THE VALUE OF PERFORMANCE.
NORTHROP GRUMMAN

Preliminary Design Review:
NAU Standoff Project

Team:
Elaine Reyes
Dakota Saska
Tyler Hans
Sage Lawrence
Brandon Bass

11/18/19

Presentation Overview

1. Project Description
2. Concept Generation and Evaluation
3. Final Design Proposal
4. Schedule and Budget

1. Project Description Overview

1.1. Project Background

1.2. Project Requirements

1.3. Literature Review

1.4. Customer Needs

1.5. Engineering Requirements

1.6. Quality Function Deployment (QFD)

1.1 Project Background

- Standoffs are bonded to motor domes using adhesive
- Adhesive is applied and bracket is taped to help cure adhesive
- Taping is unreliable and costs money and man hours when it fails
- Analyze and build a prototype that will hold standoff brackets while adhesive cures

Figure 1. Castor 50XL [1]

Figure 2. Castor 30XL [1]

1.2 Project Requirements

NORTHROP GRUMMAN

The mounting arm shall:

- ❑ Support brackets bonded 4-36 inches inboard from the motor ring
- ❑ Have 6 degrees of freedom
- ❑ Be mountable to several rocket motors
  - Orion 38
  - Orion 50XL
  - Castor 30XL
- ❑ Be ESD (electrostatic discharge) compliant
- ❑ Be adaptable to several mounting bracket templates
- ❑ Hold a bracket to up to 10 lbs
- ❑ Lock in place and apply a force of 20 lbs
- ❑ Have a Factor of Safety of 3.0 based on maximum expected loads
- ❑ Be easily manipulated by hand
- ❑ Perform a pull test of 50 lbs at 45 degrees of freedom

1.3 Literature Review

- The sources that we collected are intended to provide insight and possible solutions into the problems we are tasked with for the project.

- The subject matter relevant to the problems proposed in the project included:
  - Rocket Structure and Functionality [1,3]
  - Human Driven 6-DOF Articulated Arm [4,5]
  - Pull Test Procedure and Setup [6]

- The references were gathered to help the individual team members in their specialized tasks but can also be used by the team as a whole.

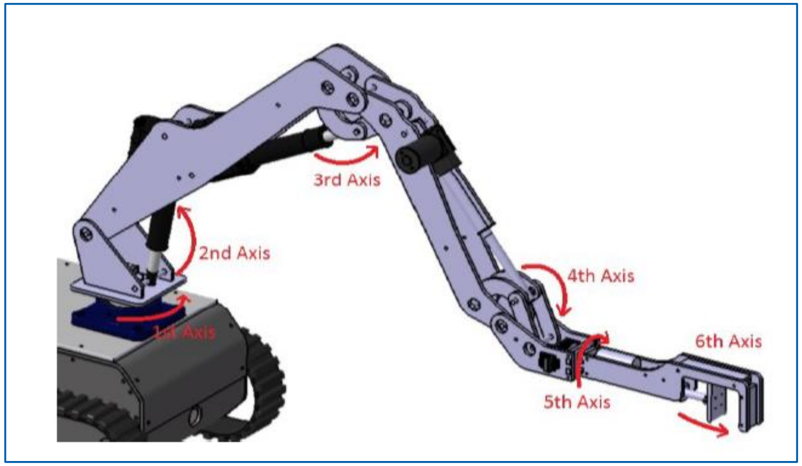

Figure 3. Six-Axis Articulated Arm [4]

NORTHROP GRUMMAN

ESD Compliance

- Transfer of electricity from high to low charged object
- Want conductive materials
  - To move electrons easily across the surface through bulk of materials

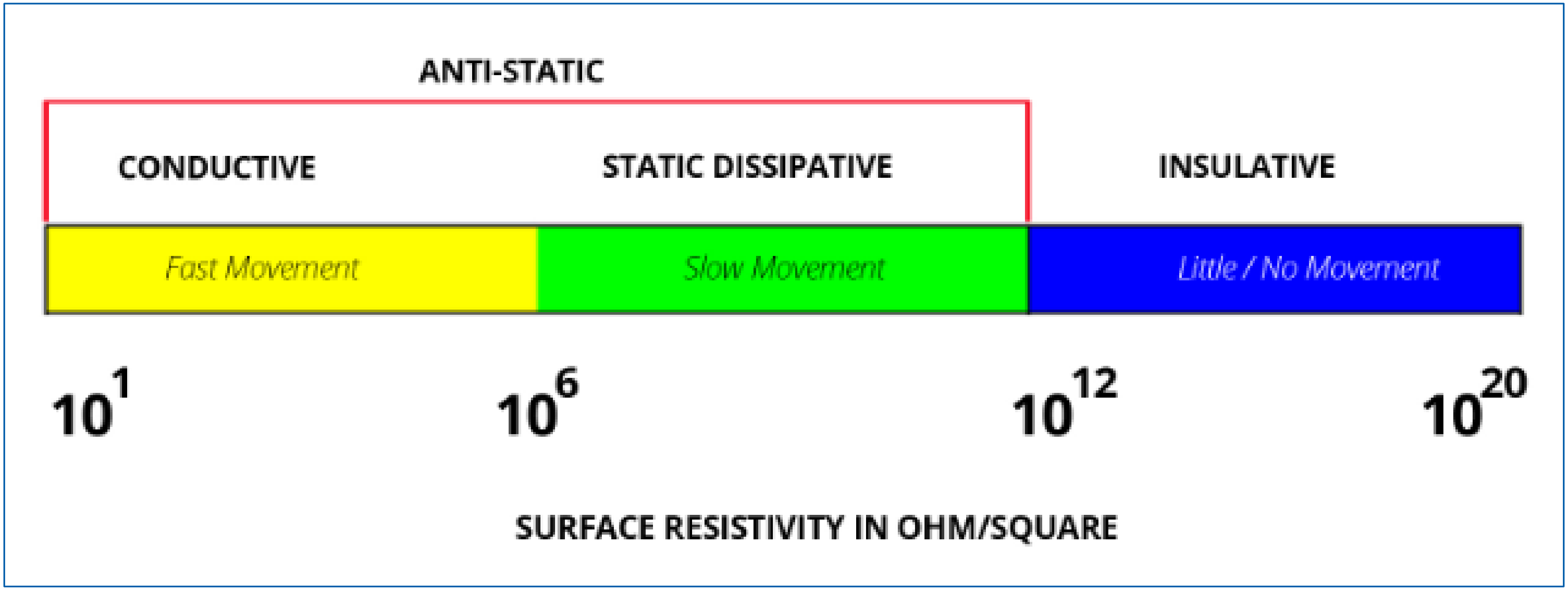

Figure 4. Difference in Resistance Between Material Types [5]

1.3 Literature Review (cont.)

ESD Compliance Solutions

- Grounding Applicability
  - Reference ESD Testing Procedures
  - Follow ESD Association's ESD Standards
- Material Selection
  - Tentatively, Aluminum 7070 due to calculations discussed later on in the presentation
    - Aluminum Conductivity: 237 W/mK

1.4 Customer Needs

1. ESD compliance
2. Apply axial forces
3. Six degrees of freedom in movement
4. Usable 4" - 36" inboard of ring
5. Transportability
6. Ease of operation
7. Durability
8. Reliability
9. Adjustable Interfaces
10. Support 10lbs in locked position
11. Minimum 3.0 Factor of Safety

Figure 5. Castor 38 [1]

1.5 Engineering Requirements

NORTHROP GRUMMAN

- Electrically Conductive (Y or N)
- Mass (slugs)
- Principal Dimensions (in)
- Working Length (in)
- Working Angle (Degrees)
- Modulus of Elasticity (lbf/in^2)

1.6 Quality Function Deployment (QFD)

NORTHROP GRUMMAN

Table 1. QFD

Customer Need	Weight	Engineering Requirement	Electrically Conductive (Y or N)	Mass (slugs)	Principal Dimensions (in)	Working Length (in)	Working Angle (Degrees)	Modulus of Elasticity (lbf/in^2)
1. ESD compliance	0.09		9	0	0	0	0	0
2. Apply axial forces	0.09		0	1	0	3	3	9
3. Six degrees of freedom in movement	0.09		0	0	0	9	9	0
4. Usable 4" - 36" inboard of ring	0.09		0	1	9	9	3	1
5. Transportability	0.04		0	9	9	3	3	0
6. Ease of operation	0.07		3	9	3	9	9	0
7. Durability	0.08		0	3	0	0	0	9
8. Reliability	0.08		0	3	0	0	0	9
9. Adjustable Interfaces	0.09		0	3	0	3	3	0
10. Support 10lbs in locked position	0.09		0	3	0	3	3	9
11. Minimum 3.0 Factor of Safety	0.06		0	3	0	0	0	9
12. Within Budget	0.03		9	9	3	9	3	9
13. Multiple Arms	0.05		0	3	3	3	3	0
14. Safe Operation	0.05		9	9	3	0	0	3
Absolute Technical Importance (ATI)			1.74	3.24	1.77	3.60	2.88	4.11
Relative Technical Importance (RTI)			0.42	0.79	0.43	0.88	0.70	1.00
Target Values			Yes	25	8" (W) x40" (L) x6" (H)	32"	360°	<10.4 *10^6
Target Tolerances			N/A	±5	±2	N/A	N/A	N/A

