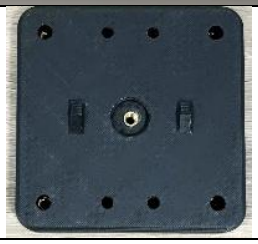
Figures 14a & b: Rail-attach brackets installed.

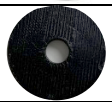
- Once complete, the background subassembly should look like Figure 15. Place endcaps on all exposed extrusion ends.

Figure 15: Complete background subassembly.

3.2 Main Rail Assembly

Set aside the following materials and components (post-cutting and printing) for this assembly, as outlined in the below table.

Item	Qty	Image
1220mm 2040 series aluminum pieces	1	
200mm 2020 series aluminum pieces	2	
Triangle connection brackets	4	
M5 10mm socket head cap screws	26+	
M5 T-Slot nuts	16	
End Caps	4	
3D Printed Skis	4	
3D Printed Base Sleds	2	

Locking screw foot	2	
3D Printed Risers	2+	
Camera Mount	1	
Off-the-shelf or 3D printed washers (for M5 screw)	2	
Heat-set inserts	14+	
Measuring tape	1	
Double-sided tape	1	

1. **Assemble the Main Rail**
    - Attach only ONE of the cut 200mm 2020 extrusions to ONE SIDE of the uncut 1220mm 2040 extrusion with two corner brackets, as displayed in Figure 16. Leave the other side of the main rail open so that the camera and experiment sleds can be slid on.

Figure 16: One end of main rail.

    - Trim the start of the measuring tape such that the background plane is considered "0". The measuring tape must also be trimmed at the end to stop before the other 200mm extrusion is attached. The sleds can be positioned at known measurements by aligning the tickers with the measuring tape.
    - Cut the double-sided tape in half lengthwise and place it incrementally along the rail, then attach the cut measuring tape, similar to Figure 17.

Figure 17: Measuring tape placed along main rail with starting measurement at 7mm.

2. **Assemble and Attach the Base Sleds**
    - Prepare the 3D-printed skis for further assembly by carefully threading the screws entirely through the plastic, ensuring they remain straight. This can be seen in Figures 18a & b.

Figures 18a & b: Threading screws through 3D-printed skis.

- Slide two 3D printed skis into the 2040 extrusion grooves, as displayed in Figure 19.

Figure 19: Skis in main rail.

- Place the locking screw foot into the groove on the bottom of the base sled. These components are displayed in Figure 20.

Figure 20: Bottom of sled and locking screw foot.

- Turn the base sled over carefully and position it on top of the skis, aligning the 4 holes in the sled to the holes in the skis. This is displayed in Figures 21a & b.

Figures 21a & b: Base sled installation to skis.

- Install the four screws connecting the sled to the skis until they bottom out, then loosen by a half-turn or so.
- Put the locking screw in the center threaded hole. Tightening this screw will push the screw foot into the rail and hold the sled tightly in place. Loosening it will allow the sled to slide along the rail. This is displayed in Figure 22.
- Repeat these steps with the second sled.

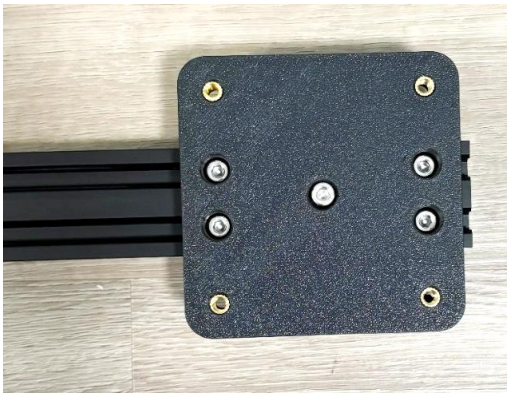


Figure 22: Center locking screw.

- Install the other 200mm extrusion to the end of the main rail with the remaining two corner brackets, as seen in Figure 23. Put extrusion caps on all free ends.

