THE VALUE OF PERFORMANCE.
NORTHROP GRUMMAN

Final Presentation: NAU Standoff Project

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

Presentation Overview

- Project Description
- Project Requirements and Specifications
- Design Solution
- Design Modifications
- Manufacturing
- Testing Procedures
- Budget
- Future Work

1.1 Project Description

- Client: Northrop Grumman
- Sponsor: Daniel Johnson
- 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 and Specifications

NORTHROP GRUMMAN

- 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
- Allow the use of multiple mounting arms at a time
- Be easily manipulated by hand
- 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
- Perform a pull test of 50 lbs at 45 degrees of freedom
- Have a Factor of Safety of 3.0 based on maximum expected loads

1.2 Project Requirements and Specifications (cont.)

NORTHROP GRUMMAN

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
- ❑ Maximum deflection of .1” for rail design

2.1 Design Solution

NORTHROP GRUMMAN

Design Process:

1. Customer Needs to Engineering Requirements
2. Black Box Model
3. Functional Model
4. Concept Generation
5. Concept Evaluation
6. Design modifications

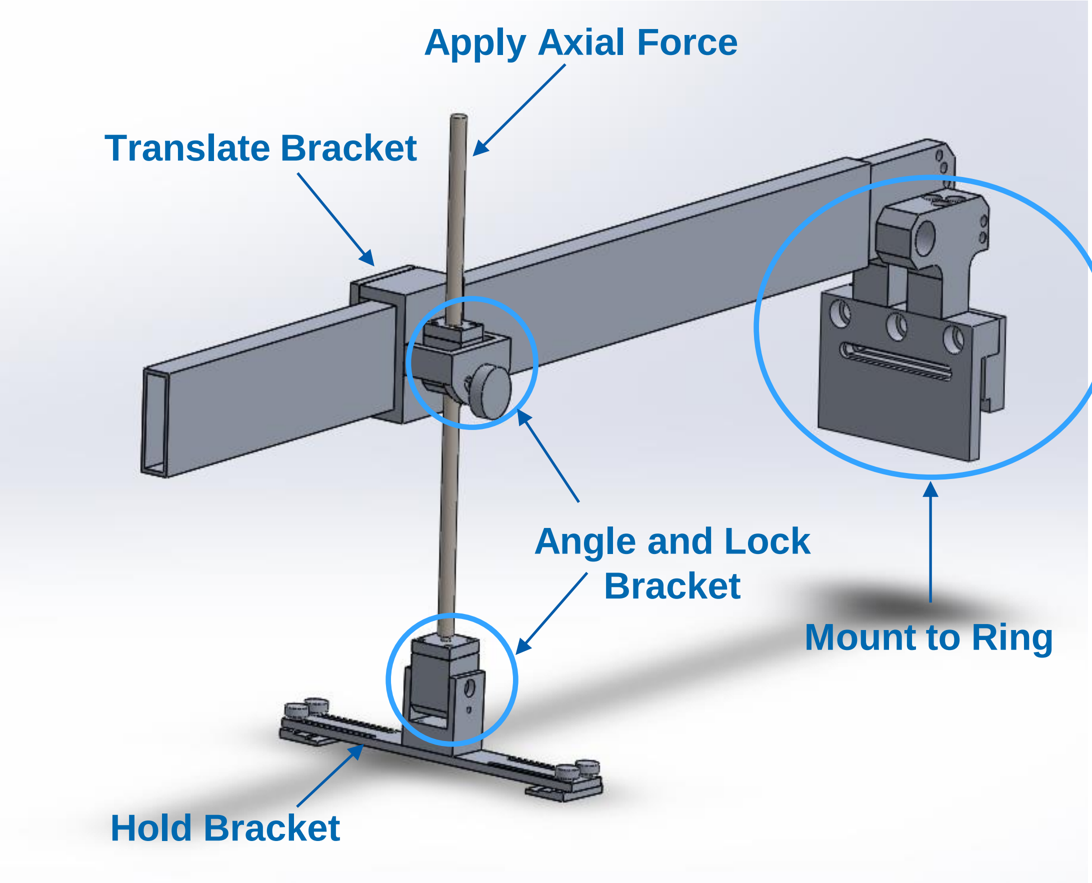

Figure 3. Final Design

2.2 Design Solution (cont.)

NORTHROP GRUMMAN

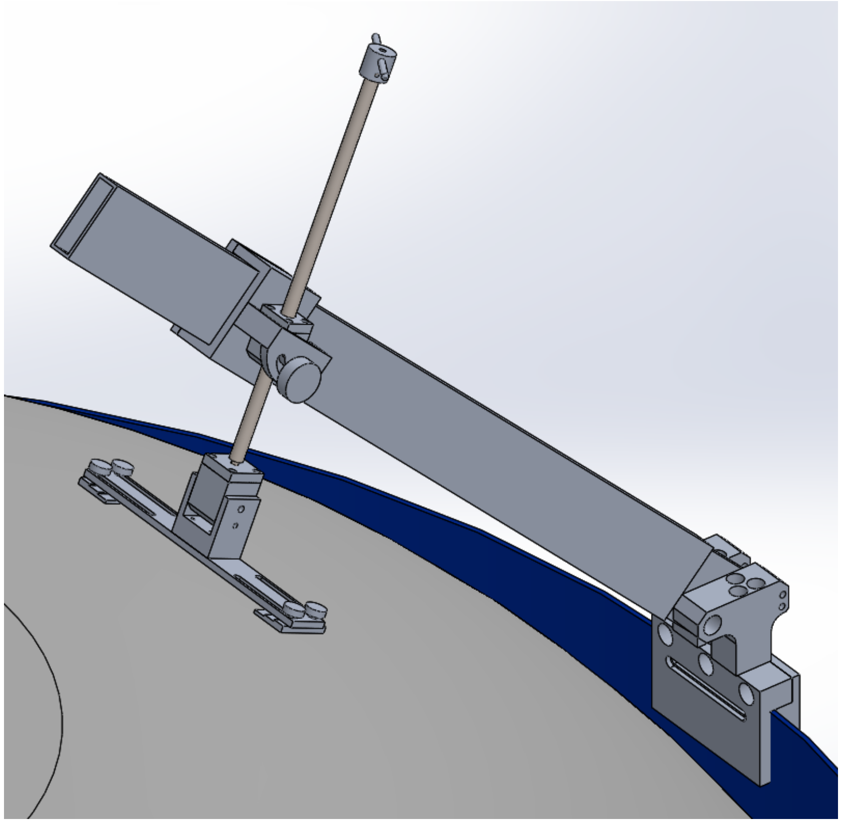

Figure 4. Final Design Clamped on Ring (1)

