



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1600334-v3

LIGO

August 8, 2016

3D Printing BSC and HAM Instructions

Ellie Parisi

Distribution of this document:
LIGO Scientific Collaboration

This is an internal working note
of the LIGO Laboratory.

California Institute of Technology
LIGO Project

Massachusetts Institute of Technology
LIGO Project

LIGO Hanford Observatory

LIGO Livingston Observatory

<http://www.ligo.caltech.edu/>

1 Introduction

This document contains the instructions to 3D-print a 1:24 scale model of the LIGO BSC and HAM Vacuum Chambers.

2 Instructions from STL File to Print File

2.1 Opening in Slicer Software

2.1.1 Files to Print

Below are the names of the STL files to print. The files can be found on the same DCC page as this document. Save the files onto your computer to be accessed later.

- BSC Lower Shell:
 - Top
 - Middle
 - Bottom
- BSC Cover (x3)
- BSC End Cover
- BSC Table:
 - Top Plate
 - Tri-Plate
 - Middle Plate
 - Bottom Plate
- HAM Chamber
- HAM Legs
- HAM 60in Cover (x2)
- HAM 84in Cover
- HAM Septum Cover
- HAM Table:
 - Top
 - Bottom

2.1.2 Opening Files

Open the files in a slicing software. Slicing softwares are designed to take STL files, and convert them into the layers that the 3D printer can print. Below is a chart of common printers and their respective softwares. If your printer is not listed, consult your printer's instruction manual.

Printer Brand	Software
MakerBot	MakerBot Desktop
LulzBot	Cura
Ultimaker	Cura
MakerGear	Simplify 3D

MatterControl is another slicing software that is adaptable to most 3D printers. The following instructions are specifically for the MatterControl software, though the instructions would be very similar in other softwares.

In the slicing software, go to File>Add File to Queue and choose the STL file you want to print from your computer. Now, the file should be previewed in your software.

2.2 Adjusting General Settings

Depending on the printer, different settings are used to produce the best printed result. The following instructions are for best results on a MakeIt Pro-M, but are similar for other printers and can be adjusted according to the printer type. If a setting is not specified, it is not used or set to 0.

Make sure you are viewing advanced settings.

2.2.1 Layers/Surface

Layer Height: standard (0.2mm)	Avoid Crossing Perimeters: checked
First Layer Height: 0.3mm	Top Solid Layers: 5 count
Perimeters: 2 count	Bottom Solid Layers: 4 count

2.2.2 Infill

Fill Density: 15%	Starting Angle: 45 degrees
Infill Type: Triangles	Infill Overlap: 0.06mm

2.2.3 Speed (mm/s)

Infill: 60	First Layer Speed: 20
Top Solid Infill: 50	Outside Perimeter: 40
Raft: 40	Support Material: 30
Inside Perimeters: 40	Travel: 150

2.2.4 Skirt and Raft

Skirt Loops: 5	Raft: set according to printer settings and as needed
Distance from Object: standard (3mm)	



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

2.2.5 Support Material

Generate Support Material: checked	Infill Angle: 45 degrees
Support Type: Lines	Air Gap: 0.3mm
Pattern Spacing: 3mm	Create Perimeter
Support Percent: Standard (50%)	

Note: If printing HAM Legs file, BSC Table Top, HAM Table Bottom, HAM Table Top, or HAM Septum Door, uncheck “Generate Support Material”.

2.2.6 Output Options

Check the box next to “Center on Bed”.

2.2.7 Other Settings

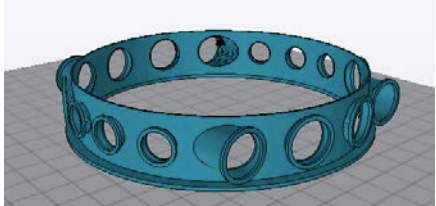
Set Filament Diameter according to the filament you are using. Set the extruder and bed temperatures according to your printer’s settings.

