THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

Critical Design Review: NAU Standoff Project

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2/27/20

Presentation Overview

1. Project Description
2. PDR State of Design vs Current Design
3. Potential Failures and Testing Procedures
4. Schedule and Budget

1. Project Description Overview

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1.1 Project Background

1.2 Project Requirements

1.3 Customer Needs

1.4 Engineering Requirements

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

Figure 2. Castor 30XL

1.2 Project Requirements

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
- Perform a pull test of 50 lbs at 45 degrees of freedom
- Maximum deflection of .1” for rail design
- 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
- Allow the use of multiple mounting arms at a time

1.3 Customer Needs

Table 1. Customer Requirements

	Customer Requirements	Weight
1	ESD Compliance	0.09
2	Apply Axial Forces	0.09
3	6 DOF Movement	0.09
4	Range of 4-36"	0.09
5	Transportability	0.04
6	Ease of Operation	0.07
7	Durability	0.08
8	Reliability	0.08
9	Adjustable Interfaces	0.09
10	Support 10lb (Fixed Position)	0.09
11	Minimum 3.0 FOS	0.06
12	Budget	0.03
13	Size	0.05
14	Operator Safety	0.05
		1.00

Figure 3. Castor 38

1.4 Engineering Requirements

1. Electrically Conductive (Y or N)
2. Weight (lbs)
3. Principal Dimensions (in)
4. Working Length (in)
5. Working Angle (Degrees)
6. Modulus of Elasticity (lbf/in2)

2.1 PDR State of Design

Action Items from the PDR Presentation:

- ❑ Simplify manufacturing
- ❑ Perform a risk analysis for failures
- ❑ Review if using the rocket ring holes is possible
- ❑ Review if galling of power screw is possible
- ❑ Verify clamping mechanism does not overstress rocket motor ring
- ❑ Reduce deflection of device rails
- ❑ Make design changes to perform 50lb. pull test directly on standoff
- ❑ Make design changes to perform 20lb. push test per standoff (max of 6) on the bracket template