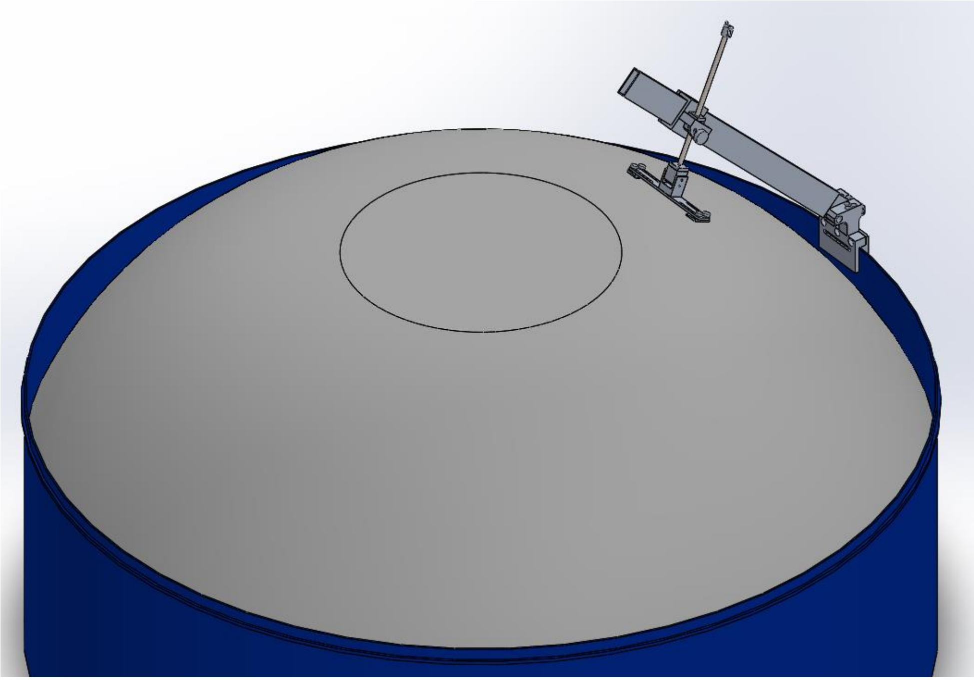

Figure 5. Final Design Clamped on Ring (2)

