Charger project report appendix

Mech 390

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Appendix

Appendix 1 - Gear Calculations

Bending:

$$\sigma = Fb.m.\ Y$$

$$602.81*1.25*5*0.446 = 216.25\ psi$$

Elastic coefficient :

$$Cp = \sqrt{\frac{1-v^2}{E*\pi}}$$

Contact stress:

$$\sigma = Cp\sqrt{\frac{F}{b*d_p}} = \sqrt{\frac{1-v^2}{E*\pi}}*\sqrt{\frac{F}{b*d_p}}$$

$$= 1635*\sqrt{\frac{602.8}{1.25*5}} = 16057\ psi$$

Spoke Torque:

$$T_{spoke} = \frac{F*r}{3}$$

$$= \frac{602.81*10}{3} = 2010\ in.lbs$$

Shear at Spoke:

$$\tau = \frac{T*h}{2J}$$

$$= \frac{T*h}{\frac{2}{3}\left(b*h^3\right)}$$

$$= \frac{2010}{\frac{2}{3}(1.25*7.51^2)} = 43\ psi$$

Appendix 2 - Shaft Calculations

- We find in Figure 1, the max torque the average man can generate is 647.03 Nm, same as 5726.698 lb*

- Material: **405 stainless steel:** Ultimate Tensile Strength (Su) = 70 ksi & Yield Strength (Sy) = 40 ksi

- Endurance Limit: Sn = 27.5 ksi (machined), Figure 5-11 – U.S customary units - Book

  S'n = Sn (Cm) (Cst) (CR) (Cs) = (27.5) (1) (1) (0.9) (0.82) = 20.3 ksi

- Minimum Diameter Calculation:

• For Kt = 2.5; sharp fillets [5]

$$\text{simplify}\left(\frac{32\cdot\ 2.5}{\pi}\cdot\sqrt{\left(\left(\frac{2.5\cdot\ 1808.43}{20300}\right)^2+\frac{3}{4}\left(\frac{5726.698}{40030}\right)^2\right)}\right)^{\frac{1}{3}}$$

Solution

$$1.86528\ldots$$

• For Kt = 3; ring grooves [5]

$$\text{simplify}\left(\frac{32\cdot\ 2.5}{\pi}\cdot\sqrt{\left(\left(\frac{3\cdot\ 1808.43}{20300}\right)^2+\frac{3}{4}\left(\frac{5726.698}{40030}\right)^2\right)}\right)^{\frac{1}{3}}$$

Solution

$$1.95754\ldots$$

• For Kt = 2.0; profile key seat [5]

$$\text{simplify}\left(\frac{32\cdot\ 2.5}{\pi}\cdot\ \sqrt{\left(\left(\frac{2\cdot\ 1808.43}{20300}\right)^2+\frac{3}{4}\left(\frac{5726.698}{40030}\right)^2\right)}\right)^{\frac{1}{3}}$$

Solution

$$1.76796\ldots$$

The minimum diameter is 1.76796 inches.

- Shear Stress due to Bending: 0.577*Sy / N = 4 (V) / 3 (π D^2 / 4)

$$\frac{40030}{2.5}=\frac{4\cdot\ 602.81}{3\left(\frac{\pi x^2}{4}\right)}$$

Solution

$$x=\sqrt{\frac{6.39122E14}{1.0E16}},\ x=\ -\sqrt{\frac{6.39122E14}{1.0E16}}$$

Decimal

$$x=0.25280\ldots,\ x=\ -0.25280\ldots$$

The minimum diameter is 0.25280-inch.

Appendix 3 - Bearing Calculation

- Selection: Single row, deep-groove ball bearing: 6011 [2].

Dynamic Equivalent Radial Load (Pd) = V * R = 1 * 301.405 = 301.405 lb

Design Life (Ld) = 6,000h x 40 rpm x 60 min/h = 14.4 x 10^6 revolutions

Ball bearing; K = 3

C = 301.405 (14.4 x 10^6 / 10^6) ^ (1/3) = 733.282437 lb

Appendix 4 - Retaining Rings Selection

- Selection: 97633A450 - retaining rings, for 2-1/2" od [3].

  2 x Basic External Retaining Ring (ASME B18.27.1 - 97633A450)

Appendix 5 - Square Key

- Selection: 0.625 x 0.625 x 2.5 Key ([5]: Table 11-1: Nominal shaft diameter between [2.25, 2.75] inches)
- Material: SAE stainless steel 316 ([5]: Table 11-4)
- Minimum Required Key Length for Shear (Lmin): 2 T / τ D W =

  τ = 0.557 Sy / N = 0.557 * (35,000) / (1.5) = 12,996.66 lb/in²

  2 (5726.698) / (12,996.66) (2.5) (0.625) = 0.564 inch

Appendix 6 - Casing Arms Calculations for Static Loading: Scenario 1

• Straight Portion of Casing Arms (Hollow Tube)

- Max shear stress due to bending:

  Distortion Energy Theory: Max shear stress(τ) = 2 V / A < 0.577 Sy / N

  Initial Material: 6061-O (SS) Aluminum: Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{0.577 \cdot 8000}{1.5} = \frac{2 \cdot 602.81}{\frac{\pi\left(D^2 - 4\right)}{4}}$$

Solution

$$D = \sqrt{\frac{4.49882E15}{1.0E15}},$$

Decimal

$$D = 2.12104\ldots,$$

The minimum outer diameter of hollow tube is 2.12104 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{0.577 \cdot 57000}{1.5} = \frac{2 \cdot 602.81}{\frac{\pi\left(x^2 - 2^2\right)}{4}}$$

Solution

$$x = \sqrt{\frac{4.07001E15}{1.0E15}},$$

Decimal

$$x = 2.01742\ldots,$$

The minimum outer diameter of hollow tube is 2.01742 inches.

- Normal stress due to bending: Normal stress (**σ**) = M * c / I < Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{8000}{1.5} = \frac{15070.25 \cdot \frac{x}{2}}{\frac{\pi\left(x^4 - 2^4\right)}{64}}$$

Solution

$$x \approx 3.23113\ldots$$

The minimum diameter is 3.23113 inches.

New material: 2024-T361 Aluminum; Sy = 57ksi & Su = 72ksi (Appendix 9 - book)

$$\frac{57000}{1.5} = \frac{15070.25 \cdot \frac{x}{2}}{\frac{\pi\left(x^4 - 2^4\right)}{64}}$$

Solution

$$x \approx 2.23687\ldots$$

The minimum diameter is 2.23687 inches.

• Bent Portion of Upper Arm: (M = -7233.72lb*in)

Book : Part 1 : #3-20 : 3-26

Curved Hollo Beam

2 in DIA hole

$r_i = 2.5$

$D = D - 2$

$r_c = r_i + \frac{D}{2}$

$r_o = 2.5 + D$

$$\sigma = \frac{M(R-r)}{Ar(r_c - R)}$$

$$R = \frac{A}{ASF} = \frac{\cancel{\pi}(D^2 - D_i^2)/4}{2\cancel{\pi}\left[r_c - \sqrt{r_c^2 - \frac{r^2}{4}}\right]}$$

$$R_i = \frac{(D^2 - 2^2)/4}{2\left[r_i + \frac{D}{2} - \sqrt{(r_i + \frac{D}{2})^2 - \frac{(D^2 - 2^2)}{4}}\right]}$$

$$R_o = \frac{(D^2 - 2^2)/4}{2\left[r_i + \frac{D}{2} - \sqrt{(r_i + \frac{D}{2})^2 - \frac{(D^2 - 4)}{4}}\right]}$$

$$\sigma_i = \frac{M(R - r_i)}{Ar_i(r_c - R)} = \frac{M}{Ar_i} \cdot -\frac{R - r_i}{R - r_c}$$

$$= \frac{M}{Ar_i} \cdot -\left(\frac{R - r_i - \frac{D}{2} + \frac{D}{2}}{R - r_i - \frac{D}{2}}\right)$$

$$\frac{M}{Ar_i} \cdot -\left(\frac{\cancel{R - r_i - \frac{D}{2}}}{\cancel{R - r_i - \frac{D}{2}}} + \frac{\frac{D}{2}}{R - r_i - \frac{D}{2}}\right)$$

$$\sigma_i = \frac{M}{\frac{\pi(D^2-4)}{4} r_i} \cdot -\left(1 + \frac{D/2}{R - 2.5 - \frac{D}{2}}\right)$$

$$\sigma_o = \frac{M}{Ar_o}\left(\frac{R - r_o}{r_c - R}\right)$$

$$= \frac{M}{A(2.5+D)}\left(\frac{R - 2.5 - \frac{D}{2}}{2.5 + \frac{D}{2} - R}\right)$$

$$= \frac{M}{A(2.5+D)}\left(-\frac{\cancel{R - 2.5 - \frac{D}{2}}}{\cancel{R - 2.5 - \frac{D}{2}}}\right)$$

- Normal outer (σo) and inner (σi) stress acceptable: Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book):

$$\frac{8000}{1.5} = \frac{-7233.72}{\left(\frac{\pi\left(x^2-2^2\right)}{4}\cdot 2.5\right)} \cdot -\left(1+\frac{\frac{x}{2}}{\left(\frac{\frac{\left(x^2-2^2\right)}{4}}{2\left(2.5+\frac{x}{2}-\sqrt{\left(2.5+\frac{x}{2}\right)^2-\frac{x^2-4}{4}}\right)}\right)-2.5-\frac{x}{2}}\right)$$

Inner normal stress: Approximation of minimum diameter gives 5.6 inches in Compression. [redo calc]

$$\frac{8000}{1.5} = \frac{7233.72}{\frac{\pi\left(x^2-2^2\right)}{4}(2.5+x)}$$

Solution

$$x \approx 2.09190\ldots$$

Outer normal stress: Approximation of minimum diameter gives 2.09190 inches in Tension.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book):

$$\frac{57000}{1.5} = \frac{-7233.72}{\left(\frac{\pi\left(x^2-2^2\right)}{4}\cdot 2.5\right)} \cdot - \left(1 + \frac{\frac{x}{2}}{\left(\frac{\frac{\left(x^2-2^2\right)}{4}}{2\left(2.5+\frac{x}{2}-\sqrt{\left(2.5+\frac{x}{2}\right)^2-\frac{x^2-4}{4}}\right)}\right) - 2.5 - \frac{x}{2}}\right)$$

Inner normal stress: Approximation of minimum diameter gives 2.7 inches in Compression. [redo calc]

$$\frac{57000}{1.5} = \frac{7233.72}{\frac{\pi\left(x^2-2^2\right)}{4}(2.5+x)}$$

Solution

$$x \approx 2.01338\ldots,$$

Outer normal stress: Approximation of minimum diameter gives 2.01338 inches in Tension.

Appendix 7 - Casing Arms Locking Mechanism Calculations for Static Loading: Scenario 2

- Shear Stress due to Torsion: τmax = T * c / J < 0.577 * Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{5726.78634 \cdot \frac{x}{2}}{\frac{\pi\left(x^4 - 2^4\right)}{32}} = \frac{0.577 \cdot 8000}{1.5}$$

Solution

$$x \approx 2.51181\ldots$$

The minimum diameter is 2.51181 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{5726.78634 \cdot \frac{x}{2}}{\frac{\pi\left(x^4 - 2^4\right)}{32}} = \frac{0.577 \cdot 57000}{1.5}$$

Solution

$$x \approx 2.08141\ldots$$

The minimum diameter is 2.08141 inches.

• Option 1: 2 solenoids

- Max shear stress due to bending for a cylinder: τmax = 4 V / 3 A < 0.577 * Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{4(818.112)}{\frac{3\pi(x^2)}{4}} = \frac{0.577 \cdot 8000}{1.5}$$

Solution

$$x = \sqrt{\frac{1.12831E14}{2.5E14}},$$

Decimal

$x = 0.67180.$

The minimum diameter is 0.67180 inches.

New material: 2024-T361 Aluminum; Sy = 57ksi & Su = 72ksi (Appendix 9 - book)

$$\frac{4(818.112)}{\frac{3\pi(x^2)}{4}} = \frac{0.577 \cdot 57000}{1.5}$$

Solution

$$x = \sqrt{\frac{3.16718E15}{5.0E16}}$$

Decimal

$x = 0.25168\ldots,$

The minimum diameter is 0.25168 inches.

- Normal stress due to bending for a cylinder: σ = M c / I < Sy / N

Initial material: 6061-O (SS) Aluminum; Sy = 8ksi & Su = 18ksi (Appendix 9 - book)

$$\frac{8137.935 \cdot \frac{x}{2}}{\frac{\pi(x^4)}{64}} = \frac{8000}{1.5}$$

The minimum diameter is 2.48 inches.

New material: 2024-T361 Aluminum; Sy = 57ksi & Su = 72ksi (Appendix 9 - book)

$$\frac{8137.935\frac{x}{2}}{\frac{\pi(x^4)}{64}} = \frac{57000}{1.5}$$

The minimum diameter is 1.32 inches.

- Normal stress due to direct axial loading:

Initial material: 6061-O (SS) Aluminum; Sy = 8ksi & Su = 18ksi (Appendix 9 - book)

$$\frac{1251.99}{\frac{\pi(x^2)}{4}} = \frac{8000}{1.5}$$

Solution

$$x = \sqrt{\frac{2.98891E15}{1.0E16}}$$

Decimal

$x = 0.54670\ldots,$

The minimum diameter is 0.54670 inch

New material: 2024-T361 Aluminum; Sy = 57ksi & Su = 72ksi (Appendix 9 - book)

$$\frac{1251.99}{\frac{\pi(x^2)}{4}} = \frac{57000}{1.5}$$

Solution

$$x = \sqrt{\frac{2.62185E14}{6.25E15}}$$

Decimal
$x = 0.20481\ldots,$

The minimum diameter is 0.20481 inches.

• Option 2: singular solenoid

- Max shear stress due to bending for a cylinder: τmax = 4 V / 3 A < 0.577 * Sy / N

Initial material: 6061-O (SS) Aluminum; Sy = 8ksi & Su = 18ksi (Appendix 9 - book)

$$\frac{4 \cdot 1991.93}{\frac{3\pi(x^2)}{4}} = \frac{0.577 \cdot 8000}{1.5}$$

Solution

$$x = \sqrt{\frac{5.49438E15}{5.0E15}}, x = -\sqrt{\frac{5.49438E15}{5.0E15}}$$

Decimal
$x = 1.04827\ldots, x = -1.04827\ldots$

The minimum diameter is 1.04827 inches.

New material: 2024-T361 Aluminum; Sy = 57ksi & Su = 72ksi (Appendix 9 - book)

$$\frac{4 \cdot 1991.93}{\frac{3\pi\left(x^2\right)}{4}} = \frac{0.577 \cdot 57000}{1.5}$$

Solution

$$x = \sqrt{\frac{1.54228E14}{1.0E15}}, x = -\sqrt{\frac{1.54228E14}{1.0E15}}$$

Decimal

$$x = 0.39271\ldots, x = -0.39271\ldots$$

The minimum diameter is 0.39372 inches.

- Normal stress due to bending for a cylinder: $\boldsymbol{\sigma}$ = M c / I < Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{8137.935 \cdot \frac{x}{2}}{\frac{\pi\left(x^4\right)}{64}} = \frac{8000}{1.5}$$

The minimum diameter is 2.48 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{8137.935\frac{x}{2}}{\frac{\pi\left(x^4\right)}{64}} = \frac{57000}{1.5}$$

The minimum diameter is 1.32 inches.

- Normal stress due to direct axial loading:

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{2830.59}{\frac{\pi\left(x^2\right)}{4}} = \frac{8000}{1.5}$$

Solution

$$x = \sqrt{\frac{6.75754E15}{1.0E16}}, x = -\sqrt{\frac{6.75754E15}{1.0E16}}$$

Decimal

$$x = 0.82204\ldots, x = -0.82204\ldots$$

The minimum diameter is 0.8204 inch.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{2830.59}{\frac{\pi\left(x^2\right)}{4}} = \frac{57000}{1.5}$$

Solution

$$x = \sqrt{\frac{2.37107E15}{2.5E16}}, x = -\sqrt{\frac{2.37107E15}{2.5E16}}$$

Decimal

$$x = 0.30796\ldots, x = -0.30796\ldots$$

The minimum diameter is 0.30796 inches.

Appendix 8 - Casing Arms Torsion Induced Calculations for Static Loading: Scenario 3

- Shear Stress Due to Torsion (τ max) = T c / J < 0.577 Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{5726.78634 \cdot \left(\frac{x}{2}\right)}{\frac{\pi\left(x^4 - 2^4\right)}{32}} = \frac{0.577 \cdot 8000}{1.5}$$

Solution

$$, x \approx 2.51181\ldots$$

The minimum diameter is 2.51181 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{5726.78634 \cdot \left(\frac{x}{2}\right)}{\frac{\pi\left(x^4 - 2^4\right)}{32}} = \frac{0.577 \cdot 57000}{1.5}$$

Solution

$$, x \approx 2.08141\ldots$$

The minimum diameter 2.08141 inches.

Appendix 9 - Arm Capsule Calculations for Static Loading: Scenario 1 and Scenario 3

- Normal Stress Due to Direct Axial Loading: $\sigma = F / A$

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{602.81}{\frac{\pi\left(x^2-8^2\right)}{4}}=\frac{8000}{1.5}$$

Solution

$$x=\sqrt{\frac{1.00225E14}{1562500000000}},$$

Decimal

$$x=8.00898\ldots$$

The minimum diameter is 8.010557 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{602.81}{\frac{\pi\left(x^2-8^2\right)}{4}}=\frac{57000}{1.5}$$

Solution

$$x=\sqrt{\frac{6.40202E15}{1.0E14}}$$

Decimal

$$x=8.00126\ldots,$$

The minimum diameter is 8.00126 inches.

- Normal stress due to Bending Moment (**σ**) = M * c / I < Sy / N

Initial material: 6061-O (SS) Aluminum; Yield Stress (Sy) = 8ksi (Appendix 9 - book)

$$\frac{5726.698 \cdot \frac{x}{2}}{\frac{\pi\left(x^4 - 8^4\right)}{64}} = \frac{8000}{1.5}$$

Solution

$$x = 8.53$$

The minimum diameter is 8.53 inches.

New material: 2024-T361 Aluminum; Yield Stress (Sy) = 57ksi (Appendix 9 - book)

$$\frac{5726.698 \cdot \frac{x}{2}}{\frac{\pi\left(x^4 - 8^4\right)}{64}} = \frac{57000}{1.5}$$

The minimum diameter is 8.02 inches.

Appendix 10 - Arm Capsule Calculations for Static Loading: Scenario 2

- Shear stress due to direct loading shear loading: τ = F / A

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{602.81}{\frac{\pi\left(x^2-8^2\right)}{4}} = \frac{0.577 \cdot 8000}{1.5}$$

Solution

$$x = \sqrt{\frac{3.21247E15}{5.0E13}}$$

Decimal

$$x = 8.01557\ldots,$$

The minimum diameter is 8.010557 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{602.81}{\frac{\pi\left(x^2-8^2\right)}{4}}=\frac{0.577\cdot\ 57000}{1.5}$$

Solution

$$x=\sqrt{\frac{6.4035E15}{1.0E14}}$$

Decimal
$x=8.00218\ldots,$

The minimum diameter is 8.00218 inches.

- Normal stress due to Bending Moment: **σ** = M * c / I

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

$$\frac{8740.745\cdot\frac{x}{2}}{\frac{\pi\left(x^4-8^4\right)}{64}}=\frac{8000}{1.5}$$

The minimum diameter is 8.73 inches.

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)

$$\frac{8740.745\cdot\frac{x}{2}}{\frac{\pi\left(x^4-8^4\right)}{64}}=\frac{57000}{1.5}$$

The minimum diameter is 8.03 inches.

Appendix 11 - Bolts

- On Wall:

- Selection:

  Zinc Yellow-Chromate Plated Hex Head Screw, Grade 8 Steel, 1/4"-20 Thread Size, 2" Long, Fully Threaded [7]

- Specifications:
  - 1/4” DIA
  - Area: pi * (1/4)^2 = 0.1963 in^2
  - 2” Length
- Details:
  - Located 4 inches from center of arm (Figure 28)
  - Tensile Strength: 150,000 psi
    - 100,000 psi with Safety Factor of 1.5
  - Shear Strength: 150,000 * 0.577 = 86,550 psi
    - 57,700 psi with Safety Factor of 1.5
  - Failure Force in Axial Loading with N: 100,000 psi * (0.19634 in^2) = 19,634.95 lb
  - Axial Force Applied on Bolts: 15,070.25 lb*in / 4 in = 3,767.56 lb (Figure 4)
  - Failure Force in Shear: 57,700 psi * (0.19634 in^2) =11,328.818 lb
  - Shear Force Applied on Bolts Due to Torsion: 5,726.786 lb* in / 4in= 1,431.70 lb (Figure7.1)

        - Shear Force Applied Directly: 602.81 lb (Figure 41)
    - Conclusion:
        - Failure vs Applied Force:
            - 19,634.95 lb > 3,767.56 lb (Tensile)
            - 11,328.818 lb > 1,431.70 lb (Shear)
- Inside the Casing:
    - Selection:

      Mil. Spec. Medium-Strength Steel Hex Head Screws, Cadmium-Plated Grade 5 Steel, 1/4"-20 Thread Size, 1” Long, Partially Threaded [11]
    - Specifications:
        - 1/4” DIA
        - Area: pi * (1/4)^2 = 0.1963 in^2
        - 1” Length
    - Details:
        - Located 2.875 inches from center of arm (Figure 28)
        - Tensile Strength: 120,000m psi
            - 80,000 psi with Safety Factor of 1.5
        - Failure in Shear Strength: 120,000 * 0.577 = 69,240 psi
            - 46,160 psi with Safety Factor of 1.5

- Failure Force in Axial Loading with N: 80,000 psi * (0.19634 in^2) = 15,707.2 lb
- Axial Force Applied on Bolts Upper Arm: 2,830.59 (Figure 10)
- Failure Force in Shear: 46,160 psi * (0.19634 in^2) = 9,063.0544 lb
- Shear Force Applied Directly: 602.81 lb (Figure 41)

- Conclusion:
  - Failure vs Applied Force:
    - 15,707.2 lb > 2,830.59 (Tensile)
    - 9,063.054 lb > 602.81 lb (Shear)

Appendix 12 – Safe Stress Values for Each Material

Initial material: 6061-O (SS) Aluminum; Yield Strength (Sy) = 8ksi (Appendix 9 - book)

Shear Stress: 3.077 ksi

Normal Stress: 5.3 ksi

New material: 2024-T361 Aluminum; Yield Strength (Sy) = 57ksi (Appendix 9 - book)\

Shear Stress: 38 ksi

Normal Stress: 21.926 ksi

Appendix 13 – Impact Strength

$$\sigma = \frac{F}{A}$$

$$= \frac{5000\ lbf}{\frac{\pi * 3^2}{4}} = 708\ psi$$

Deflection:

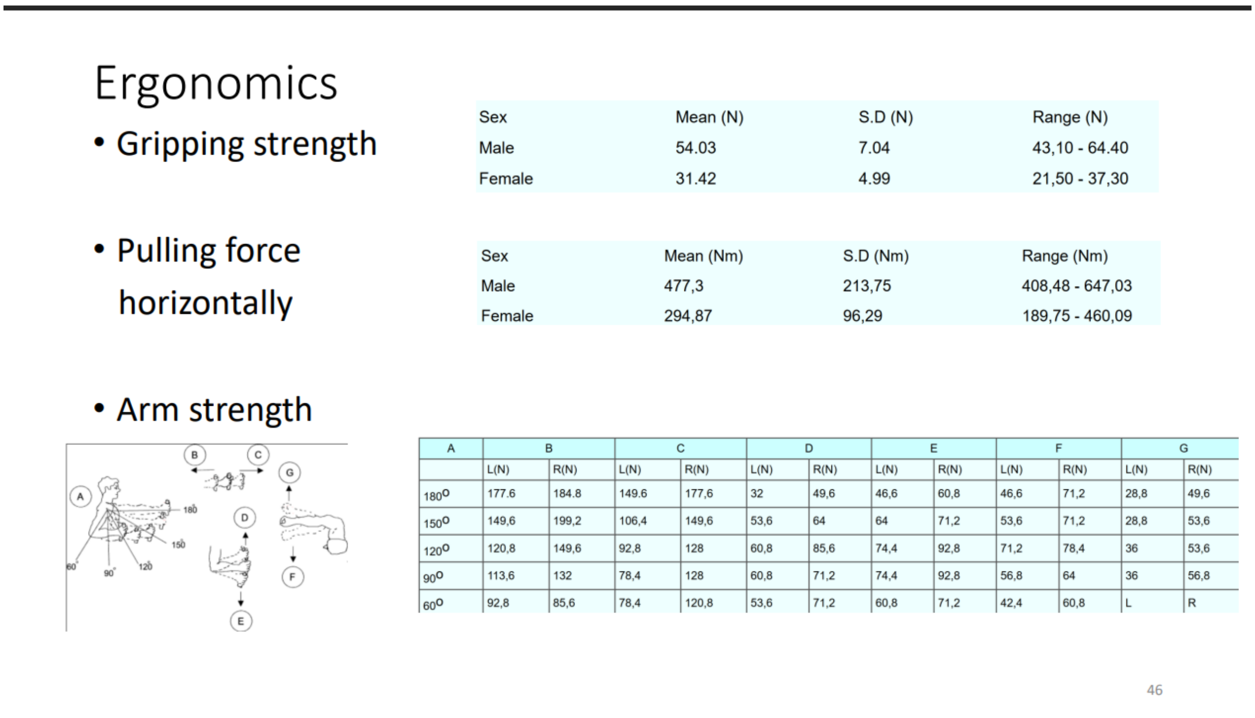
Area 1 = 536.75 in^2

Area 2= 97.53 in^2

$$\delta = \frac{F*L}{A*E}$$

$$= \frac{5000*25}{97.53*10000000} = 1.28*10^{-4}\ in$$

Appendix 14 – Figures



Ergonomics

- Gripping strength

Sex	Mean (N)	S.D (N)	Range (N)
Male	54.03	7.04	43,10 - 64.40
Female	31.42	4.99	21,50 - 37,30

- Pulling force horizontally

Sex	Mean (Nm)	S.D (Nm)	Range (Nm)
Male	477,3	213,75	408,48 - 647,03
Female	294,87	96,29	189,75 - 460,09

- Arm strength

A	B		C		D		E		F		G	
	L(N)	R(N)	L(N)	R(N)	L(N)	R(N)	L(N)	R(N)	L(N)	R(N)	L(N)	R(N)
180°	177.6	184.8	149.6	177,6	32	49,6	46,6	60,8	46,6	71,2	28,8	49,6
150°	149,6	199,2	106,4	149,6	53,6	64	64	71,2	53,6	71,2	28,8	53,6
120°	120,8	149,6	92,8	128	60,8	85,6	74,4	92,8	71,2	78,4	36	53,6
90°	113,6	132	78,4	128	60,8	71,2	74,4	92,8	56,8	64	36	56,8
60°	92,8	85,6	78,4	120,8	53,6	71,2	60,8	71,2	42,4	60,8	L	R

46

Figure 1: Slide 46 of power point 3, MECH 390.

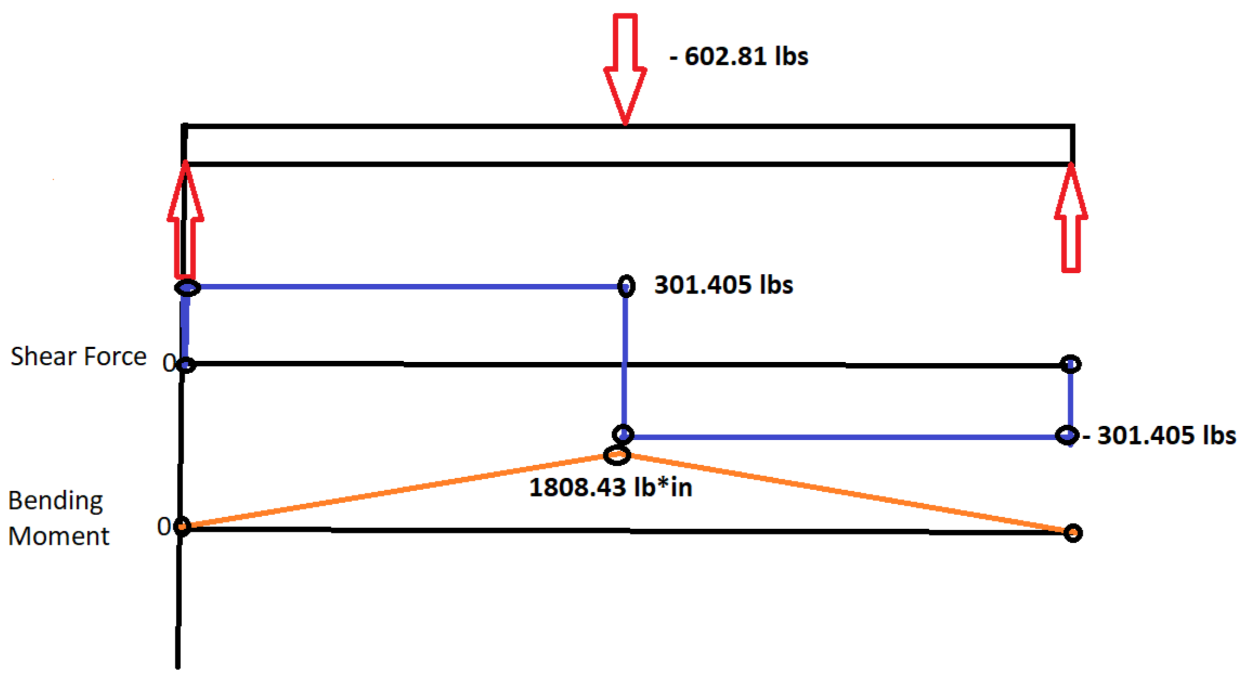


Figure 2: Bending and Shear Diagram of a 12 in Shaft.

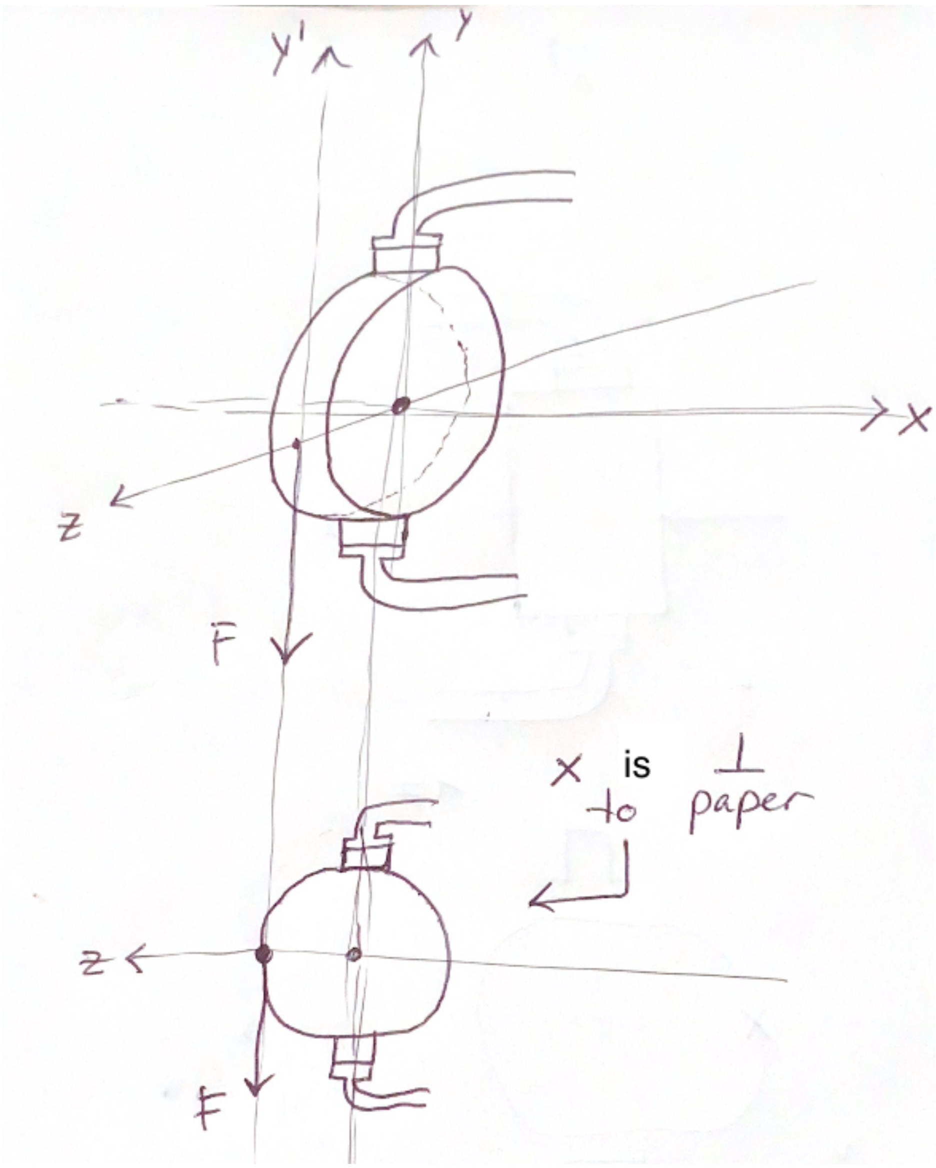


Figure 3: Scenario 1, Sketch of the Forces and Moments on the Casing.

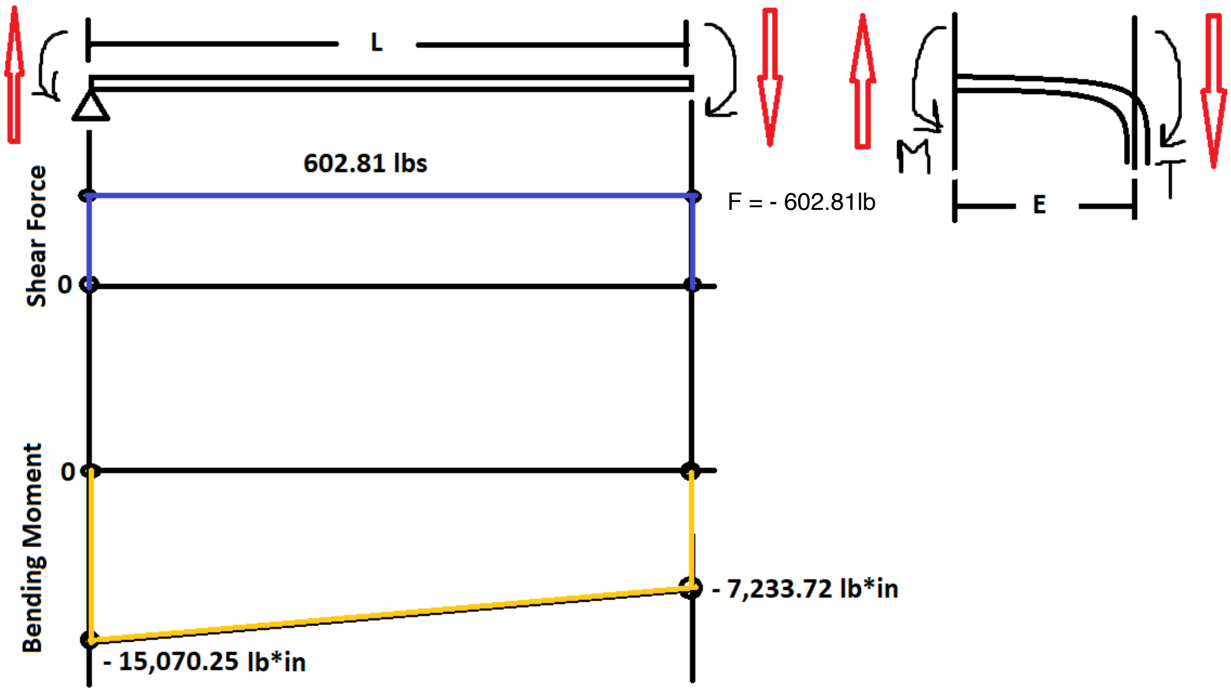


Figure 4: Scenario 1, Bending and Shear Diagram of Straight Portion of Casing Arms (L = 13).

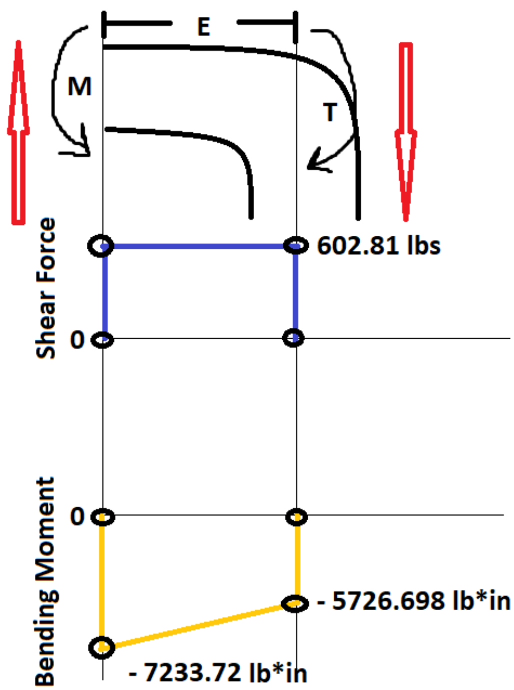


Figure 5: Scenario 1, Bending and Shear Diagram of the Bent Portion of Casing Arms (E = 2.5).

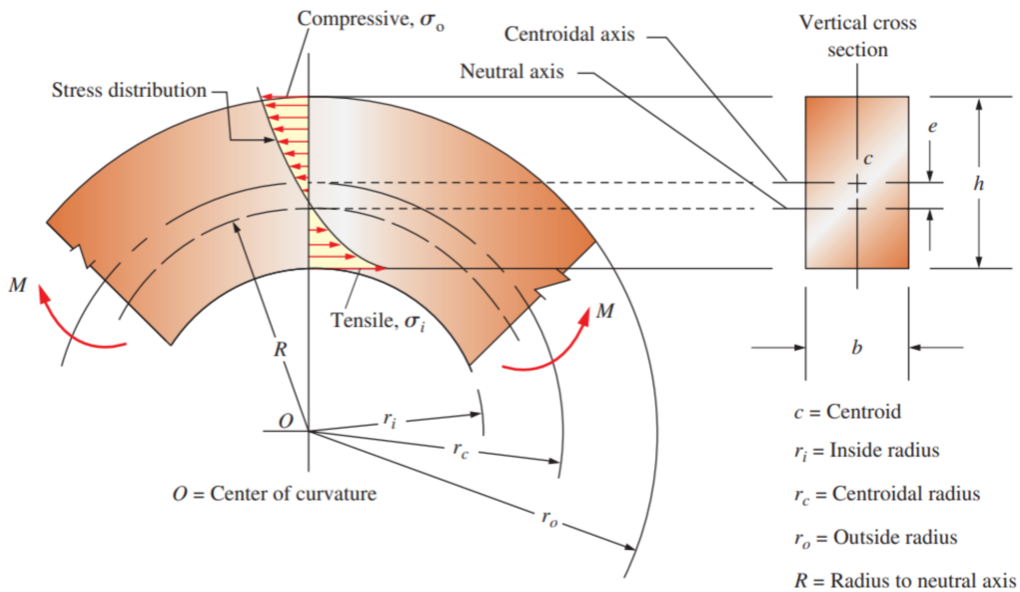


Figure 6: Segment of a Curved Beam Carrying a Positive Bending Moment.

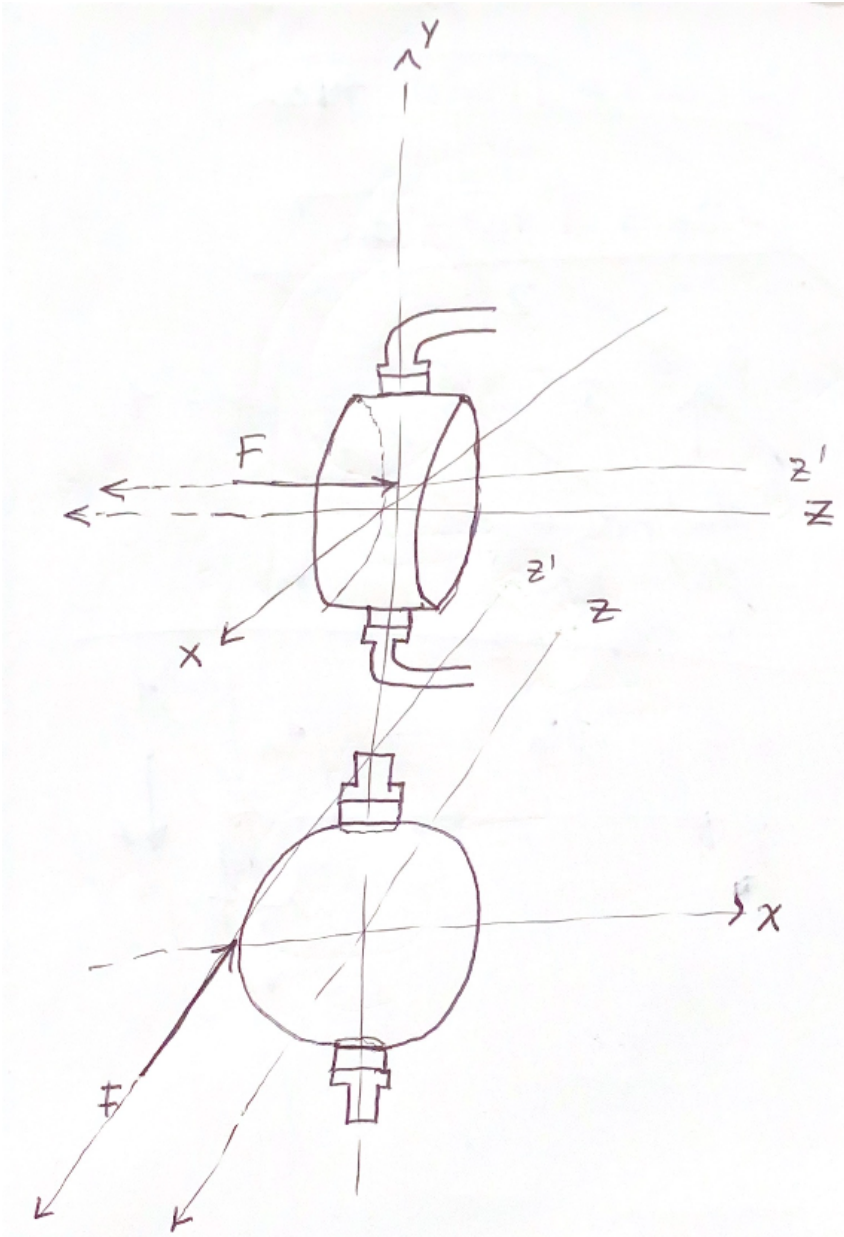


Figure 7: Scenario 2, Sketch of the Forces and Moments on the Casing.

