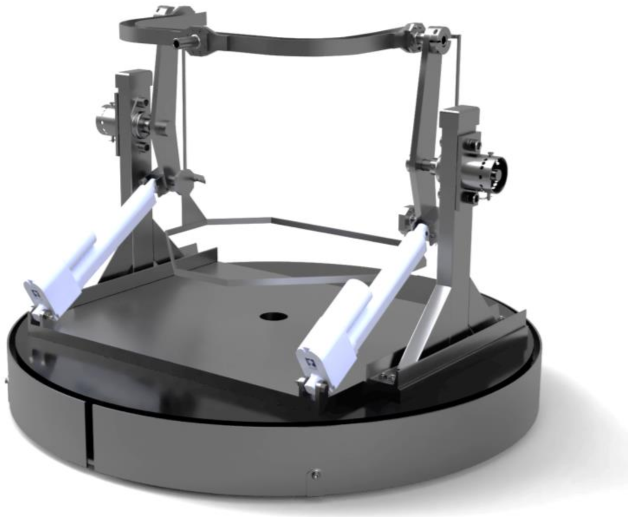
Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

MECH MOTION DYNAMICS



MT0C-1

April 23rd, 2024 **MAE-A-221**

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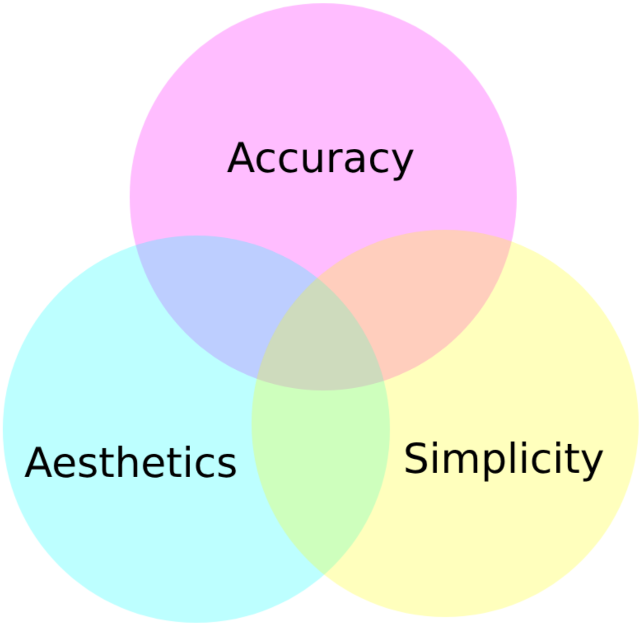
Astro Restoration Project

Outline and Table of Contents

Hedgehog Concept

- Our goal was the creation of a simple design that can show the aesthetics of the payload while being accurate in all engineering decisions.



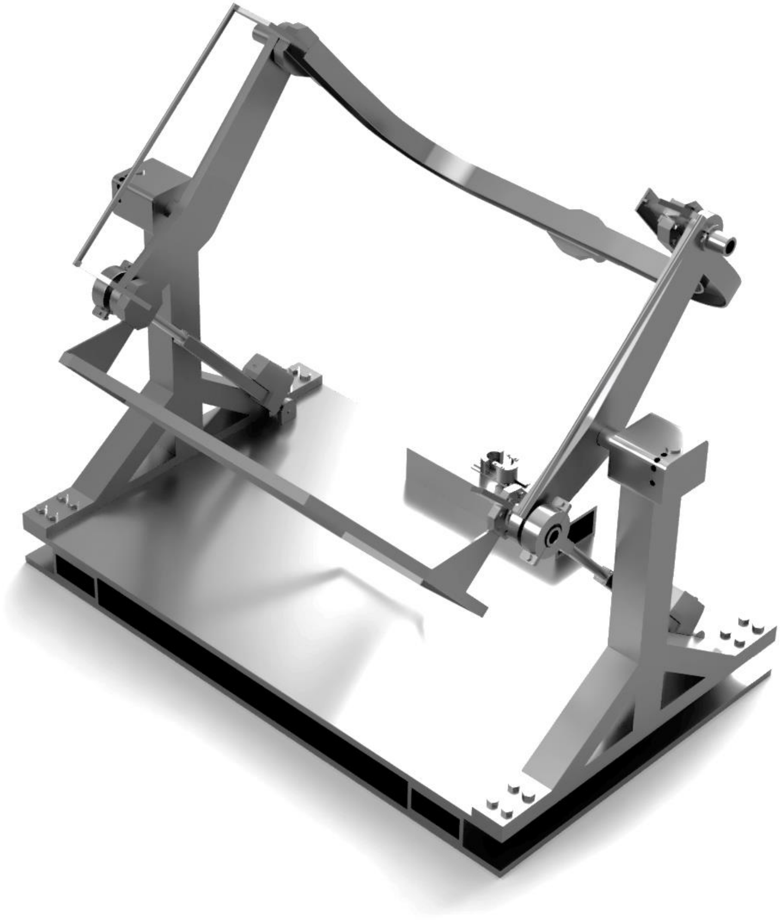
Full Scale Key Product Specifications

- Safely hold & and secure the fully integrated Astro Cruciform, with the full telescope complement and associated payload hardware. Estimated total weight is **~8,000 lbs**. A minimum **3.0 Factor of Safety.**
- Support rotation of the integrated payload from the **horizontal, vertical, or intermediate position** to accommodate both integration activates and exhibition display.
- Concepts Shall include possible use of the **stand for transportation** of the payload from the USRRC to the Smithsonian's National Air & Space Museum.
- Support Tilting of Astro so that the internal payload will be **visible to exhibit visitors**.
- Total cost of the full-scale ADS shall **not exceed $25k** (note: turntable is customer provided, not part of total cost).
- **Museum max height: 300 Inches or 25 Feet.**
- In addition to Vertical & Horizontal, fixed angles for **static tilt positions (15/30/45 deg from horizontal).**
- Capability to **secure the Integrated Payload Cruciform independent of the tilt mechanism** used (e.g. lock pins) (Note: tilt operations will only be performed occasionally as required by the ARP team).
- ADS conforms to **multiples weights & CGs** to reflect various Astro Cruciform configuration.
- **Two fault tolerant** requirement for any potential loss of tilt angle during static display

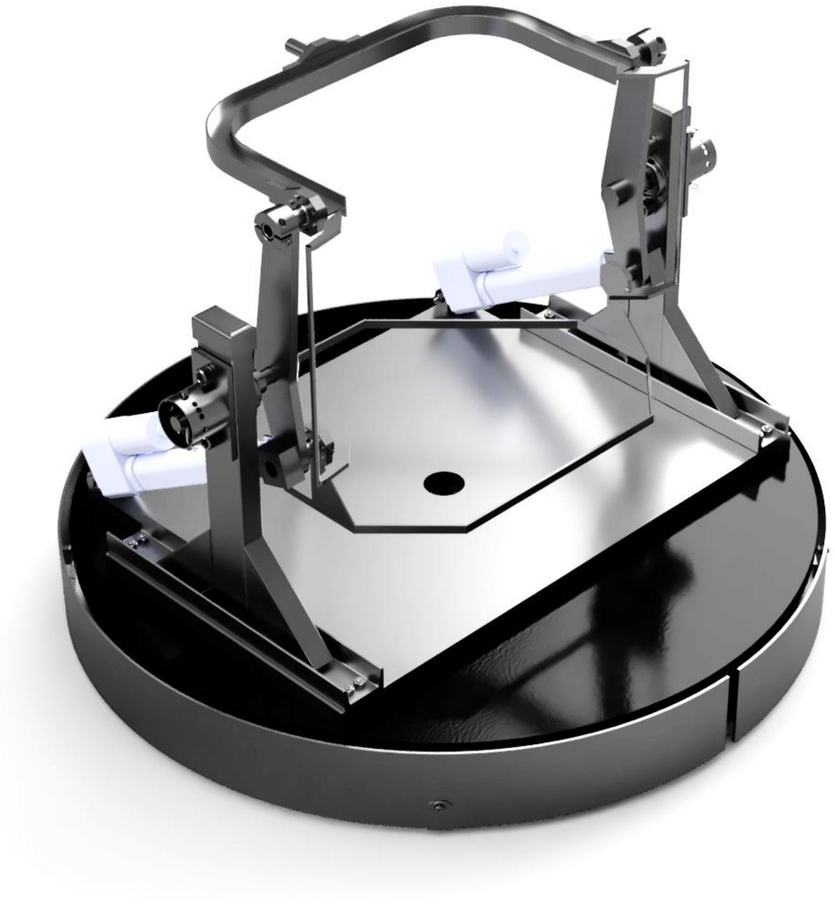
1/5 Scale Key Product Specifications

- A **dimensionally accurate 1/5 scaled model** of the Astro Integrated Cruciform Payload.
- A **scaled model of the ASTRO Integrated Cruciform Display Stand(ADS)** to hold the Astro payload 1/5 scale model and rotate it from vertical to horizontal.
- A **functional turntable** sized to rotate the 1/5 scale model ADS and Astro payload 360 degrees.
- An **intuitive control panel** for visitors as young as 5 years old.
- The scaled ASD and turntable shall **utilize full-scale electrical and mechanical components** where applicable.

