General Atomics CubeSat Fixture

Operation & Assembly Manual

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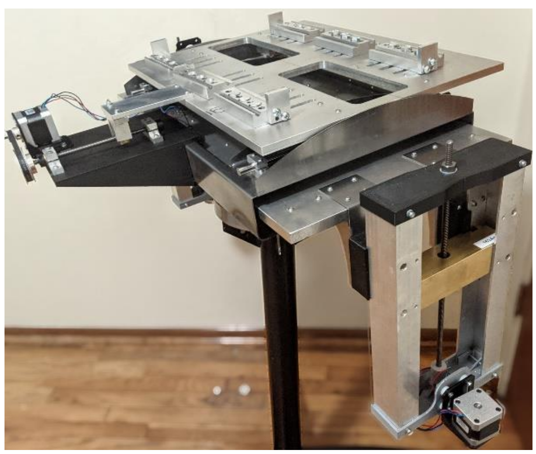

Project Sponsor: General Atomics EMS

Instructor: Dr. David Willy

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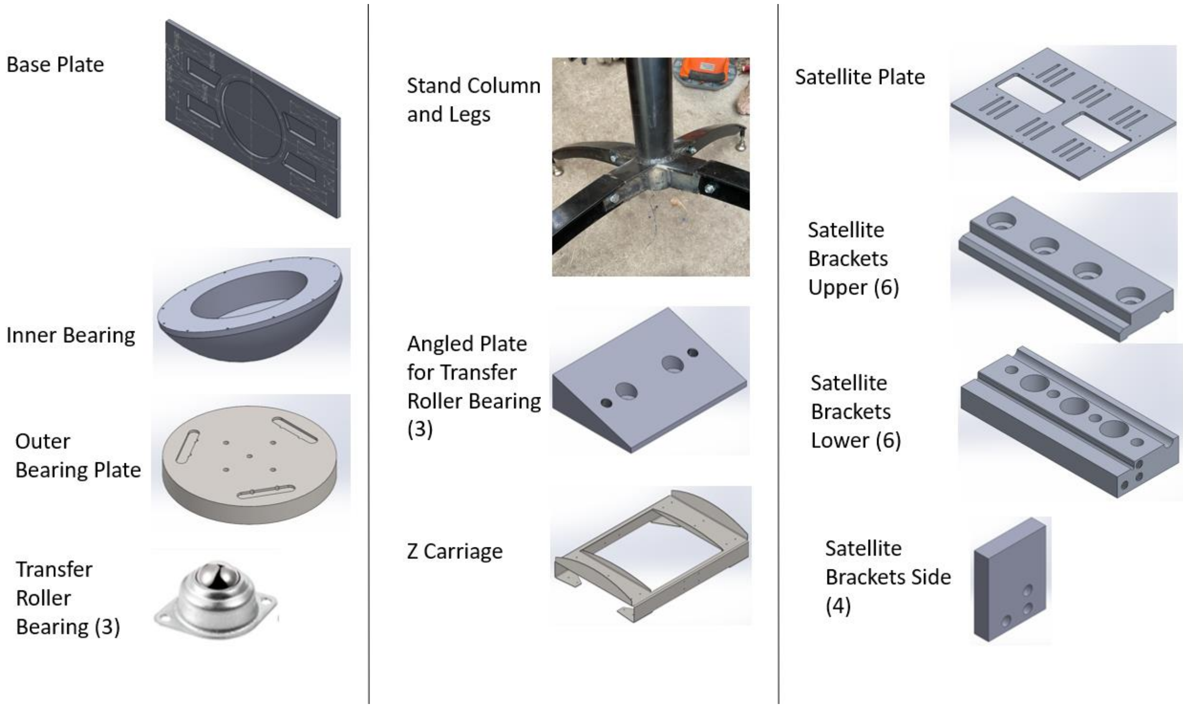


Figure 1: Parts List (1/3)