2. PDR State of Design vs Current Design Overview

2.1 PDR State of Design

2.2 Intermediate Design Change

2.3 Current State of Design

2.4 Design Modifications

2.1 PDR State of Design

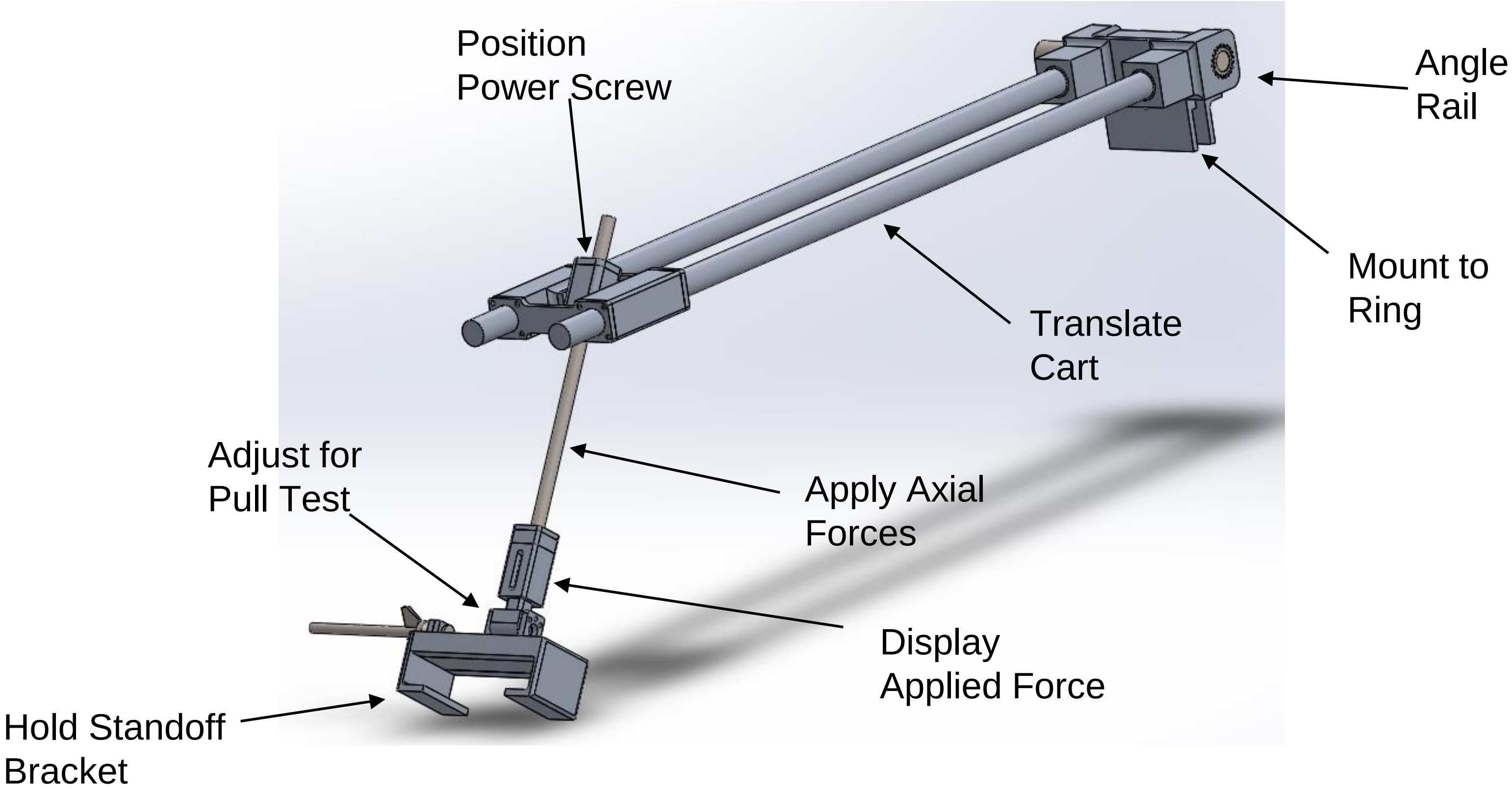

Figure 4. PDR CAD Model

2.2 Intermediate Design Change

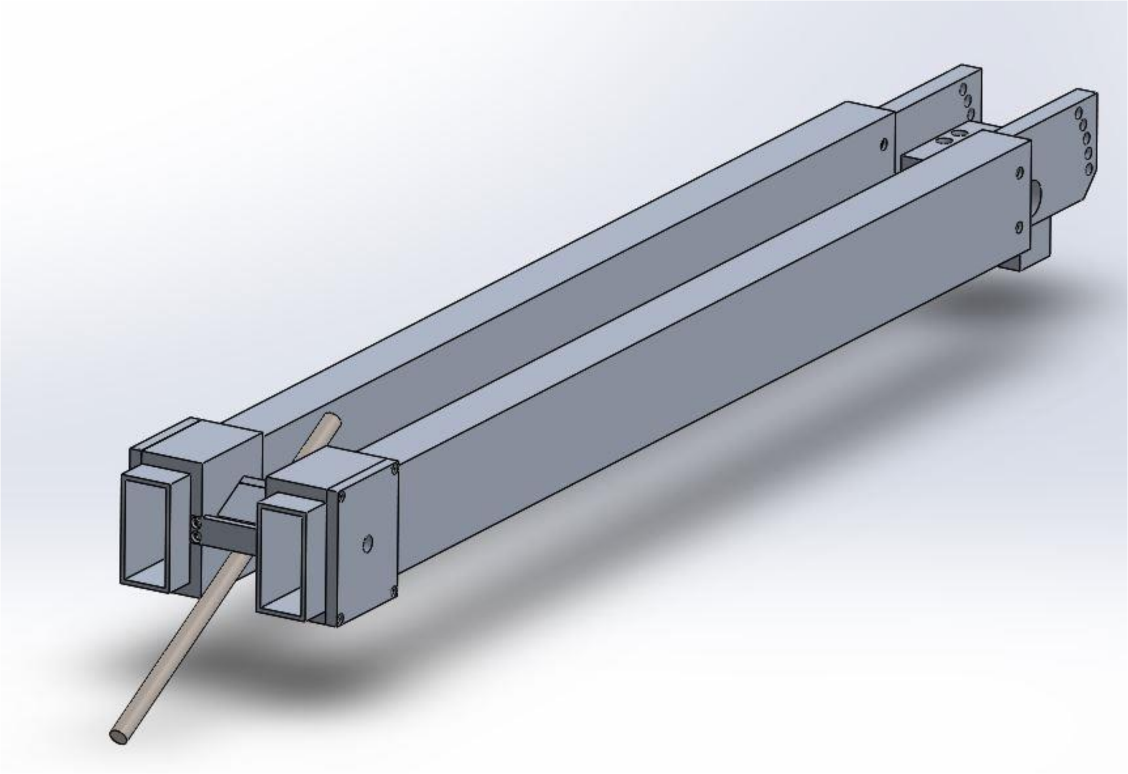

Figure 5. Intermediate CAD Model

2.2 Intermediate Design Change

- Change of Design Requirements
  - Make design changes to perform a push test of 20lb. per standoff (max of 6) on the bracket template (120lb max)
- Recently reverted back to perform a 20lb. push test per bracket template
  - Intermediate Design was overbuilt, cumbersome, and was lacking useful features

2.3 Current State of Design

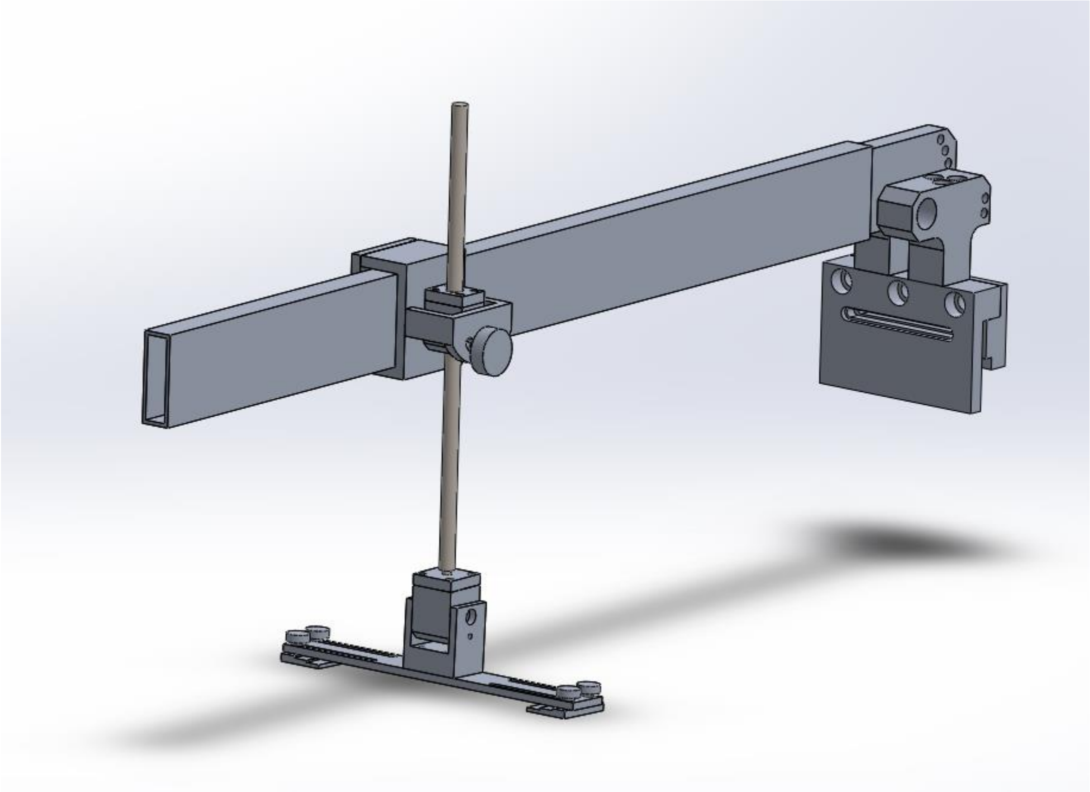

Figure 6. Current CAD Model

2.4 Design Modifications

Rocket Motor Clamp

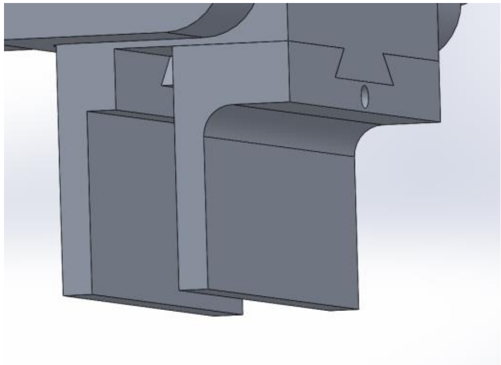

Figure 7. PDR Motor Ring Clamp

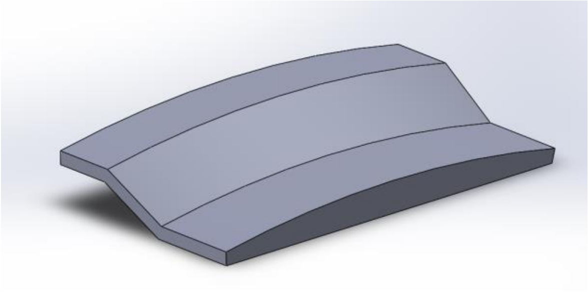

Figure 8. Custom Clamp Jaw for Orion 50 Motor Rings

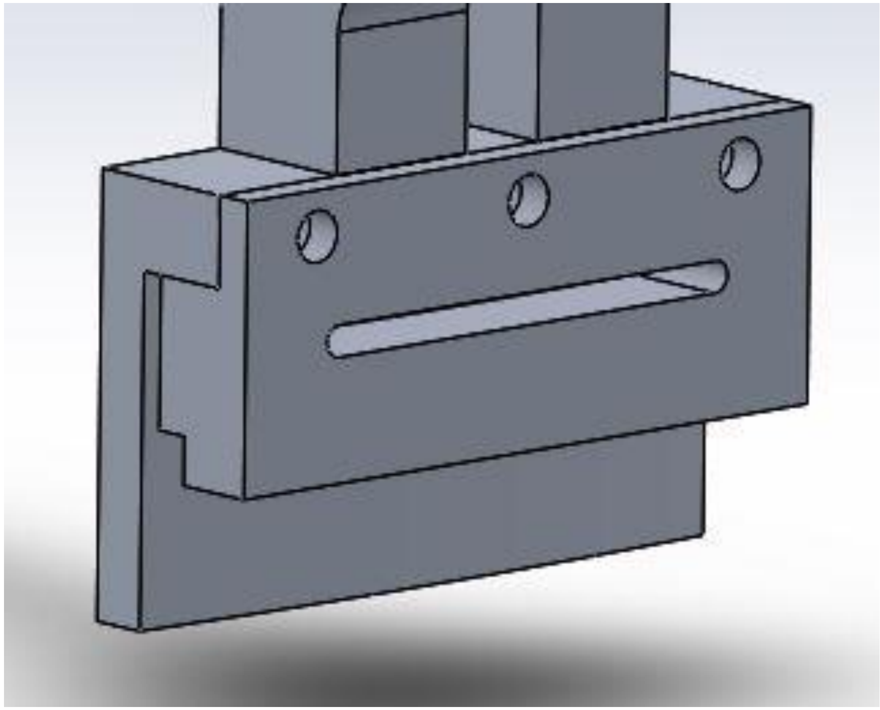

Figure 9. Current Motor Ring Clamp

2.4 Design Modifications (cont.)

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Motor Clamp Analysis

- FEA to determine stresses and deflections of ring when loaded (F.O.S. 42)
- Ring could experience punching shear when loaded
    - Coating
    - Screw threads would fail first
- Complex hand calculations