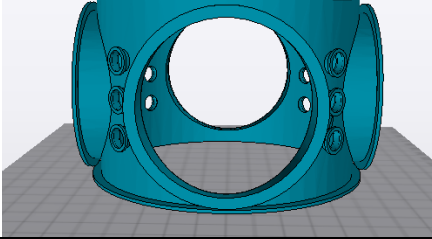
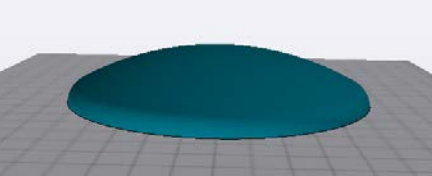
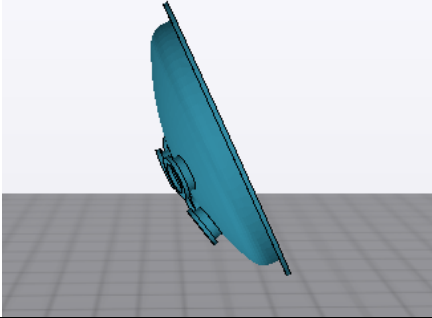
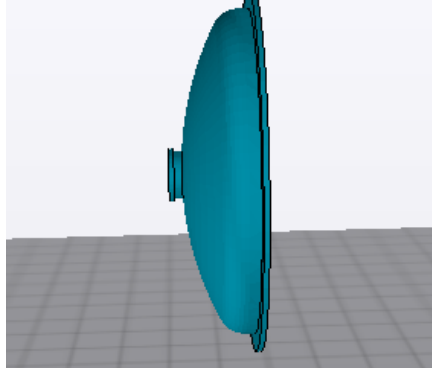
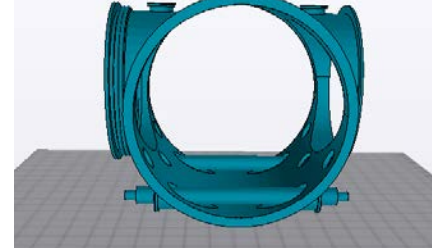
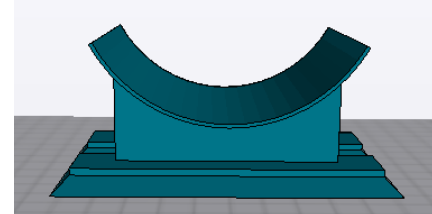
3 Positioning Model and Exporting

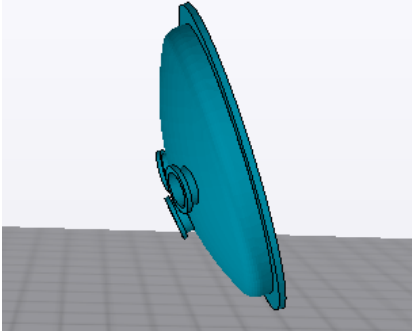
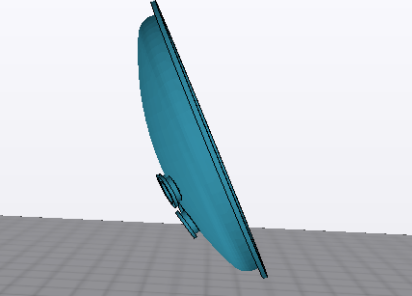
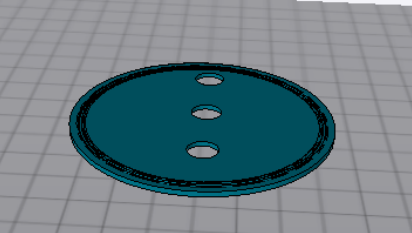
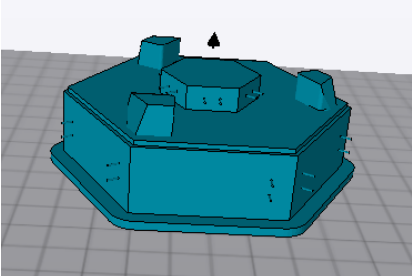
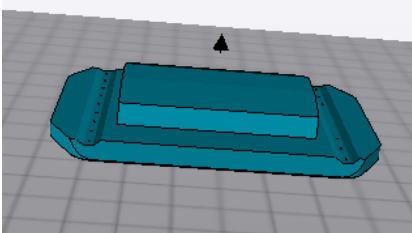
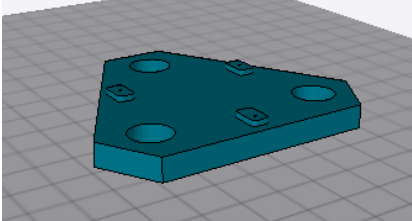
3.1 Positioning

