WILLIAM E. BOEING DEPARTMENT OF
AERONAUTICS & ASTRONAUTICS
College of Engineering

Test Stand Manufacturing Plan

Version 1.0
2024-06-01

SPACE Lab Thrust Stand

Team Members:	Nathan Cheng
	Felicity Cundiff
	Adam Delbow adelbow@uw.edu
	Ben Fetters bfetters@uw.edu
	Lillie LaPlace llapla@uw.edu
	Kai Laslett-Vigil
	Winston Wilhere
Faculty Advisor:	Dr. Justin Little
TA:	Harry Furey-Soper

Table of Contents

1 Introduction

This plan outlines the procedures required to manufacture and assemble every structural component that makes up the Test Stand. Each subsystem's components' manufacturing is

detailed, followed by an instruction manual for both the assembly and disassembly of the Test Stand's structure. Following this assembly, the stand will be capable of leveling the pendulum through the GUI-controlled stepper motor and leave the stand ready for test operation with the pendulum returning to its zero point after every firing.

2 Technical Description

2.1 Overview

2.1.1 Chamber Interface:

The chamber interface consists of 29 manufactured parts. Two materials are used: G10 Garolite for structural components and Buna-N rubber for vibration damping. Additionally, two sleeve bearings and a stepper motor were purchased and used in their off-the-shelf form.

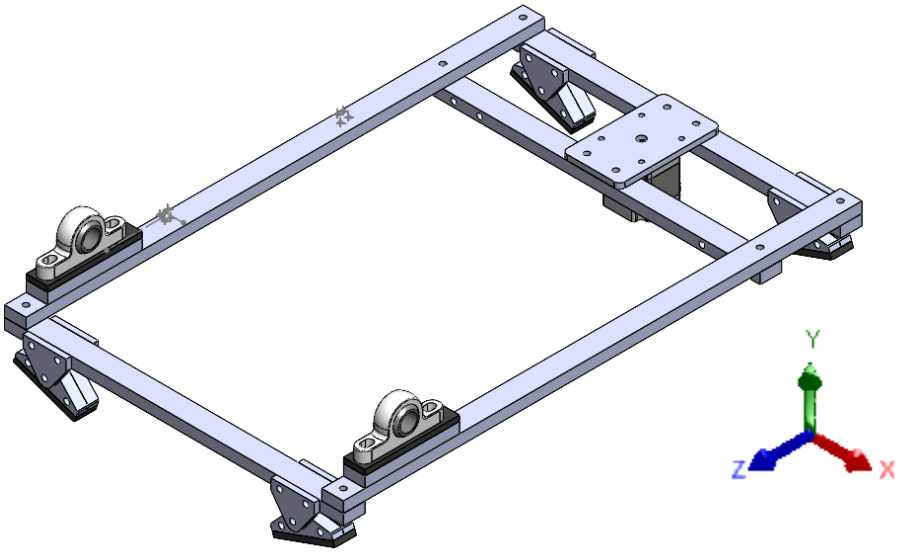

Figure XX. Chamber Interface System Overview

2.1.2 Leveling System:

The leveling system consists of 8 manufactured parts. The stepper motor is mounted between the chamber interface and leveling system, and is a key, COTS component of both systems' structures. The longitudinal and radial struts are all made from ½" G10 Garolite sheet, while the doublers are made of ⅛" G10 Garolite sheet doubled together to produce ¼" assemblies. The pivot