Render of Full Scale Model



Render of 1/5 Scale Model



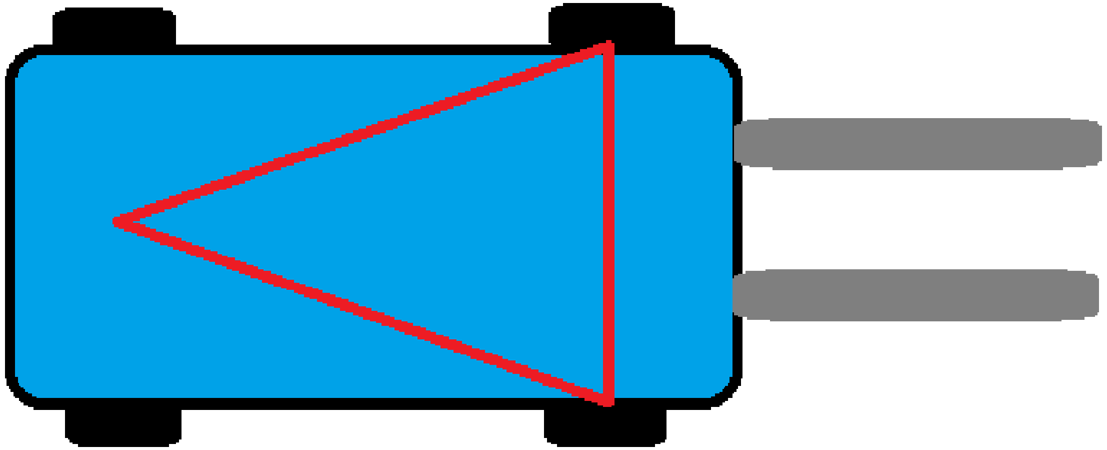
Built Prototype

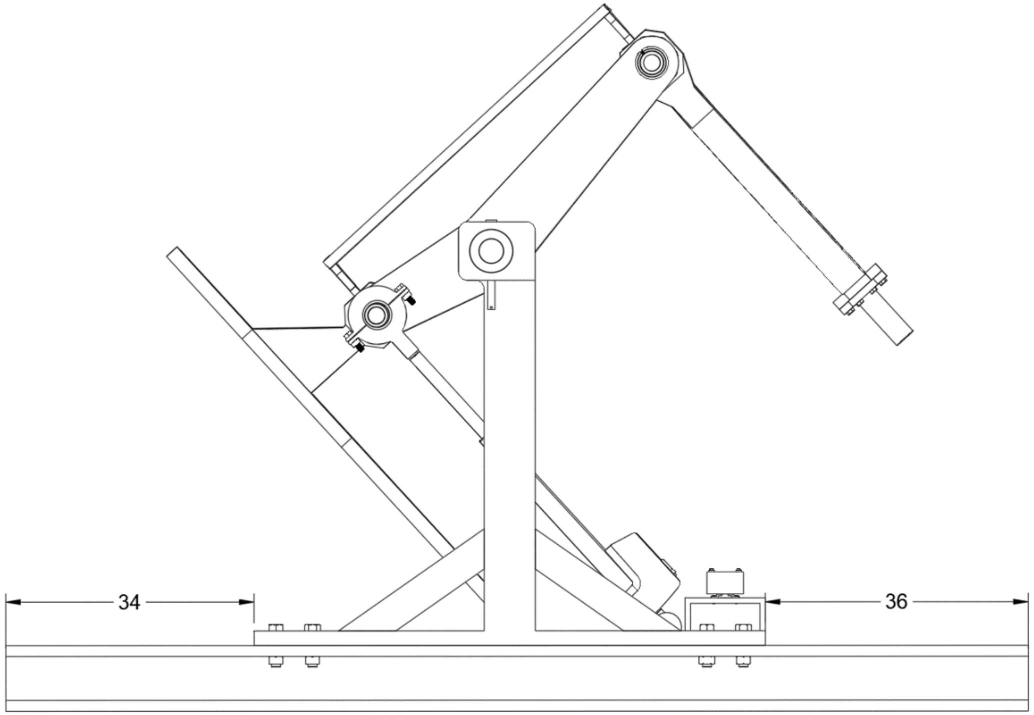
Key Features

- Forklift Stable
- Configurable Cg’s and Tipping
- Museum Height Requirements
- Linear Actuators
- Locking Pins
- Turn Table
- Electrical Diagrams

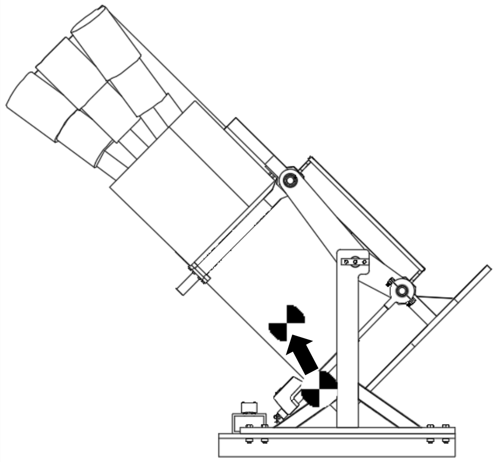
MECH MOTION DYNAMICS

Forklift Stable





Configurable CG's and Tipping



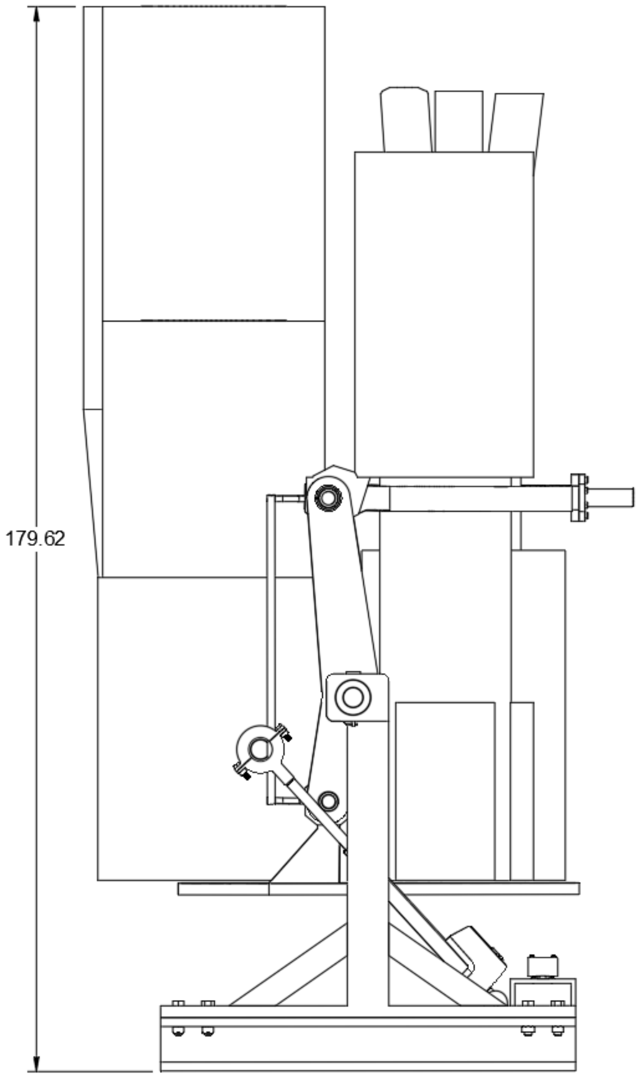
Item	Weight (lbs)	CG, X (in)	CG, Y (in)	CG, Z (in)
Composite Astro System	6601	46.2	1	0.4
HUT	1555	44.4	-16.2	25.1
UIT	816	46.3	25.3	21
IRS	633	34.8	27	-31.1

Configuration	Weight (lbs)
Composite	6601
Composite-HUT-UIT	4230
Composite-HUT-UIT-IRS	3597
Assumed Mass for Maximum Load	8000

$$CG_x = \frac{\sum W_i x_i}{\sum W_i}, CG_y = \frac{\sum W_i y_i}{\sum W_i}, CG_z = \frac{\sum W_i z_i}{\sum W_i}$$

Item	Weight (lbs)	CG, X (in)	CG, Y (in)	CG, Z (in)
Composite Astro System	6601	46.2	1	0.4
Composite-HUT-UIT	4230	46.842	2.635	-12.654
Composite-HUT-UIT-IRS	3597	48.962	-1.652	-9.408
Assumed Mass for Maximum Load	8000	46.2	1	0.4

Museum Height Requirements

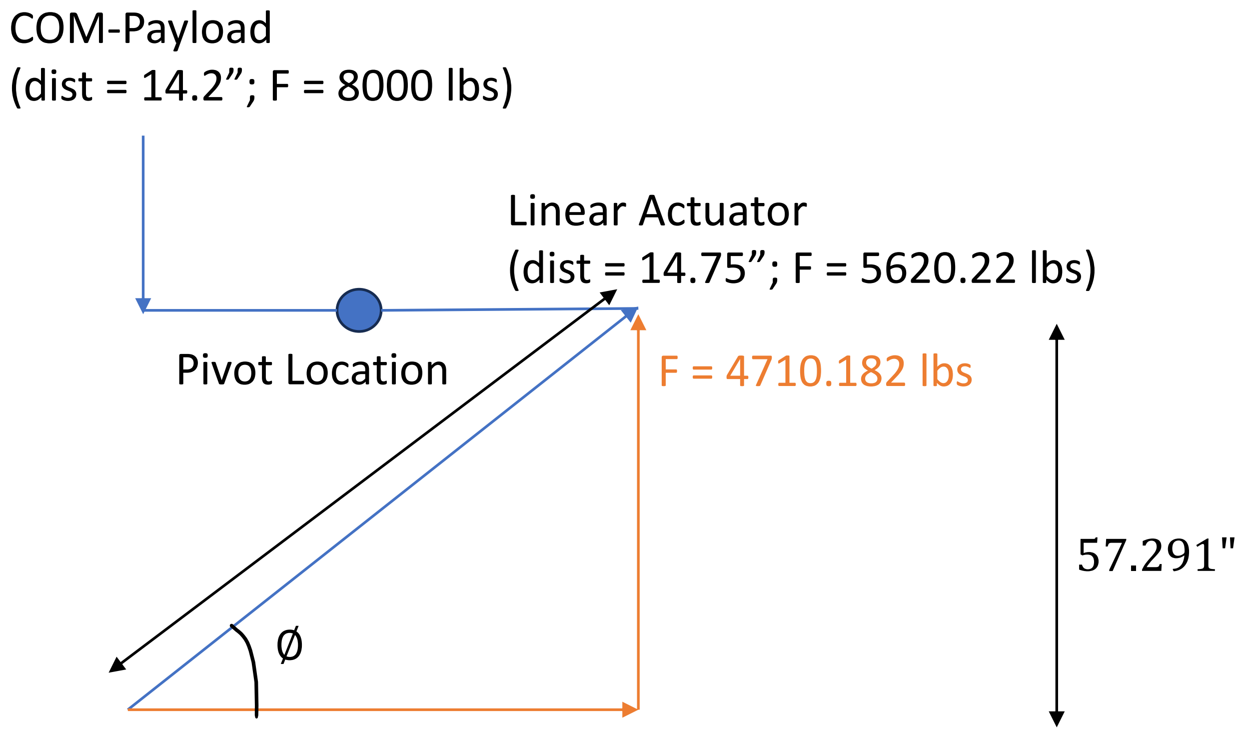


Linear Actuators

- Designed to pitch the payload to a desired orientation
- Two Thomas Electrak XD Actuators (Model B250)
- Each capable of 25,000 N (5620.22 lbs) loads

- Torque required :113,600 lbs-in
- Torque capable: 138,950 lbs-in

Linear Actuators - Math



$$\text{Torque}_{\text{Payload}} = (9605 \text{ lbs}) * (14.2 \text{ in.})$$
T_{Payload}= 136,391 lbs-in

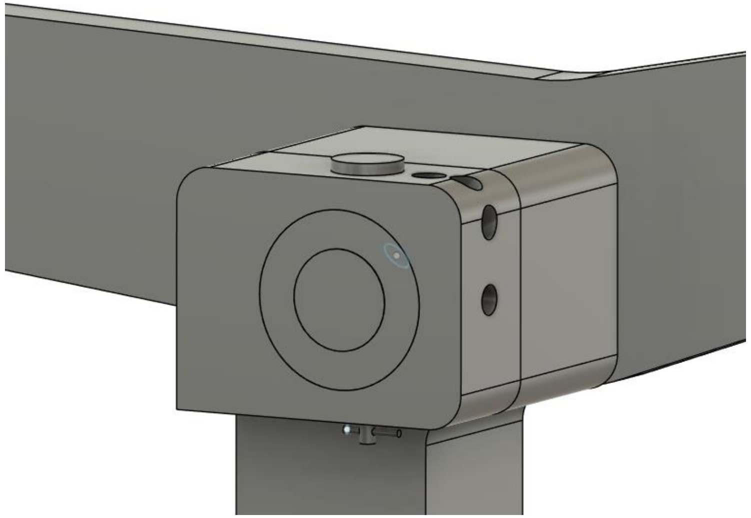
$$\text{Torque}_{\text{Actuator}} = (4710.182 \text{ lbs}) * (14.75 \text{ in.})*(2)$$
T_{Actuator}= 138,950 lbs-in