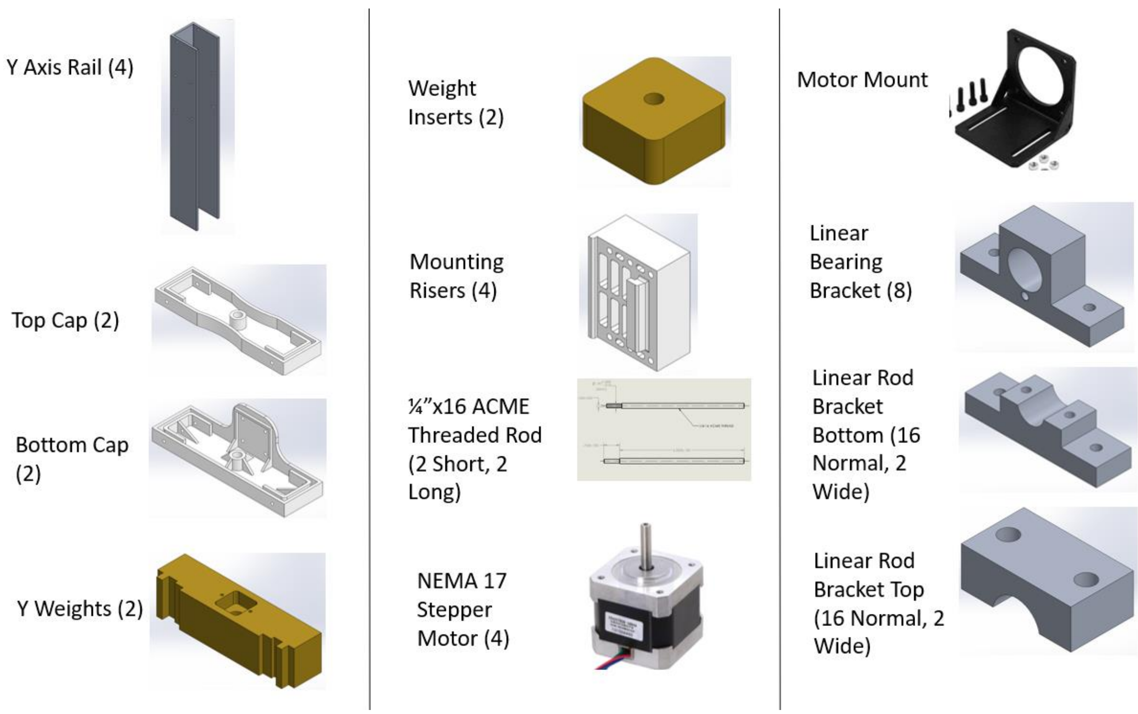


Figure 2: Parts List (2/3)

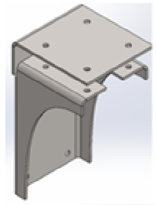
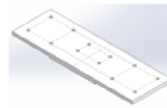
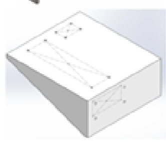
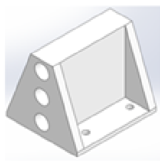
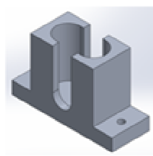
Y Rail Bracket (4) 	Z Motor Riser 	
X Motor Mount 		
X Follower Bracket 		
Nut Bracket (Z is mounted to a Plate, X to a Bar) 		

Figure 3: Parts List (3/3)

Test Stand Assembly

The Test Stand consists of the following parts:

- Outer Bearing Plate
- Angled Plate for Outer Bearing x3
- Transfer Roller Bearing x 3
- Stand Column
- Stand Legs x 4

To start assembly, attach all 4 Stand Legs to the Stand Column as shown in Figure 4 with the supplied 5/16” bolts and nuts.

Figure 4: Stand Column and Legs Bolt Arrangement

Next, place the Outer Bearing Plate along the top of the column so that all holes are lined up. Attach the plate to the stand with the 4 central bolts and associated nuts. Afterward, place the Angled Plates in the correct position with the flat portion facing outward. Fixture these in place with the M3 bolts and nuts provided using washers beneath the nuts. Once all bolts are in place, attach the transfer roller bearings to the mounted angle plates with the necessary bolts. The completed setup for the stand is shown in Figure 5 with the Inner Bearing for context.

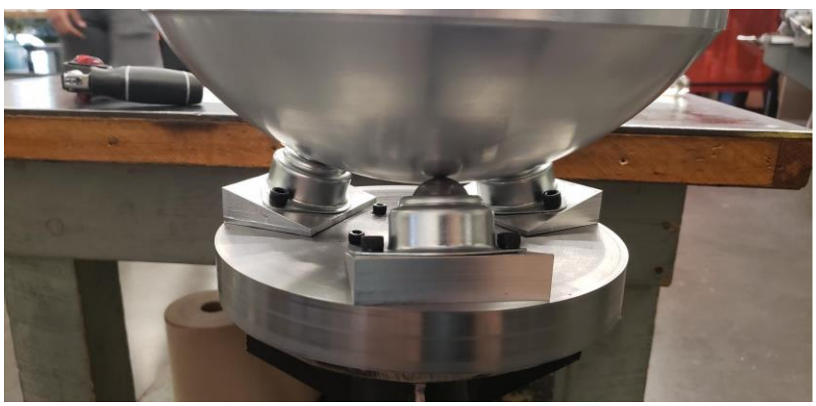


Figure 5: Completed Test Stand Assembly

Satellite Fixture Assembly

The Satellite Fixture consists of the following parts:

- Base Plate
- Inner Bearing
- Z Carriage
- Satellite Plate
- Satellite Brackets Upper x 6

- Satellite Brackets Lower x 6
- Satellite Brackets Side x 4
- Y Rail Brackets x 4
- Y Axis Rails x 4
- Top Cap x 2
- Bottom Cap x 2
- Y Weights x 2
- Y Weight Inserts x 2
- Mounting Risers x 4
- ¼"x16 ACME Threaded Rod x 2
- ¼"x16 ACME Threaded Rod (Short) x 2
- NEMA Stepper Motor x 4
- Motor Mount x 4
- Motor Pulley Small x 4
- Motor Pullet Large x 5
- Linear Rod x 8
- Linear Bearing Brackets x 8
- Linear Rod Brackets Bottom x 16
- Linear Rod Brackets Top x 16
- Linear Rod Brackets Wide Bottom x 2
- Linear Rod Brackets Wide Top x 2
- Z Motor Riser
- X Motor Mount
- X Follower Bracket
- X Nut Bracket
- Z Nut Bracket
- Shaft Coupler x 2
- Adapter Shaft x 2

The first step to assembly the Satellite Fixture Assembly will involve the Base Plate, 10x Linear Rod Brackets Bottom, 8 x Linear Rod Brackets Top, the Y Rail Brackets x 4, Linear Rods x 4, NEMA Stepper Motor x 1, Motor Mount x1, Linear Rod Brackets Wide Bottom x 2, and the Z Motor Riser.

Start by mounting the 10 Linear Rod Brackets Bottom as shown below with the correct length M3 bolts provided.

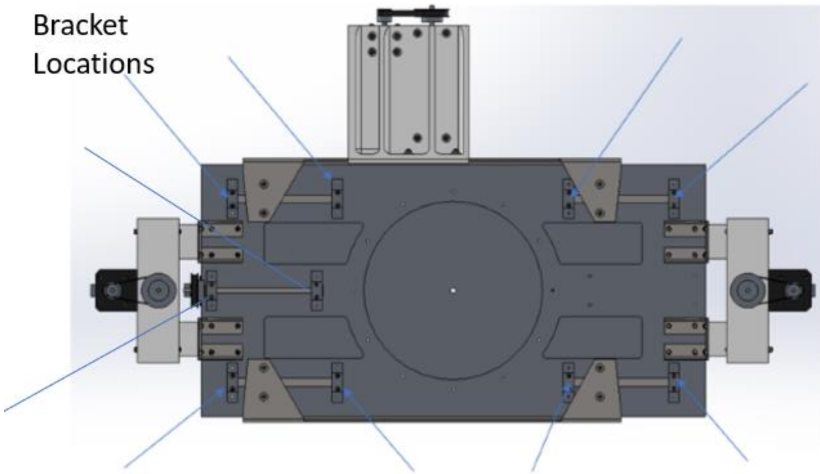


Figure 6: Base Plate Bracket Locations

Next, Mount 4 of the Linear Bearing Brackets as shown on the Z Carriage using the same bolts to mount the X Nut Bracket on one side. Additionally, mount 4 of the Linear Rod Brackets Bottom and 2 of the Wide versions on the top as shown in Figure 8. Afterward, attach the X Motor Mount to the side of the Z Carriage in the orientation shown in Figure 9.

