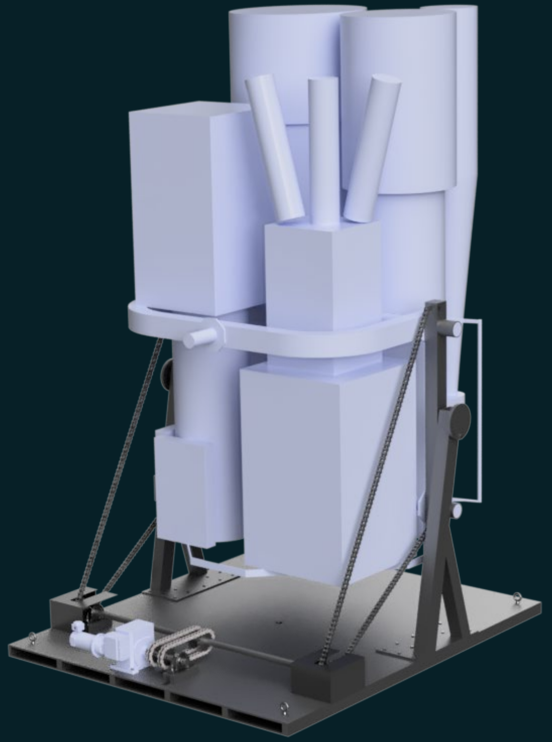
MTOC-3
Celestial Interactions

CEO: Matthew Stutzman

COO: Jacob Elorrieta

CFO: Samuel Theis

Members: Tyler Austhof, Sage Bachus, Brendan McMurrer, Tony Pham, Raquel Schlicht, Grant Trautweiler, James Wardlaw

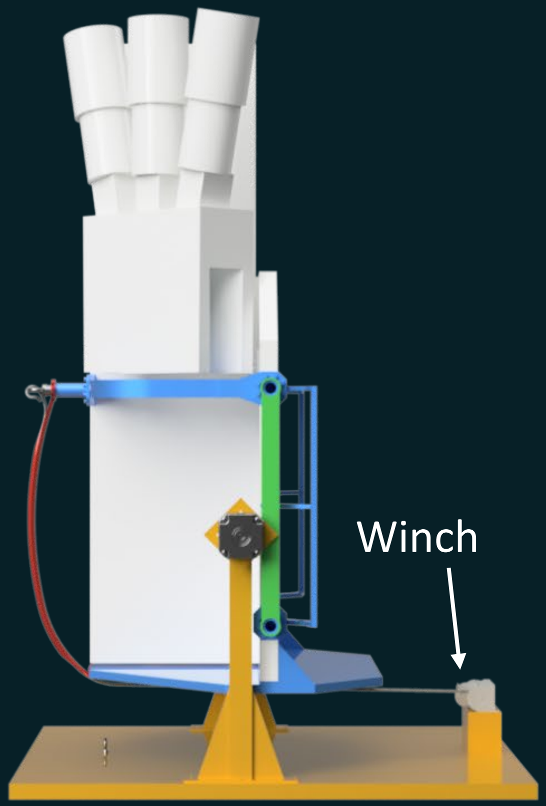


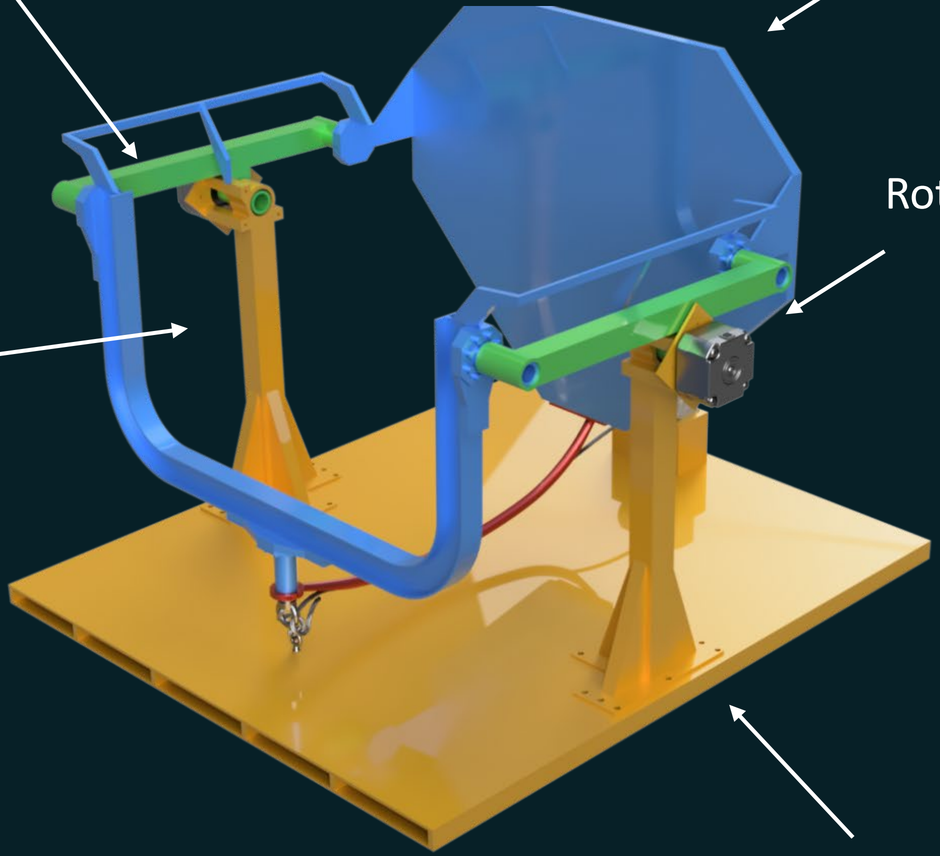
CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Agenda

- Original design and hedgehog concept
- Design Revisions and prototype
- Final design
- Structural analysis
- Manufacturing process
- Cost analysis
- Controls and systems

Original Design

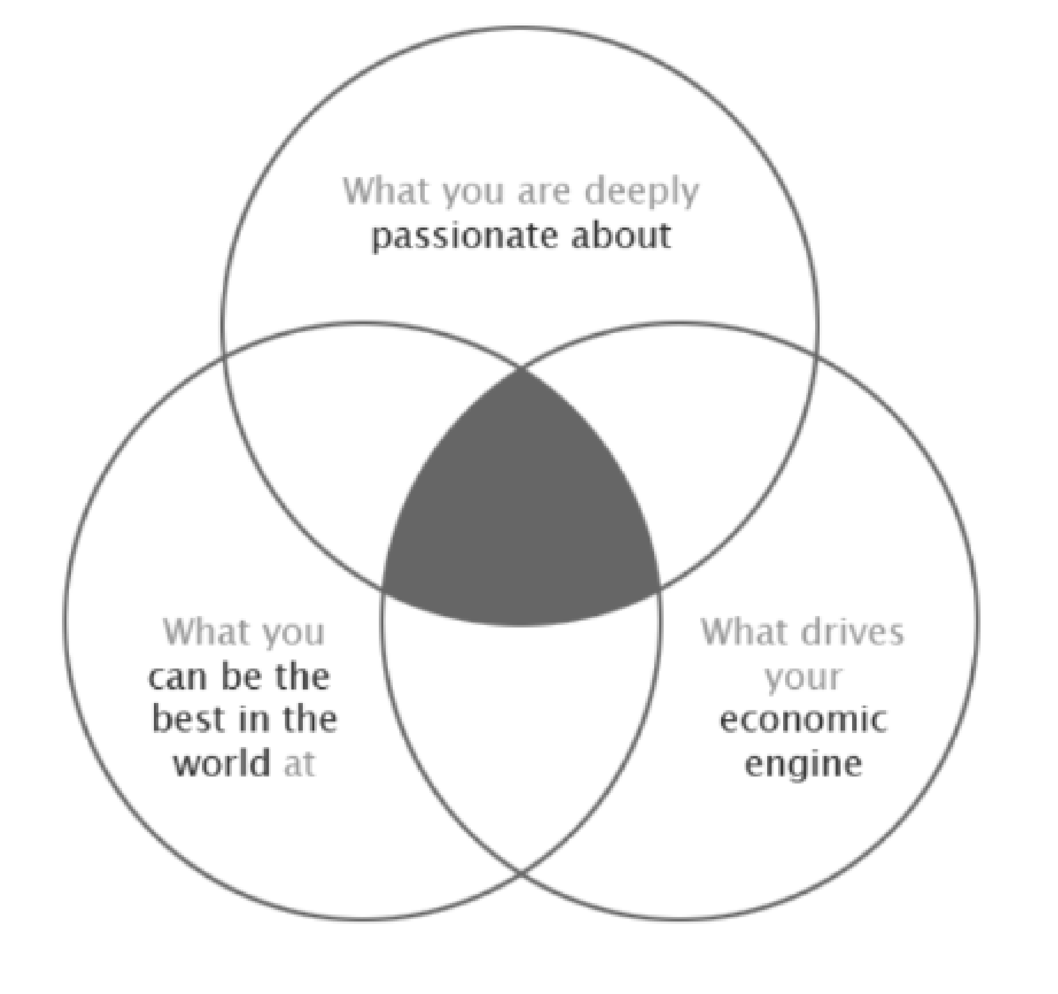




Hedgehog Concept

Design Approach

The celestial interactions team aimed to develop a design for the astro display stand that was as simple as possible, while maintaining a minimal aesthetic to avoid detracting from what is important within the display.