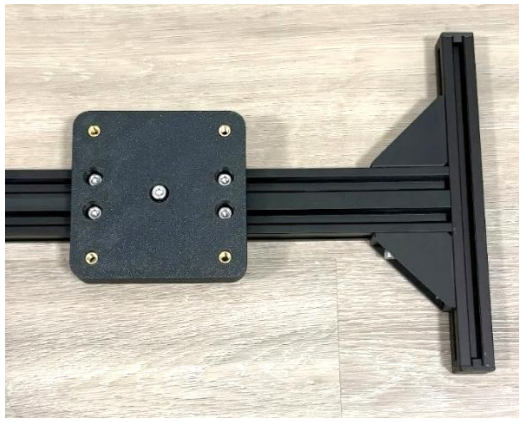
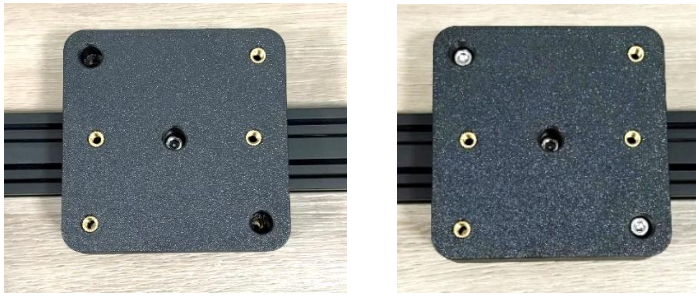


Figure 23: Close off the main rail with other 200mm extrusion.

3. Attach Risers and Camera Mount

- Install the desired number of riser plates to boost the height of the experiments or camera mount. Rotate each added plate 90 degrees to obtain new hole locations to screw the plates into, as displayed in Figures 24a & b.



Figures 24a & b: Stacking riser plates.

- Remove center hole guide from camera mount and install the mount to the base sled that is further from the background assembly using two screws and washers. This is displayed in Figures 25a & b.

Figures 25a & b: Camera mount attachment to plate.

- Screw a DSLR camera to the mount using and adjust as needed, pictured in Figure 26.

Figure 26: Camera mount lifted in z.

- Place experiment on the other sled
- Once complete, the finished apparatus should look like Figure 27.

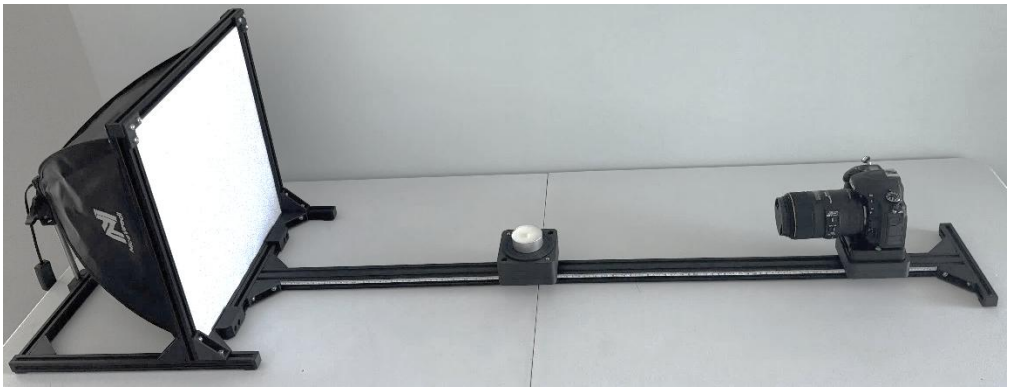


Figure 27: Completed setup.

- Note that the sled positions can be identified using the tickers and measuring tape along the main rail, as seen in Figure 28. These measurements will be inputted as parameters into the software. See Software Manual.
- Tested positions with the tealight experiment (yielded best results):
    - Experiment sled at 56cm mark
    - Camera sled at 119.5cm mark

Figure 28: Sled position identification using the tickers and measuring tape.

- Section 4.0 provides information for set-up and camera best practices to ensure the experiment yields accurate results.