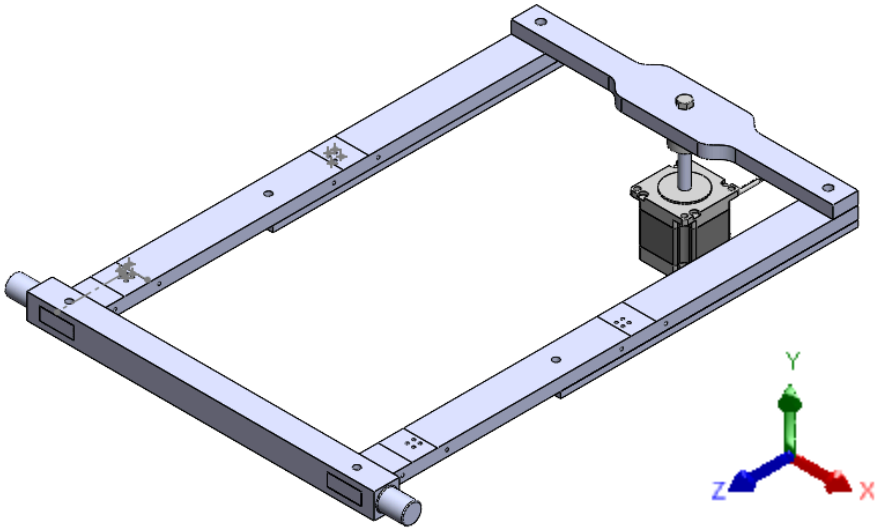

Figure XX. Leveling System Overview

2.1.3 Pendulum:

The pendulum consists of 55 total manufactured components, with 27 parts included in any flexure configuration. All parts are made of G10 Garolite, with brackets consisting of ⅛” thickness 1x1” angle stock, the top being cut from ⅛” thickness G10 Garolite sheet stock, two sets of 8 ⅛” thickness arms, 16 bracket connectors, and 4 sets of 8 flexures made of spring steel in thicknesses of 0.01”, 0.015”, 0.020”, and 0.025”.

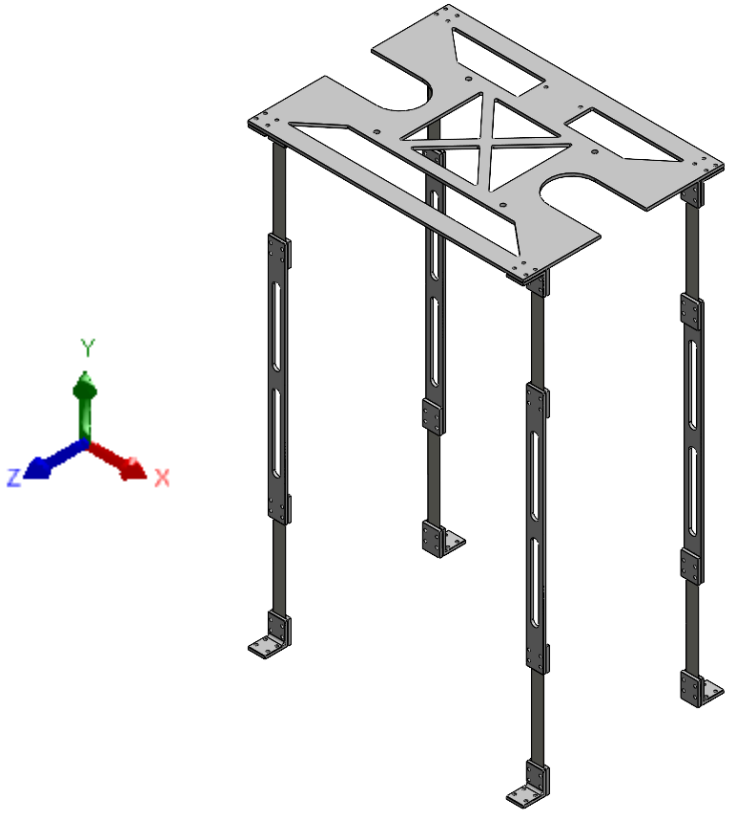

Figure XX. Pendulum

2.1.4 PPT Mount:

The PPT Mount consists of 6 manufactured parts, with 4 used in a given configuration. All components are made of ½” Delrin sheet stock. The mount consists of a base upon which thrusters are placed, 2 sets of 2 side panels to accommodate VC1 and VC2’s dimensions, and a strap to ensure structural rigidity of the mount.

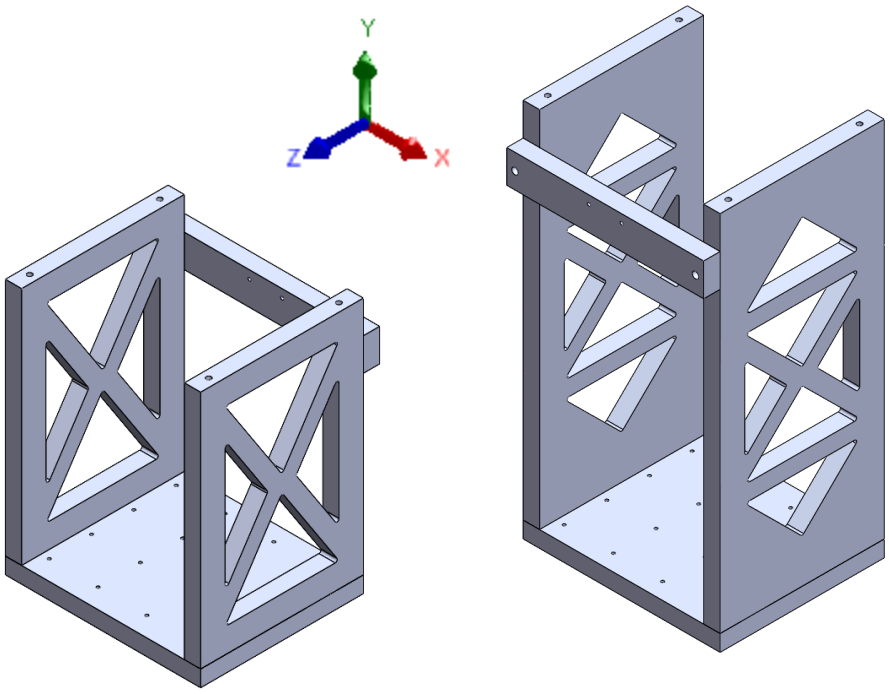

Figure XX. PPT Mount VC1 (Left) and VC2 (Right) Configurations

2.1.4 Pendulum Housing:

The pendulum housing consists of 15 manufactured parts. The four arms are made of ⅛” 1x1” G10 Garolite angle stock and the four leveling brackets, three top panels, and four side panels are made of ⅛” G10 Garolite sheet stock.

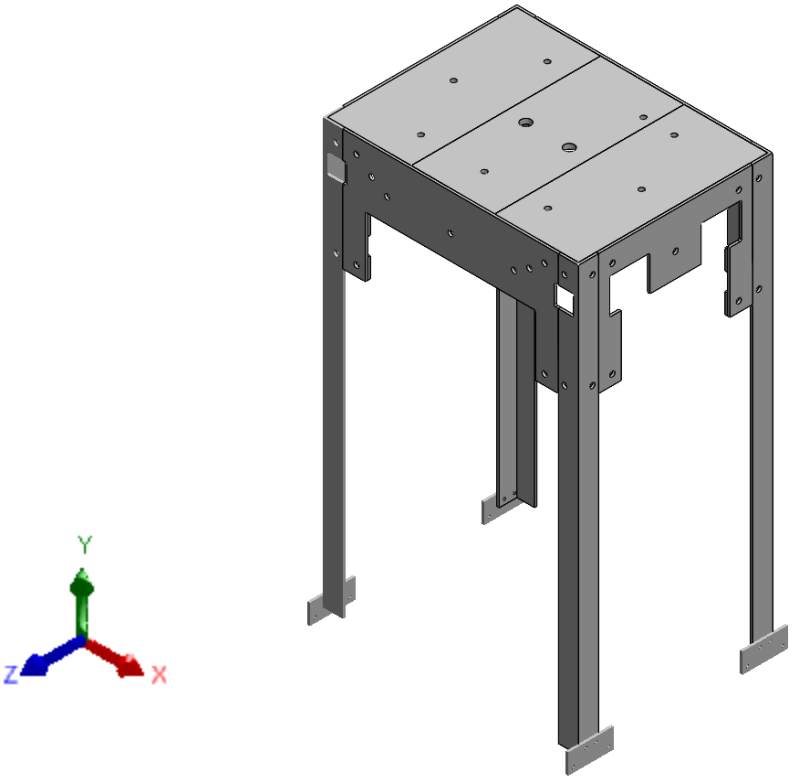

Figure XX. Pendulum Housing

2.1.5 Magnetic Damping System:

The magnetic damping system consists of 2 manufactured parts: a magnet housing and aluminum plate. The magnet housing was 3D printed out of PLA, while the 0.1” thick aluminum plate was cut out of larger sheet stock using shears.

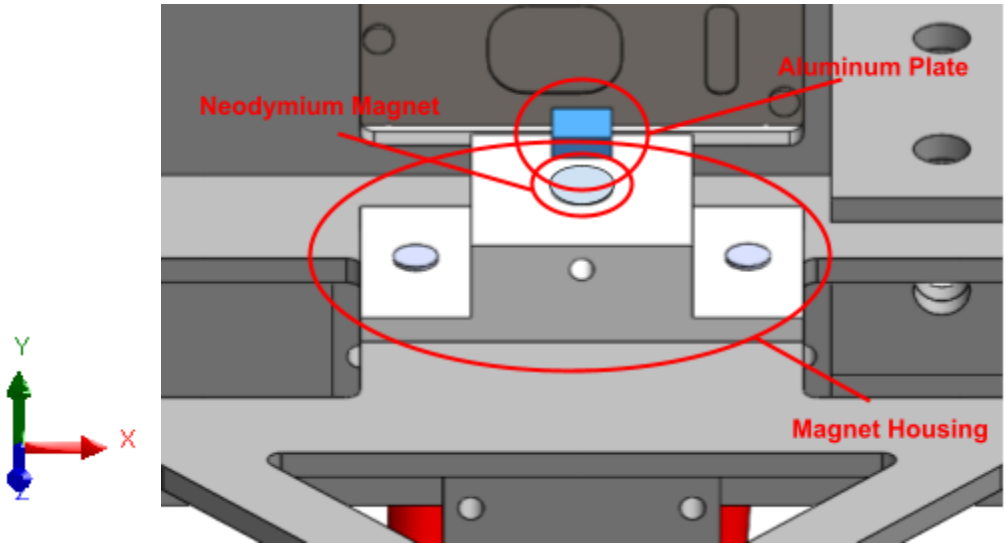

Figure XX. Magnetic Damping System

2.1.6 Wire Waterfall System:
The wire waterfall system's structure consists of four manufactured clamp parts from a single design. The clamp part is symmetrical, and is printed from PLA.

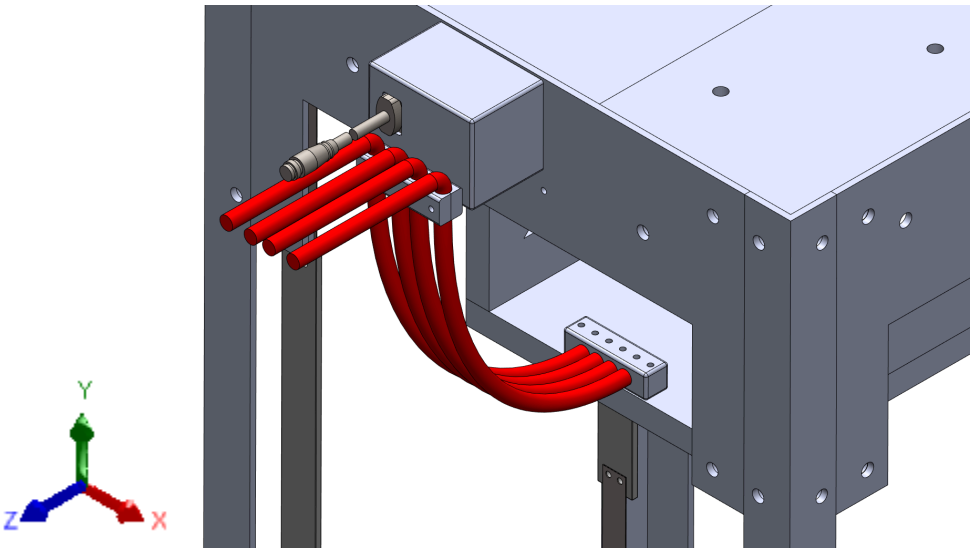

Figure XX. Wire Waterfall System

3 Detailed Drawings

All parts manufactured were produced using the following equipment and any further references to these tools are made with respect to their shortened titles below:

- Laser cutter: The 8 Makerspace Universal Laser System ILS12.75
- Drill press: C. Bossart Machine Shop Atlas 863 drill press
- Waterjet: Material Science & Engineering Shop Omax 2652 30 HP 60,000 PSI waterjet
- Dremel: C. Bossart Machine Shop Dremel 332-5 rotary cutting tool
- Bandsaw: C. Bossart Machine Shop bandsaw

Several manufacturing procedures are detailed below, for which standard procedures were defined: waterjetting, laser cutting, and drilling Garolite holes. For any work involving cutting Garolite outside of a waterjet, PPE including an N95 mask, safety glasses, and nitrile gloves were required.

All Garolite sheet stock parts were waterjetted to size without any internal features to avoid delamination using the following procedure:

1. Export .dxf from SolidWorks for relevant parts' feature faces to QCAD
    a. Export all parts for the same thickness Garolite sheet stock into the same QCAD workspace
    b. Delete all internal feature (lightening or screw holes) lines
2. Arrange all .dxf files for the same thickness Garolite sheet to fit within 26"x52" Omax waterjet area
3. Save file as single .dxf for all parts to be cut

4. Send .dxf file to MSE shop with one part's reference dimension for approval
5. Bring appropriate Garolite sheet stock to MSE shop
6. Return cut parts to AERB 139 lab space when notified of part completion

Paper templates were then laser cut for each part with all internal features included using the following procedure:

1. Export .dxf from SolidWorks for relevant parts' feature faces to QCAD
2. Arrange all .dxf files to fit within the ILS12.75 laser cutter's 24"x48" area (create several pages to accommodate all parts) for a 22"x34" sheet

   For templates only:
   a. Use masking tape to tape together 8 sheets of copier paper in two rows of four arranged into a 22"x34" sheet
   b. Tape the 22"x34" sheet to the laser cutter bed to prevent any shifting during cutting

   For all other parts:
   a. Place part material into upper lefthand corner ensuring square alignment with cutter bed

3. Email the .dxf generated in QCAD to one of the 8 Makerspace's computers and open in Adobe Illustrator
4. Select all drawing features and set line thickness to 0.01 pt and color to RGB: 255,0,0
5. Select Adobe Illustrator's print command to export the file to the laser cutter using the 8 Makerspace's presets, ensuring the print position on the laser cutter bed is set to the upper left corner
6. Open the file in the ILS application and ensure proper cut location in upper left corner
7. Turn on air compressor underneath computer by opening valve and flipping power switch
8. Turn on fume hood by pushing green button
9. Turn on laser cutter by flipping power switch
10. When laser cutter has powered on, re-zero the Z-height and X,Y position using the ILS application commands
11. Under ILS application material tab, set material to "printer paper" and do not change any other settings
12. Click the play button on the ILS application
13. When cutting has finished, remove the part templates and remaining paper from the cutter bed and discard excess material
14. Turn off laser cutter, fume hood, and air compressor using reverse steps from 9-11

All internal hole features were added using the following procedure:

1. Put on safety glasses, nitrile gloves, and an N95 mask
2. Tape paper template to part using masking tape, ensuring square alignment with all corners
3. Clamp part to drill press base

4. Use a second clamp to attach a shop vacuum nozzle to the drill press base and position to remove drilled debris
5. Select and install appropriate drill bit, for holes larger than 17/128”, use a 17/128” pilot hole and step through larger drill bits until target size is reached
6. Align clamp-part assembly below drill bit and center bit on template hole center (check front and side for visible alignment)
7. Turn on vacuum
8. Turn on drill press
    a. If speed is not set to 1000 RPM, change while turned on
9. Drill hole
10. Turn off drill press
11. Realign clamp-part assembly and bit to drill next hole
12. Repeat Steps 8-11 until all holes are drilled

Any additional interior or external features in a part not cut using a drill press were added using a Dremel as specified in their relevant drawings. Internal features for the Garolite angle stock were added prior to any bandsaw cuts to produce individual brackets and arms. For all Dremel and bandsaw cuts, proper PPE including gloves, safety glasses, N95 respirators were used in addition to continuously operating a shop vacuum chamber.

3D Printed Parts

1. Load filament into Prusa i3
    a. If any filament is previously loaded, unload
    b. If filament settings are not set to PETG, change accordingly
2. Export SolidWorks file as .stl
3. Open .stl file in PrusaSlicer
4. Set filament to PETG
5. Set print settings to 0.10 mm DETAIL
6. Set supports to “Support on build plate only”
7. Level part and place largest flat side on print bed in print editor
8. Export .gcode to SD card
9. Insert SD card into Prusa i3 and load file
10. Start print
11. When print is complete, remove from print bed
12. Remove excess support material (sanding as needed)

Technical drawings are attached as a separate document named “Test Stand Technical Drawings” and specify all dimensions and materials. Manufacturing instructions above detail how to produce each feature called out in each drawing.

4 Bill of Materials

Purchased Parts			
Fasteners			
Part	Quantity	Specification	
94613A537 (McMaster)	40	1/4"-20 x 3/8" hex bolt (nylon)	Frame bolts
94613A537 (McMaster)	40	1/4"-20 nut (nylon)	Frame nuts
94613A108 (McMaster)	18	#4-40 x 3/8" hex bolt (nylon)	Bolts for pendulum arms to top, and magnet housing to top
94812A700 (McMaster)	20	#4-40 nut (nylon)	Nuts for pendulum top and laser mount
B0C3QLVR6J (Amazon)	40	#40-40 x 3/8" (stainless steel)	Bolts for flexures and frame to radial struts
92314A108 (McMaster)	32	#40-40 x 3/8" (stainless steel)	Bolts for flexures and frame to leveling brackets
B0C3QLVR6J (Amazon)	96	#4-40 nut (stainless steel)	Nuts for pendulum top and laser mount
94613A831 (McMaster)	16	#10-32 x 3/4" hex bolt (nylon)	Bolts for thruster shelf, no nuts needed, tapped holes
95649A229 (McMaster)	16	#10 ID-0.203" OD-0.438" Washer (UHMW Plastic)	Washers for thruster shelf bolts
B0C3QLVR6J (Amazon)	16	#4-40 x 1" hex bolt (stainless steel)	Pendulum to radial strut bolts
95868A266 (McMaster)	4	#4-40 x 1 1/8" hex bolts (nylon)	Laser mount to frame and laser to laser mount bolts
92196A215 (McMaster)	8	#40-4 x 1 5/8" hex bolts (stainless steel)	Leveling bracket to radial strut bolts

Part	Quantity	Material	Manufacturing Technique	Complete?	Re-Manufacture?
VS1	4	1/8" G10 Sheet	waterjet, drill press holes, dremel lightening slots	Y	Y
CILS1	2	1/2" G10 Sheet	waterjet, drill press holes	Y	N
CIRS1	3	1/2" G10 Sheet	waterjet, drill press holes	Y	N
CILS1	2	1/2" G10 Sheet	waterjet, drill press holes	Y	N
LSL1	2	1/2" G10 Sheet	waterjet, drill press holes	Y	N

LSR1	1	1/2" G10 Sheet	waterjet, drill press holes	Y	N
LSP1	1	2" G10 Bar Stock	N/A, planned lathe and drill press	N	Y
CISMM1	1	1/2" G10 Sheet	N/A, planned waterjet and mill	N	Y
LSD1	4	1/8" G10 Sheet	waterjet, drill press holes (double to reach 1/4" thickness)	Y	N
CIFU1	8	1/2" G10 Sheet	waterjet, drill press holes	Y	Y
CIFL1	4	Buna-N Rubber Sheet	N/A, planned to cut out	Y	N
CIFM1	8	1/8" G10 Sheet	waterjet, drill press holes	Y	N
CIBED1	2	1/2" G10 Sheet	waterjet, drill press holes	Y	N
CIBD1	2	Buna-N Rubber Sheet	N/A, planned to cut out	Y	N
FB2	4	1/8" G10 Sheet	waterjet, drill press holes	Y	N
BC1	16	1/8" G10 Sheet	waterjet, drill press holes	Y	Y
CB4	8	1/8" Thick 1x1" G10 Angle Stock	drill press holes, bandsaw individual brackets	Y	Y
FX1	8	0.010" Spring Steel Sheet	laser cut	Y	N
FX2	8	0.0150" Spring Steel Sheet	laser cut	Y	N
FX3	8	0.020" Spring Steel Sheet	laser cut	Y	N
FX4	8	0.0250" Spring Steel Sheet	laser cut, dremel to release flexures not fully cut	Y	N
LG1	2	1/8" Thick 1x1" G10 Angle Stock	bandsaw to length, drill press holes, dremel access tabs	Y	N
LG2	2	1/8" Thick 1x1" G10 Angle Stock	bandsaw to length, drill press holes, dremel access tabs	Y	N
FT1	2	1/8" G10 Sheet	waterjet, drill press holes	Y	N
FT2	1	1/8" G10 Sheet	waterjet, drill press holes	Y	N
FS2	1	1/8" G10 Sheet	waterjet, drill press holes	Y	N

FS3	1	1/8" G10 Sheet	waterjet, drill press holes	Y	N
FS1	2	1/8" G10 Sheet	waterjet, drill press holes	Y	N
FB1	12	1/8" Thick 2x2" G10 Angle Stock	drill press holes, bandsaw individual brackets	Y	Y
PT1	1	1/8" G10 Sheet	waterjet, drill press holes, dremel lightening slots	Y	Y
SS1	2	1/2" Delrin Sheet	laser cut, drill press holes, tap holes	Y	N
SS2	2	1/2" Delrin Sheet	laser cut, drill press holes, tap holes	Y	N
SB1	1	1/2" Delrin Sheet	laser cut, drill press holes, tap holes	Y	N
FB3	1	1/2" Delrin Sheet	laser cut, drill press holes, tap holes	Y	N
MH1	1	PLA Filament	3D print	Y	N
MA1	1	0.1" Aluminum-6061 Sheet	cut with shears	Y	N
WF1	4	Carbon Fiber-Reinforced PETG Filament	3D print, drill press holes, tap holes	Y	Y
PSP1	2	Carbon Fiber-Reinforced PETG Filament	3D print	Y	N

Borrowed Parts

Name	Quantity	Specification	Owner	Location
printer paper	50 sheets	8.5"x11"	DBF	The 8 Makerspace
masking tape roll	1	1" wide	Capstone Lab	AERB 139

5 Assembly Plans

See “Assembly Plans” file attached with submission for full system assembly steps.

6 Check-Out

See “System Test Procedure” file attached with submission for details on full system functionality check-out..