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Design Revisions and Prototype

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

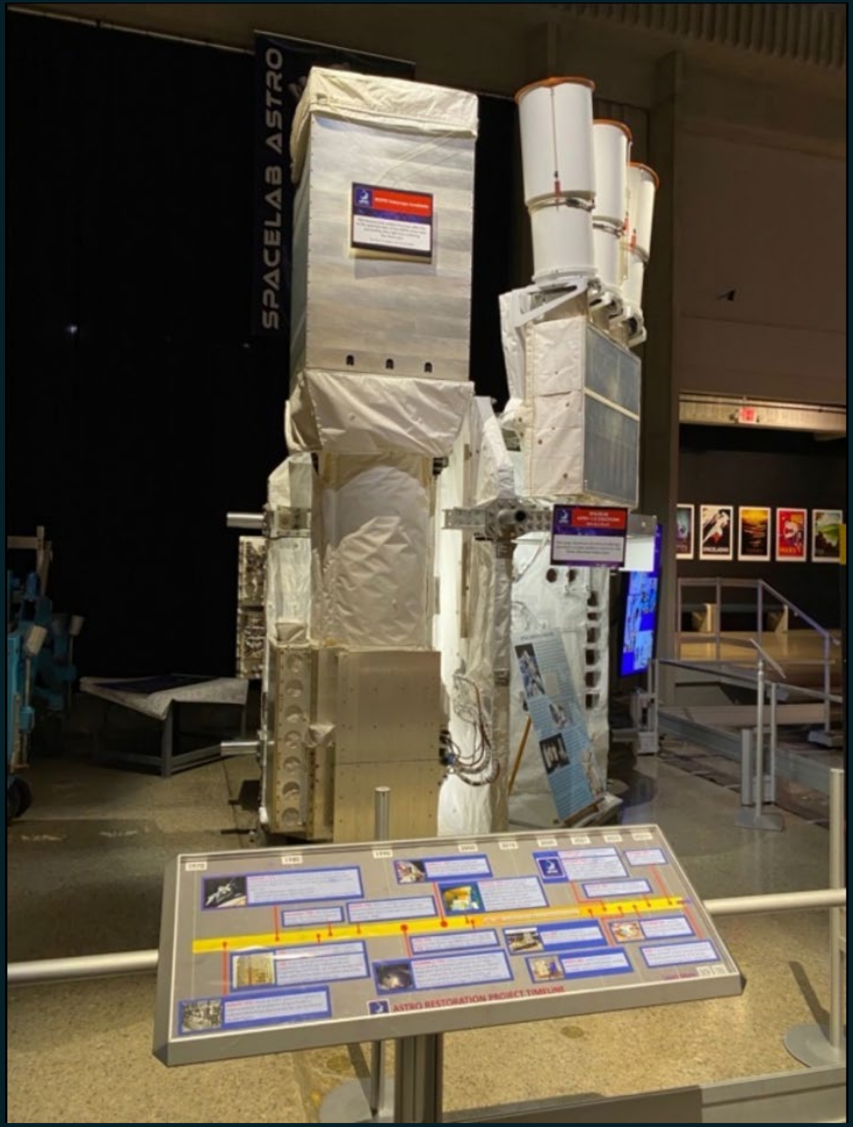
Key Components

1. 1/5 scaled prototype of the Astro Cruciform payload

2. An Astro display stand (ADS) to hold and tilt the 1/5th scale model payload

3. A turntable to display and rotate the product

4. An intuitive control panel



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Key Design Requirements

- Must account for variable CG
- Cost must not exceed $25,000
- Must be able to lock at 15 °, 30 °, and 45°
- Must be two fault tolerant
- Assembled width of for transportation ≤104.3in
- Assembled width for display ≤ 120.0in
- Structural components $F_s \geq 3$

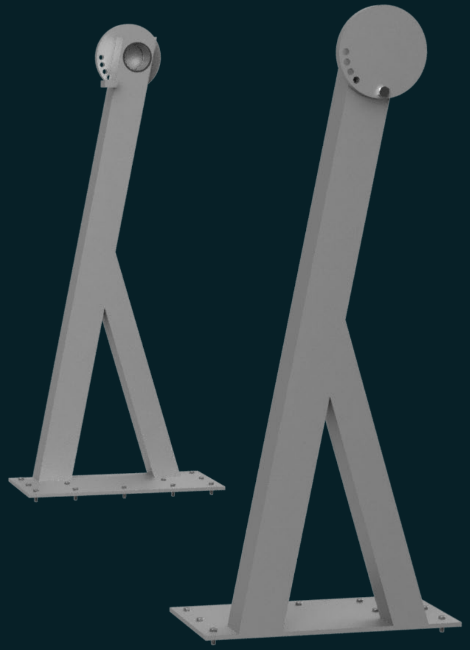
CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Vertical Support Revisions

- Angled to allow trunnion clearance in vertical position

- Added a second support member

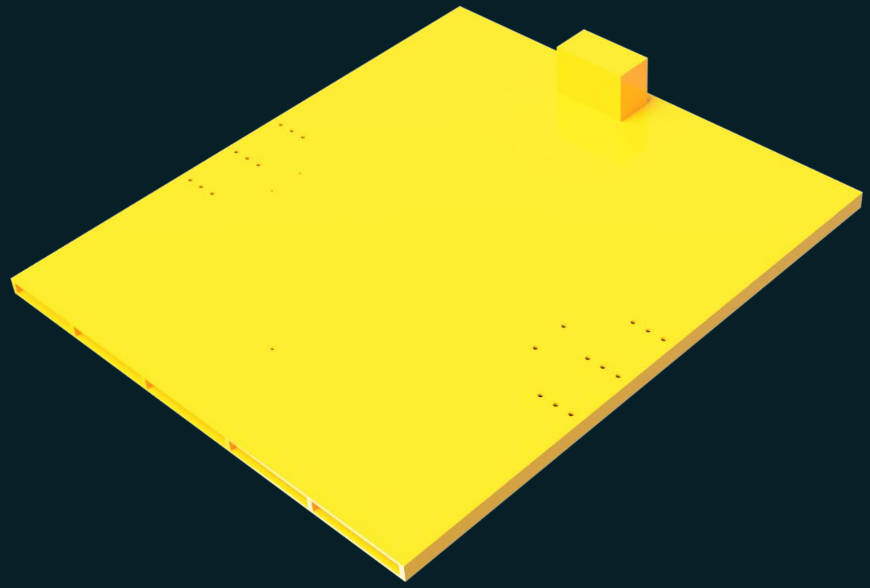
- Replaced rotary damper with locking pin