$$T_{\text{Actuator}} > T_{\text{Payload}}$$

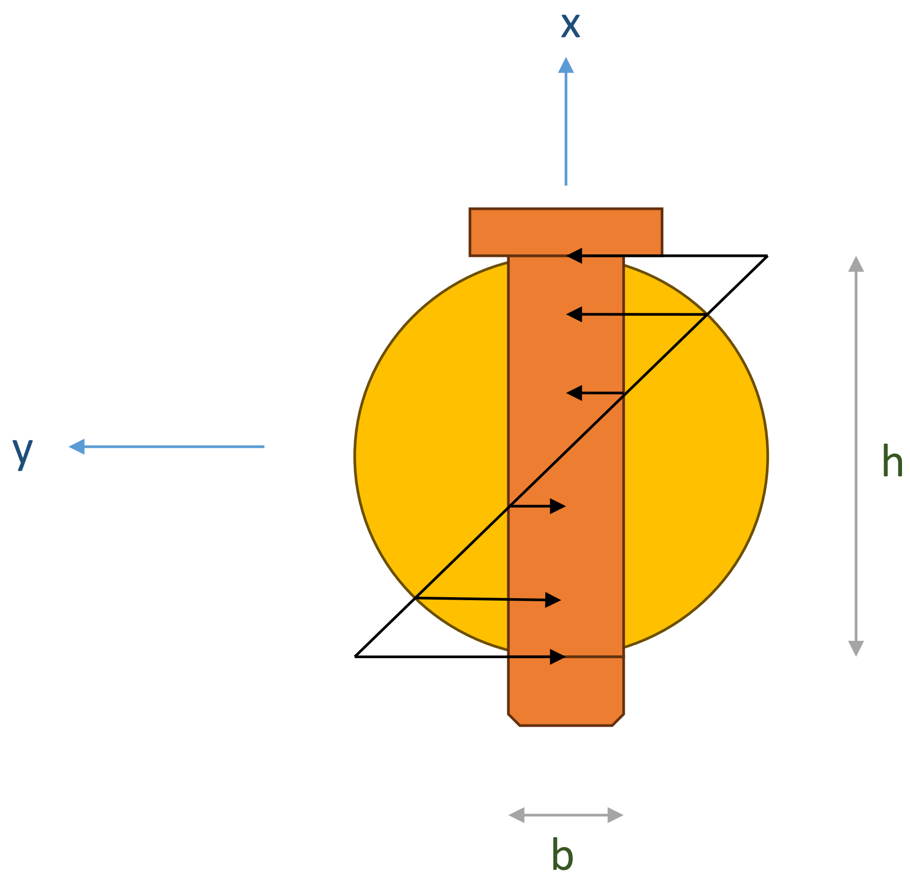
Payload Configuration	Weight [lbs]	Torque [lbs-in]
Full Payload	9,605	136,391
CAS + HUT + UIT	8,972	134,116
CAS + HUT	8,156	121,599
CAS	6,601	100,491

Locking Pins

- Designed to assist with keeping payload in desired orientation by mitigating stress on other components
- 6”-Ø2” center part; points out for ease of insert; cap and pin hole to be secured into place



Locking Pins - Math



Torque of 7,700 N-m acting on the shaft which goes into the pin

- h = 6” = 0.1524 m
- Sy = 210 MPa
- No normal stress
- n = 3

$$\tau_{xy} = \frac{Tr}{J}; r = \frac{h}{2} \qquad J = I_{xx} + I_{yy} = \frac{1}{12}b^3h + \frac{1}{12}h^3b$$

$$\sigma' = \sqrt{\sigma_x^2 + \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2} = \frac{S_y}{n}$$

$$b = 0.045233 \text{ m} = 1.78'' \approx 2''$$

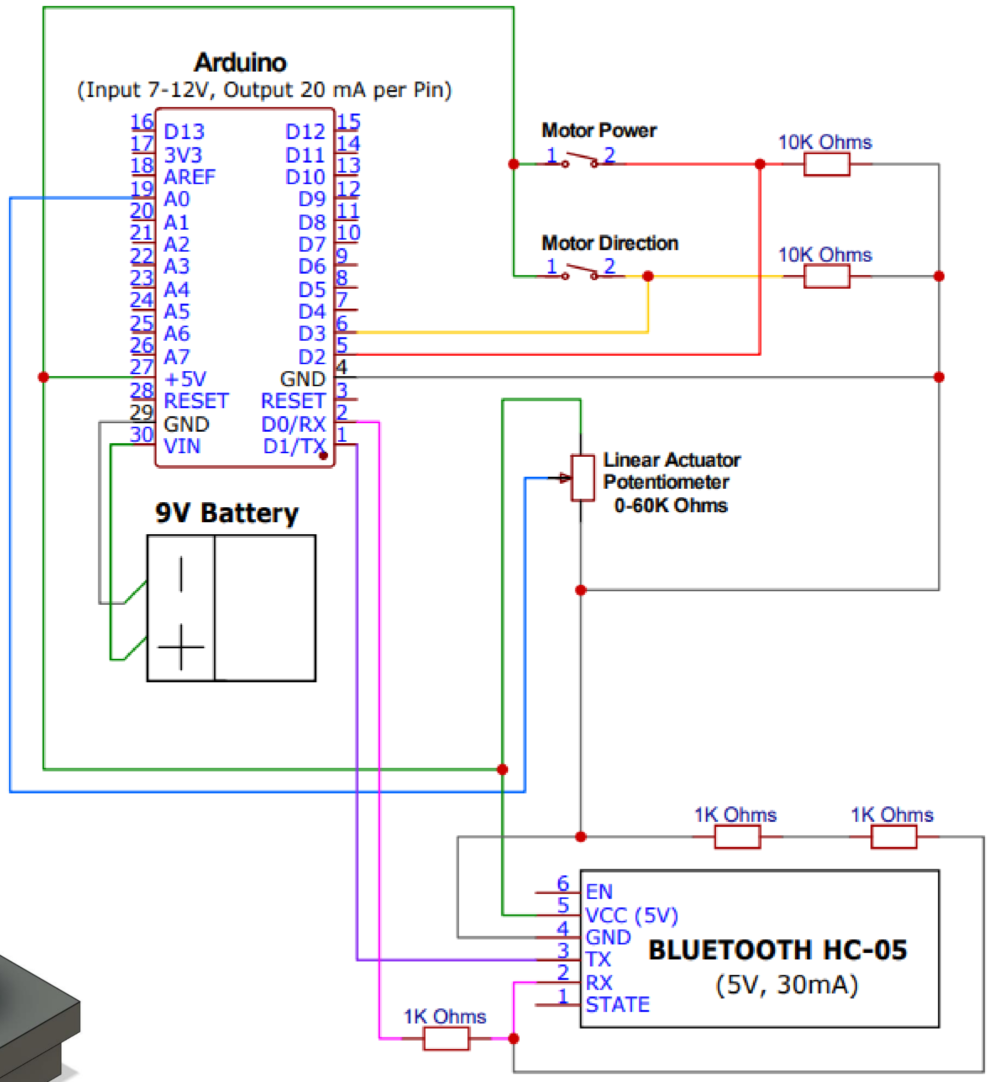
Payload Configuration	Weight [kg]	Torque [N-m]
Full Payload	4,357	7,700
CAS + HUT + UIT	4,069	7,570
CAS + HUT	3,699	6,864
CAS	2,994	5,672

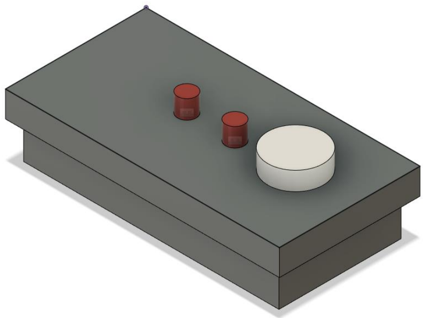
Turntable

- Designed to be low-profile and discrete so as not to distract from the display.
- Powered using a compliant rubber wheel attached to a 12V motor.

Electrical Schematic – Controller

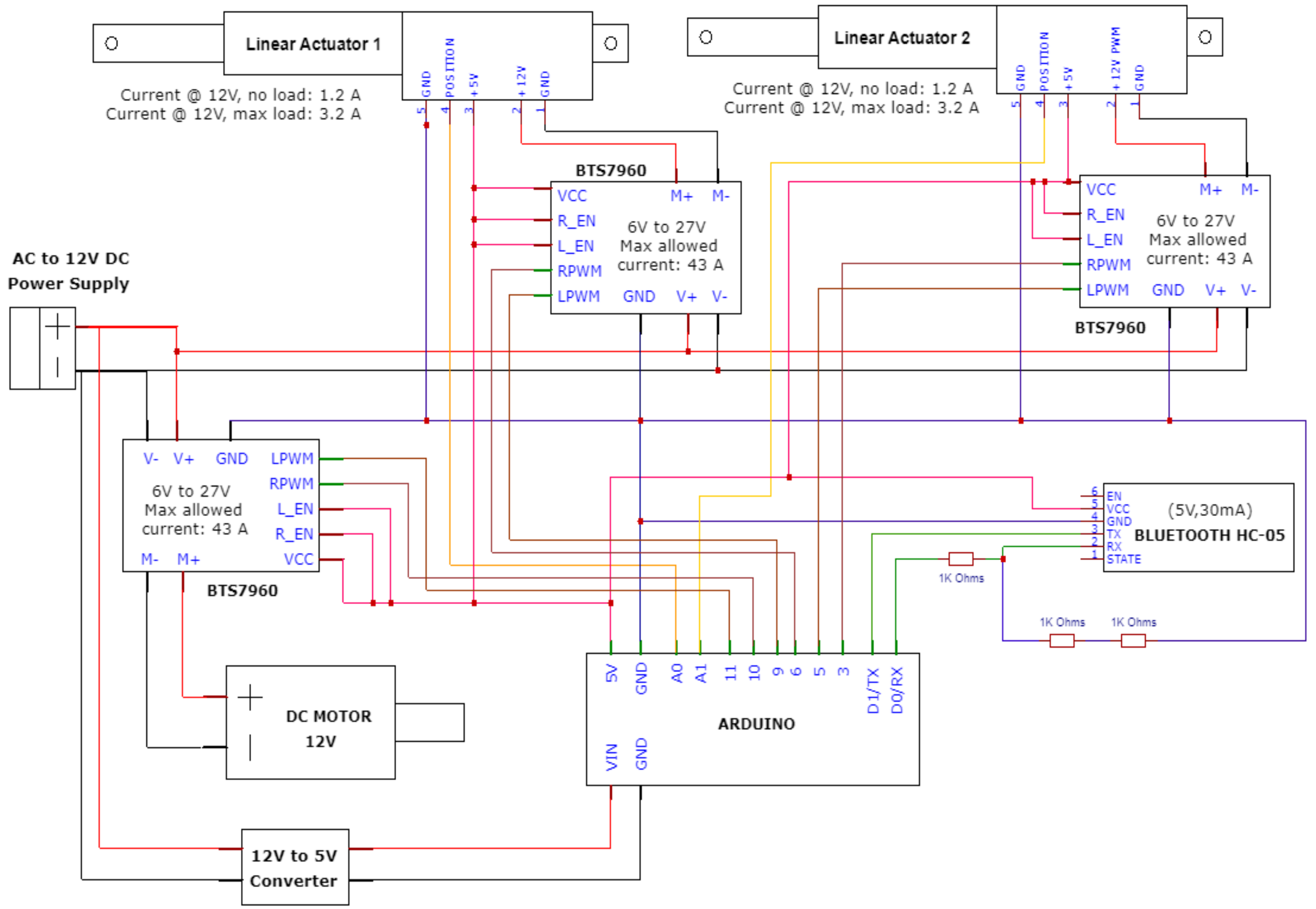
- Separate Bluetooth Controller
- Powered with a replaceable battery
- Button and Potentiometer states are transmitted to the receiver Bluetooth module on the stand
- States are put into a string and are transmitted through the Arduino Serial connection