2.3 Design Modifications

Rocket Motor Clamp

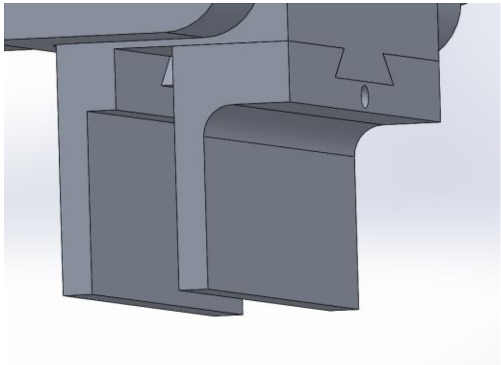

Figure 6. Previous Motor Ring Clamp

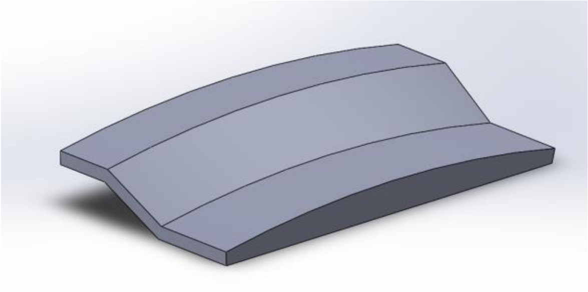

Figure 7. Custom Clamp Jaw for Orion 50 Motor Rings

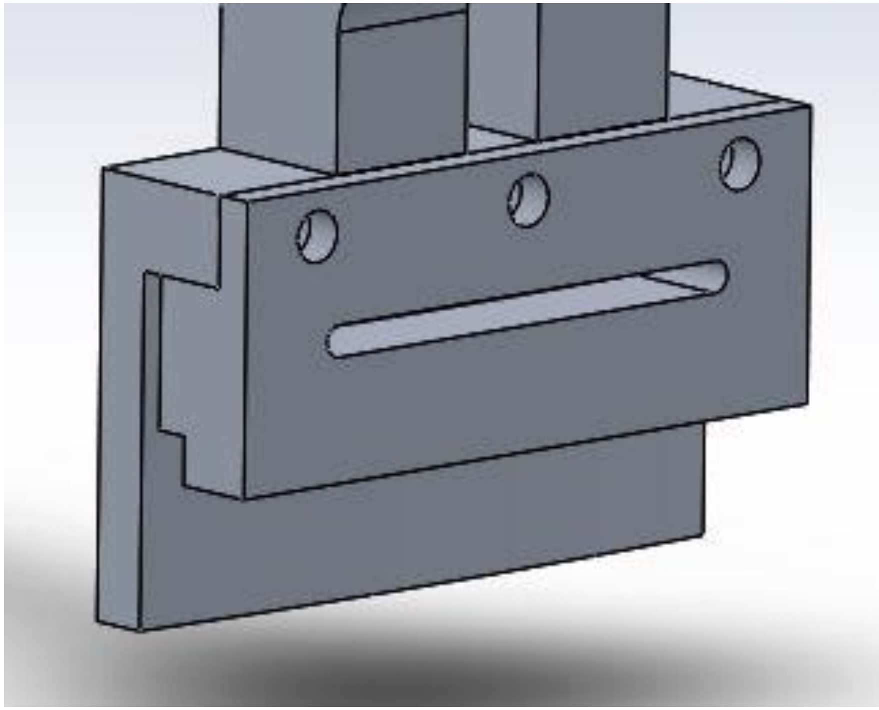

Figure 8. Current Motor Ring Clamp

2.3 Design Modifications (cont.)

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

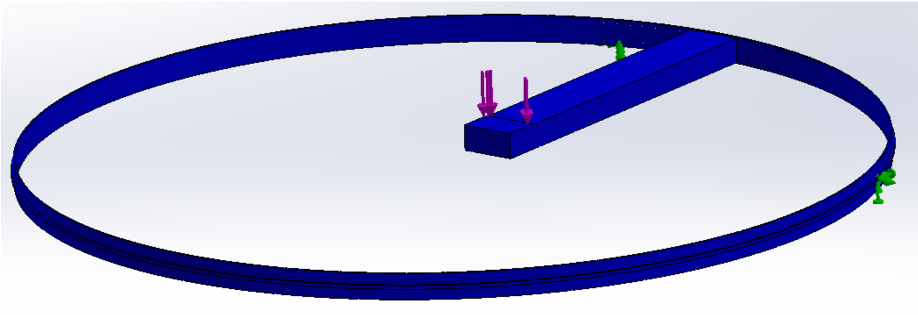

Figure 9. Ring Moment FEA Analysis

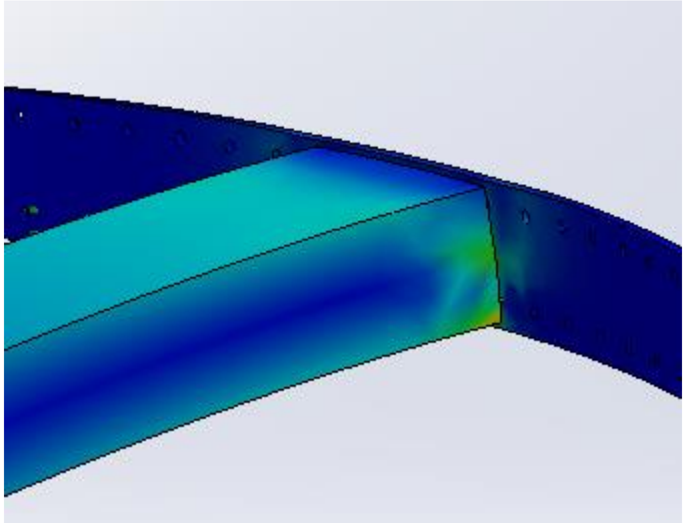

Figure 10. Ring Stress Distribution

Angling Mechanism

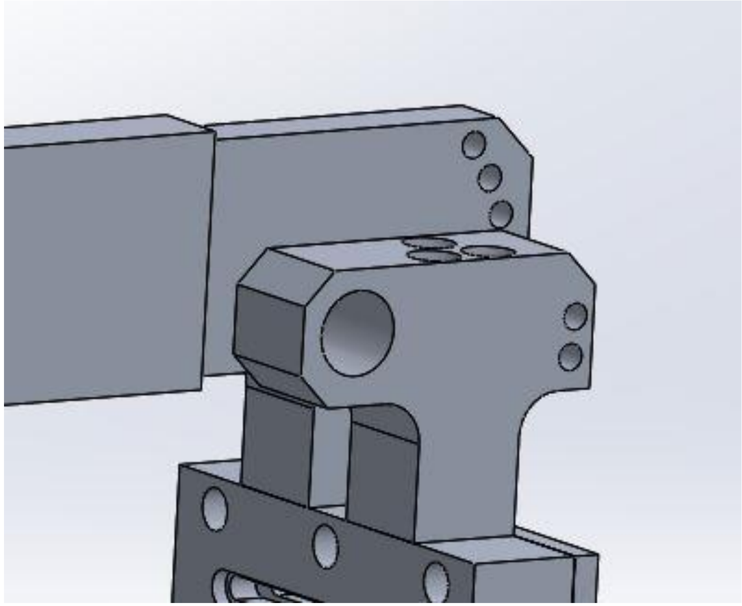

Figure 11. Previous Angling Mechanism Design

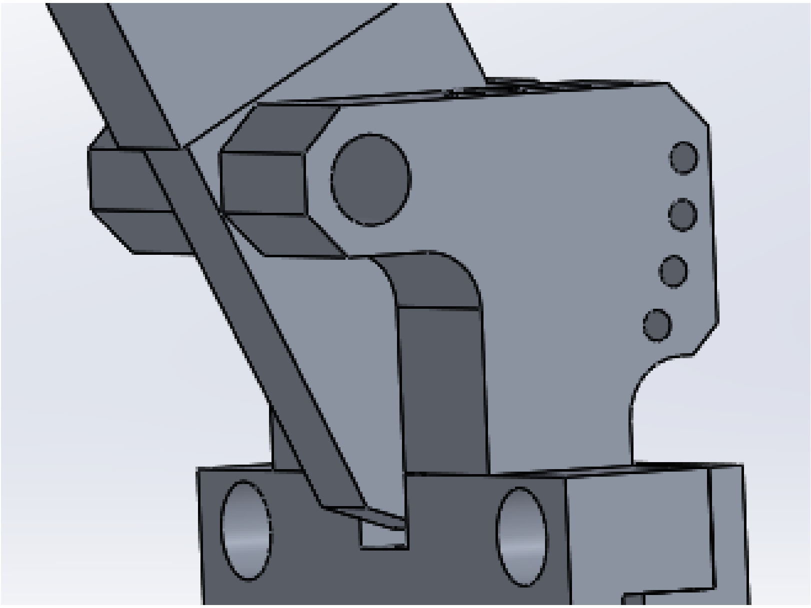