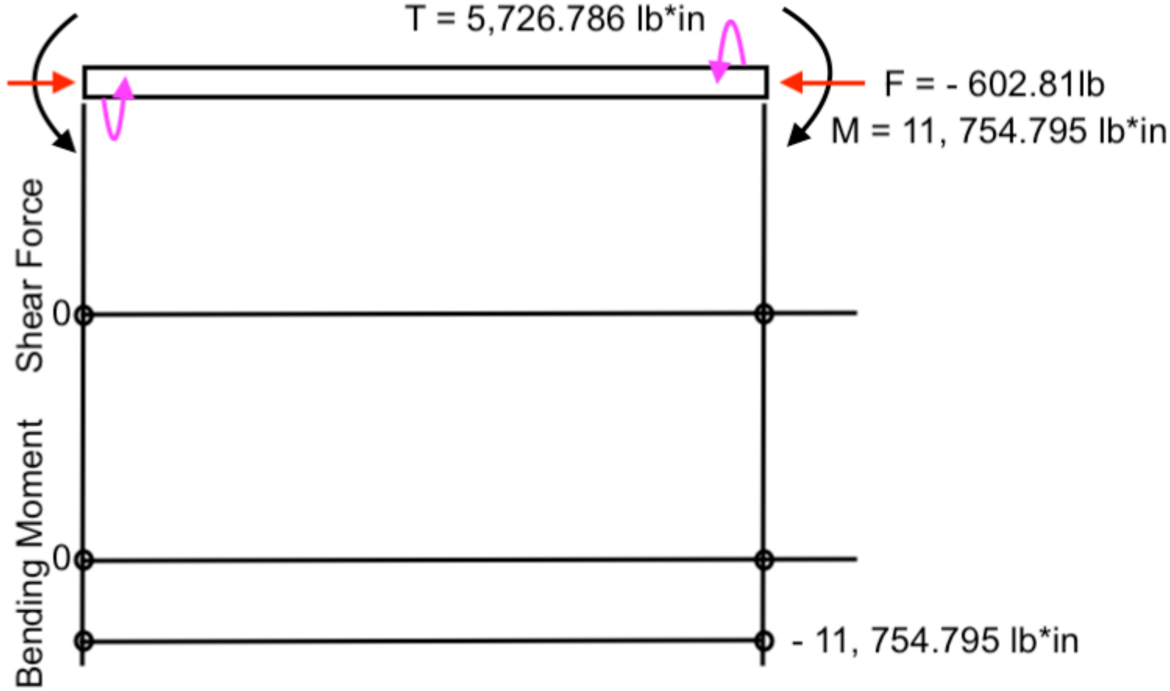


Figure 7.1: Scenario 2, Bending and Shear Diagram of Straight Portion of Casing Arms.

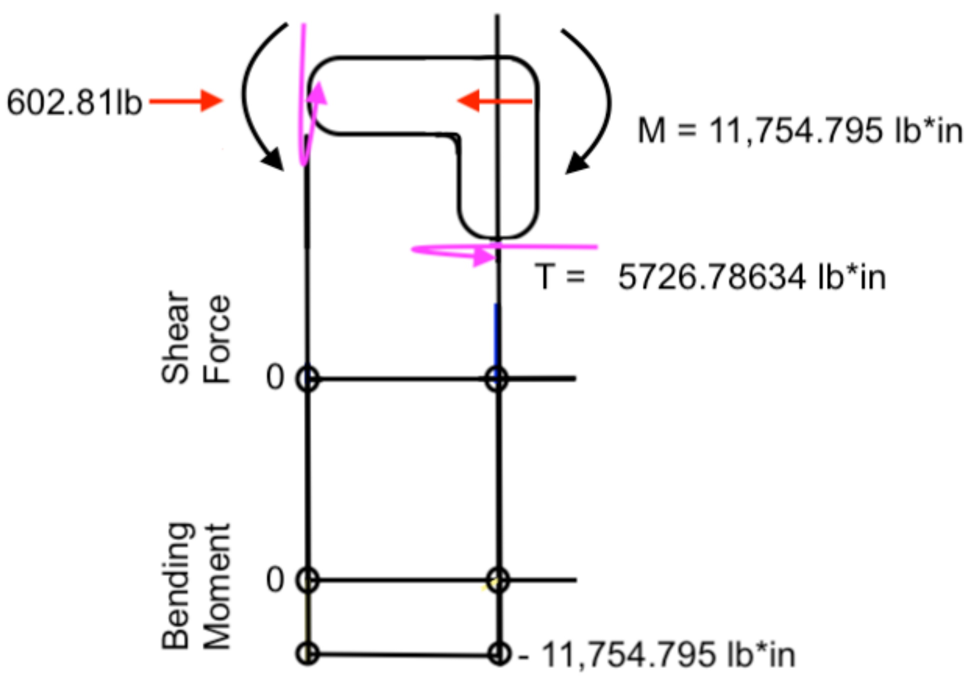


Figure 7.2: Scenario 2, Bending and Shear Diagram of the Bent Portion of Casing Arms.

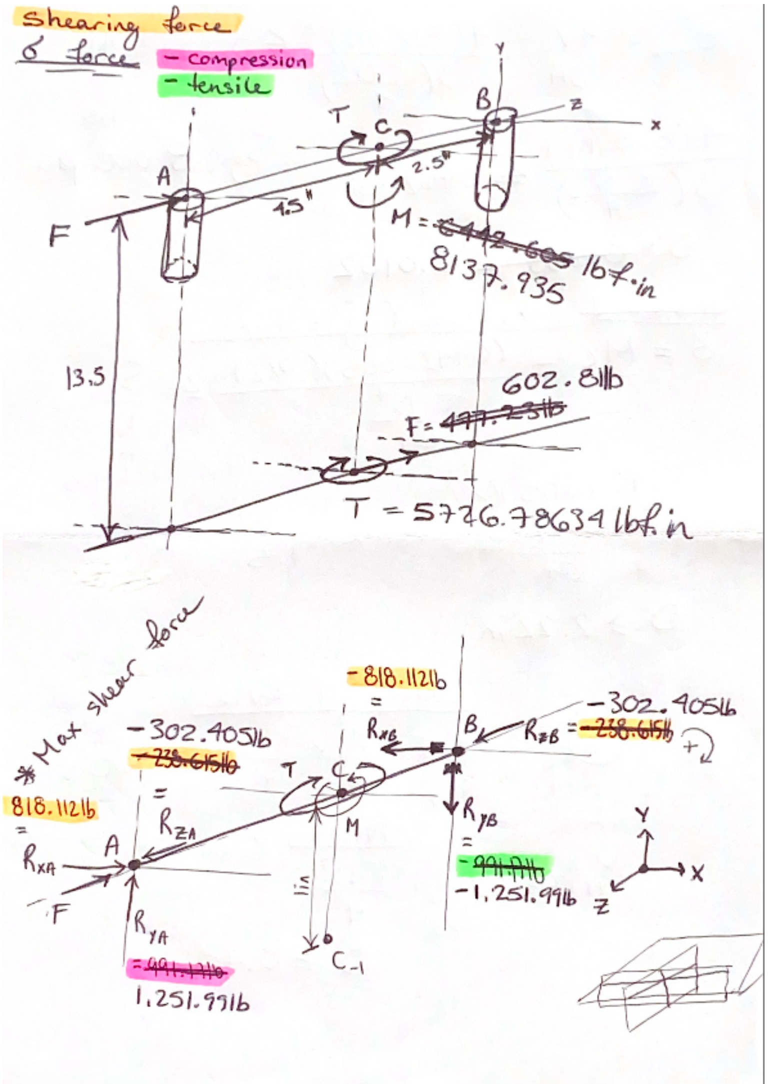


Figure 8: Scenario 2, Option 1, Sketch of the Reaction Forces and Moments on Locking Mechanism of Upper Arm.

$$\Sigma F_x = R_{xA} + R_{xB} = 0 \quad R_{xA} = -R_{xB} \quad \Rightarrow \quad \Sigma F_x = R_{xA} - R_{xB} = 0$$

$$\Sigma F_y = R_{yA} + R_{yB} = 0 \quad R_{yA} = -R_{yB} \qquad \Sigma F_y = R_{yA} - R_{yB} = 0$$

$$\Sigma F_z = F - R_{zA} - R_{zB} = 0 \qquad \cancel{-2.5R_{xA}} \quad R_{xA}$$

$$\Sigma M_{C_{xz}} = T - R_{xA}\cdot 4.5 - R_{xB}\cdot 2.5 = 0 \; ; \; 5726.78634 - 4.5R_{xA} - 2.5R_{xB} = 0$$

$$5726.78634 = 2R_{xA} \; ; \; R_{xA} = \cancel{2863.393175 lb} \quad \cancel{R_{xB} = -2863.393175 lb} \quad = 818.112 lb$$

$$\Sigma M_{C_{yz}} = -M + R_{yA}\cdot 4.5 + R_{yB}\cdot 2.5 = 0 \; ; \; -\underset{8137.935}{\cancel{6442.605}} + 6.5R_{yA} = 0 ; \; R_{yA} = \cancel{991.17 lb} \; 1{,}251.99 lb$$

$\Sigma M_{C_{xy}} = 0$, no moment there.

picking $\Sigma M_{C_{-1}}$ 1 in below C
to get z-values

$$\Sigma M_{C_{-1}\,yz} = F\cdot 1 - R_{zA}\cdot 1 - R_{zB}\cdot 1 \overbrace{- M + R_{yA}\cdot 4.5 + R_{yB}\cdot 2.5}^{0} = 0$$

$$\frac{\underset{}{\overset{602.81}{\cancel{477.23}}}}{2} = \underset{301.405 lb}{\cancel{238.615 lb}} = R_{zA\,\&\,B}$$

$$\begin{bmatrix} 1 & -1 & -1 \\ 2 & -2 & -2 \\ \vdots & \vdots & \vdots \\ n & -n & -n \end{bmatrix} \begin{bmatrix} F \\ R_{zA} \\ R_{zB} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Reactions must be even $\therefore \frac{1}{2}F$

Figure 9: Scenario 2, Option 1, Calculations of the Forces and Moments on Locking Mechanism of Upper Arm.

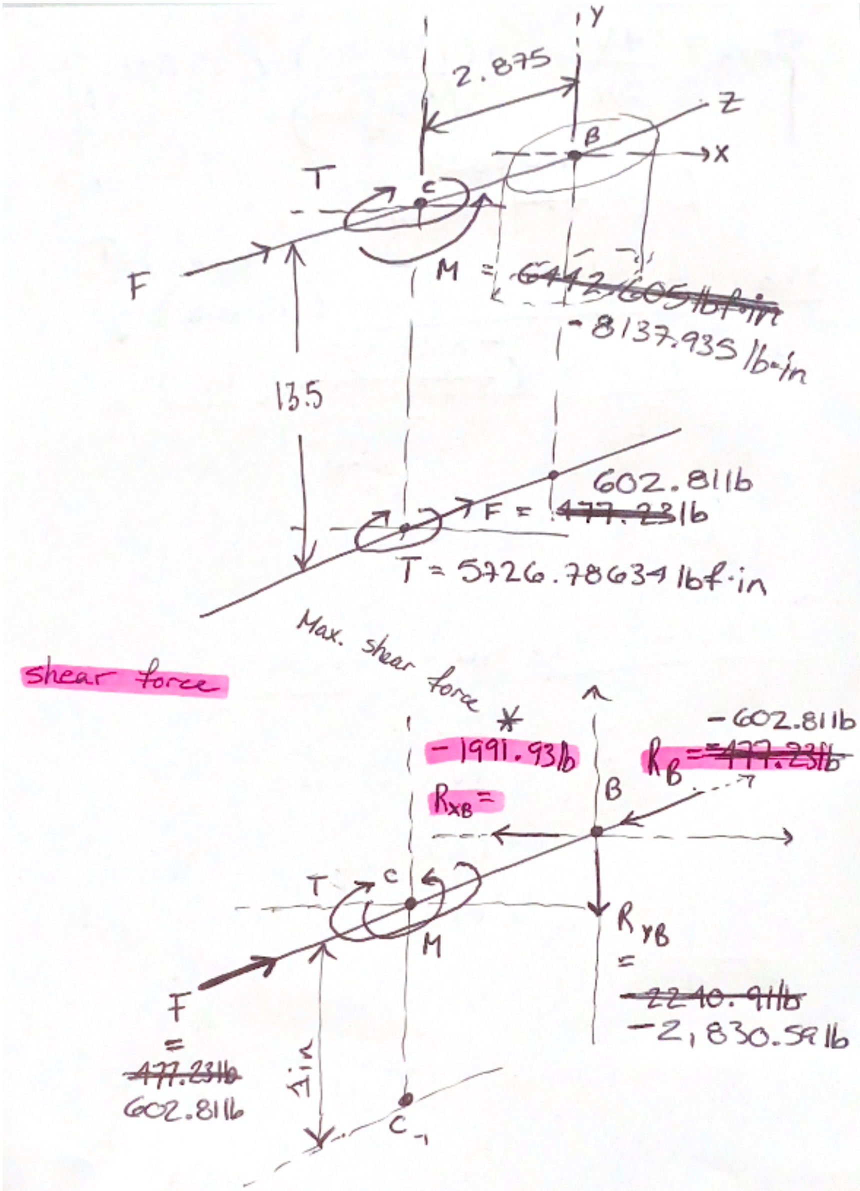
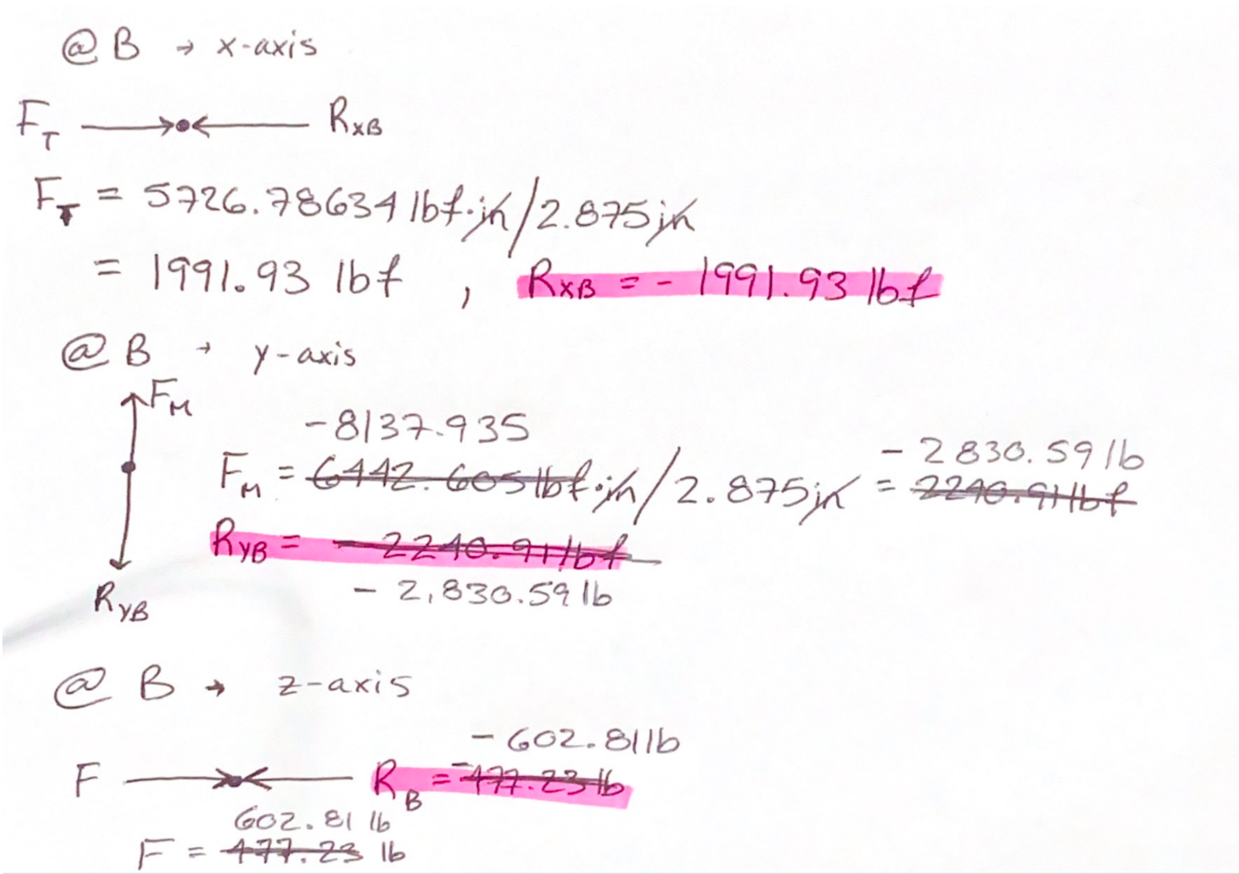