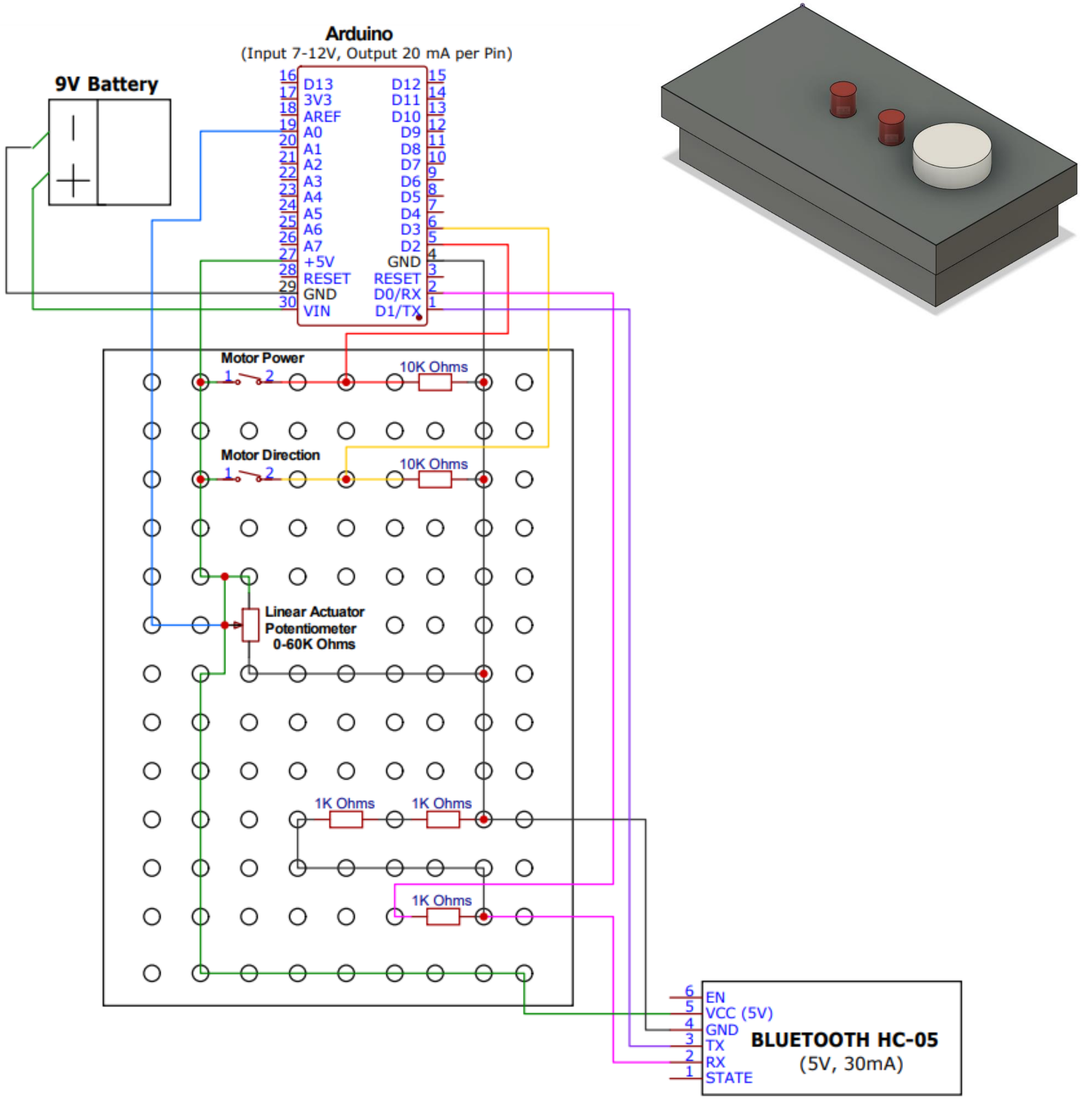


Electrical Schematic – Display

- Motor controller for each linear actuator
- Power supplied from the 12V outlet
- Receives String from Bluetooth module and uses it to set motor states
- Controls Linear Actuator position with a bang-bang controller

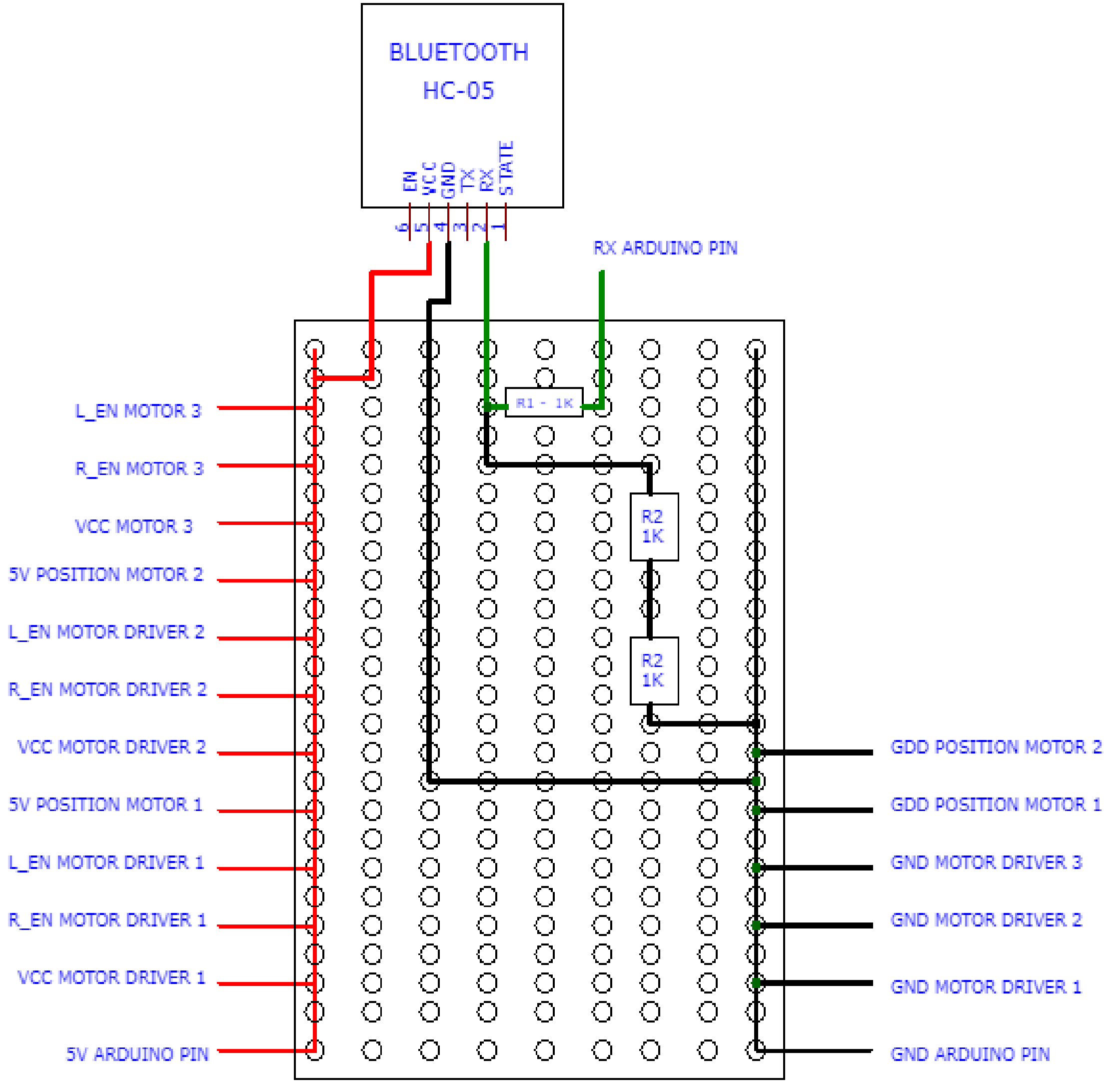


Perf Board Schematic - Controller



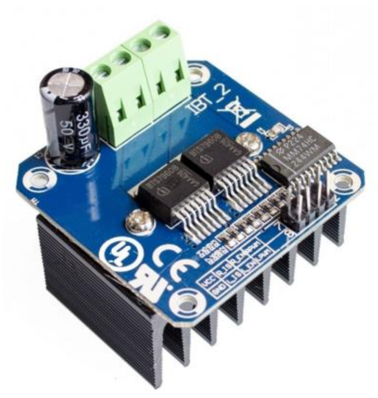
- Main items that are attached are resistors, voltage divider
- Buttons/Potentiometers are attached to the perf board through wires as they are glued to the controller

Perf Board Schematic - Display



- Connects the 5V output pin of the Arduino:
  - VCC, R_EN, and L_EN pins on the motor driver module
  - 5V motor wire of the position feedback circuit on the motor.
  - Bluetooth device
- Connects the GND pin of the Arduino:
  - Motor Driver 1, 2 and 3
  - Bluetooth Device GND

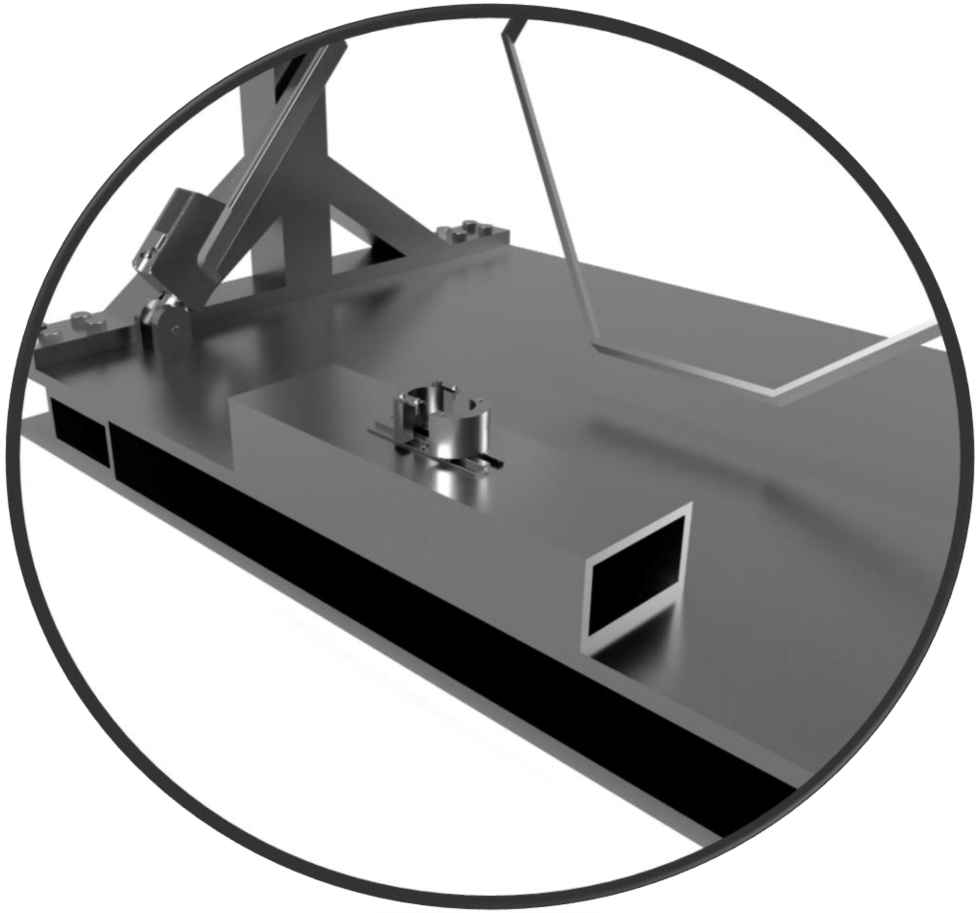
Voltage and Current specs for Full and 1/5 Scale Linear Actuators