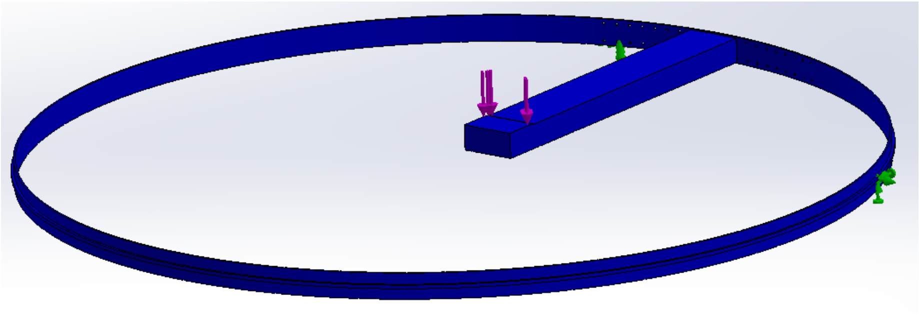

Figure 10. Ring Moment FEA Analysis

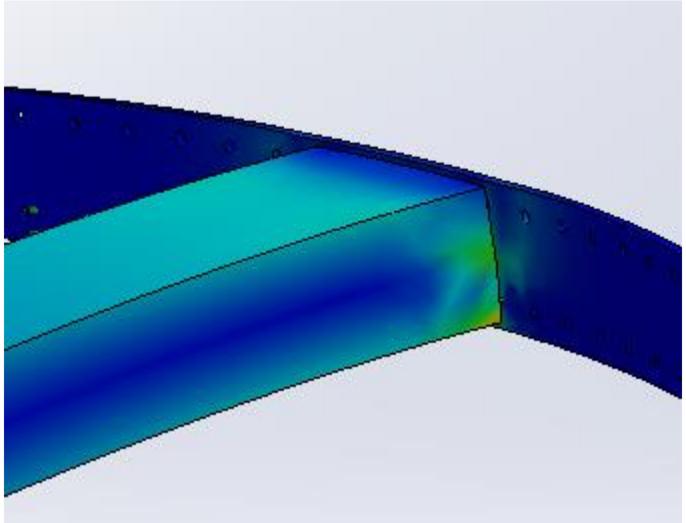

Figure 11. Ring Stress Distribution

2.4 Design Modifications (cont.)

Angling Mechanism

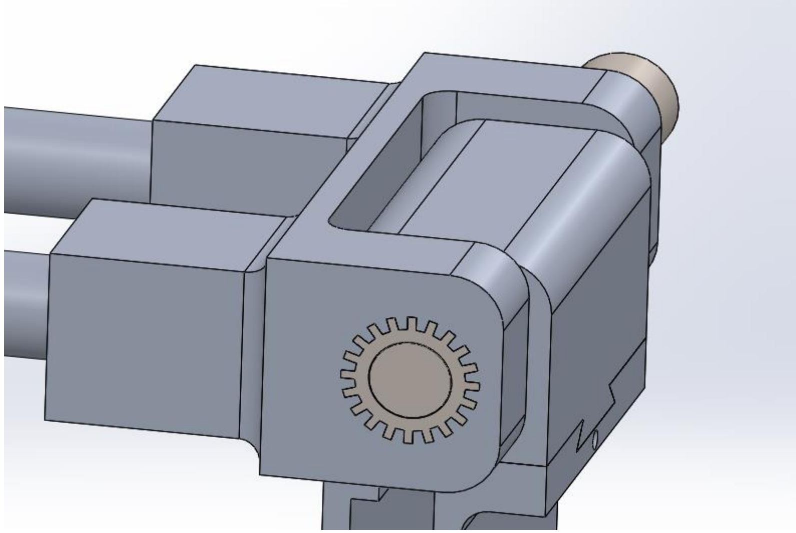

Figure 12. Spline Shaft used to Adjust Rail Angle

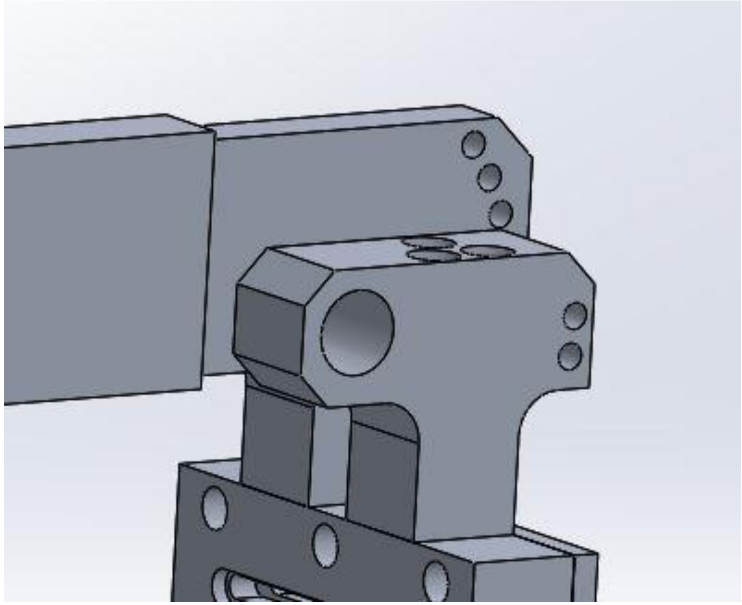

Figure 13. Updated Angling mechanism to Adjust Rail Angle

2.4 Design Modifications (cont.)

Pin Shear Analysis

- Single pin must resist moment from entire rail cart lever arm.
  - One long, single pin going through both sides subjected to double shear.
- Max Load 50 lbs, results in 360lb internal shear on pin.
- Required diameter for desired factor of safety in pins is 0.207 in.

$$\tau_{failure} = 32\ ksi$$

$$F.O.S. = 3$$

$$\tau_{allowable} = 10.67\ ksi$$

$$\tau_{Avg} = \frac{V_{internal}}{A_c}$$

$$D_{required} = \sqrt{\frac{4\,V_{internal}}{\Pi\,\tau_{allowable}}}$$

2.4 Design Modifications (cont.)

Rail System

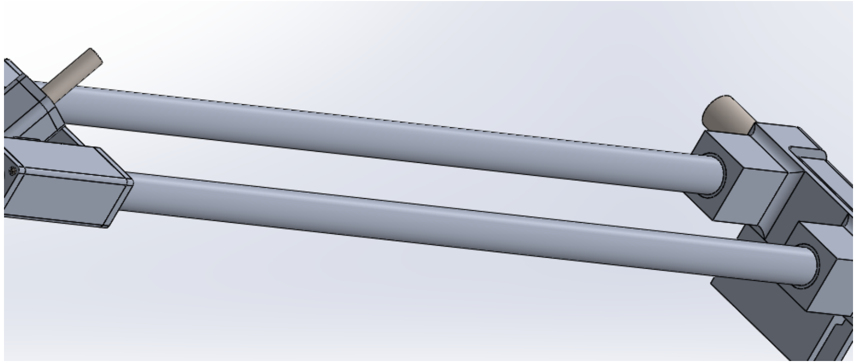

Figure 14. PDR Rail System

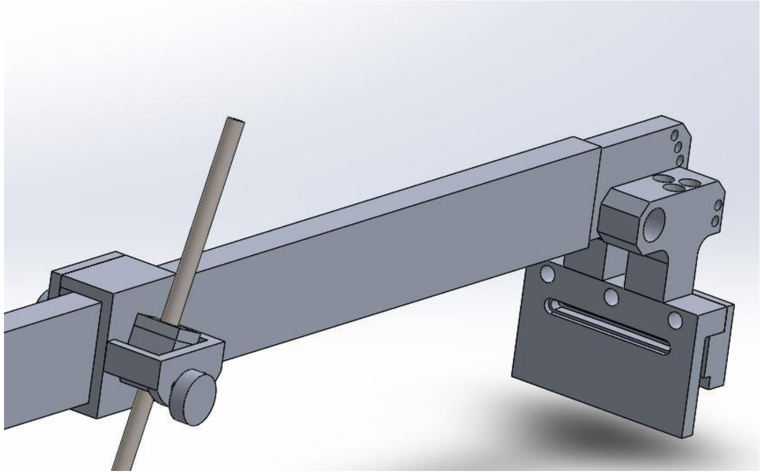

Figure 15. Current Rail System

2.4 Design Modifications (cont.)

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Rail System

- Hollow Cylindrical Tube:
  - I_{xx} = .199 in^4
  - A_c = .982 in^2
- Hollow Rectangular Tube:
  - I_{xx} = .95 in^4
  - A_c = .9375 in^2
- Deflection of Cantilever Beam:
  - δ_c = .391 in
  - δ_r = .082 in
    - F = 50 lb
    - E = 10000 ksi
    - L = 36 in
- Weight of Rail System:
  - W_c = 3.46 lb
  - W_r = 3.31 lb
    - ρ = .098 lb/in^3

Hollow Cylindrical Tube:

$$Ixx = \frac{\Pi}{64}(D^4 - d^4)$$

$$A_c = \frac{\Pi}{4}(D^2 - d^2)$$

Hollow Rectangular Tube:

$$Ixx = \frac{1}{12}(BH^3 - bh^3)$$

$$A_c = BH - bh$$

Deflection of Cantilever Beam:

$$\delta = \frac{F L^3}{3 I E}$$

Weight of Rail System:

$$W = \rho A_c L$$

2.4 Design Modifications (cont.)

Rail Cart

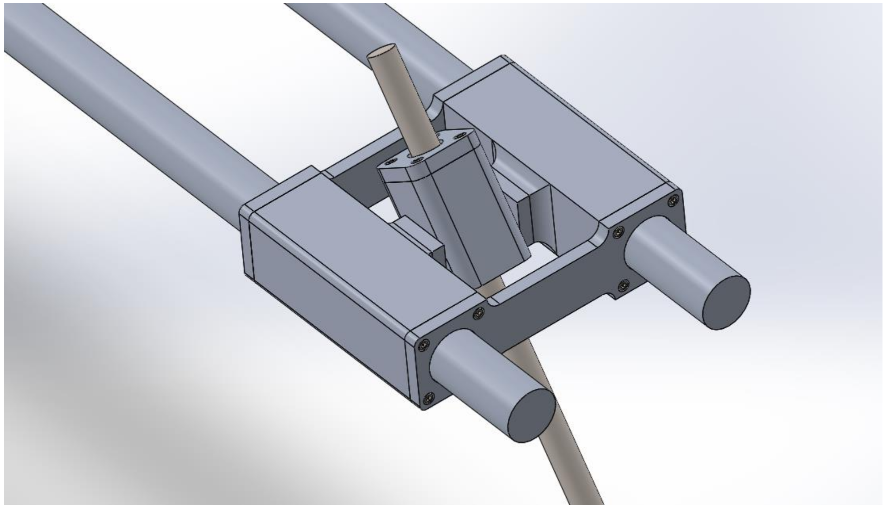

Figure 16. PDR Rail Cart and Angleable Lead Screw

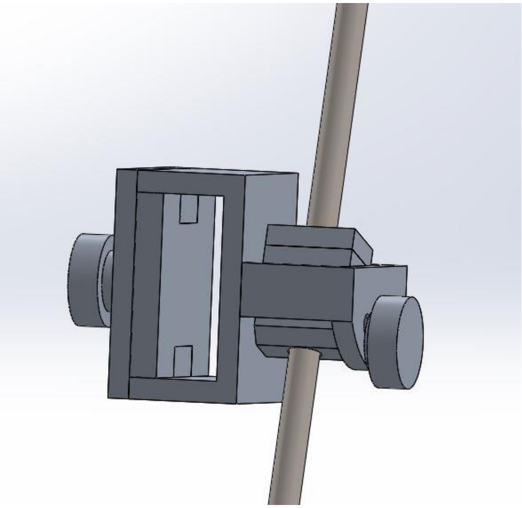

Figure 17. Current Rail Cart and Angleable Lead Screw

2.4 Design Modifications (cont.)

Angle of Twist

- Length = 36 in
- Torque = 81.625 in-lbs
  - 1.3625” * 50lbs
- Modulus of Rigidity = $3.8*10^6$ psi
- Polar Moment of Inertia = 1.104 in^4
  - Ix = .950 in^4
  - Iy = .153 in^4
- Angle of Twist = .04°

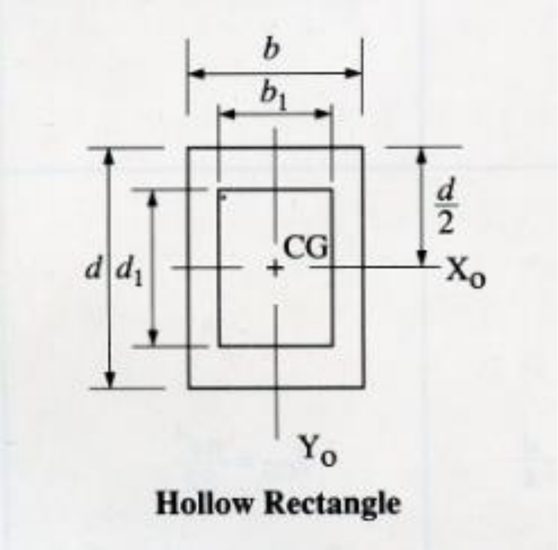

Figure 18. Angle of Twist Dimension Drawing

$$\theta = \frac{TL}{J_{CG}G}$$

$$I_{x_0} = \frac{bd^3 - b_1 d_1^{\ 3}}{12}$$

$$I_{y_0} = \frac{db^3 - d_1 b_1}{12}$$

$$J_{CG} = I_{x_0} + I_{y_0}$$

Angle Locking Mechanism

- Locking of the power screw angle is essential
- Easier for operator to set up and use
  - Counteracts moment created from weight of bracket template

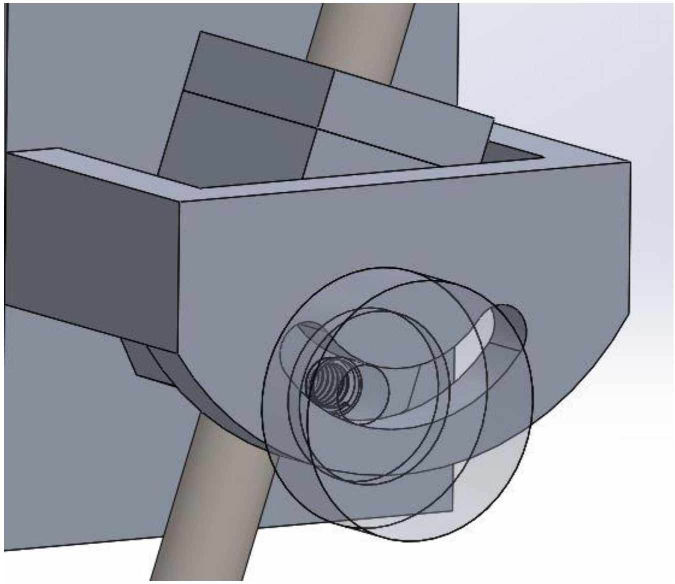

Figure 19. Current Angleable Lead Screw

2.4 Design Modifications (cont.)

- Power Screw Analyses
  - Self-Locking Condition
    - To ensure screw maintains position under axial loads
  - Buckling
    - Determine the critical force at which the screw buckles
  - Torque
    - Determine the torque required to push or pull on bracket
  - Thread Galling
    - Reduce coefficient of thread friction between screw and nut

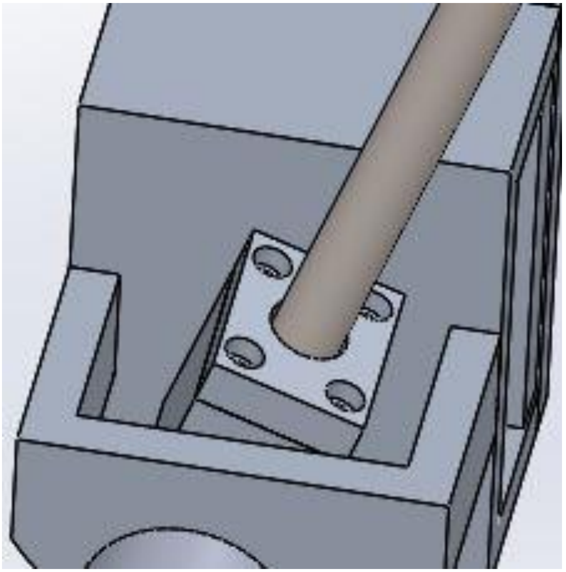

Figure 20. Power Screw Assembly

2.4 Design Modifications (cont.)

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- Self-Locking Condition
  - ACME ½” SS Lead Screw
  - μ, coefficient of static friction
  - d_m, mean screw diameter
  - l, lead distance
  - λ, lead angle

- Buckling
  - F_c, critical force
  - C, end condition
  - E, young’s modulus
  - L_c, critical length
  - I, moment of inertia

Table 2. Self-Locking Inequalities and Buckling Equations

Parameter	Equation
Self-Locking Inequality (1)	$\tan(\lambda) < \mu$
Self-Locking Inequality (2)	$\pi \mu d_m > l$
Critical Force	$F_C = \left(\frac{C\pi^2 E}{L_C^2}\right) * I$
Moment of Inertia	$I = \pi \frac{d^4}{64}$

2.4 Design Modifications (cont.)

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- Torque to Raise/Lower
  - T, torque
  - F, force
  - d_m, mean screw diameter
  - l, lead distance
  - α, lead angle
  - f, coefficient of static friction
  - f_c, coefficient of collar friction
- Thread Galling
  - Coefficient of thread friction is 0.2
  - Friction and galling can be diminished by applying machine oil
  - Expected axial loads far below standard ACME thread operation