Figure 10: Scenario 2, Option 2, Sketch of the Reactions Forces and Moments on Locking Mechanism of Upper Arm.



@ B → x-axis

$F_T \longrightarrow \bullet \longleftarrow R_{xB}$

$F_T = 5726.78634 \text{ lbf}\cdot\text{in} / 2.875 \text{ in}$

$= 1991.93 \text{ lbf}$, $R_{xB} = -1991.93 \text{ lbf}$

@ B → y-axis

F_M

R_{yB}

$F_M = \cancel{6442.605 \text{ lbf}\cdot\text{in}}\ -8137.935 / 2.875 \text{ in} = \cancel{2240.91 \text{ lbf}}\ -2830.59 \text{ lb}$

$R_{yB} = \cancel{-2240.91 \text{ lbf}}\ -2{,}830.59 \text{ lb}$

@ B → z-axis

$F \longrightarrow \times \longleftarrow R_B = \cancel{-477.23 \text{ lb}}\ -602.81 \text{ lb}$

$F = \cancel{477.23}\ 602.81 \text{ lb}$

Figure 11: Scenario 2, Option 2, Calculations of the Reaction Forces and Moments on Locking Mechanism of Upper Arm.

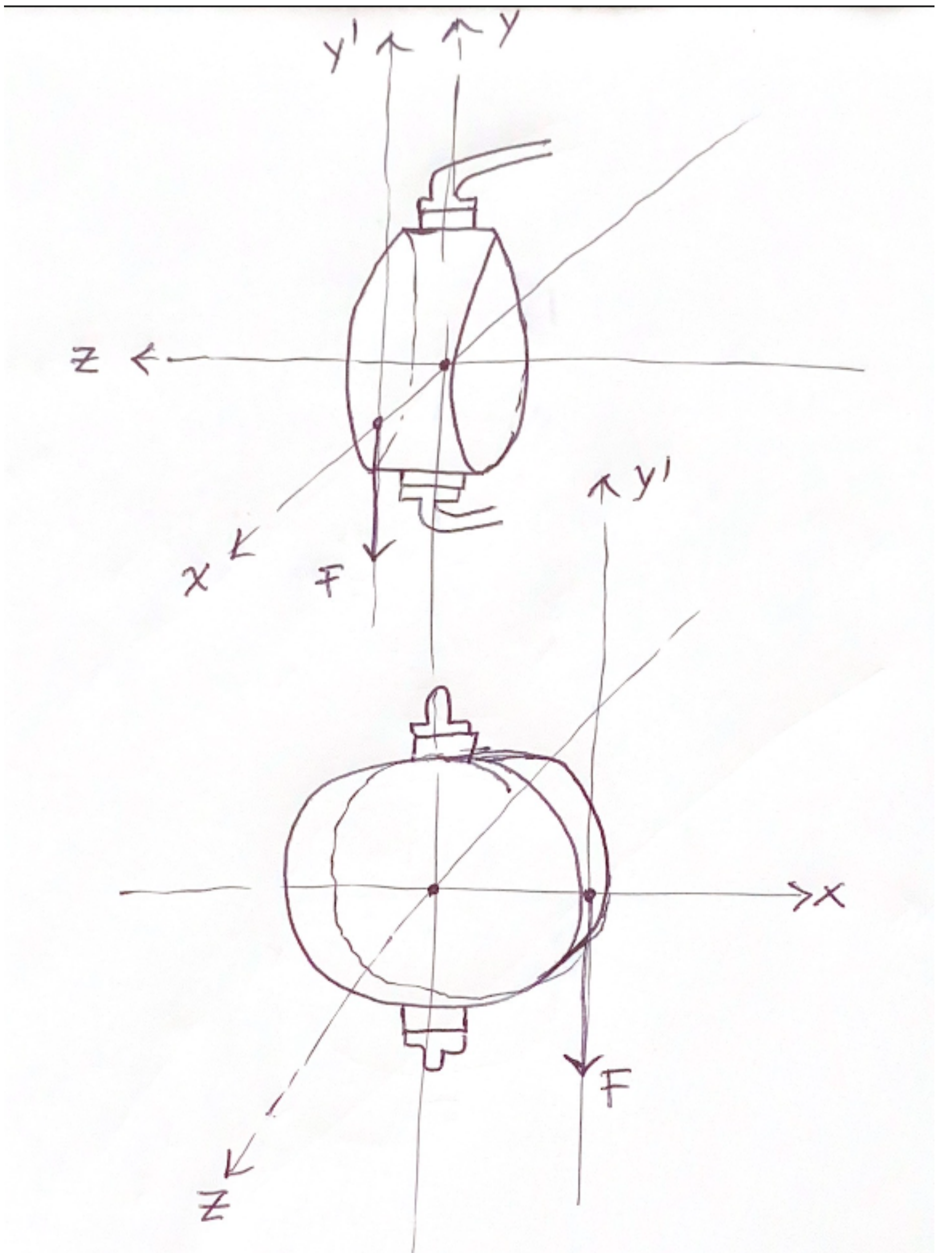


Figure 12: Scenario 3, Sketch of the forces and moments on the Casing.

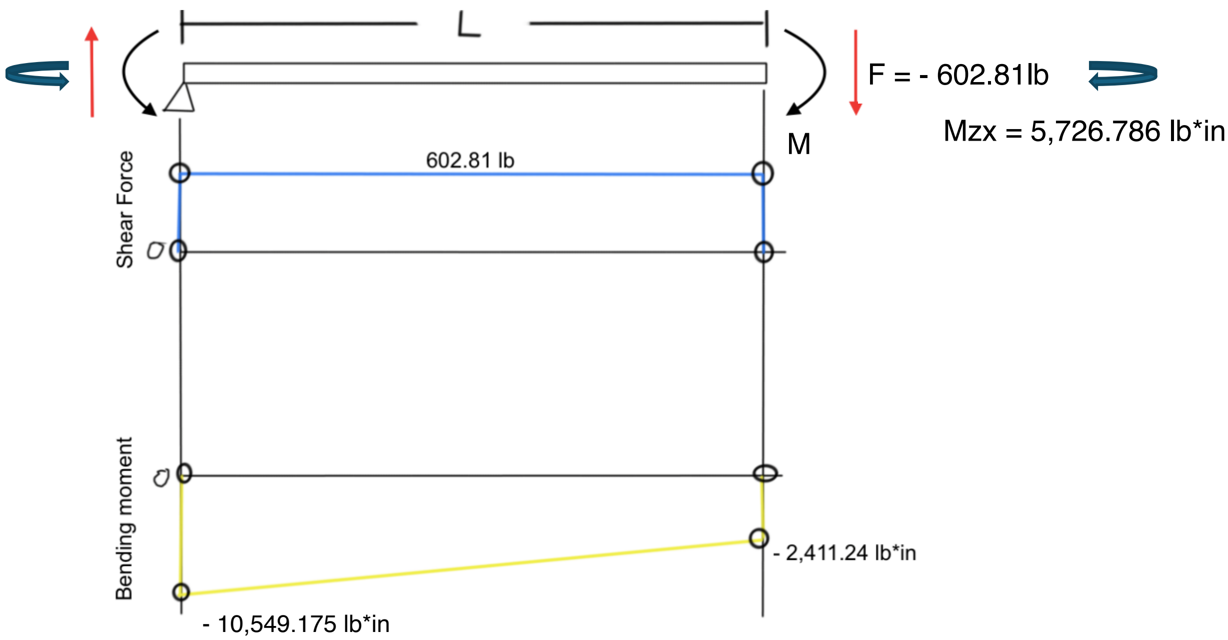


Figure 13: Scenario 3, Bending and Shear Diagram of Straight Portion of Casing Upper Arm.

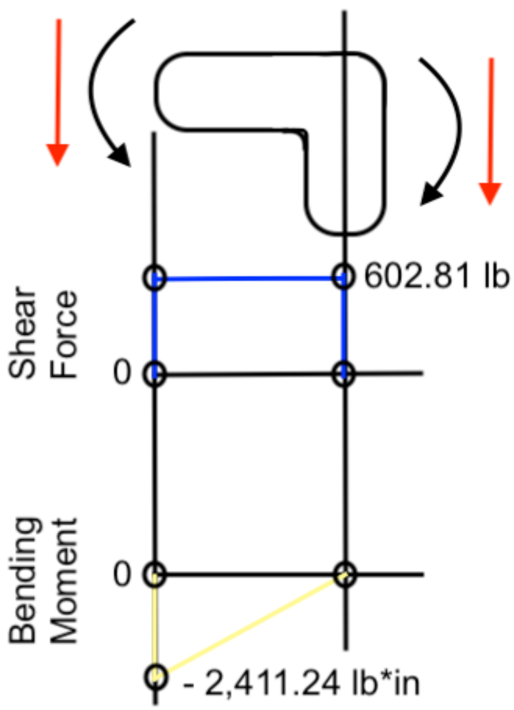


Figure 14: Scenario 3, Bending and Shear Diagram of Bent Portion of Casing Upper Arm.

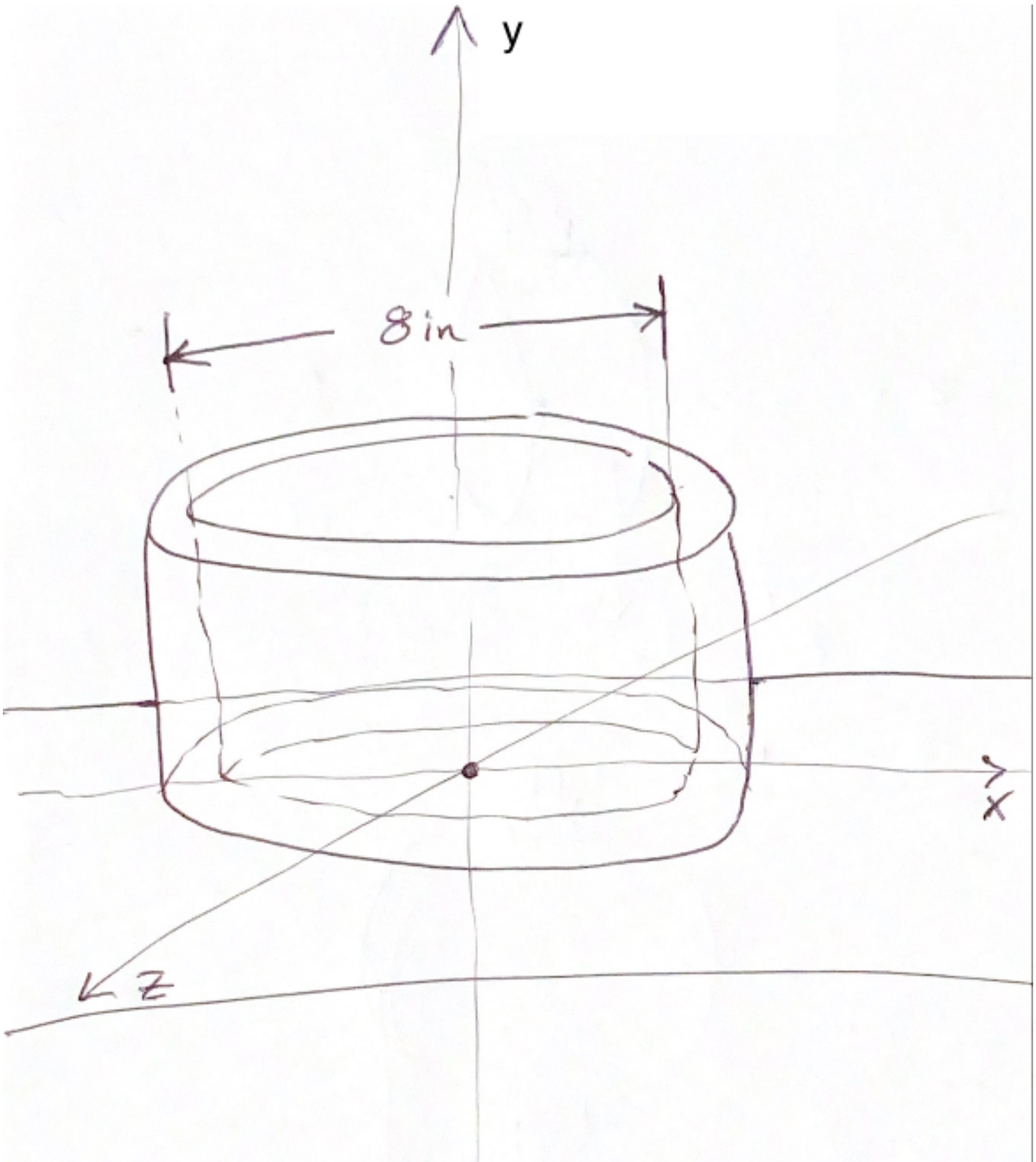


Figure 15: Sketch of 8-in inner DIA Capsule for Arms on Casing.