BTS7960 Motor Driver	Voltage and max allowed current	1/5 scale Linear actuator LACT6P-12V-20 Light-Duty Linear Actuator with Feedback 	Full-scale Linear Actuator Electrak® XD Linear Actuators 
	6 - 27 V	12 V	24 V
	43 A	3.2 A	30 A

Design Highlights

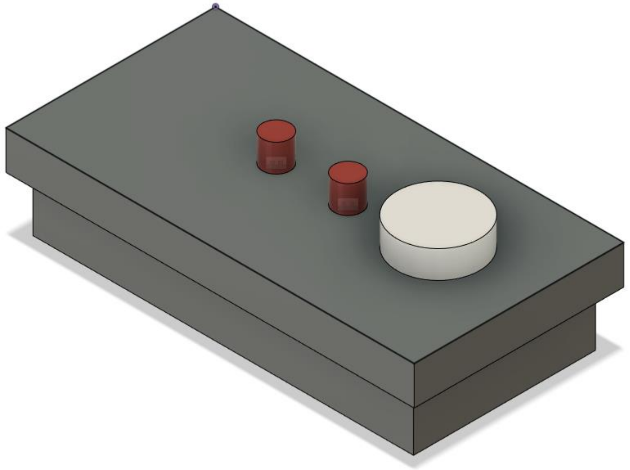
- Horizontal Locking Mechanism
- Bluetooth Controller
- Locking Mechanism
- Forklift Transportable Base Plate

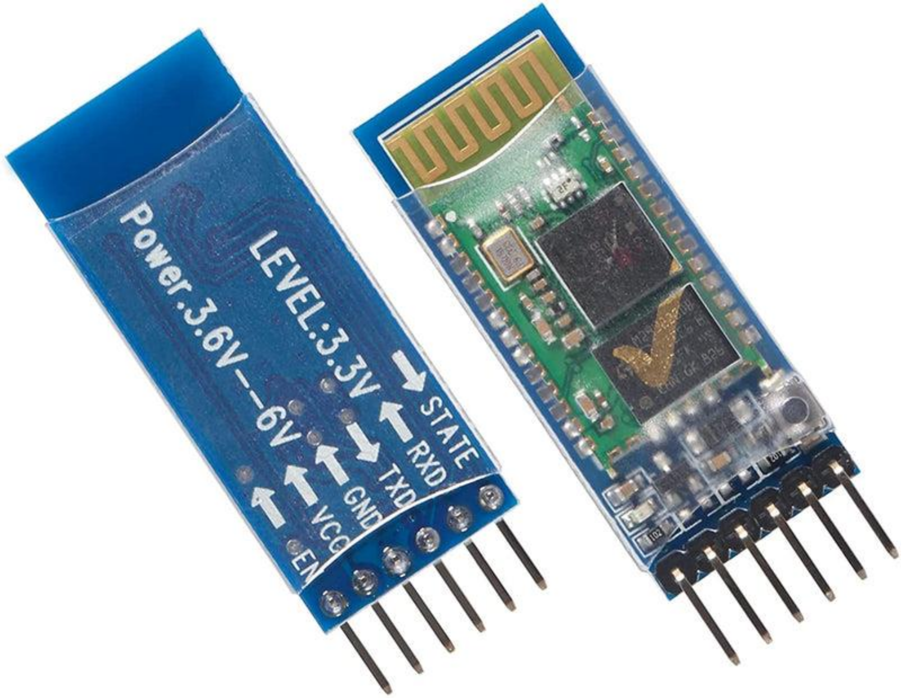
Horizontal Locking Mechanism



Bluetooth Controller

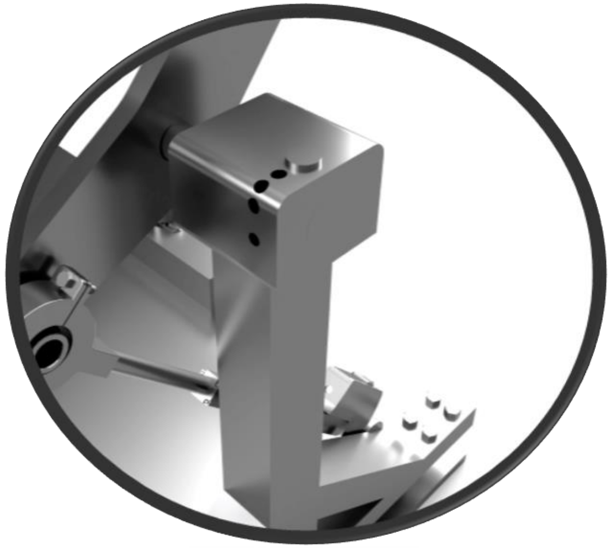
- Utilizing HC-05 Bluetooth Module
- Remotely connect the controller and the motors/actuators on the turntable
- Removes need for another wired connection
- Aesthetically pleasing
- Easily replaced and accessible for maintenance
- Connection up to 100 meters away



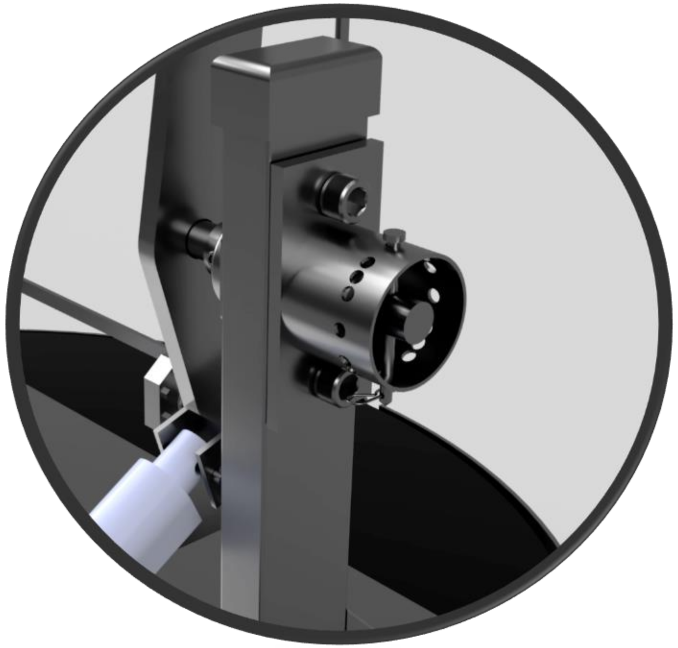


Locking Mechanism

- Full Scale Locking Mechanism



- 1/5 Scale Locking Mechanism



Forklift Transportable Base Plate

Design Evolution

- Changes in full-scale model
  - Changes were made due to customer needs, safety, and simplicity
- Changes in 1/5th – scale model
  - Changes were made to increase manufacturability in lab and to represent the functions of the full-scale model

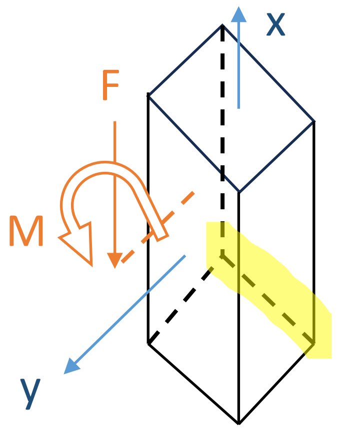
Evolution of Full-Scale Model

- Moved support beams so that linear actuators were not going through them and changed thickness
- Changed how the shaft works and its dimensions
- Added locking mechanism
- Changed the size of the baseplate

Support Beams - Full-Scale Evolution

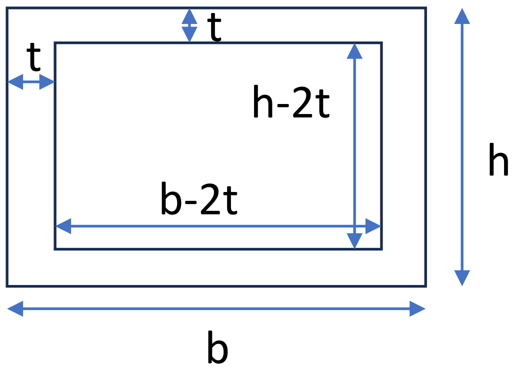
- Increased manufacturability, added to ease of maintenance, and kept simple by removing hole where actuator goes through
- Changed the thickness of the support beam to meet a factor of safety of 3

Support Beams - Math



Location of concern for the support beams (lower outside edge)

Cross-Section area of beam



$$\sigma_{x,normal} = \frac{F}{A} \qquad \sigma_{x,bending} = \frac{Mc}{I_{yy}}$$

$$A = A_w - A_o = hb - (h-2t)(b-2t)$$

$$I_{yy} = I_{yy,w} - I_{yy,o} = \frac{1}{12}(hb^3) - \frac{1}{12}\left((h-2t)(b-2t)^3\right)$$

$$\sigma' = \sqrt{\sigma_x^2 + \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2} = \frac{S_y}{n}$$

$$\sigma_x = \sigma_{x,bending} - \sigma_{x,normal}$$

$$t = 0.0023871\ m$$

$$t = 0.094\text{“} \approx 0.125\text{"} = 1/8\text{"}$$

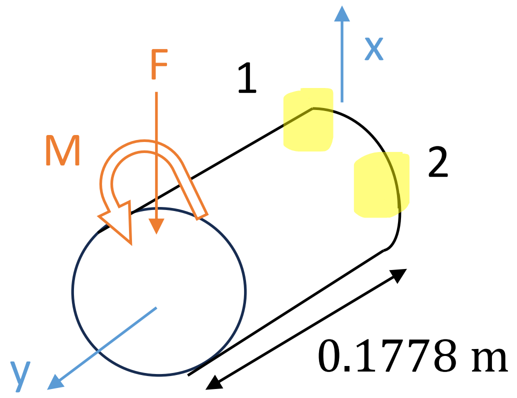
- b = 0.3098 m
- h = 0.1651m
- Only normal stress in x-direction
- n = 3
- F = 42,696 /2 N
- M = 55,308 /2 N-m
- Sy = 210 MPa

Payload Configuration	Weight [kg]	Force [N] * 2	Moment [N-m] * 2
Full Payload	4,357	42,696	55,308
CAS + HUT + UIT	4,069	39,876	51,663
CAS + HUT	3,699	36,249	46,964
CAS	2,994	29,338	38,010

Shaft - Full-Scale Evolution

- Increased diameter to meet factor of safety of 3
- Welded into transverse beams
- Attached to support beams via bearings
- Attachment changes allow for use of locking pin

Shaft - Math



Locations 1 and 2 are areas of concern for failure

$$\tau_{yx} = \frac{VQ}{I_{xx}t};\ Q = A\frac{\bar{y}}{2};\ V = F$$

$$\sigma_{y,bending} = \frac{Mc}{I_{xx}}$$

$$I_{xx} = \frac{\pi d^4}{64}$$

$$A = \pi r^2$$

- n = 3
- F = 42,696 /2 N
- M = 55,308 /2 N-m
- Sy = 210 MPa

$$\sigma' = \sqrt{\sigma_x^2 + \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{yx}^2} = \frac{S_y}{n}$$