Figure 12. Current Angling Mechanism

2.3 Design Modifications (cont.)

Rail System

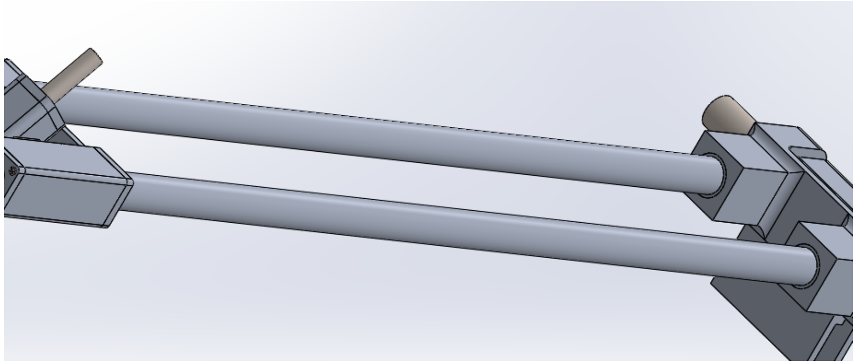

Figure 13. Previous Rail System

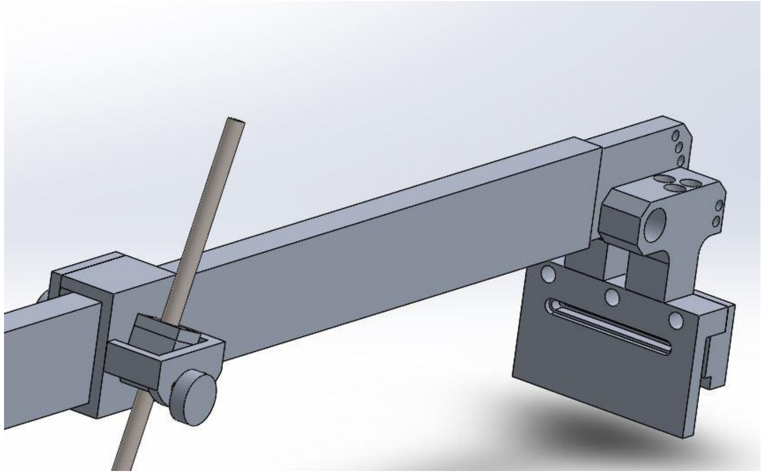

Figure 14. Current Rail System

2.3 Design Modifications (cont.)

NORTHROP GRUMMAN

Rail System

- Hollow Cylindrical Tube:
  - $Ixx = .199\ in^4$
  - $Ac = .982\ in^2$
- Hollow Rectangular Tube:
  - $Ixx = .95\ in^4$
  - $Ac = .9375\ in^2$
- Deflection of Cantilever Beam:
  - $\delta c = .391$ in
  - $\delta r = .082$ in
    - F = 50 lb
    - E = 10000 ksi
    - L = 36 in
- Weight of Rail System:
  - Wc = 3.46 lb
  - Wr = 3.31 lb
    - $\rho = .098\ lb/in^3$

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:

$$W = \rho A_c L$$

2.3 Design Modifications (cont.)

NORTHROP GRUMMAN

Rail Cart

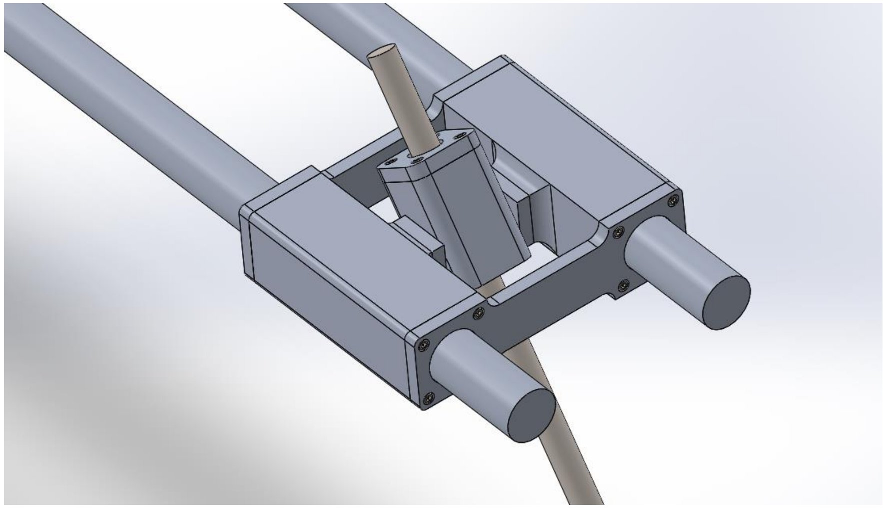

Figure 15. Previous Rail Cart and Angleable Lead Screw

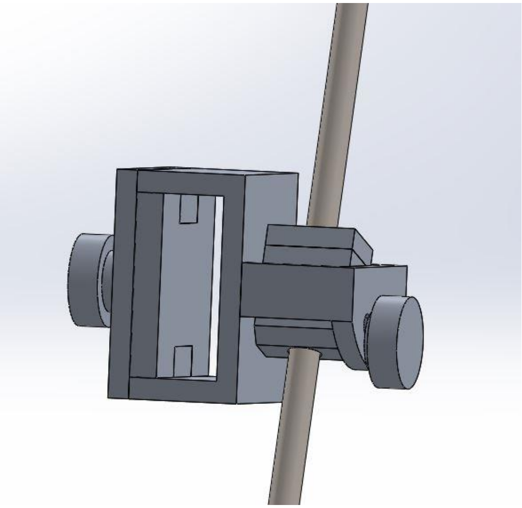

Figure 16. Current Rail Cart and Angleable Lead Screw

NORTHROP GRUMMAN

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°

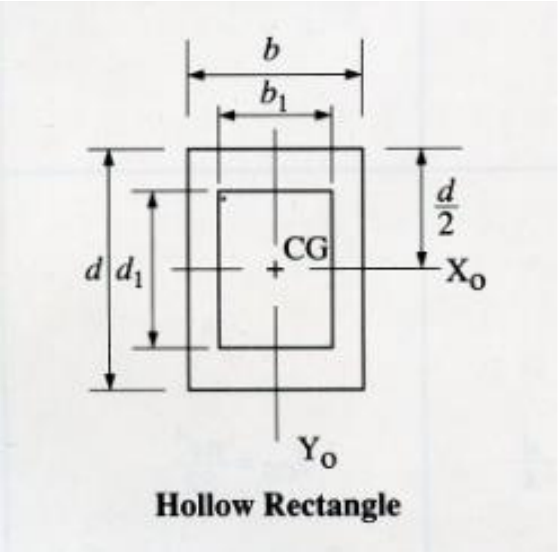

Figure 17. Angle of Twist Dimension Drawing

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

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

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

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

2.3 Design Modifications (cont.)

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

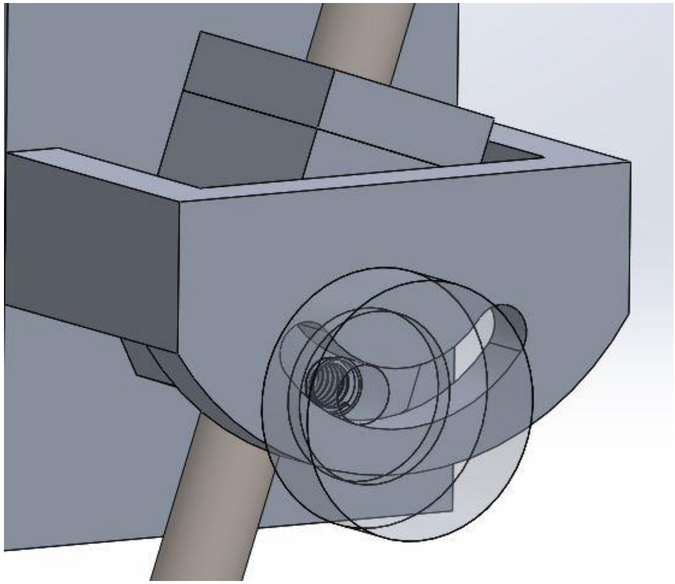

Figure 18. Current Angleable Lead Screw

2.3 Design Modifications (cont.)

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

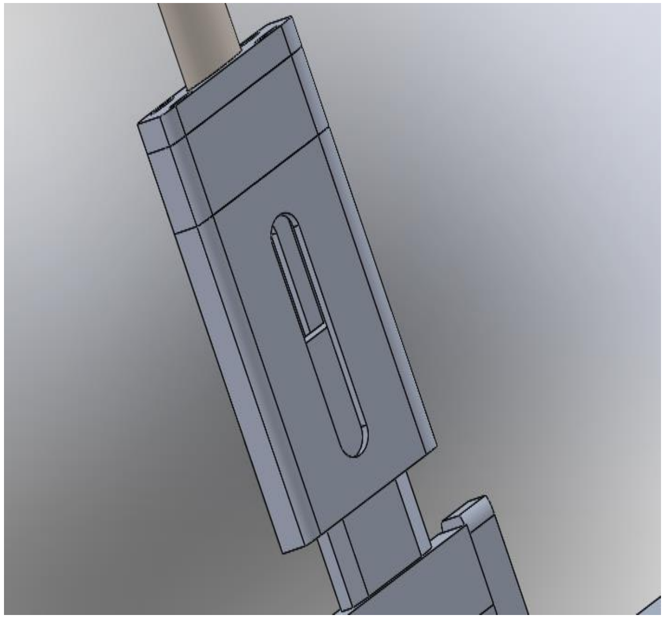

Figure 19. Force Gauge Spring Housing

2.3 Design Modifications (cont.)

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

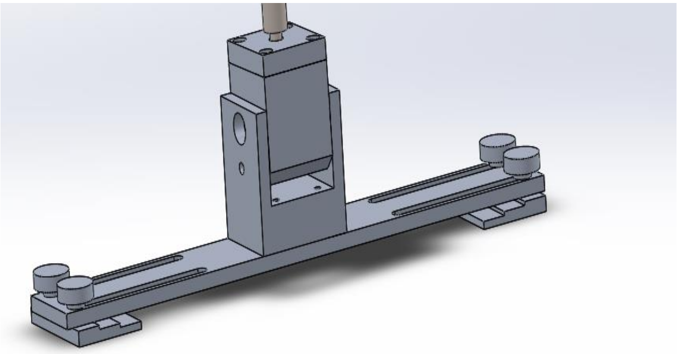