2. Concept Generation and Evaluation Overview

2.1. Black Box Model

2.2. Functional Model

2.3. Concept Generation

2.4. Concept Evaluation

2.1 Black Box Model

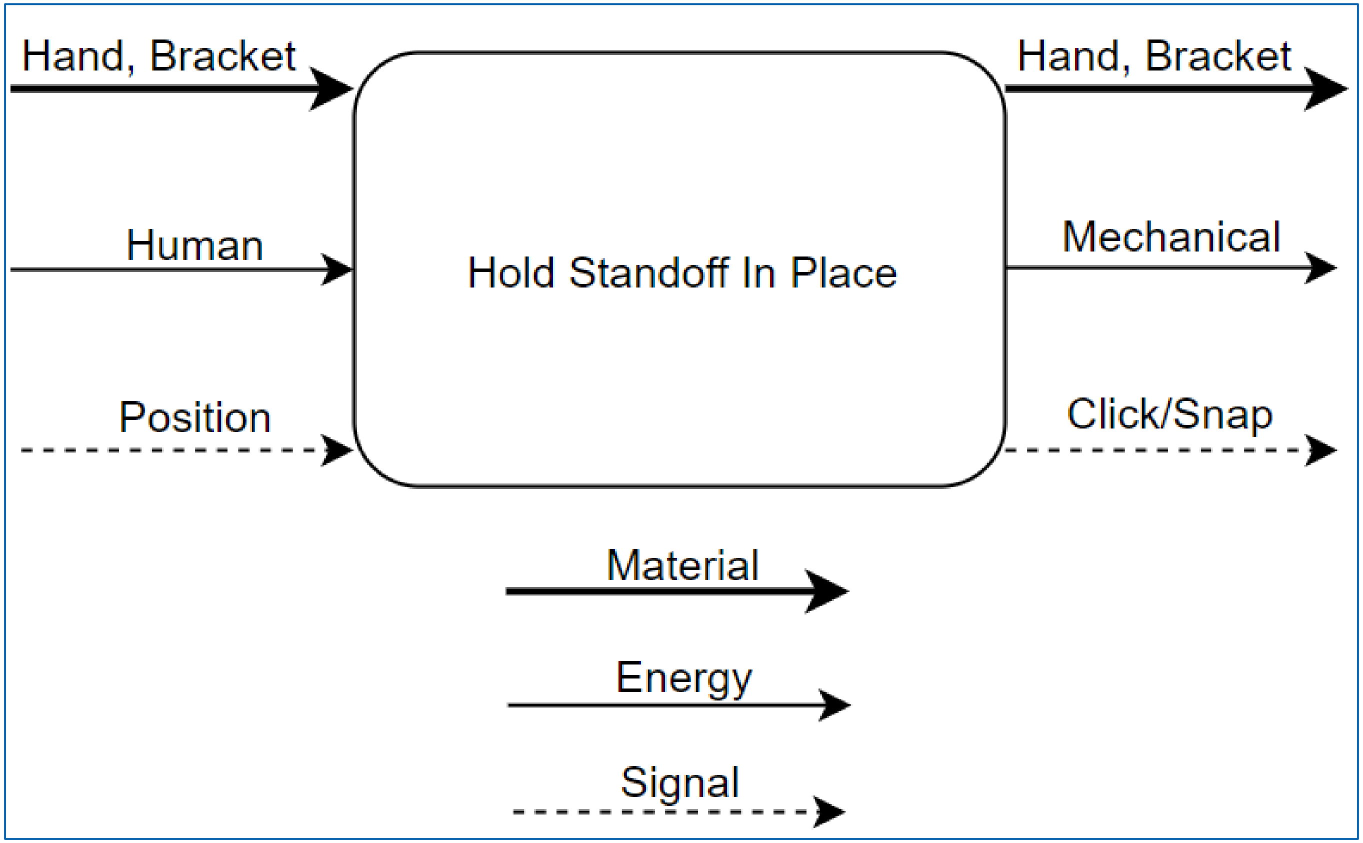

Figure 6. Black Box Model

2.2 Functional Model

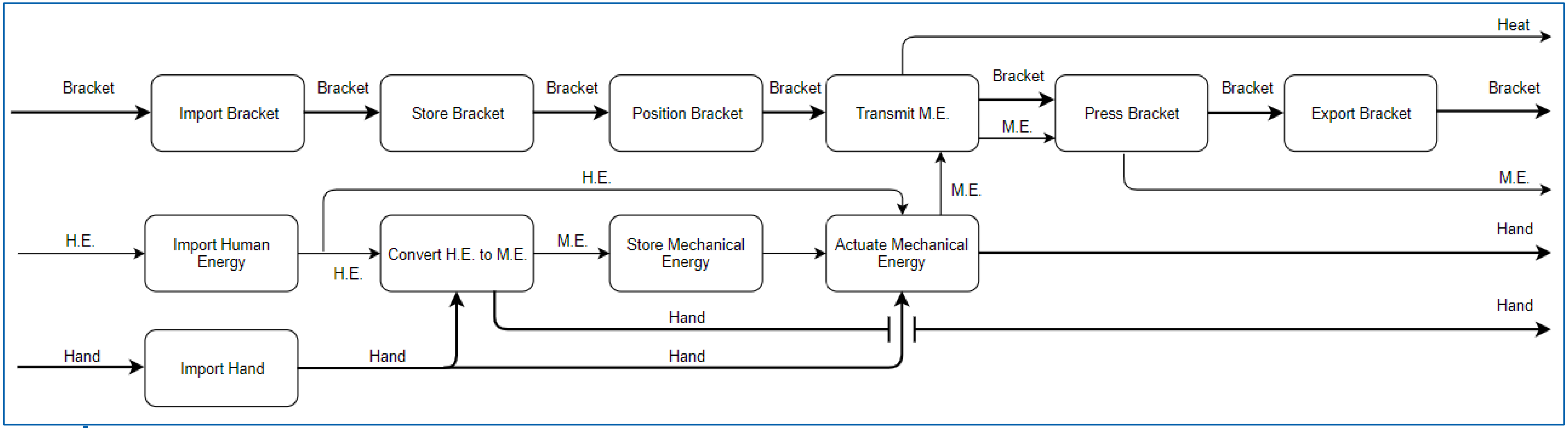

Figure 7. Functional Model

Concept Generation Sub-Functions:

1. Mount to Ring (“Import Bracket”)
2. Hold Bracket (“Press Bracket”)
3. Apply Axial force (“Transmit M.E”)
4. Angle bracket (“Position Bracket”)
5. Translate bracket (“Position Bracket”)
6. Locking (“Position Bracket”)

2.3 Concept Generation

NORTHROP GRUMMAN

- From the six sub-functions of our design, a morphological matrix was constructed.
- Using the morph matrix as a reference, the team used a variation of the gallery method to develop concepts.
- Developing concepts by taking one method from each sub function and essentially building the design from the ring to the bracket.

2.3 Concept Generation (cont.)

Morphological Matrix

- Six sub-functions for the concepts
- Using the Morph Matrix, six designs were created that are displayed in a design table

Table 2. Morph Matrix

Sub-Functions	Concepts		
Mount to Ring	C-Clamp	Hose-Clamp	Spring Clamp
Hold Bracket	Spring Clamp	Threaded Clamp	Claw
Apply Axial Forces	Telescope	Locking Screw	Floor Jack
Angle & Socket	Ball & Socket	U-Joint	Parallel Plates
Translate Bracket	Rail	Telescope	Sleeve
Locking	Threaded Joint	Spring Lock	Self Locking Screw
Grip	1	2	3

2.3 Concept Generation (cont.)

Table 3. Design Table

	Sub-Functions							
	Design Name	Mount to Ring	Hold Bracket	Apply Axial Forces	Angle Bracket	Translate Bracket	Locking	Grip
Datum	Computer Articulating Arm	C-Clamp	Threaded Clamp	Locking Screw	U-Joint	Telescope	Threaded Joint	1
Design 1	Rail System	C-Clamp	Threaded Clamp	Locking Screw	U-Joint	Rail	Threaded Joint	2
Design 2	Rail Crane	Spring Clamp	Claw	Locking Screw	Ball & Socket	Rail	Self Locking Screw	1
Design 3	Construction Crane	C-Clamp	Claw	Telescope	Ball & Socket	Telescope	Self Locking Screw	1
Design 4	Biological Design	Hose-Clamp	Spring Clamp	Telescope	Parallel Plates	Telescope	Spring Lock	1
Design 5	Mechanical Design	Hose-Clamp	Threaded Clamp	Foor Jack	U-Joint	Sleeve	Self Locking Screw	3
Design 6	Spider Web	Spring Clamp	Threaded Clamp	Locking Screw	U-Joint	Rail	Self Locking Screw	3

2.4 Concept Evaluation

NORTHROP GRUMMAN

Table 4. Pugh Chart

		Concepts						
Engineering Characteristics	Weights	Standard	Rail System	Rail Crane	Construction Crane	Biological Crane	Mechanical Design	Spider Web
ESD Compliance	4	Computer Articulating Arm	(s)	(s)	(s)	(s)	(s)	(s)
Mass	3		(-)	(-)	(-)	(-)	(+)	(-)
Principle Dimensions	2		(+)	(+)	(+)	(-)	(+)	(+)
Working Length	4		(+)	(+)	(+)	(-)	(-)	(+)
Working Angle	4		(s)	(-)	(-)	(+)	(s)	(s)
Durability	5		(+)	(+)	(+)	(-)	(-)	(-)
Reliability	3		(+)	(+)	(-)	(-)	(-)	(-)
Use of Space	3		(-)	(-)	(-)	(s)	(-)	(-)
Adjustable Interfaces	4		(s)	(-)	(-)	(-)	(s)	(s)
Total +		0	4	4	3	1	2	2
Total -		0	2	4	5	6	-4	4
Overall Score		0	2	0	-2	-5	-2	-2
Weighted Total +		0	14	14	11	4	5	6
Weighted Total -		0	6	14	17	21	15	14
Weighted Overall Score		0	8	0	-6	-17	-10	-8