4.0 Optimal Set-up & Experimental Tips

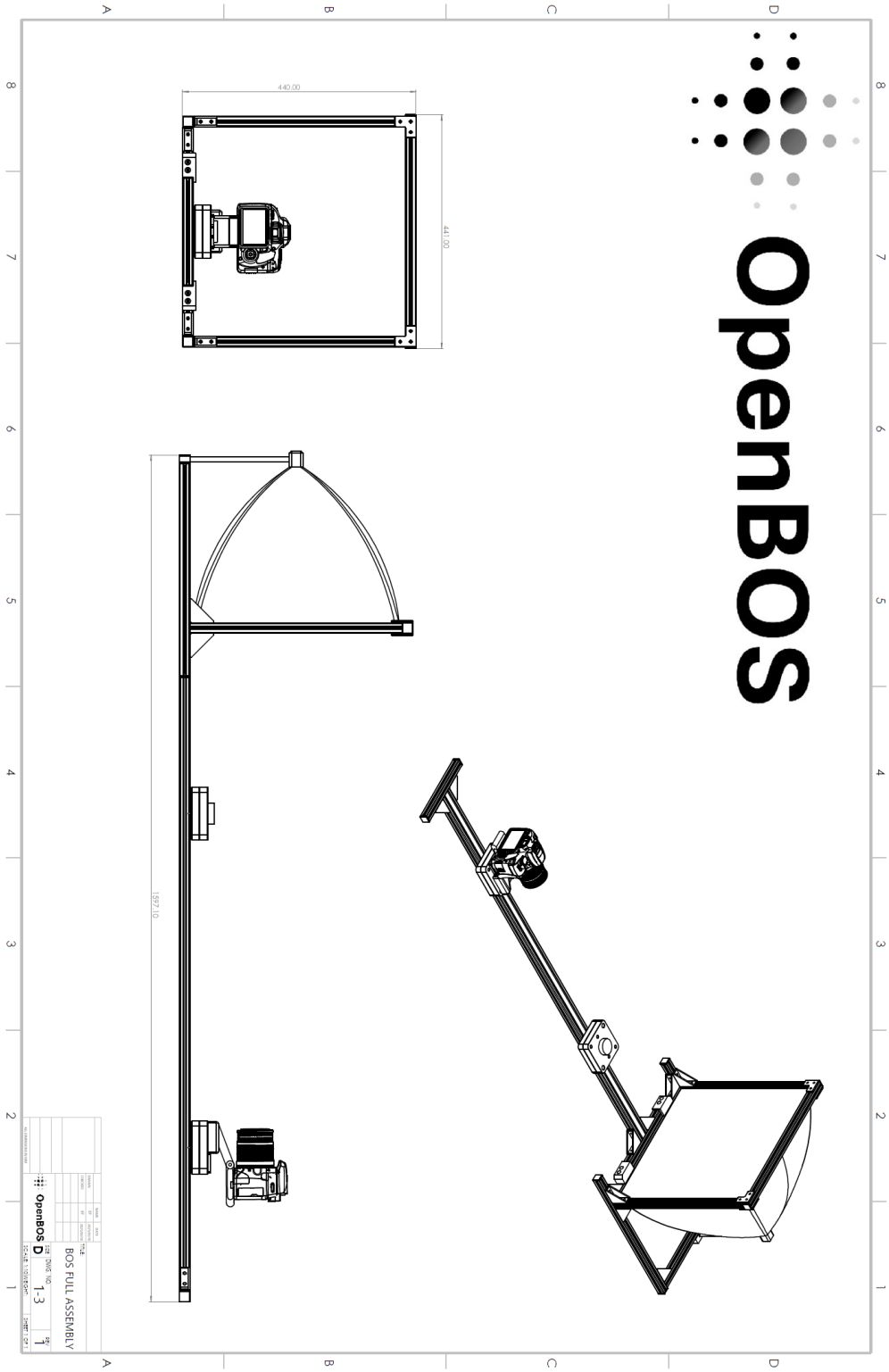
4.1 BOS Experimental Set-up

1. **Lighting**
   - Bright and uniform continuous lighting
   - Diffuse
2. **Camera and Lens Specifications**
   - High resolution camera
   - Macro 1:1 lens
   - Focal length around 50 mm
   - Manual focus
3. **Camera set-up**
   - Ensure camera is in video mode
   - Try to focus both experiment and background in frame
   - Set aperture such that the background and experiment are in focus (~f/11)
     - Wide aperture for more light but small DOF (f/2.8 or f/4)
     - Small aperture for larger DOF (f/8 or f/11)
   - Set iso value between 1200 and 2500
     - Use a lower iso for better image quality, but too low will make field of view too dark
   - Set white light balance to auto
4. **Spacing and Distance**
   - Position camera at a distance such that the entire background takes up the full width in the viewfinder
   - Object should be placed slightly closer to the background than the camera, but these distances must be on the same order of magnitude