Table 3. Torque Equations

Parameter	Equation
Torque required to raise the load [T_R] [1,2,3]	$T_R = \frac{F \cdot d_m}{2}\left(\frac{l + \pi f d_m \sec\alpha}{\pi d_m - f l \sec\alpha}\right) + T_c$
Torque required to lower the load [T_L] [1,2,3]	$T_R = \frac{F \cdot d_m}{2}\left(\frac{-l + \pi f d_m \sec\alpha}{\pi d_m + f l \sec\alpha}\right) + T_c$
Frictional torque of the thrust collar [T_c]	$T_c = \frac{F f_c d_c}{2}$
Efficiency during lifting the load [e] [3]	$e = \frac{Fl}{2\pi T_R}$

2.4 Design Modifications (cont.)

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- Self-Locking Condition
  - Given the current conditions, the ACME screw is expected to be self-locking
- Torque
  - Torque to Raise, 0.313 lbf-ft
  - Torque to Lower, 0.176 lbf-ft
- Buckling
  - Using a design factor of 3.0, the critical force was determined to be 1000-lbf
- Thread Galling
  - Not expected to be an issue given the current operating conditions

Torque Wrench (Added Feature)
Spring Scale (Removed Feature)

- Reason for Change
  - Complicated to Manufacture
  - Requires Spring Analysis
- Justification:
  - Gives reading for torque applied to lead screw
  - Allows the operator to know when to stop applying torque
  - Allows for more precise application of force to the bracket templates

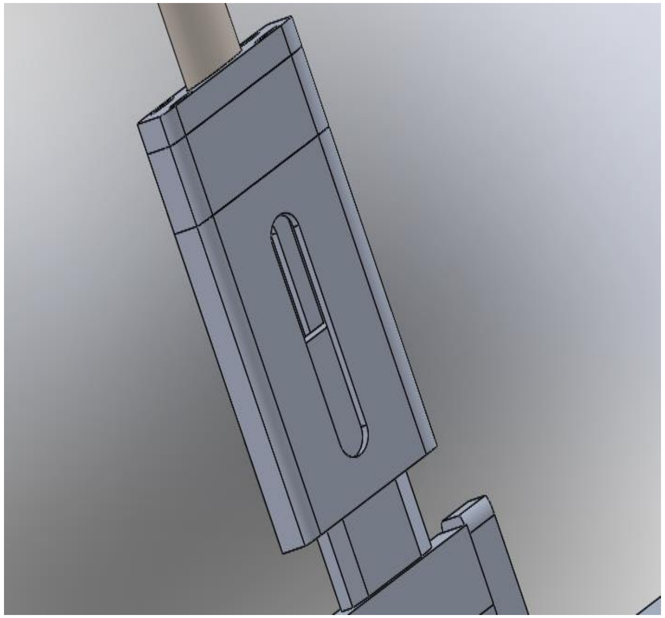

Figure 21. Force Gauge Spring Housing

Push Test Template

- Lightweight universal solution to hold all bracket templates
- Easy to secure brackets with knurled knobs
- Can be angled normal to the surface
- Accommodates plates of both given thicknesses

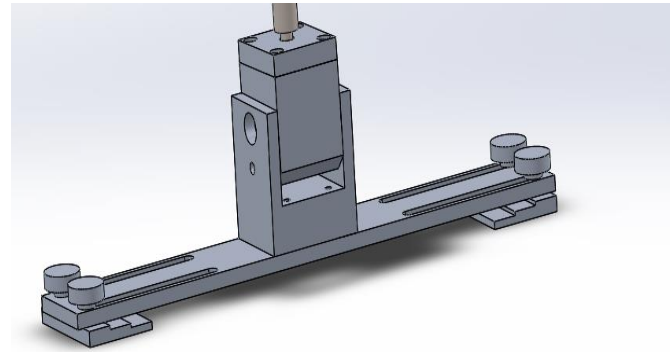

Figure 22. Template Holder for push test

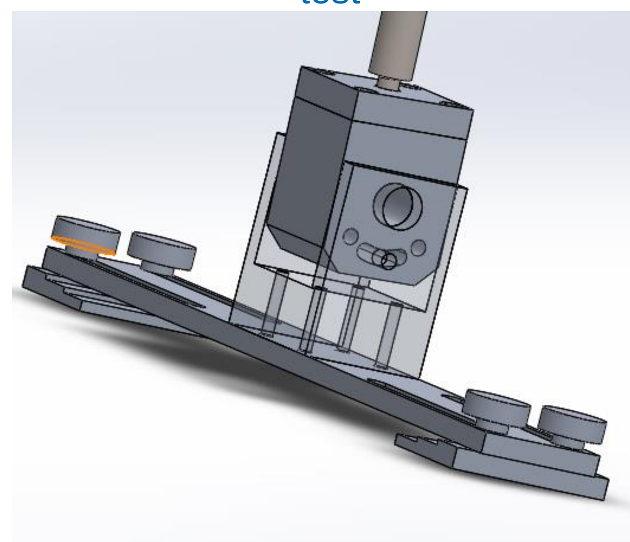

Figure 23. Template Holder Angling Mechanism

2.4 Design Modifications (cont.)

Pull Test Piece

- Allows for the 45° pull test needed for the device
- Threads into the standoffs directly
- Easily interchangeable with the push bracket with two pins