Figure 20. Template Holder for push test

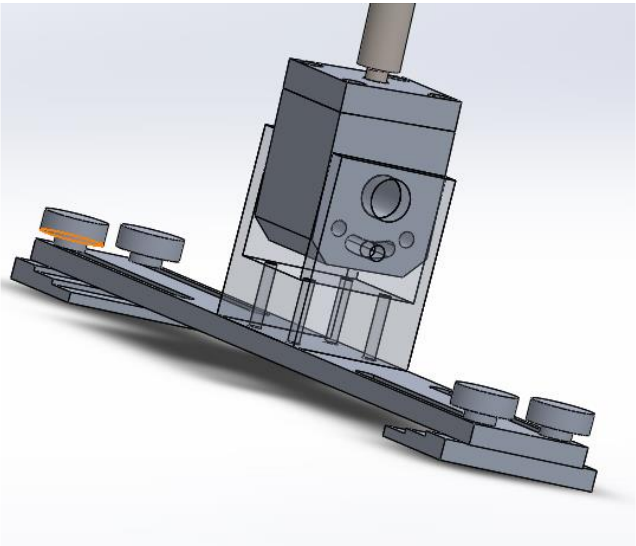

Figure 21. Template Holder Angling Mechanism

2.3 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

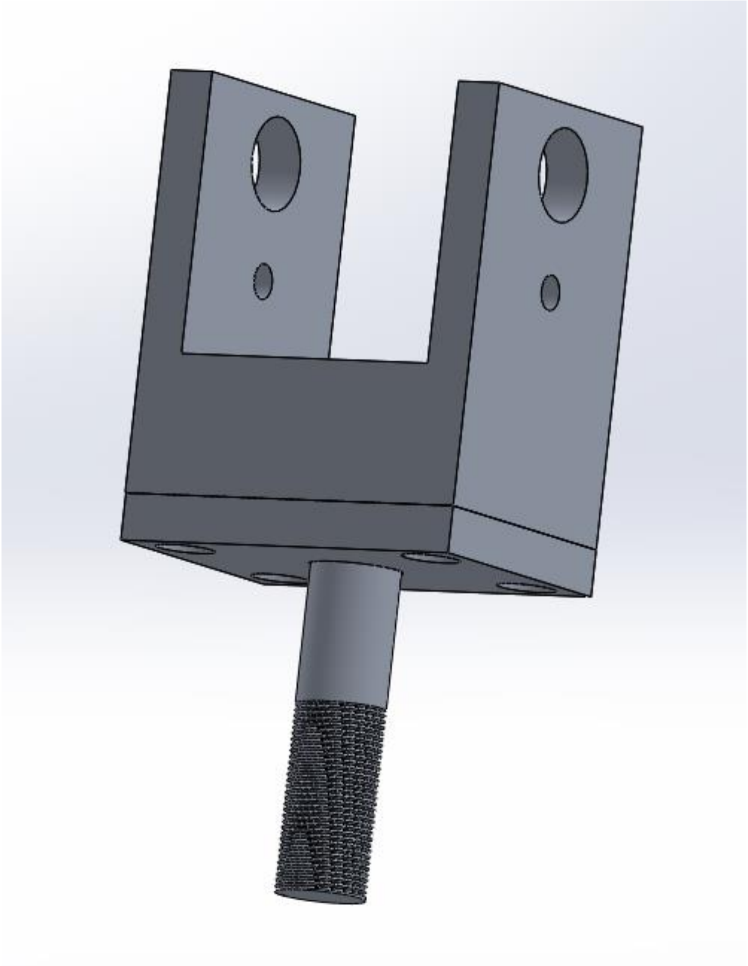

Figure 22. Standoff threaded piece for pull test

3.1 Manufacturing

- Device was manufactured in building 98C
- Majority of the parts created using the manual mills and lathes
- Bulk of design constructed from Aluminum 6061

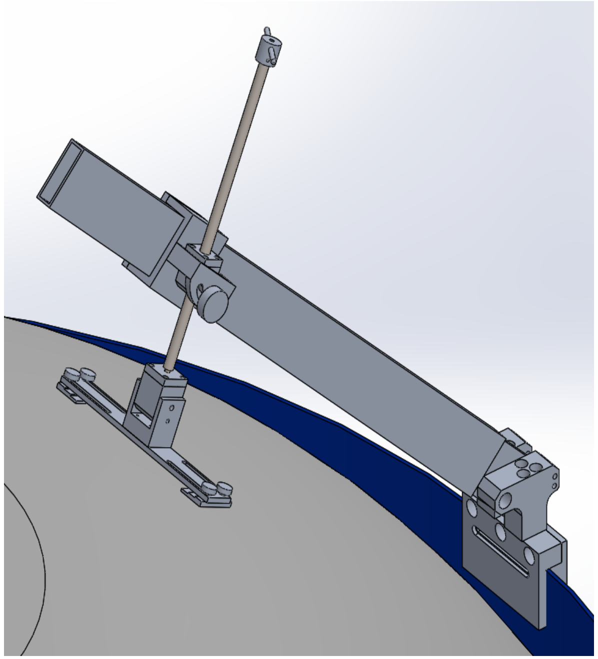

Figure 23. Final Design

Figure 24. Manufactured Final Product

3.2 Manufacturing Subassemblies

- Utilizes the premade holes on the ring
- Allows for attachment at any point on the ring
- Composed of inner and outer clamp pieces
- Designed to prevent marring or deformation
- Constructed from Aluminum 6061

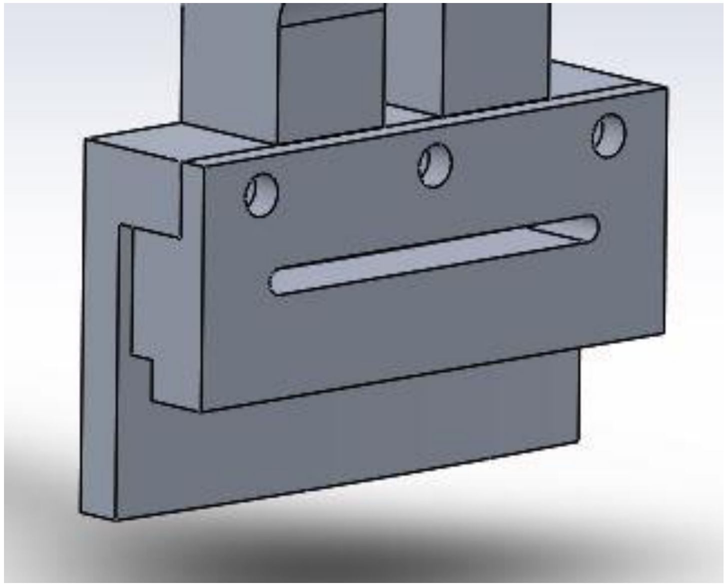

Figure 25. Motor Ring Clamp CAD

Figure 26. Manufactured Motor Ring Clamp

3.2 Manufacturing Subassemblies (cont.)

- Allows an adjustable angle for optimal bracket adherence
- Acts as a rail mount which will be inserted into the rail to combine both systems
- Constructed from Aluminum 6061