2.4 Concept Evaluation (cont.)

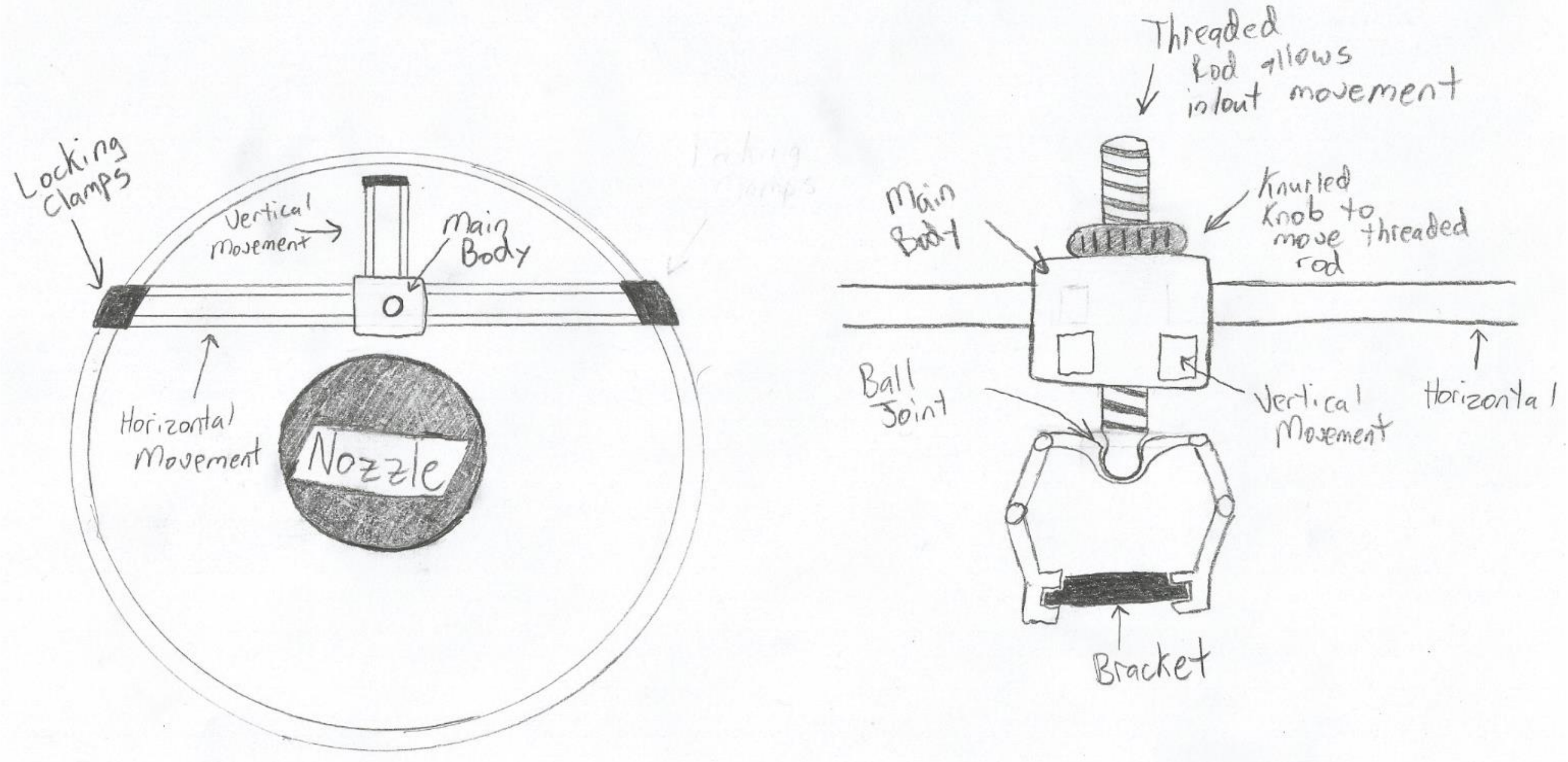

Figure 8. Rail System Concept

2.4 Concept Evaluation (cont.)

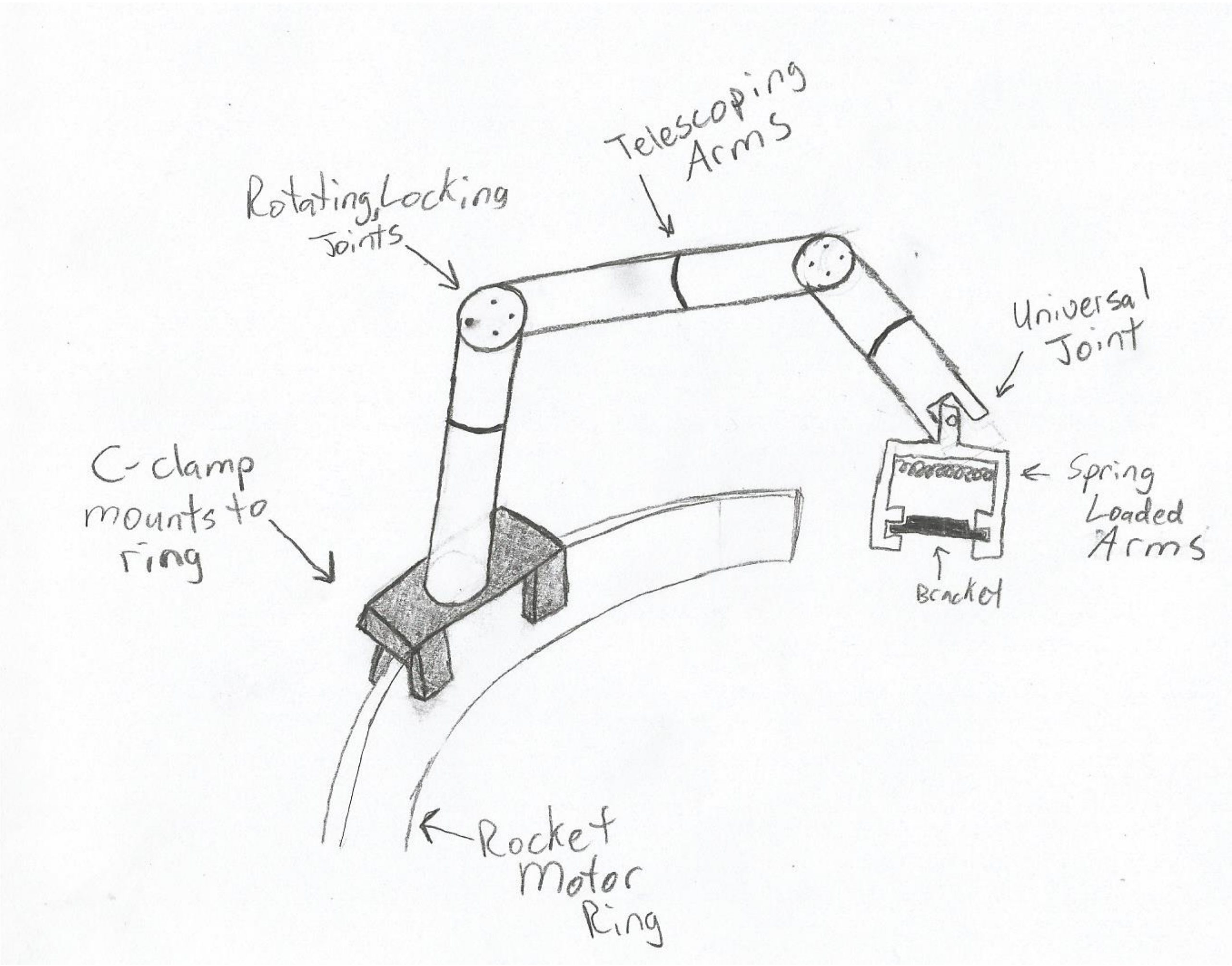

Figure 9. Articulated Arm Concept

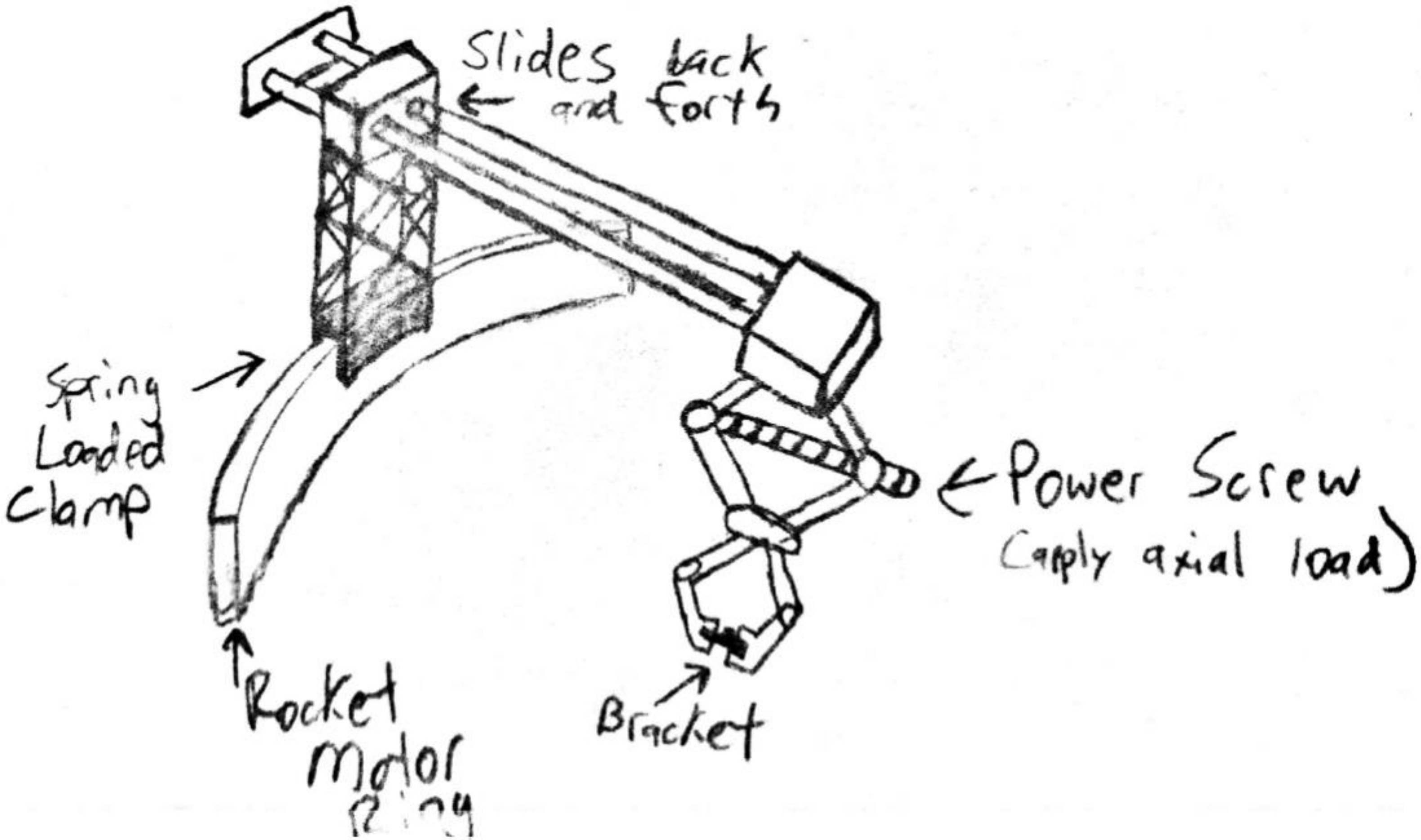

Figure 10. Rail Crane Concept

2.4 Concept Evaluation (cont.)

Table 5. Decision Matrix

		Computer Articulating Arm		Rail System		Rail Crane	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
ESD Compliance	10	100	10	100	10	100	10
Mass	10	60	6	30	3	60	6
Principle Dimensions	5	70	3.5	40	2	60	3
Working Length	15	85	12.75	90	13.5	90	13.5
Working Angle	15	85	12.75	80	12	80	12
Durability	20	50	10	70	14	70	14
Reliability	15	50	7.5	60	9	70	10.5
Use of Space	5	80	4	30	1.5	80	4
Adjustable Interfaces	5	80	4	80	4	80	4
Total	100		70.5		69		77

3. Final Design Proposal Overview

3.1. Design Description

3.2. Design Components

3.3. Design Requirements

3.4. Design Analyses

3.5. Design Validation

3.1 Design Description

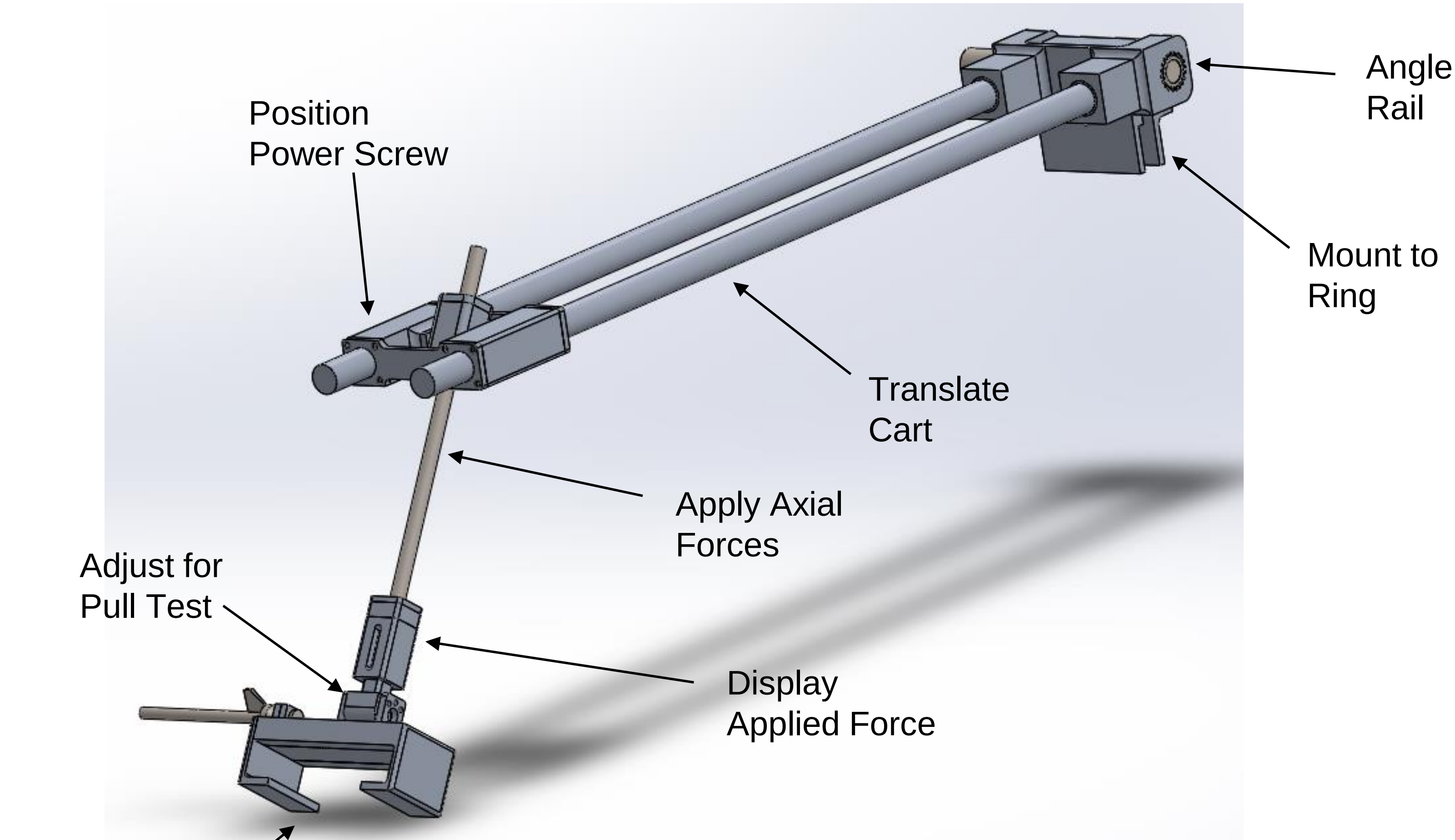

Figure 11. CAD Model

3.1 Design Description (cont.)

- Main body components of design will be constructed out of 6061 aluminum stock.
- The rail system will be made of 7075 aluminum round stock, as it will deflect less than the 6061 aluminum.
- The lead screw, splined shaft, spline nuts, and spring will all have to be purchased from outside sources.
- The current weight of the design is less than 20 lbs when implementing the theoretical material densities.

Figure 12. Exploded CAD Model

NORTHROP GRUMMAN

NORTHROP GRUMMAN

Rocket Motor Clamp (1/2)

- Clamping mechanism to the ring of the rocket motor, similar to the quick interchange tools of a lathe.

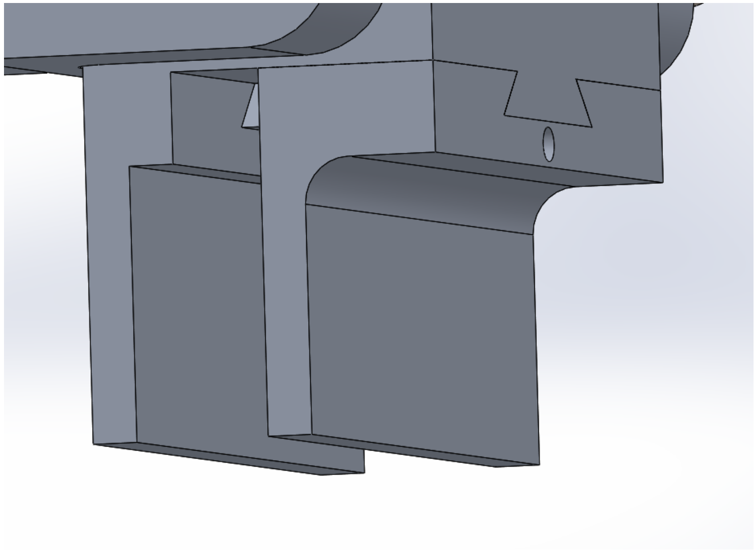

Figure 13. Motor Ring Clamp

3.2 Design Components (cont.)

Rocket Motor Clamp (2/2)

- This component will have different templates that can slide in to adhere to the different rocket motor ring geometries.

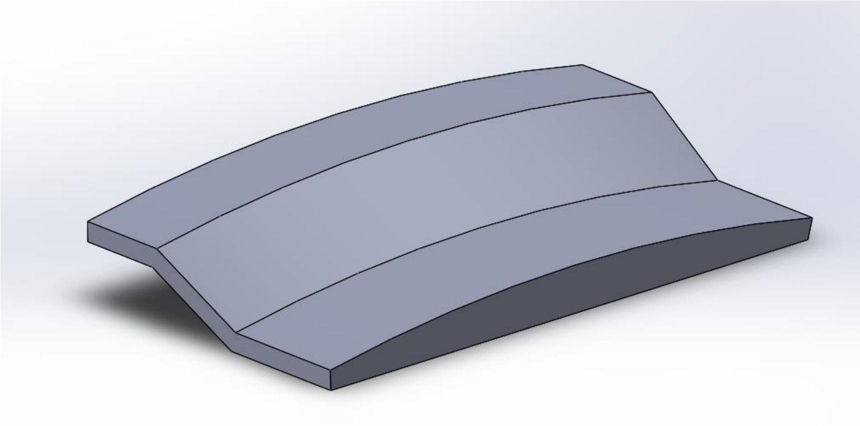

Figure 17. Custom Clamp Jaw for Orion 50 Motor Rings

3.2 Design Components (cont.)

Splined Shaft for Rail Angle

- Splined shaft that will allow the hinge section to adjust to multiple angles to conform to the rockets dome profiles.
- Unless complicated tool paths are used to create a spline shaft with a CNC machine, these components will likely be outsourced for production.

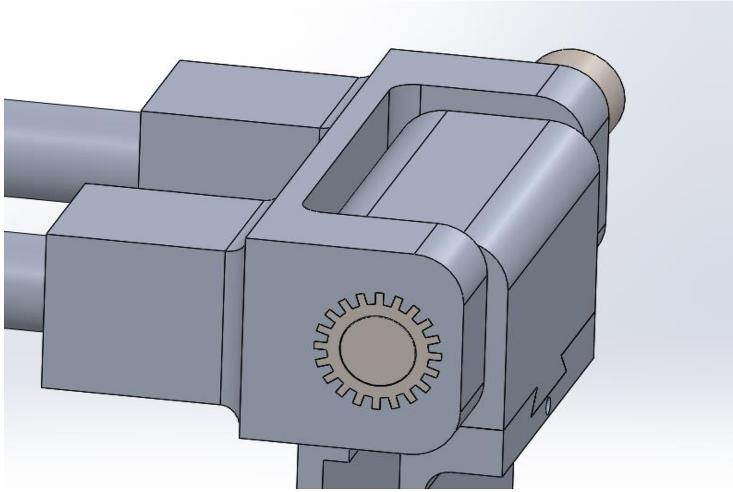

Figure 18. Spline Shaft used to Adjust Rail Angle

Rail System (1/2)

- Two sets of cylindrical rails allow the cart to slide inward from the hinge component.
- With a 36 inch rail length, the maximum deflection from a 50 pound load can be found using equation (1)
- To minimize the deflection while maintaining a high factor of safety, low weight and high corrosion resistance, 7075 aluminum was chosen for this application

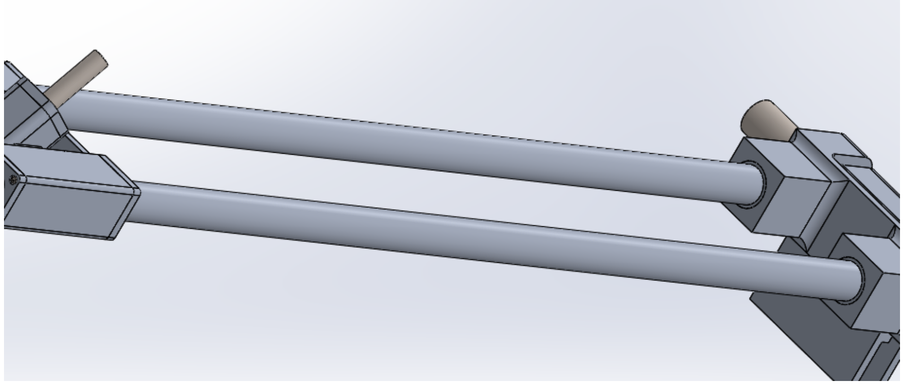

Figure 19. Rail System

$$\delta = \frac{PL^3}{3EI} \qquad [1]$$

Figure 20. Deflection Equation

3.2 Design Components (cont.)

Rail System (2/2)

- Considering an elastic modulus of 10400 ksi and an even distribution of the load between the rails, the maximum expected deflection is 0.83 inches with a rail diameter of 0.98 inches.
- While more calculations will be made in the analytical reports to ensure that this material and geometrical choice was optimal, early FEA provides a factor of safety much larger than the minimum requirement for this project.

3.2 Design Components (cont.)

Rail Cart (1/2)

- The cart component holds the power screw assembly and allows for a variety of applicable angles.
- As the stresses on this material were lower due to the axial, non-moment inducing loads, cheaper 6061 aluminum with high machinability, low weight and the same corrosion resistance was selected.

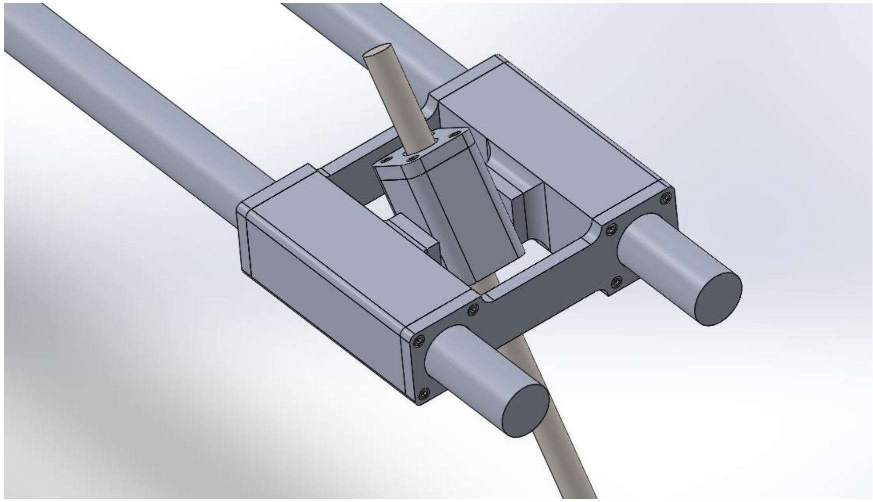

Figure 21. Rail Cart and Angleable Lead Screw

3.2 Design Components (cont.)

Rail Cart (2/2)

- The rail cart itself is braced by plates at the front and rear
- The total weight of the aluminum cart pieces is less than 3 pounds, while the use of a plastic lead screw nut also serves to decrease weight

3.2 Design Components (cont.)

Lead Screw

- The power screw provides the axial force required to adhere the brackets to the dome. A knurled nut on top will move the screw up and down.
- Total weight of stainless steel lead screw, which was chosen for corrosion resistance properties, will depend on the length needed for the application.
- Less than 1 pound for this component is expected when considering the given rocket motor geometries

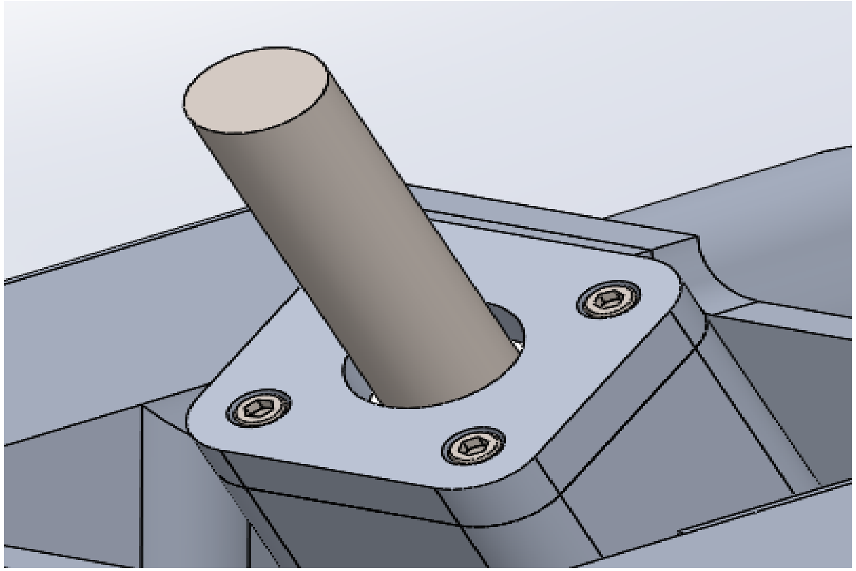

Figure 22. Angleable Lead Screw

Force Gauge

- Measure applied force
- Given tolerances of ±2 pounds allow for the force to be measured with low resolution instrumentation.
- Force gauge spins freely around the end of the power screw allowing the bracket to remain in place.
- This gauge will provide feedback on both the pushing and pulling force from the power screw.
- Spring constant will be determined during testing and an analytical analysis

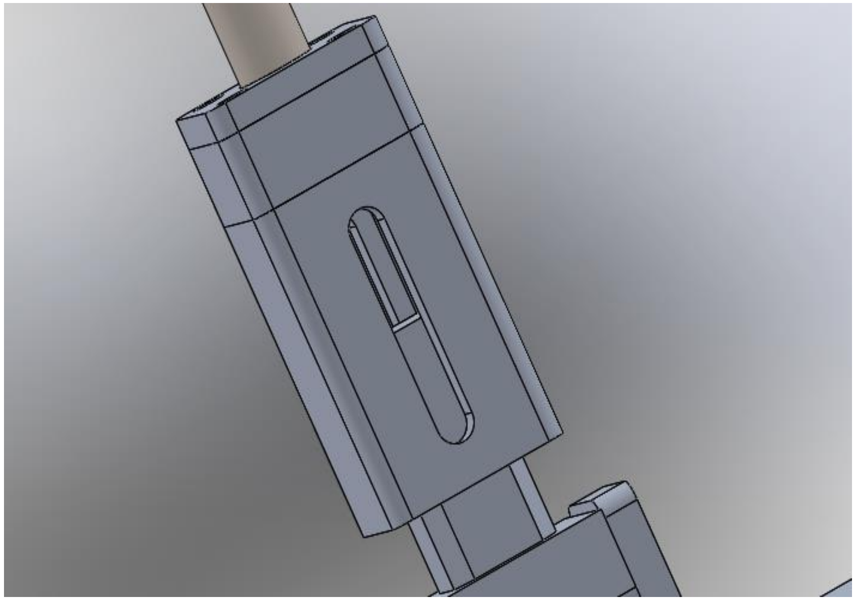

Figure 23. Force Gauge Spring Housing

3.2 Design Components (cont.)

Joint for setting angles

- Setting the cure and pull test angles
- The bracket holding component will mount to the bottom of the force gauge and will lock in three positions (90° and ±45°) to perform the pull test.
- A joint with pin holes drilled at the necessary locations for these settings is to be positioned at the end of the lead screw assembly.
- The smaller holes will house a pin that will set the angle of the applied force relative to the surface

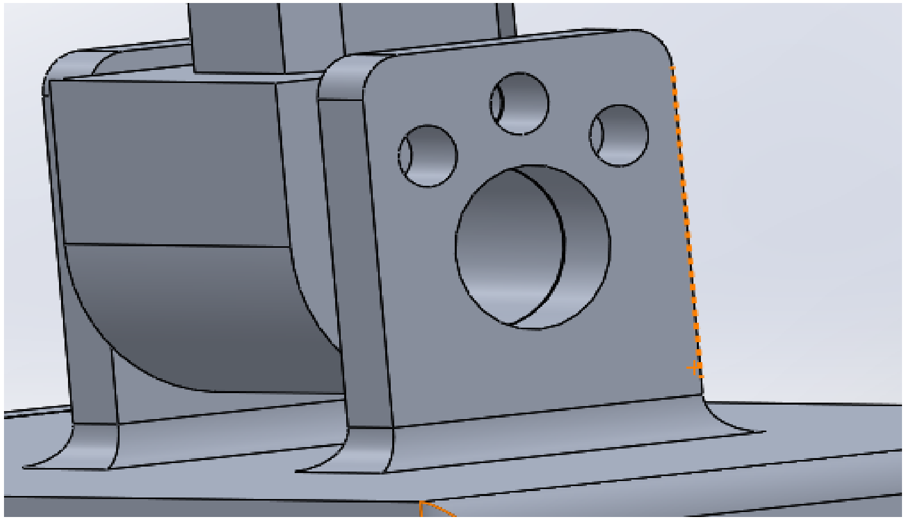

Figure 24. Joint for Setting Angle Relative to the Dome

Bracket Retention

- The last component is the bracket holding mechanism itself. It will be adaptable to hold the different sized brackets provided by Northrop Grumman.
- A simple wing nut and stud combination will make using the clamp easy for any operator while ensuring that a force can be applied to keep the standoff bracket in place.

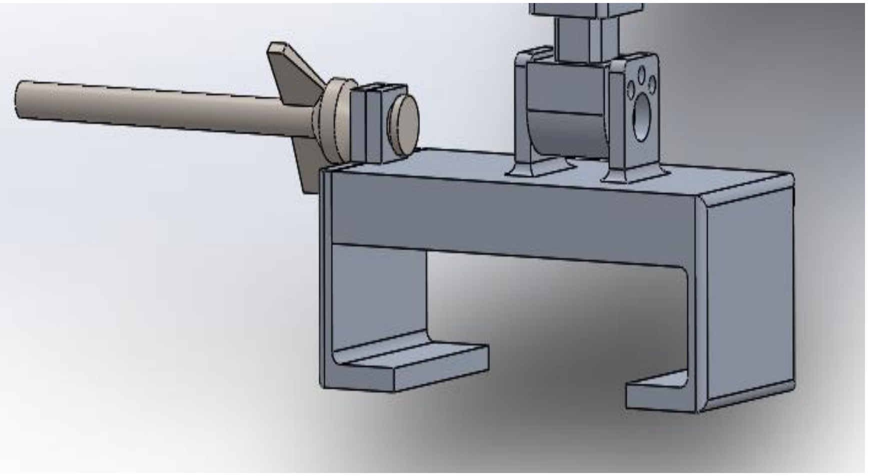

Figure 25. Bracket Retention Subsystem

3.3 Design Requirements

Customer Requirements (1/2)

- Electrostatic Discharge Compliant
- Durability
- Reliability
- Adjustable Interfaces
- Minimum 3.0 Factor of Safety

Figure 26. Exploded CAD Model

3.3 Design Requirements

Customer Requirements (2/2)

- 20 lbf Push Test
- 50 lbf Pull Test
- Six degrees of freedom in movement
- Usable 4” - 36” inboard of ring
- Transportability
- Ease of operation
- Support 10 lbs in locked position

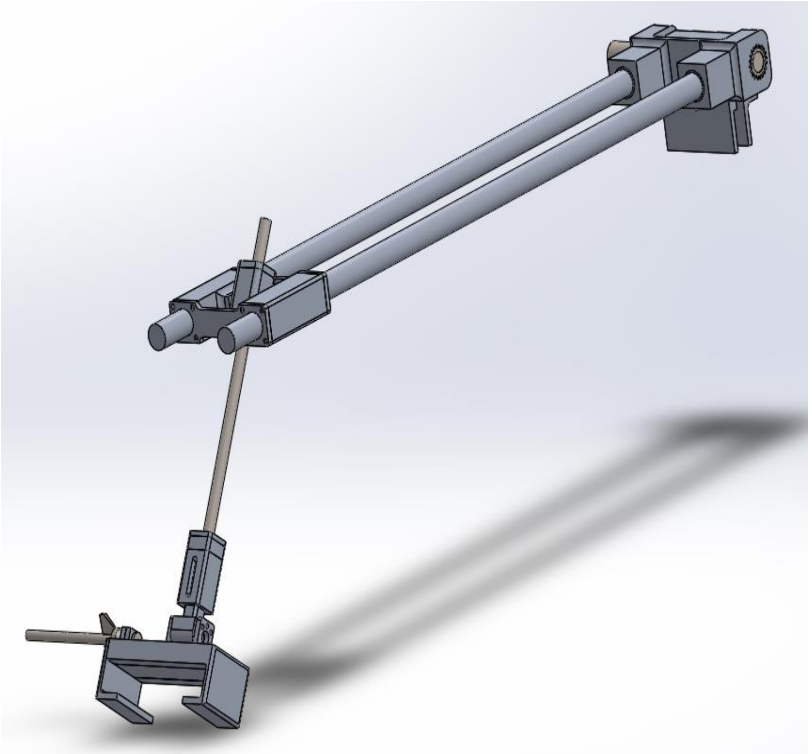

Figure 27. CAD Model

NORTHROP GRUMMAN

Ring Moment Analysis (1/2)

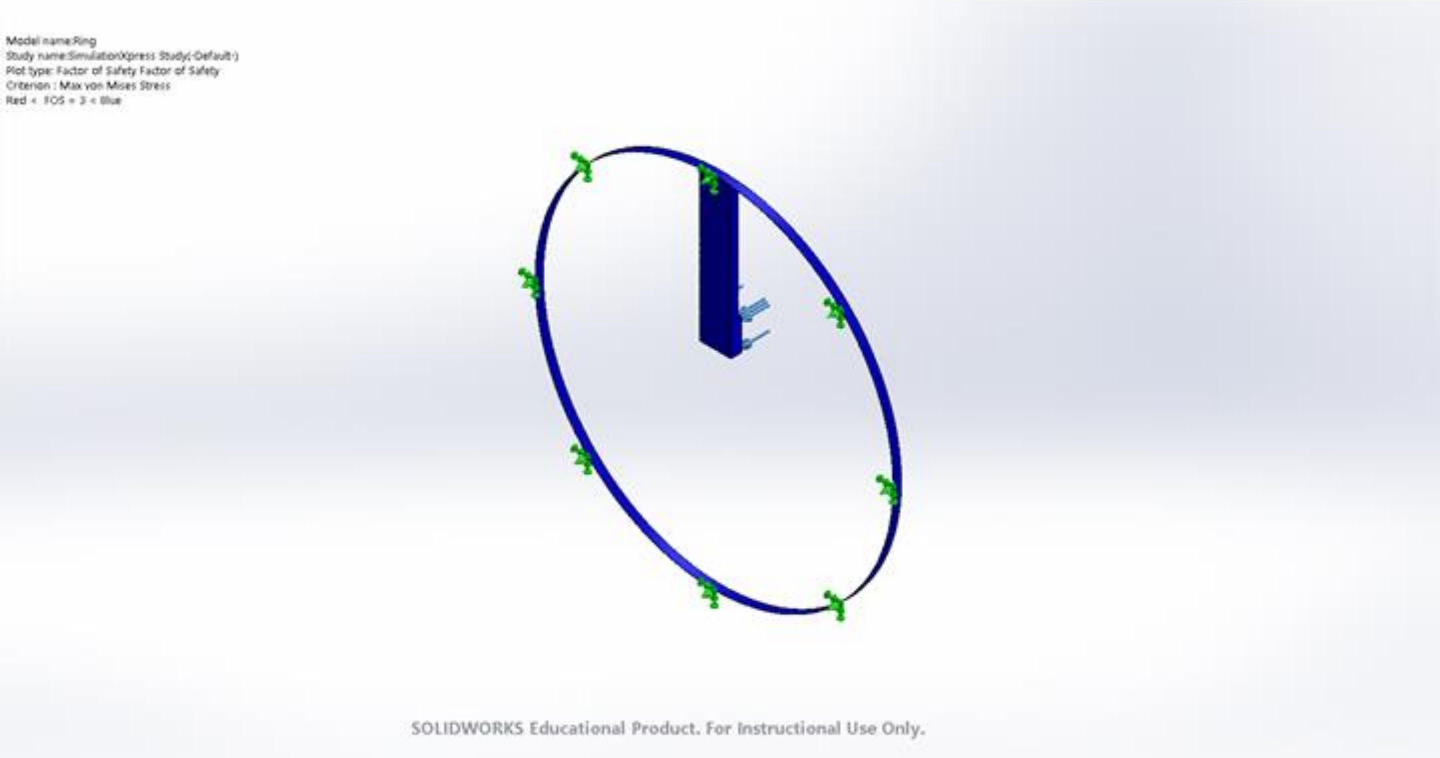

Figure 14. Finite Element Analysis of Motor Ring

NORTHROP GRUMMAN

Ring Moment Analysis (2/2)

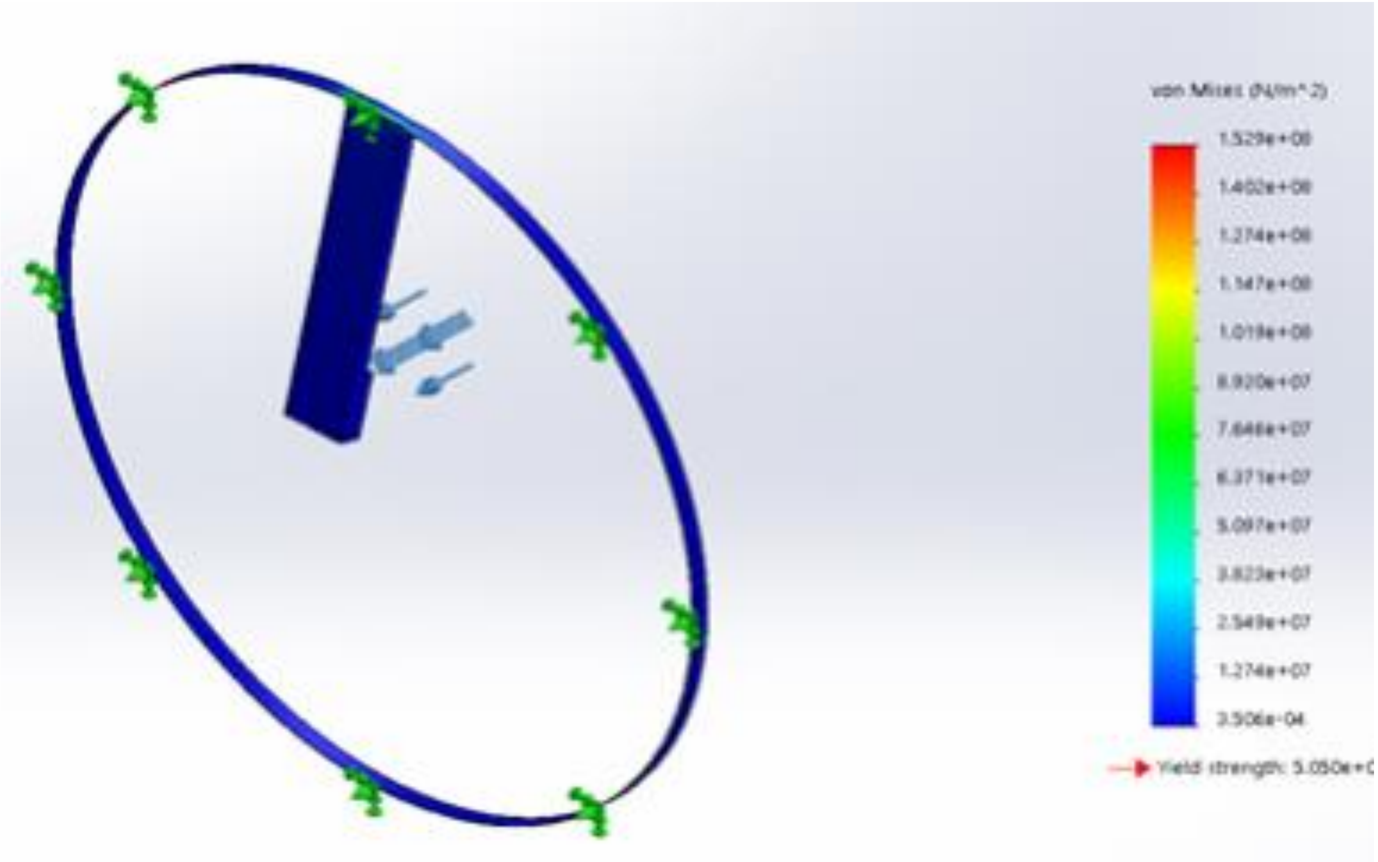

Figure 15. Ring Stress Distribution

NORTHROP GRUMMAN

Clamping Force Analysis

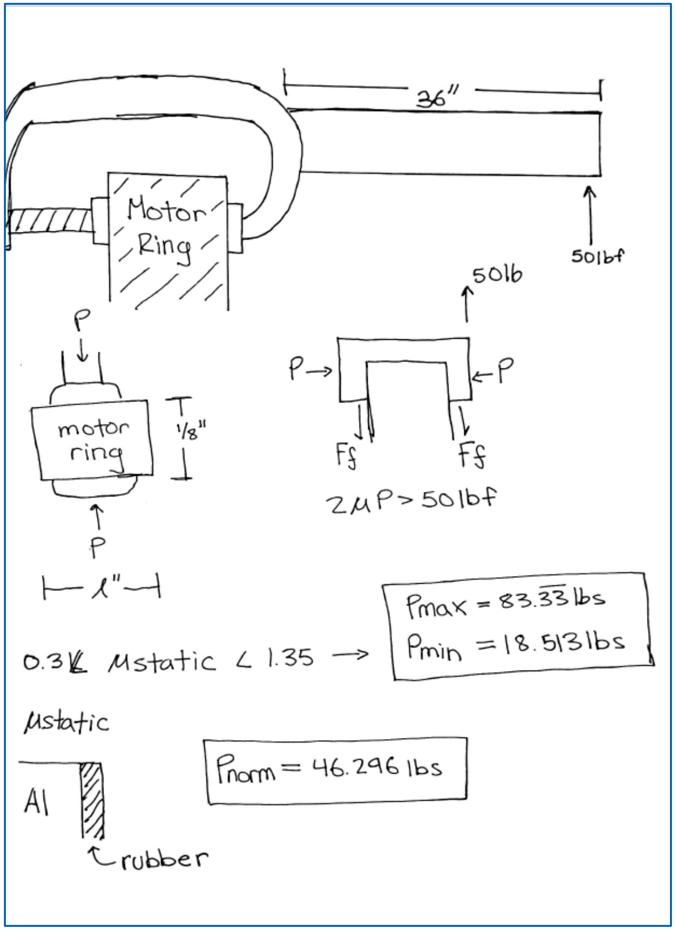

Figure 16. Clamping Force Hand Calculations [9] [10] [11]

3.5 Design Validation

NORTHROP GRUMMAN

Table 6. Standards, Codes, and Regulations

Standard Number or Code	Title of Standard	How it applies to Project
ASME Y14.5-2009	Dimensioning and Tolerancing	This standard could help facilitate the creation of engineering drawings that effectively communicate design intent.
ASME B30.2-2009	Overhead and Gantry	Applies the operation and safety procedures associated with cantilevered gantry cranes which can be related to our product.
ASME B18.29.1 - 2010	Helical Coil Screw Thread Inserts--Free Running and Screw Locking	This standard relates to our project by providing information on threaded hole helical screw inserts which are included within the power screw assembly.
ASME B5.48 - 1977	Ball Screws with Errata	A ball screw will likely be utilized for the power screw assembly. This resource will give information on the definition and classes of ball screws.
ASME B1.5 - 1997	Acme Screw Threads	This resource gives information related to acme screw threads which is the thread form which will be used for the power screw.