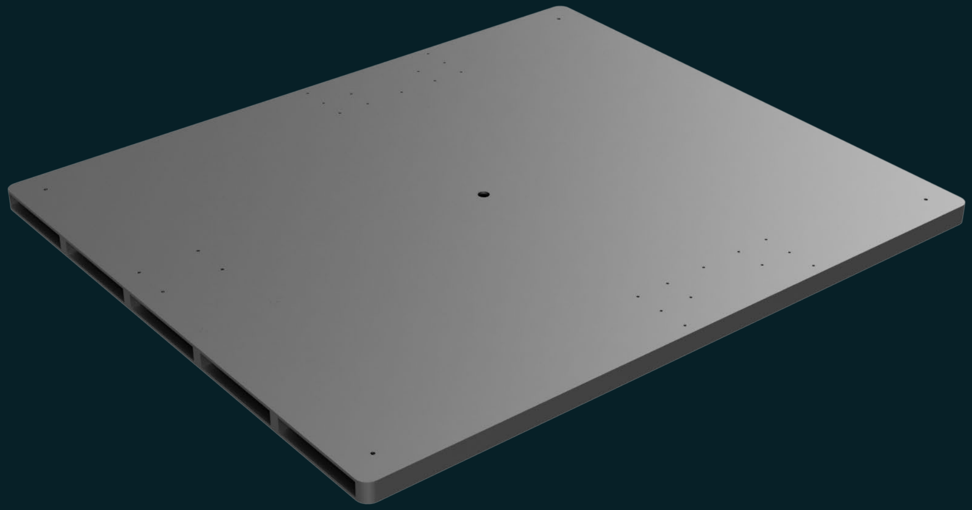


CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Baseplate Revisions

- Rounded corners for safety and aesthetics
- Winch pedestal removed
- Load is placed under columns

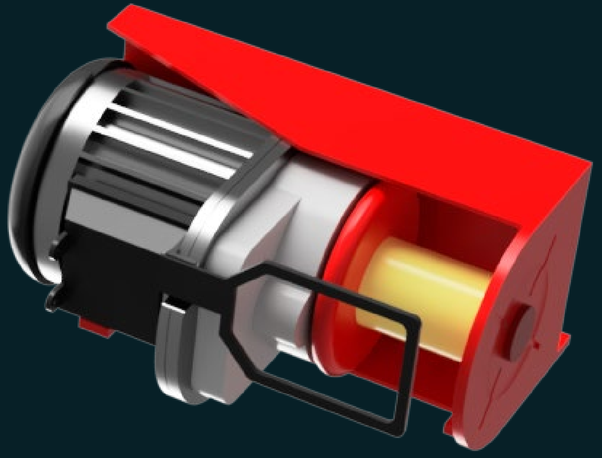


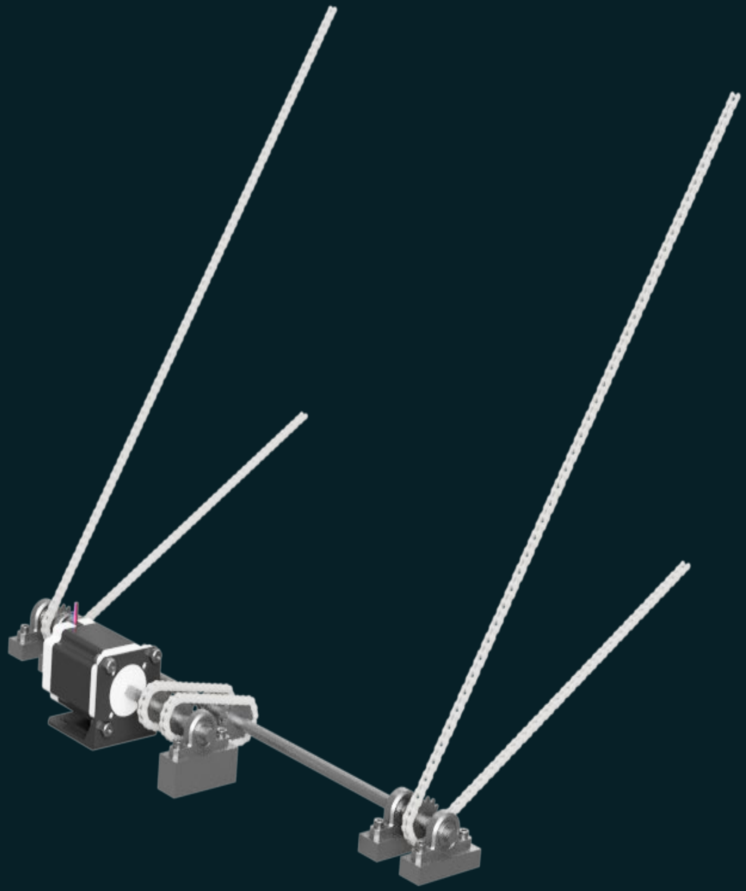


CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Driving System Revisions

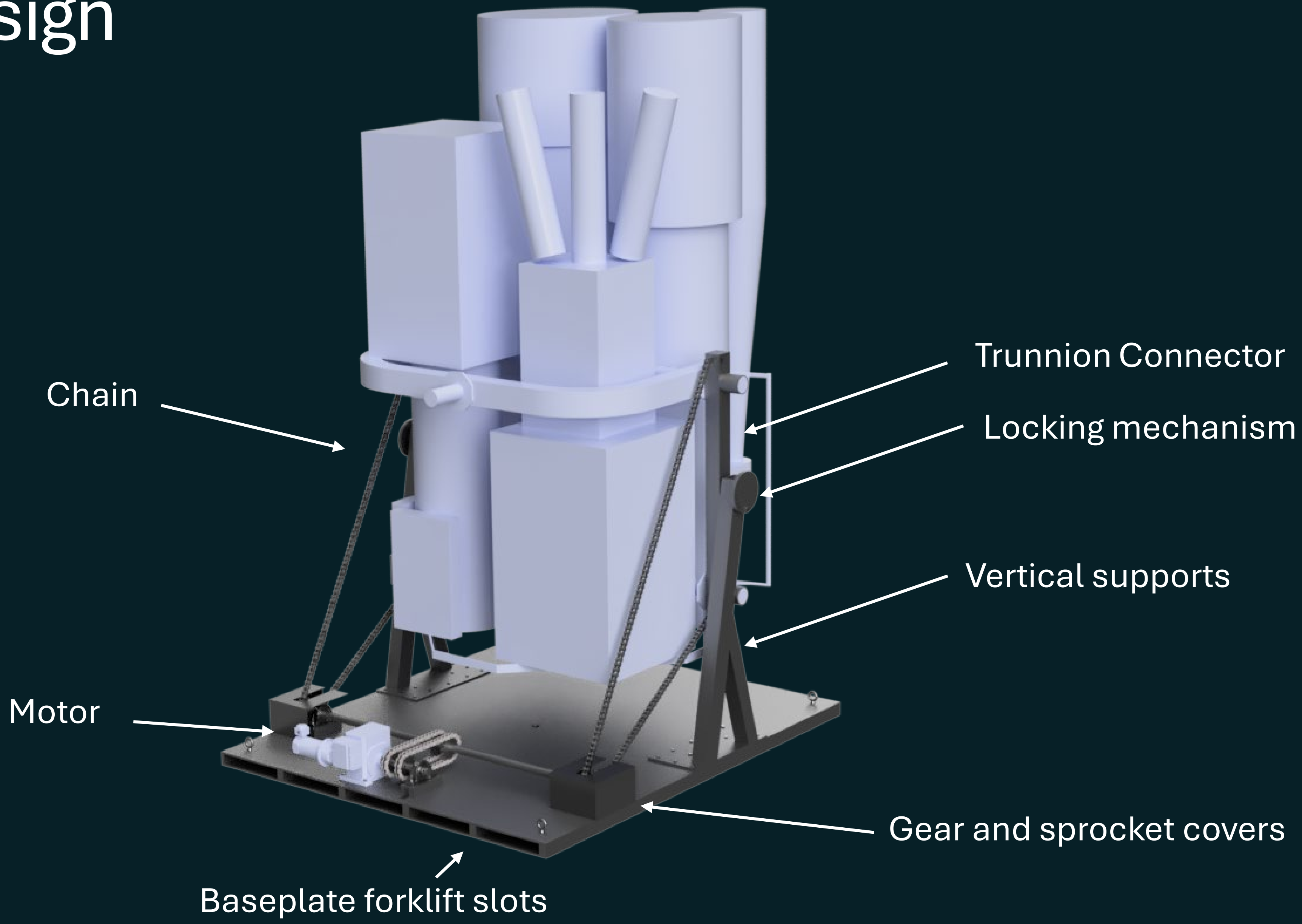
- Removed the winch system to not be reliant on CG
- Replaced cable with chains to prevent slippage
- Added driveshaft and second chain for failure protection





CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

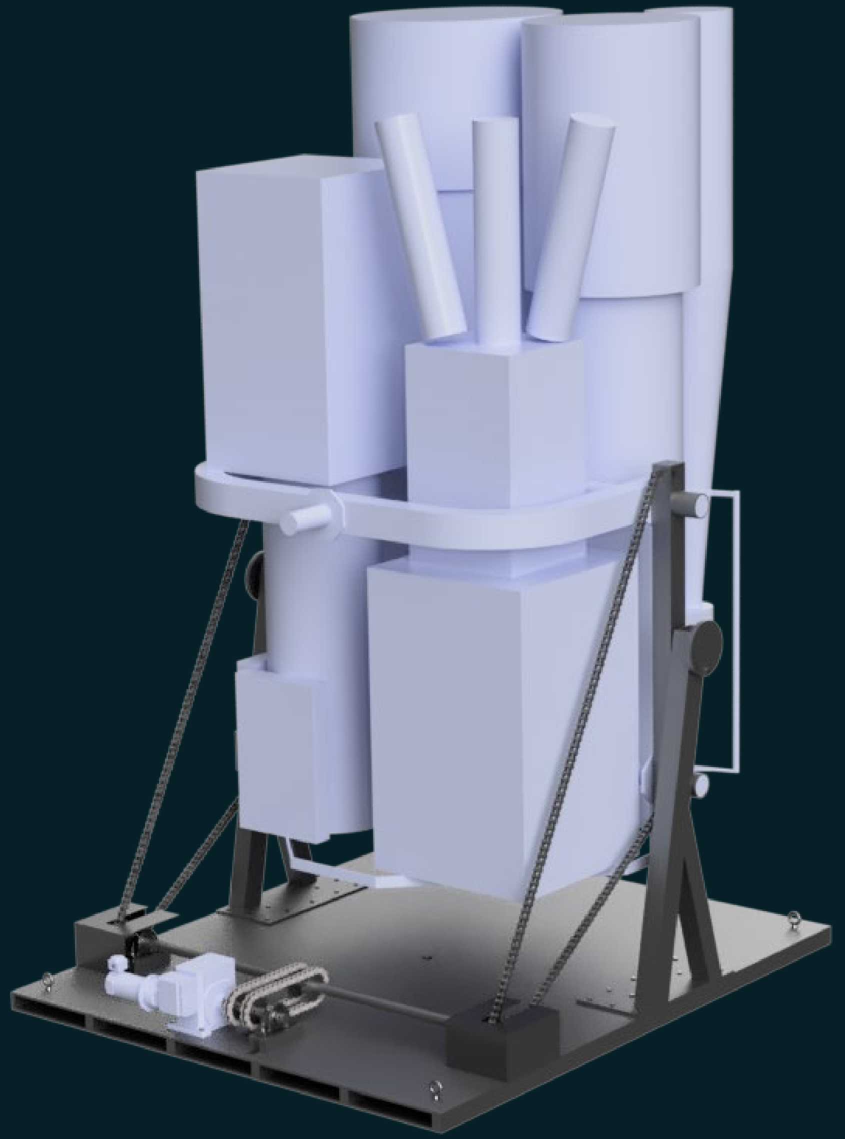
Final Design



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Notable Features

- Driving system: Motor actuated by a gear and chain system
- Two fault tolerant: Locking pins and dual chain system
- Safety covers on moving parts
- Set pin slots to lock at desired angle locations



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

1/5 Scale Model

Differences:

- Single Stepper motor
- Mounted control box on the baseplate
- 3D printed payload

Isometric View

CELESTIAL INTERACTIONS™

ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

1/5 Scale Model

Side View

Front View

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY


FOOD ONLY

1/5 Scale Controls

Turntable

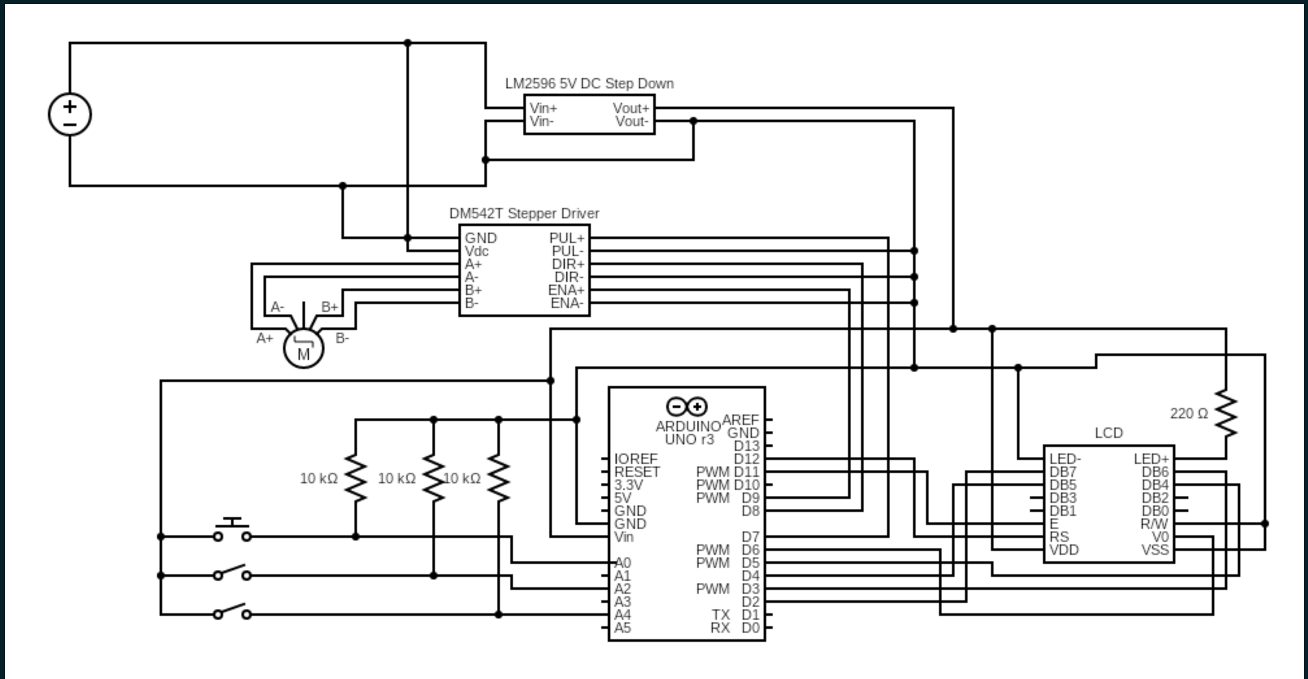
- OTS with minimalistic design
- Battery powered and rechargeable
- Remote control with multiple operating methods

ADS

- 3-position switch to control rotation direction
- Programmable LCD screen
- Control box located near locking mechanism