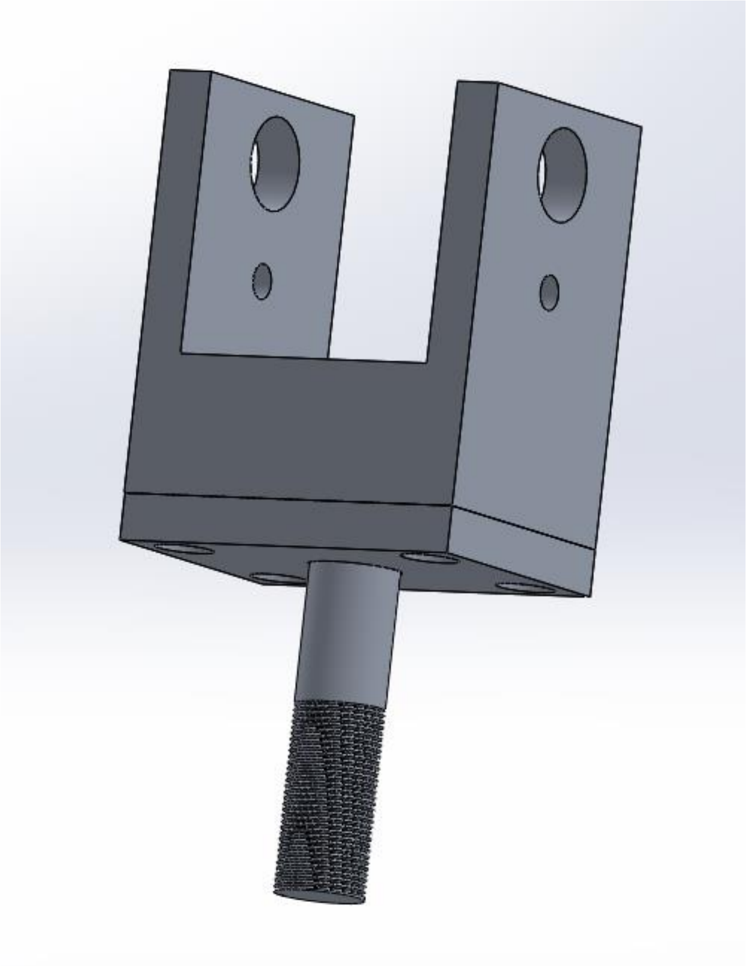

Figure 24. Standoff threaded piece for pull test

3. Potential Failures and Testing Procedures

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3.1 Design Requirements

3.2 Potential Failures

3.3 Test Procedures

3.2 Potential Failures

- Bending the Circumferential Motor Ring
  - FEA
- Deformation of the Motor Ring holes
  - Shoulder Screws of smaller diameter
- Torsional Deformation of the Rails
  - Angle of Twist
- Rail Deflection

3.3 Test Procedures

Procedure 1: ESD Compliance

Objective: To verify that the device is electrically conductive

Testing Procedure:

1. Place the anti-static table mat onto a table, anti-static mat on the floor, and ground the table mat
2. Mount the entire device on the anti-static table mat
3. Use a multimeter between a team member who’s standing on the anti-static mat and the device to read 0V

Table 5. Test Procedure 1 BOM

Index	Tool	Dimensions	Reference	Price ($)
1	Anti-Static Table Mat	2'x4'	https://www.uline.co	85.00
2	Common Ground Cord	15'	https://www.uline.co	17.00
3	Multimeter	n/a	https://www.homedep	40.00
4	Anti-Static Mat	2'x3'	https://www.uline.co	50.00
				192.00

3.3 Test Procedures

Procedure 2: Torque Wrench

Objective: To evaluate the actual torque input to obtain a 20lb push and a 50lb pull.

Testing Procedure:

1. Place a spring scale at the end of the device
2. Apply torque to the wrench at incremental forces and record results
3. Plot the results of torque vs force

Figure 25. Torque Wrench

3.3 Test Procedures

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Procedure 3: Working Angle and Length

Objective: To prove the functionality, reliability of the angling mechanisms of both the ring clamp and bracket holder, and that the device meets the required mass and working length applying a maximum force of 50 lbf

Testing Procedure:

1. Weigh individual parts
2. Mount device
3. Apply a 50 lbf force
4. Repeat procedure at all angles

Table 6. Test Procedure 3 BOM

Index	Tool	Dimensions	Source	Price ($)
1	Torque Wrench	n/a	https://www.onlineme	159.99
2	Digital Scale	n/a	NAU	0
3	Ruler	n/a	NAU	0
4	Measuring Tape	n/a	NAU	0
5	Calipers	n/a	NAU	0
				159.99

4. Schedule and Budget

4.1 Schedule

4.2 Budget

4.1 Schedule

- March 13th: Individual analyses
- March 25th: Final product completion
- March 30th: Conduct Testing procedures
- April 10th: Testing Proof Report
- Week of April 27th: Northrop Grumman University Symposium Day

4.2 Budget

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Table 7. Current Spendings Chart

Material	Unit Cost	Quantity	Total Cost	Source
6061 Aluminum Block, 4"x4"x12"	100.25	2	248.84	McMaster-Carr
PLA 3D Printing Filament	12.99	1	14.18	Amazon.com
Linear Sleeve Bearing, for 1-1/2" Diameter	141.17	1	175.05	McMaster-Carr
6061 Polished Aluminum Tube, 1/4" wall thickness, 1-1/2" OD	28.95	1	35.90	McMaster-Carr
Acme Lead Screw, 1/2"x10, 2ft long	31.68	1	39.28	Roton.com
Acme Sleeve Nut, 1/2"x10, Bronze	19.09	1	23.67	Roton.com
6061 Aluminum Rect. Tube, 1-1/2"x3"x3/16" thickness, 6 ft long	93.16	2	231.04	McMaster-Carr
Aluminum Socket Head Screws, 8-32, 1/2" long, Blue-Anodize	11.88	5 Packs of 5	73.66	McMaster-Carr
Strain Gauges	52	1 Pack of 8	80.78	Omega.com
		Total Cost to Date	922.40	
		Remaining Budget	9077.60	

Summary

1. Project Description
2. PDR State of Design vs Current Design
3. Final Design Justification
4. Schedule and Budget

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