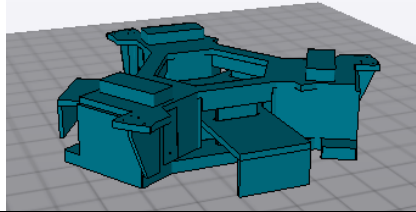
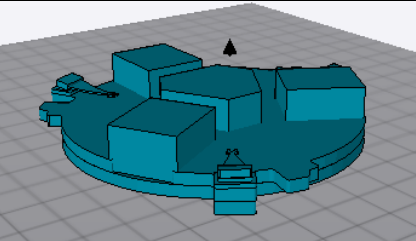
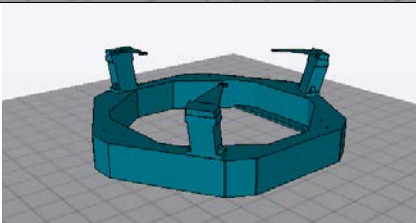
3.1.1 Rotating

In the model view there should be settings to adjust the angle (rotate) and position of the part. First, rotate the part. The rotation degrees and directions for each part are specified below.

File to Print	Rotation	Preview
BSC lower shell top	X rotates -90°	

<p>BSC lower shell middle</p>	<p>X rotates -90°</p>	
<p>BSC lower shell bottom</p>	<p>X rotates -90°</p>	
<p>BSC cover</p>	<p>X rotates -25°</p>	
<p>BSC end cover</p>	<p>No rotation</p>	
<p>HAM chamber</p>	<p>X rotates 90°</p>	
<p>HAM legs</p>	<p>X rotates 90°</p>	

<p>HAM 60in cover</p>	<p>X rotates -90° Y rotates -20°</p>	
<p>HAM 84in cover</p>	<p>X rotates 155°</p>	
<p>HAM Septum Door</p>	<p>No rotation</p>	
<p>HAM ISI Top</p>	<p>X rotates -90°</p>	
<p>HAM ISI Bottom</p>	<p>X rotates -90°</p>	
<p>BSC Table Top Plate</p>	<p>X rotates 90°</p>	

BSC Table Tri-Plate	X rotates -90°	
BSC Table Middle Plate	X rotates 90°	
BSC Table Bottom Plate	X rotates 90°	

3.1.2 Centering

Center the part on the print bed (if not already centered), so no part of the model is off the print bed. Some softwares have a button to automatically center the model. If the software has an option to save the orientation of the part (ie. a save button near the preview window), then click it at this time.

3.2 Exporting

3.2.1 Layer View

Open Print Preview or Layer View on the software. This should generate a preview of each of the layers the 3D printer will make. Drag the slider up and down to see each layer step by step. Make sure there are no obvious problems in the result. Supports and raft should be visible. Note the print time estimate.