1/5 Scale Electrical Components

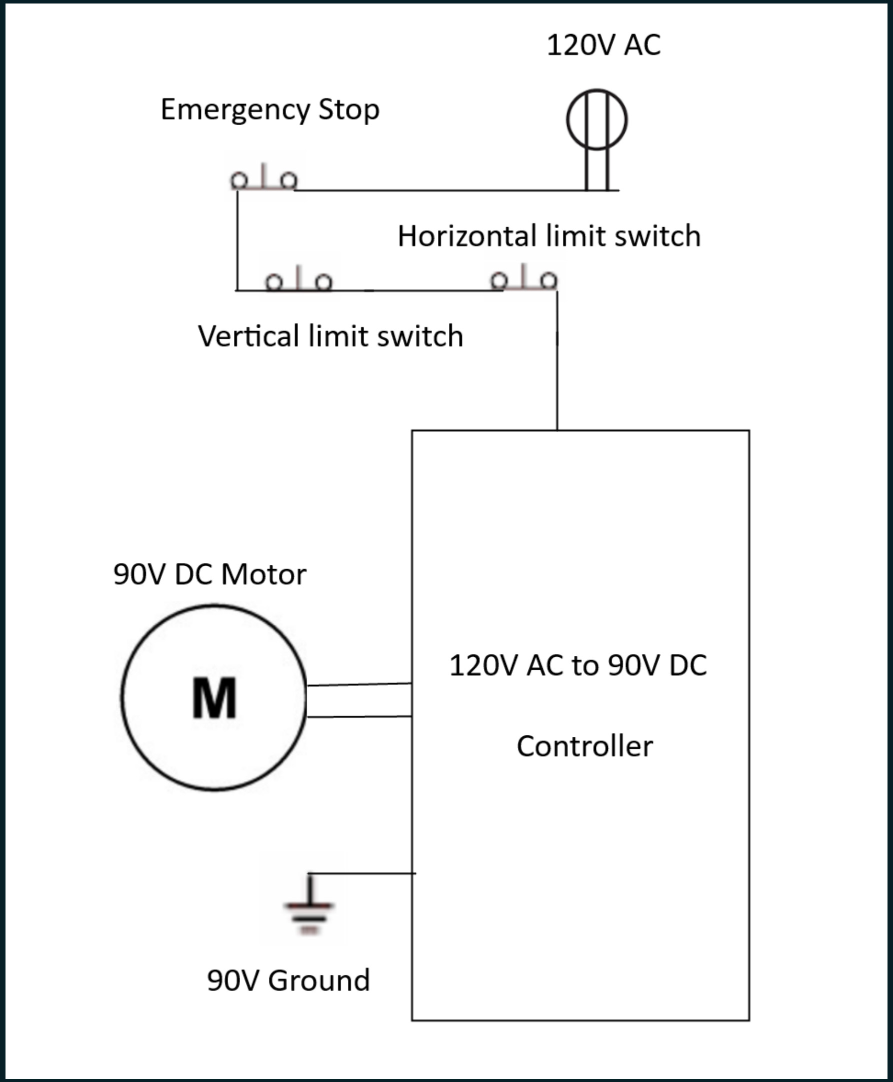
- 24V, 3A external power supply
- Stepper motor and stepper driver
- Arduino microcontroller
- A voltage reducer provides 5V



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Electrical System

- 90V DC motor drives movement system
- Normally closed limit switches and emergency stop
- Controller allows user to change speed and direction



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Structural Calculations

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Structural Calculations

Furthest CG Location

$$Z_{CG_{crit}} \frac{0.4\ in * 6601\ lbs - (1555\ lbs)(25.1\ in) - (816\ lbs)(21\ in)}{(6601\ lbs - 1555\ lbs - 816\ lbs)} = -12.65\ in$$

Table 7.1 Astro System and Selected Component CGs				
Description	Weight (lbs)	CG Location (inches)		
		X_{CG}	Y_{CG}	Z_{CG}
Composite Astro System	6,601	46.2	1.0	0.4
HUT	1,555	44.4	-16.2	25.1
UIT	816	46.3	25.3	21.0
Integrated Radiator System	633	34.8	27.0	-31.1

Three configurations to be considered:

1. Composite Astro System
2. Composite minus HUT and UIT
3. Composite minus HUT, UIT, and IRS

Note: Table data is to be used only for determination of various CGs. Governing weight of Astro System is provided in paragraph 7.1.

Torque From Payload Weight

$$T = 4230\ lbs * 12.65\ in = 53509.5\ lb\ in$$

Horizontal Force on Support

$$F_{horz} = \frac{T}{y_{dist}} = \frac{53509.5\ lb\ in}{31.3\ in} = 1715.05\ lbs$$

Per Side

$$F_{horz_{side1}} = F_{horz_{side2}} = \frac{F_{horz}}{2} = 857.5\ lbs$$

CELESTIAL INTERACTIONS™

ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Structural Calculations– Vertical Supports

Force Generated by Chain

$$\cos(33) = \frac{F_{horz}}{F_{chain}} = \frac{1715.05\ lbs}{F_{Chain}}$$

$$F_{chain} = 2044.96\ lbs$$

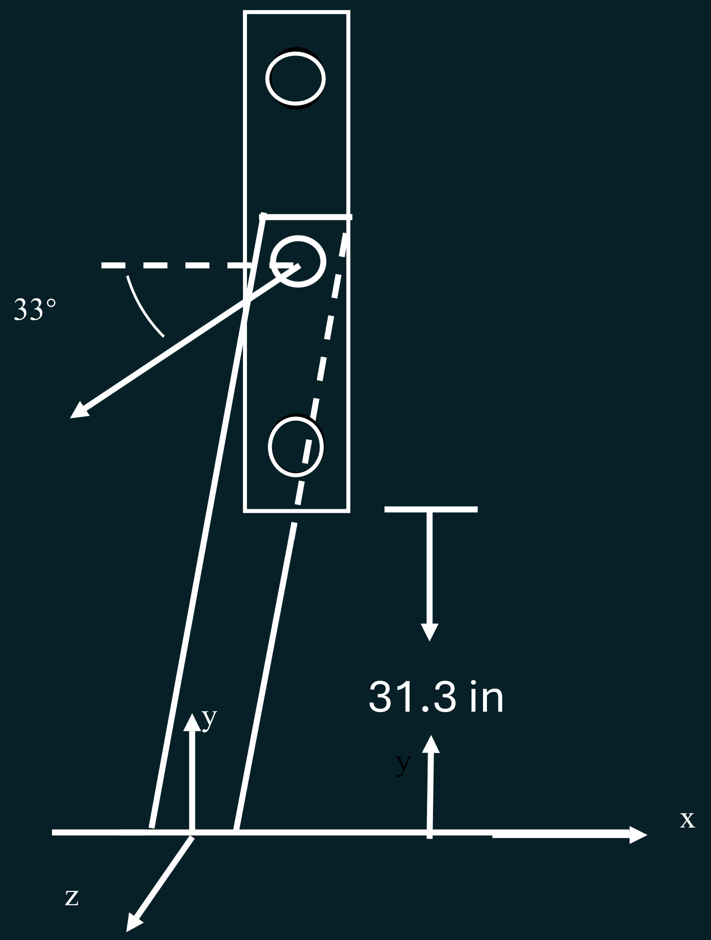
$$F_{chain_{side1}} = F_{chain_{side2}} = 1022.48\ lbs$$