3.5 Design Validation (cont.)

NORTHROP GRUMMAN

Table 7. Failure Modes and Effects Analysis

Product Name	Standoff Bonding Tool	Development Team	18F19					FMEA Number	3	
								Date	11/14/19	
Part #	**Function**	**Potential Failure Mode**	**Potential Effects for Failure**	**Severity** (1-10)	**Potential Cause(s) for Failure**	**Occurance** (1-10)	**Current Design Controls Test**	**Detection** (1-10)	**RPN** (SxOxD)	**Reccomended Action(s)**
2	Mount to ring	Bending of the ring	Rocket Motor Ring will break	10	Overstressing the ring	5	Visual Indicator	8	400	Moment Ring Analytical Analysis
11	Angle Bracket	Bracket Joint Pin Shear Failure	Inability to carry out the pull test	7	Applied axial force	6	Visual Indicator	8	336	Material Selection Analysis
5, 6	Angle Bracket	Spline Mounting Screw Shears	Device will be unsupported	8	Applied axial force	6	Audibe and Visual Indicators	5	240	Spline Shaft Gear Analysis
2	Mount to ring	Clamp slips off	The device will be unsupported	8	Inefficient clamping force	3	Visual Indicator	8	192	Clamp force analysis
4, 13	Locking	Force block slides during axial force tests	Device cannot be applied to a specific location	7	Applied force exceeds lock capacity	5	Audibe and Visual Indicators	5	175	Material Selection Analysis
3	Bracket slips off	Unable to hold standoff bracket	Unable to hold standoff bracket	7	Incefficent clamping force	3	Visual Indicator	8	168	Clamp force analysis
22	Apply Axial Force	Lead Screw Breaks	Unable to apply axial force	8	Force induced deformation of screw	3	Audibe and Visual Indicators	5	120	Lead Screw Stress analysis
1	Translate the brackets	Bending of the rails	Device is not able to translate toward the standoff location	7	Overstressing the pivots	2	Visual Indicator	8	112	Deformation Test
4	Translate the brackets	Force Block does not slide	Device is not able to translate toward the standoff location	7	Ball Bearing Breaks	2	Visual Indicator	8	112	Bearing Analytical Analysis
15	Apply Axial Force	Fish Scale does not read correctly	Force will not display to operator	5	Spring does not function with the device	2	Visual Indicator	8	80	Spring Analysis

3.5 Design Validation (cont.)

FMEA

- Critical Potential Failures
  - Bending the Circumferential Motor Ring
  - Device Losing Grip onto the Ring
  - Angled Bracket Joint Failure
- Proposed Design Solutions
  - Wider grip
  - Increase clamp force
  - Spline design to increase strength of locking mechanism
- Risk Trade-off Analysis
  - Increasing the complexity of the design adds more failure points
  - Proposed solutions increased the overall weight

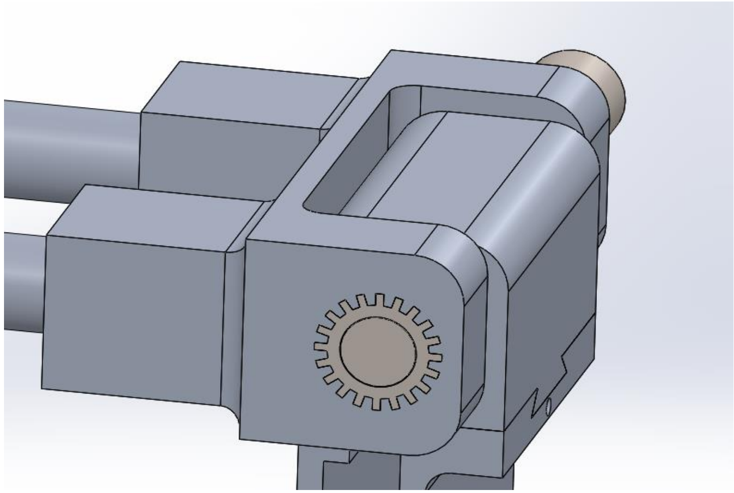

Figure 28. Spline Shaft used to Adjust Rail Angle

Potential Critical Failure 1: Bending of the Ring (1/2)

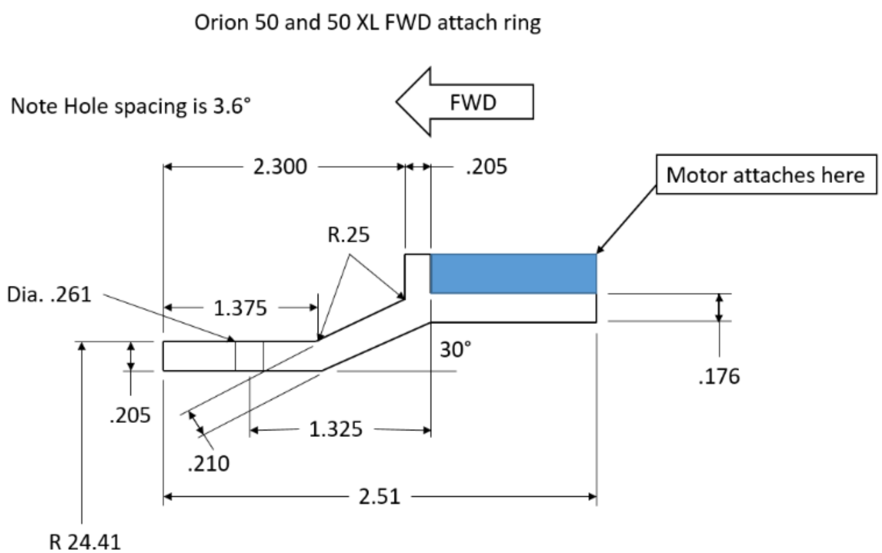

Figure 29. Orion 50 and 50XL FWD attach rings

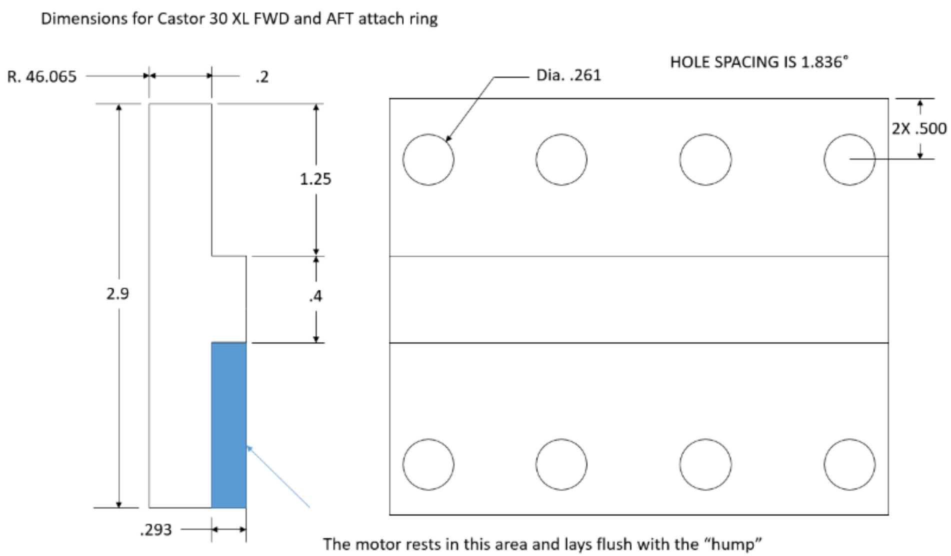

Figure 30. Castor 30XL FWD and AFT attach rings

3.5 Design Validation (cont.)

Potential Critical Failure 1: Bending of the Ring (2/2)

- Due to the thin dimensions of the rocket motor ring, bending is possible while applying the standoff device
- This could cause the rocket to be ruined
- Actions to mitigate this failure:
  - Rocket Moment Analysis
  - Solidworks FEA
  - Hand Calculations

Potential Critical Failure 2: Bracket Joint Pin Shear Failure

- To angle the bracket, a pin will lock in device in three positions (90° and ±45°)
- Due to the axial forces applied on the device, a large amount of stress will be applied to the locking pin
- Actions to mitigate this failure:
  - Material selection analysis
  - Further analytical analysis may be performed

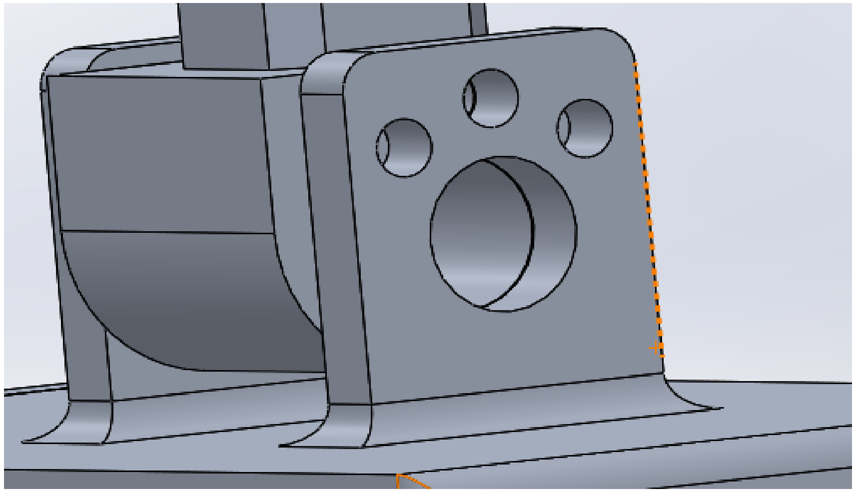

Figure 31. Joint for Setting Angle Relative to the Dome

3.5 Design Validation (cont.)

Potential Critical Failure 3: Spline Mounting Screw Shears

- To angle vertically over the Castor 30 series rocket dome, a spline design was formulated
- Due to the teeth of the spline, axial force could cause damage to the design
- Actions to mitigate this failure:
    - Spline Gear Analysis
    - Formation of a Spline Excel Sheet

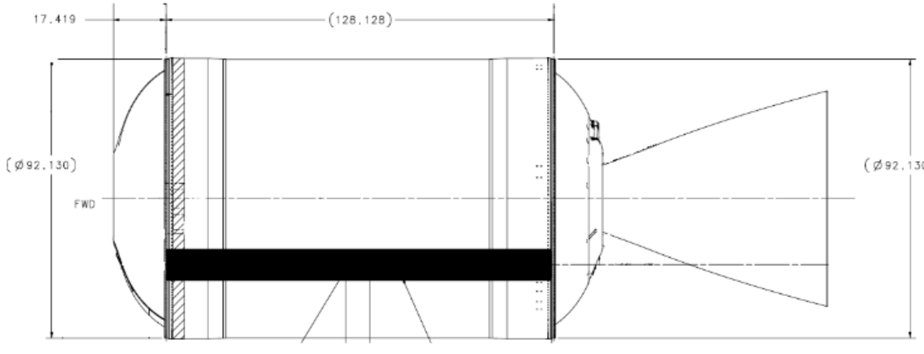

Figure 32. Castor 30 Series Drawing

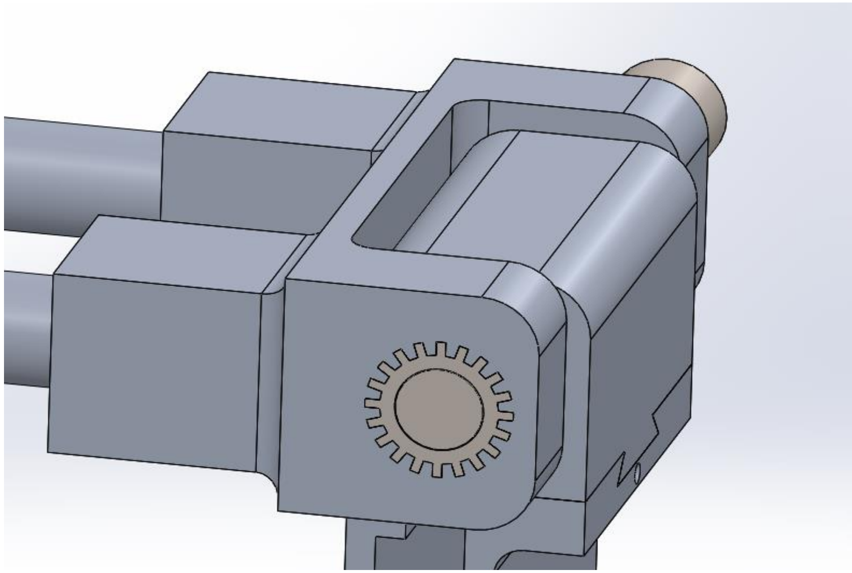

Figure 33. Spline Shaft used to Adjust Rail Angle

3.5 Design Validation (cont.)

Potential Critical Failure 4: Rocket Ring Clamp Slips Off

- Rocket Ring Clamp will experience a large moment which could cause the clamp to slip off the locked position
- Actions to mitigate this failure:
  - Clamping Force Analysis
  - Clamping Test

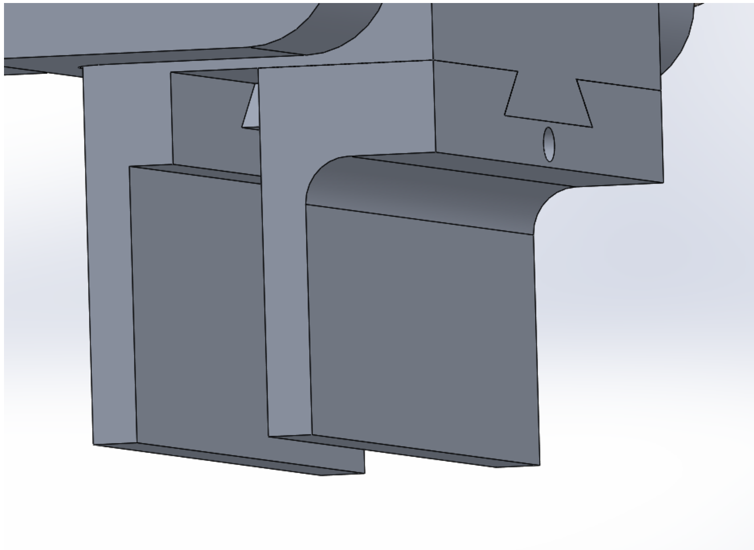

Figure 34. Motor Ring Clamp

3.5 Design Validation (cont.)

Potential Critical Failure 5: Force Block Slides due to Axial Force

- In order to secure the force block in place, locking rings will be placed on each end of the force block rails
- Due to the axial force applied, the locking rings (nylon hose clamps) could fail
- Actions to mitigate this failure:
  - Material Analysis
  - FMEA will be reanalyzed
  - Further testing could be conducted
  - Another option could be selected if this fails further

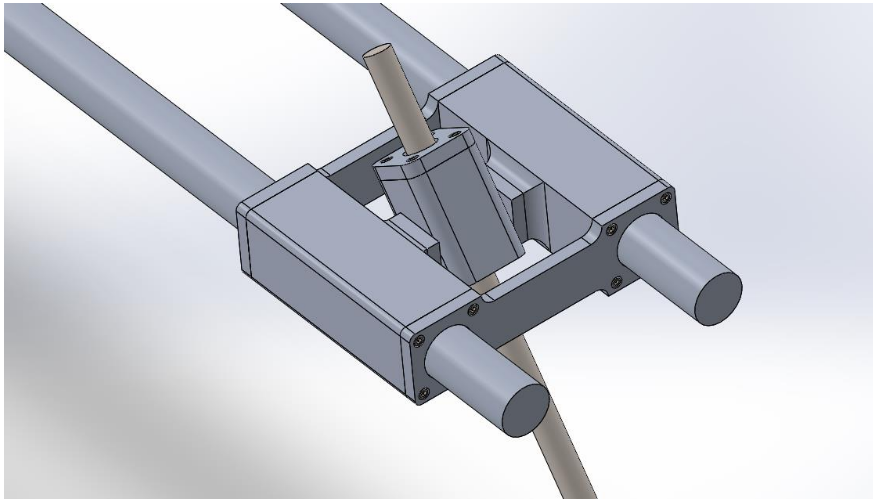

Figure 35. Rail Cart and Angleable Lead Screw

3.5 Design Validation (cont.)

Potential Critical Failure 6: Bracket Clamp Slips Off

- Similarly to the rocket ring clamp, the bracket clamp could slip off during testing
- Actions to mitigate this failure:
  - Clamping test will be referenced to analyze this failure
  - Secondary clamping analysis is planned for the spring semester
  - FEA analysis will be conducted

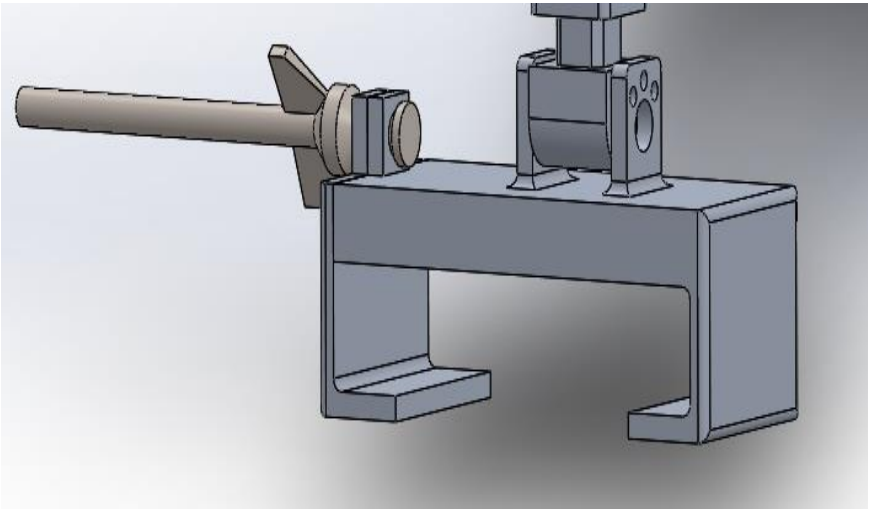

Figure 36. Bracket Retention Subsystem

3.5 Design Validation (cont.)

Potential Critical Failure 7: Lead Screw Breaks

- Lead screw could experience deformation after axial force is applied
- Actions to mitigate this failure:
  - Power Screw Analysis
  - Formation of a power screw design Excel sheet

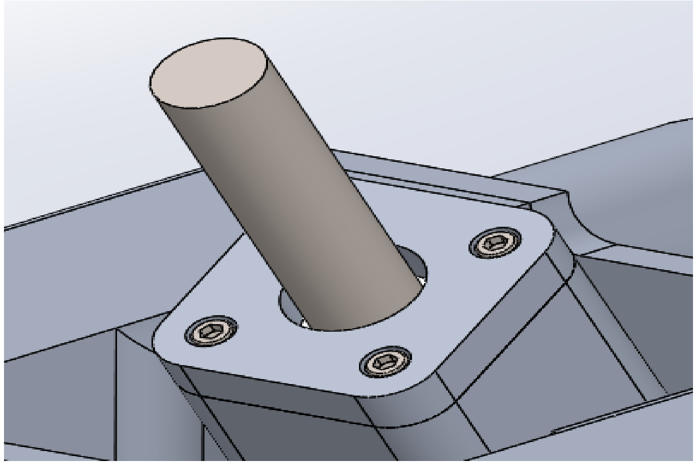

Figure 37. Angleable Lead Screw

3.5 Design Validation (cont.)

Potential Critical Failure 8: Bending of the Rails

- Rails designed will be subjected to moment and deflection from the applied axial force
- Actions to mitigate this failure:
  - Rail Deformation Test
  - Rail Analytical Analysis
  - Solidworks FEA
  - MATLAB code to verify the values

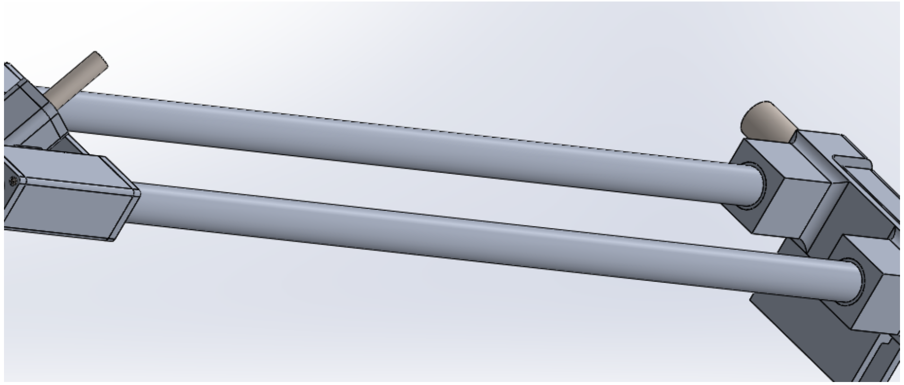

Figure 38. Rail System

3.5 Design Validation (cont.)

Potential Critical Failure 9: Force Block does not Slide

- To ease the sliding function of the force block, bearings are being considered to make sliding the block easier for operators
- The bearings could break due to the force applied by the device
- Actions to mitigate this failure:
  - Bearing Analytical Analysis
  - Hand Calculations
  - Excel or MATLAB worksheet to verify the results

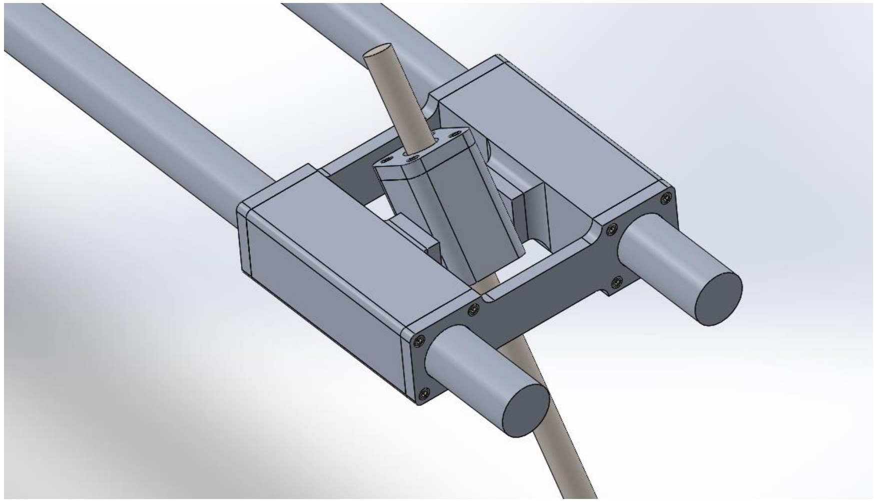

Figure 39. Rail Cart and Angleable Lead Screw

3.5 Design Validation (cont.)

Potential Critical Failure 10: Force Scale does not Read Correctly

- In order to allow operators to read the force being applied to the standoff brackets, a force gauge is to be installed
- A spring with a given spring constant value will be installed to display force readings
- This could result in spring deformation
- Actions to mitigate this result:
  - Spring Analytical Analysis in the spring semester
  - Formation of an excel sheet to allow the changing of design variables

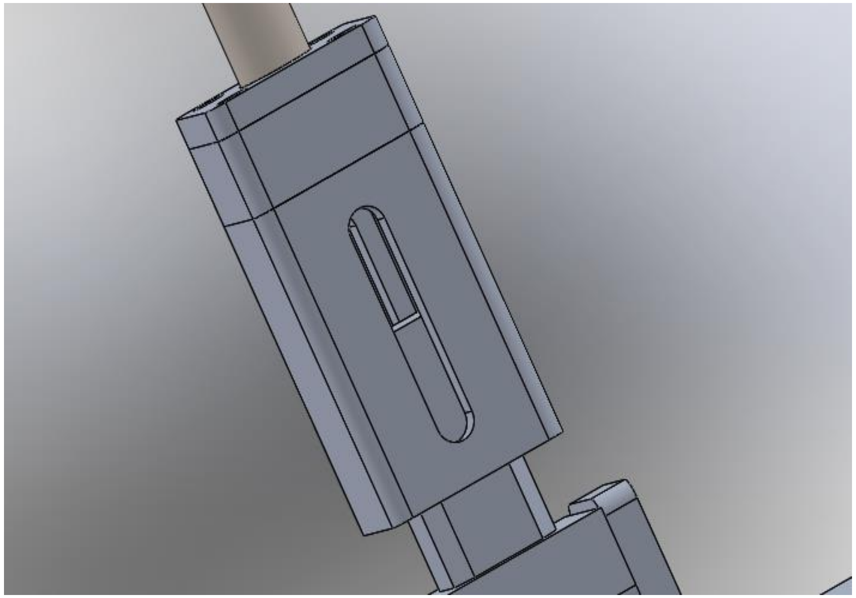

Figure 40. Force Gauge Spring Housing

3.5 Design Validation (cont.)

NORTHROP GRUMMAN

Testing Procedure #1: ESD Compliance

Customer Needs: ESD compliance, safe operation

Objective: To test the ESD Compliance of the device

Resources Required: Device prototype, multimeter, wires, ESD mat
Estimated total cost: $50