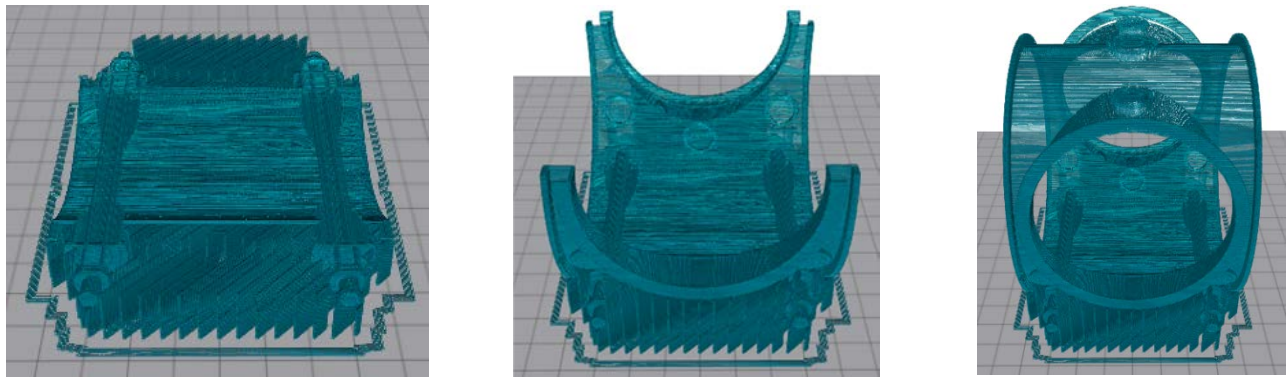


Figure 1: Layer View of the HAM Chamber file. The diagonal lines near the bottom of the model are the supports, and the outline of the model is the skirt. Both the supports and the skirt will be removed after printing.

3.2.2 Exporting

Next, click Export or Print in the software. Export the file as a GCode and save to an SD card (or other location which your printer can access the file—read your printer’s instructions to see which method is compatible). Eject the SD card.

4 Printing

4.1 Starting the Print

Follow your printer’s instructions of how to load filament, insert SD card, and print file. Watch the first layer be printed to make sure the printer is functioning well, the bed is level, and the model is adhering to the print bed. Watch for the nozzle being too close or far away from the print bed (in which case, stop the print and level the print bed), and for the plastic “curling” up from the bed. After the first layer is printed, the printer can be left running to completion without supervision.

4.2 After Printing

When the print has finished, carefully pry off the model from the bed. Remove supports carefully with pliers or other tools (they should come off relatively easily). Supports are thin sheets of plastic holding up the model. They are found at the base of the model, and can also be inside holes. Sand any rough edges. The model is complete.

5 Assembling the Model

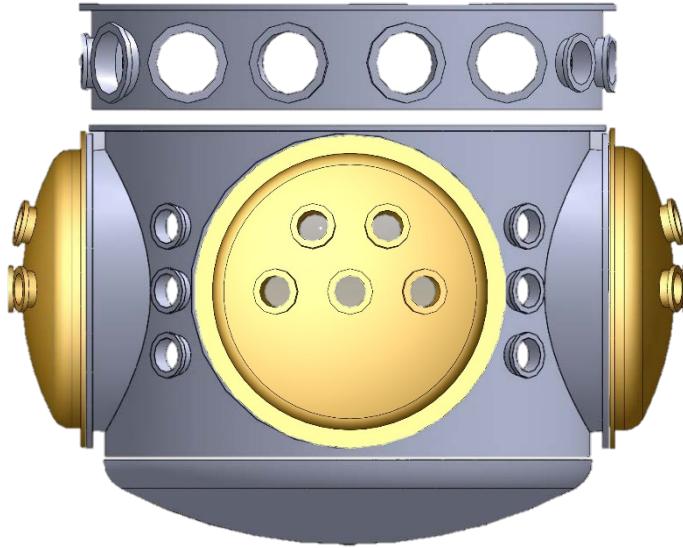
Once all the models are printed, they can be assembled to make the BSC and HAM vacuum chambers. They are put together with super glue or other adhesive.