Decomposed to Vertical Component

$$\sin(33) = \frac{F_{vert}}{F_{chain}} = \frac{F_{vert}}{2044.96\ lb}$$

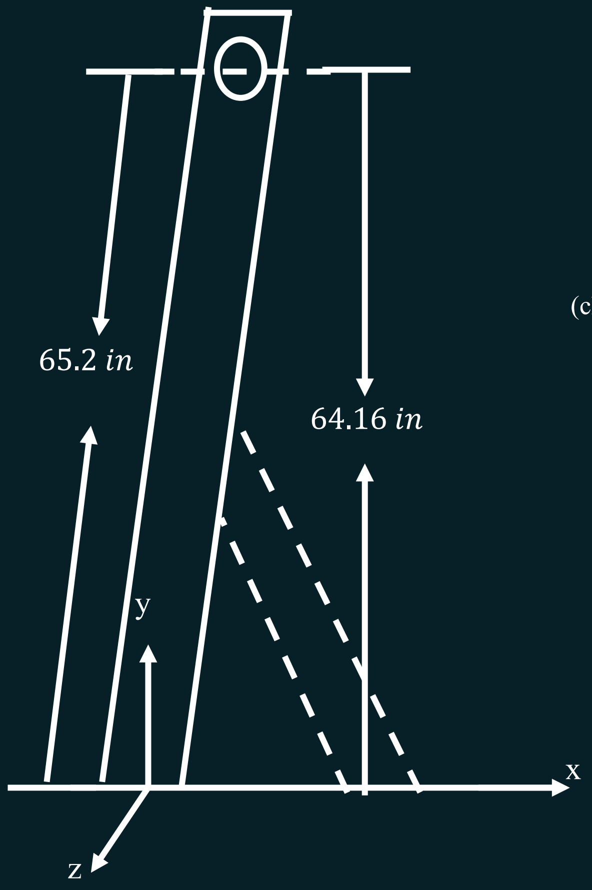
$$F_{vert} = 1113.77\ lb$$

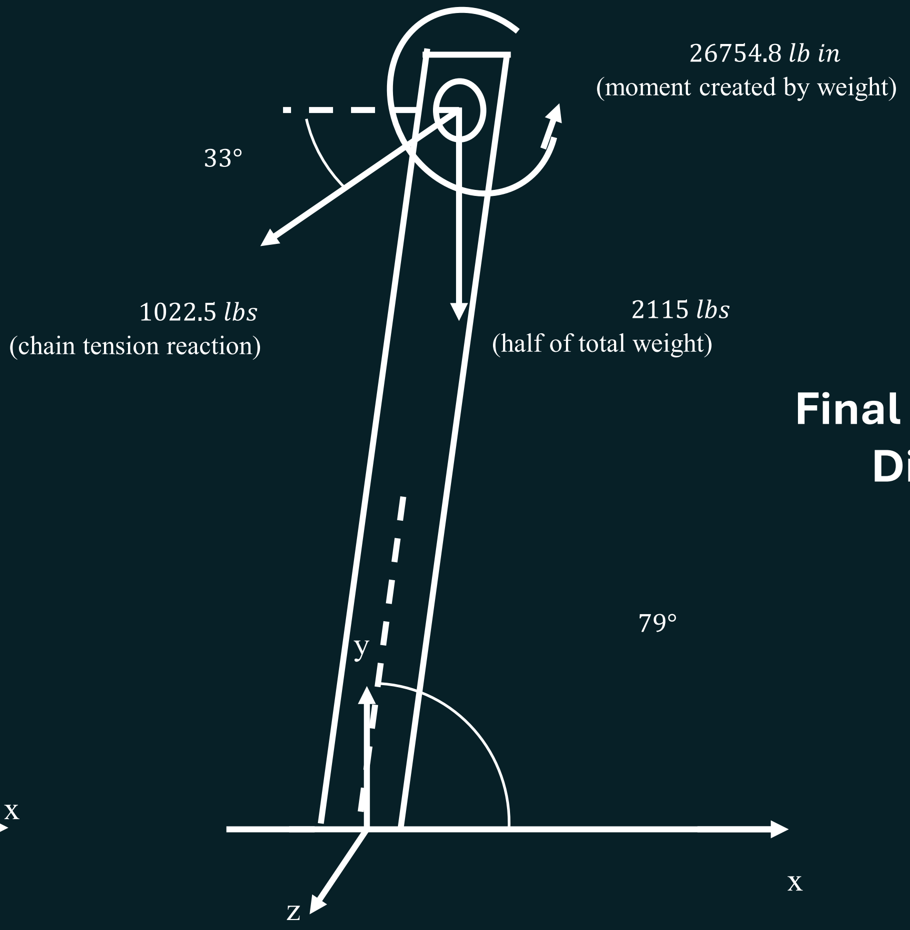
$$F_{vert_{side1}} = F_{vert_{side2}} = 556.88\ lb$$



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Structural Calculations– Vertical Supports





Final Free-Body Diagram

Structural Calculations– Vertical Supports

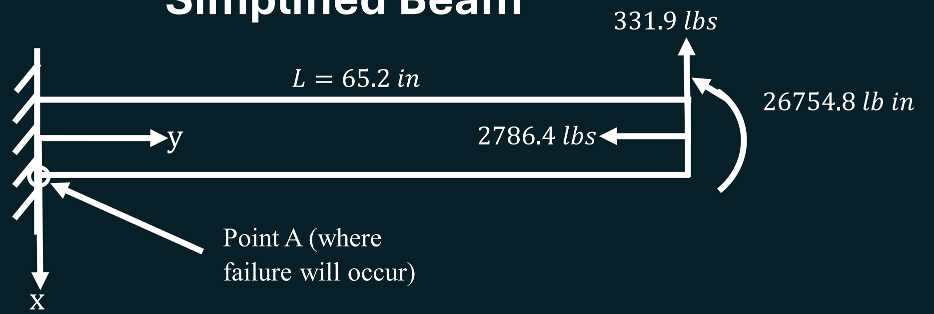
Cross-Section Properties

$$A = (5\ in \cdot 5\ in) - (4.5\ in \cdot 4.5\ in) = 4.75\ in^2$$

$$c = \frac{5\ in}{2} = 2.5\ in$$

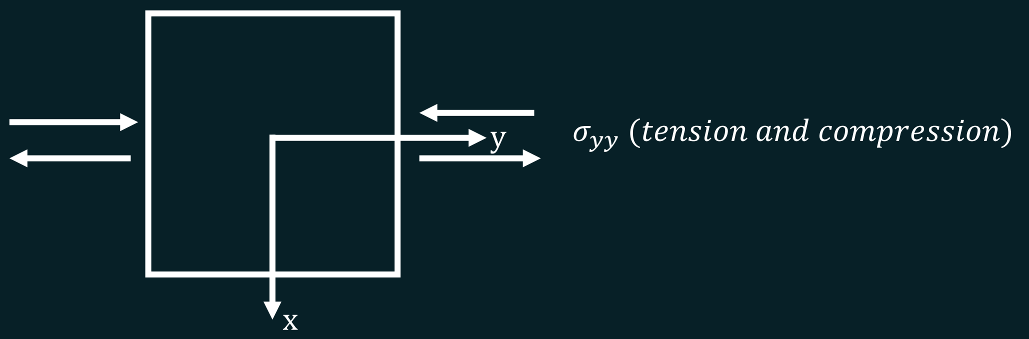
$$I = \frac{1}{12}bh^3 = \frac{1}{12}(5\ in)(5\ in)^3 - \frac{1}{12}(4.5\ in)(4.5\ in)^3 = 17.91\ in^4$$

Simplified Beam



State of Stress

$$\sigma_{yy} = \frac{M_1 c}{I} + \frac{M_z c}{I} - \frac{P}{A}$$



Stress Calculation

$$\sigma_{yy} = \frac{(26754.8\ lb\ in)(2.5\ in)}{17.91\ in^4} + \frac{(331.9\ lbs)(65.2\ in)(2.5\ in)}{17.91\ in^4} - \frac{(2786.4\ lb)}{4.75\ in^2} = 6169\ psi$$

$$N_{VM} = \frac{\sigma_y}{\sigma_{VM}} = \frac{36{,}600\ psi}{6169\ psi} = 5.9$$

< Factor of Safety

CELESTIAL INTERACTIONS™

ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Factor of Safety – Major Components

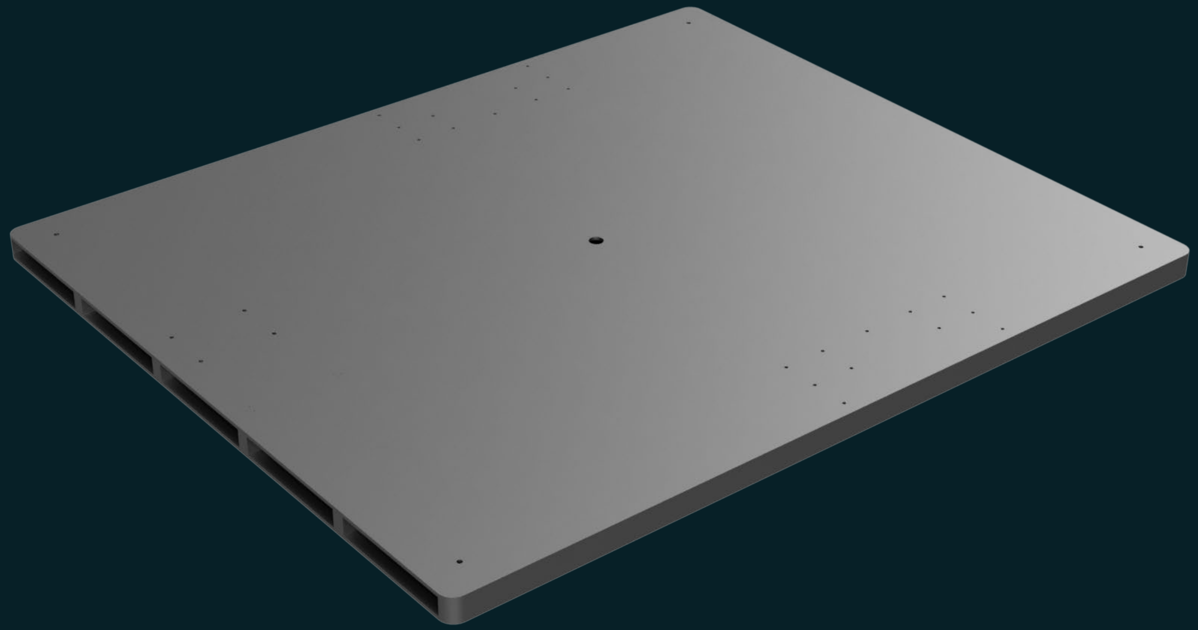
Part	Expected load (psi)	Max load (psi)	FoS
Vertical Supports	6169	36,600	5.9
Vertical Support Buckling	2786.4	301,466	108
Trunnion Connector	1525.5	36,600	24.0
Trunnion Bolt	12,200	36,600	>3.0
Motor System	1809.3	8800	4.0

Manufacturing and Cost

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Manufacturing Process- Baseplate

- The base plates were cut on an abrasive water jet
- Pre-cut square tube bar stock was used to separate the top and bottom sheet
- Due to the limited welding clearance, square groove and tack welds were utilized
- Holes were made in the top plate for the driving system and the vertical support mounting plates



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Manufacturing Process- Vertical Supports

- The short and long vertical supports achieved angular cuts using a mill with THRU holes produced using a drill press
- Each fastener plate was machined on a water jet, with THRU holes cut using a drill press
- Short and long vertical supports were welded to each fastener plate

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

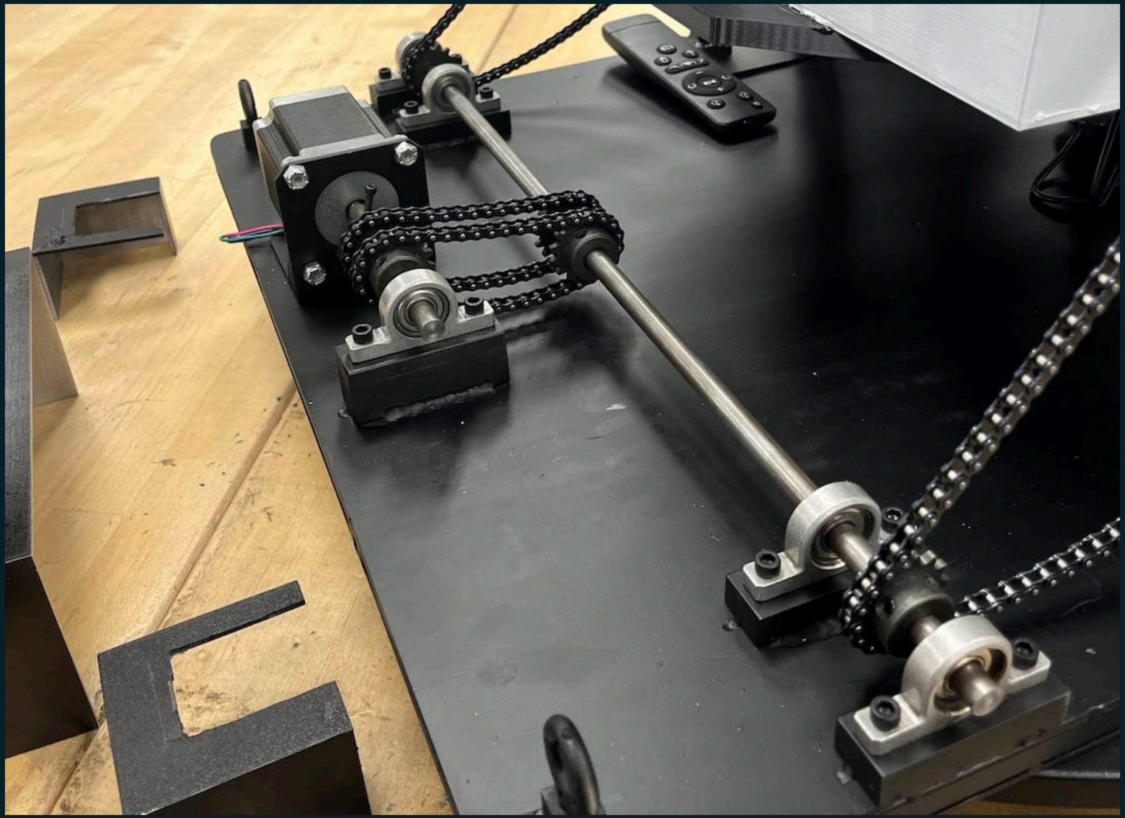
Manufacturing Process- Locking Mechanism

- The locking mechanism was machined using a water jet
- It was welded to the vertical support in a predefined position
- Clevis and cotter pins were purchased to pair alongside the manufactured parts

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Assembly Process- Driving System

- The gears, bearings, barrels, and motor were all fastened before the bearing blocks were welded in place
- Chain sections were sized first and tensioned during assembly
- The motor wiring was run between the top and bottom plate to the control box



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Ease of Transportation Features

- The ADS base is compatible with the use of forklifts
- Eyebolt hooks on the corners of the stand to aid in the assembly and transportation process
- A stand sizing that falls within the maximum width for standard transportation

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Costs

1/5th Scale Prototype Cost	
Subsystem	**Approximate Cost**
Structural Support	$380
Driving System	$450
Controlling System	$105
Turntable and Battery Backup	$255
Misc	$80
Total	**$1260**

1/5th Scale Prototype Production Cost	
Subsystem	**Approximate Cost**
Holes Drilled	$17.50
Cuts Made	$35
Waterjet Cuts	$36
Welding	$40
Total	**$128.50**

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

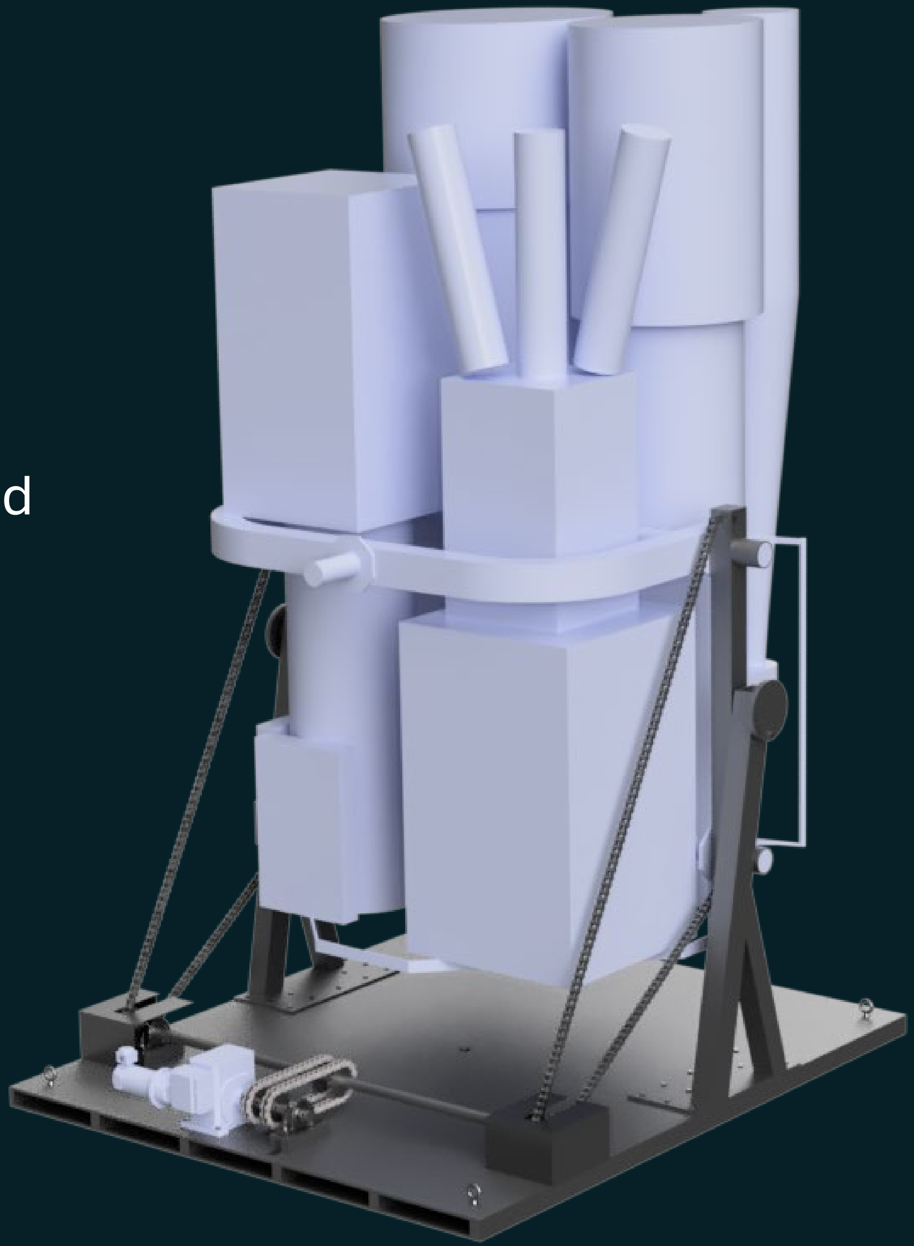
Final Specifications

- Estimated Material Cost: $12,302
- Average machinist in Florida $23.50 per/hour
- Number of Components: 155 (including fasteners)
- Estimated manufacturing and assembly time: 50 hours
- Total cost **$13,477**

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Summary/Conclusion

- Structurally viable design for CG variations
- Minimalistic design enables focus on the payload
- Locking and chain safety mechanisms
- Total estimated cost of **$13,477**



CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Questions

Structural Calculations– Vertical Support Buckling Calculations

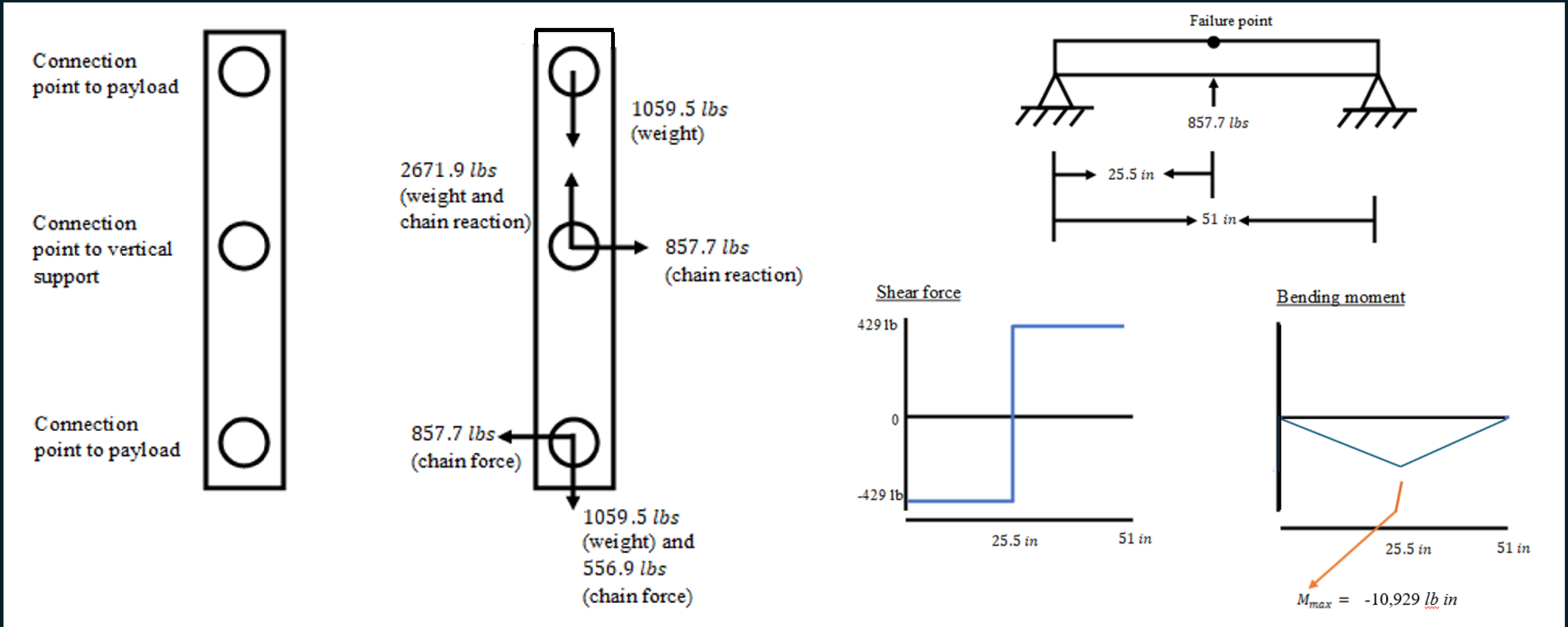
$$P_{cr} = \frac{\pi^2 EI}{(Kl)^2}$$

$$P_{cr} = \frac{\pi^2 * 2.9 * 10^7 * 17.91}{(2.0 * 65.2)^2} = 301{,}466\ lbs$$

$$N = \frac{P_{cr}}{Axial\ Load} = \frac{301{,}466}{2786.4} = 108$$

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

Structural Calculations– Trunnion Connector



Structural Calculations– Trunnion Connector

$$\sigma_{yy} = \frac{|M_{max}|c}{I} = \frac{(10{,}929\ lb\ in)(2.5\ in)}{17.91\ in^4} = 1525.5\ psi$$

$$N_{VM} = \frac{\sigma_y}{\sigma_{VM}} = \frac{36{,}600\ psi}{1525.5\ psi} = 24.0$$

CELESTIAL INTERACTIONS™
ELEVATING DISPLAYS WITH STRENGTH AND STABILITY

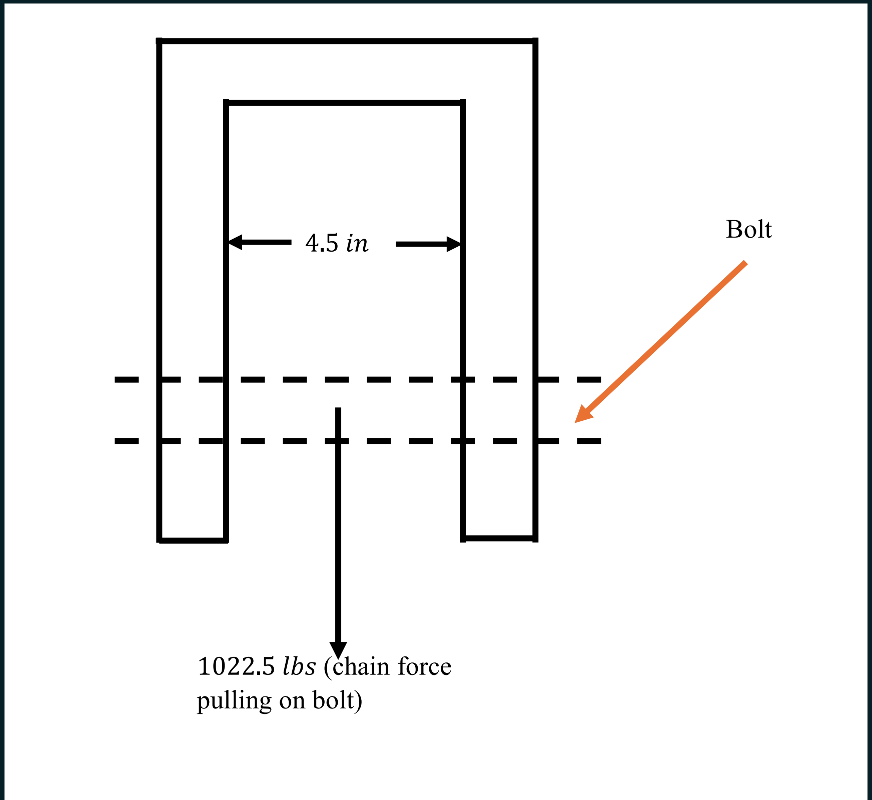
Structural Calculations– Trunnion Bolt

$$\tau_{ave} = \frac{\frac{1}{2}F}{A}$$

$$\sigma_{allow} = \frac{\sigma_y}{N} = \frac{36{,}600\ psi}{3} = 12{,}200\ psi$$

$$12{,}200\ psi = \frac{\frac{1}{2}F}{A} = \frac{\frac{1}{2}(1022.5\ lbs)}{\frac{\pi D^2}{4}}$$

$$D = 0.231\ in$$



Motion System Calculations

$$F_{chain,center} = \frac{5880\ lb \cdot in}{3.25\ in} = 1809.3\ lb$$

$$FOS = \frac{F_{WLL}}{F_{chain,center}} = \frac{8800\ lb}{1809.3\ lb} = 4.86$$

* WLL = working load limit of ANSI 100 chain

$$F_{chain,sides} = \frac{5880\ lb \cdot in}{3.25\ in} = 1809.3\ lb$$

$$FOS = \frac{F_{WLL}}{F_{chain,sides}} = \frac{8800\ lb}{1809.3\ lb} = 4.86$$