At point 1, only normal force in the y-direction from bending occurs

$$\sigma_{y,1} = \sigma_{y,bending\ (M)} + \sigma_{y,bending\ (F)}$$

$$\sigma_{y,1} = \frac{Mc}{I_{xx}} + \frac{(F * 0.1778m)c}{I_{xx}}$$

$$r = 0.092019 \text{ m} = 3.62''$$

At point 2, normal force in the y-direction from bending and shear in yx-plane occurs

$$r = 0.079545 \text{ m} = 3.13''$$

$$r = 3.75''$$

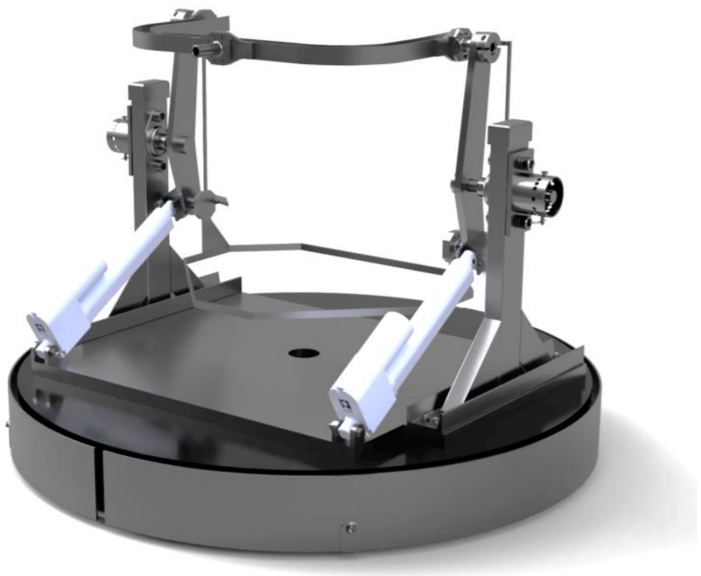
Payload Configuration	**Weight [kg]**	**Force [N] * 2**	**Moment [N-m] * 2**
Full Payload	4,357	42,696	55,308
CAS + HUT + UIT	4,069	39,876	51,663
CAS + HUT	3,699	36,249	46,964
CAS	2,994	29,338	38,010

Locking Mechanism - Full-Scale Evolution

- Was not used previously
- Added extra layer of security for payload orientation
- Helps keep payload in desired angle
- Relieves stress from actuators while stationary
- Meets customer needs
- Meets factor of safety of 3

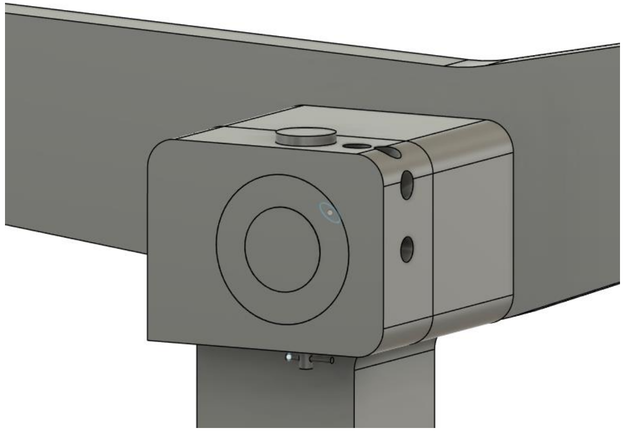
Evolution of 1/5th – Scale Model

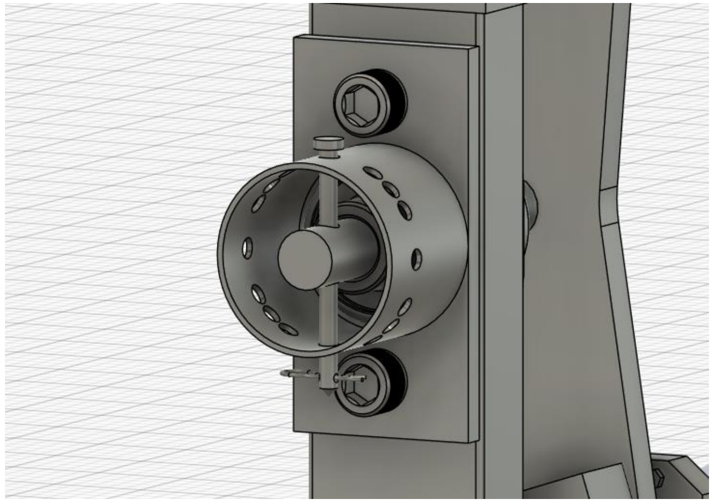
- Changed everything to utilize nominal sized parts and ensure manufacturability



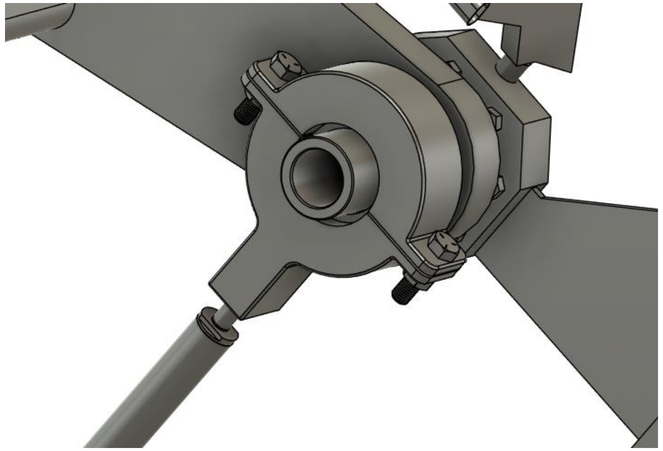
Notable Changes - Scaled Model Evolution

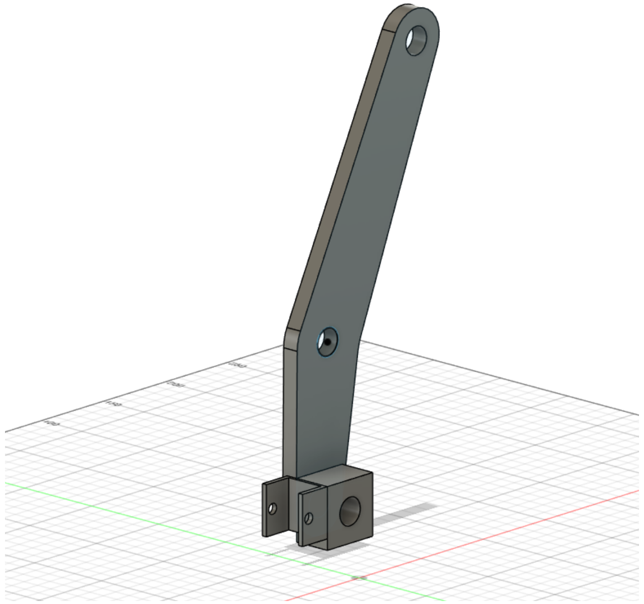
Locking Mechanism



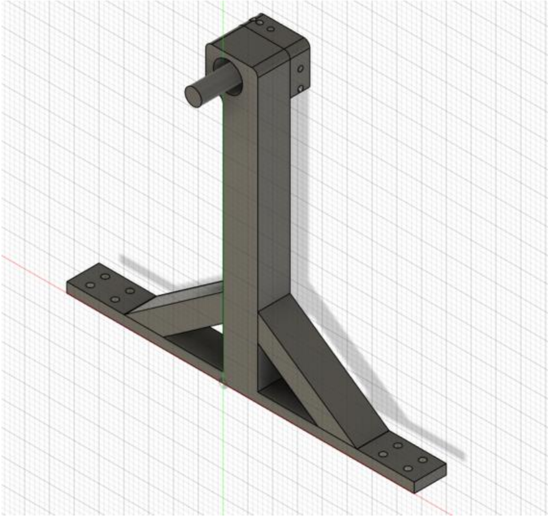


Linear Actuator Connection

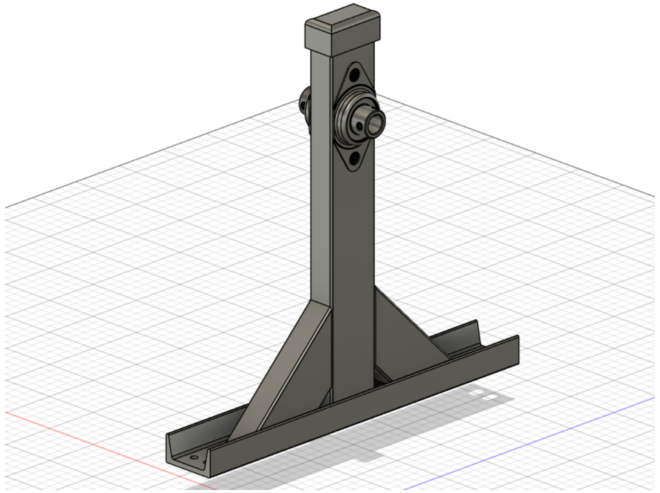




Support Beams

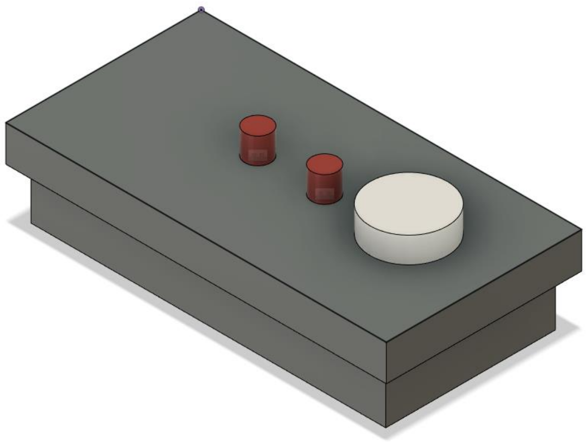


Full-Scale

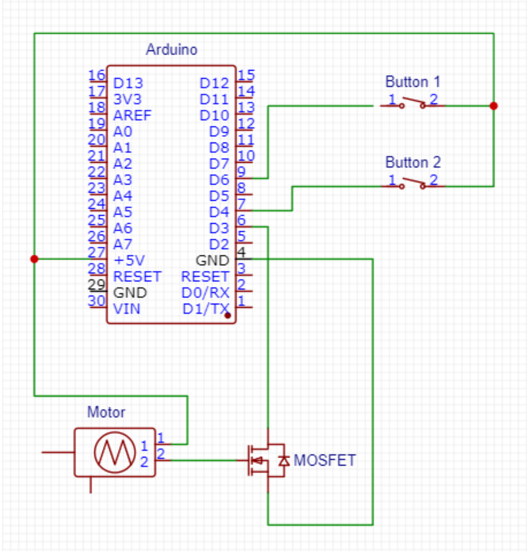


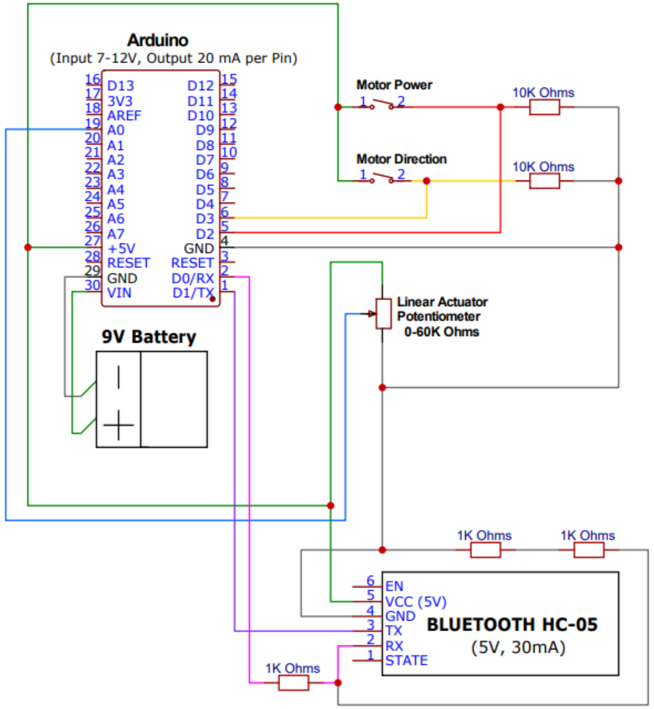
1/5th-scale

Electrical Diagrams – Notable Changes



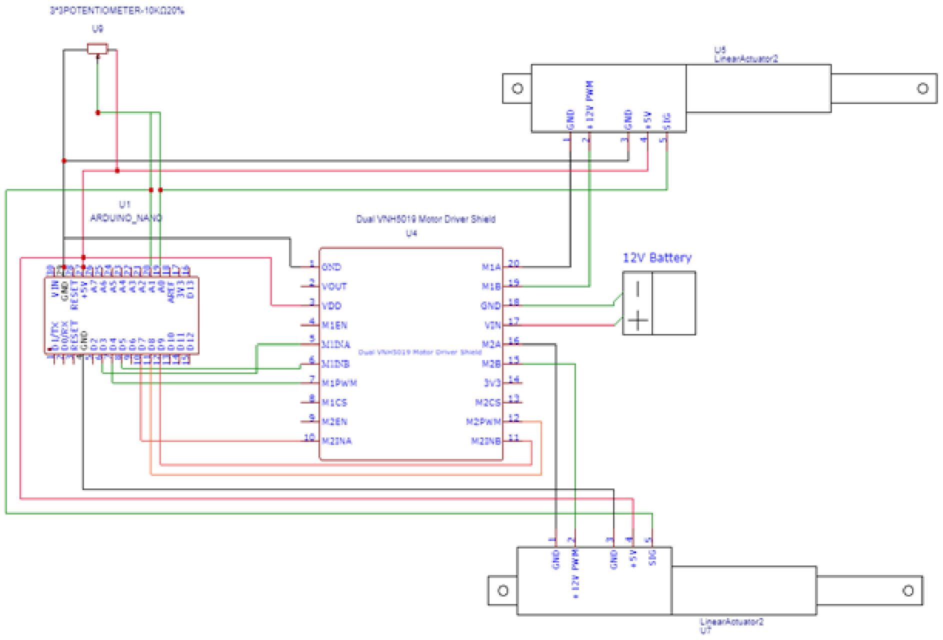
- Moved motor and linear actuators to the same circuit with motor controller
- Use of dedicated controller with Bluetooth

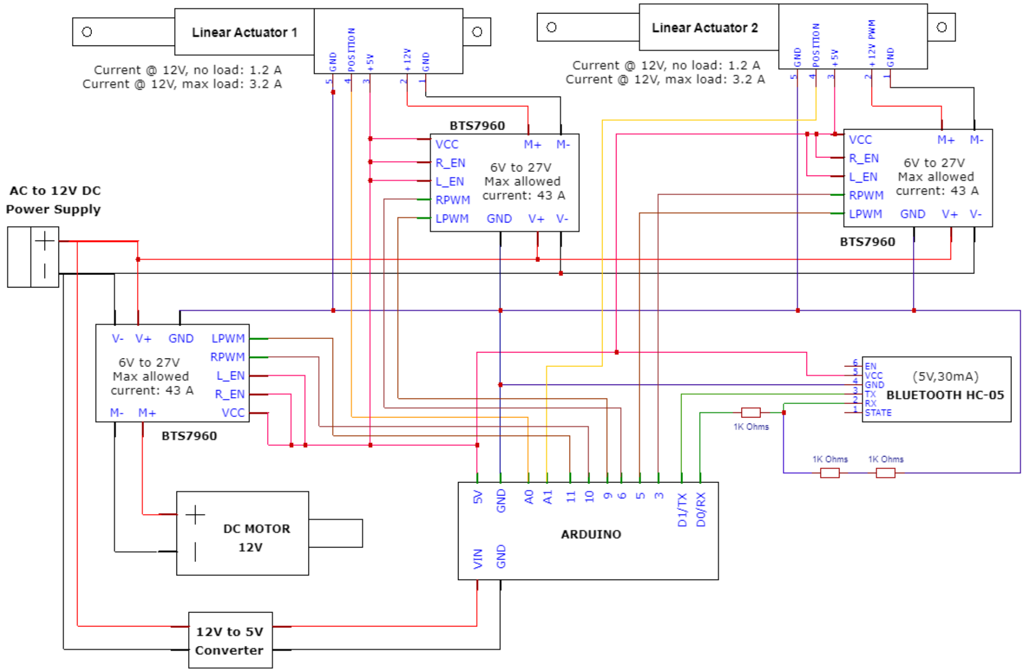




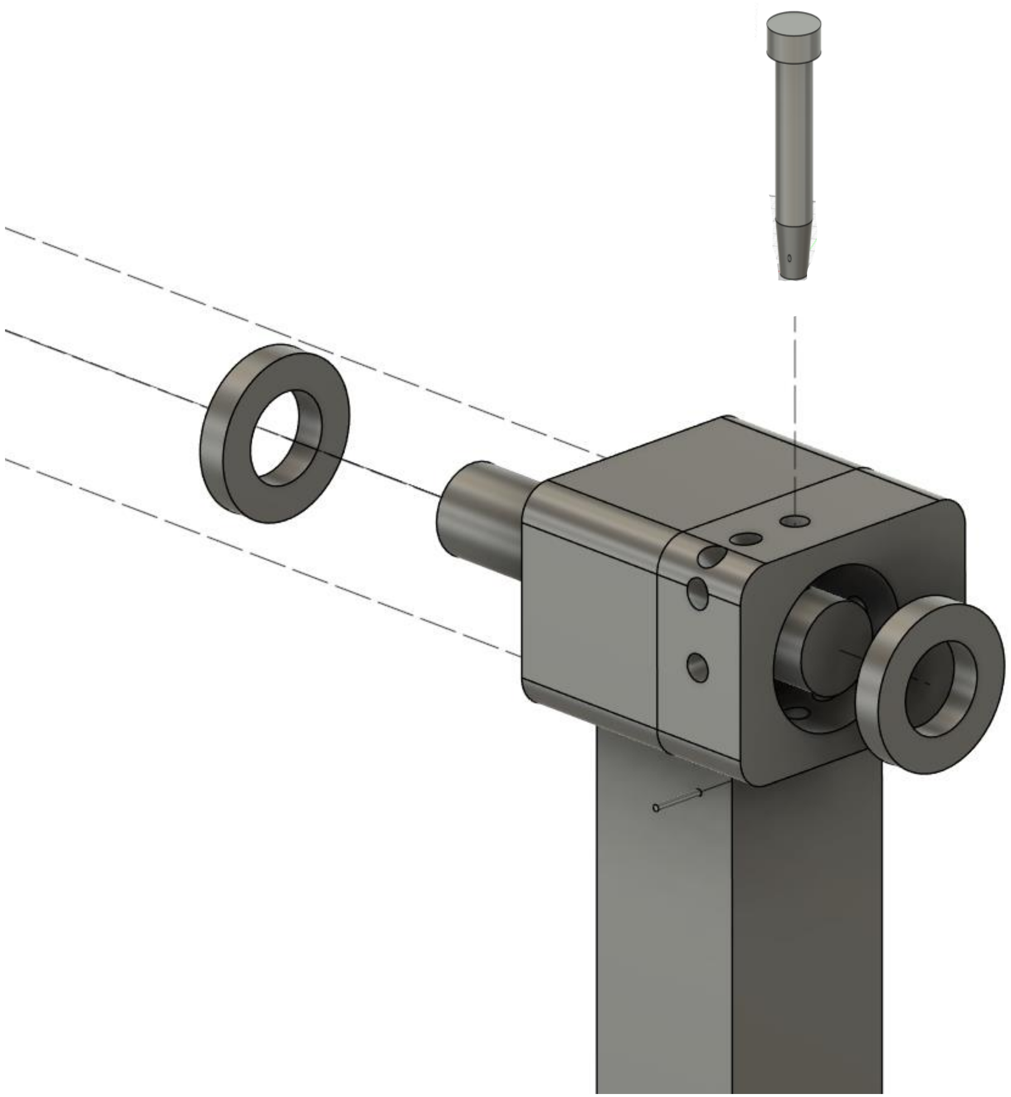
Electrical Diagrams – Notable Changes

- Potentiometer moved to the controller, utilization of multiple motor controllers to avoid use of more Arduinos
- Proper power supplied by the wall outlet

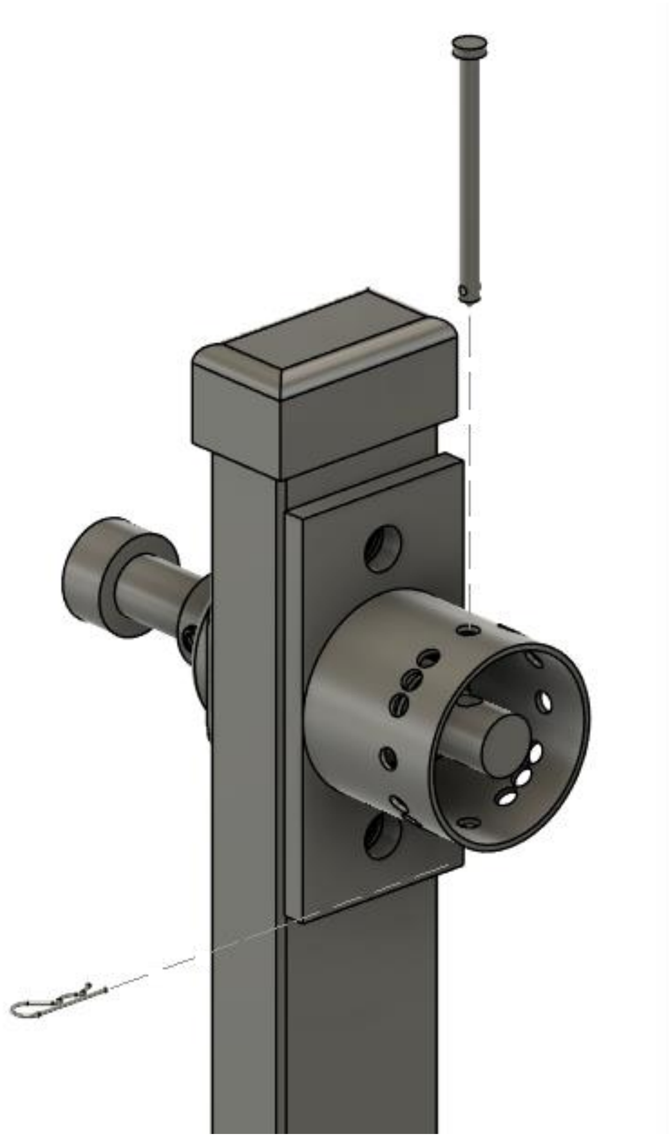




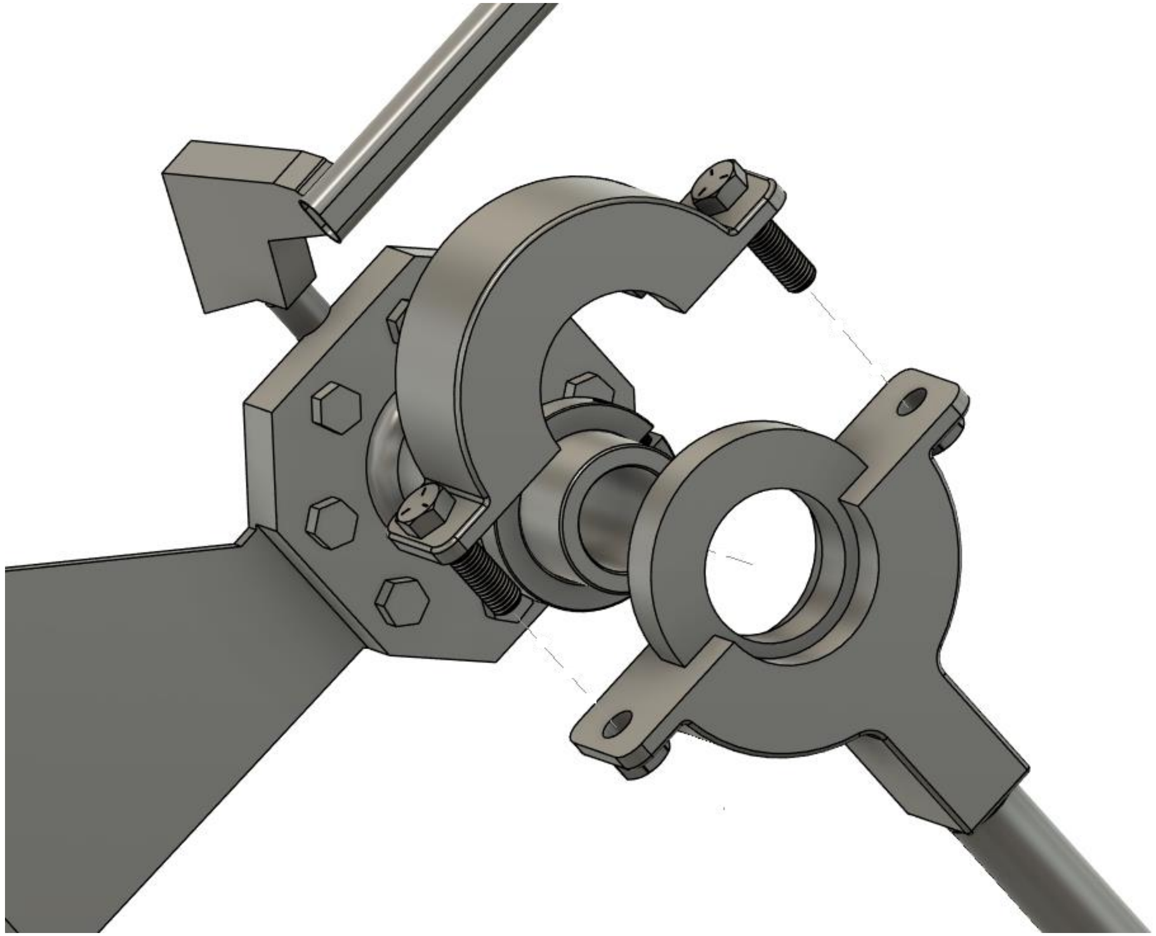
Full Scale Exploded CAD View



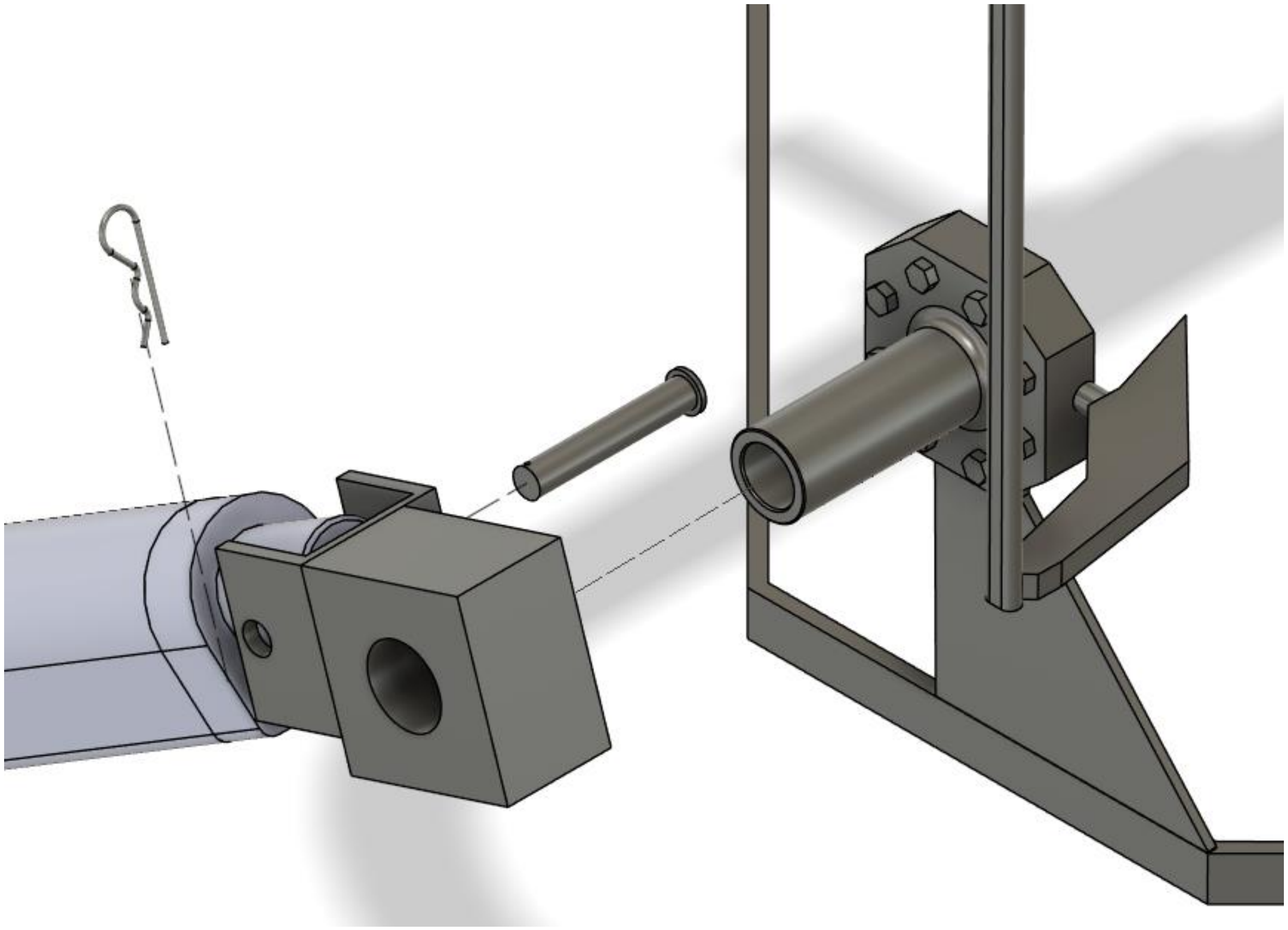
1/5 Scale Exploded CAD View



Full Scale Exploded CAD View



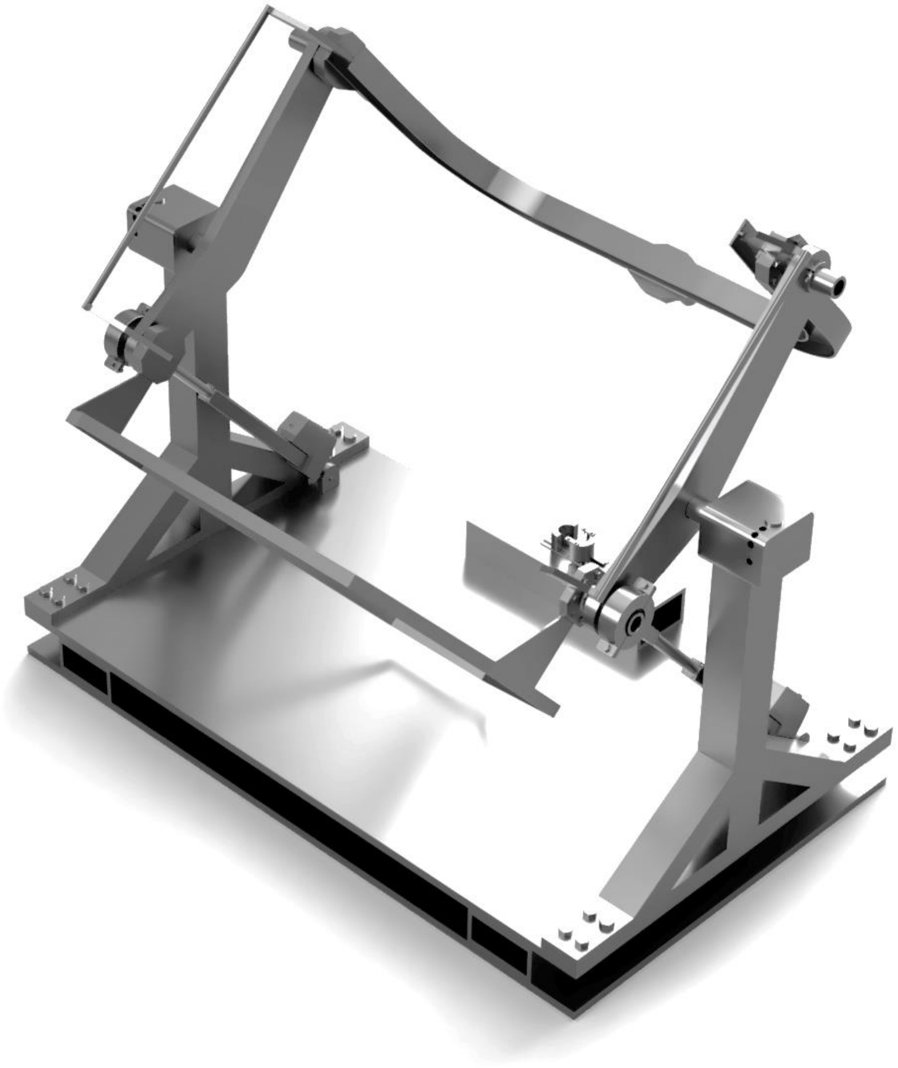
1/5 Scale Exploded CAD View



Cost Table Summary

- 1/5 Scale Cost Breakdown
  - OTS Parts - $795.40
  - Manufacturing - $368.62
  - Assembly - $44.51
  - **Total – $1,208.53**
- Full Scale Cost Breakdown
  - OTS Parts - $7,844.24
  - Manufacturing - $15,038.04
  - **Total - $22,882.28**

Why us?



MECH MOTION DYNAMICS

ASTRO CRADLE

MECH MOTION DYNAMICS