Procedure:
Estimated Testing time - 15 minutes
Location - 98C (Machine Shop Classroom)

1. Lay ESD mat flat on the table
2. Clamp device to the table and ensure that the device is placed on the mat
3. Use the multimeter to detect voltage between the device and the user.
4. If the multimeter reads 0V then the device is ESD Compliant

3.5 Design Validation (cont.)

Testing Procedure #2: Clamping Force (1/2)

Customer Needs: Usable 4”-36” inboard of ring, transportability, durability, reliability, minimum 3.0 factor of safety, use of multiple mounting arms at a time, safe operation

Engineering Requirements: mass, modulus of elasticity

Objective: To determine the optimal dimensions and materials of the clamp necessary to support the device without deforming the outer ring material

Resources Required: pressure sensor, strain gauge, multimeter, arduino, vise grips, wires, rubber, soldering kit, aluminum sheet
Estimated total cost: $70.97

3.5 Design Validation (cont.)

Testing Procedure #2: Clamping Force (2/2)

Procedure:
Estimated Testing time - 2 hours
Location - ME495L Room

1. Conduct mechanics of materials calculations on aluminum
2. Conduct analytical analysis on clamping force
3. Create a program(s) that will read pressure
4. Attach pressure sensor to the aluminum sheet
5. Measure clamping force while the program runs
6. Compare data to analytical analysis

3.5 Design Validation (cont.)

Testing Procedure #3: Rail Deflection (1/2)

Customer Needs: apply axial forces, durability, reliability, minimum 3.0 factor of safety, usable 4”-36” inboard of ring, and safe operation

Engineering Requirements: mass, principal dimensions, working length, and modulus of elasticity

Objective: To determine the best material for the rails

Resources Required: steel or aluminum rods, strain gauges, wires
Estimated Total Cost: $155

3.5 Design Validation (cont.)

Testing Procedure #3: Rail Deflection (2/2)

Procedure:
Estimated Testing time - 3 hours
Location - ME495L Room

1. Apply strain gauges to both ends of the steel rod
2. Connect strain gauges to computer software
3. Apply axial forces to the end of the rod while the software is running
4. Compare data to analytical results
5. Repeat procedure for the aluminum rod

3.5 Design Validation (cont.)

Testing Procedure #4: Power Screw Effectiveness (1/2)

Customer Needs: apply axial forces, six degrees of freedom in movement, usable 4”-36” inboard of ring, ease of operation, durability, reliability, adjustable interfaces, support 10lbs in locked position, minimum 3.0 factor of safety, and safe operation

Engineering Requirements: mass, principal dimensions, working length, working angle, and modulus of elasticity

Objective: To test the functionalities of the bracket holder, bracket holding component, splined shaft, and the power screw effectiveness

Resources Required: Final Prototype, Bracket
Estimated total cost: $0

3.5 Design Validation (cont.)

Testing Procedure #4: Power Screw Effectiveness (2/2)

Procedure:
Estimated Testing time - 1 hour
Location - 98C (Machine Shop Classroom)

1. Secure bracket to the bracket holder
2. Mount device onto the edge of the desk
3. angle device 45 degrees to the surface of the desk
4. apply axial force
5. read force scale

4. Schedule and Budget Overview

NORTHROP GRUMMAN

4.1. Schedule

4.2. Budget

4.1 Schedule

- Final Bill of Materials and CAD [11/22]
- Analytical Analyses [11/27]
    - Rail Deflection
        - Testing [11/21]
    - Ring Moment
    - Clamp Friction Force
        - Testing [11/22]
    - Power Screw
    - Bearing
- Final Prototype [12/6]
- Website Check 2 [12/9]

4.1 Schedule (cont.)

- Self Learning [1/24]
- Hardware Review [2/14]
- Analytical Analyses II [3/13]
  - Spline Hub and Gear
  - Force Gauge Spring
  - Bracket Clamp
- Final Product [3/27]
- Testing Proof [4/10]
- UGRADS Presentation [4/24]

4.2 Budget

NORTHROP GRUMMAN

Table 8. Bill of Materials Final Design

Bill of Materials Final Design								
Team				Northrop Grumman Standoff Project				
Part #	**Part Name**	**Qty**	**Description**	**Functions**	**Material**	**Dimensions**	**Cost**	**Link to Cost estimate**
1	Rail	2	41L40 Alloy Steel Round Rod 1/2" Diameter x 3' Length	Mode of translation for the Bracket Holder Mechanism (rail cart).	7075 Aluminum	1/2" x 1/2" x 3'	154.71	https://www.onlinemetals.com/en/search/results?q=aluminum+bar%3Aprice-asc%3AMaterial%3AAluminum%3AShape%3ARound%2BBar%3AAlloy%3A7075&checkbox=on&sort=price-asc#
2	36" Clamp	1	Adjustable Clamp 9133 Corner/Splicing Clamp	Secure the device to the motor ring.	6061 Aluminum	1.5" x 7.8" x 6"	240.16	https://www.metalsdepot.com/aluminum-products/aluminum-square-bar
3	Bracket Holder	2	Custom made bracket holder, to be manufactured in machine shop.	Secure the bracket to the device.	6061 Aluminum	16" x 3" x 2"		
4	Rail Cart Rail Connectors	2	Custom made for fabrication at machine shop	Transports bracket holder across rail system.	6061 Aluminum	4" x 3" x 1"		
5	Spline Rail Connector	1	Custom made for fabrication at machine shop	Adjusts the angle of the device	6061 Aluminum	4" x 8"		
6	Spline Clamp Connector	1	Custom made for fabrication at a machine shop	Adjusts the angle of the device	6061 Aluminum	4" x 8"		
7	Shaft Collar	1	Custom made for fabrication at a machine shop	To prevent the bracket clamp from rotating while the handling arm is lowered onto the rocket dome	6061 Aluminum	1/2" x 4"		
8	92 " Clamp	1	Adjustable Clamp 9133 Corner/Splicing Clamp	Secure the device to the motor ring.	6061 Aluminum	1.5" x 7.8" x 6"		
9	Bracket Clamp Screw	1	Custom made for fabrication at a machine shop	Tighten the bracket clamp around the bracket templates	6061 Aluminum	1/2" x 10"		
10	Spline Pin	1	Custom made for fabrication at a machine shop	Secure spline location in place	6061 Aluminum	1/2" x 2"		
11	Universal Joint Pin	1	Small metal rod	Lock joint in place	6061 Aluminum	1/4" x 2"		

4.2 Budget (cont.)

Table 8. Bill of Materials Final Design

12	Rail Cart Rotational Positioner	1	Custom made for fabrication at a machine shop	Allows team to move the location of the axial force on the rail cart	6061 Aluminum	4" x 4" x 8"		
13	Locking Rings	4	Circular Rubber stoppers that can clamp onto the metal rods	Lock the Force Block in place	Rubber	1/2" x 36"	2.99	https://www.rockler.com/non-skid-rubber-bumpers?sid=V9146?utm_source=google&utm_medium=cpc&utm_term=&utm_content=pla&utm_campaign=PL&gclid=EAIaIQobChMIz52AkMjW5QIVbxitBh39DQsrEAQYBSABEgJ_ePD_BwE
14	Design Screws	24	2" long screws	To assemble seperate parts together in the final assembly	Stainless Steel	#4 x 5/8"	8	https://www.amazon.com/Screws-Thread-Stainless-Self-Tapping-Quantity/dp/B01CRE76IK/ref=sr_1_2?keywords=%234+metal+screws&qid=1573076036&refinements=p_n_feature_nine_browse-bin%3A17426584011&rnid=17426558011&s=hi&sr=1-2
15	Lubricant	1	Super Lube 51004 Synthetic Oil with PTFE, High Viscosity, 4 oz Bottle	Reduce friction of the rail system.	Synthetic PTFE Oil	2" x 2" x 6.5"	4.60	https://www.amazon.com/Super-Lube-51004-Synthetic-Viscosity/dp/B000UKUHXK/ref=sr_1_1?keywords=Synthetic+PTFE+Oil&qid=1570591173&s=industrial&sr=1-1
16	Fastener	3	Black Oxide Alloy Steel Socket Head Screw 1/4-20, 4" Long	Works with wing nut to secure bracket to the clamp.	Black Oxide Alloy Steel	3/8" x 4"	9.25	https://www.mcmaster.com/90044a131
17	Wing Nut	1	18-8 Stainless Steel Wing Nut 1/4"-20	Part of clamping mechanism to secure bracket to clamp.	Stainless Steel	31/64" x 1 1/8" x 5/8"	7.32	https://www.mcmaster.com/92001a321
18	Universal Joint	1	Custom made for fabrication at a machine shop	Universal joint to help position the bracket onto the rocket.	Vanadium Steel	6.5" x 5" x 1.1"	11.98	https://www.amazon.com/TEKTON-4964-Impact-Universal-3-Piece/dp/B000NPZ40I/ref=sr_1_21?keywords=Ball+and+Socket+Joint&qid=1570592342&sr=8-21
19	Drive Knob for Cart	1	Genuine Echo KNOB, FASTENER for driveshaft coupler assembly	Transmit force into the push/pull system.	Steel	4" x 1" x 2.5"	10.59	https://www.amazon.com/Echo-V299000160-Fastener-driveshaft-Assembly/dp/B07FDJSSFZ
20	Lead Screw	1	Metal Screw	Drives the bracket toward the rocket dome	Stainless Steel	2' x 1/2"	178.36	https://www.mcmaster.com/lead-screws
			Total Cost Estimate:				994.14	

4.2 Budget (cont.)

NORTHROP GRUMMAN

- Expected Final Design Cost ≈ $994.14
- Clamp Force Experiment ≈ $78.00
- Rail Test ≈ $154.25
- Travel ≈ $80.00
- Low Fidelity Prototype ≈ $13.00
- Prototype ≈ $200.00
- Remaining Budget ≈ 8,480.61
- Budget Uncertainties
  - Design Revisions
  - Machine Shop Costs
  - Component Failures

Summary

1. Project Description
2. Concept Generation and Evaluation
3. Final Design Proposal
4. Schedule and Budget

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

References

[1] *Propulsion Products Catalog*, Northrop Grumman, Falls Church, VA, June 2018

[2] "The Prevention and Control of Electrostatic Discharge (ESD)", *Minicircuits.com*, 2019. [Online]. Available: https://www.minicircuits.com/app/AN40-005.pdf. [Accessed: 17- Sep- 2019].

[3] D. Kumar B and S. Nayana B, "Design and Structural Analysis of Solid Rocket Motor Casing Hardware used in Aerospace Applications", *Journal of Aeronautics & Aerospace Engineering*, vol. 5, no. 2, 2016. Available: 10.4172/2168-9792.1000166.

[4] O. Olwan, A. Matan, M. Abdullah and J. Abu-Khalaf, "The design and analysis of a six-degree of freedom robotic arm," *2015 10th International Symposium on Mechatronics and its Applications*

[5] "Difference Between Conductive, Dissipative, Insulative and Antistatic: ESD & Static Control Products: Transforming Technologies," ESD & Static Control Products | Transforming Technologies, 29-Mar-2012. [Online]. Available: https://transforming-technologies.com/esd-fyi/difference-between-conductive-dissipative-and-insulative/. [Accessed: 18-Oct-2019].

[6] G. Elert, "Coefficients of Friction for Rubber," Coefficients of Friction for Rubber - The Physics Factbook. [Online]. Available: https://hypertextbook.com/facts/2005/rubber.shtml. [Accessed: 09-Oct-2019].

[7] "Friction and Friction Coefficients for various Materials," Friction and Friction Coefficients for various Materials. [Online]. Available: https://www.engineeringtoolbox.com/friction-coefficients-d_778.html. [Accessed: 09-Oct-2019].

[8] R. C. Hibbeler, Mechanics of Materials. Harlow, England: Pearson, 2019.