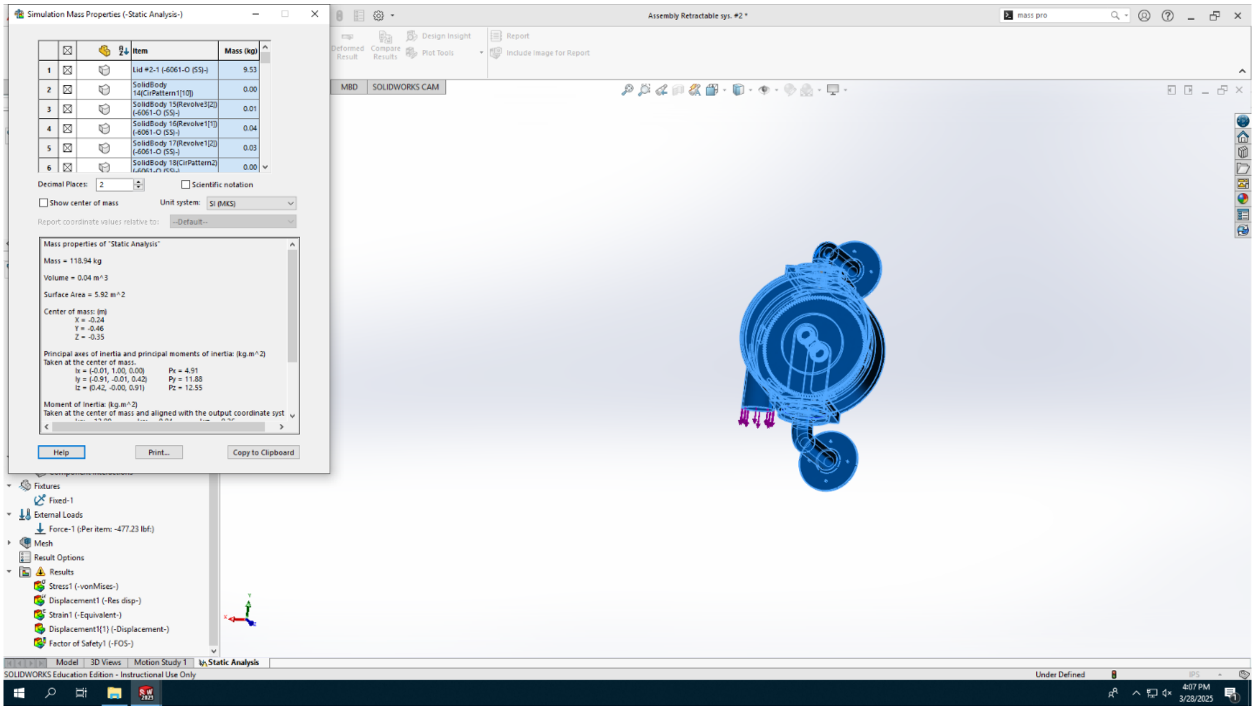


Figure 16: Initial Weight of the Assembly.

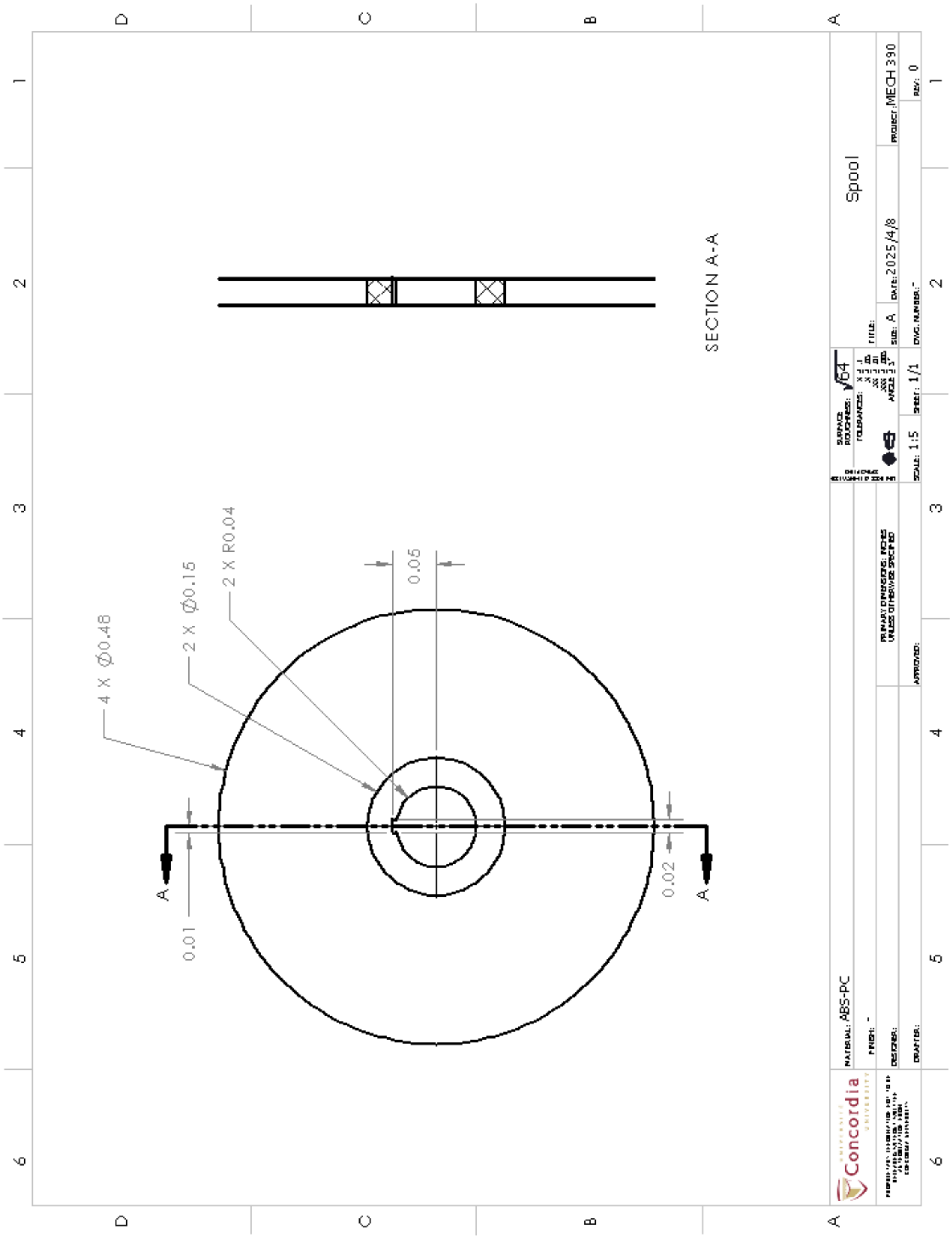


Figure 17: Spool Drawing.

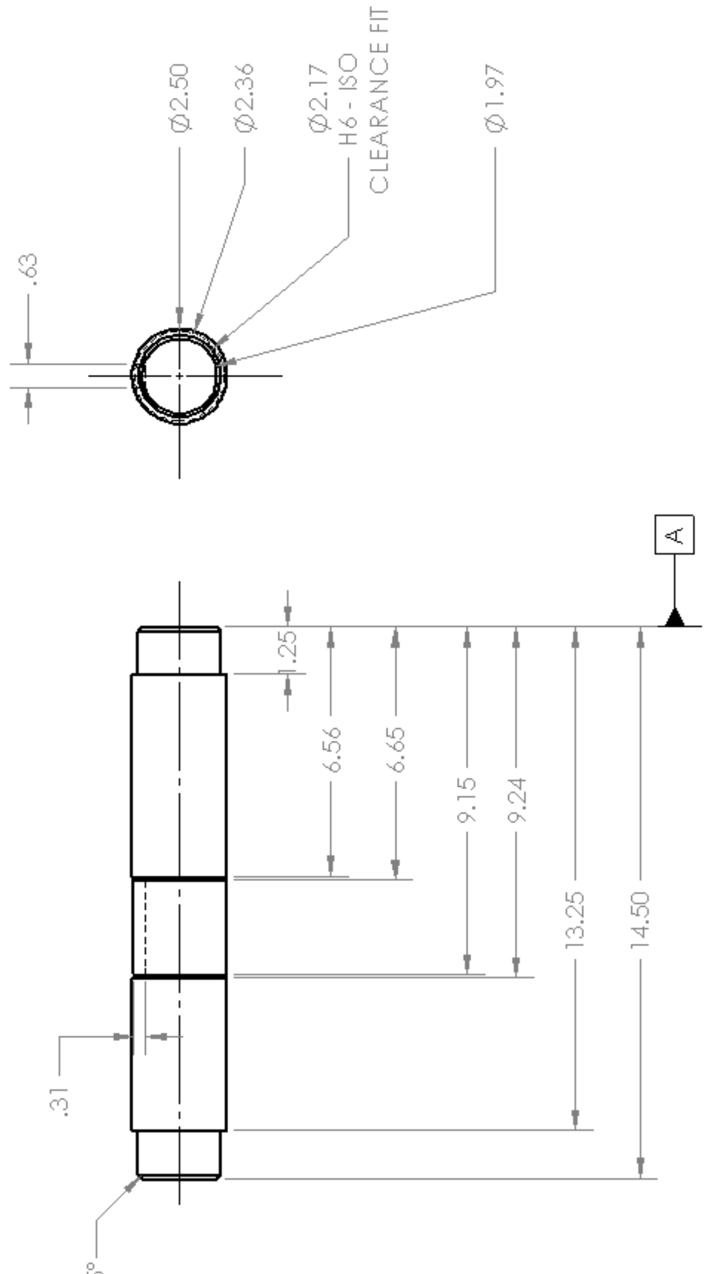


Figure 18: Shaft Drawing.

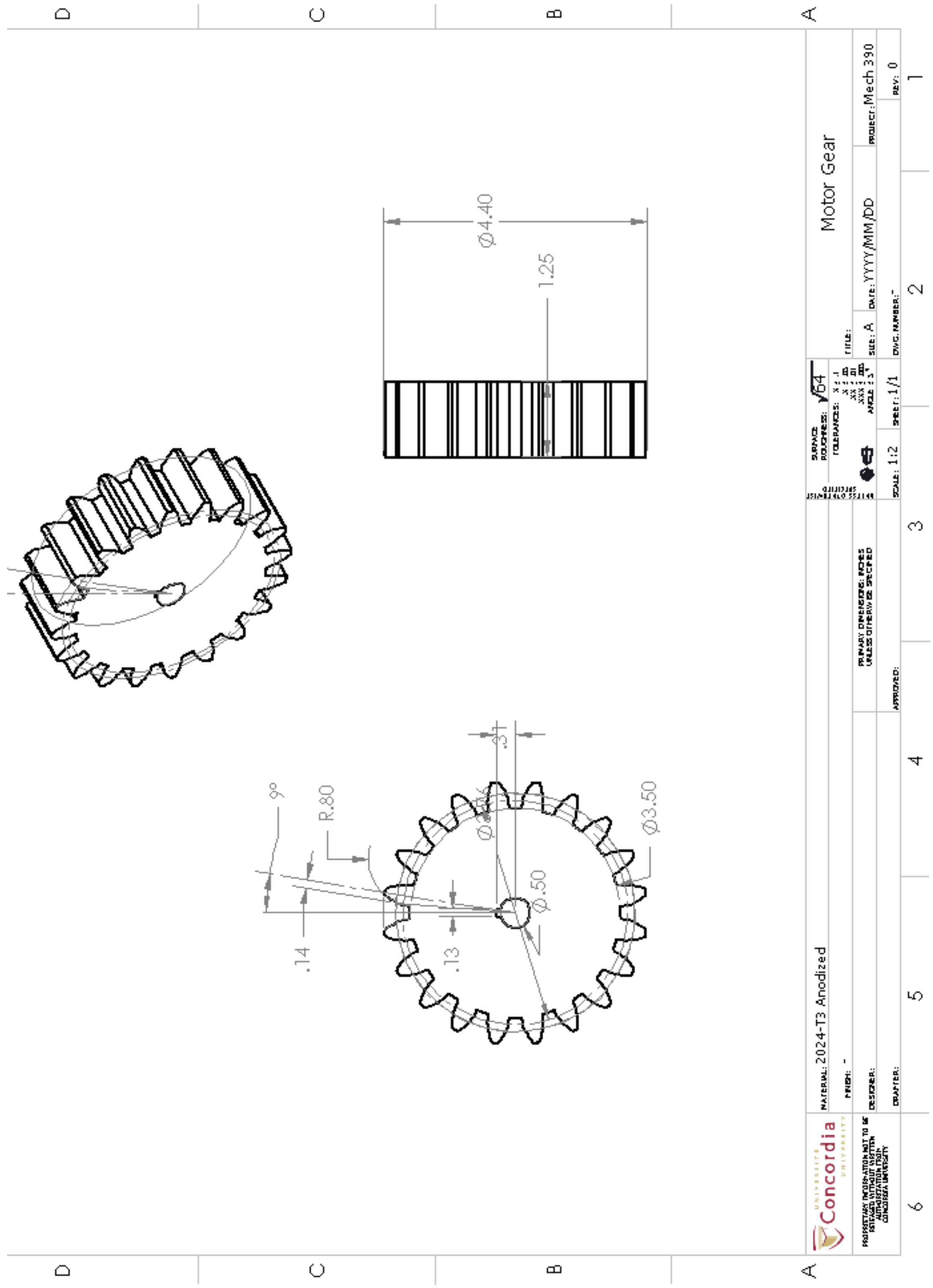


Figure 19: Motor Gear Drawing.

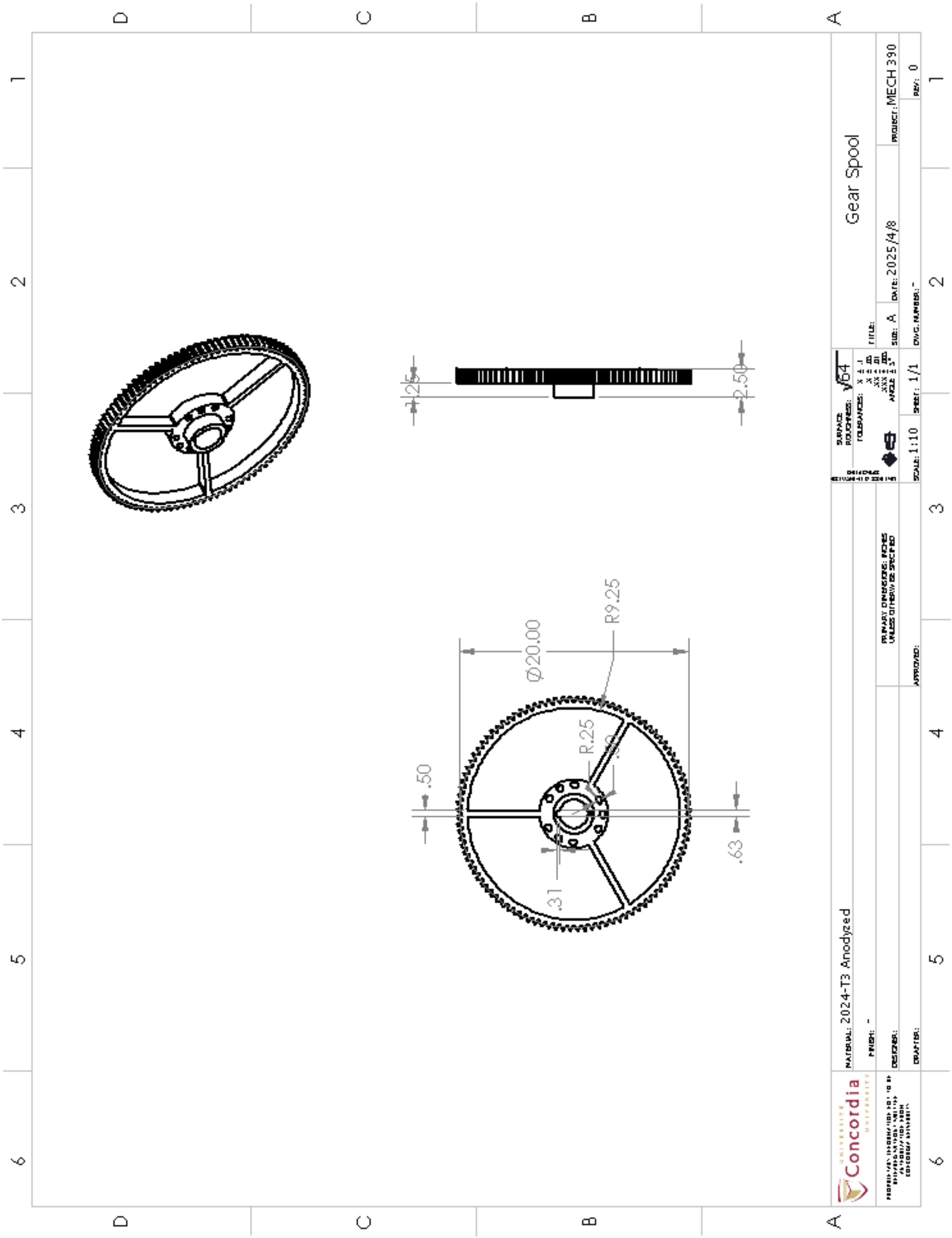


Figure 20: Spool Gear Drawing.

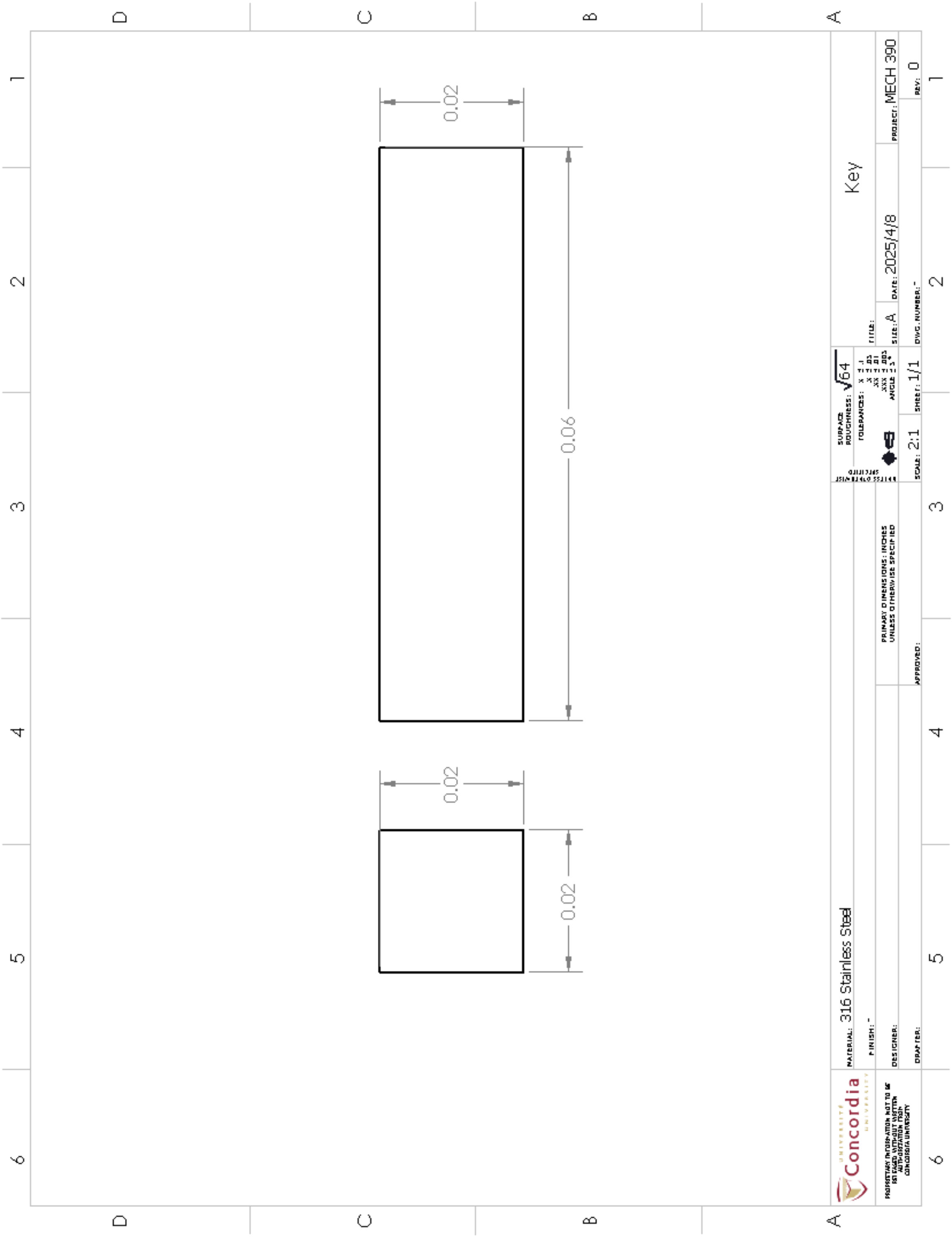


Figure 21: Key Drawing.

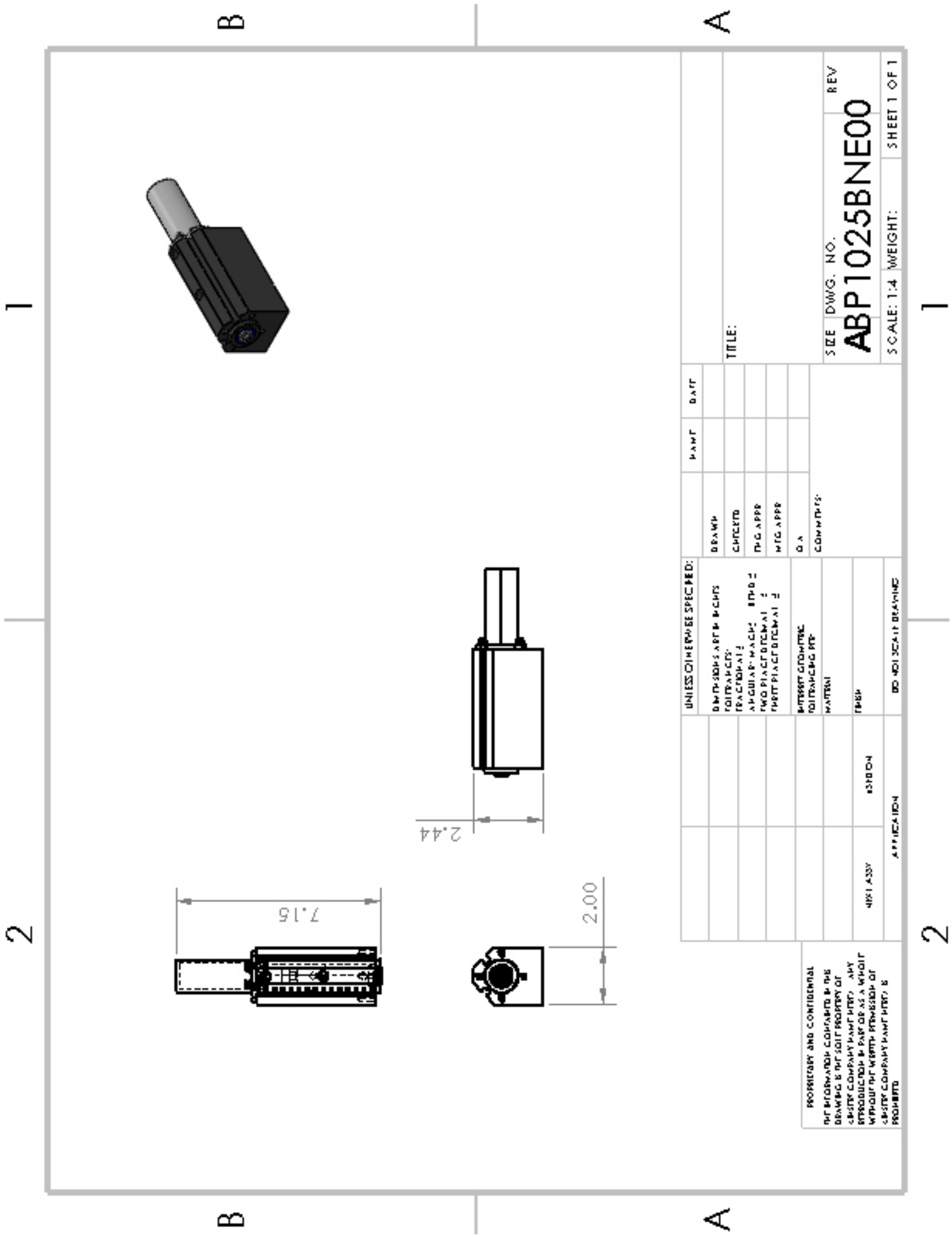


Figure 22: Solenoid pin.

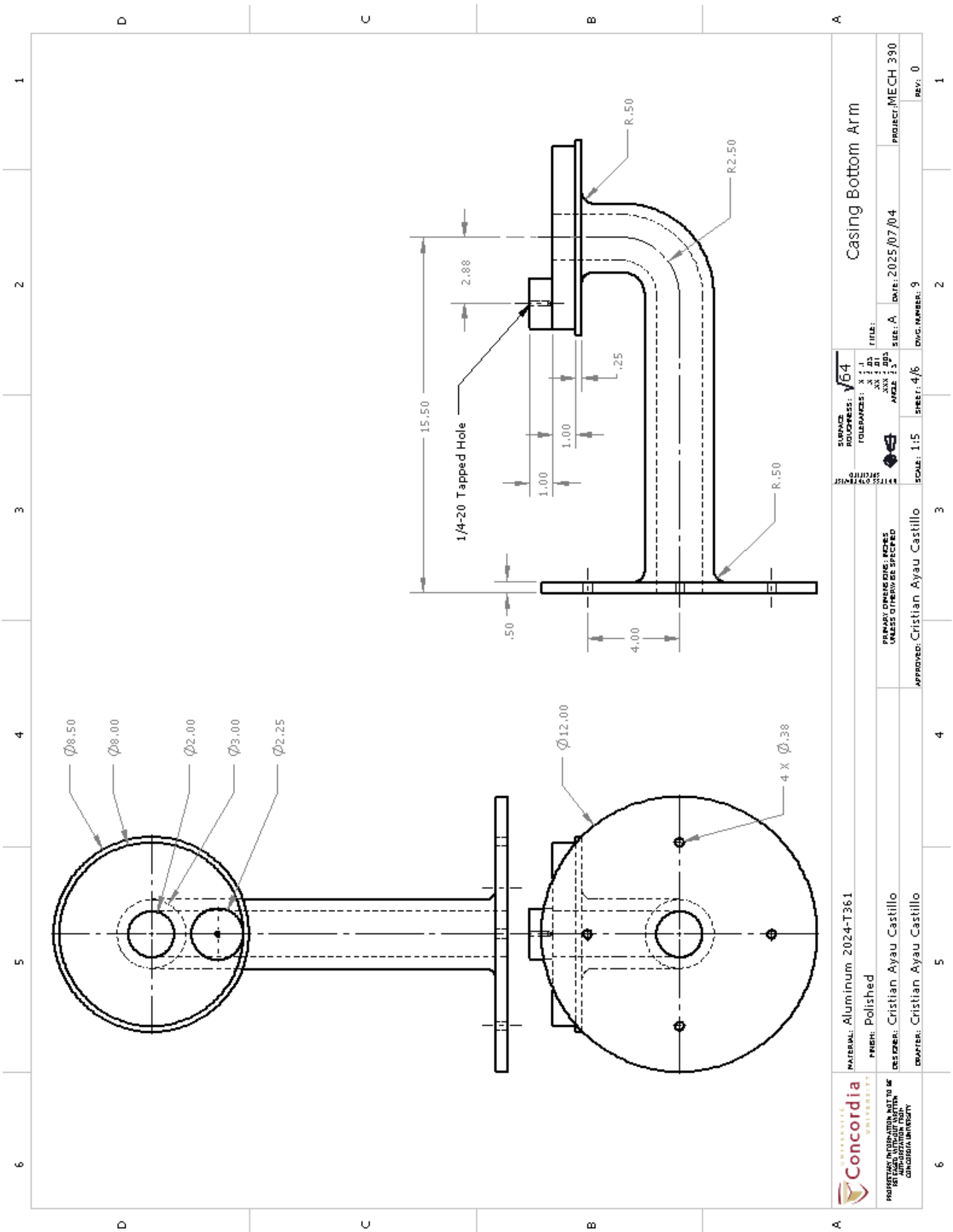


Figure 23: Bottom Arm Drawing.