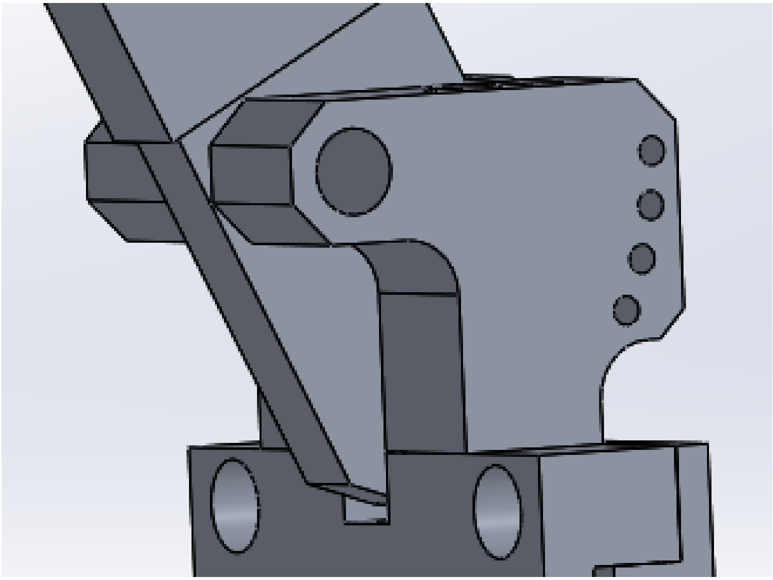

Figure 27. Angling Mechanism CAD

Figure 28. Manufactured Angling Mechanism

3.2 Manufacturing Subassemblies (cont.)

- Hollow rectangular beam used for main support of rail system
- Prevents deformation and can be attached to the angling system via support pins
- Allows for translation of rail cart system
- Constructed from Aluminum 6061

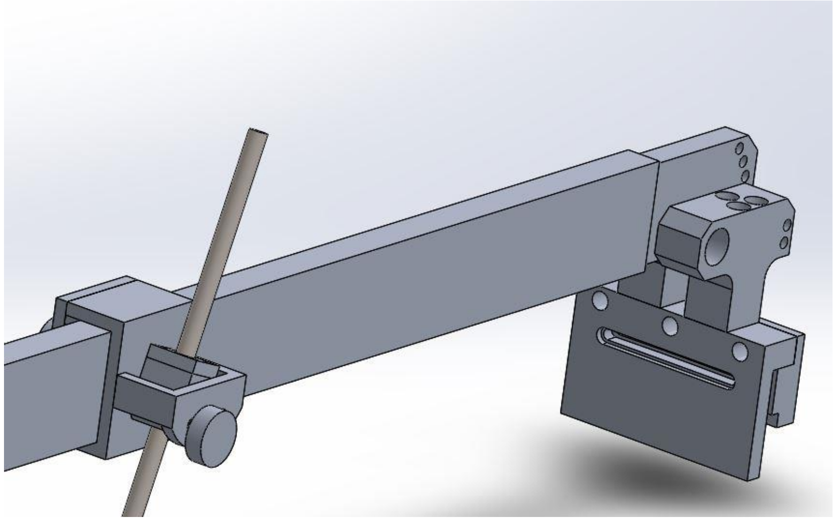

Figure 29. Rail System CAD

Figure 30. Rail System

3.2 Manufacturing Subassemblies (cont.)

NORTHROP GRUMMAN

- The rail system holds the frame for the power applicator and template holder
- Allows for proper angle of the power screw
- Can be locked in place along the support beam
- Constructed from AL 6061

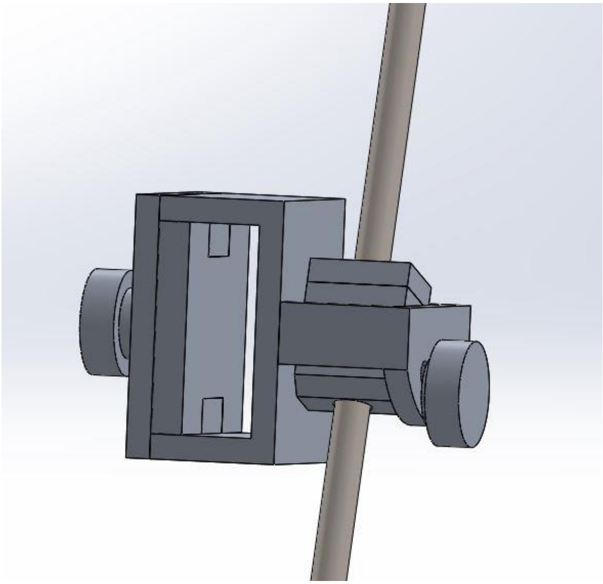

Figure 31. Rail Cart CAD

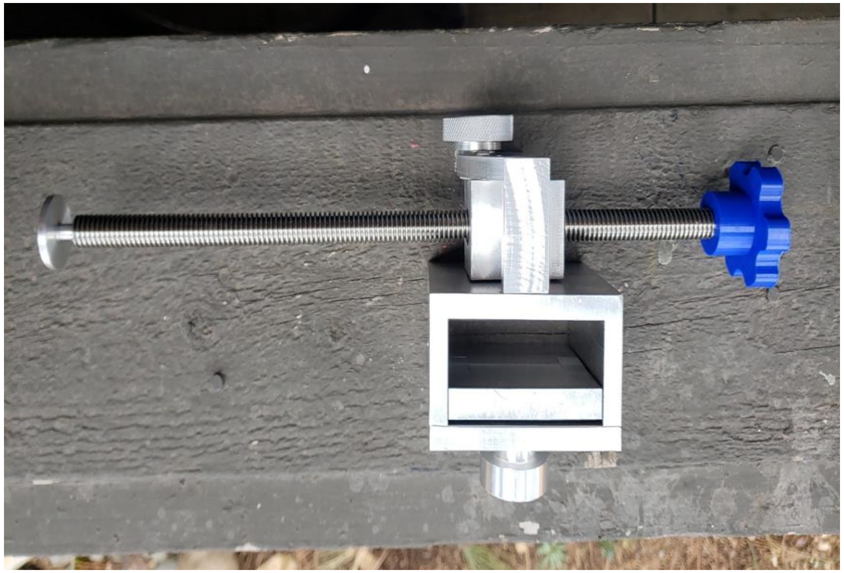

Figure 32. Rail Cart

3.2 Manufacturing Subassemblies (cont.)

NORTHROP GRUMMAN

- 7075 aluminum block CNC'd to represent small section of actual motor ring.
- 3D Printed hole template to place positioning holes in correct locations around aluminum ring.
- Allows for testing of final device without utilizing entire 92" diameter ring.