5.1 Assembly

5.1.1 BSC Chamber

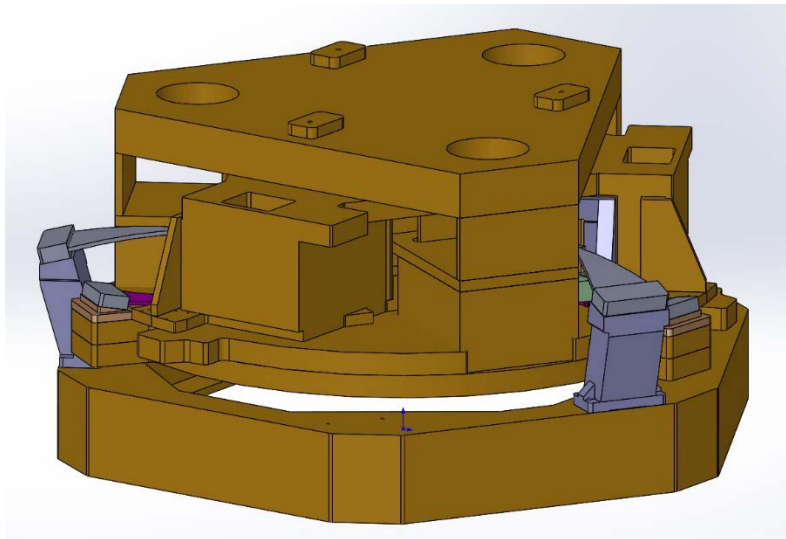
Attach the bottom of the Lower Shell Top to the top of the Lower Shell Middle. Both should be positioned with the smaller holes on the sides, and the small overhang on the top. Then, attach the dome-shaped Lower Shell Bottom to the bottom of the Lower Shell Middle, opposite the Lower Shell Top. The flat part of the dome connects to the Lower Shell Middle, and rounds outward away from the dome. Attach the three Covers to the large holes on the side of the Lower Shell Middle, with the

holes on the doors oriented to be on the Cover's upper half. Attach the final End Cover to the last large hole.



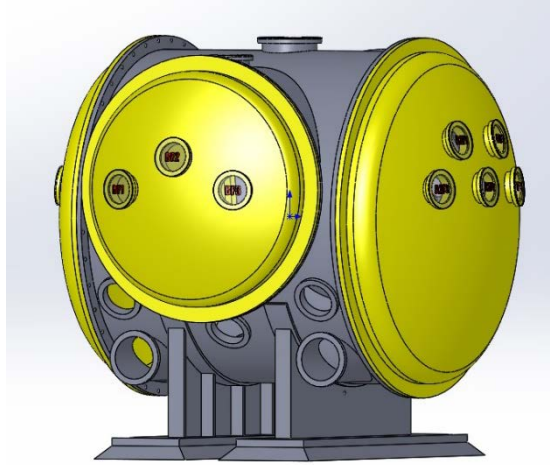
5.1.2 BSC ISI Table

The BSC Table parts stack on top of each other in the following order (from bottom to top): Bottom Plate, Middle Plate, Triplate, and Top Plate.



5.1.3 HAM Chamber

First, remove the thin curved plate on the top of the HAM Legs. The HAM Chamber then is placed on top of the HAM Legs, so the legs are parallel with the tubes in the HAM Chamber. The two 84in Covers are attached, with the holes oriented to the top half of the cover, to the sides of the HAM Chamber in the corresponding holes. Of the remaining two holes on the HAM Chamber, one should have ridges on its sides. On that hole, the Septum Cover is attached, while on the other, the 60in Cover is attached.



5.1.4 HAM ISI Table

The HAM Table parts stack on top of each other, with both parts oriented so their flat plate is on top. The Top Plate is positioned on top of the Bottom Plate.