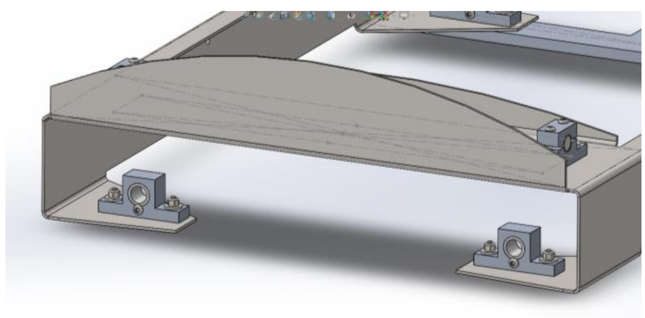


Figure 7: Linear Bearing Bracket Locations

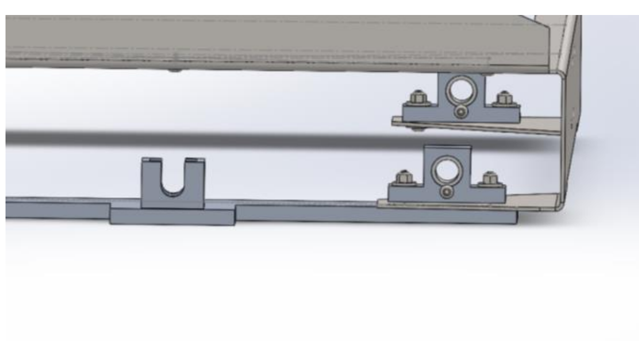


Figure 8: X Nut Bracket Location

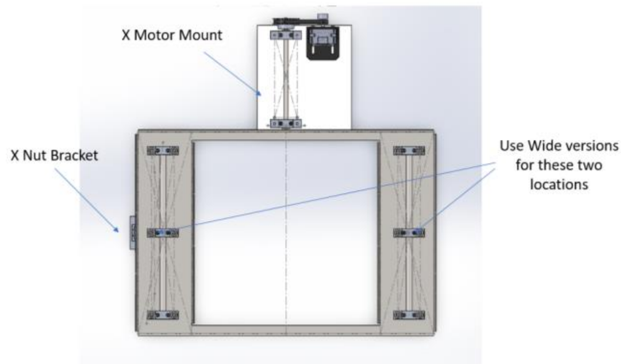


Figure 9: Z Carriage Linear Bearing Bracket Locations

Next, mount the Motor Mount to the Z Motor Riser. With this attached, attach 2 Y Axis Brackets as shown in Figure 10. Note that only one side requires the Z Motor Riser. The other side is mirrored but simply mounted directly to the base plate. That side will be attached after the Z Carriage is installed. If exact belt sizes are not available, attach the X Follower Bracket to function as a belt tensioner as shown in Figure 11.

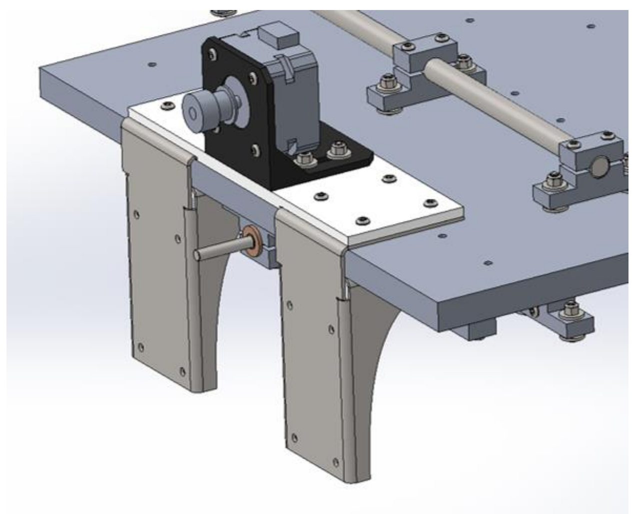


Figure 10: Y Axis Brackets with Z Motor Riser

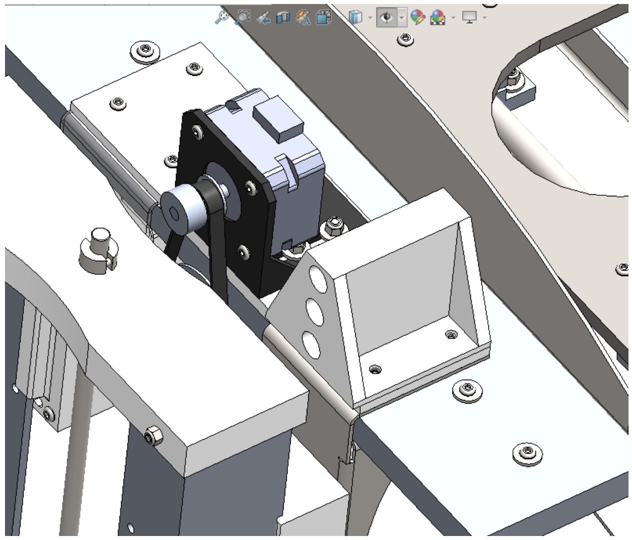


Figure 11: X Follower Bracket Installation Location

Next, using 4 of the linear rods and 4 of the Linear Bearing Bracket Tops, connect the Z Carriage as shown below. Note that this is a complicated process and will likely require more than one person or significant patience.

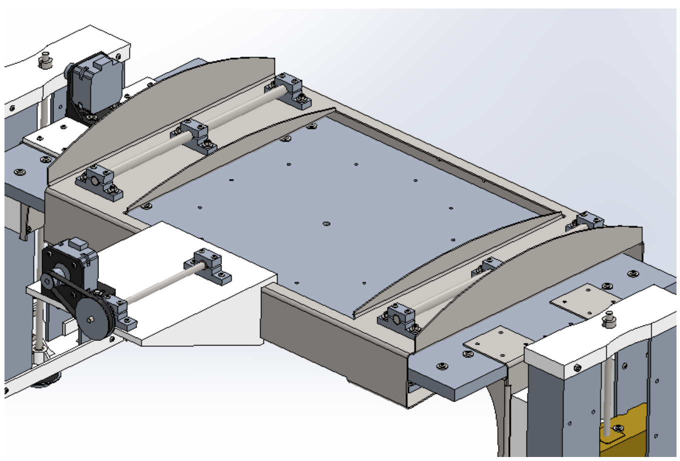


Figure 12: Z Carraige Installation Orientation

After the Z Carriage is mounted, attach the other two Y Axis Brackets. The Inner Bearing can now be installed to the system. To do so, use the M3 bolts provided and line up the holes in the center of the base plate with those on the bearing. This is easiest when the Inner Bearing is supported in some manner, but not when placed on the Test Stand. Our tests found the simplest way was to place the Inner Bearing on a soft platform on the corner of a sturdy table and insert a single bolt with the associated washer. After one bolt is aligned and slightly tightened, a second can be inserted and slightly tightened as well. After a 3rd bolt is properly positioned, all remaining bolts can be inserted with relative ease and tightened, as necessary. After the Inner Bearing is attached, the system can be placed in the Test stand for following installation steps for convenience.

The following requirement is to attach the Y Axis Weights. The subassemblies for these are identical so complete each of the following steps for each side. Start by aligning the bolt holes on two of the Y Axis Rails with the Mounting Risers as shown in Figure 13. Fixture the Mounting Risers with the inset bolt holes to the corresponding rails. Then, attach the top and bottom caps to the set of rails and use the M3 threaded rod inserts and bolts to hold the caps in place. The Y Axis Rails can now be mounted to the Y Axis Brackets of the Satellite Fixture.

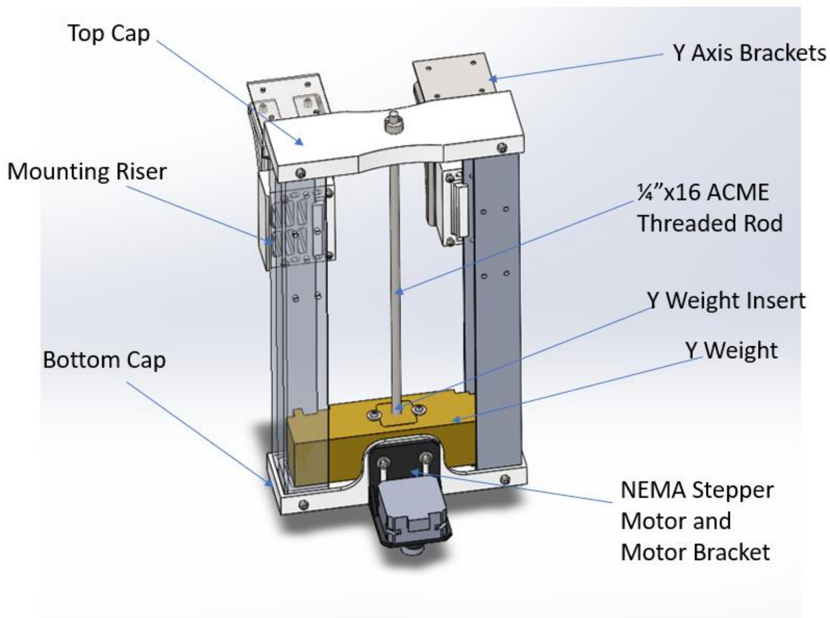


Figure 13: Y Axis Subassembly

The Motor Mount, NEMA stepper Motor, and associated pulleys can now be added to the subassembly. Place the Y Weight in the assembly as shown in Figure 13. The Threaded rod is attached through a shaft coupler through the hole in the bottom of the Bottom cap to the larger pulley. A Large washer is to be placed between the Bottom Cap and the Shaft Coupler to the Adapter Shaft, as well as on top of the Top Cap so that the threaded rod can be held in place with one of the nuts provided. The threaded rod will have to be fed through the Y Weight Insert as it is installed. Then, bolt the Y Weight Insert into the Y Weight with some of the fender washers provided to prevent the insert from falling out.

Afterward, install the remaining NEMA Stepper Motors, Motor Mounts, and Linear Rod Brackets to the X Motor Mount as shown in Figure 14. The ¼"x16 ACME Threaded Rods (Short) can be installed for the X and Z directions now, using a bushing in each of the Linear Rod Brackets with the Threaded Rod inserted and some of the shaft locking fasteners provided to prevent the threaded rod from translating during operation. Additionally, thread one of the provided inserts on to interface with the respective Nut Bracket while installing the threaded rods.

The second set of linear rods can now be mounted in the corresponding brackets on top of the Z Carriage. Place a Linear Bearing Bracket along each threaded rod before fixturing these with the top brackets. If necessary for clearance, use the spacers provided on top of each of the Linear Bearing

Brackets and attach the Satellite Plate as shown in Figures 14 and 15. Note that the holes shown in the Satellite Plate are replaced by slots in later iterations for ease of use.

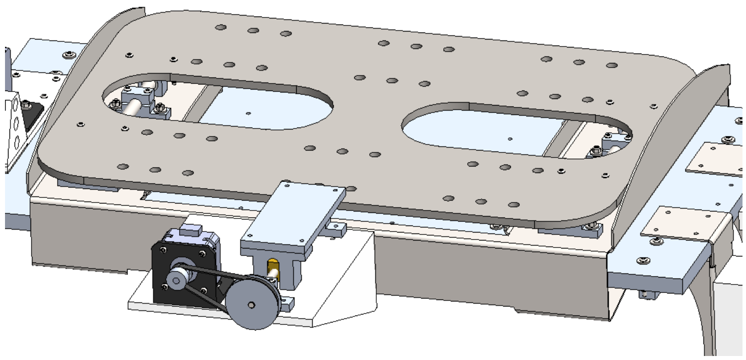


Figure 14: Satellite Plate Installation and Remaining X Motor Mount Fixtures

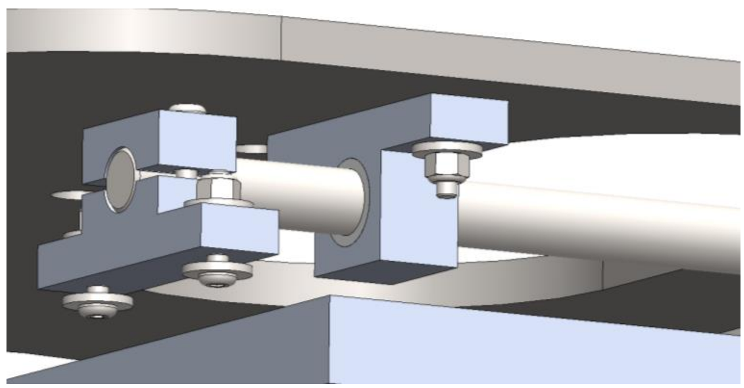


Figure 15: Mounting Position for Satellite Plate to Linear Bearing Bracket

Mount the Z Nut Bracket making sure to have it interface with the Threaded Insert. Attach the corresponding cords for the electronics and motors.

Next, connect the 6 Satellite Bracket Lower's to the Satellite Plate along the slots, make sure to have the outside ones have the correct orientation for the side brackets to attach. Mount the Side Brackets (loosely) to these. A CubeSat can then be placed along the Lower Satellite Brackets; it can be adjusted as necessary to match the exact dimensions of the CubeSat. After these are fastened securely in place and the side brackets are tightened to accommodate the CubeSat, the Top Satellite Brackets can be mounted with the supplied bolts and washers. The system is now ready for operation.

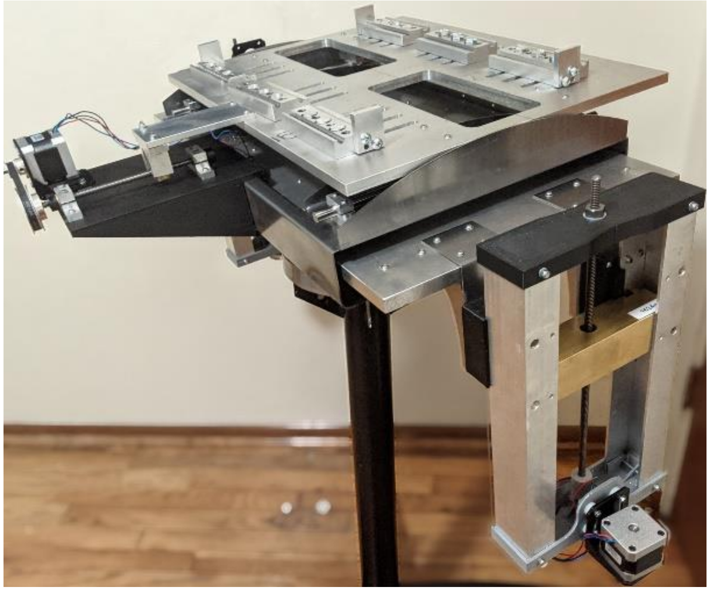


Figure 16: Completed Assembly

Operation

At the current point of documenting this operation manual the project is still in a state of limited functionality. Although the fixture is not fully functional the basics of its operating system have been constructed with simulation and have proven to be effective. Within the simulation, the user can run a program which detects the orientation of the fixture and shifts the mass accordingly.

At the current state, the fixture can only perform relocations utilizing manual controls. This begins by uploading code from a raspberry pi to an Arduino located on the fixture. This code utilizes a series of scripts that convert inputs from three toggle switches to outputs actuating the stepper motors. The manual controls are used to then shift the mass of the CubeSat until the center of mass is collocated with the center of rotation of the bearing. To determine that the center of mass is located with the center of gravity there are two steps. The first step which assures the user that the center of mass is located directly below the center of rotation begins by shifting the weights to their lowest position lowering the center of mass. Then, by observing if the fixture's horizontal plane is parallel to the ground a centered horizontal mass is determined. This is done by shifting the horizontal axes and observing the levels provided. Once the fixtures horizontal plane is parallel to the ground the next step of centering the mass vertically can begin. To center the mass vertically the vertical weights will need to be raised. Slowly raise the weights and periodically check if the fixture will revert to parallel to the ground by tilting the fixture, if the fixture returns to parallel with ground the vertical mass is not centered. Once the fixture remains at the tilted position the mass is centered vertically.

For the future of operating the fixture the goal is to have each of these manual steps automated. The center of mass will need to be level to properly align it with the center of rotation. An inertia measurement unit (IMU) is used to determine the angle the system is resting at on any one axis. The motors are manually controlled to engage the motors one at a time. The motors in the X and Z direction are fed through a reduction to decrease the amount of distance moved per rotation. The lead screws turn and push against the threaded inserts to move the satellite plate and z carriage. This continues until the IMU indicates there is an angle of zero on that axis. The motors in the Y axis are engaged simultaneously through the same process. The threaded rods feed through a brass weight that moves the system up or down based on the direction it turns. When all the angles read zero, the center of mass is aligned with the center of rotation.

Maintenance / Failure Mitigation

The fixture has few maintenance and failure mitigation procedures, but regular checking is beneficial to the reliability of the fixture. Below is a check list of procedures and inspections to perform before use of the fixture.

Table 1: Maintenance Check List

Procedure / Inspection	**Description**	**Check**
Linear rods inspection / lubrication	Check if linear rods are well lubricated with light grease and are void of obstructions.	

Vertical weights inspection	Check if vertical weights have wear left in bushings if bushing is worn out replace.	
Motor connection inspection	Check if all leads to each motor (x4) is securely connected.	
Stand security inspection	Check if all legs (x4) on stand are securely tightened.	
Roller bearing inspection / lubrication	Check if all roller bearings (x3) are well lubricated if not oil with a light grease.	
Drive belt inspection	Check if all belts (x4) are tensioned.	
Stand level inspection	Use level to balance stand.	

Trouble Shooting

The primary issues that have been experienced thus far have been a connection issue with motor controls. In the event a motor stops working, it would be imperative to check the wires. They can disconnect and prevent the signals from traveling. Occasionally, the brass weights on the Y axis rails will need some maintenance. The threaded rods can wear away at the softer metal. Smaller brass inserts have been placed within the brass weights; those have the threads in them. They will need replacing after extensive use. They rails will need to be partially disassembled to remove the brass weights and swap the failing piece.

Refer to *Figure 17*, and *Table 3* for troubleshooting stepper motor drivers.

Refer to *Table 2* for troubleshooting stepper motors.

Table 2: Stepper Motor Spec Sheet

General specifications		Electrical specifications	
Step Angle (°)	1.8	Rated Voltage (V)	2.8
Temperature Rise (℃)	80 Max (rated current, 2 phase on)	Rated Current (A)	1.68
Ambient Temperature (℃)	-20~+50	Resistance Per Phase (±10% Ω)	1.65 (25℃)
Number of Phase	2	Inductance Per Phase (±20% mH)	3.2
Insulation Resistance (MΩ)	100 Min (500VDC)	Holding torque (N.cm)	36
Insulation Class	Class B		
Max.radial force (N)	28 (20mm from the flange)		
Max.axial force (N)	10		

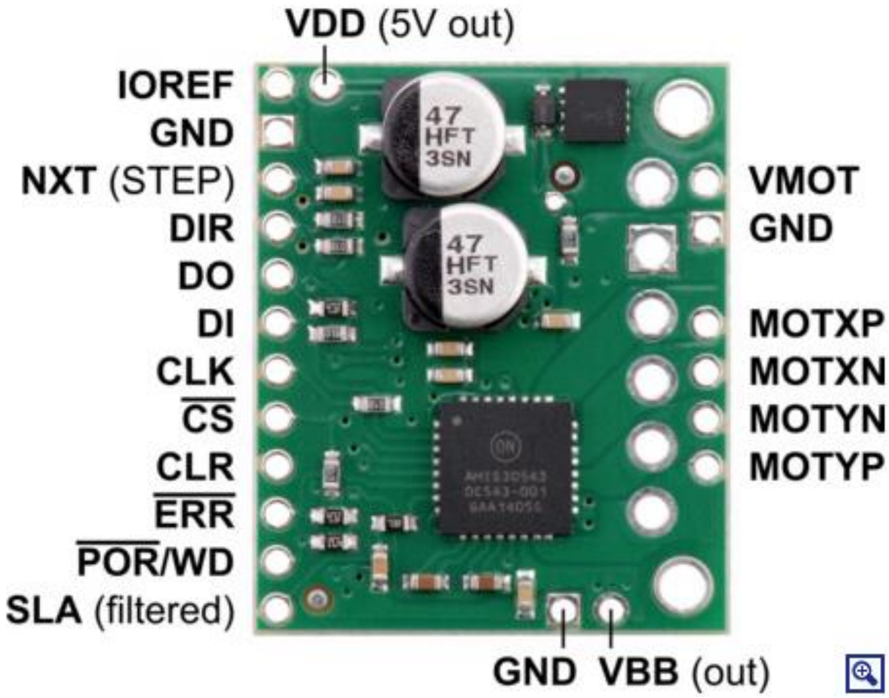


Figure 17: Stepper Motor Driver Diagram

Table 3: Motor Driver Diagram Description

Pin	Description
VMOT	Reverse-protected 6 V to 30 V board power supply connection. **Note:** Available VDD current is reduced for input voltages under 8 V, and sleep mode is not available for input voltages under 9 V.
VBB	This pin gives access to the motor power supply after the reverse-voltage protection MOSFET (see the board schematic below). It can be used to supply reverse-protected power to other components in the system. It is generally intended as an output, but it can also be used to supply board power.
GND	Ground connection points for the motor power supply and control ground reference. The control source and the motor driver must share common ground.
MOTXP	Motor output: “positive” end of phase X coil.
MOTXN	Motor output: “negative” end of phase X coil.
MOTYP	Motor output: “positive” end of phase Y coil.
MOTYN	Motor output: “negative” end of phase Y coil.
VDD (5V OUT)	The board is powered by an internal 5V regulator, and this pin gives access to the regulated 5 V **output**. This can be used to supply the neighboring IOREF pin when using this board in 5V systems, and it can be used to power an external microcontroller. When VMOT is over 8 V, approximately 30 mA is available for external components; when VMOT is less than 8 V, the available current drops to less than 10 mA.
IOREF	All the board signal outputs (except SLA) are open-drain outputs that are pulled up to IOREF, so this pin should be supplied with the logic voltage of the

	controlling system (e.g., 3.3V for use in 3.3V systems). For convenience, it can be connected to the neighboring VDD pin when it is being used in a 5V system.
NXT	Changes on this input move the motor current one step up or down in the translator table (even when the motor is disabled). The edge that triggers the step depends on the NXT-polarity configuration bit, which can be changed through the SPI interface (rising edge by default).
DIR	Input that determines the direction of rotation. The direction can also be controlled through the SPI interface.
DO	SPI data output. (This pin is also often referred to as “MISO.”)
DI	SPI data input. (This pin is also often referred to as “MOSI.”)
CLK	SPI clock input.
CS	SPI chip select input. Logic transitions on this pin are required for SPI communication, even if this is the only device on the SPI bus.
CLR	Chip reset input. A logic high on this input clears all internal registers, except in sleep mode.
ERR	Error output. This pin drives low to indicate that an error condition has occurred. The specific error can be determined by using the SPI interface to check the error flags.
POR/WD	Power-on reset/watch dog function output. This pin provides an active-low signal that can be used as a reset input for an external microcontroller.
SLA (filtered)	SLA (speed and load angle) output after a low-pass filter. The result is an analog voltage between 0 V and 5 V that indicates the level of the back-EMF voltage of the motor. This signal can be used for stall detection or closed-loop control of the torque and speed based on the load angle. **Note:** Since the output of this pin ranges from 0 V to 5 V regardless of IOREF, extra precautions should be taken when connecting this pin to a 3.3V device (such as passing it through an appropriate voltage divider).