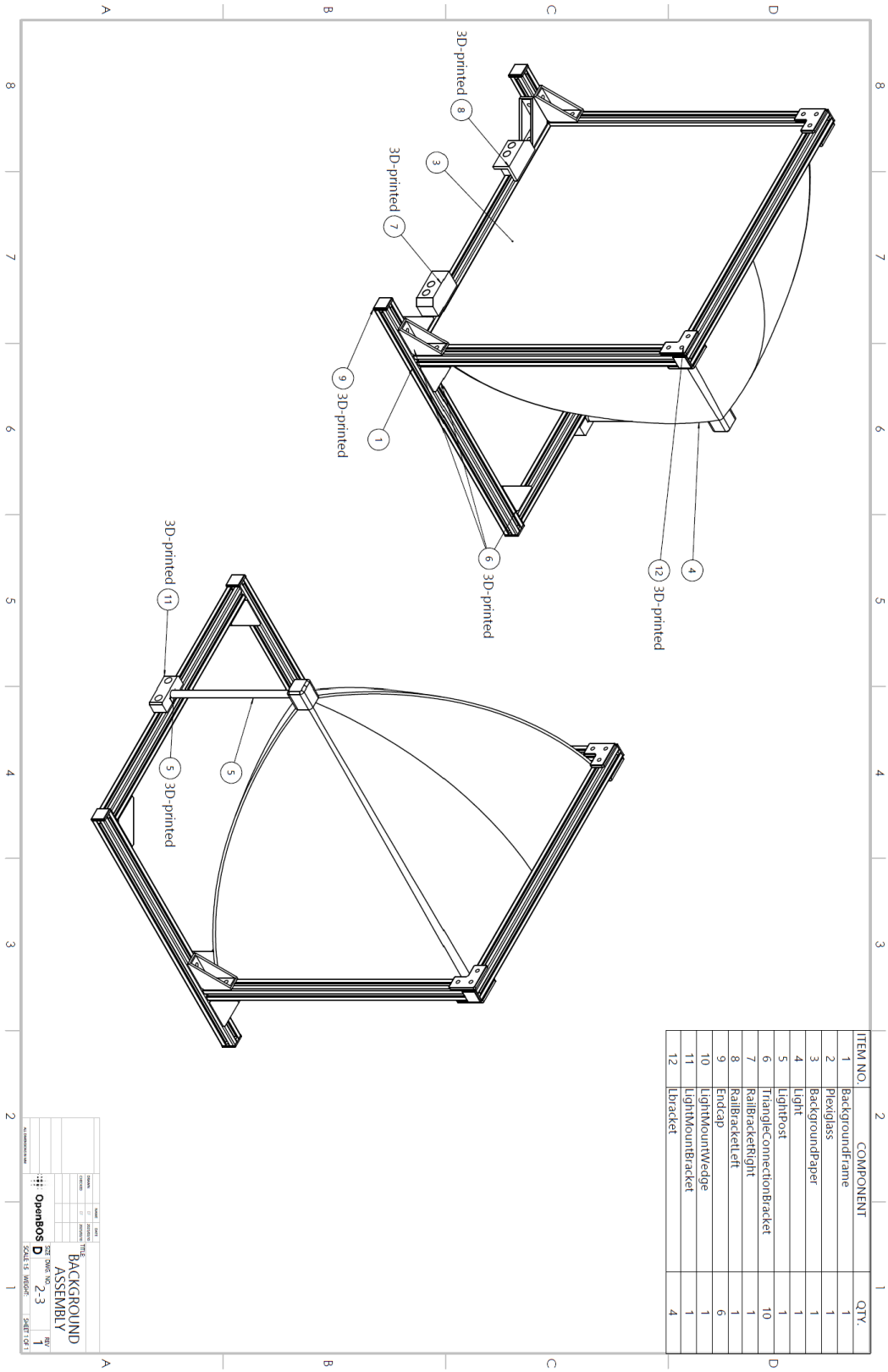
For more information about optimal set up see Chapter 2.2: BOS example in practice from Background-oriented schlieren (BOS) techniques by Markus Raffel in Exp Fluids (2015) 56:60 (DOI 10.1007/s00348-015-1927-5)

5.0 Engineering Drawings

5.1 BOS Full Assembly



5.2 Background Assembly



5.3 Main Rail Assembly