Figure 33. 3D Printed Template

Figure 34. Finished Test Ring

3.3 Testing Final Project Solution

- Proposed testing methods require in-person meetings to be conducted which is unfeasible due to the lockdown
- The calculations made in the engineering analysis, which preceded the testing, will be used to validate the engineering requirements

3.3 Testing Final Project Solution (cont.)

NORTHROP GRUMMAN

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

The proof is viable without an ESD Compliance test as Metallic products are naturally conductive

Table 1. 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 Testing Final Project Solution (cont.)

Procedure 2: Torque Wrench

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

Expected Values:

- Torque to Raise, 0.313 lbf-ft
- Torque to Lower, 0.176 lbf-ft

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 35. Torque Wrench

3.3 Testing Final Project Solution (cont.)

NORTHROP GRUMMAN

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 2. 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

4.1 Budget

NORTHROP GRUMMAN

Material	Unit Cost	Quantity	Total Cost	Source	Material	Unit Cost	Quantity	Total Cost	Source
6061 Aluminum Block, 4"x4"x12"	100.25	2	248.84	McMaster-Carr	Aluminum 6061 3/8"x2"x2ft	23.53	1	23.53	McMaster-Carr
PLA 3D Printing Filament	12.99	1	14.18	Amazon.com	PTFE Plastic Washer pack of 10	5.88	1	5.88	McMaster-Carr
Linear Sleeve Bearing, for 1-1/2" Diameter	141.17	1	175.05	McMaster-Carr	Aluminum Socket Head Screw, pack of 5	11.88	3	35.64	McMaster-Carr
6061 Polished Aluminum Tube, 1/4" wall thickness, 1-1/2" OD	28.95	1	35.90	McMaster-Carr	Aluminum Shoulder Screw, Socket Head Cap, Hex Socket Drive, Standard Tolerance, 1/16"-18 Thread Size, 3/8" Sholder Diameter, 2" Shoulder Length	5.58	8	44.64	Amazon
Acme Lead Screw, 1/2"x10, 2ft long	31.68	1	39.28	Roton.com	2"x4"x6" 7075 Aluminum Block	99.14	1	99.14	McMaster-Carr
Acme Sleeve Nut, 1/2"x10, Bronze	19.09	1	23.67	Roton.com	3/8" - 8 ACME lead screw	8.88	1	8.88	McMaster-Carr
6061 Aluminum Rect. Tube, 1-1/2"x3"x3/16" thickness, 6 ft long	93.16	2	231.04	McMaster-Carr	3/8" - 8 ACME Bronze Nut	24.62	1	24.62	McMaster-Carr
Aluminum Socket Head Screws, 8-32, 1/2" long, Blue-Anodize	11.88	5 Packs of 5	73.66	McMaster-Carr	TAS 1/2" Aluminum Shredder end mill	110.57	1	110.57	LakeShore Carbide
Strain Gauges	52	1 Pack of 8	80.78	Omega.com	TAS 5/8" Aluminum Shredder end mill	63.74	1	63.74	LakeShore Carbide
Aluminum 6061 3"x1"x1/8" rectangular tubing 6 ft long	76.68	1	23.53	McMaster-Carr	5/8" extended length variable flute	109.94	1	109.94	LakeShore Carbide
6061 Aluminum Rod, 2"x1ft	32.31	1	32.31	McMaster-Carr	5/8" variable flute carbide roughing mill	90.57	1	90.57	LakeShore Carbide
18-8 Stainless Steel Ring-Grip Quick-Release Pin, 3/4"x4"	19.42	1	19.42	McMaster-Carr	5/8" 0.09 radius variable 3 flute	96.83	1	96.83	LakeShore Carbide
18-8 Stainless Steel Ring-Grip Quick-Release Pin, 1/4"x4"	6	1	6	McMaster-Carr	3/8" 0.03 radius variable 3 flute	48.88	1	48.88	LakeShore Carbide
18-8 Stainless Steel Ring-Grip Quick-Release Pin, 1/4"x1-1/8"	4.48	2	8.96	McMaster-Carr	1/4" 1.0 LOC variable 3 flute	31.91	1	31.91	LakeShore Carbide
18-8 Stainless Steel Ring-Grip Quick-Release Pin, 1/4"x2-1/16"	4.69	2	9.38	McMaster-Carr			Total Cost of Materials	1816.77	
							Remaining Budget	8183.23	

Figure 36. Team's Budget

5.1 Future Work

- Finalize Final Product
  - Bracket Clamp
  - Pull Test
  - Polishing of Final Design
- Testing Procedures
  - Torque Wrench
  - Working Angle and Length
- Weight Reduction
- Higher Speed Ratio Lead Screw
- Finalize CAD Package with updates to overall design

Table 3. Upcoming Tasks

Final Product Memo	Everyone	0%	4/23/20	5/1/20
Final Report	Everyone	0%	4/23/20	5/1/20
Operations/Assembly Manual	Everyone	0%	4/23/20	5/1/20
Final Website Check	Elaine, Brandon	0%	4/23/20	5/1/2020
Final CAD package with BOM	Everyone	0%	4/23/20	5/4/20
Client Handoff	Everyone	33%	4/18/20	5/6/20

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN