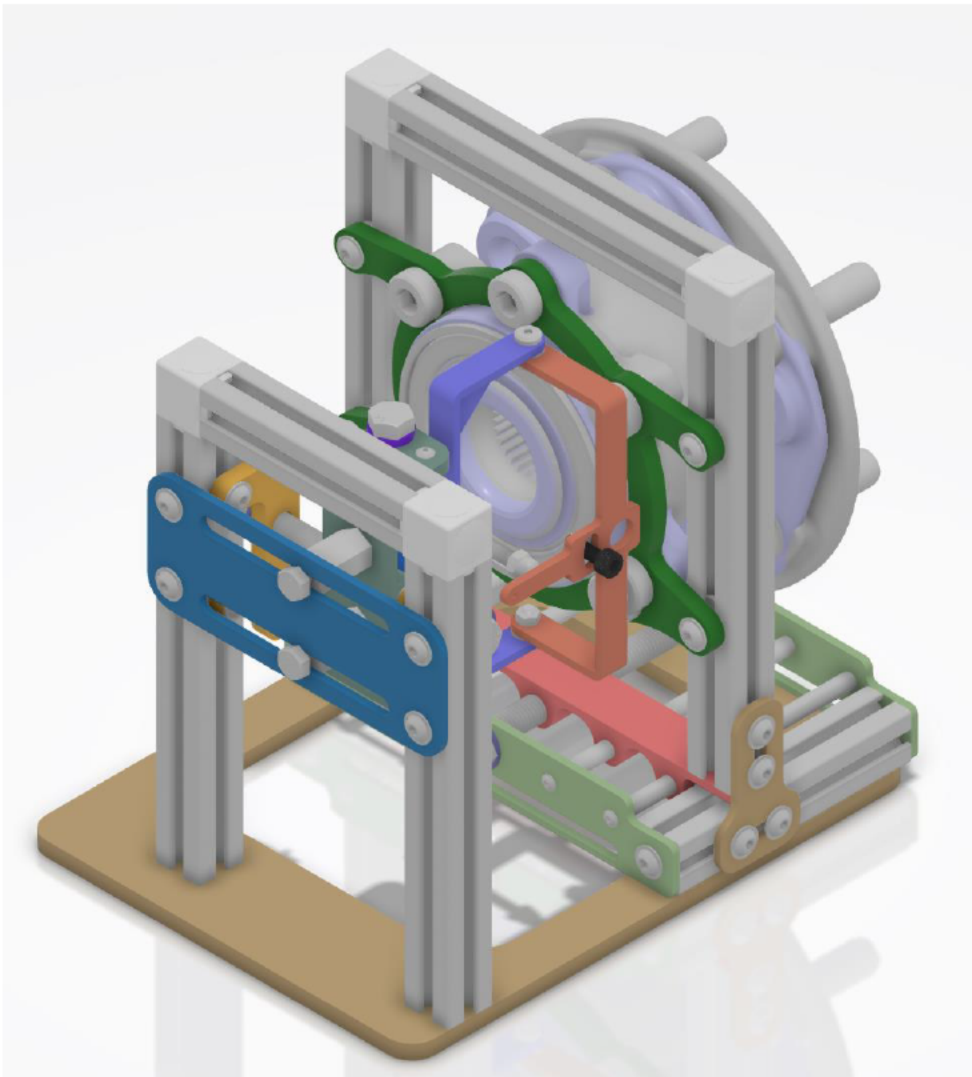
Wheel Speed Sensor Test Bench Guide



Author: Aditya Bhatnagar

DOCUMENT HISTORY

Revision	Date	Description	Author
1.0	12-AUG-22	Project Summary (Internship)	Aditya Bhatnagar

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1. Introduction and Overview

The goal of this project was to design and manufacture a test bench upon which various air gaps and orientations between the wheel speed sensor and hub could be tested to investigate their impact on the sensor output.

The result of the project is a 5 DOF test bench in which the angle of the wheel speed sensor can be varied along two axes, and the position of the sensor can be varied linearly along all three axes as shown below in Figure 1.0.1.

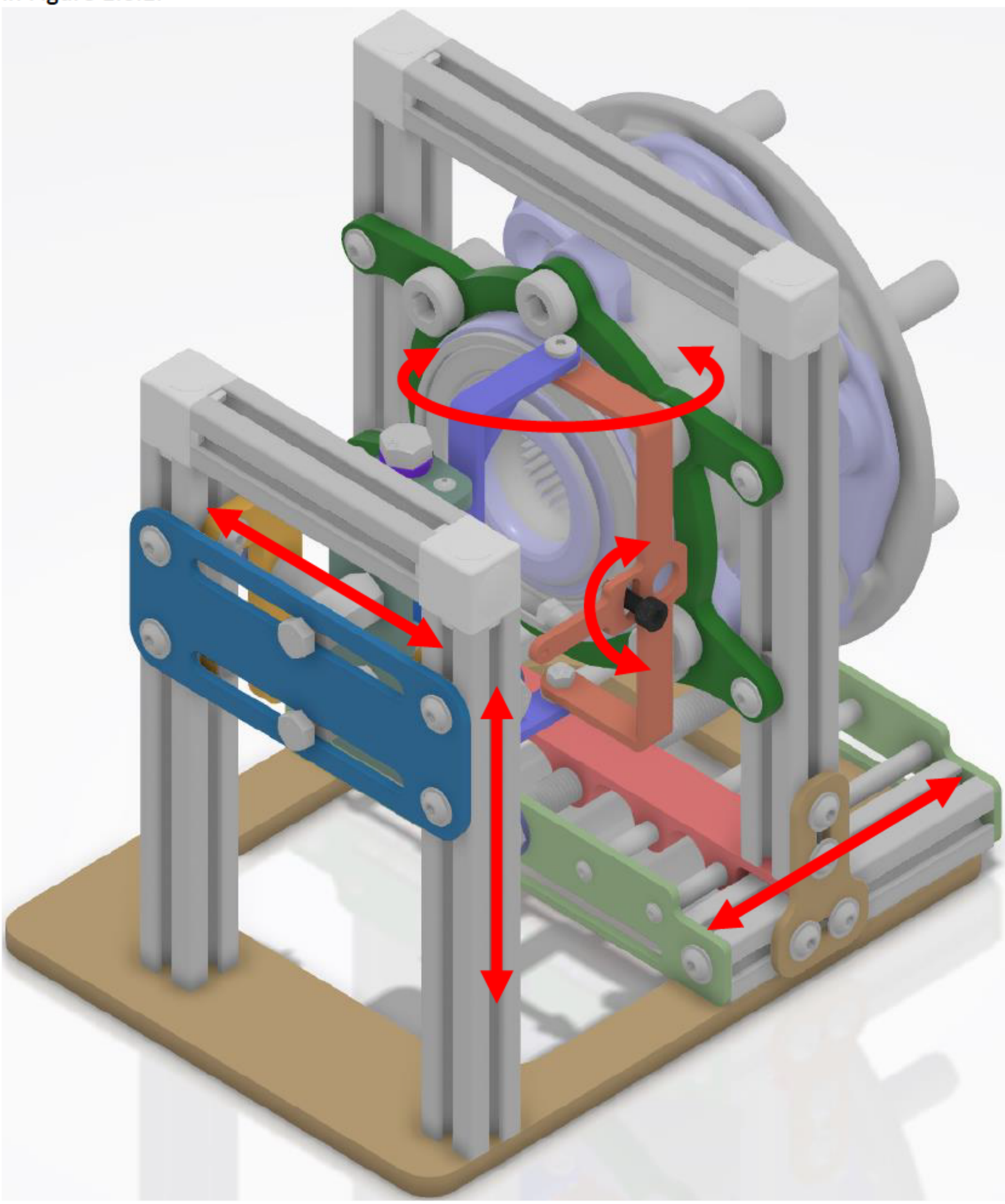

Figure 1.0.1: 5 DOF are present on the wheel speed sensor test bench. 2 angular and 2 linear DOF are attained through adjusting the sensor, while 1 linear DOF is attained through adjusting the hub mount.

2. Project Status

As of the date indicated in the most recent document history entry, the following tasks have been completed:

- Design of the first revision of the project has been completed and reviewed
- Manufacturing drawings for all custom components have been completed and reviewed
- Purchase orders and/or JIRA tickets for all components have been sent out
- All eProcurement orders have been received
- The sensor mounting bracket has been received
- The base plate has been received
- The knuckle has been 3D printed
- All spacers have been 3D printed
- CNC components from SLP Machining have been received (28-JUL-22)
- Waterjet components from Advanced Laser and Waterjet have been received (28-JUL-22)
- Advanced Laser and Waterjet forgot(??) a hole in the Side Blocks so it has to be added by hand now. (Completed 2-AUG-22)
- The T-slot stock from McMaster must be cut down to the correct length before assembly can begin (Completed 2-AUG-22)
- The threaded hex spacers must be turned down to the correct length (Completed 2-AUG-22)
- Assembly of the entire test bench has completed
- The test bench was tested through its range of motion to identify any interferences known and unknown.

As of the date indicated in the most recent document history entry, the following tasks are in progress:

- The nominal air gaps between the sensor and magnet ring must be determined for all makes and models from CAD
    - Measure distance from main sensor body axis to hub mounting face and then use hub drawing to determine distance from hub mounting face to tone ring

As of the date indicated in the most recent document history entry, the following tasks remain:

- The air gap gauge(s) must be designed and manufactured

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3. Major Assemblies and Components

3.1. Tilt Assembly

The Tilt assembly is a decoupled 2-degree of freedom assembly that can rotate the wheel speed sensor about its tip about the Y-axis and Z-axis. It is comprised of two major components: the sensor mounting bracket, and the knuckle. The knuckle acts as a fixed point for the sensor mounting bracket to rotate about, around the Z-axis. Its operation is explained in more detail in Section 4.2.

The extension spring is not listed in the components as two different springs were ordered in order to test them and determine which one performs better. The two springs under contention are both from McMaster-Carr, PNS: 3630N112 & 1942N49. Any spring should be able to perform similarly given that its nominal lengh is less than the distance between the two spring mounting points in the 80 degree configuration, and the spring's maximum length is greater than the distance between the spring mounting points in the 100 degree position.

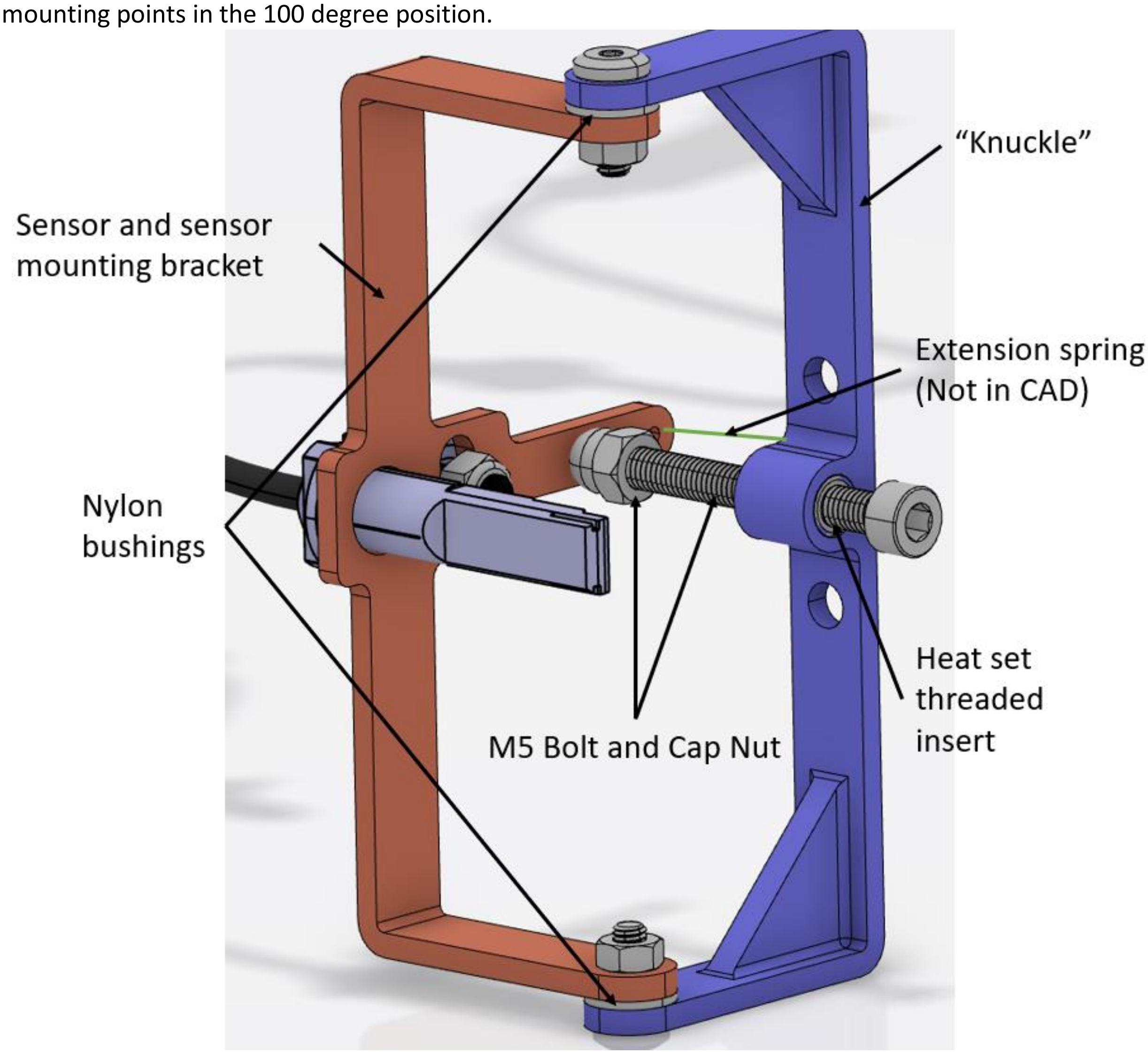

Figure 3.1.1: Labeled tilt assembly diagram.

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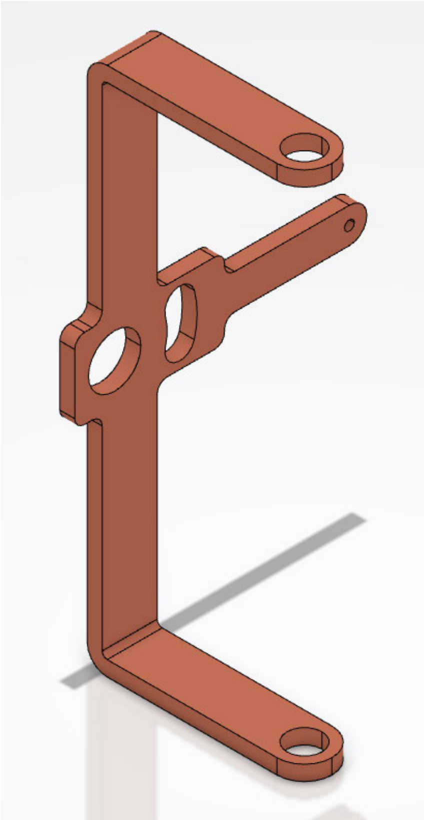


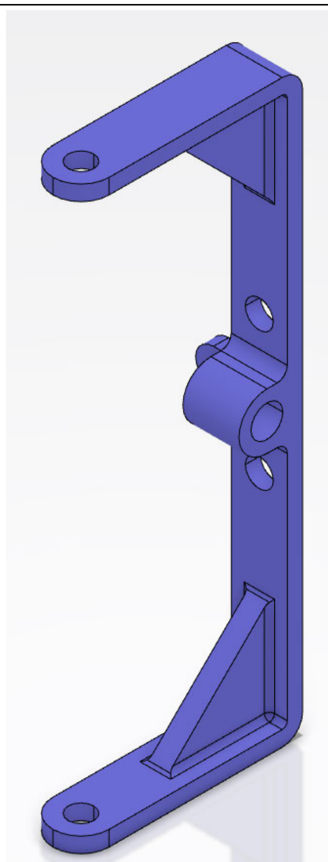
Name: WSS Mounting Bracket

Description:

This is the component that the sensor itself is mounted to. The large hole on the face of the mounting bracket is allows for the main sensor body to pass through while the curved slot allows the tester to rotate the sensor about the Y-axis 30 degrees from the nominal in both directions. The arm with the small hole at the left is for mounting a spring that is used to pull the mounting bracket and knuckle closer together. The mounting point for the bracket is designed such that it rotates as close to the senor tip as possible.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** [redacted]
- **Material:** AL-5052 (if bent), AL-6061 (if machined)
- **Fabrication Method:** Bent sheet metal or CNC machining.
- **Quantity Needed:** 1
- **Supplier:** Fabricated at the Kato Fab Shop out of 5052 that was then bent into shape using a press brake
- **Supplier PN:** N/A
- **PO Number/JIRA Ticket:** RDF-7923



Name: WSS Knuckle

Description:

This component was initially designed as a component to be machined, however due to the complexity, it was redesigned for 3D printing by adding ribs. It is the component against which the sensor mounting bracket can rotate about the Z-axis with and features a small protrusion with a hole for mounting the same spring as the mounting bracket. The Knuckle mounts to the WSS Tilt Assembly Mounting block through two M5 bolts that pass through the two holes in the back of the knuckle. An extrusion with a hole is present for the heat set insert that an M5 bolt with cap screw goes through to push the mounting bracket arm as a cam mechanism responsible for the bracket rotation.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** [redacted]8
- **Material:** Rigid 4000 Resin
- **Fabrication Method:** 3D SLA Printing
- **Quantity Needed:** 1
- **Supplier:** Printed on the FormLabs printers in 25U in DC
- **Supplier PN:** N/A
- **PO Number/JIRA Ticket:** N/A

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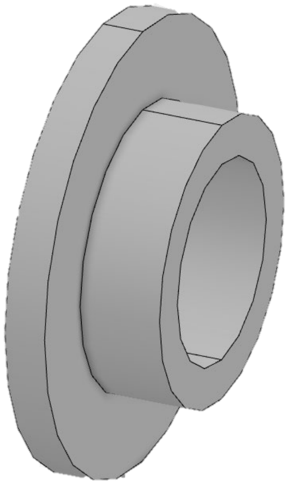
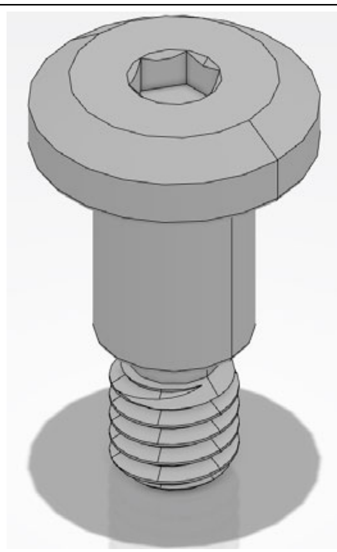
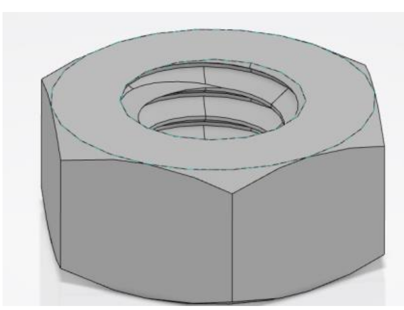
	**Name:** Light Duty Dry-Running Flanged Sleeve Bearing **Description:** This flanged sleeve bearing allows the mounting bracket and knuckle to rotate smoothly against each other with minimal friction. It is press fit into the mounting bracket with both flanges facing outwards. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Teflon • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 2705T116 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 18-8 Stainless Steel Low-Profile Precision Shoulder Screw **Description:** This 7 mm long M4x0.7 shoulder screw is used to fasten the mounting bracket and knuckle together to allow for smooth rotation and good location when fastening the parts together. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Stainless Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 90323A451 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 18-8 Stainless Steel Hex Nut **Description:** M4x0.7 Nut for the above shoulder screw **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Stainless Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 91828A231 • **PO Number/JIRA Ticket:** [redacted]

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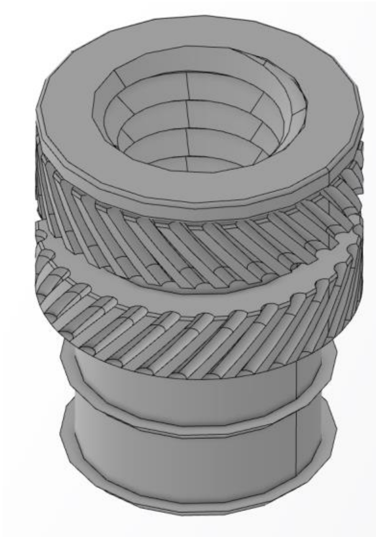
<td></td>
<td>
Name: Tapered Heat Set Inserts for Plastic
Description:
M5x0.8 mm heat set insert. This component sets into the 3D printed knuckle and provides the threads for the M5 bolt and cap nut combination which are responsible for rotating the sensor mount about the Z-axis.
Details:

ENOVIA/3DX PN: [redacted]
Drawing Number: N/A
Material: 303 Stainless Steel
Fabrication Method: Purchased
Quantity Needed: 1
Supplier: McMaster-Carr
Supplier PN: 97163A155
PO Number/JIRA Ticket: [redacted]

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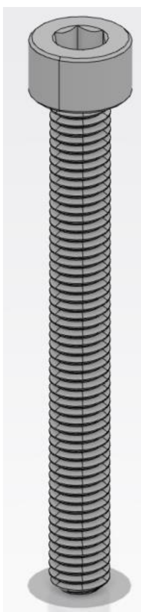
<td></td>
<td>
Name: 45mm Long M5x0.8 Socket Head Cap Screw
Description:
This 45mm long M5x0.8 socket head cap screw is used to push against the long arm on the mounting bracket in order to rotate the sensor about the Z-axis. A cap screw on the end of the bolt keeps the contact smooth and reduces scratching of the mounting bracket surface.
Details:

ENOVIA/3DX PN: [redacted]
Drawing Number: N/A
Material: Black-Oxide Alloy Steel
Fabrication Method: Purchased
Quantity Needed: 1
Supplier: McMaster-Carr
Supplier PN: 91290A197
PO Number/JIRA Ticket: [redacted]

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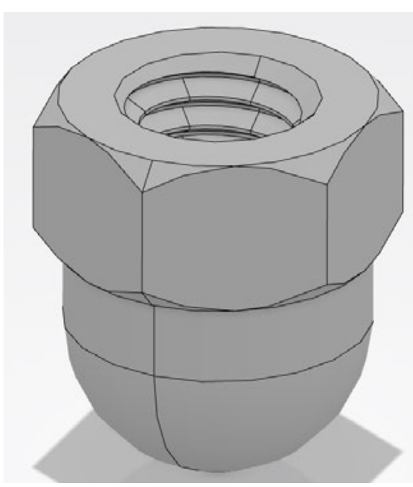
<td></td>
<td>
Name: 18-8 M5 Stainless-Steel Cap Nut
Description:
M5x0.8 Cap Nut for above screw. This component contacts the sensor mount arm to rotate it about the Z-axis.
Details:

ENOVIA/3DX PN: [redacted]
Drawing Number: N/A
Material: 18-8 Stainless Steel
Fabrication Method: Purchased
Quantity Needed: 1
Supplier: McMaster-Carr
Supplier PN: 94000A037
PO Number/JIRA Ticket: [redacted]

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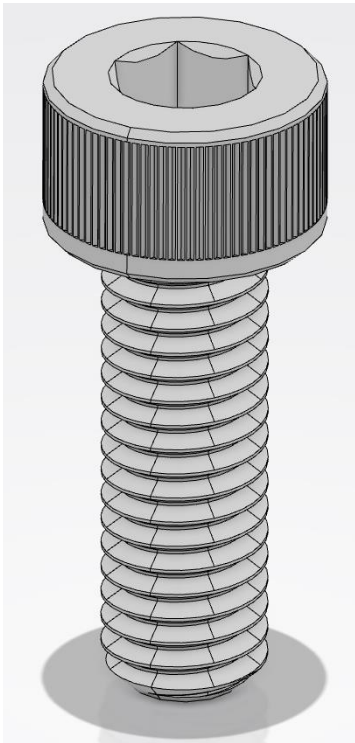
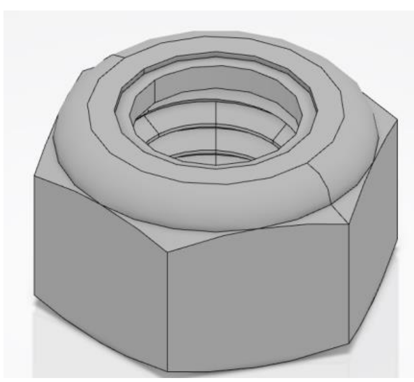
	**Name:** 15mm Long M5x0.8 Socket Head Cap Screw **Description:** This 15mm M5 bolt is responsible for fastening the wheel speed sensor directly to the mounting bracket. It is also responsible for locking the rotation of the sensor about the Y-axis during regular operation. The original mounting procedure for the wheel speed sensor calls for an M6 bolt, however, in order to reduce complexity an M5 bolt was chosen. The M5 bolt head still maintains adequate surface area contact with the sensor and allows for machining tolerances to be a little bit looser. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 91290A231 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** Low-Strength Nylon Insert M5x0.8 Locknut **Description:** Locknut for above fastener. It may be considered to change this to a non-Nylock nut if frequent adjustment is desired. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 90631A113 • **PO Number/JIRA Ticket:** [redacted]

3.2. Vertical Slider Assembly

The Vertical Slider Assembly is a 1-DOF assembly that can move the entire Tilt Assembly along the Z-axis and provides roughly 18 mm of travel in both directions from the nominal position. While its operation is discussed in more detail in Section 4.3, the major components for the Vertical Slider Assembly are the Tilt Assembly Mounting block – which acts as a carrier for the Tilt Assembly, the Top Block – which acts as the main supporting structure and limits, and a Guide Rail – to prevent rotation of the Top Block while the main M8 bolt is operated to raise and lower the Tilt Assembly Mounting Block. The Vertical Slider Assembly is a sub-component of the Plane Slider Assembly.

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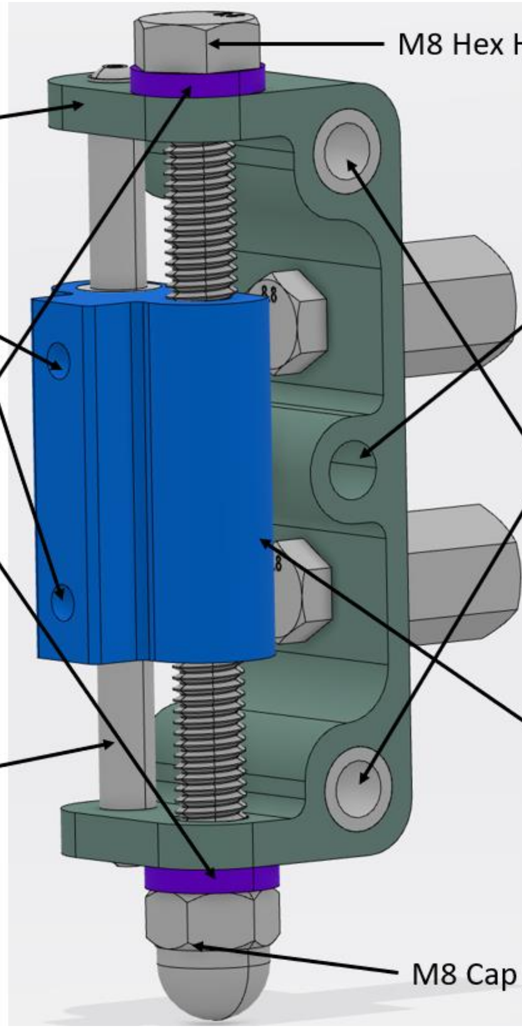


Figure 3.2.1: Labeled image of the vertical slider assembly. The unlabeled hex bolts and standoffs are for a locking feature discussed later.

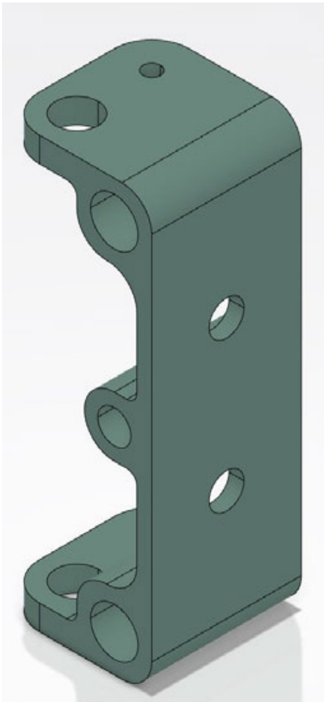
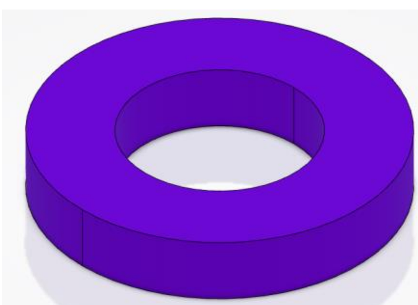
Name: WSS Test Bench Tilt Assembly Mounting Block

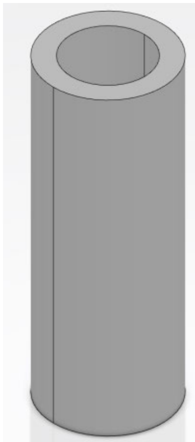
Description:

The Tilt Assembly Mounting Block does what its name implies and serves as a mounting point for the entire tilt assembly. It contains a counterbored hole for a bronze oil-embedded bushing (for a guide rail to pass through) and an M8x1.25 threaded hole to raise and lower the entire block along with the attached Tilt Assembly.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** [redacted]
- **Material:** Aluminum 6061-T6
- **Fabrication Method:** CNC Milling
- **Quantity Needed:** 1
- **Supplier:** [redacted]
- **Supplier PN:** N/A
- **PO Number/JIRA Ticket:** [redacted]

	**Name:** WSS Test Bench Top Block **Description:** The Top Block serves as the main structure and support for the Vertical Slider Assembly. It also acts as the dynamic component for the Plane Slider Assembly discussed later and contains through holes for bronze oil-embedded bushings and an M8x1.25 threaded hole for travel along the Y-axis. The two holes in the back of the Top block are used for fastening two female-threaded hex standoffs to the block to act as a locking mechanism (discussed more in Section 5.6). **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** Aluminum 6061-T6 • **Fabrication Method:** CNC Milling • **Quantity Needed:** 1 • **Supplier:** [redacted] • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** [redacted]
	**Name:** WSS Test Bench Bolt Spacer **Description:** This spacer aims to create the right amount of spacing between the bolt and the Top Block so that the cap nut may be tightened completely without clamping the components but still limiting the vertical play in the bolt in its assembled state. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** Rigid 4000 • **Fabrication Method:** 3D Printing • **Quantity Needed:** 2 • **Supplier:** Printed on FormLabs 3 Printer in 25U in DC • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** N/A



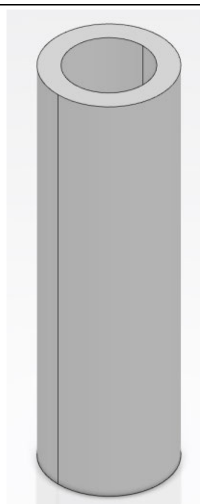
Name: 1” Oil-Embedded Bronze Sleeve Bearing

Description:

This bronze self-lubricating bushing is press-fit into the Top Block to allow smooth travel along the Y-axis.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Bronze
- **Fabrication Method:** Purchased
- **Quantity Needed:** 2
- **Supplier:** McMaster-Carr
- **Supplier PN:** 6391K135
- **PO Number/JIRA Ticket:** [redacted]



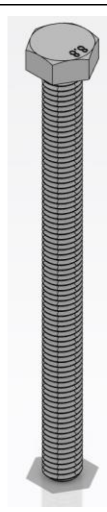
Name: 1.25” Oil-Embedded Bronze Sleeve Bearing

Description:

This bronze self-lubricating bushing is press-fit into the Tilt Assembly mounting block to provide smooth travel along the Z-axis.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Bronze
- **Fabrication Method:** Purchased
- **Quantity Needed:** 1
- **Supplier:** McMaster-Carr
- **Supplier PN:** 6391K335
- **PO Number/JIRA Ticket:** [redacted]



Name: 100 mm Long M8x1.25 Hex Head Bolt

Description:

This Hex Head bolt is responsible for sustaining the weight of the tilt assembly mounting block and tilt assembly and moving it along the Z-axis as a leadscrew.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 1
- **Supplier:** McMaster-Carr
- **Supplier PN:** 91280A091
- **PO Number/JIRA Ticket:** [redacted]

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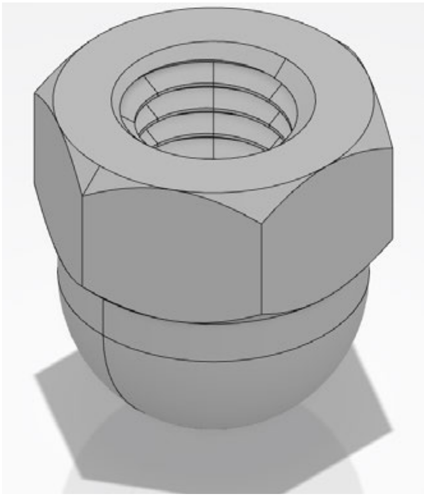
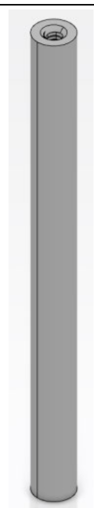
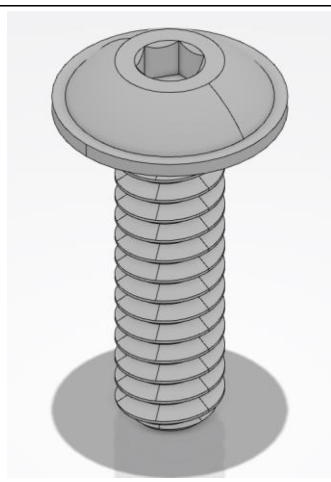
	**Name:** 18-8 Stainless Steel M8x1.25 Cap Nut **Description:** Cap nut for the above bolt. The cap nut should be able to be tightened completely without compressing the members and locking the rotation of the bolt. If this is not the case, check that the Test Bench Bolt Spacers are within tolerance or remove the spacers entirely. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 94000A039 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 3" Female Threaded Round Standoff **Description:** This threaded round standoff acts as a guide rail for the Tilt Assembly Mounting Block so that the block does not rotate about the Z-axis while the bolt is being turned. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated 12L14 Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 93265A031 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 3/8" 4-40 Flanged Button Head Screw **Description:** These screws fasten the above threaded standoff in place to the Top Block. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 91355A155 • **PO Number/JIRA Ticket:** [redacted]

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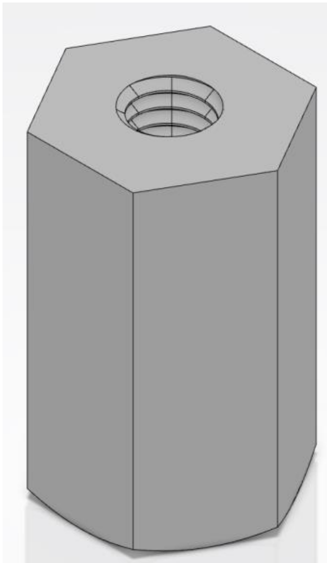
<td></td>
<td>Name: 25mm M6x1 Threaded Hex Spacer
Description:
These standoffs are used to lock the plane slider assembly in place by clamping it against the Clamp Plate. Before use, these standoffs must be reduced in length by 2.5mm for a final length of ~22.5 mm.
Details:
• ENOVIA/3DX PN: [redacted]
• Drawing Number: N/A
• Material: 18-8 Stainless Steel
• Fabrication Method: Purchased, Turned Down on Lathe
• Quantity Needed: 2
• Supplier: McMaster-Carr
• Supplier PN: 94868A777
• PO Number/JIRA Ticket: [redacted]</td>
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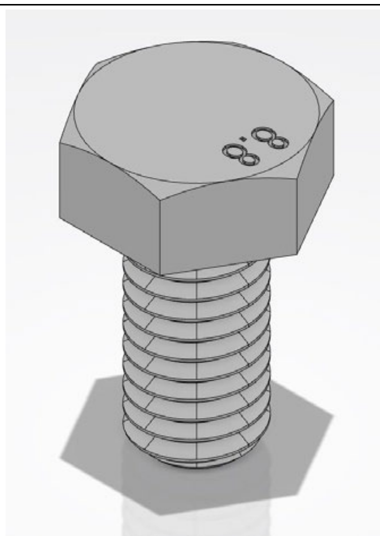
<td>
</td>
<td>Name: 12mm M6x1 Hex Head Bolts
Description:
These bolts are responsible for fastening the above standoff to the Top Block. Once these bolts are set, there should be no reason to loosen them during operation, unless the test bench is being disassembled.
Details:
• ENOVIA/3DX PN: [redacted]
• Drawing Number: N/A
• Material: Steel
• Fabrication Method: Purchased
• Quantity Needed: 2
• Supplier: McMaster-Carr
• Supplier PN: 91280A062
• PO Number/JIRA Ticket: [redacted]</td>
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3.3. Plane Slider Assembly

The Plane Slider Assembly is a 1DOF super-assembly containing the Vertical Slider Assembly above and can move it roughly +/- 23 mm along the Y-axis. The major components of the Plane Slider Assembly are the assembled Vertical Slider Assembly – which acts as the carrier for the sensor along the Y-axis, Side Blocks – which provide the main structural support, and Slider Frame Assembly – to which the Side Blocks mount. The vertical position of the main slider assembly can be set by loosening the four M5x0.8 bolts that secure the Side Blocks to the Slider Frame Assembly. The Slider Frame Assembly is constructed from simple 6061 Aluminum T-slot extrusion and corner pieces to link the corner extrusions together. Once construction of the Plane Slider Assembly is complete, it can be rigidly mounted to the Base Plate through 2 M5x0.8 screws that thread into the Slider Frame Assembly Legs.

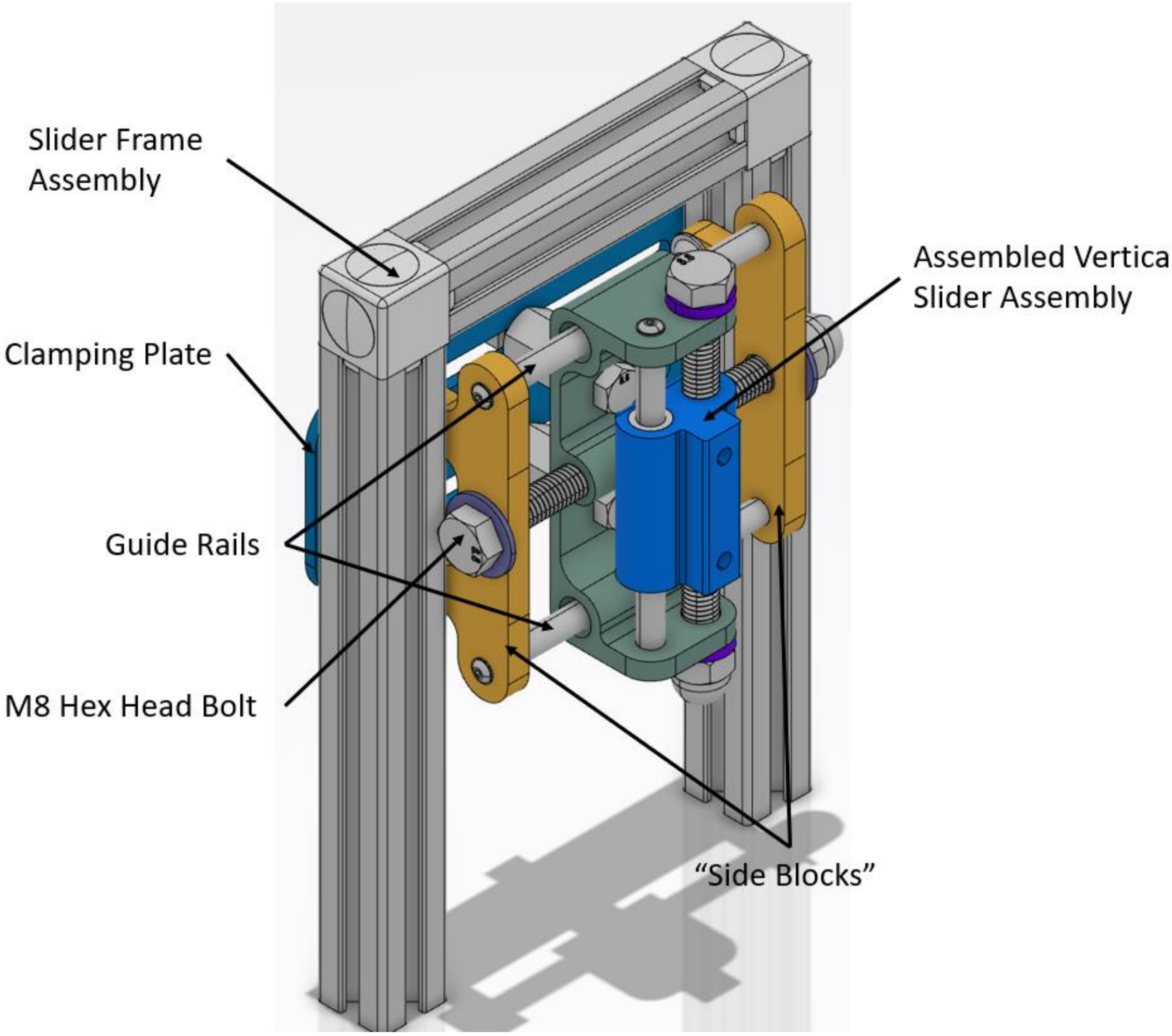
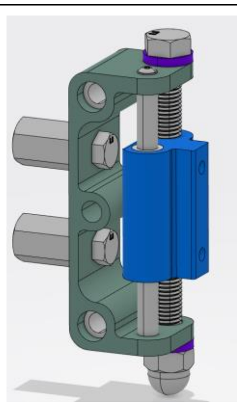
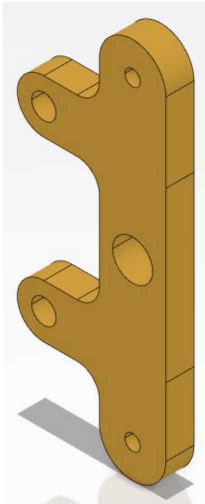
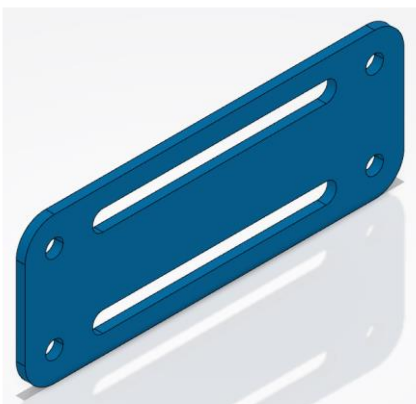
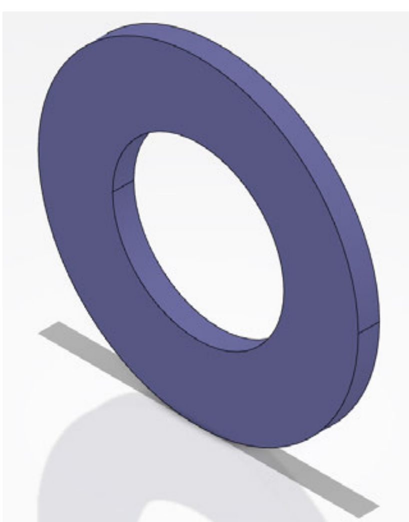


Figure 3.3.1: Labeled diagram of the Plane Slider Assembly.

	**Name:** Vertical Slider Assembly **Description:** See Section 3.2 **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Various • **Fabrication Method:** Assembled • **Quantity Needed:** 1 • **Supplier: N/A** • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** N/A

	**Name:** Side Block **Description:** This quarter inch aluminum plate along with the female threaded round standoffs, act as the main structure for the Plane Slider Assembly **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** Quarter-Inch Aluminum 6061-T6 Plate • **Fabrication Method:** Waterjet/Laser Cut • **Quantity Needed:** 2 • **Supplier:** [redacted] • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** [redacted]
	**Name:** Clamp Plate **Description:** This plate is used for locking the plane slider assembly's translation along the Y-axis by tightening two M6 Hex Head bolts to clamp threaded hex spacers against it. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** 3mm Aluminum 6061-T6 Plate • **Fabrication Method:** Waterjet/Laser Cut • **Quantity Needed:** 1 • **Supplier:** [redacted] • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** [redacted]
	**Name:** WSS Test Bench Frame Bolt Spacer **Description:** This spacer aims to create the right amount of spacing between the bolt and the Top Block so that the cap nut may be tightened completely without clamping the components but still limiting the horizontal play in the bolt in its assembled state. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** Draft V2 • **Fabrication Method:** 3D Printing • **Quantity Needed:** 2 • **Supplier:** Printed on FormLabs 3 Printer in 25U in DC • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** N/A

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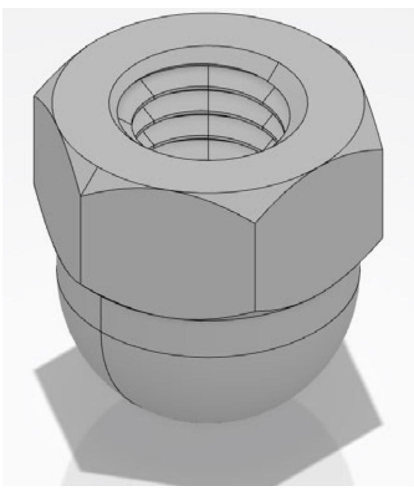
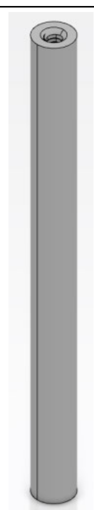
Name: 100 mm Long M8x1.25 Hex Head Bolt
Description:
This Hex Head bolt is responsible for translating the vertical slider assembly along the Y-axis.
Details:
- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 1
- **Supplier:** McMaster-Carr
- **Supplier PN:** 91280A091
- **PO Number/JIRA Ticket:** [redacted]



Name: 18-8 Stainless Steel M8x1.25 Cap Nut
Description:
Cap nut for the above bolt. The cap nut should be able to be tightened completely without compressing the members and locking the rotation of the bolt. If this is not the case, check that the Frame Bolt Spacers are within tolerance. The spacers may have to be removed entirely depending on part tolerances.
Details:
- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 1
- **Supplier:** McMaster-Carr
- **Supplier PN:** 94000A039
- **PO Number/JIRA Ticket:** [redacted]



Name: 3” Female Threaded Round Standoff
Description:
This threaded round standoff acts as a guide rail for the Vertical Slider Assembly so that misalignment during operation is minimized.
Details:
- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Zinc-Plated 12L14 Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 2
- **Supplier:** McMaster-Carr
- **Supplier PN:** 93265A031
- **PO Number/JIRA Ticket:** [redacted]

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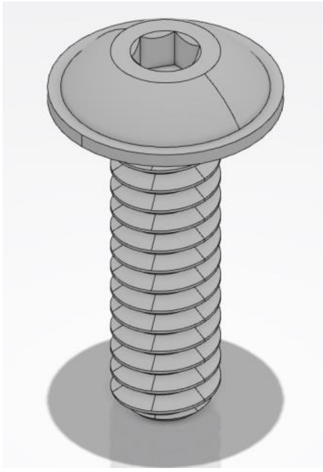
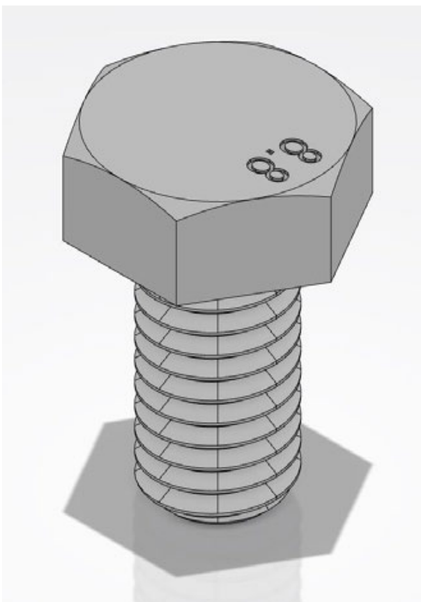


Name: 3/8” 4-40 Flanged Button Head Screw
Description:

These screws fasten the above threaded standoff in place to the Side Blocks

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Black-Oxide Alloy Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 4
- **Supplier:** McMaster-Carr
- **Supplier PN:** 91355A155
- **PO Number/JIRA Ticket:** [redacted]

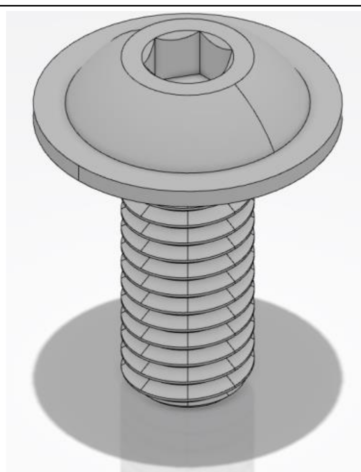


Name: 12mm M6x1 Hex Head Bolts
Description:

These bolts are responsible for clamping the hex standoffs in the vertical slider assembly to the Clamp Plate. When adjusting the position of the Vertical Slider Assembly along the Y-axis these bolts should be loosened to allow translation and then tightened again to lock the assembly in place.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 2
- **Supplier:** McMaster-Carr
- **Supplier PN:** 91280A062
- **PO Number/JIRA Ticket:** [redacted]

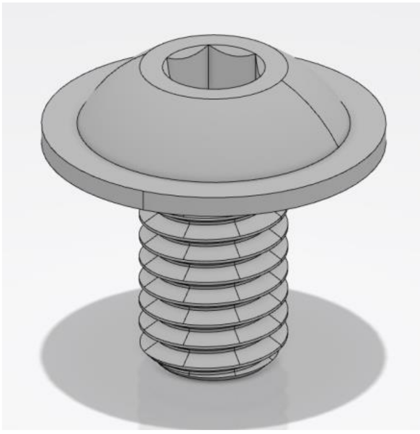
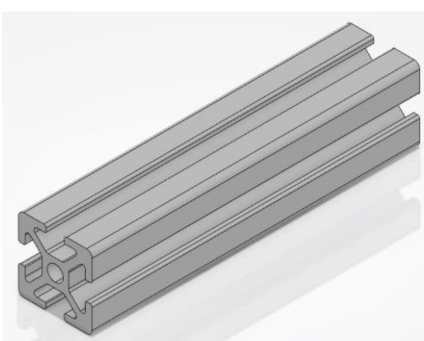


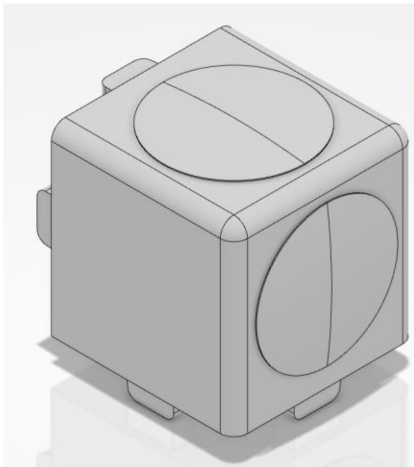
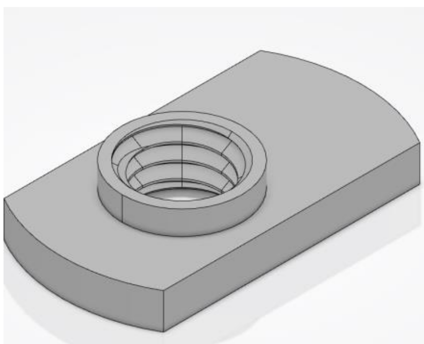
Name: 12mm Long M5x0.8 Flanged Button Head Screws
Description:

These bolts are used to fasten the side blocks to the Slider Frame Assembly.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Black-Oxide Alloy Steel
- **Fabrication Method:** Purchased
- **Quantity Needed:** 4
- **Supplier:** McMaster-Carr
- **Supplier PN:** 92137A416
- **PO Number/JIRA Ticket:** [redacted]

	**Name:** 8mm Long M5x0.8 Flanged Button Head Screws **Description:** These bolts are used to fasten the clamp plate to the Slider Frame Assembly **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 4 • **Supplier:** McMaster-Carr • **Supplier PN:** 92137A412 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 170mm Long 20mm Wide Square T-Slot Rail **Description:** Vertical members in the Slider Frame Assembly. These must be shorted to the required length after purchase and tapped with M5x0.8 threads at the end. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Aluminum 6061-T6 • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T501 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 89mm Long 20mm Wide Square T-Slot Rail **Description:** Horizontal member in the Slider Frame Assembly. It must be shorted to the required length after purchase and tapped with M5x0.8 threads at the end. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Aluminum 6061-T6 • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T501 • **PO Number/JIRA Ticket:** [redacted]

	**Name:** Outside Corner Bracket for 20mm Single Rail **Description:** Used to join the Slider Frame Assembly's individual rails together. The fasteners are included when purchasing this item. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Lacquer-Coated Aluminum • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T286 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** M5x0.8 T-Slot Framing Rail Nut **Description:** Nuts for use in the T-slot framing rail. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 8 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T651 • **PO Number/JIRA Ticket:** [redacted]

3.4. Hub Frame Assembly

The Hub Frame Assembly is responsible for carrying the Hub once mounted to a hub mounting plate and translating along the X-axis. It is also a sub-assembly of the Hub Mount Assembly. The main components are the Hub Mounting Plate, Frame Slider Block, and T-slot rails of various lengths. There are two Hub Mounting Plates, the first plate (called the "Turtle Plate" affectionately due to its somewhat turtle like appearance) is capable of mounting both S/X and 3/Y Hubs, a second plate has been designed and manufactured for the Cybertruck Hub. While it was possible for the Cybertruck hub mounting pattern to be put on the Turtle Plate, the bore required for the Cybertruck hub would interfere with the other hole patterns.

The vertical position of the hub mounting plates can be adjusted as they are mounted to the T-slot frame rails. The Hub Frame Assembly is translated along the X-axis through an M10 bolt that acts as another leadscrew mechanism and rides along 4 4" long steel threaded spacers that act as guide rails to support the weight of the hub and prevent misalignment during operation. The Hub Frame Assembly can be locked in place with respect to its translation along the X-axis through clamping the Hub Clamping Plates against the horizontal frame rails in the Hub Mount Assembly (Section 3.5).

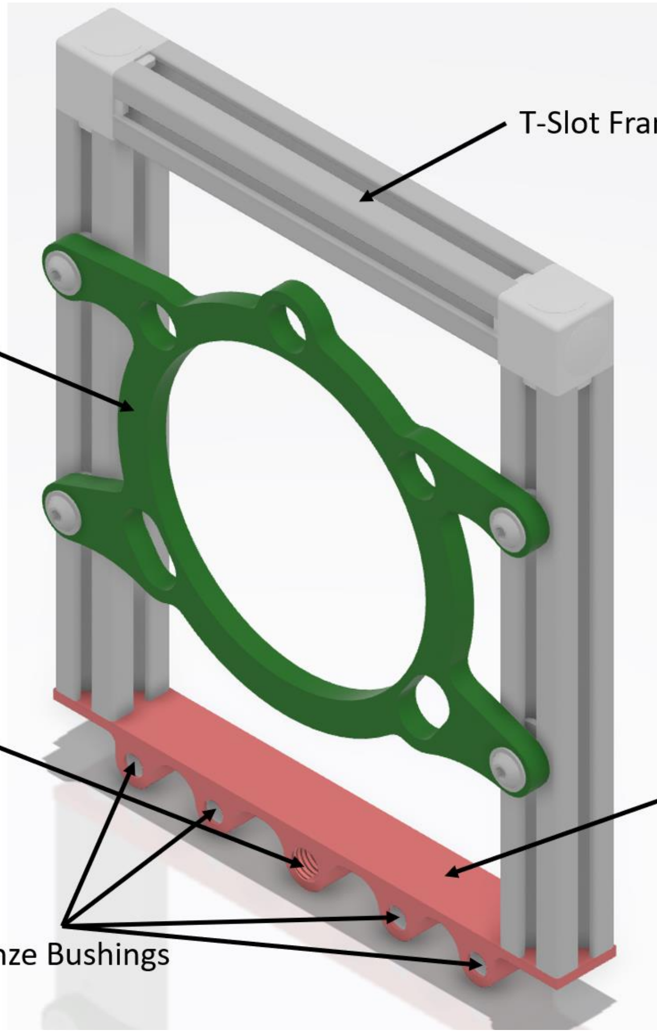
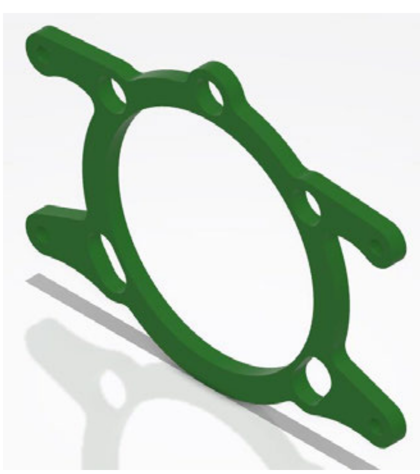
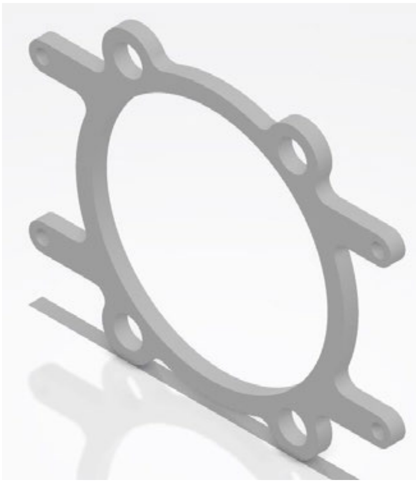
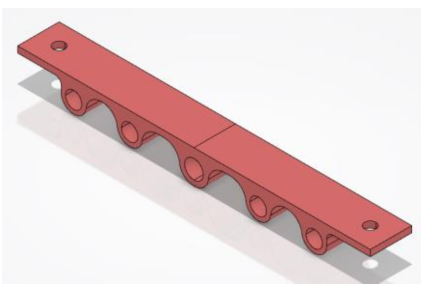
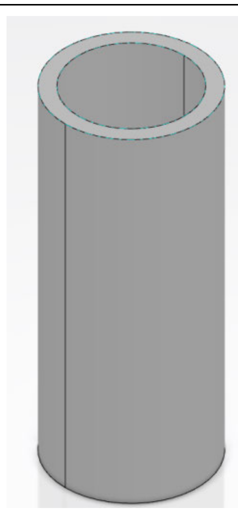


Figure 3.4.1: Labeled image of the Hub Frame Assembly. In this image it is shown with the Turtle plate rather than with the Cybertruck Hub Mounting Plate

<table>
<tr>
<td></td>
<td>

Name: Hub Mounting Plate ("Turtle Plate")
Description:
This quarter inch aluminum plate is what the hub is mounted to through M12x1.75 bolts for the 3/Y hubs and M12x1.25 bolts for the S/X hubs. This plate supports both the S/X hubs and the 3/Y hubs.
Details:
• **ENOVIA/3DX PN:** [redacted]
• **Drawing Number:** [redacted]
• **Material:** Quarter-Inch Aluminum 6061-T6 Plate
• **Fabrication Method:** Waterjet/Laser Cut
• **Quantity Needed:** 1
• **Supplier:** [redacted]
• **Supplier PN:** N/A
• **PO Number/JIRA Ticket:** [redacted]

</td>
</tr>
</table>

<table>
<tr><td></td><td>Name: CT Hub Mounting Plate
Description:
This quarter inch aluminum plate is what the Cybertruck hub is mounted to through 4 M12x1.75 bolts.
Details:
ENOVIA/3DX PN: [redacted]
Drawing Number: [redacted]
Material: Quarter-Inch Aluminum 6061-T6 Plate
Fabrication Method: Waterjet/Laser Cut
Quantity Needed: 1
Supplier: [redacted]
Supplier PN: N/A
PO Number/JIRA Ticket: [redacted]</td></tr>
<tr><td></td><td>Name: WSS Test Bench Frame Slider Block
Description:
The Frame Slider Block fastens to the frame rails through two M5x0.8 holes that are tapped into the ends of the 170mm extrusions. It is the main component that is responsible for moving the entire assembly through its M10x1.5 hole and supporting its weight, through the 4 bronze bushings that ride on threaded steel standoffs.
Details:
ENOVIA/3DX PN: [redacted]
Drawing Number: [redacted]
Material: Aluminum 6061-T6
Fabrication Method: CNC Milling
Quantity Needed: 1
Supplier: [redacted]
Supplier PN: N/A
PO Number/JIRA Ticket: [redacted]</td></tr>
<tr><td></td><td>Name: 0.75” Oil-Embedded Bronze Sleeve Bearing
Description:
This bronze self-lubricating bushing is press-fit into the Frame Slider Block to provide smooth translation along the guide rods
Details:
ENOVIA/3DX PN: [redacted]
Drawing Number: N/A
Material: Bronze
Fabrication Method: Purchased
Quantity Needed: 4
Supplier: McMaster-Carr
Supplier PN: 6391K401
PO Number/JIRA Ticket: [redacted]</td></tr>
</table>

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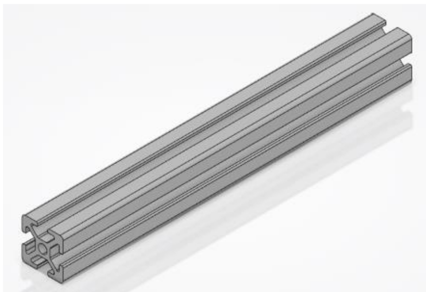
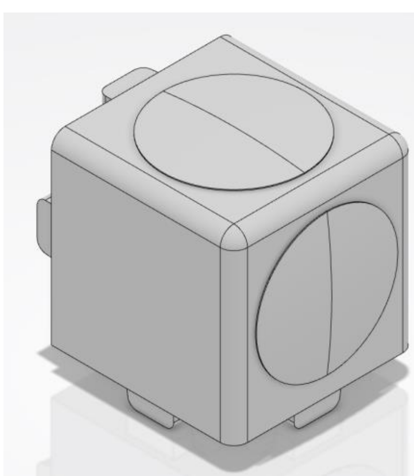


Name: 170mm Long 20mm Wide Square T-Slot Rail
Description:
Vertical members in the Hub Frame Assembly. These must be shorted to the required length after purchase and tapped with M5x0.8 threads at the end.
Details:
- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Aluminum 6061-T6
- **Fabrication Method:** Purchased
- **Quantity Needed:** 2
- **Supplier:** McMaster-Carr
- **Supplier PN:** 5537T501
- **PO Number/JIRA Ticket:** [redacted]

Name: 130mm Long 20mm Wide Square T-Slot Rail
Description:
Horizontal member in the Hub Frame Assembly. These must be shorted to the required length after purchase and tapped with M5x0.8 threads at the end.
Details:
- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Aluminum 6061-T6
- **Fabrication Method:** Purchased
- **Quantity Needed:** 1
- **Supplier:** McMaster-Carr
- **Supplier PN:** 5537T501
- **PO Number/JIRA Ticket:** [redacted]



Name: Outside Corner Bracket for 20mm Single Rail
Description:
Used to join the Hub Frame Assembly's individual rails together. The fasteners are included when purchasing this item.
Details:
- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Lacquer-Coated Aluminum
- **Fabrication Method:** Purchased
- **Quantity Needed:** 2
- **Supplier:** McMaster-Carr
- **Supplier PN:** 5537T286
- **PO Number/JIRA Ticket:** [redacted]

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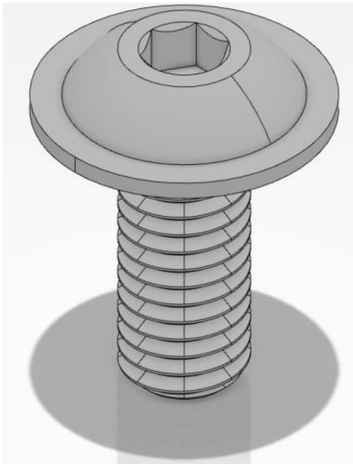
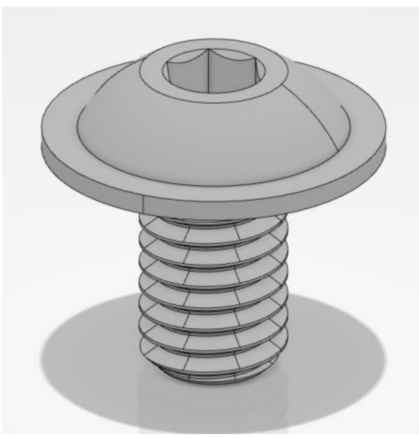
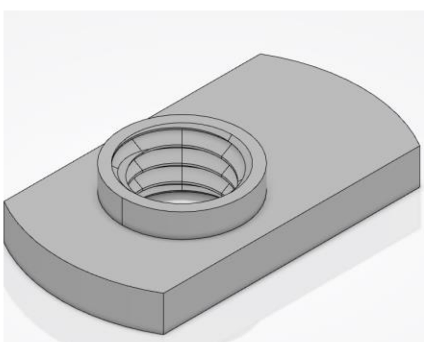
	**Name:** 12mm Long M5x0.8 Flanged Button Head Screws **Description:** These bolts are used to fasten the hub mounting plates to the frame rails. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 4 • **Supplier:** McMaster-Carr • **Supplier PN:** 92137A416 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 8mm Long M5x0.8 Flanged Button Head Screws **Description:** These bolts are used to fasten the Frame Slider Block to the bottom of the 170mm long frame rails. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 92137A412 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** M5x0.8 T-Slot Framing Rail Nut **Description:** Nuts for use in the T-slot framing rail. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 4 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T651 • **PO Number/JIRA Ticket:** [redacted]

3.5. Hub Mount Assembly

The Hub Mount assembly is a 1DOF slider assembly which translates the hub along the X-axis to modify the air gap between the wheel speed sensor and the magnetic tone ring in the hub. The Hub Frame Assembly is a sub-assembly of the Hub Mount assembly and rides on four threaded steel spacers which support the weight of the Hub Frame Assembly and prevent misalignment of the Frame Plates and Frame Slider Block. The Hub Mount Assembly mounts to the test bench base plate through 4 M5x0.8 button head screws that bolt into T-slot framing nuts in the bottom of the Hub Mount Assembly Rails.

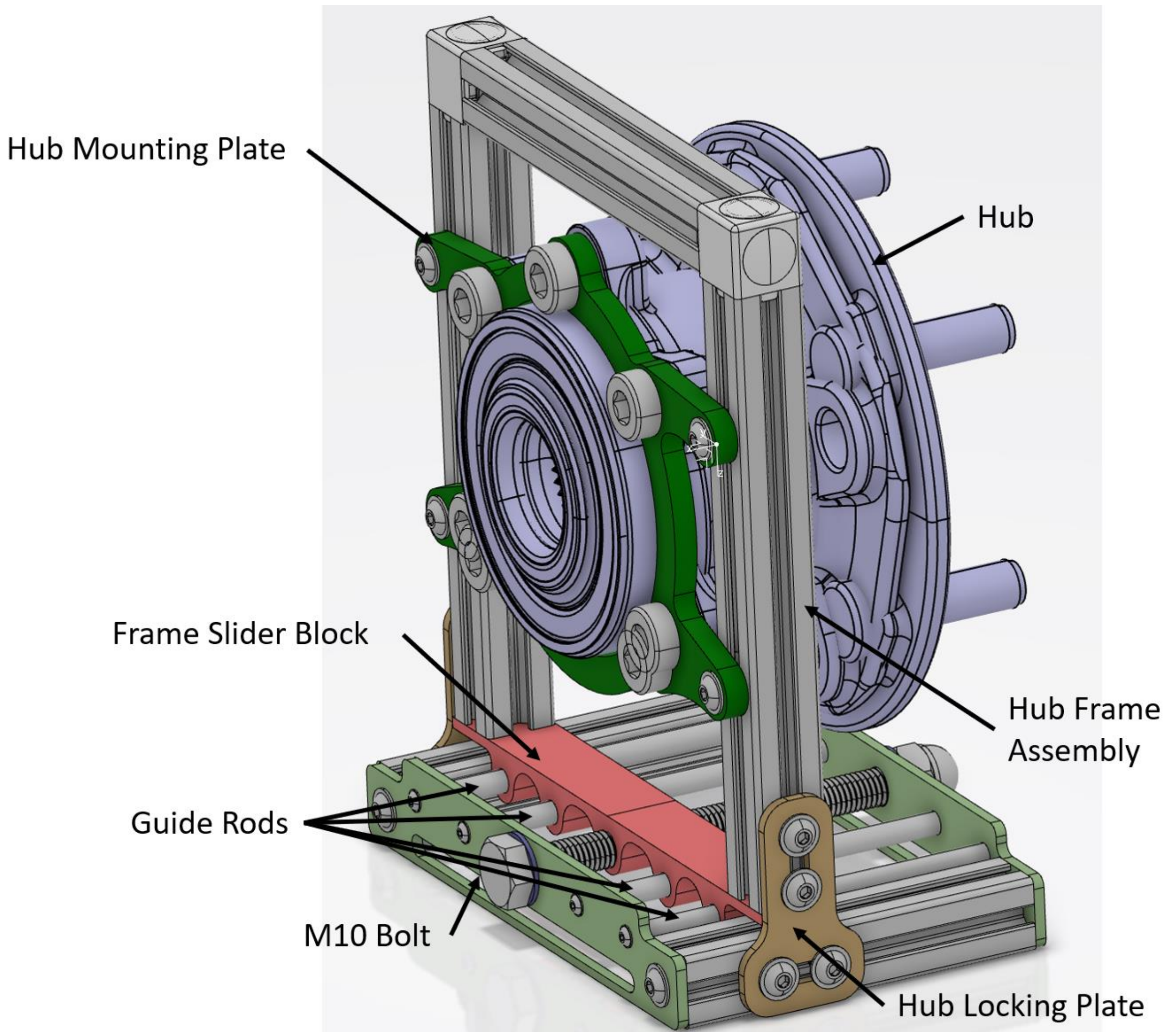
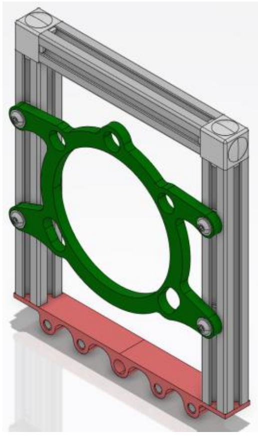
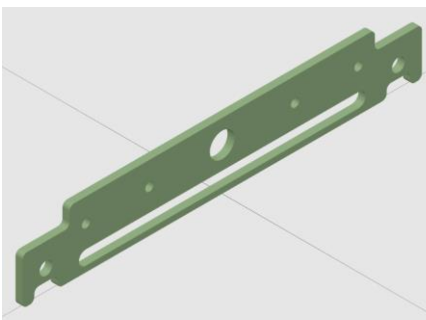
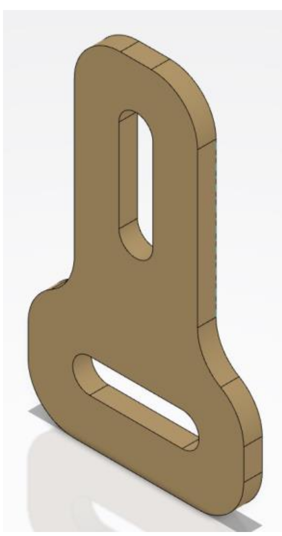
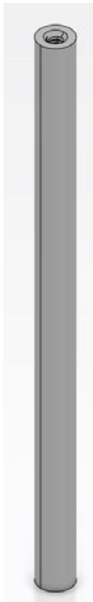
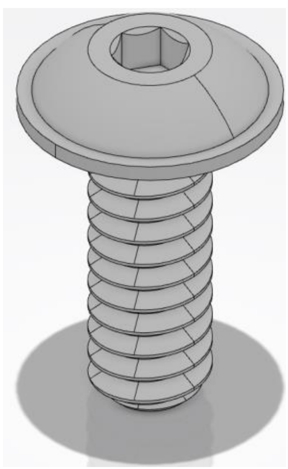
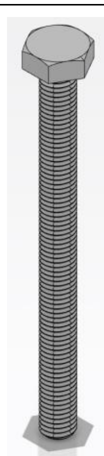
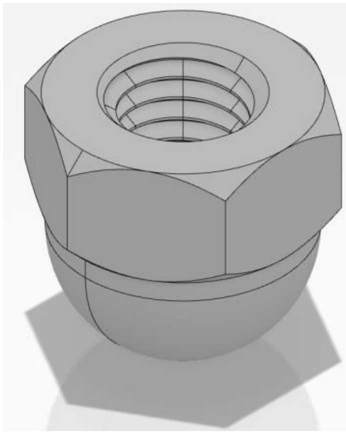
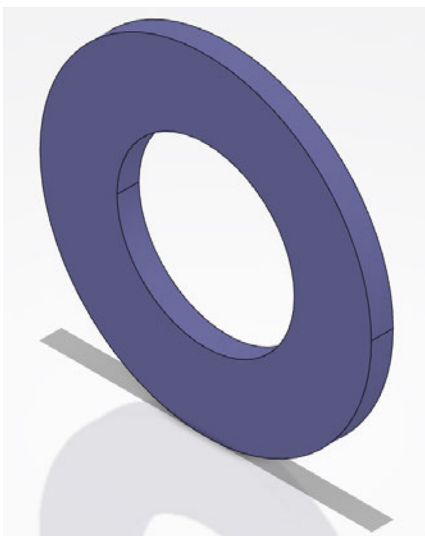
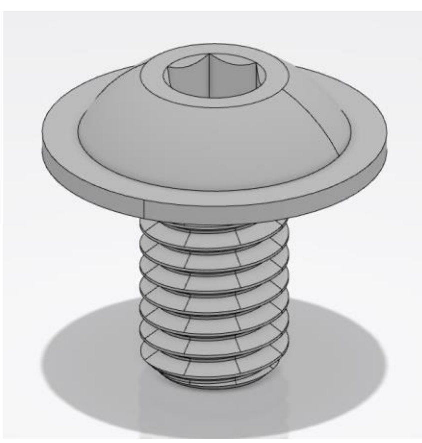
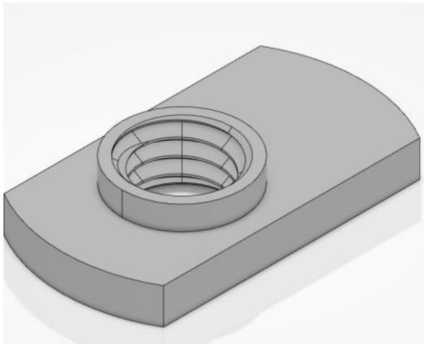
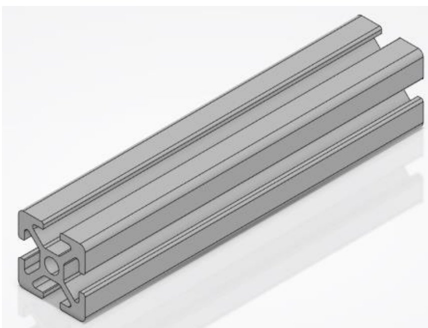


Figure 3.5.1: Labeled diagram of the Hub Mounting Assembly which is responsible for translating the hub along the X-axis. Extra clearance is provided in the negative X-direction to provide space for tools used for tightening or loosening the bolts that mount the Hub

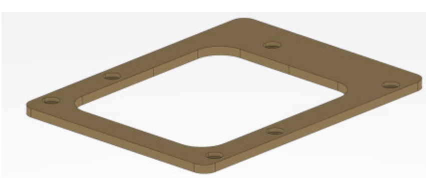
	**Name:** Hub Frame Assembly **Description:** See Section 3.4 **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Various • **Fabrication Method:** Assembled • **Quantity Needed:** 1 • **Supplier: N/A** • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** N/A
	**Name:** Frame Plate **Description:** The Frame Plate is responsible for correctly spacing the T-slot extrusions that make up the base of the Hub Mount Assembly, providing mounting points for the threaded spacers that act as guide rods for the Hub Frame Assembly, and reacting the forces from the M10x1.5 bolt that acts as a leadscrew to move the Hub Frame Assembly. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** 3mm Aluminum 6061-T6 Plate • **Fabrication Method:** Waterjet/Laser Cut • **Quantity Needed:** 2 • **Supplier:** [redacted] • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** [redacted]
	**Name:** Hub Locking Plate “The Seatbelt” **Description:** The Hub Locking plate is responsible for locking the translation of the Hub Frame along the X-axis by clamping against the Hub Frame Assembly and Hub Mount Assembly T-slot frame rails. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** 3mm Aluminum 6061-T6 Plate • **Fabrication Method:** Waterjet/Laser Cut • **Quantity Needed:** 2 • **Supplier:** [redacted] • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** [redacted]

	**Name:** 4” Female Threaded Round Standoff **Description:** This threaded round standoff acts as a guide rail for the Hub Frame Assembly to support its mass and minimize misalignment during operation. During initial testbench assembly it was found that these had to be turned down to slide smoothly through the bronze bushings in the Frame Slider Block. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated 12L14 Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 93265A039 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 5/16” 4-40 Flanged Button Head Screw **Description:** These screws fasten the above threaded standoff in place to the Frame Plates. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 4 • **Supplier:** McMaster-Carr • **Supplier PN:** 91355A154 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 120 mm Long M10x1.5 Hex Head Bolt **Description:** This Hex Head bolt is responsible for translating the Hub Frame Assembly along the X-axis. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** 316 Stainless Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 93635A481 • **PO Number/JIRA Ticket:** [redacted]

	**Name:** 18-8 Stainless Steel M10x1.5 Cap Nut **Description:** Cap Nut for the Above Bolt **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** 18-8 Stainless Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 1 • **Supplier:** McMaster-Carr • **Supplier PN:** 94000A040 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** WSS Test Bench Frame Bolt Spacer **Description:** This spacer aims to create the right amount of spacing between the bolt and the Frame Plates so that the cap nut may be tightened completely without clamping the components but still limiting the horizontal play in the bolt in its assembled state. Depending on part tolerances, it may be necessary to remove the spacers entirely for smooth operation. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** Draft V2 • **Fabrication Method:** 3D Printing • **Quantity Needed:** 2 • **Supplier:** Printed on FormLabs 3 Printer in 25U in DC • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** N/A
	**Name:** 8mm Long M5x0.8 Flanged Button Head Screws **Description:** These bolts are used to fasten the Frame Plates and Hub Locking Plates to the T-Slot Frame Rails. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 12 • **Supplier:** McMaster-Carr • **Supplier PN:** 92137A412 • **PO Number/JIRA Ticket:** [redacted]

	**Name:** M5x0.8 T-Slot Framing Rail Nut **Description:** Nuts for use in the T-slot framing rail. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 8 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T651 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** 4in Long 20mm Wide Square T-Slot Rail **Description:** Horizontal member in the Hub Mount Assembly. These must be shorted to the required length after purchase and tapped with M5x0.8 threads at the end. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Aluminum 6061-T6 • **Fabrication Method:** Purchased • **Quantity Needed:** 2 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T501 • **PO Number/JIRA Ticket:** [redacted]

3.6. Final Assembly

	**Name:** WSS Test Bench Base Plate **Description:** This is the component that all the previous assemblies are mounted to either directly or indirectly. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** [redacted] • **Material:** AL-6061 • **Fabrication Method:** Waterjet and Post-Machining • **Quantity Needed:** 1 • **Supplier:** Fabricated at R&D Fab Shop • **Supplier PN:** N/A • **PO Number/JIRA Ticket:** RDF-7924

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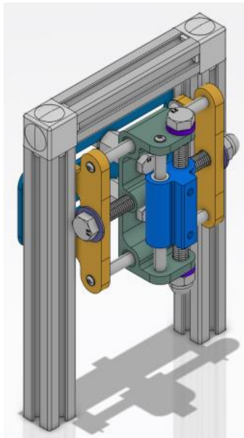


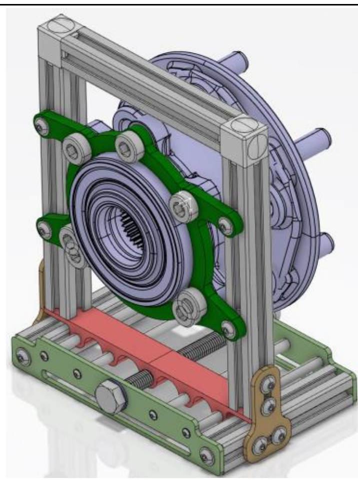
Name: Plane Slider Assembly

Description:

Provides 2 DOF in the test bench by manipulating the sensor position along the Y and Z axes.

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Various
- **Fabrication Method:** Assembled
- **Quantity Needed:** 1
- **Supplier: N/A**
- **Supplier PN:** N/A
- **PO Number/JIRA Ticket:** N/A



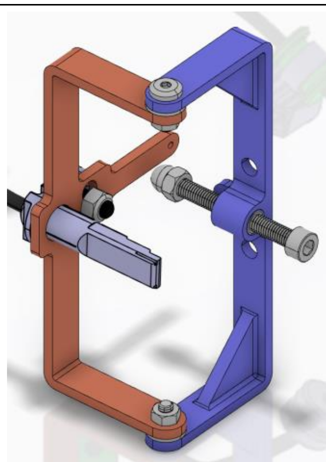
Name: Hub Mount Assembly

Description:

Provides the final degree of freedom in the test bench by manipulating the hub position along the X axis

Details:

- **ENOVIA/3DX PN:** [redacted]
- **Drawing Number:** N/A
- **Material:** Various
- **Fabrication Method:** Assembled
- **Quantity Needed:** 1
- **Supplier: N/A**
- **Supplier PN:** N/A
- **PO Number/JIRA Ticket:** N/A



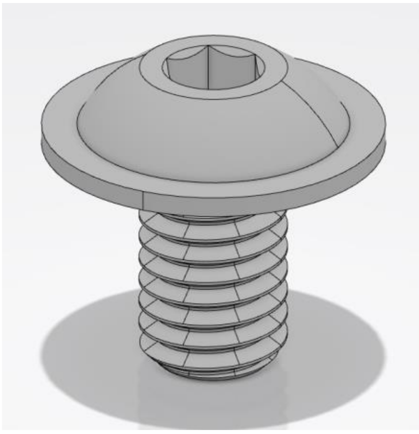
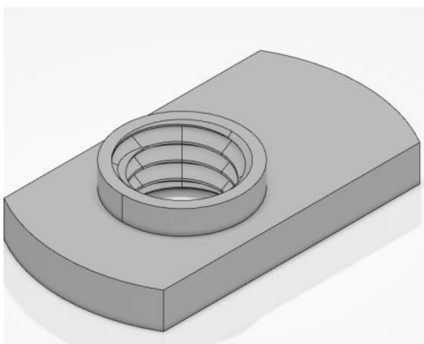
Name: Tilt Mount Assembly

Description:

Provides 2 DOF by manipulating the sensor orientation about the Y and Z axes.

Details:

- **ENOVIA/3DX PN** [redacted]
- **Drawing Number:** N/A
- **Material:** Various
- **Fabrication Method:** Assembled
- **Quantity Needed:** 1
- **Supplier: N/A**
- **Supplier PN:** N/A
- **PO Number/JIRA Ticket:** N/A

	**Name:** 8mm Long M5x0.8 Flanged Button Head Screws **Description:** These bolts are used to fasten the Tilt Assembly to the Tilt Assembly Mounting Block, the Plane Slider Assembly to the Base Plate, and the Hub Mount Assembly to the Base Plate. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Black-Oxide Alloy Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 8 • **Supplier:** McMaster-Carr • **Supplier PN:** 92137A412 • **PO Number/JIRA Ticket:** [redacted]
	**Name:** M5x0.8 T-Slot Framing Rail Nut **Description:** Nuts for use in the T-slot framing rail. **Details:** • **ENOVIA/3DX PN:** [redacted] • **Drawing Number:** N/A • **Material:** Zinc-Plated Steel • **Fabrication Method:** Purchased • **Quantity Needed:** 4 • **Supplier:** McMaster-Carr • **Supplier PN:** 5537T651 • **PO Number/JIRA Ticket:** [redacted]

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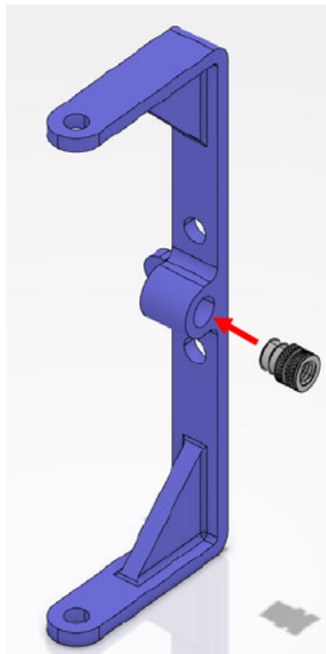
4. Assembly Guide

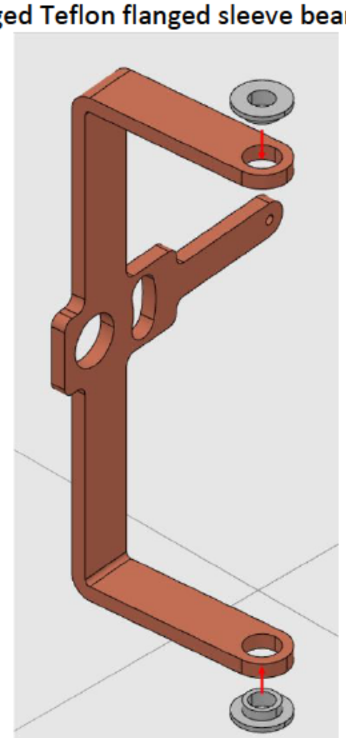
The following section should be a comprehensive set of instructions on how to assembly the Wheel Speed Sensor test bench, once all the parts have been received and any post-machining has been completed.

4.1. Tilt Assembly

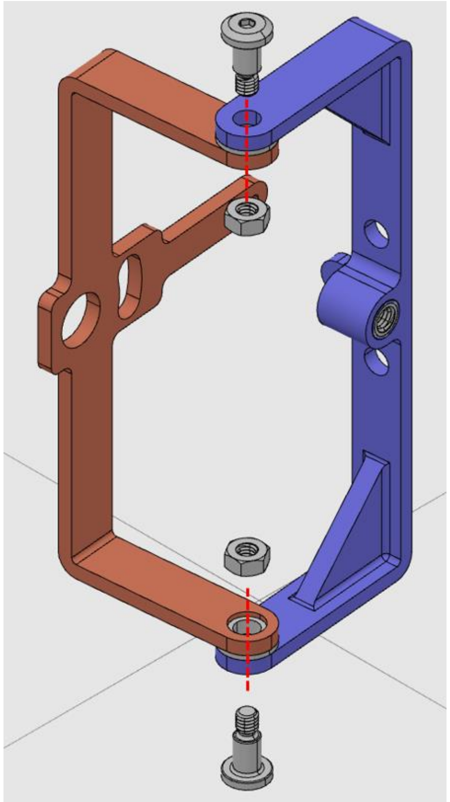
STEP 1: Heat set the M5 threaded insert into the WSS Knuckle



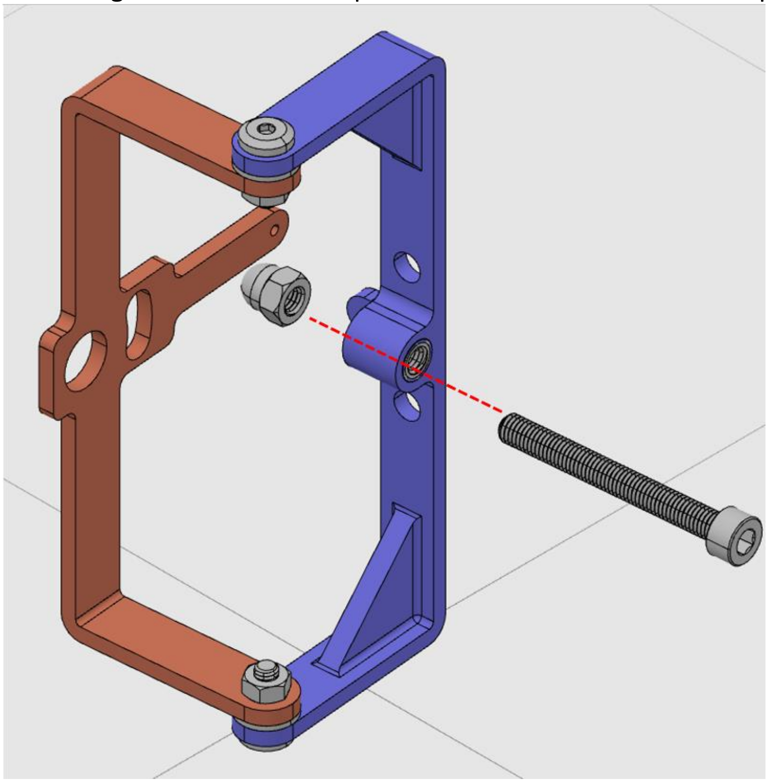
STEP 2: Press-fit the dry-running flanged Teflon flanged sleeve bearings into the WSS Mount



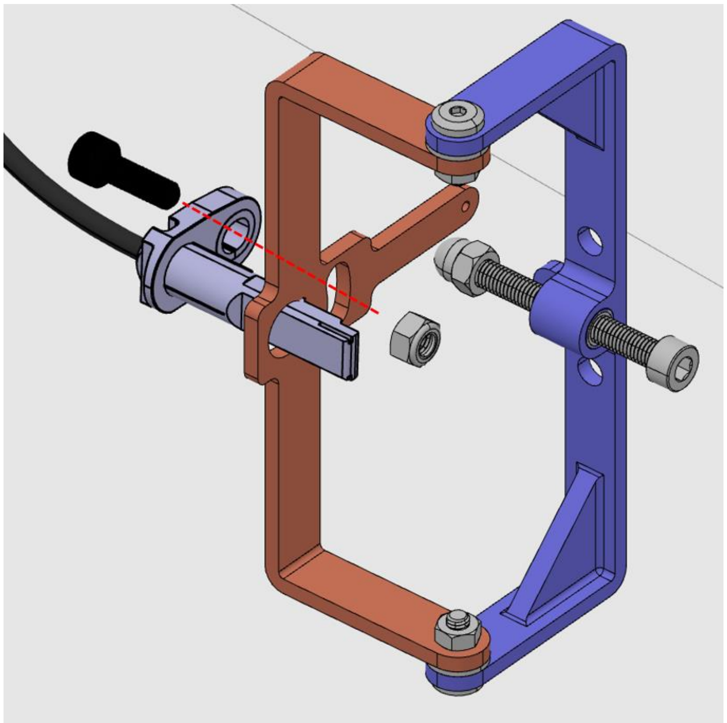
STEP 3: Align the Knuckle and WSS Mount and fasten them together with the M5 shoulder screws and 18-8 Hex Nuts



STEP 4: Insert the 45 mm Long M5 socket head cap screw and thread the M5x0.8 cap nut on the end



STEP 5: Fasten the selected sensor to the WSS Mount using the 15mm Long M5x0.8 socket head cap screw and Nylock nut

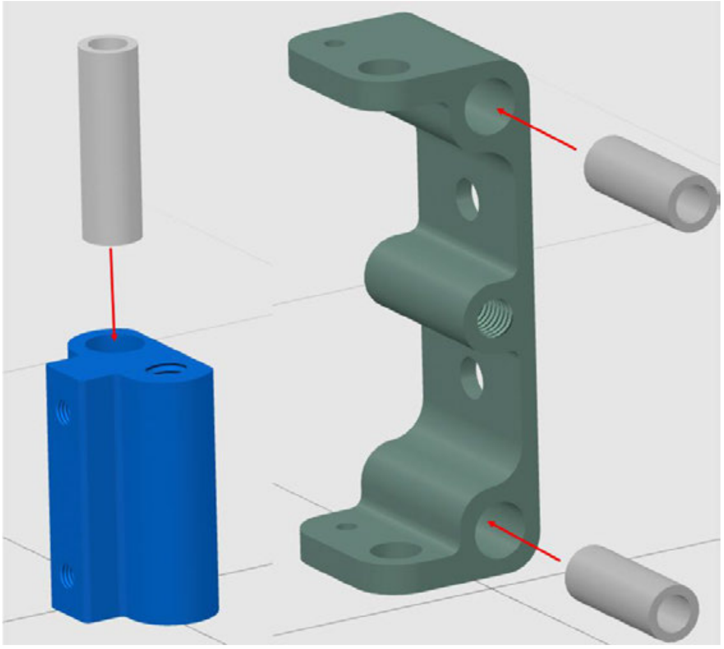


STEP 6: Loop the chosen spring into the provided holes on the Mount and Knuckle

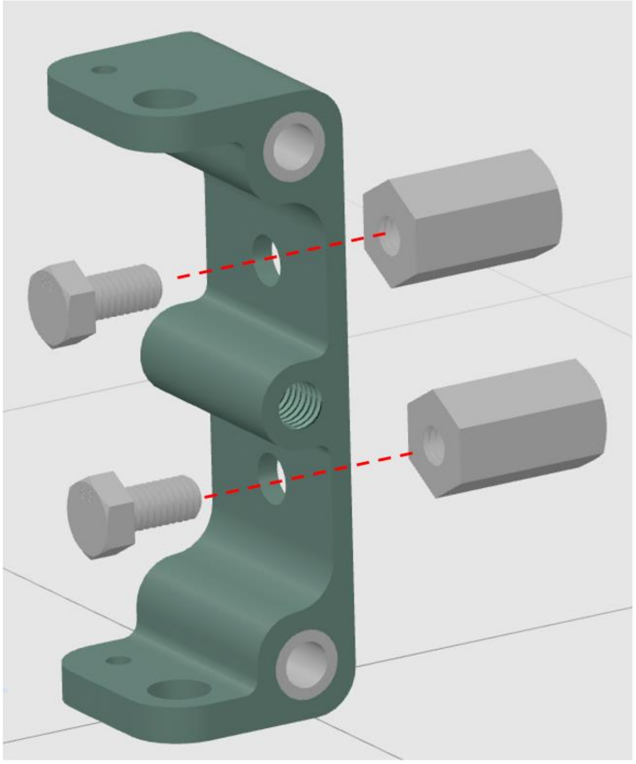
[no image intentionally]

4.2. Vertical Slider Assembly

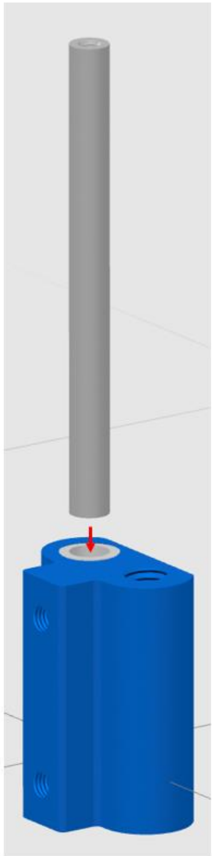
STEP 1: Press-fit the 1.25" Bronze Sleeve Bearing into the Tilt Assembly Mounting Block and the 1" Bronze Sleeve Bearings into the Top Block.



STEP 2: Fasten the turned down M6 Hex Thread standoffs to the Top Block using the M6 Hex Head Bolts.



STEP 3: Insert the 3” 4-40 Threaded round standoff into the Bearing in the Tilt Assembly Mounting Block



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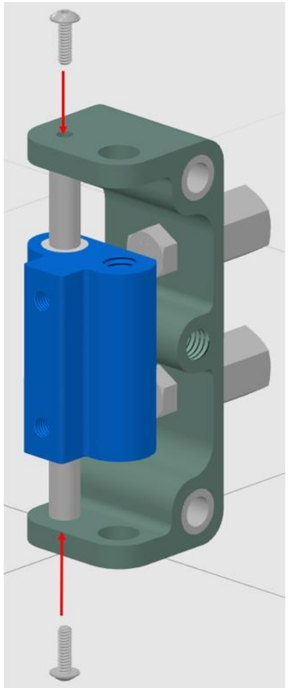
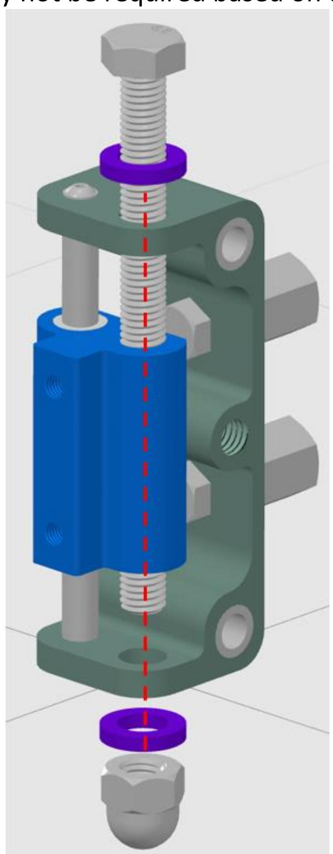
STEP 4: Slide the Tilt Assembly Mounting Block and 3" Steel standoff into the top block and fasten with the 3/8" Flanged Button Head 4-40 screws.

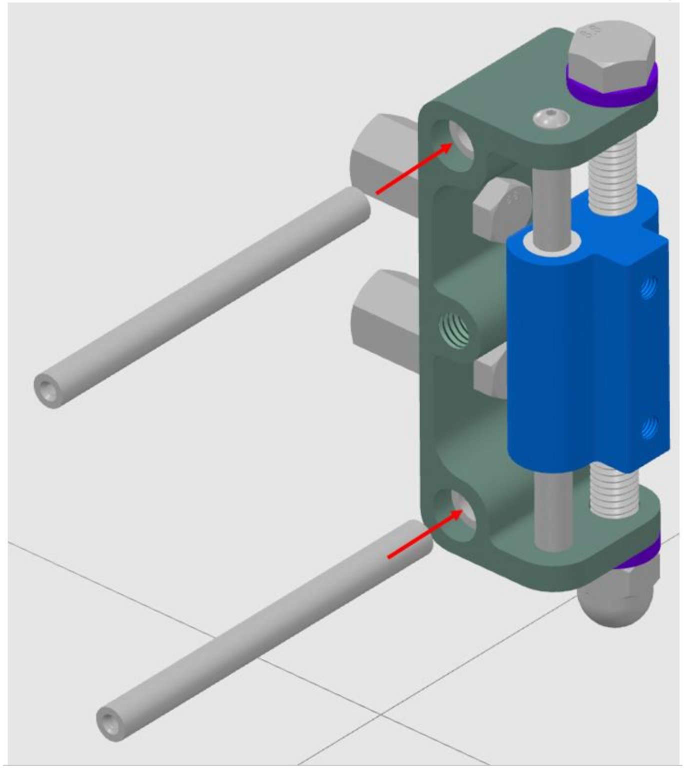


STEP 5: Slide the Bolt Spacers over the M8 Hex Head bolt and thread into the Tilt Assembly Mounting Block and Cap Nut. Spacers may or may not be required based on tolerances

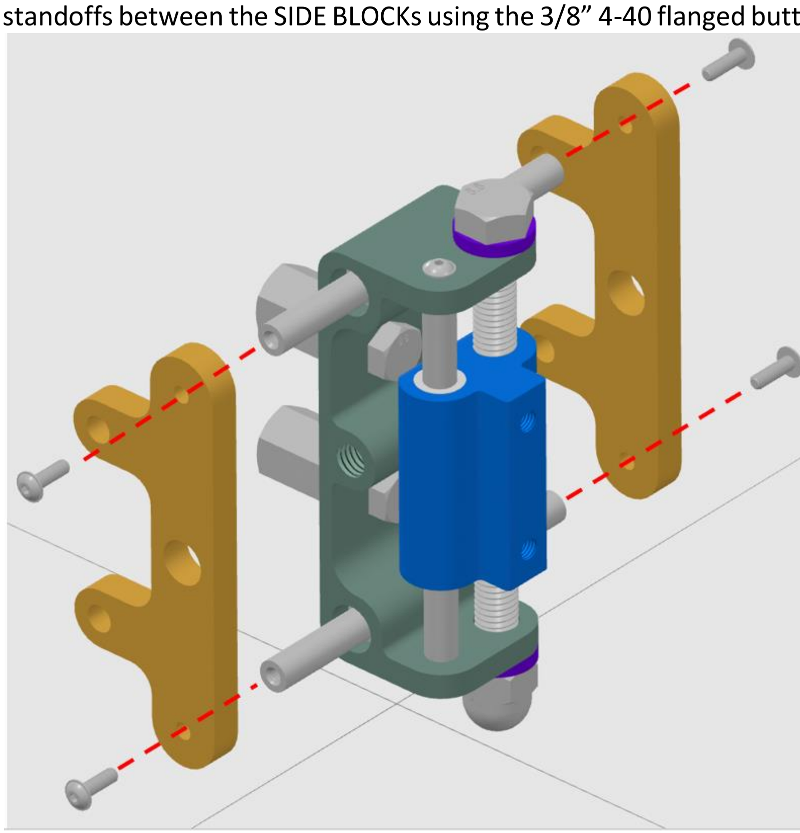


4.3. Plane Slider Assembly

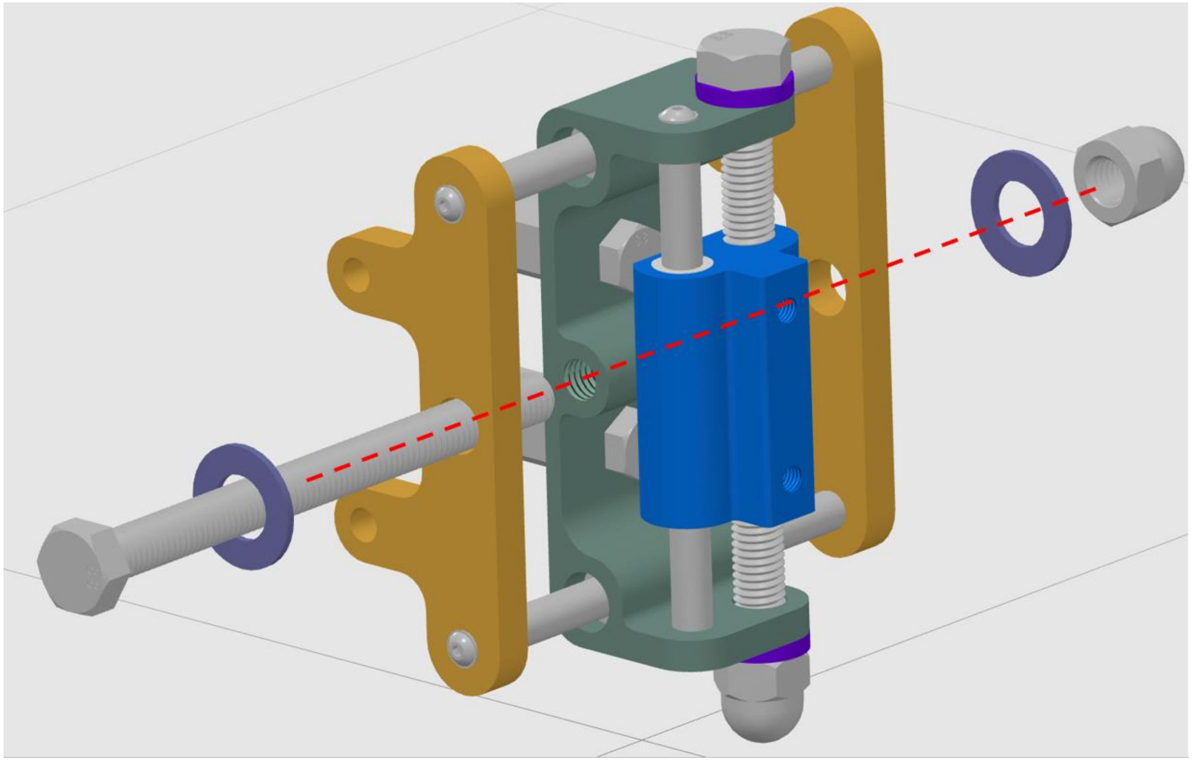
STEP 1: Slide the 3" 4-40 threaded round steel standoffs into the bronze bushings in the TOP BLOCK.



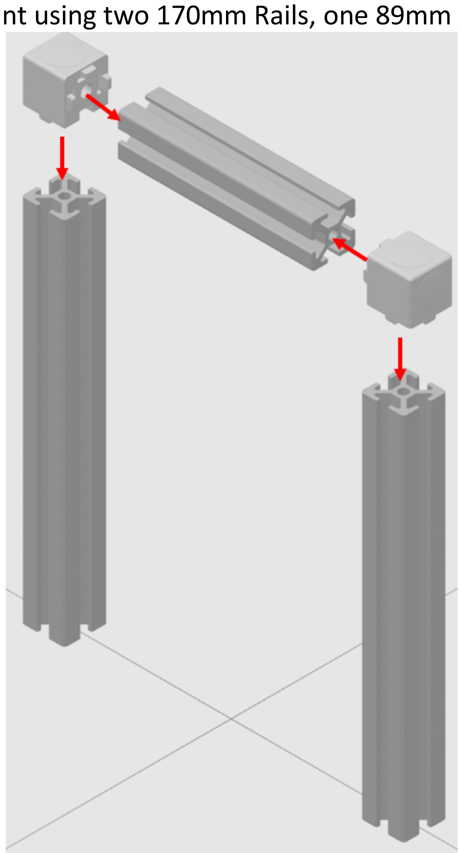
STEP 2: Fasten the standoffs between the SIDE BLOCKs using the 3/8" 4-40 flanged button head cap screws



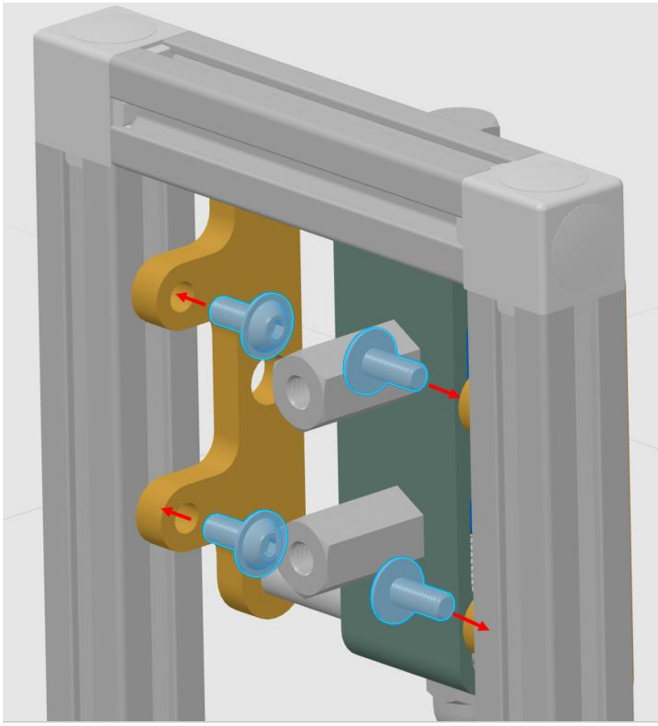
STEP3: Slide one Frame Bolt Spacer over the M8 Hex Head bolt, thread it through the Top Block, add another Frame Bolt Spacer on the outside of the second side block and thread it completely into the M8 Cap Nut. The spacers may or may not be needed based on part tolerances.



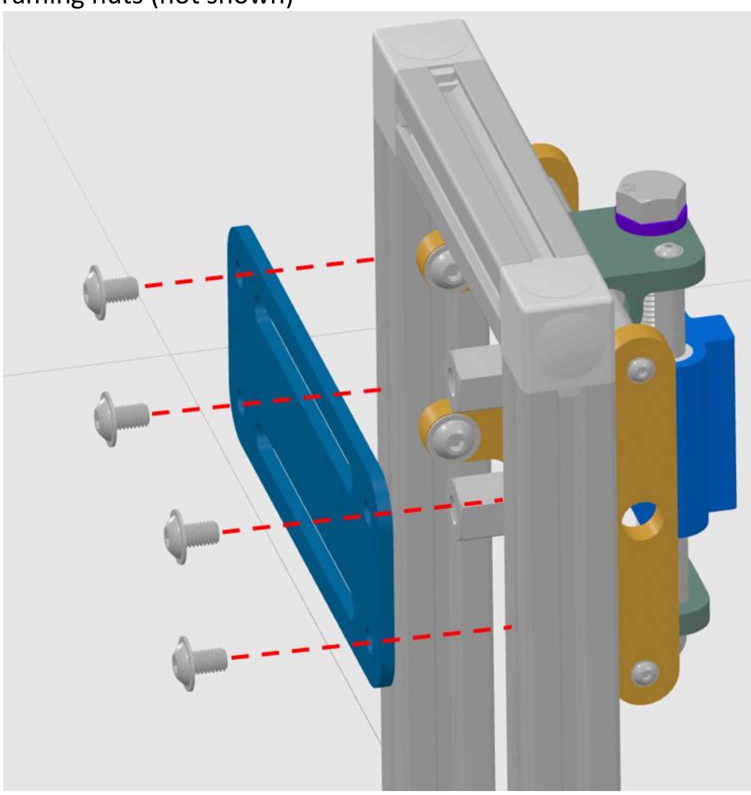
STEP 4: Assemble the Slider Mount using two 170mm Rails, one 89mm Rail, and two Corner Brackets



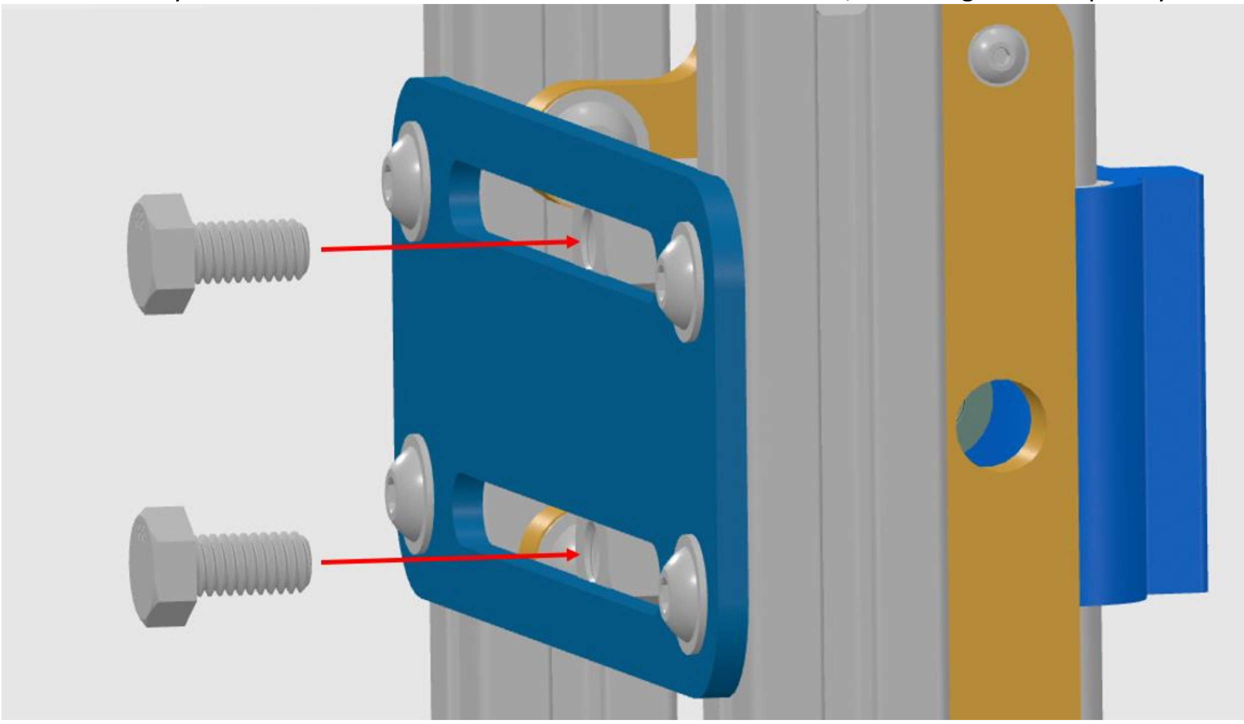
STEP 5: Assemble the Plane Slider Assembly to the Slider Mount Assembly by fastening the SIDE BLOCKs to the two 170mm Rails by using 4 12mm long M5x0.8 flanged button head screws that thread into 4 T-slot framing nuts (not shown).



STEP 6: Loosely assemble the Clamp Plate to 170mm Rails using 4 8mm Long M5x0.8 flanged button head screws and 4 T-Slot framing nuts (not shown)

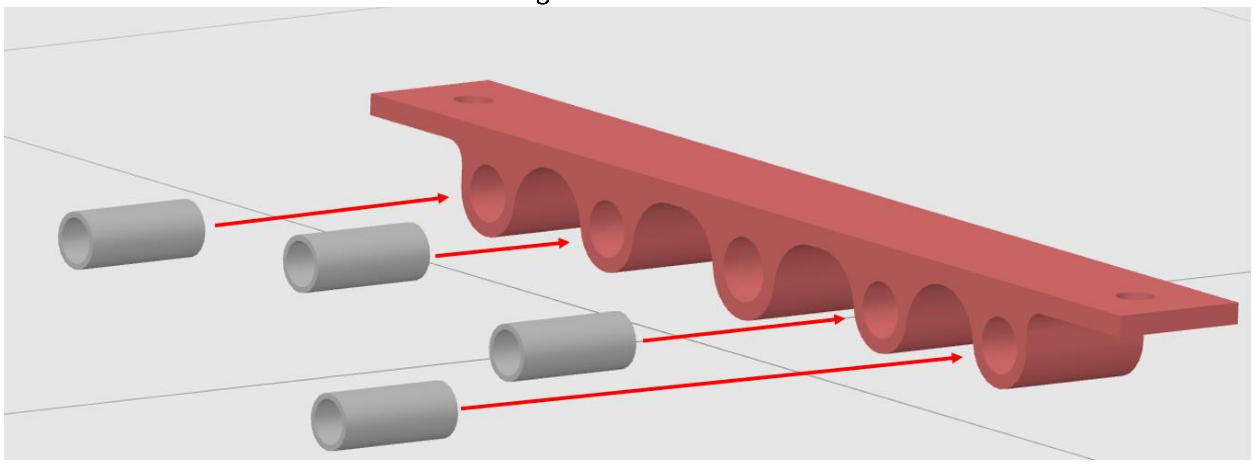


STEP 7: Loosely thread the 2 M6 Hex Head Bolts into the Hex Standoffs, do not tighten completely.

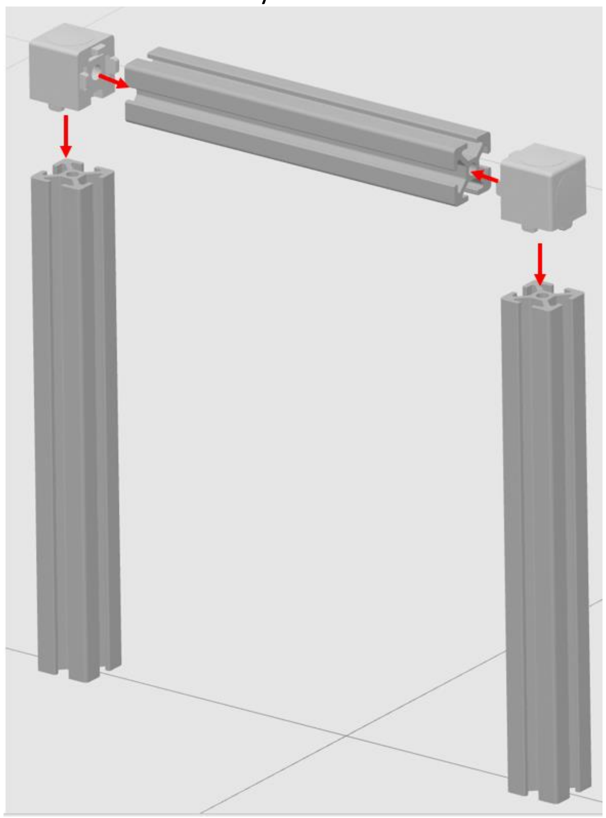


4.4. Hub Frame Assembly

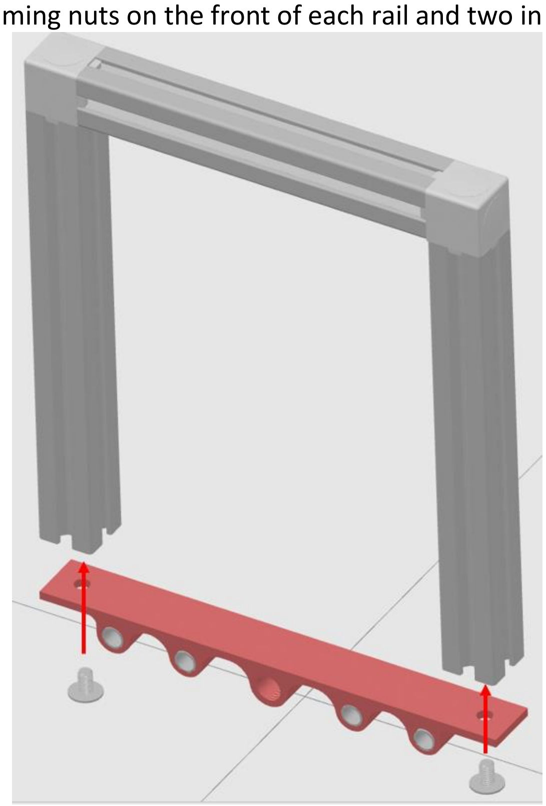
STEP 1: Press the 0.75" Bronze Sleeve Bearings into the Frame Slider Block



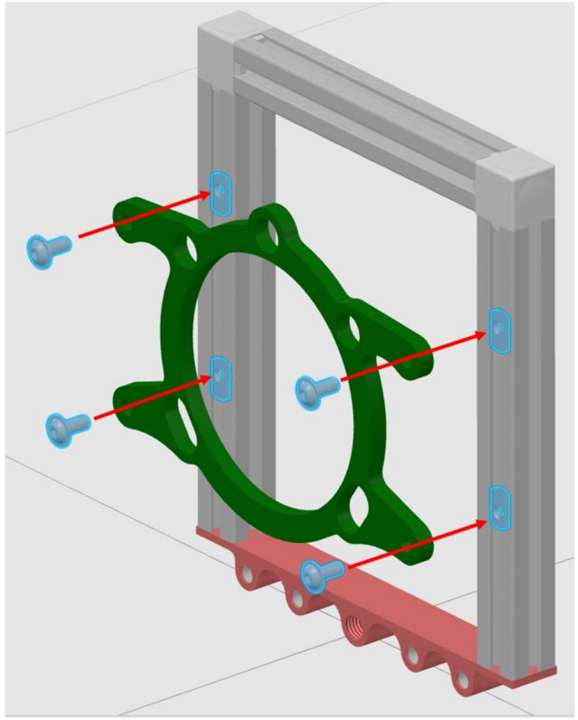
STEP 2: Assemble the Main T-slot frame assembly



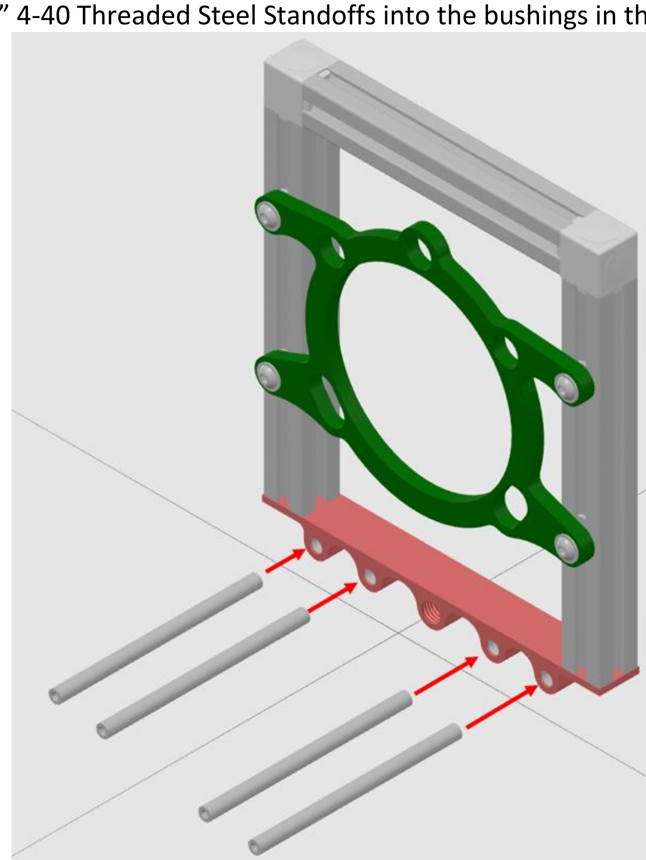
STEP 3: Assemble the T-slot frame to the Frame Slider block using 2 8mm long M5x0.8 Flanged Button Head bolts. Put two T-slot framing nuts on the front of each rail and two in the side of each rail.



STEP 4: Fasten the desired Hub Mounting Plate to the Frame Rail using 4 12mm M5x0.8 that screw into 4 T-slot mounting nuts. It does not matter which side of the frame rail the plate is mounted on.

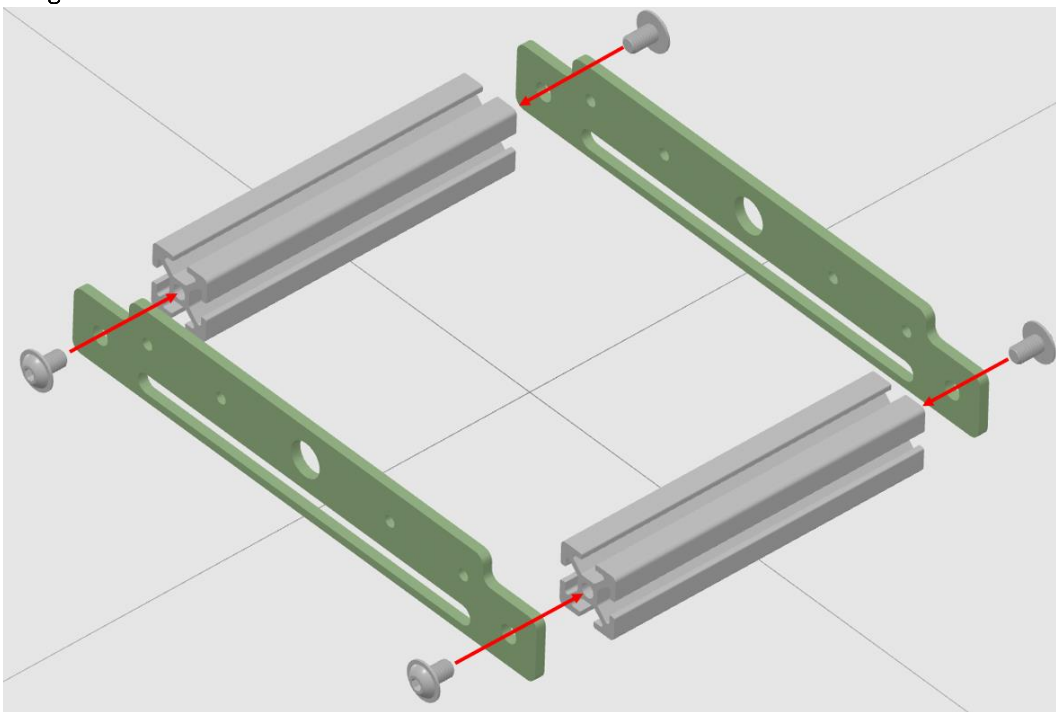


STEP 5: Insert the four 4” 4-40 Threaded Steel Standoffs into the bushings in the Frame Slider Block.

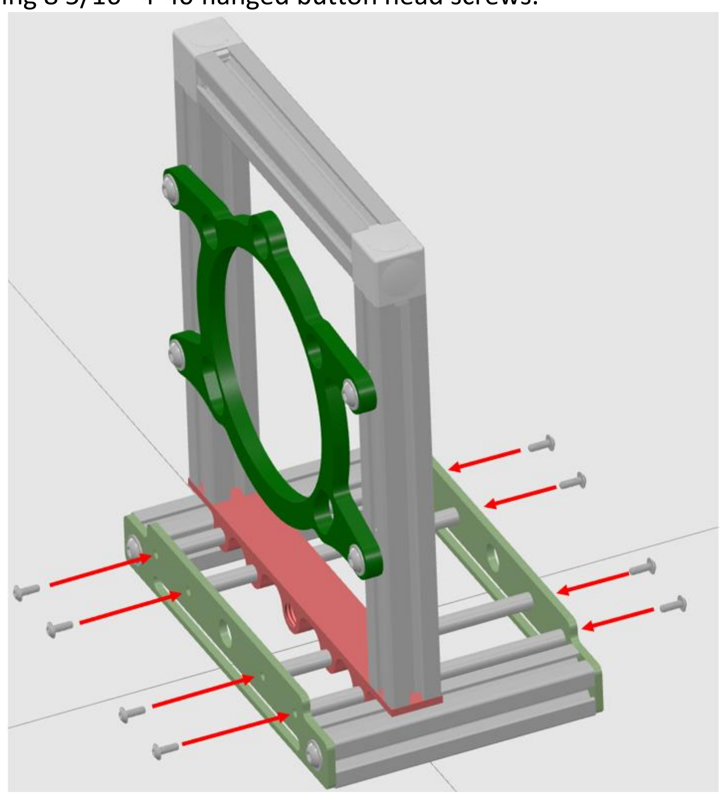


4.5. Hub Mount Assembly

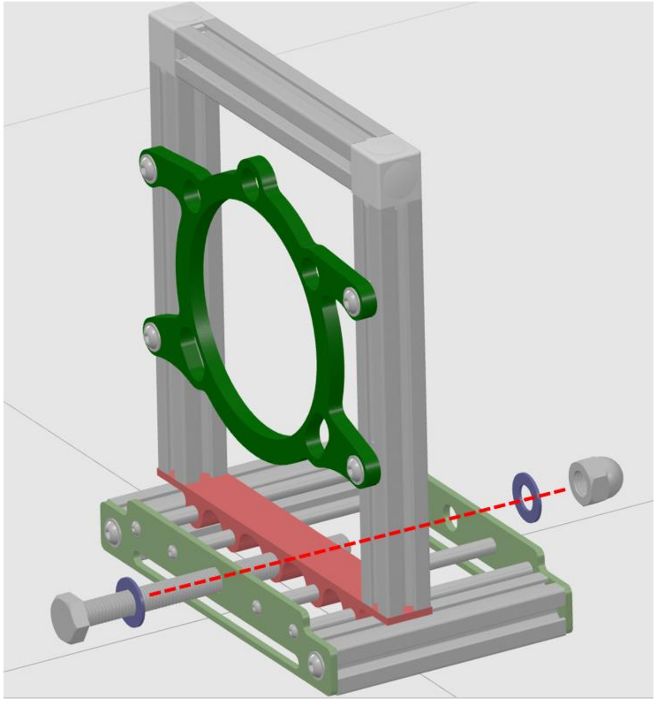
STEP 1: Assemble the base of the Hub Mount Assembly from the 4" frame rails, Frame Plates, and 4 8mm M5x0.8 flanged button head screws.



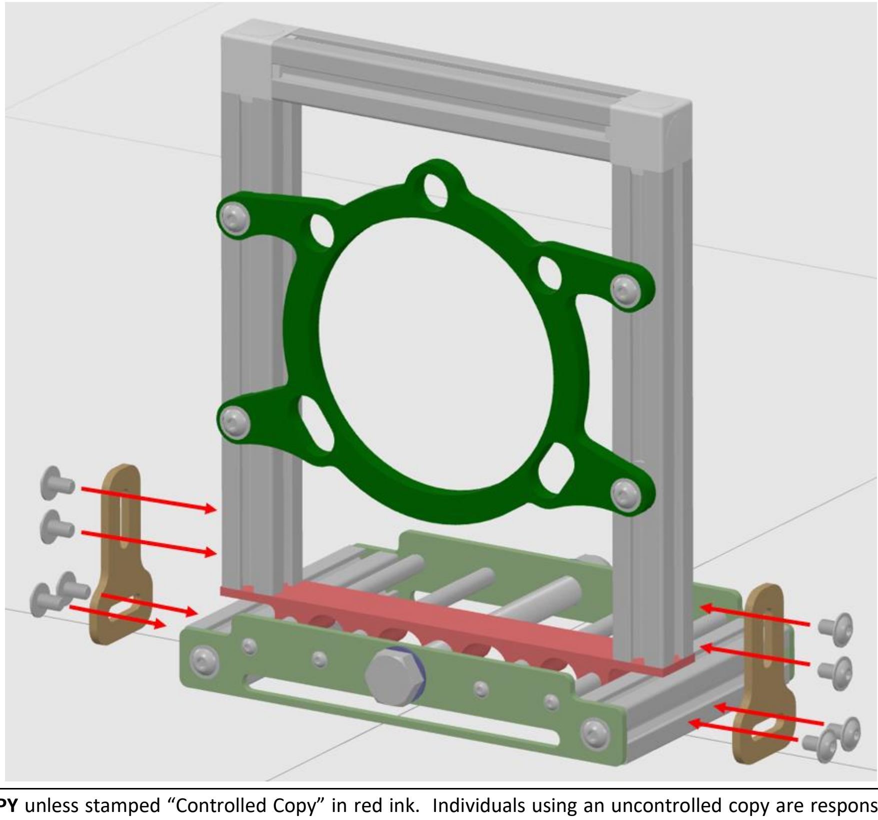
STEP 2: Slide the Hub Frame Assembly and standoffs between the frame plates and fasten the standoffs to the frame plates using 8 5/16" 4-40 flanged button head screws.



STEP 3: Pass the M10 bolt through a Frame Bolt Spacer, Frame Plate, thread it through the Frame Slider Block, and pass it through the other frame plate and frame bolt spacer to finally tighten it onto the M10 cap nut. The bolt and nut assembly should be free to rotate together and move the Hub Frame Assembly along the X-axis.

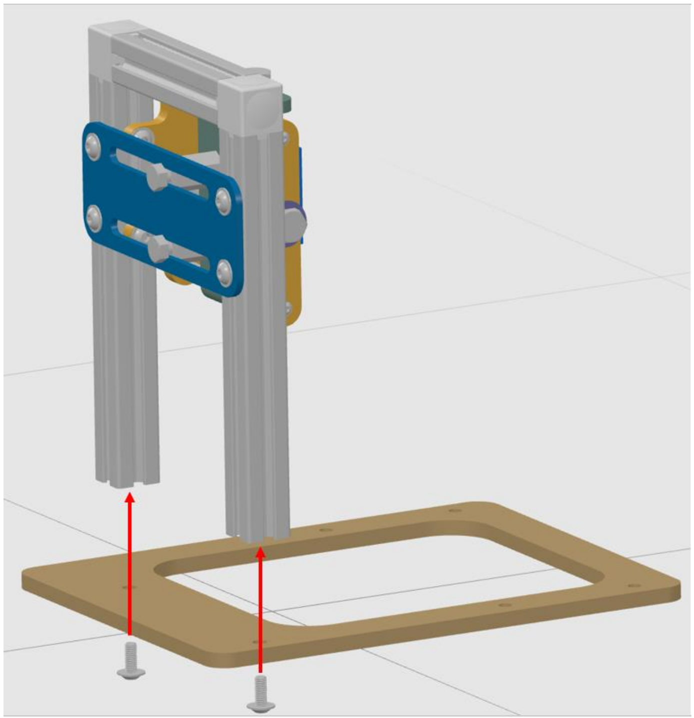


STEP 4: Fasten the Hub Locking Plates to the Hub Frame Assembly and 4" Rails using 8 8mm M5x0.8 flanged button head screws and 8 T-slot framing nuts (nuts not shown).

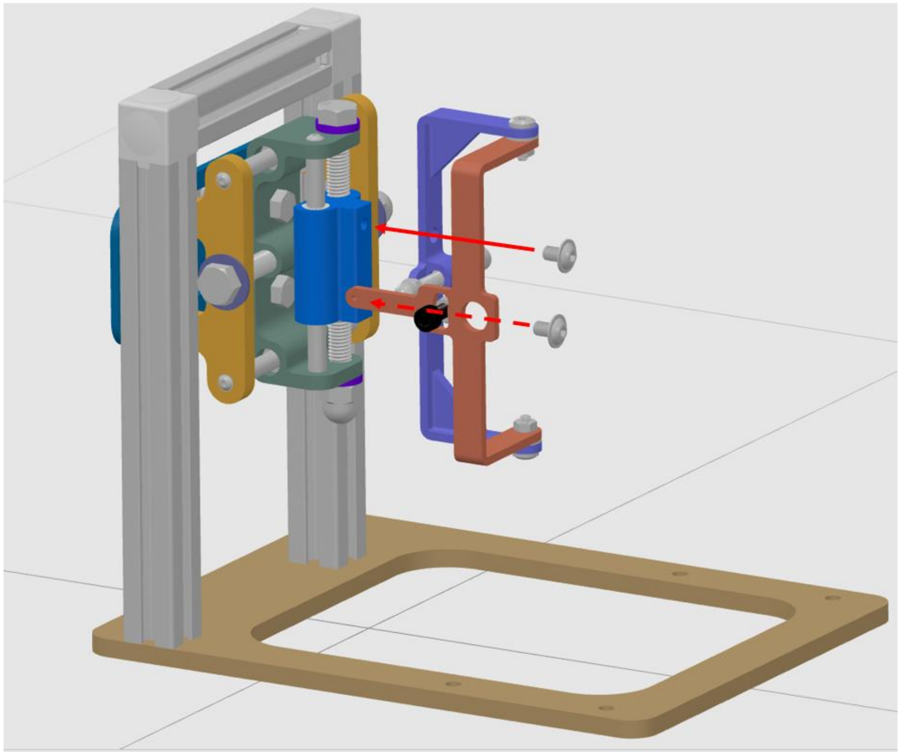


4.6. Final Assembly

STEP 1: Fasten the Plane Slider Assembly to the Base Plate using 2 8mm M5x0.8 flanged button head screws. Make sure the counterbored side of the base plate is downward



STEP 2: Fasten the Tilt Assembly to the Tilt Assembly Mounting Block using two 8mm M5x0.8 flanged button head screws. (Wheel Speed Sensor omitted in below image for clarity)



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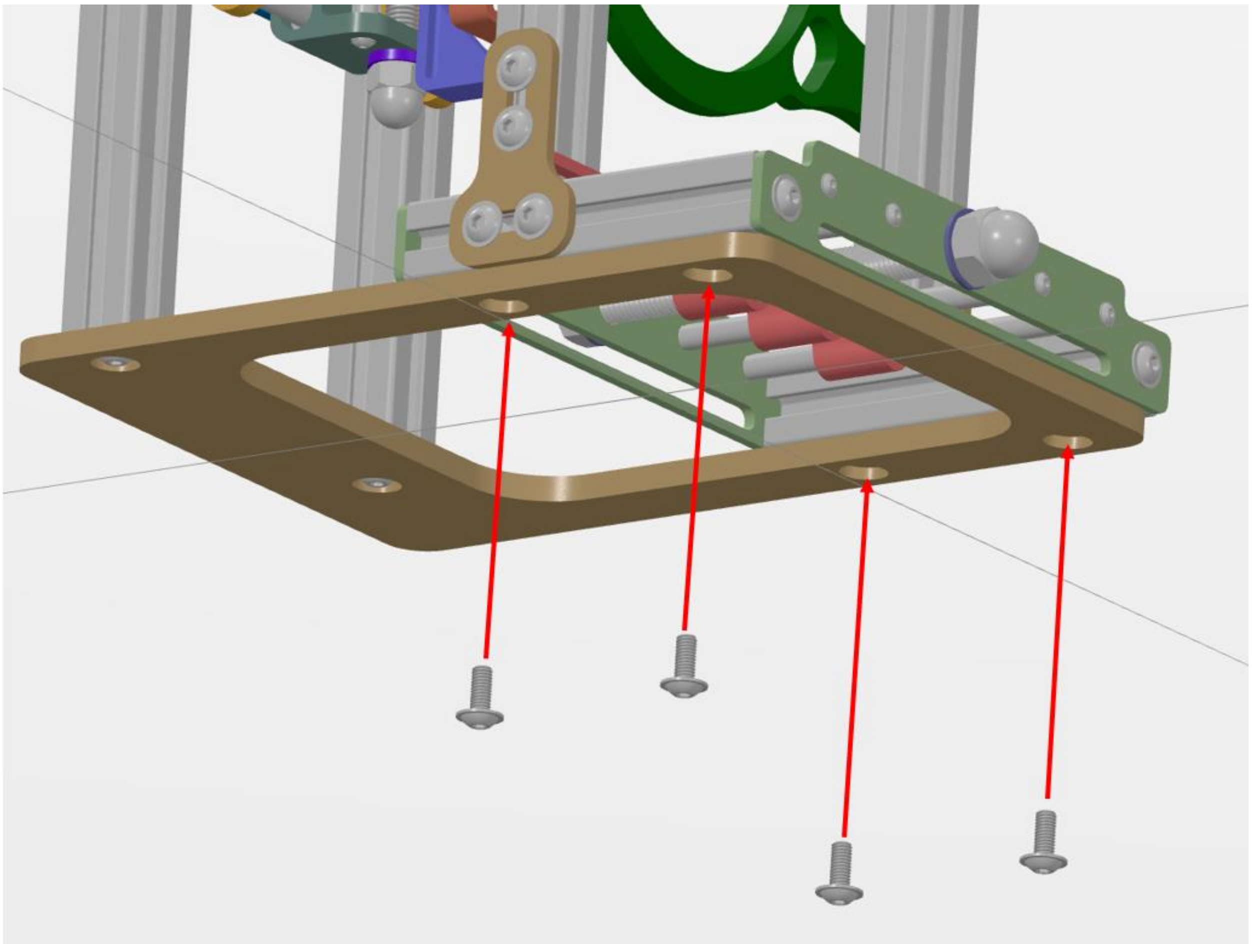
STEP 3: Fasten the Hub Mount Assembly to the base plate using 4 8mm M5x0.8 screws that thread into 4 T-slot framing nuts inside the Hub Mount Rails. (T-slot Framing Nuts not shown). If using the revision B frame plates, the Hub Mount Assembly can be slid onto loose T-slot framing nuts from along the X-axis. If using the revision A frame plates then the 4" rails will have to be slid on individually and then fastened to the frame plates.



Congratulations, if you've followed all the steps correctly, you've successfully completed the Wheel Speed Sensor Test Bench! You can now mount the desired hub and plate using their respective M12 socket head cap screws.

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5. Operation

Except for one angular degree of freedom, the position and orientation of the wheel speed sensor relative to the hub can be adjusted by tightening or loosening bolts that drive leadscrew-type mechanisms - in the case of the linear degrees of freedom, or a cam-like system - in the case of the second angular degree of freedom. The first angular DOF is controlled by rotating the sensor itself and locking its position by tightening the Nylock nut that fastens it to the WSS Mount.

5.1. Rotation about the Y-Axis

As mentioned earlier, the first angular degree of freedom is set coarsely by eye. This is done by rotating the sensor body about its main axis by hand and then tightening the bolt that is used to secure it to the sensor mount. The curved slot allows for thirty degrees of adjustment from nominal in both directions. Rotation about the y-axis was chosen to be the closest degree of freedom to the sensor due to its ease of implementation - as originally, the curved slot was simply a hole for the sensor mounting bolt to pass through. An image of the sensor mount with the curved slot is shown below in Figure 5.1.1 and an image of the sensor in various positions is shown in Figure 5.1.2.

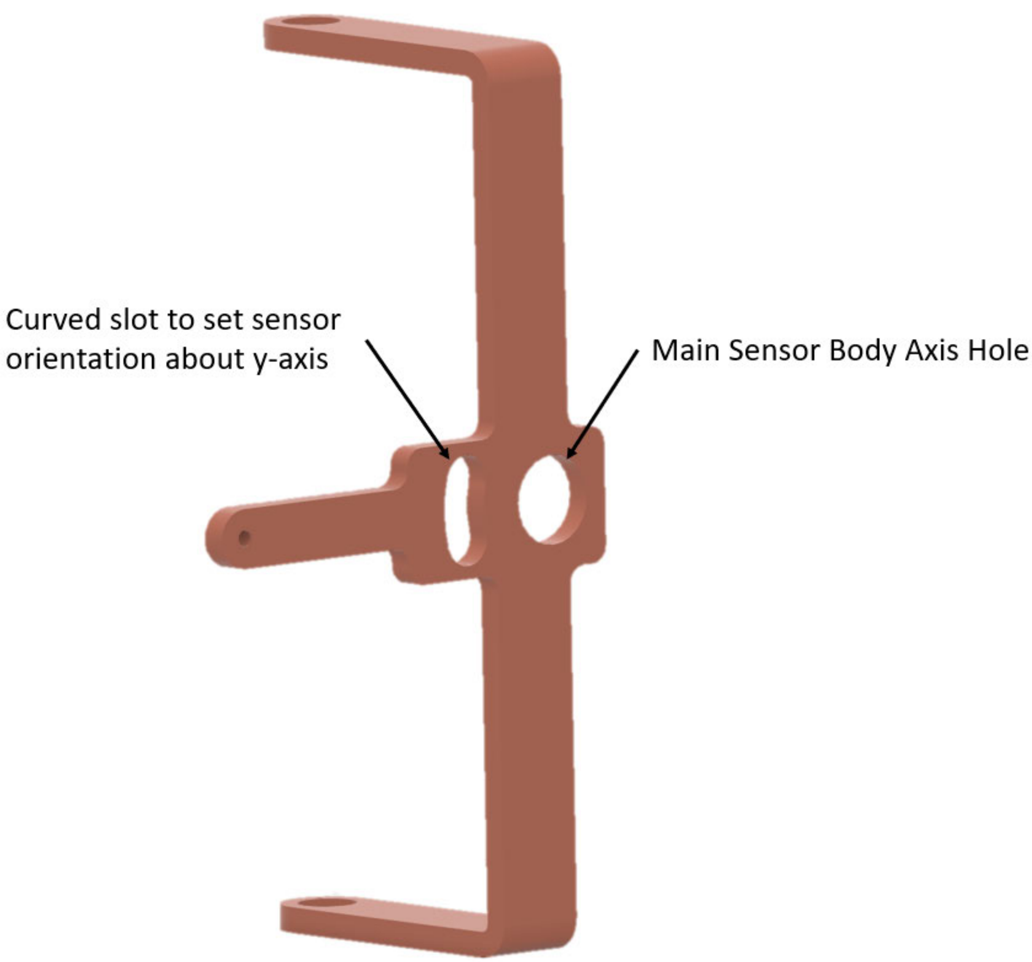
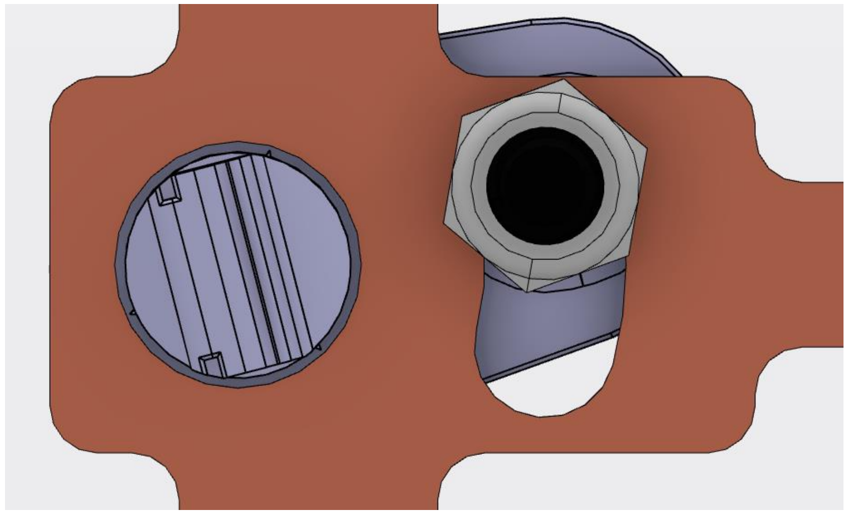
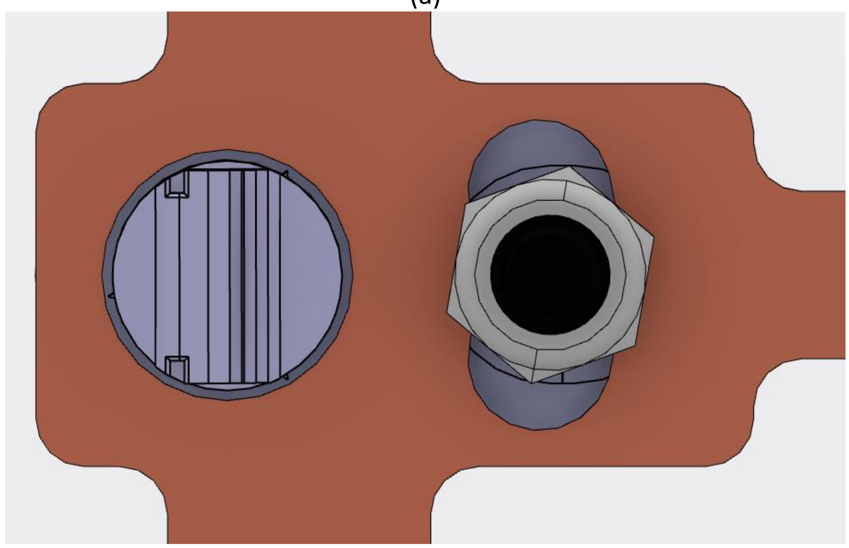


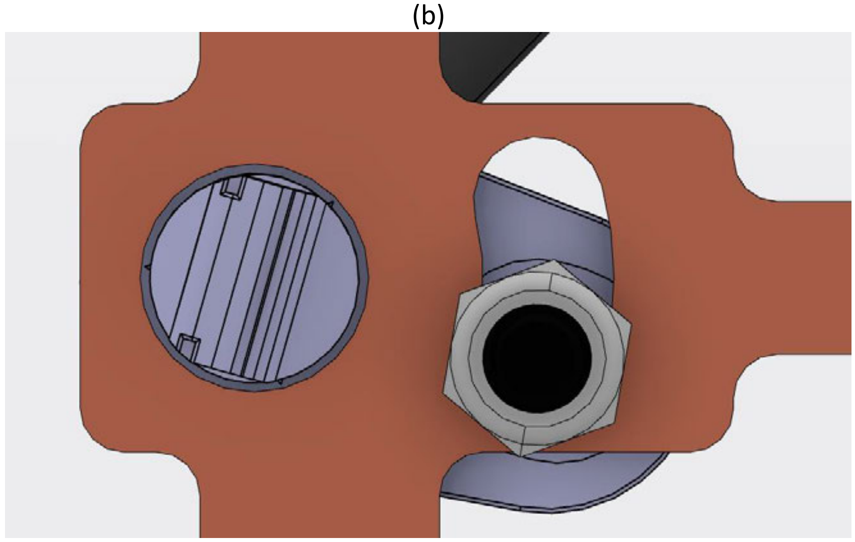
Figure 5.1.1: An image of the wheel speed sensor mounting bracket. The curved slot allows for 30 degrees of rotation about the y-axis in both directions from the horizontal.



(a)



(b)



(c)

Figure 5.1.2: Images showing the sensor rotation about the Y-axis in multiple orientations: +30 degrees (a), 0 degrees (b), and -30 degrees (c).

5.2. Rotation about the Z-axis

The second angular degree of freedom on the sensor is rotation about the Z-axis and is controlled by operating an M5 screw with a cap nut on the end to act as a cam mechanism. The rotation axis is designed to be as close to the tip as possible and there are roughly ten degrees of rotation in both directions allowed from the nominal position; however, this value will vary with different distances between the sensor and the hub, as components may begin to interfere with each other sooner or later, depending on how the linear degrees of freedom have been set.

The M5 screw and cap nut combination is responsible for increasing the angle with respect to the z-axis, while a spring linking the two components is responsible for reducing it when the bolt is loosened. Rotation about the z-axis was chosen to be the second closest degree of freedom to the senor in order to minimize the inertia and mass that is being rotated about this axis. An image of the tilting mechanism is shown below in Figure 5.2.1, while Figure 5.2.2 shows the sensor in various positions with respect to the z-axis.

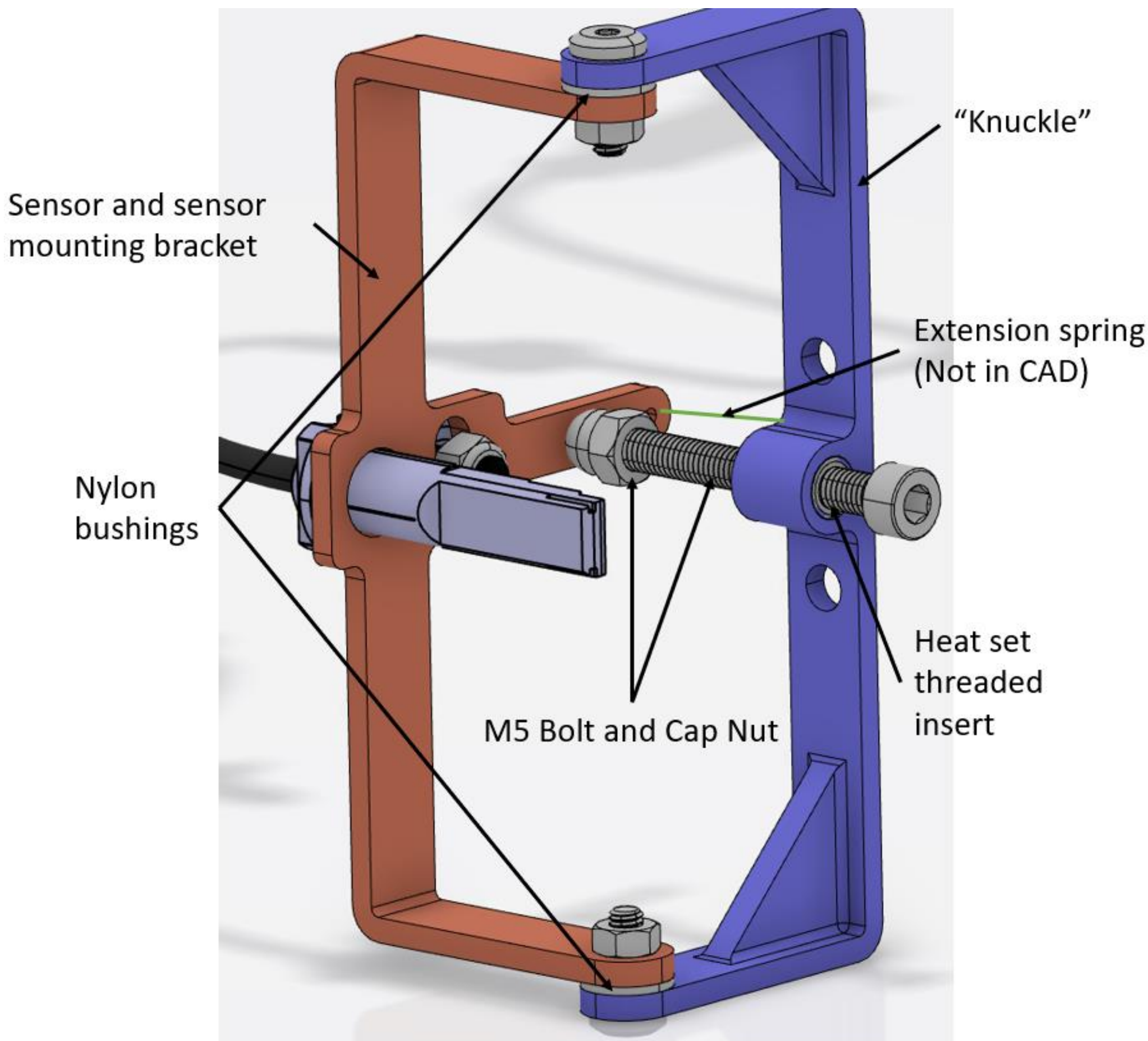
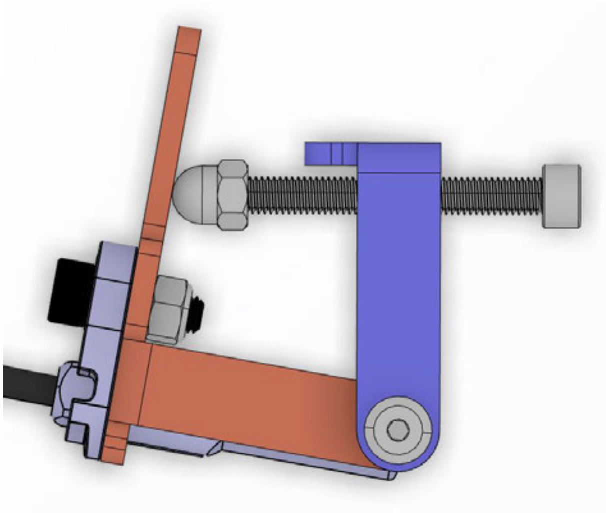
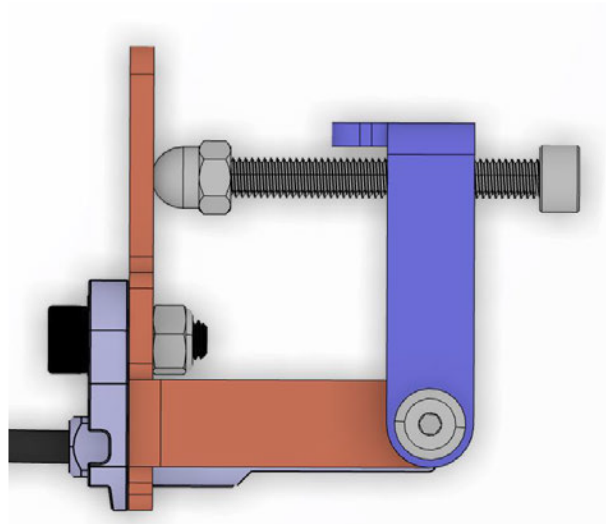


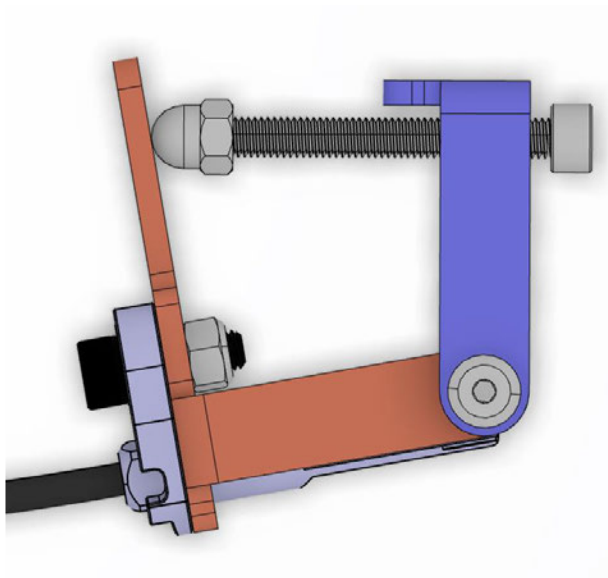
Figure 5.2.1: Tilt Mounting Assembly for the wheel speed sensor test bench with labeled components.



(a)



(b)



(c)

Figure 5.2.2: Images of the Tilt Mount Assembly in its various positions that control the z-axis orientation of the sensor: (a) 80 degrees, (b) 90 degrees, and (c) 100 degrees. Note the spring that is responsible for retracting the sensor mount when the bolt is loose is not shown in the CAD or in the images above.

5.3. Translation along the Z-axis

The first linear degree of freedom was chosen to be translation in Z to minimize the mass that the threads on the leadscrew are responsible for supporting. Vertical translation is achieved by twisting an M8 bolt with cap nut combination to move a threaded aluminum block up and down vertically while guided by a steel rod to prevent rotation. Do not rotate the nut and bolt relative to each other once assembled, simply turn the bolt head. The assembly provides approximately 18.1 millimeters of vertical translation in both directions from the nominal. The Tilt Assembly from above mounts to the threaded aluminum block via threaded M5 holes. An image of the Vertical Slider Assembly is shown below in Figure 5.3.1, and in various positions in Figure 5.3.2.

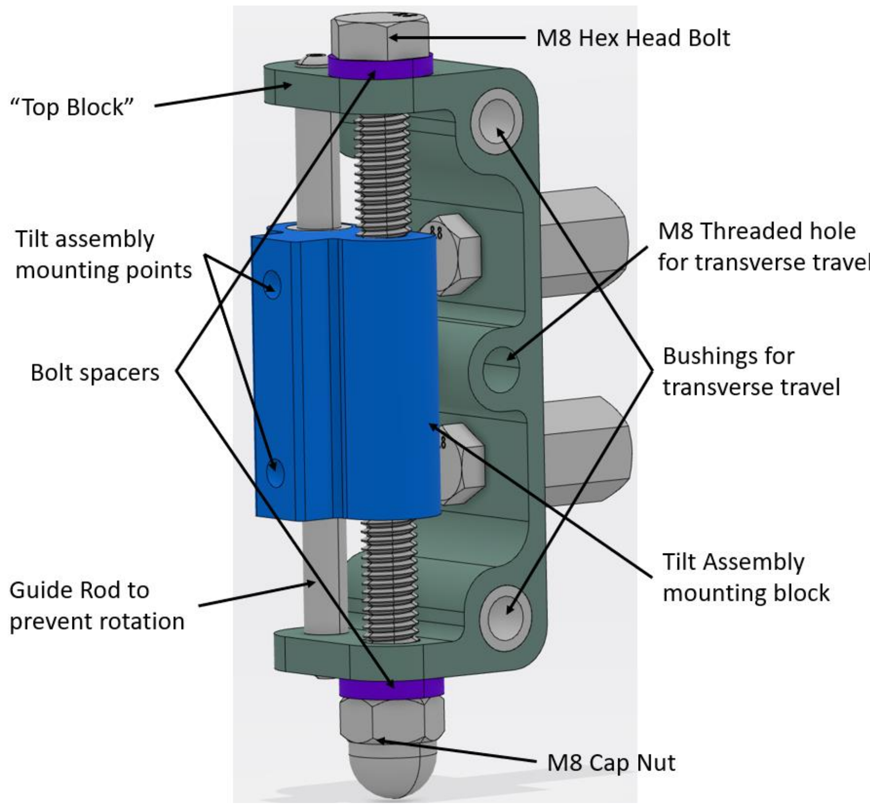


Figure 5.3.1: Labeled image of the vertical slider assembly. The unlabeled hex bolts and standoffs are for a locking feature discussed later.

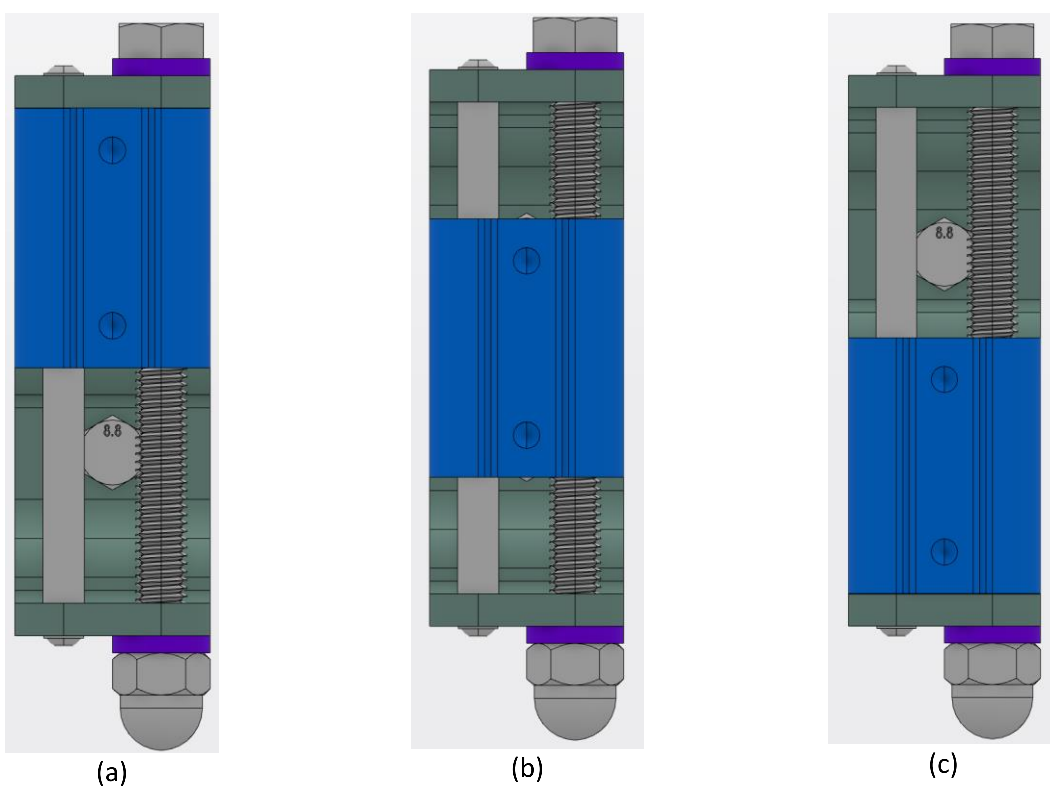


Figure 5.3.2: Vertical slider assembly in: (a) +18.1 mm, (b) 0 mm, and (c) -18.1 mm positions.

5.4. Translation along the Y-Axis

The second linear degree of freedom was chosen to be translation along the Y-axis due to ease of integration with the Vertical Slider Assembly above. It was determined through engineering judgement that attempting to integrate translation along the x-axis into the vertical slider assembly components would drastically increase manufacturing complexity.

Translation along the Y-axis works quite similarly to translation along the Z-axis where the “Top Block” from the above assembly is threaded with an M8 thread and rides on two guide rods to prevent misalignment during operation. The assembly provides roughly 23mm of travel in either direction. The Plane Slider Assembly is mounted via M5 bolts to 20mm T-slot rails from McMaster (or a similar vendor) so that the nominal vertical position of the sensor can be adjusted relative to the hub, and to allow for ease of assembly. Ensure that the locking bolts on the clamping plate are loosened before attempting to move the sensor along the y-axis. An image of this “Plane Slider Assembly” is shown below in Figure 5.4.1. Figure 5.4.2 shows the plane slider assembly in various positions with respect to the hub.

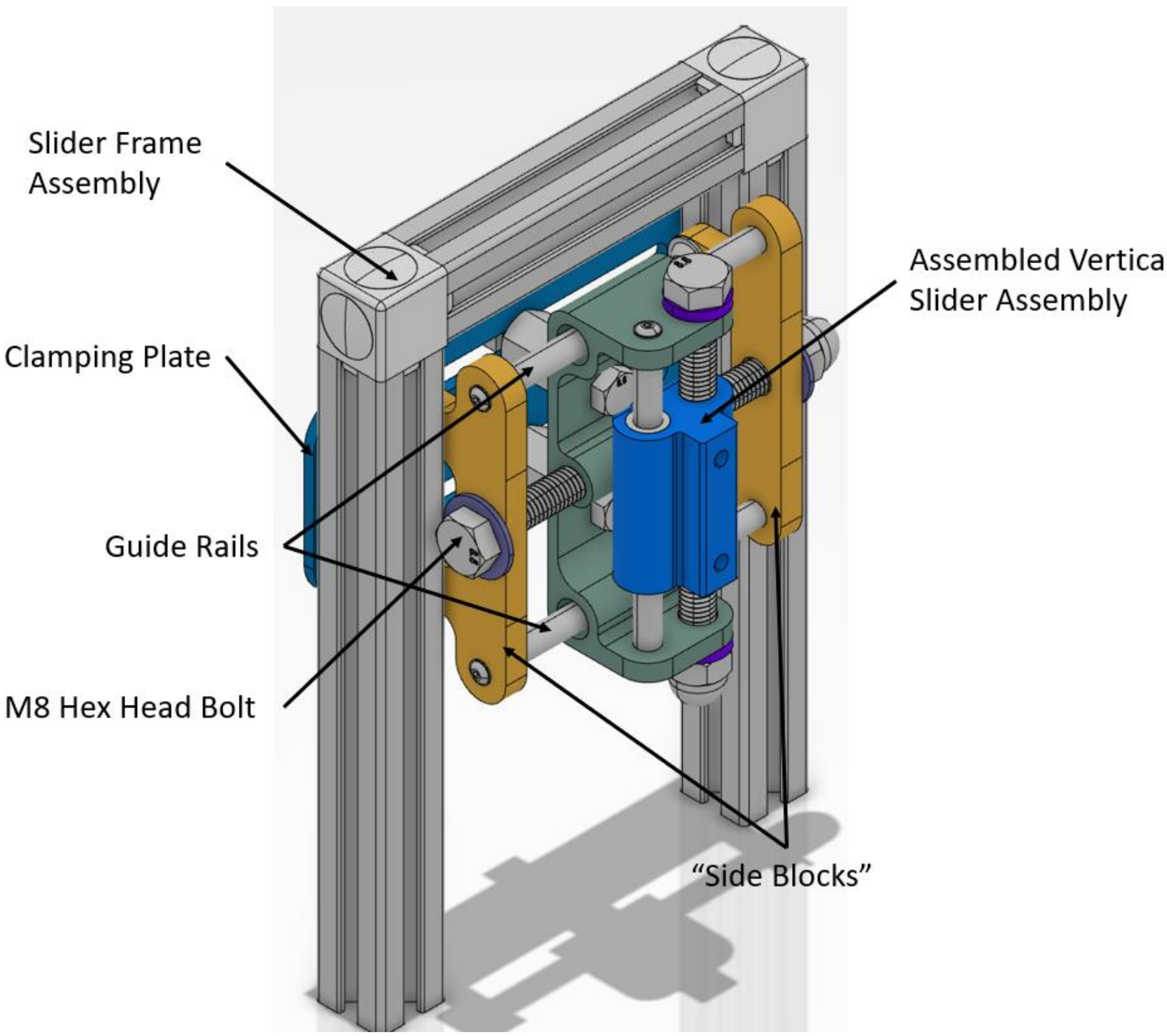
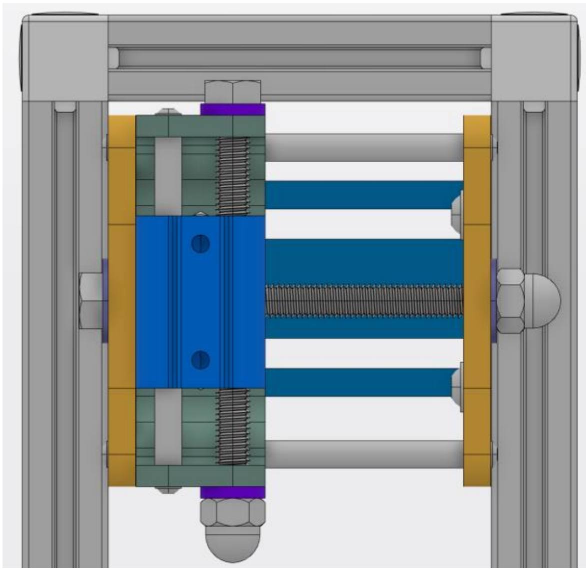
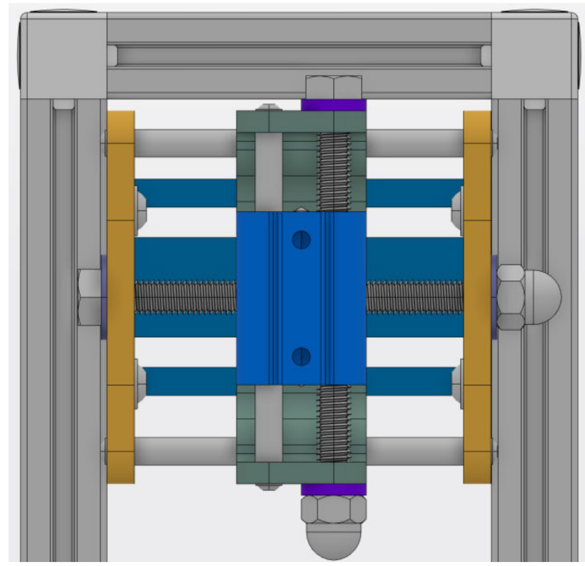


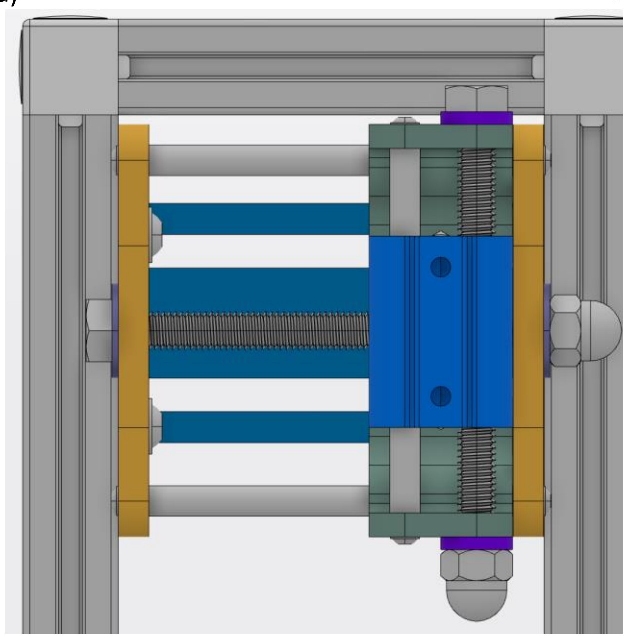
Figure 5.4.1: Labeled image of the transverse Plane Slider Assembly which allows for ~23 mm of travel in both directions from nominal.



(a)



(b)



(c)

Figure 5.4.2: Image collection of the transverse Plane Slider Assembly in its various positions: (a) +23.1 mm, (b) 0 mm, and (c) -23.1 mm.

5.5. Translation along the X-Axis

The final linear degree of freedom is translation along the X-axis which is attained through adjusting the position of the hub, rather than the sensor assembly. This was chosen to minimize the complexity of the project both from a design and manufacturing perspective.

An M10 bolt threads into a block as shown below in Figure 5.5.1 to pull or push the Hub Frame Assembly either closer or farther away from the sensor. The travel along the X-axis is asymmetric as the air gaps that need to be tested span less than 5 millimeters, whereas the clearance needed for a tool to loosen the bolts fastening the hub to the hub mounting plate are much greater. Therefore, a larger tolerance in the negative x-axis was chosen.

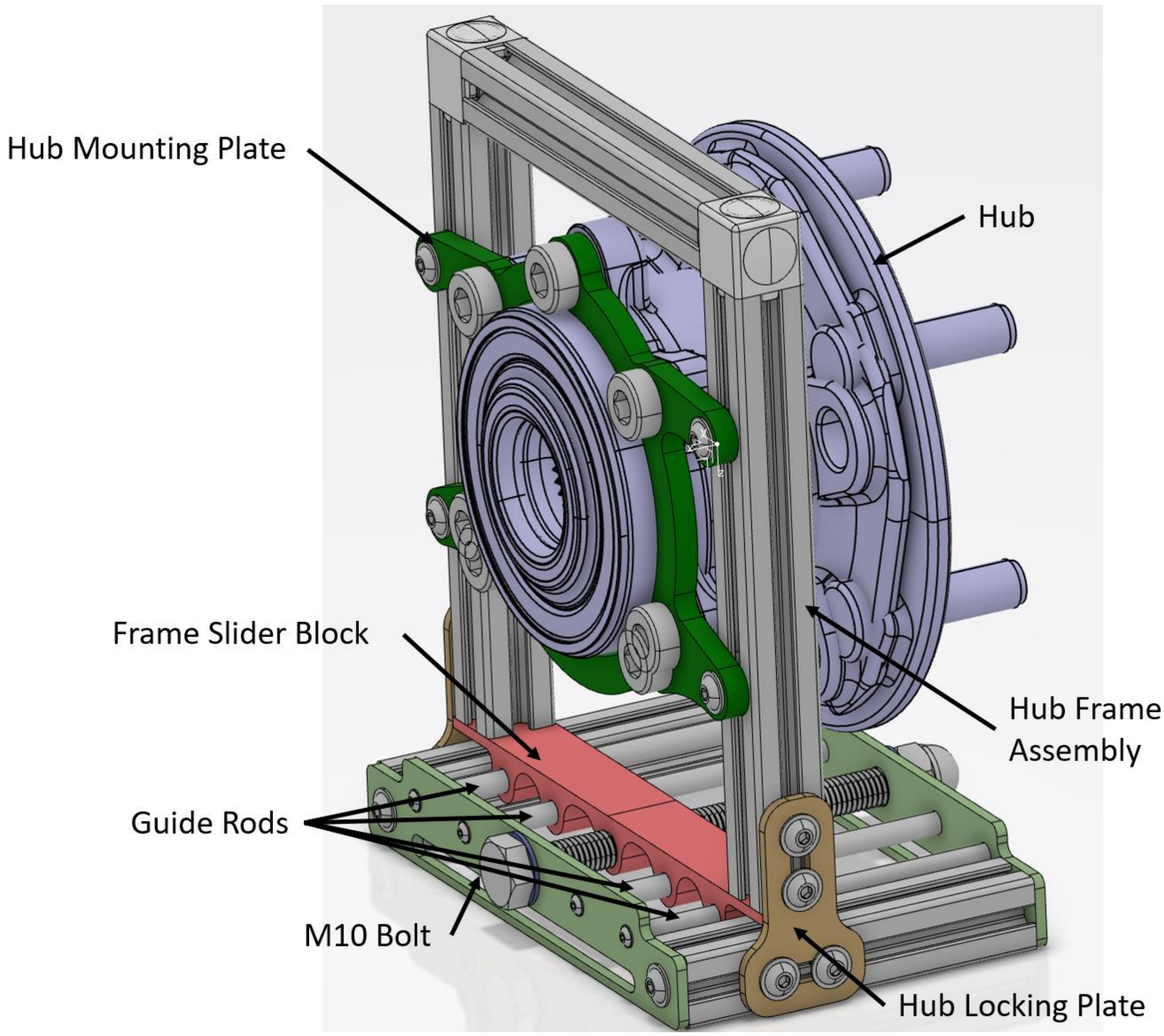


Figure 5.5.1: Labeled diagram of the Hub Mounting Assembly which is responsible for translating the hub along the X-axis. Extra clearance is provided in the negative X-direction to provide space for tools used for tightening or loosening the bolts that mount the Hub to the mounting plate. Please don't move this assembly in the CAD, the fasteners are in their own assembly and won't move with everything else properly.

5.6. Locking Features

Except for the first linear degree of freedom, it is possible to lock the position of the sensor by tightening different bolts. In the case of the angular degrees of freedom, this is achieved by tightening the bolts that mount the components together and in the case of the two other linear degree of freedom this is accomplished by tightening the bolts on clamping plates to lock features together. Due to the complexity of adding a dedicated vertical DOF locking feature, it was left out.

Should a locking feature be desired in the future along the vertical translation degree of freedom, the recommendation is to drill and tap a small hole in the Tilt Assembly Mounting block below where the bronze self-lubricating bushings sit and to use a set screw to dig into the steel guide rod. Another solution could be to replace the cap nut with a regular hex nut. This would require during operation that the bolt and nut be tightened relative to each other to lock the components and carefully loosened to allow both the nut and bolt to rotate together when one is turned, without disengaging the nut entirely.

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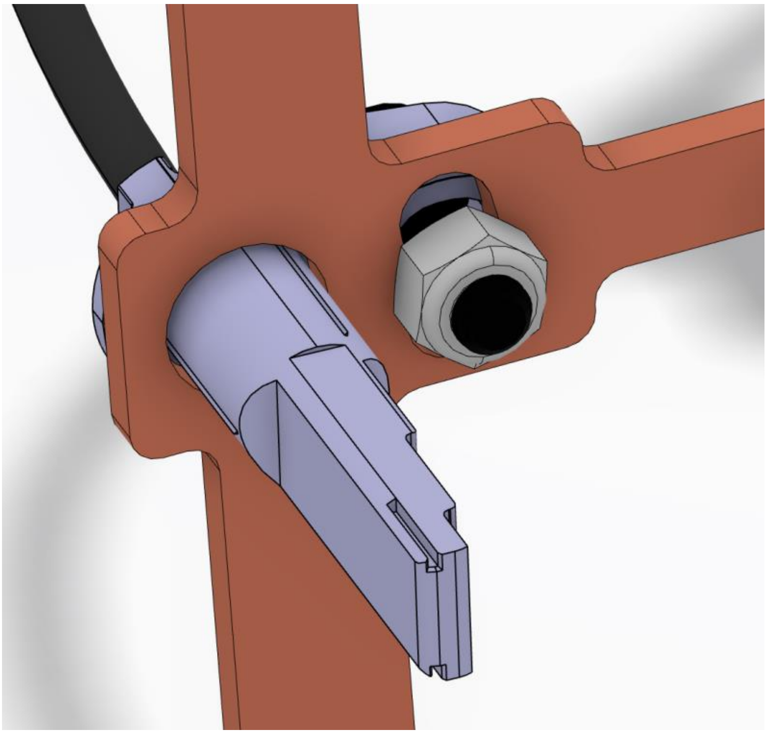

Figure 5.6.1: Tightening the M5 bolt that is responsible for fastening the wheel speed sensor also acts as a locking feature to prevent unnecessary rotation or slippage during operation of the test bench.

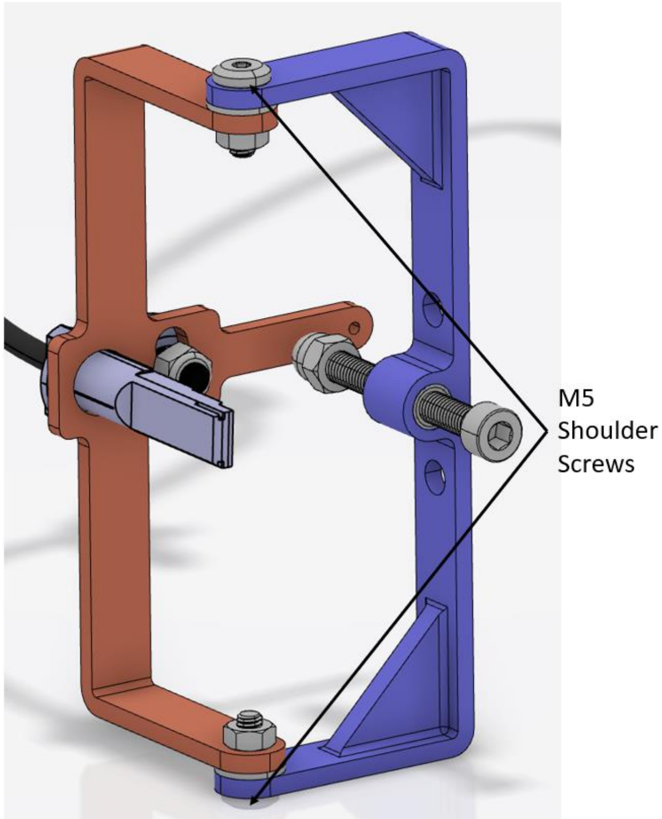

Figure 5.6.2: Tightening the M5 shoulder screws linking the sensor mounting bracket and knuckle together will clamp the two parts together to prevent rotation about the Z-axis.

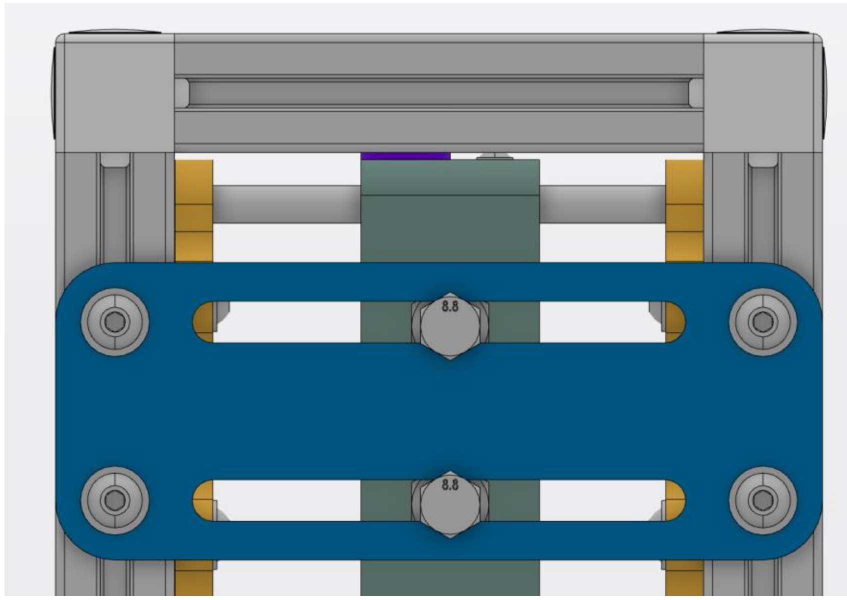

Figure 5.6.3: Tightening the M6 Hex head bolts on the back of the clamping plate will lock the translation of the sensor along the Y-axis. Do not use the hex head bolts that reside on the "Top Block" component as these should always remain tightened.

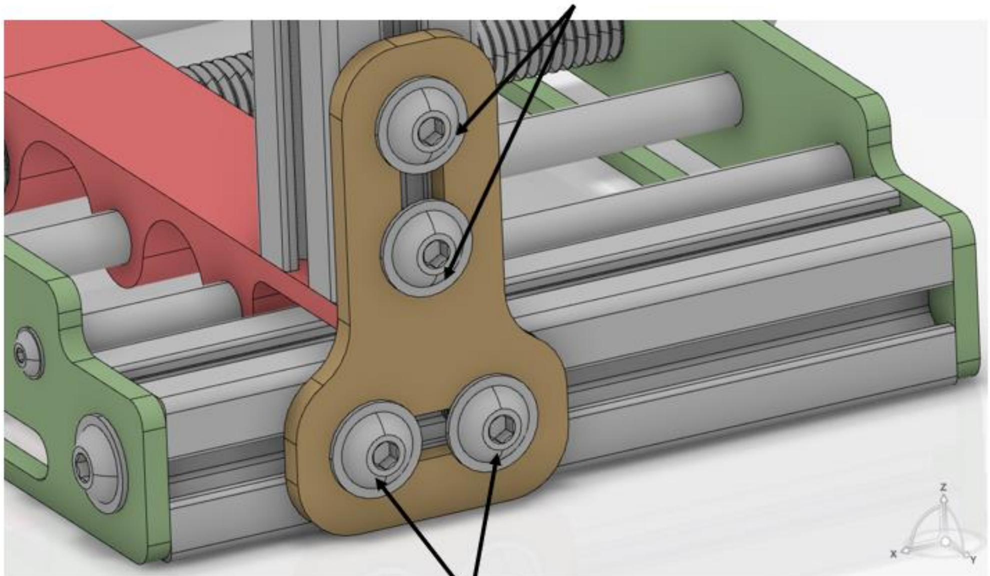

Figure 5.6.4: Hub Locking Plate for restricting travel along the X-axis. The pair of horizontal bolts are used to clamp the Hub Frame Assembly in place, while the two vertical bolts are used to fasten the plate to the frame.

5.7. Tools Required for Operation and Adjustment

1. 13mm Socket Head and Ratchet for Plane Slider Assembly
2. 17mm Socket Head and Ratchet for Hub Mount Assembly
3. 10mm Wrench for Plane Slider locking bolts
4. 3mm Hex Allen Wrench for M5 flanged button head bolts
5.

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6. Troubleshooting

This section aims to predict and provide advice for problems that may arise during the fabrication, assembly, or operation of the Wheel Speed Sensor Test Bench. As every single problem that may arise cannot feasibly be covered, this section can no means be considered an exhaustive list. The issues below aren't listed in any specific order pertaining to when you might encounter them so be sure to skim the problem statements, in bold, beforehand.

6.1. Sensor and Tilt Assembly

The sensor doesn't fit or mount correctly to the mounting bracket.
If the main sensor body is unable to pass through the hole in the sensor mount, then it may be carefully drilled out larger by hand. If the bolt does not align with the curved slot, ensure it is compatible with the mount. The sensor that this mount was designed off of (Bosch DF30I used on the Model S Front) was capable of accepting a bolt that mounted anywhere between 13.5 and 14.5 mm away from the main sensor body axis. The mount was designed with an arc that is centered around a bolt mounting location that is 13.5 mm away from the main sensor axis. If your sensor requires a further mounting point, a new bracket will have to be designed.

The sensor is slipping against its mounting bracket.
This should be a relatively simple problem as the most obvious solution would be to further tighten the M5 bolt and nut that are responsible for securing it to the bracket. If you find yourself having to frequently tighten the bolt and nut combination to prevent it from slipping, try wiping away any dust, grim or build-up that could be causing the coefficient of friction between the two materials to decrease. It would also be recommended to replace the Nylock nut every so often, as the Nylock effectiveness decreases significantly after the first loosening of the joint.

The spring isn't retracting the mount to the knuckle when I loosen the 45mm M5 bolt.
This issue was identified early in the design process as a potential problem, but due to its nature and the timeframe of the project, it could not be designed around perfectly. Try loosening the nuts that secure the M5 shoulder bolts that secure the knuckle and mount together. If this does not resolve the issue, it may be due to excessive misalignment between the top and bottom rotation points – which would require more precise refabrication of one or both components or a redesign of the components to accept looser tolerances (sorry). The final option which may be taken is that a stiffer spring be used to retract the components, however, the issue with this is that over time a very stiff spring may cause warping in the small sliver of aluminum that extends from the main mounting surface.

The sensor and mount are sagging relative to the knuckle.
This problem could manifest due to the material choice for the part (3D printing resin) or due to the length of the arms on the knuckle. If you wish to keep the same arm length on the knuckle (which would be desired for clearance reasons) then the ribs may be enlarged, or a fillet be added, so long as they don't interfere with the M5 bolt head flanges. If clearances are not a concern or the working intent for the test bench has changed, the arms may be shorted to reduce the stress inside of them that is leading to the observed creep. The final, but most complex solution would be to remove the ribs entirely and machine the part out of 6061 or harder aluminum. Due to the thickness of the arms (3mm) this would be an extremely complicated machining request and most likely is not feasible. Should a material change (that can't be 3D printed) be needed, a redesign of the knuckle may be required.

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The Heat-Set Insert doesn't fit quite right in the Knuckle.

If you've read through the entirety of this guide, you would know that the knuckle is 3D printed. As 3D printed parts are not known for their extremely tight tolerances, it could be possible that during the washing or curing process the hole dimension may have deviated from that which it was originally designed to. Ensure that the maximum diameter of the hole does not exceed the maximum allowable diameter by the M5 heat set insert. If the diameter is too large, the hole should be shrunk in CAD and reprinted, if the diameter is too small, it may be possible to carefully drill out the hole, but a note of this should be made in a revision of the part drawing with a post-printing step that involves drilling out a hole of the required size.

The heat-set insert seems to be off axis.

Due to the nature of how the cam-like rotation system works, some small misalignment may be allowed without any noticeable impact on the performance. However, cases of extreme misalignment may cause interferences between the cap nut and other components, earlier in the range of motion of the part or the cap nut completely missing the arm in other cases of misalignment. In these cases, a new knuckle will have to be printed and the heat-set insert more careful set.

The holes in the knuckle to mount to the Tilt Assembly Mounting Block don't seem to line up with the holes in the Tilt Assembly Mounting Block.

The holes in the knuckle may be drilled larger to accommodate misalignment and tolerances.

The sensor seems to be rotated about the X-axis and does not rest completely vertical once assembled in the nominal position.

This could be due to various manufacturing tolerances and so is difficult to pinpoint. As there are no mechanisms to rotate the sensor about its tip around the X-axis the only solution would seem to be identify the components causing the misalignment and refabricated them with tighter tolerances. As no rotation about the X-axis was desired in the original project definition, it was inferred that rotation about this axis would not be important.

The sensor is interfering with the knuckle under rotation about the Z or Y axes.

Due to how the sensor mounts are designed to rotate about the tip of the sensor and not the head, this interference may be unavoidable depending on how the sensor has been placed linearly along the X, Y, or Z axes. For example, an extremely small air gap between the hub and sensor would not permit rotation of the sensor about any axis without causing undesired interference. Attempts have been made in the design of the WSS Mount to reduce the possible instances in which the mount contacts the hub or its mounting system during operation.

The flanges on the M5 bolts to mount to the Tilt Assembly Mounting Block interferes with the geometry of the knuckle.

This could be due to the fillets on the heat-set insert hole being unnecessarily large. The first attempt should be to acquire bolts with a smaller head diameter than 11.6mm. If this does not seem possible, then investigate the possibility of enlarging the holes to allow the bolts to sit farther apart, granted that they still thread into the Tilt Assembly Mounting Block properly. Another attempt to remedy the issue would be to Dremel away material until the flanges appear to sit flush. If this isn't the case, then the very expensive and time-consuming task of refabricating one or more components may be considered. Though extremely unlikely that this course of action would be taken in any scenario, the final option would be to turn down the head diameter on a lathe.

I can't seem to fasten the mount and knuckle together properly.
This could be due to misalignment in the placement of the holes for the M5 shoulder screws. If possible, it may be considered to carefully drill out the holes in the knuckle to allow for more misalignment. Another option would be to flip the flanged bushings and push them into enlarged holes in the knuckle and see if the larger hole in the mount allows for the necessary misalignment. If none of the above options work, refabrication of one or more components may be required.

The cap nut doesn't seem centered on the mount's arm vertically.
This could be due to imperfect fabrication of either the knuckle or the mount, or due to the threaded insert not being set properly into the knuckle. As long as the cap nut remains in contact with the arm throughout the desired range of motion – as a downward tilt would result in no contact if the bolt was tightened enough, and vice versa – then this shouldn't be considered a serious issue. However, if at any point through the arms range of motion the nut no longer contacts the mount then a new knuckle will have to be printed and the threaded insert carefully assembled.

It's impossible or very difficult to turn the 45mm M5 bolt.
Verify that that the correct bolt is being used. The test bench has been designed to minimize the number of unique threads present: 4-40 threads are reserved for fastening the guide rail standoffs, M8 and M10 are reserved for linear translation and adjustment components, the few M6 components are used as locking features for the plane slide assemble, and M5 are used everywhere else. If the correct bolt is being used, verify that the insert has not been stripped or cross threaded. If one of these conditions are the case, then refabrication of the knuckle is required.

6.2. Linear Slider Assemblies

The 4-40 threaded steel round standoff doesn't fit in the bushing(s).
It was observed when the parts were received that the steel standoffs/guide rods sometimes had burrs on the end that prevented them from smoothly being inserted into the bushings. If this is the case then you may either use brute force and a hammer to push it in – though this is not recommended as the burrs can scar the inside of the standoff. The more civilized option would be to use a file or sandpaper to carefully remove the burrs.

The 4-40 threaded steel round standoff(s) don't slide smoothly in the bushing.
As both components are purchased, this could be due to a tolerancing issue on the manufacturing side. The quickest solution would be to turn down the steel rods on a lathe until they reach the desired amount of play. Another factor to check would be that the counterbored hole in the aluminum sliding components that house the bushings are within tolerance. If the counterbore bushing housings are too small, they may excessively crush the bushings, causing their ID to reduce past the nominal amount.

The 4-40 threaded steel round standoff(s) don't seem to fit in between the components they're supposed to.
This could be caused by incorrect machining tolerances various components or slightly out of tolerance lengths on the threaded standoffs themselves. The recommended course of action would be to slightly turn down the standoffs in order to make them fit snugly inside their respective plates or blocks. However, care must be taken with the bolts that are used for fastening the standoffs to their respective components as shortening the standoffs too much could result in insufficient thread length and the bolt bottoming out before being able to completely tighten.

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The bushings seem to be off axis with each other and/or other components.
This issue could be potentially caused by two different problems. One is that the counterbored bushing housing hole itself is off axis. This problem would necessitate the re-machining of the incorrect component. The second issue is that the bushing may have been pressed in at an angle. For some components it may or may not be possible to press out the bushings and reseat it properly. If this is not possible then a new bushing will have to be correctly set into a new component.

The Plane Slider Assembly or Hub Mount Assemblies seem to be misaligned or sitting at an angle.
This could be due to manufacturing or assembly tolerances that are excessively loose or are incorrect. If the “Block” components (i.e. Frame Slider Block, Top Block, Side Block, etc.) have incorrect tolerances, then they may need to be fabricated more carefully the next time. This issue could be caused by misaligned bushings, in which case see the above problem and suggested course of action.

I’m having to thread the bolt spacers on rather than slide them on.
STOP! Do not continue. Do not pass Start, do not collect your $200. Monopoly references aside, the act of threading the 3D printed spacers will cause the plastic to deposit onto the surface of the bolt. Pair this with the aluminum threads that all of the dynamic blocks are composed of, and it could very quickly lead to a problem that destroys the aluminum threads. If this is the case, redesign the spacers with a larger tolerance (be sure to save it as a new revision to keep track of the changes) and reprint the spacers in 25U. If tolerancing continues to be an issue, contact Romson Abbat, who oversees and knows quite a bit about the FormLabs printers in 25U or consider manufacturing them in the shop down stairs in 26B.

I’m finding it very difficult if not impossible to turn the slider bolts by hand to adjust the position of the sensor and/or hub.
As the threads are relatively large and the tolerances tight, this could be caused by naturally occurring friction between the steel bolt threads and aluminum block threads so a tool may be required for regular operation. Another issue which could cause excessive friction is that the spacers are too tall for the bolt stack and completely tightening the cap nut causes the entire assembly to clamp together. Either use a tool for regular operation, redesign and reprint (or remove entirely) the spacers, or carefully loosen the cap nut to prevent the clamping from occurring. When using a tool, take extra care to not strip or cross-thread the aluminum threads in the blocks. Should the threads be stripped or cross-threaded new components will have to be fabricated.

It’s easier to turn the bolt when the block is in certain positions along its range of motion.
This could be caused by angular misalignment between components that worsens or gets better with certain positions along the Blocks’ range of motion. Proper assembly and seating of components should be checked first. Refabrication of components may be required if assembly does not turn out to be the source of the problem. The straightness of the guide rods and bolts should also be checked to make sure that no warping has occurred. Warping may cause localized angular misalignment that may not be due to manufacturing or assembly tolerances.

Turning the bolt in one direction is extremely easy but becomes extremely difficult in the other direction after a little bit.
Make sure that the nut is rotating with the bolt when it is being turned in either direction. It may be the case that turning the bolt in one direction easily is due to it loosening from the cap nut and becoming difficult in the other direction is due to the bolt bottoming out in the cap nut. As per usual, check misalignment during assembly and manufacturing tolerances to make sure that those issues do not play

a role. In certain scenarios it may be advisable to completely remove the thin frame bolt spacers and allow the vertical play that would not be there otherwise.

Without the bolt, there seems to be binding between the bushings and the guide rods.
As per usual, the reported binding could be caused be various factors such as misalignment, poor manufacturing tolerances, and warping of the parts. It will be up to the engineer in change to determine the source of this problem and rectify the issue. A possible mitigation method for misalignment could include drilling bigger holes in components that will not be adversely affected, similarly, components may be post-machined or re-machined in order to improve the dimensional tolerances placed upon the part. Warping of the guide rods and other parts is difficult to combat and would most likely require a repurchase of the component. The engineer may also consider cleaning the guide rods and applying a thin film of lubricant to ease sliding motion. If lubricant is applied, make sure it is compatible with the Oil-Embedded Bronze Sleeve bearings that are in use.

The M10 bolt seems to be supporting the weight of the Hub Frame Assembly.
The Frame Plates were designed to allow significant misalignment of the M10 bolt stack so that it did not support the weight of the assembly. If this is the case, then the holes in the frame plate should be drilled out larger to allow the bolt to float relative to the rest of the plate. Allowing the bolt to carry the weight of the Hub Frame Assembly would result in significant friction between the threads, making it nearly impossible to adjust the X-position of the assembly.

I'm twisting the bolt but it's not moving the assembly.
You may have stripped the aluminum threads; this requires a complete refabrication of the component. If you find that this frequently occurs, it may be a consideration to manufacture the Block components out of steel to prevent this issue. It would also be important to check that no unexpected loading on the threads is occurring from misalignment or manufacturing tolerances.

What tool should I use to translate the Top Block along the Y-axis?
A 13mm socket wrench must be used. I've tried a couple different socket wrenches from the tool chest in 24M and they all fit and spun without interfering with the T-slot rails.

What tool should I use for the Vertical Slider Assembly?
It may be possible to use a regular ratcheting wrench, however the recommendation is to use a socket or extra-long socket wrench like with the Top Block above.

6.3. Locking Features

The Hub Locking Plate doesn't align with one or more components.
If the side of the Hub Frame Assembly and the rails for the base of the Hub Mount Assembly don't lie within a plane (most likely due to manufacturing tolerances), then it is possible the Hub Locking Plate may have to bend in order to completely clamp the components. In order to mitigate this issue, it is recommended to fabricate thin shims that bridge the gap between the Hub Locking Plate and the component that is offset. If only one plate is the offender, the locking feature can still be used with only one plate.

Loosening the M6 Hex Bolts doesn't release the Plane Slider Assembly to move along the Y-axis.
It may be that the Hex Standoffs are too tall and are pushing against the clamp plate in their loosened position. This extra clamp force may act as an undesired locking mechanism. The recommendation in this scenario is to further turn down the hex standoffs. Additionally, the clamp plate may be loosened so it is free to float slightly along the X-axis, this should reduce the friction between the components enough for the Top Block to slide.

The Clamp Plate is flexing when I tighten the bolts.
I'm not too sure how you generate enough torque by hand to generate enough force to flex the plate, but this shouldn't be a concern. The aluminum will spring back as there's not enough room for deflection within tolerances to cause permanent deformation. Creep shouldn't be an issue on any realistic timescale.
The M6 bolt is having trouble threading into the standoffs.
As the standoffs are turned down, the bolt may be having trouble getting started as the process of turning down the length of the standoffs has caused the threads to start strangely on that side. I'm unsure of what the proper course of action would be, but it may be possible to drill out the threads and tap it with a larger size, conversely, it may be advisable to replace the hex standoffs with threaded round standoffs that we fabricated in the shop in DC itself.

The M5 nuts securing the knuckle and sensor mount together bottom out before it gets tight.
This was identified as a possible issue due to the fact that shoulder bolts are being used. A possible fix is that a small but high friction spacer be used between the nut and mount to increase the stack height. This would allow tightening of the nut to compress the spacer against the mount and clamp the components in that way. Another possible solution would be to get rid of the shoulder bolts entirely and rely on regular fully threaded bolts.

The T-slot framing nuts for the Hub locking plate are interfering with each other.
Flip one of them the other way.

The Nylock nut fastening the sensor doesn't stay tight and causes the sensor to slip.
The Nylock nut may have outlived its life and should most likely be replaced. A regular hex nut may be substituted if frequent adjustment is required. In hindsight, it most likely should have been a regular nut as adjustment of the nut to set the sensor orientation is part of the test bench's responsibility.

6.4. General Issues

The base plate does not lie flat on the table.
This could be due to counterbores that are too shallow, I realized while the base plate was being fabricated that in certain tolerancing conditions allowed by the drawing, the button head bolts could stick out from under the plate, causing it to sit at an angle with respect to the surface it is resting on. The offending holes should be manually deepened.

The T-slot rails (intentionally vague) are sitting skewed.
This could be due to a mismatch in length between them. The rails should be taken to the shop downstairs in Deer Creek and shortened to the same length.

7. Future Improvements

Without the restrictions of cost, mass, or complexity, the imagination can run wild on what the next version of the test bench could be. The items listed below are merely suggestions should a second revision be needed or features that were originally requested before the scope of the project narrowed.

- **MOTORIZED HUBS:** At the original project briefing Michael Parrot requested that the hub be driven by a motor at designated speeds, either constant or varying. This would be the first change I would make by adding a motor that – through a gear reduction – interfaced with the hub through the lug nuts. I would choose lug nuts for the interface as this would allow both driven and non-driven hubs to be used. The motor choice would have to be researched but Michael Parrot himself could probably assist with the control mechanisms – i.e. motor controller and microprocessor. This would probably require some type of protective polycarbonate cover due to the moving components.
- **DIGITAL READ-OUT:** Late in the design of the test bench it was suggested that DROs (or digital read-outs) be added on each of the linear degrees of freedom so it would be easy to see how much the sensor has moved without having to manually measure it. After some researching on the DROs available on the market, it seems that even the "mini" DROs are much too big and bulky for our application. My recommendation would be to use a rotary Hall-effect encoder embedded into the bolts to measure the rotation. In order to accurately measure the position of the sensor, it would have to go through a zeroing procedure at startup where (either manually or automatically) each linear degree of freedom is put at one end of its range of motion, rotated through to the end, and then this information be transmitted to the mechanism, along with the known thread pitch. Using the number of revolutions between ends and the thread pitch, it should be trivial to calculate the linear distance available for adjustment. This would require careful design to ensure that components don't clash with each other if the process were to take place autonomously. The angular measurements could be handled similarly.
- **FINAL DOF:** Another possible change is to add the 6^{th}, and final, degree of freedom for the tip to rotate about the X-axis around the tip of the sensor. There are multiple methods to accomplish this so I won't be going into detail about what they could be.
- **REPACKAGING:** I would personally rotate the hub so it lies flat in the X-Y plane to reduce the footprint of the test bench. Other changes would include adding the 3 linear DOFs to the laying down hub, while the sensor would be responsible for the, rather delicate, angular DOFs.
- **MOTORIZED DOFS:** A stretch goal (but really cool) would be to have motors on each of the degrees of freedom so they could be computer controlled to reach a certain value. This addition would intrinsically require some form of the digital read out discussed above.
- **AUTOMATED TESTING:** Further extending the digital read out and motorized DOFs concept, a microcontroller could be added to the board to simultaneously control all six DOFs remotely – like the steering dyno. This would enable any team, anywhere to be able to test tolerances between the hub and wheel speed sensor. It may also be able to greatly accelerate the development of our own sensor, but either way, isn't too practical of an ask.
- **REALLY COOL ENCLOSURE**: Imagine if it wasn't made from lame 80/20 rails and used bolts for translation. Imagine all custom linear rails and bearings and ball screws for smooth translation. *Chef's kiss*

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APPENDIX A: CUSTOM PART DRAWINGS

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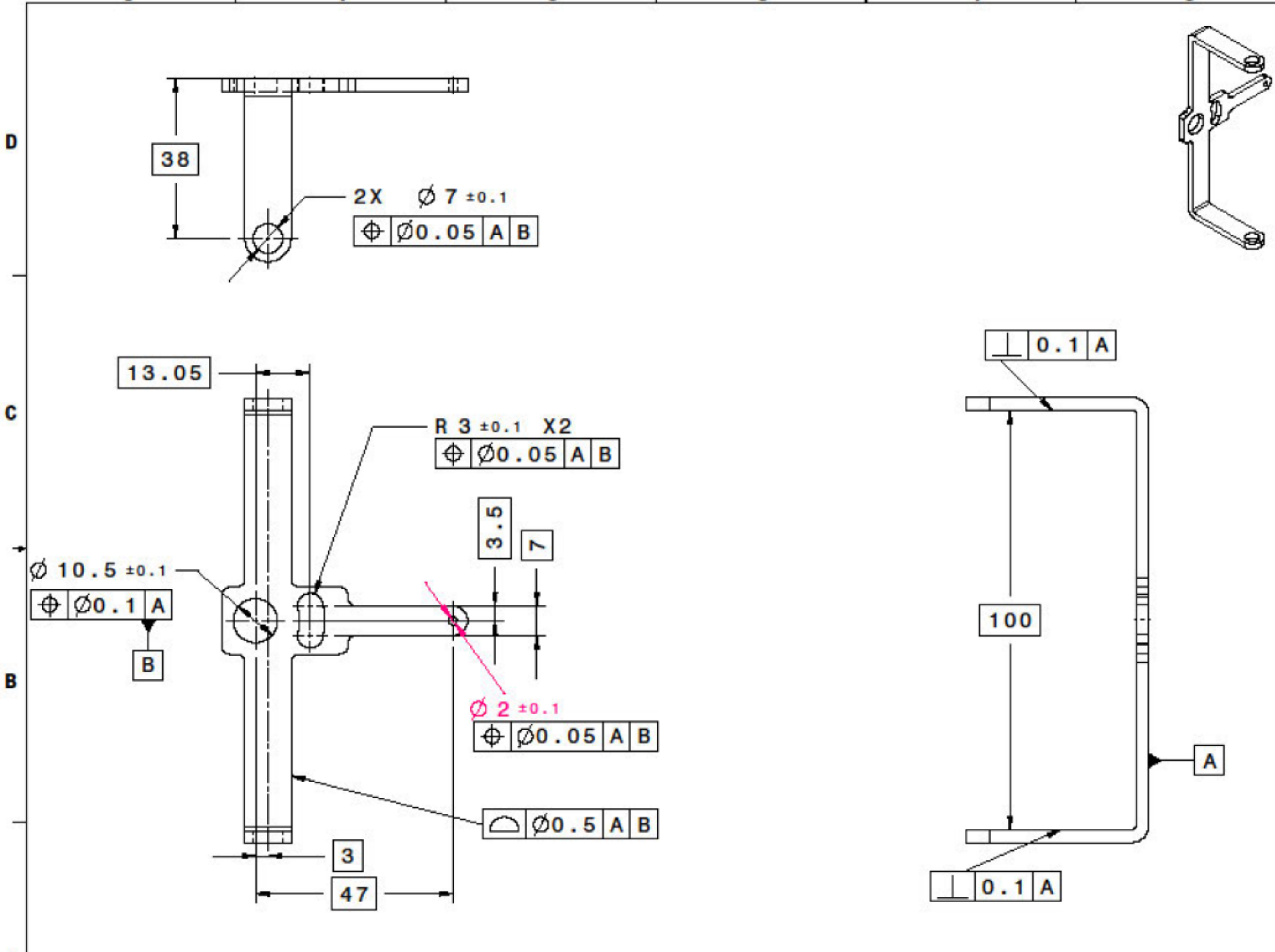
Project: WSS TEST BENCH



DATE	REV	DESCRIPTION	DRN	APPD

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R3. MATERIAL MUST COMPLY WITH FMVSS 302 OR BETTER
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D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
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D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY; ALL TRIM EDGES; ØSIZE ±0.25 CIRCULAR FEATURES; SIZE ±0.25 NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

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CAD FILE NAME: [redacted]	CAD FILE VERSION: 01
DRAWN BY: --	DATE: 01-JAN-21

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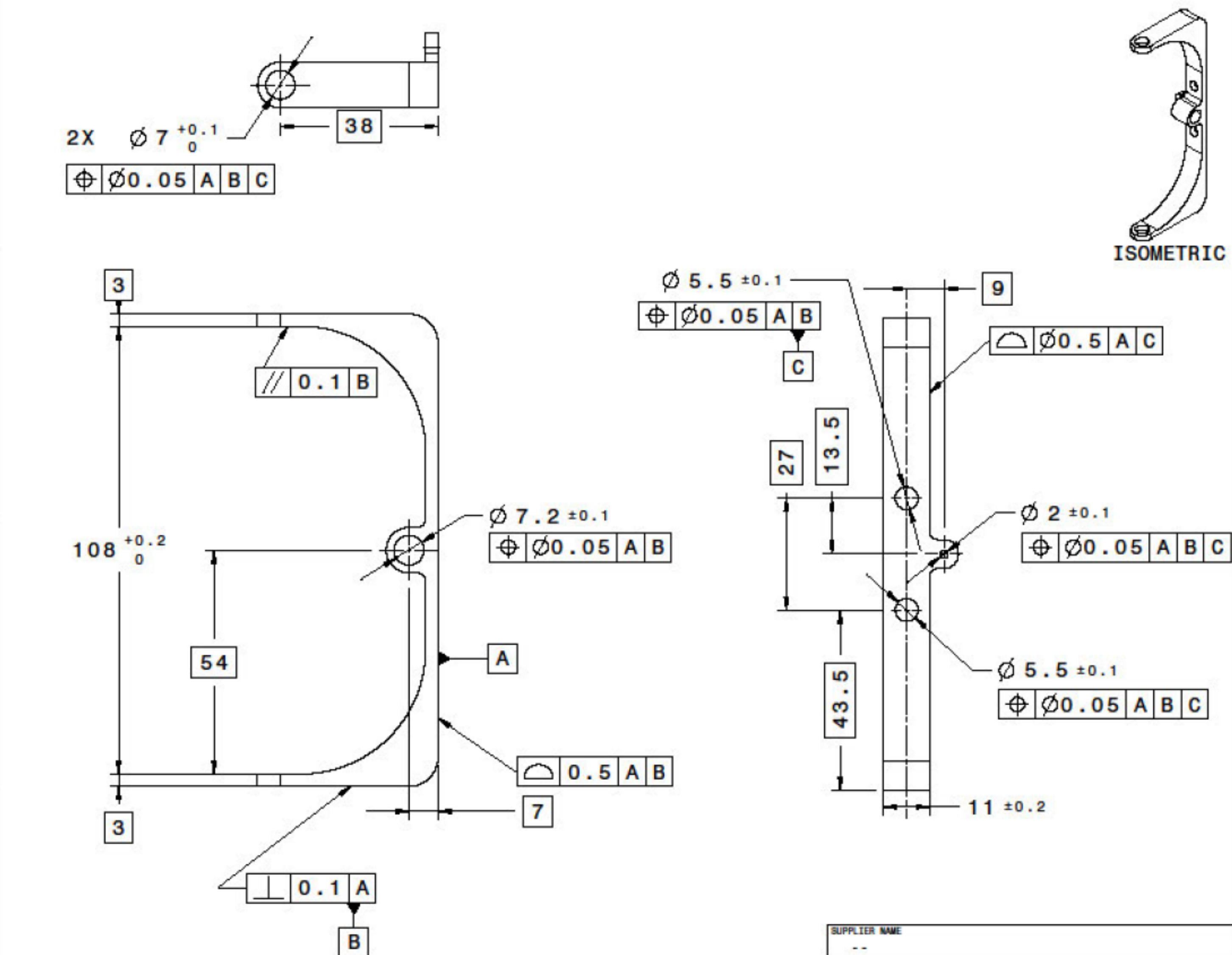
SUPPLIER NAME: --	MATERIAL: ALUMINUM 6061			
SUPPLIER PART NUMBER: --	FINISH: AS MACHINED		EST. MASS (g): MASS	
	THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE: 1:1	SHEET SIZE: B
SYMMETRIC ITEM NAME: --	ITEM NAME: WSS MOUNTING BRACKET			
SYMMETRIC ITEM NUMBER: --	ITEM NUMBER: [redacted]		REVISION: 01	SHEET 1 OF 1

B WSS MOUNTING BRACKET 01 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD
20-JUL-22	A	INITIAL RELEASE	AB	
4-AUG-22	B	INCREASED HOLE SIZE TO 7MM	AB	
10-AUG-22	C	INCREASED THREADED INSERT HOLE SIZE TO 6.4	AB	
11-AUG-22	D	INCREASED THREADED INSERT HOLE SIZE TO 7.2 AND REFINED STRENGTH RIBS	AB	



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D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

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CAD FILE NAME	[redacted]	CAD FILE VERSION	03
DRAWN BY	A. BHATNAGAR	DATE	11-AUG-22

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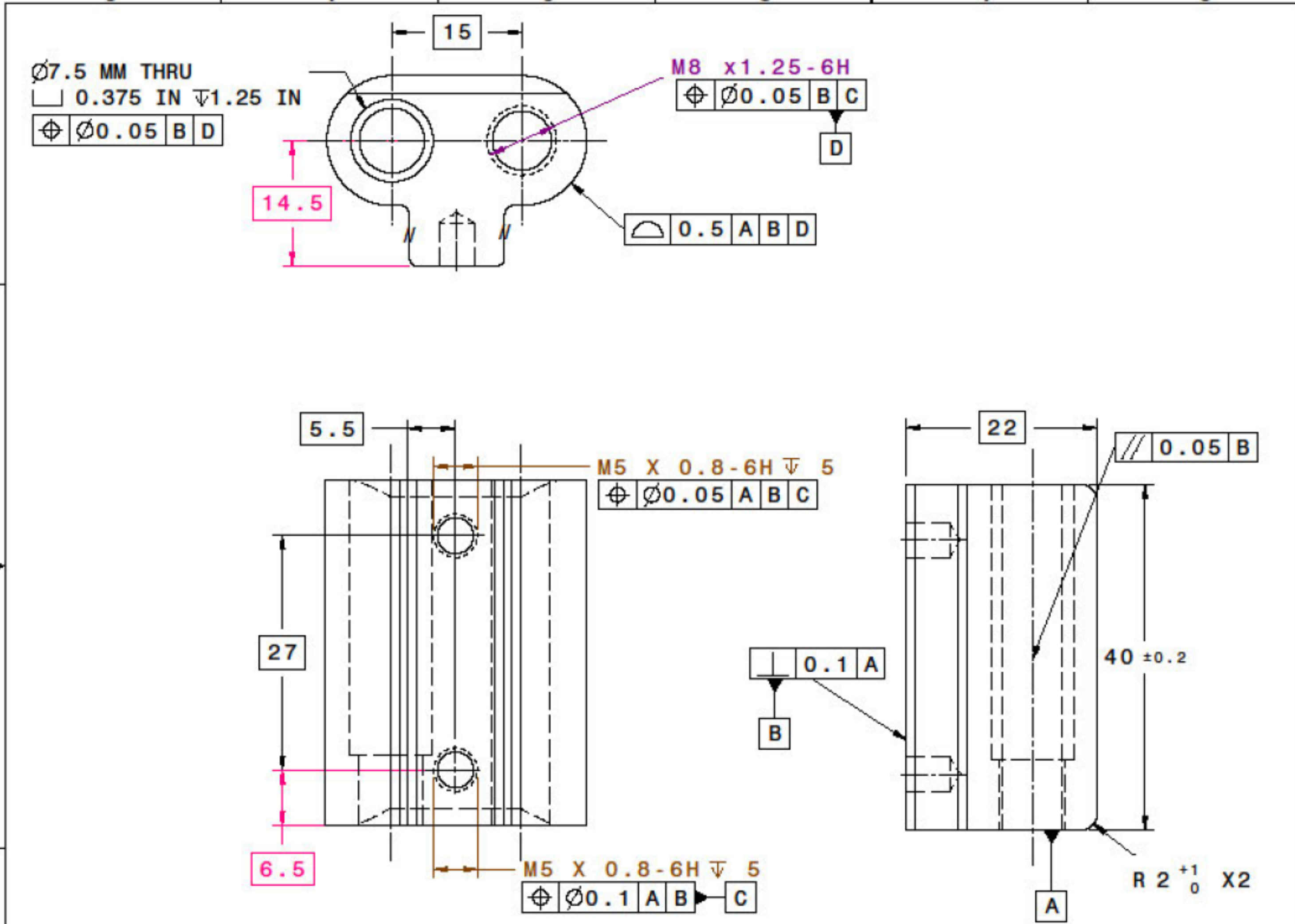
SUPPLIER NAME: --	MATERIAL: ALUMINUM 6061-T6		
SUPPLIER PART NUMBER: --	FINISH: AS MACHINED	EST. MASS (g): MASS	
	THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE: 1:1 / SHEET SIZE: B
SYMMETRIC ITEM NAME: --	ITEM NAME: WSS KNUCKLE		
SYMMETRIC ITEM NUMBER: --	ITEM NUMBER: [redacted]	REVISION: D	SHEET 1 OF 1

B WSS KNUCKLE

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



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CAD FILE NAME [redacted]	CAD FILE VERSION 01
DRAWN BY: A. BHATNAGAR	DATE: 20-JUL-22

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MATERIAL: ALUMINUM 6061-T6

FINISH: AS MACHINED — EST. MASS (g): MASS

SUPPLIER NAME	--
SUPPLIER PART NUMBER	--
SYMMETRIC ITEM NAME	--
SYMMETRIC ITEM NUMBER	--

THIRD ANGLE PROJECTION — DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES. — SCALE 1:1 — SHEET SIZE B

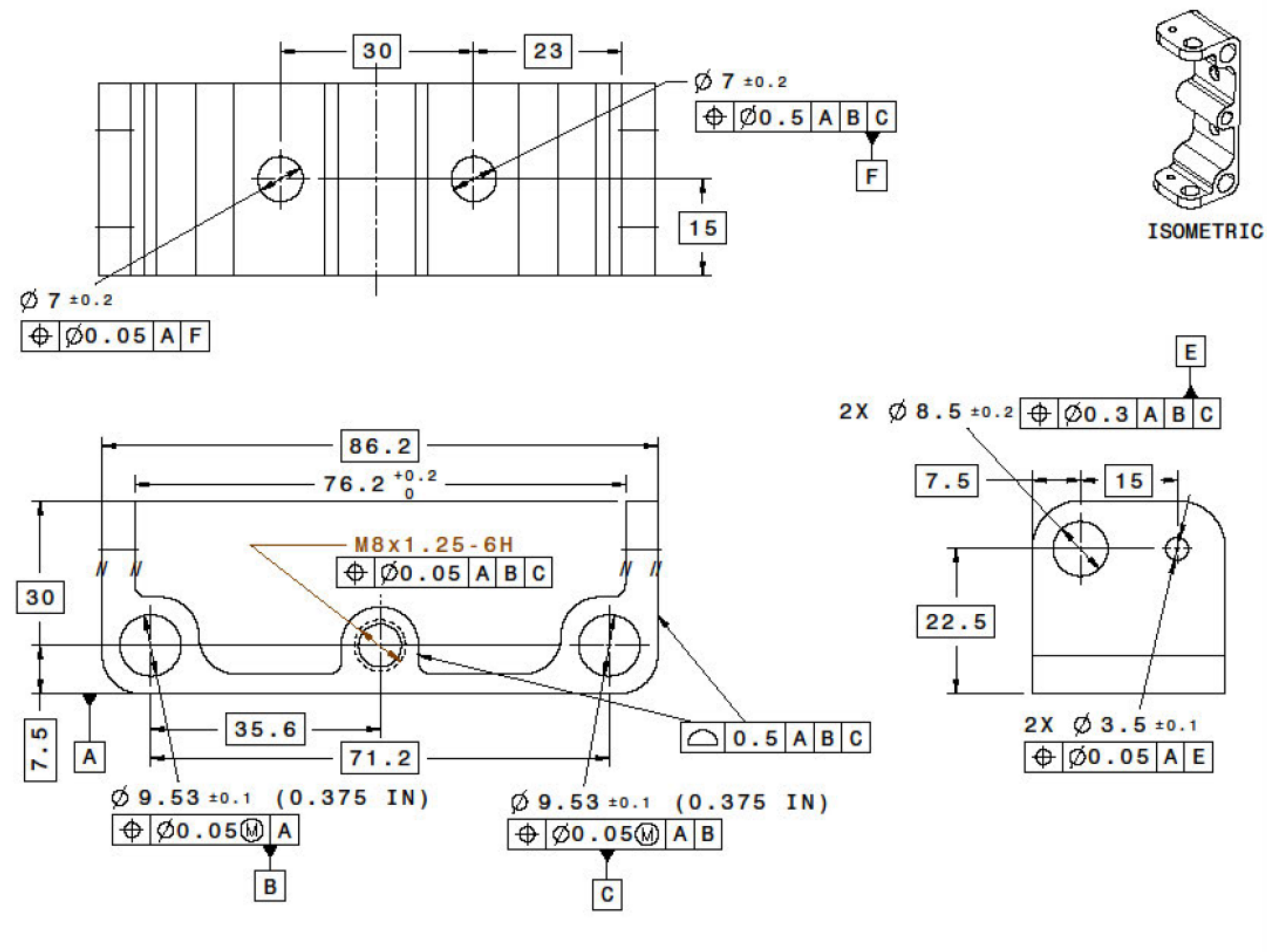
ITEM NAME: TILT ASSEMBLY MOUNTING BLOCK

ITEM NUMBER: [redacted] — REVISION 01 — SHEET 1 OF 1

B TILT ASSEMBLY MOUNTING BLOCK

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



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[redacted]	01

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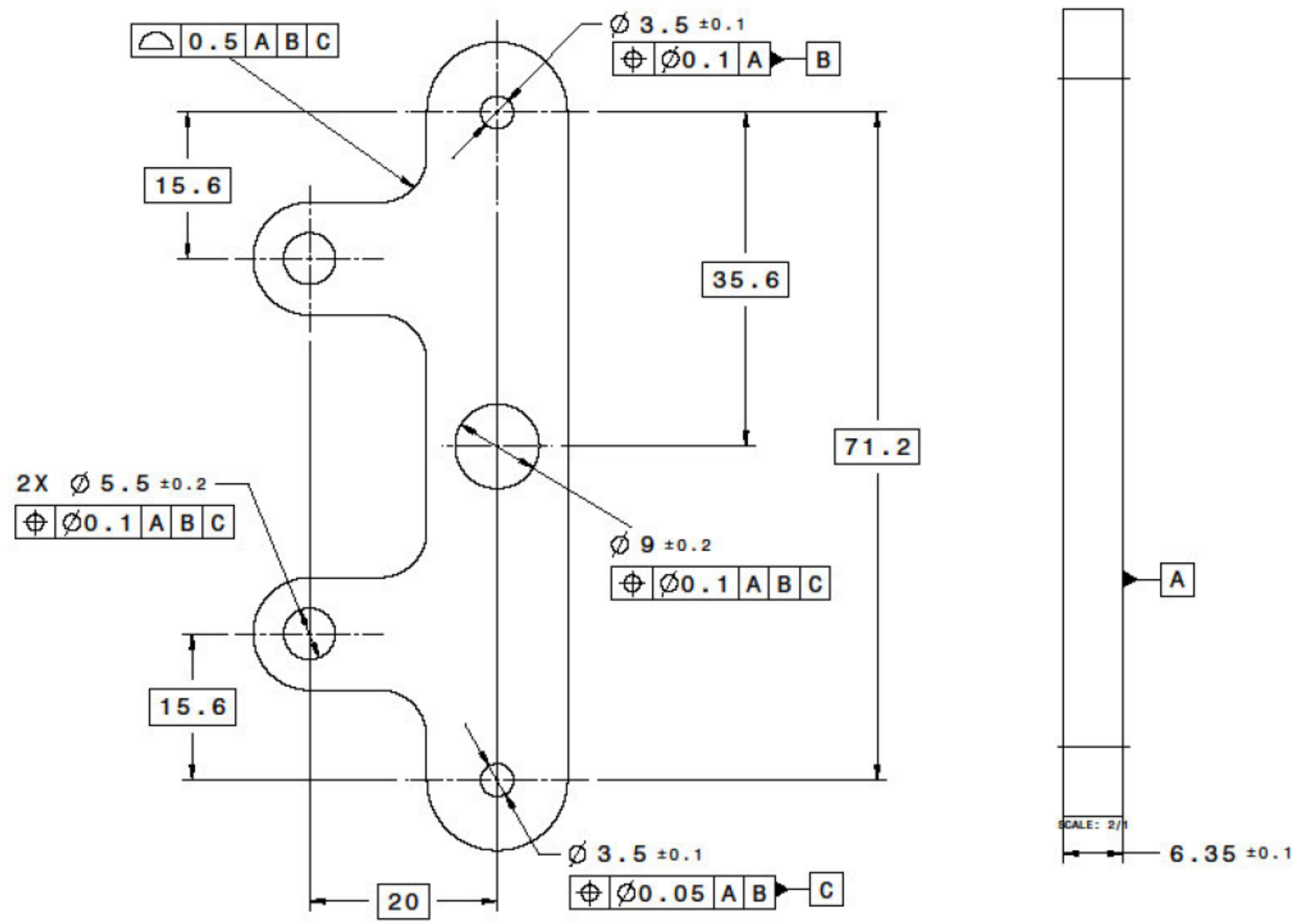
SUPPLIER NAME	--
SUPPLIER PART NUMBER	--
SYMMETRIC ITEM NAME	--
SYMMETRIC ITEM NUMBER	--

MATERIAL	
ALUMINUM 6061-T6	
FINISH: AS MACHINED	EST. MASS (g): MASS
THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
SCALE: 1:1	SHEET SIZE: B
ITEM NAME: WSS TEST BENCH TOP BLOCK	
ITEM NUMBER: [redacted]	REVISION: 01 — SHEET 1 OF 1

B WSS TEST BENCH TOP BLOCK 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



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CAD FILE NAME: [redacted]	CAD FILE VERSION: 01
DRAWN BY: A. BHATNAGAR	DATE: 18-JUL-22

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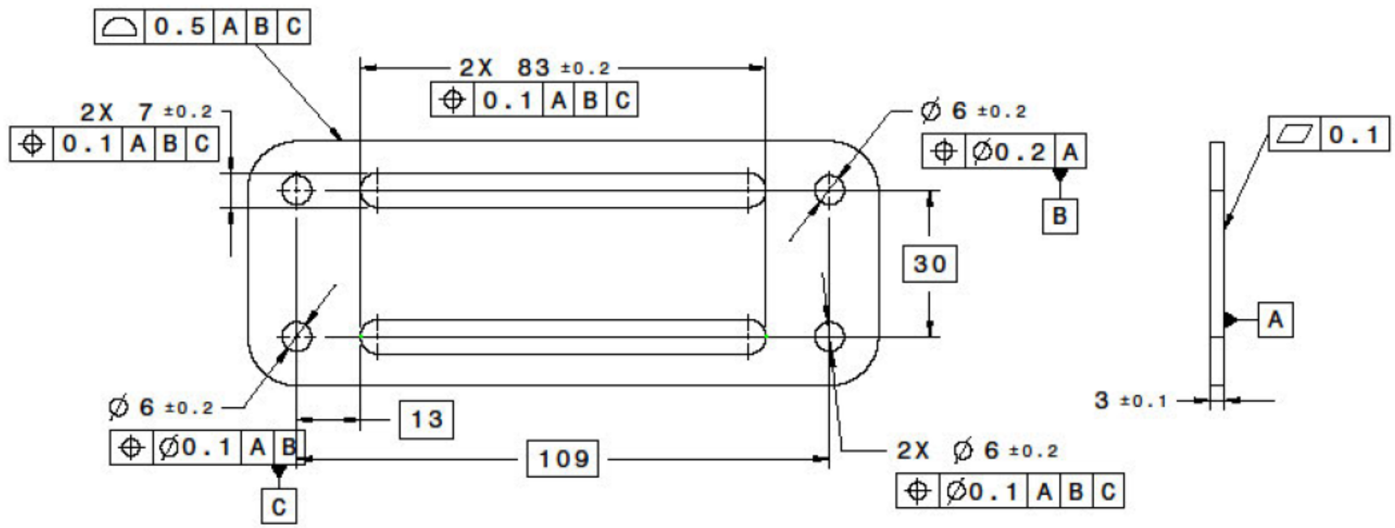
SUPPLIER NAME: --	MATERIAL: ALUMINUM 6061-T6, QUARTER-INCH PLATE		
SUPPLIER PART NUMBER: --	FINISH: AS MACHINED	EST. MASS (g): MASS	
SYMMETRIC ITEM NAME: --	THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE: 2:1 / SHEET SIZE: B
SYMMETRIC ITEM NUMBER: --	ITEM NAME: WSS TEST BENCH SIDE BLOCK		
	ITEM NUMBER: [redacted]	REVISION: 01	SHEET: 1 OF 1

B WSS TEST BENCH SIDE BLOCK | 01 | 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



REGULATORY COMPLIANCES

R1. ALL PART MATERIALS, COATINGS AND PART MARKINGS MUST COMPLY WITH ALL APPLICABLE INTERNATIONAL REGULATIONS, AS DETAILED IN BMS-0000408 - MATERIAL COMPLIANCE REPORTING.
R2. CONTACT TESLA HOMOLOGATION AND ENGINEERING BEFORE UNDERTAKING DESIGN MODIFICATIONS. ANY UNAUTHORIZED CHANGES ARE STRICTLY PROHIBITED.
R3. MATERIAL MUST COMPLY WITH FMVSS 302 OR BETTER
R4. FOR A COMPREHENSIVE LIST OF ALL SUPPLIER QUALITY ASSURANCE REQUIREMENTS, REFERENCE THE SUPPLIER HANDBOOK BMS-0000051.

GENERAL NOTES

G1. THE MASTER SOURCE OF INFORMATION FOR THIS DOCUMENT IS A COMPUTER DATABASE.
G2. 3D CAD DATA SUPPLIED IS TO BE USED TO PRODUCE PRODUCTION TOOLING AND FOR INSPECTION.
G3. PRINTED DOCUMENT IS UNCONTROLLED - DOCUMENT OBSOLETE WHEN PRINTED.
G4. THIS COMPONENT MUST BE PACKAGED IN ACCORDANCE WITH TESLA MOTORS SPECIFICATION BMS-0000005. CONTACT TESLA PACKAGING/LOGISTICS GROUP FOR OTHER PACKAGING REQUIREMENTS.

DIMENSIONAL NOTES

D1. INTERPRET SPECIFICATIONS PER GEOMETRIC DIMENSIONING & TOLERANCING ASME Y14.5-2009
D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
D3. DIMENSIONS APPLY AFTER FINISHING OPERATIONS, UNLESS OTHERWISE SPECIFIED.
D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY — ALL TRIM EDGES — ØSIZE ±0.25 CIRCULAR FEATURES — SIZE ±0.25 NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
M2. WORKMANSHIP STANDARD DOCUMENT BMS-0000026 APPLIES.
M3. NO CHANGES SHALL BE MADE TO RAW MATERIALS, PROCESSING MATERIALS/CHEMICALS, DESIGN, TOOLING, PROCESS, OR PACKAGING WITHOUT THE PRIOR WRITTEN CONSENT OF TESLA MOTORS.

CAD FILE NAME	[redacted]	CAD FILE VERSION	01
DRAWN BY	A. BHATNAGAR	DATE	18-JUL-22

TESLA

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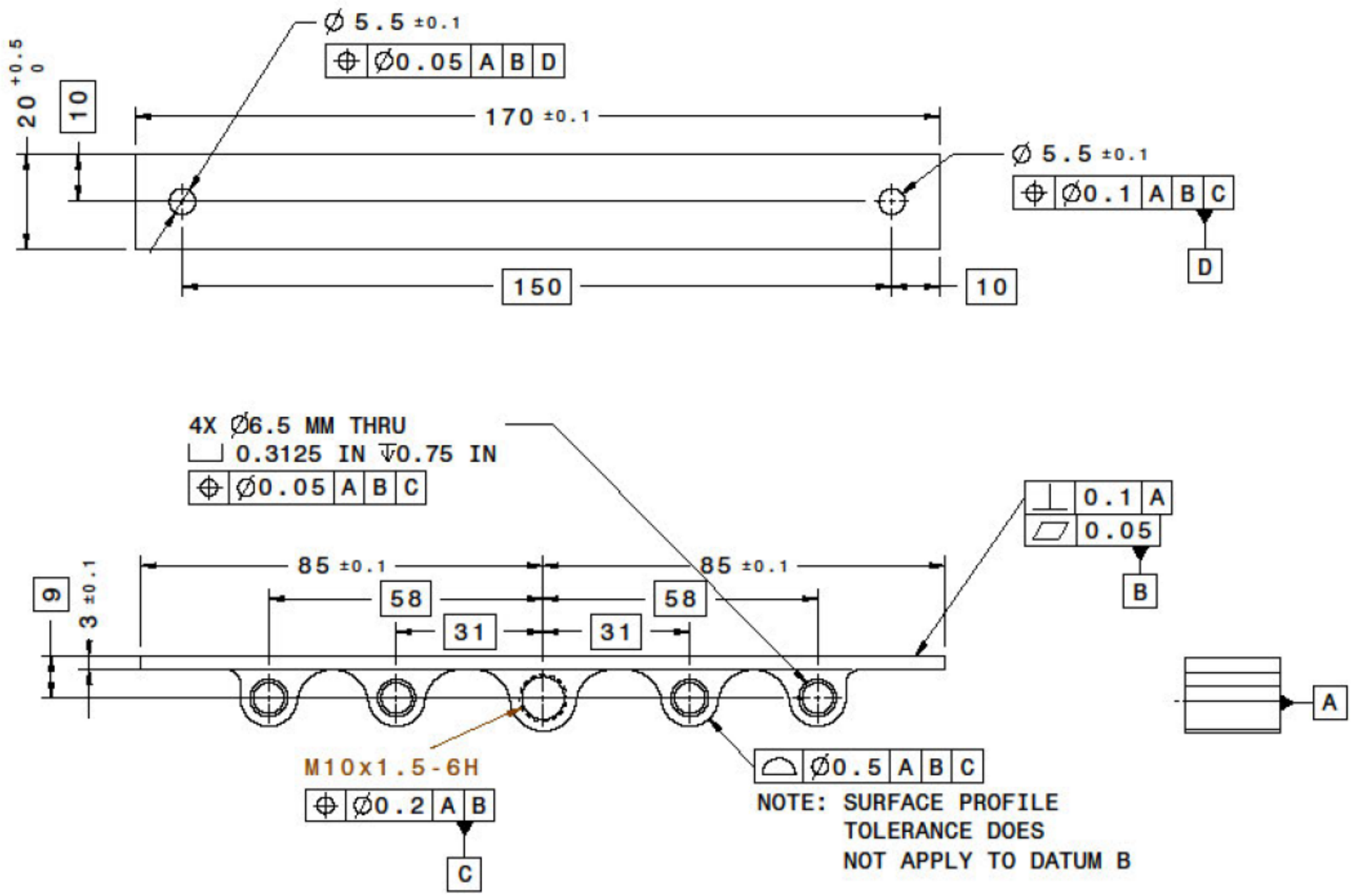
SUPPLIER NAME	--	MATERIAL	ALUMINUM 6061-T6
SUPPLIER PART NUMBER	--	FINISH	AS MACHINED
		EST. MASS (g)	MASS
		THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
		SCALE	1:1
		SHEET SIZE	B
SYMMETRIC ITEM NAME	--	ITEM NAME	WSS TEST BENCH CLAMP PLATE
SYMMETRIC ITEM NUMBER	--	ITEM NUMBER	--
		REVISION	01
		SHEET	1 OF 1

B WSS TEST BENCH CLAMP PLATE 01 01



Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD

REGULATORY COMPLIANCES

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R4. FOR A COMPREHENSIVE LIST OF ALL SUPPLIER QUALITY ASSURANCE REQUIREMENTS, REFERENCE THE SUPPLIER HANDBOOK BMS-0000051.

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DIMENSIONAL NOTES

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D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY — ALL TRIM EDGES — CIRCULAR FEATURES (SIZE ±0.25) — NON-CIRCULAR FEATURES (SIZE ±0.25)
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
M2. WORKMANSHIP STANDARD DOCUMENT BMS-0000026 APPLIES.
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CAD FILE NAME	[redacted]	CAD FILE VERSION	01
DRAWN BY	A. BHATNAGAR	DATE	18-JUL-22

TESLA

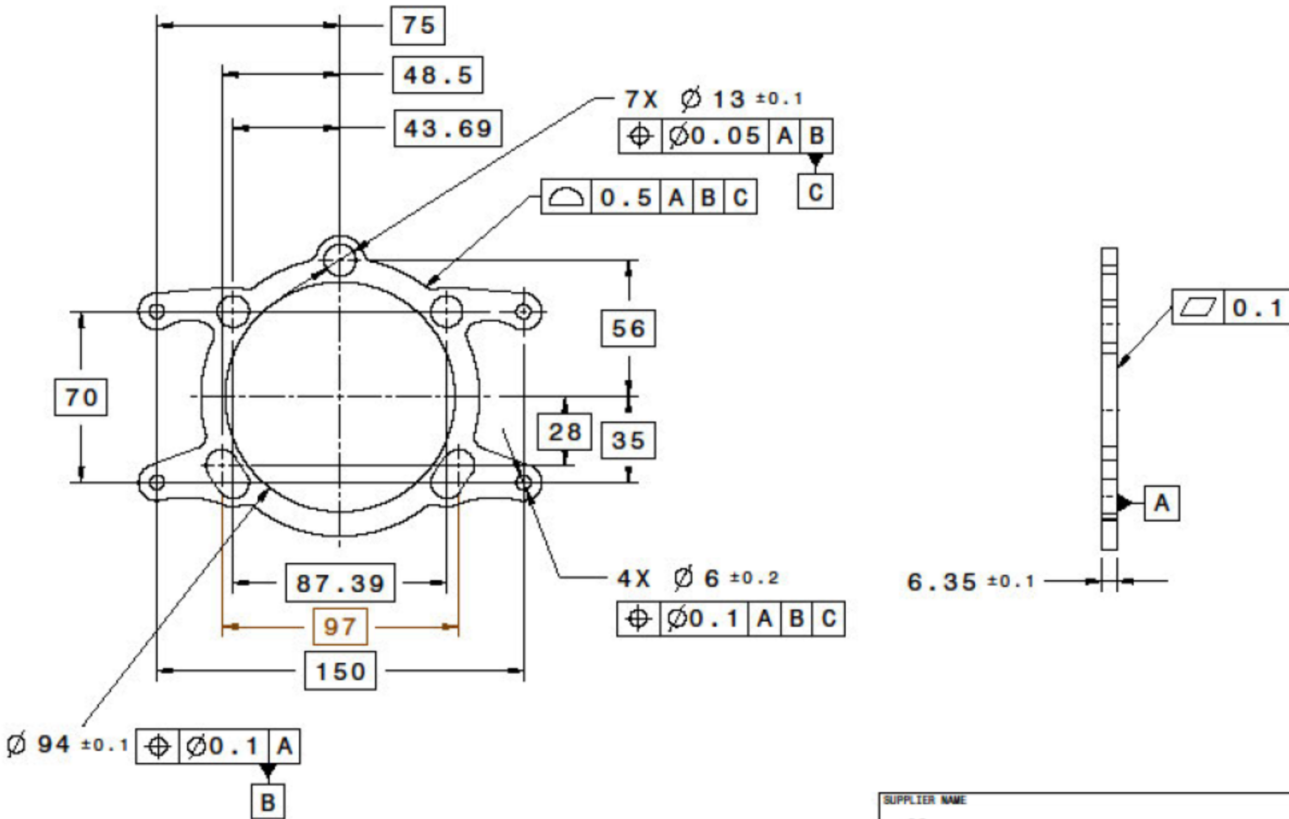
SUPPLIER NAME	--
SUPPLIER PART NUMBER	--
SYMMETRIC ITEM NAME	--
SYMMETRIC ITEM NUMBER	--

MATERIAL	ALUMINUM 6061-T6		
FINISH	AS MACHINED	EST. MASS (g)	MASS
THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE 1:1	SHEET SIZE B
ITEM NAME	WSS TEST BENCH FRAME SLIDER BLOCK		
ITEM NUMBER	[redacted]	REVISION 01	SHEET 1 OF 1

B | WSS TEST BENCH FRAME SLIDER BLOCK | 01 | 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



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DIMENSIONAL NOTES

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D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
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D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY | ALL TRIM EDGES | CIRCULAR FEATURES (ØSIZE ±0.25) | NON-CIRCULAR FEATURES (SIZE ±0.25)
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:
Rz 25, Rz1max 50

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
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CAD FILE NAME: [redacted]
CAD FILE VERSION: 01
DRAWN BY: A. BHATNAGAR
DATE: 18-JUL-22

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MATERIAL: ALUMINUM 6061-T6, QUARTER-INCH PLATE
FINISH: AS MACHINED
EST. MASS (g): MASS

SUPPLIER NAME: --
SUPPLIER PART NUMBER: --
SYMMETRIC ITEM NAME: --
SYMMETRIC ITEM NUMBER: --

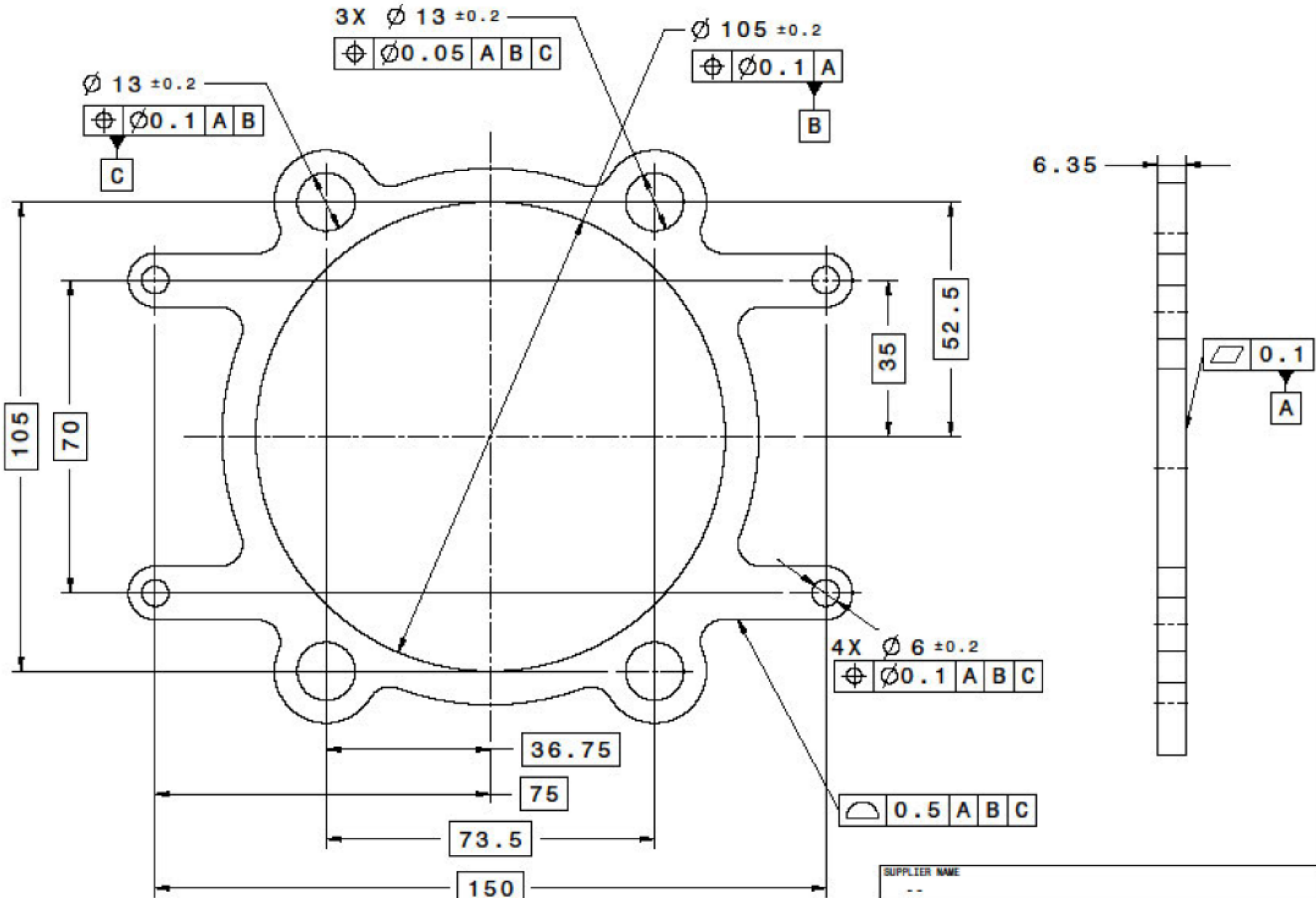
THIRD ANGLE PROJECTION
DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
SCALE: 1:1
SHEET SIZE: B

ITEM NAME: HUB MOUNTING PLATE
ITEM NUMBER: [redacted]
REVISION: 01
SHEET: 1 OF 1

B | HUB MOUNTING PLATE | 01 | 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



REGULATORY COMPLIANCES

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R4. FOR A COMPREHENSIVE LIST OF ALL SUPPLIER QUALITY ASSURANCE REQUIREMENTS, REFERENCE THE SUPPLIER HANDBOOK BMS-0000051.

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DIMENSIONAL NOTES

D1. INTERPRET SPECIFICATIONS PER GEOMETRIC DIMENSIONING & TOLERANCING ASME Y14.5-2009
D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
D3. DIMENSIONS APPLY AFTER FINISHING OPERATIONS, UNLESS OTHERWISE SPECIFIED.
D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY — ALL TRIM EDGES — ØSIZE ±0.25 CIRCULAR FEATURES — SIZE ±0.25 NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:
Rz 25, Rz1max 50

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
M2. WORKMANSHIP STANDARD DOCUMENT BMS-0000026 APPLIES.
M3. NO CHANGES SHALL BE MADE TO RAW MATERIALS, PROCESSING MATERIALS/CHEMICALS, DESIGN, TOOLING, PROCESS, OR PACKAGING WITHOUT THE PRIOR WRITTEN CONSENT OF TESLA MOTORS.

CAD FILE NAME: [redacted]		CAD FILE VERSION: 01	
DRAWN BY	A. BHATNAGAR	DATE	18-JUL-22

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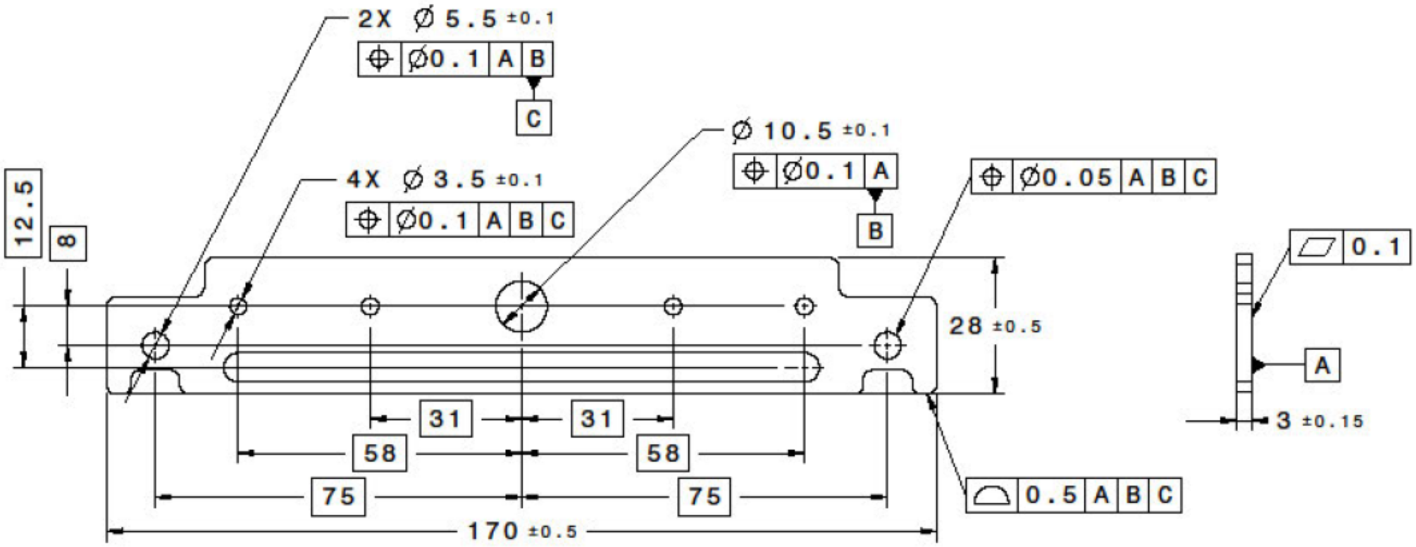
SUPPLIER NAME: --	MATERIAL: ALUMINUM 6061-T6, QUARTER-INCH PLATE		
SUPPLIER PART NUMBER: --	FINISH: --	EST. MASS (g): MASS	
	THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE: 1:1 / SHEET SIZE: B
SYMMETRIC ITEM NAME: --	ITEM NAME: WSS TEST BENCH CT HUB MOUNTING PLATE		
SYMMETRIC ITEM NUMBER: --	ITEM NUMBER: --	REVISION: 01	SHEET: 1 OF 1

B PART NAME

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD
18-JUL-22	A	INITIAL RELEASE	AB	
3-AUG-22	B	ADDED T-SLOT FRAMING NUT CUT-OUT FOR ASSEMBLY	AB	



REGULATORY COMPLIANCES

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DIMENSIONAL NOTES

D1. INTERPRET SPECIFICATIONS PER GEOMETRIC DIMENSIONING & TOLERANCING ASME Y14.5-2009
D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
D3. DIMENSIONS APPLY AFTER FINISHING OPERATIONS, UNLESS OTHERWISE SPECIFIED.
D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
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D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY — ALL TRIM EDGES — SIZE ±0.25 CIRCULAR FEATURES — SIZE ±0.25 NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
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CAD FILE NAME: [redacted]		CAD FILE VERSION: 02	
DRAWN BY	A. BHATNAGAR	DATE	3-AUG-22

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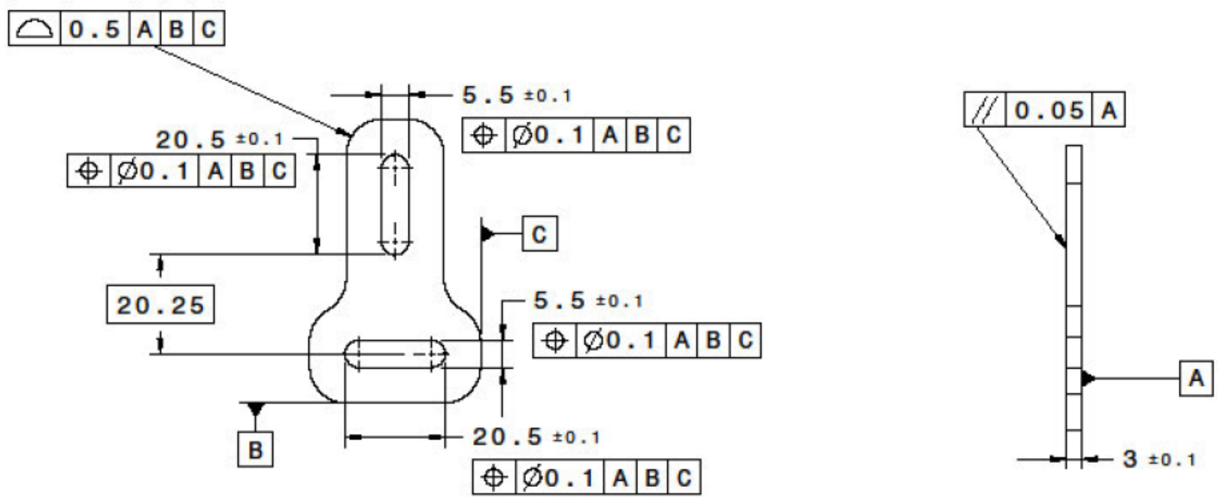
SUPPLIER NAME	--
SUPPLIER PART NUMBER	--
SYMMETRIC ITEM NAME	--
SYMMETRIC ITEM NUMBER	--
MATERIAL	ALUMINUM 6061-T6
FINISH	AS MACHINED
EST. MASS (g)	MASS
THIRD ANGLE PROJECTION	
DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	
SCALE	1:1
SHEET SIZE	B
ITEM NAME	WSS TEST BENCH FRAME PLATE
ITEM NUMBER	--
REVISION	B
SHEET	1 OF 1

B WSS TEST BENCH FRAME PLATE

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



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D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
ØSIZE ±0.25 SIZE ±0.25
SURFACES WITH BLENDED UNIFORMITY — ALL TRIM EDGES — CIRCULAR FEATURES — NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:
Ra 3.2 / Rz max 50

MATERIAL SPECIFICATIONS

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CAD FILE NAME: [redacted]	CAD FILE VERSION: 01
DRAWN BY: --	DATE: 18-JUL-22

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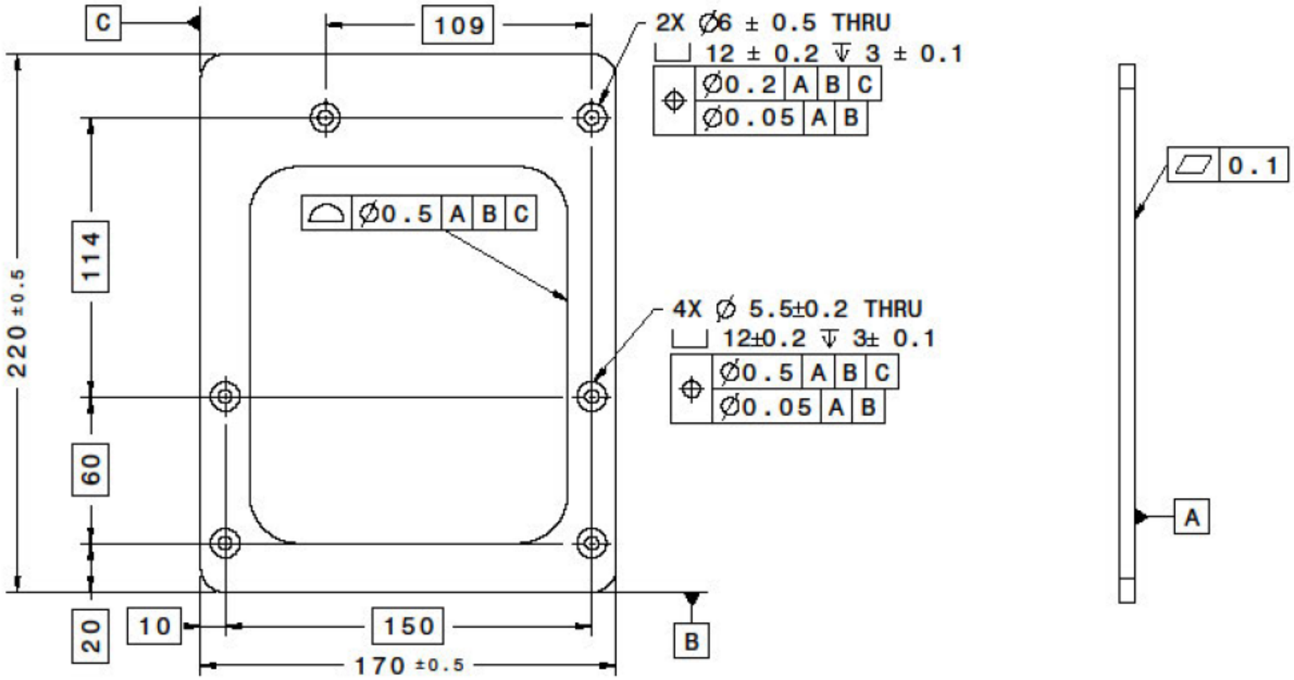
SUPPLIER NAME: --	MATERIAL: ALUMINUM 6061-T6		
SUPPLIER PART NUMBER: --	FINISH: --	EST. MASS (g): MASS	
	THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE 1:1 / SHEET SIZE B
SYMMETRIC ITEM NAME: --	ITEM NAME: HUB LOCKING BRACKET		
SYMMETRIC ITEM NUMBER: --	ITEM NUMBER: --	REVISION: 01	SHEET 1 OF 1

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



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R4. FOR A COMPREHENSIVE LIST OF ALL SUPPLIER QUALITY ASSURANCE REQUIREMENTS, REFERENCE THE SUPPLIER HANDBOOK BMS-0000051.

GENERAL NOTES

G1. THE MASTER SOURCE OF INFORMATION FOR THIS DOCUMENT IS A COMPUTER DATABASE.
G2. 3D CAD DATA SUPPLIED IS TO BE USED TO PRODUCE PRODUCTION TOOLING AND FOR INSPECTION.
G3. PRINTED DOCUMENT IS UNCONTROLLED - DOCUMENT OBSOLETE WHEN PRINTED.
G4. THIS COMPONENT MUST BE PACKAGED IN ACCORDANCE WITH TESLA MOTORS SPECIFICATION BMS-0000005. CONTACT TESLA PACKAGING/LOGISTICS GROUP FOR OTHER PACKAGING REQUIREMENTS.

DIMENSIONAL NOTES

D1. INTERPRET SPECIFICATIONS PER GEOMETRIC DIMENSIONING & TOLERANCING ASME Y14.5-2009
D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
D3. DIMENSIONS APPLY AFTER FINISHING OPERATIONS, UNLESS OTHERWISE SPECIFIED.
D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY; ALL TRIM EDGES; CIRCULAR FEATURES (SIZE ±0.25); NON-CIRCULAR FEATURES (SIZE ±0.25)
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
M2. WORKMANSHIP STANDARD DOCUMENT BMS-0000026 APPLIES.
M3. NO CHANGES SHALL BE MADE TO RAW MATERIALS, PROCESSING MATERIALS/CHEMICALS, DESIGN, TOOLING, PROCESS, OR PACKAGING WITHOUT THE PRIOR WRITTEN CONSENT OF TESLA MOTORS.

CAD FILE NAME: [redacted]	CAD FILE VERSION: 01
DRAWN BY: A. BHATNAGAR	DATE: 18-JUL-22

TESLA

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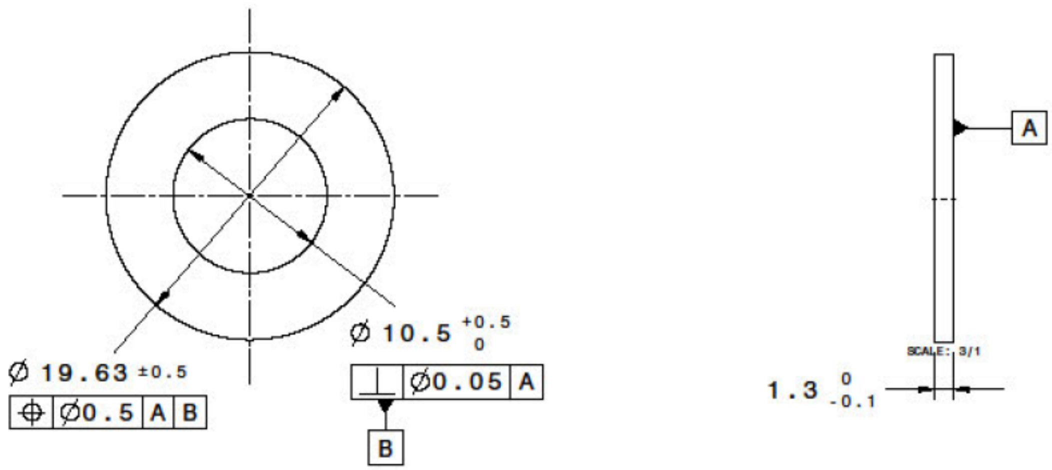
SUPPLIER NAME: --	MATERIAL: ALUMINUM 6061-T6, QUARTER-INCH PLATE		
SUPPLIER PART NUMBER: --	FINISH: AS MACHINED	EST. MASS (g): MASS	
SYMMETRIC ITEM NAME: --	THIRD ANGLE PROJECTION / DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE: 1:2	SHEET SIZE: B
SYMMETRIC ITEM NUMBER: --	ITEM NAME: WSS TEST BENCH BASE PLATE		
	ITEM NUMBER: [redacted]	REVISION: 01	SHEET: 1 OF 1

B | WSS TEST BENCH BASE PLATE | 01 | 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



REGULATORY COMPLIANCES

R1. ALL PART MATERIALS, COATINGS AND PART MARKINGS MUST COMPLY WITH ALL APPLICABLE INTERNATIONAL REGULATIONS, AS DETAILED IN BMS-0000408 - MATERIAL COMPLIANCE REPORTING.
R2. CONTACT TESLA HOMOLOGATION AND ENGINEERING BEFORE UNDERTAKING DESIGN MODIFICATIONS. ANY UNAUTHORIZED CHANGES ARE STRICTLY PROHIBITED.
R3. MATERIAL MUST COMPLY WITH FMVSS 302 OR BETTER
R4. FOR A COMPREHENSIVE LIST OF ALL SUPPLIER QUALITY ASSURANCE REQUIREMENTS, REFERENCE THE SUPPLIER HANDBOOK BMS-0000051.

GENERAL NOTES

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G4. THIS COMPONENT MUST BE PACKAGED IN ACCORDANCE WITH TESLA MOTORS SPECIFICATION BMS-0000005. CONTACT TESLA PACKAGING/LOGISTICS GROUP FOR OTHER PACKAGING REQUIREMENTS.

DIMENSIONAL NOTES

D1. INTERPRET SPECIFICATIONS PER GEOMETRIC DIMENSIONING & TOLERANCING ASME Y14.5-2009
D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
D3. DIMENSIONS APPLY AFTER FINISHING OPERATIONS, UNLESS OTHERWISE SPECIFIED.
D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
ØSIZE ±0.25 SIZE ±0.25
SURFACES WITH BLENDED UNIFORMITY / ALL TRIM EDGES / CIRCULAR FEATURES / NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
M2. WORKMANSHIP STANDARD DOCUMENT BMS-0000026 APPLIES.
M3. NO CHANGES SHALL BE MADE TO RAW MATERIALS, PROCESSING MATERIALS/CHEMICALS, DESIGN, TOOLING, PROCESS, OR PACKAGING WITHOUT THE PRIOR WRITTEN CONSENT OF TESLA MOTORS.

CAD FILE NAME [redacted]		CAD FILE VERSION 01	
DRAWN BY	A. BHATNAGAR	DATE	20-JUL-22

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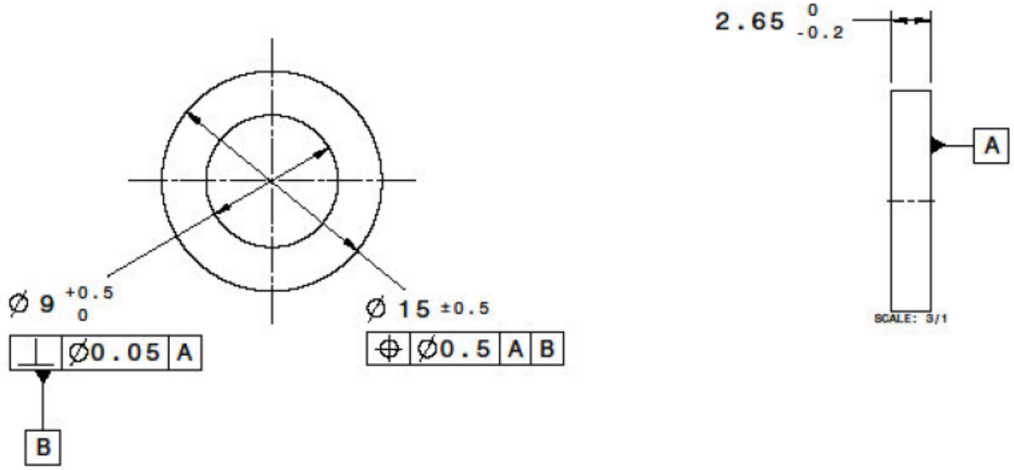
MATERIAL: 3D PRINTED PLASTIC			
FINISH: AS PRINTED		EST. MASS (g): MASS	
THIRD ANGLE PROJECTION	DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.	SCALE 1:1	SHEET SIZE B
ITEM NAME: WSS TEST BENCH FRAME BOLT SPACER			
ITEM NUMBER [redacted]		REVISION 01	SHEET 1 OF 1

SUPPLIER NAME	--
SUPPLIER PART NUMBER	--
SYMMETRIC ITEM NAME	--
SYMMETRIC ITEM NUMBER	--

B WSS TEST BENCH FRAME BOLT SPACER 01 01

Project: WSS TEST BENCH

DATE	REV	DESCRIPTION	DRN	APPD



REGULATORY COMPLIANCES

R1. ALL PART MATERIALS, COATINGS AND PART MARKINGS MUST COMPLY WITH ALL APPLICABLE INTERNATIONAL REGULATIONS, AS DETAILED IN BMS-0000408 - MATERIAL COMPLIANCE REPORTING.
R2. CONTACT TESLA HOMOLOGATION AND ENGINEERING BEFORE UNDERTAKING DESIGN MODIFICATIONS. ANY UNAUTHORIZED CHANGES ARE STRICTLY PROHIBITED.
R3. MATERIAL MUST COMPLY WITH FMVSS 302 OR BETTER
R4. FOR A COMPREHENSIVE LIST OF ALL SUPPLIER QUALITY ASSURANCE REQUIREMENTS, REFERENCE THE SUPPLIER HANDBOOK BMS-0000051.

GENERAL NOTES

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DIMENSIONAL NOTES

D1. INTERPRET SPECIFICATIONS PER GEOMETRIC DIMENSIONING & TOLERANCING ASME Y14.5-2009
D2. CAD UNITS ARE MILLIMETERS AT 1:1. TOOLING SUPPLIER TO ALLOW FOR MATERIAL SHRINKAGE AND/OR SPRINGBACK.
D3. DIMENSIONS APPLY AFTER FINISHING OPERATIONS, UNLESS OTHERWISE SPECIFIED.
D4. HARDCOPY IS NOT TO SCALE. DO NOT SCALE IMAGES.
D5. DIMENSIONS ARE TO THEORETICAL SHARP CORNERS.
D6. PART MUST BE FREE OF BURRS, FLASHING, SHARP EDGES WHICH MAY BE DETRIMENTAL TO SATISFACTORY ASSEMBLY, SAFE HANDLING, APPEARANCE OR FUNCTION OF THE PART OR ASSEMBLY.
D7. DEBURR AND BREAK ALL SHARP EDGES 0.3mm UNLESS OTHERWISE SPECIFIED.
D8. TOLERANCES UNLESS OTHERWISE NOTED:
SURFACES WITH BLENDED UNIFORMITY — ALL TRIM EDGES — ØSIZE ±0.25 CIRCULAR FEATURES — SIZE ±0.25 NON-CIRCULAR FEATURES
D9. SURFACE ROUGHNESS OF MACHINED SURFACES UNLESS OTHERWISE NOTED:
Rz 25
Rz1max 50

MATERIAL SPECIFICATIONS

M1. CLEANLINESS: PART TO BE FREE OF ANY OILS, GREASE, LUBRICANTS, FLUIDS, MOLD RELEASE, OR OTHER CONTAMINANTS ON ALL SURFACES UNLESS OTHERWISE NOTED.
M2. WORKMANSHIP STANDARD DOCUMENT BMS-0000026 APPLIES.
M3. NO CHANGES SHALL BE MADE TO RAW MATERIALS, PROCESSING MATERIALS/CHEMICALS, DESIGN, TOOLING, PROCESS, OR PACKAGING WITHOUT THE PRIOR WRITTEN CONSENT OF TESLA MOTORS.

CAD FILE NAME [redacted]	CAD FILE VERSION 01
DRAWN BY: A. BHATNAGAR	DATE: 20-JUL-22

TESLA

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SUPPLIER NAME	--
SUPPLIER PART NUMBER	--
SYMMETRIC ITEM NAME	--
SYMMETRIC ITEM NUMBER	--

MATERIAL: 3D PRINTED PLASTIC

FINISH: AS PRINTED — EST. MASS (g): MASS

THIRD ANGLE PROJECTION — DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES. — SCALE 1:1 — SHEET SIZE B

ITEM NAME: WSS TEST BENCH BOLT SPACER

ITEM NUMBER: [redacted] — REVISION 01 — SHEET 1 OF 1

B | WSS TEST BENCH BOLT SPACER | 01 | 01

APPENDIX B: PURCHASE ORDERS

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TESLA
APPROVED

Tesla, Inc.
45500 Fremont Blvd Fremont,CA
94538

Purchase Order	
PO #:	[redacted]
Last Release Date:	
REVISED:	

Vendor	Ship To
[redacted]	Tesla, Inc. Tesla Deer Creek 3600 Deer Creek Palo Alto, CA 94304 USA Requestor /Contact: Aditya Bhatnagar Email: abhatnagar@tesla.com

Terms & Payment	Bill To
[redacted]	Submit all invoices through company's selected E-Invoicing channel. If you have not selected an E-Invoicing channel, please contact E-Invoicing@tesla.com for onboarding.

Line #	Tesla Part Number	Description	Detail# / Sub Assembly	Qty	UM	Due Date	Unit Price (USD)	Tax Charged by Supplier	Rcvd Qty	Status	Total (USD)
10		[redacted]		1.00	EA	2022-08-06	330.000000	Yes	0.00	Open	330.00
20				1.00	EA	2022-08-06	520.000000	Yes	0.00	Open	520.00
30				1.00	EA	2022-08-06	320.000000	Yes	0.00	Open	320.00
											1,170.00

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TESLA

APPROVED

Tesla, Inc.
45500 Fremont Blvd Fremont,CA
94538

Purchase Order	
PO #:	[redacted]
Last Release Date:	
REVISED:	

Vendor	Ship To
[redacted]	Tesla, Inc. Tesla Deer Creek 3600 Deer Creek Palo Alto, CA 94304 USA Requestor /Contact: Aditya Bhatnagar Email: abhatnagar@tesla.com

Terms & Payment	Bill To
[redacted]	Submit all invoices through company's selected E-Invoicing channel. If you have not selected an E-Invoicing channel, please contact E-Invoicing@tesla.com for onboarding.

Line #	Tesla Part Number	Description	Detail# / Sub Assembly	Qty	UM	Due Date	Unit Price (USD)	Tax Charged by Supplier	Rcvd Qty	Status	Total (USD)
10		[redacted]		1.00	EA	2022-07-29	487.000000	Yes	0.00	Open	487.00
											487.00

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APPENDIX C: MANUFACTURING QUOTES

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[redacted]

Quotation

Date	7/22/22
Q-No.	Tesla_AB_F_0722_01

Quotation for	
Company	Tesla
Name	Aditya Bhatnagar

Part Name		Material	QTY	Unit Price	Total	Note
1	[redacted]	AL 6061	1	$ 320.00	$ 320.00	
2	[redacted]	AL 6061	1	$ 520.00	$ 520.00	
3	[redacted]	AL 6061	1	$ 330.00	$ 330.00	
4				$ -	$ -	
5				$ -	$ -	
6				$ -	$ -	
7				$ -	$ -	
8				$ -	$ -	
9				$ -	$ -	
10				$ -	$ -	
11				$ -	$ -	
12				$ -	$ -	
13				$ -	$ -	
14				$ -	$ -	
15				$ -	$ -	
					$ 1,170.00	

[redacted]

Estimate

Date	Estimate #
7/19/2022	[redacted]

Name / Address
[redacted]

THIS QUOTE IS FOR CUTTING ONLY UNLESS OTHERWISE SPECIFIED!

ALL QUANTITIES QUOTED ARE BASED ON ONE SHIPMENT. SPLIT DELIVERIES ARE SUBJECT TO REQUOTE BASED ON DELIVERY REQUIREMENTS!!

GOOD THRU	TERMS	CONTACT
10/17/2022	net 90	ADITYA

Item	Description	Qty	Cost	Total
[redacted]	ADVANCED LASER SUPPLIED MATERIAL: ALUM 6061	1	0.00	0.00
	ADVANCED LASER SUPPLIED MATERIAL: ALUM 6061	1	0.00	0.00
	ADVANCED LASER SUPPLIED MATERIAL: ALUM 6061	1	0.00	0.00
	ADVANCED LASER SUPPLIED MATERIAL: ALUM 6061	2	0.00	0.00
	ADVANCED LASER SUPPLIED MATERIAL: ALUM 6061	2	0.00	0.00
	ADVANCED LASER SUPPLIED MATERIAL: ALUM 6061	2	0.00	0.00
	FOR THE ABOVE LINE ITEMS		487.00	487.00

THANK YOU FOR THE OPPORTUNITY TO PROVIDE YOUR QUOTE. THIS QUOTE IS FOR CUTTING ONLY UNLESS OTHERWISE SPECIFIED. IT DOES NOT INCLUDE MATERIAL OR ANY OUTSOURCED REQUIREMENTS UNLESS NOTED ABOVE. DUE TO MATERIAL PRICE INCREASES THE ABOVE PRICES ARE SUBJECT TO CHANGE AT THE TIME OF ORDER. PLEASE CONFIRM QUOTED PRICING WHEN PLACING ORDER. LEAD TIME MAY VERY UPON SCHEDULE DATE. ALL JOBS ARE CONSIDERED C.O.D. UNTIL YOU HAVE BEEN CREDIT QUALIFIED.
A 3% SURCHARGE WILL BE ADDED TO ALL INVOICES PROCESSED BY CREDIT CARDS.

Total $487.00