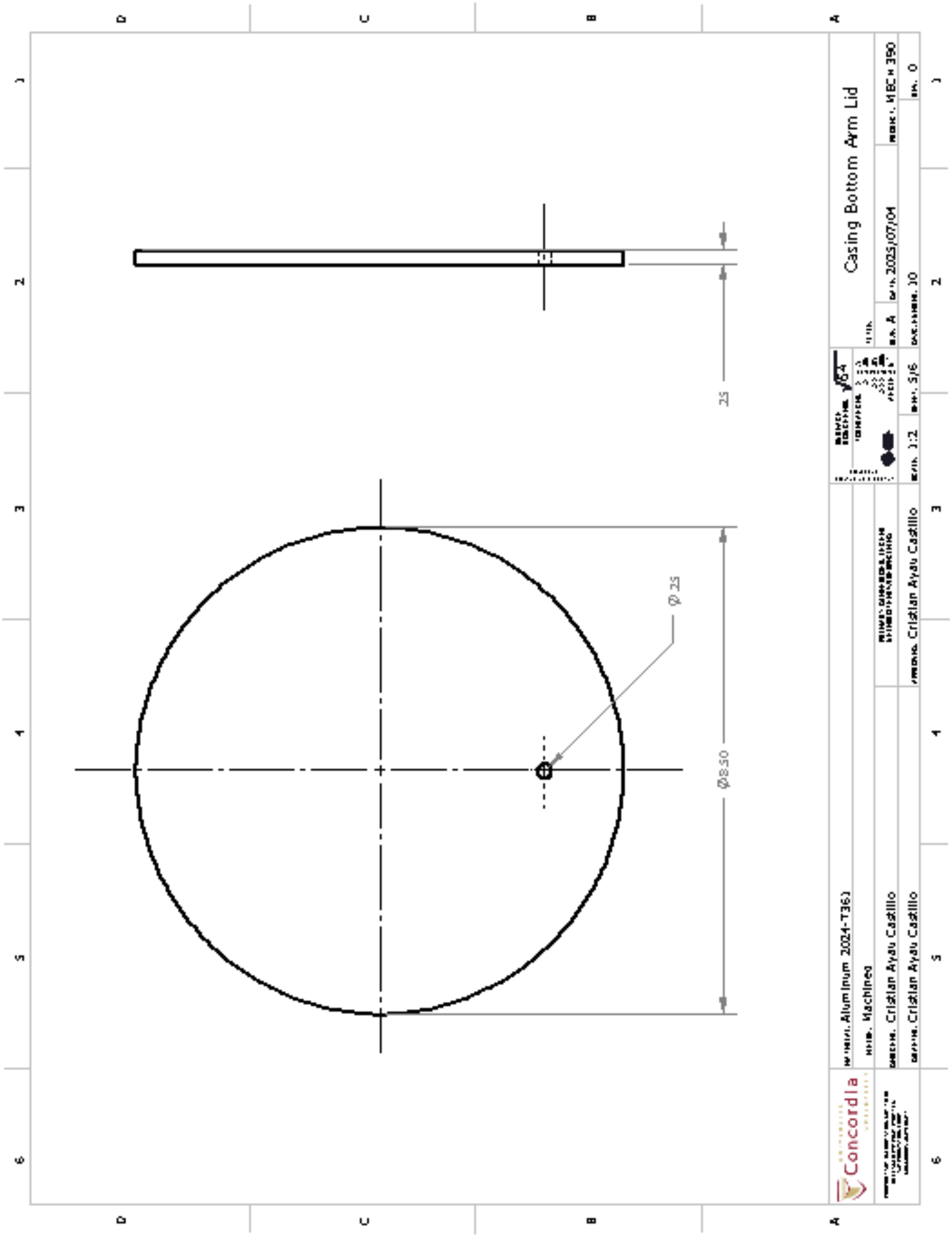


Figure 24: Bottom Arm Lid Drawing.

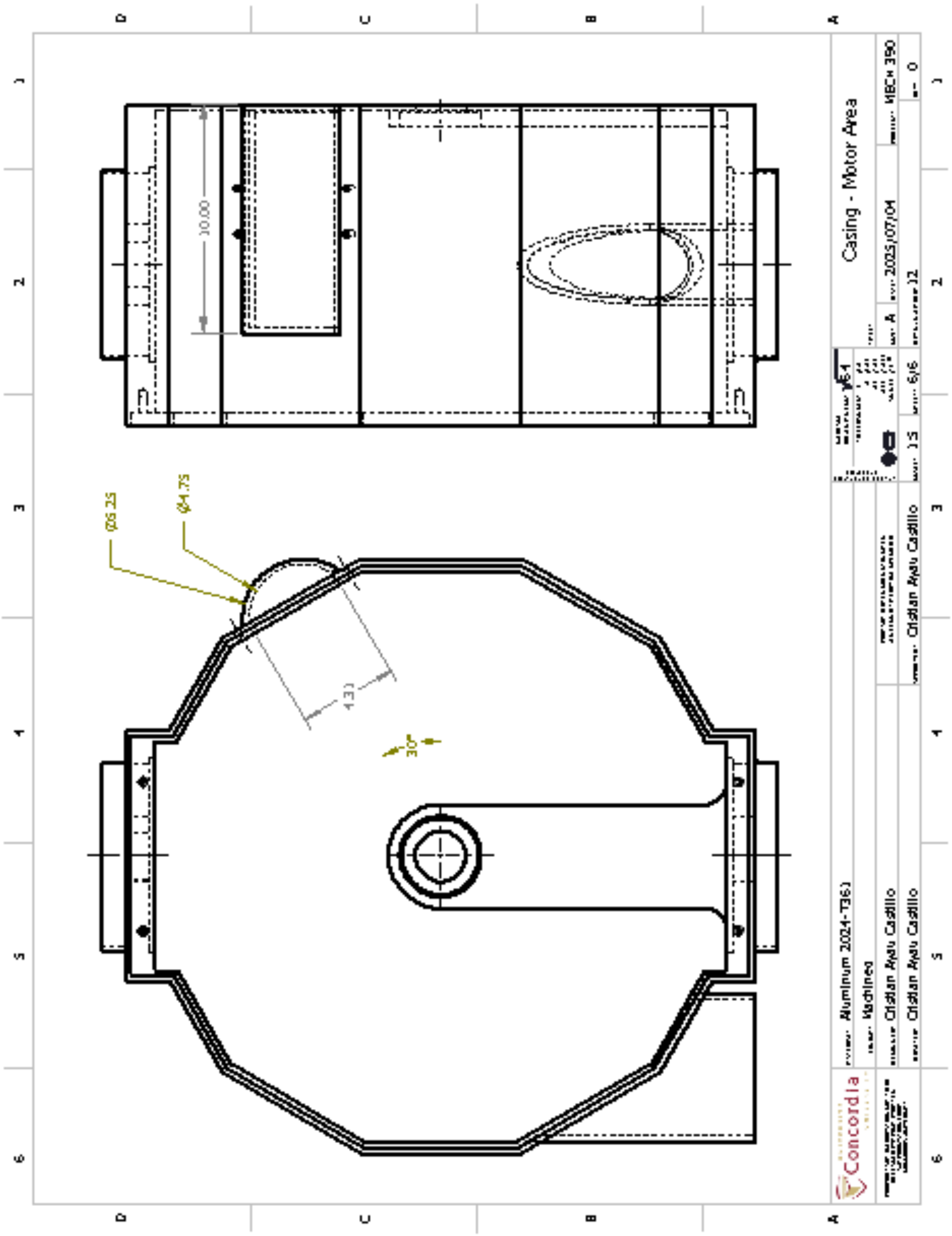


Figure 25: Motor Casing Drawing.

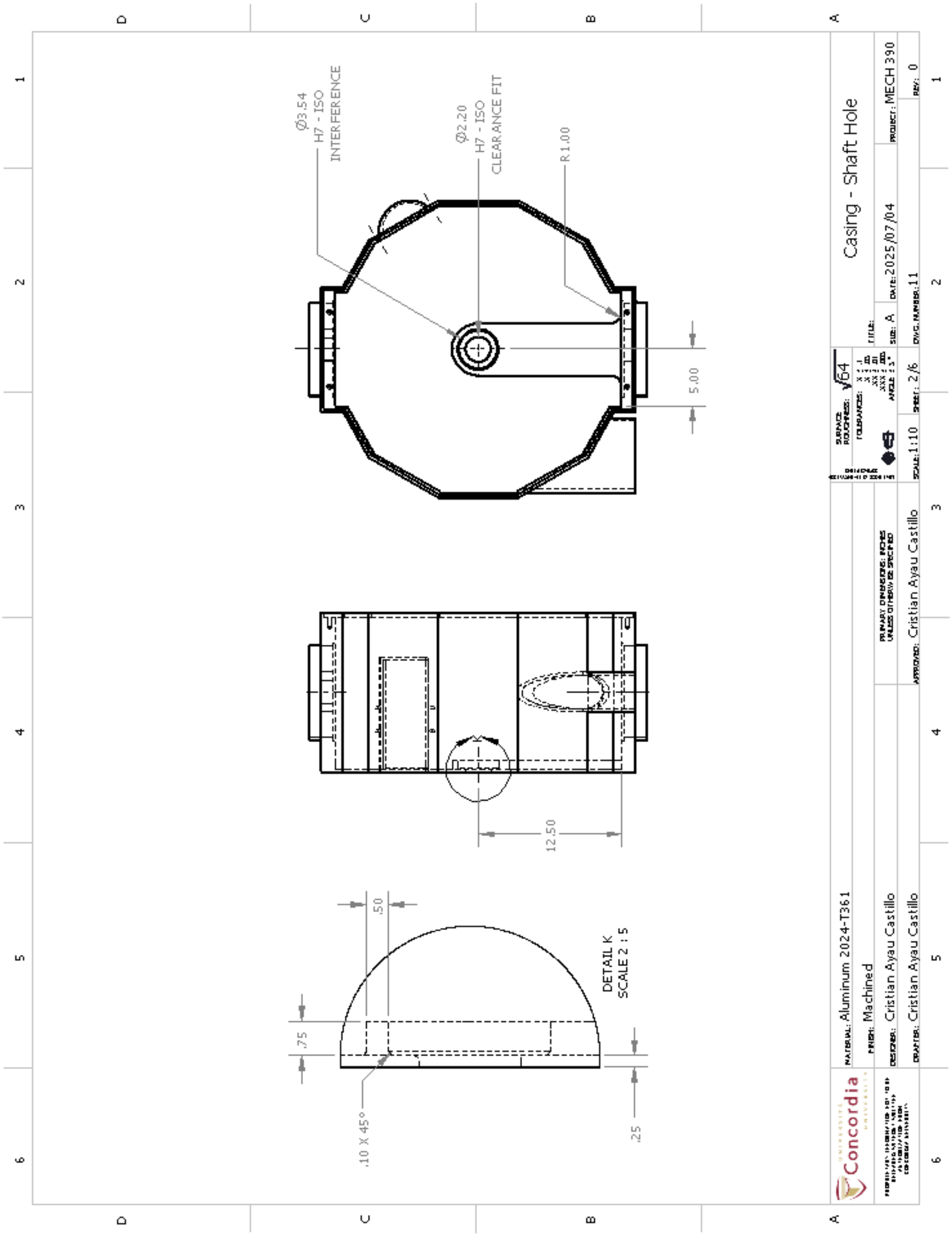


Figure 26: Shaft Casing Drawing.

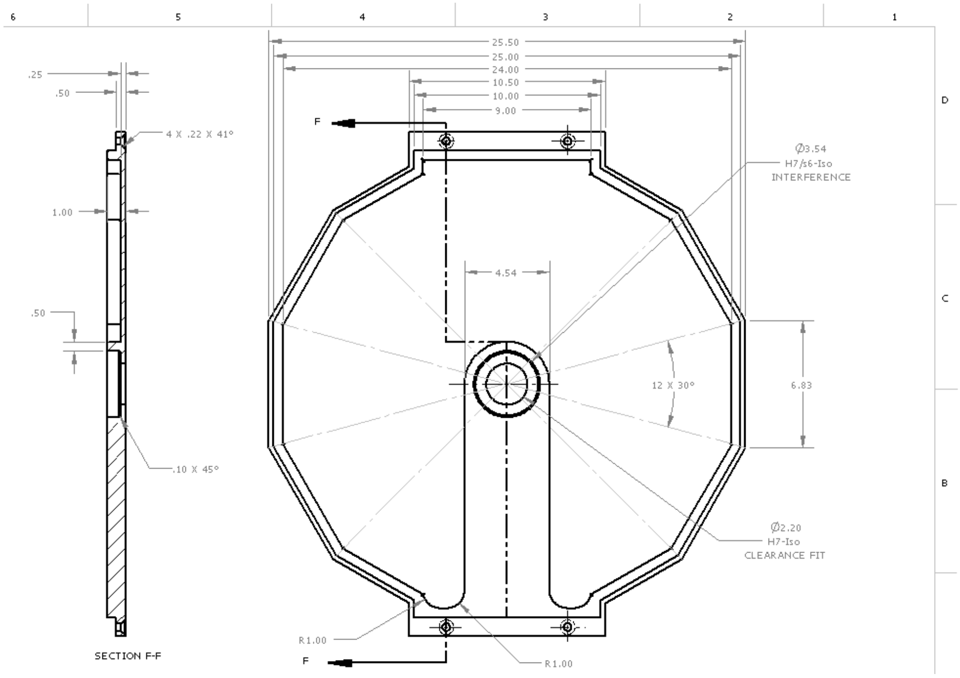


Figure 27: Casing Lid Drawing.

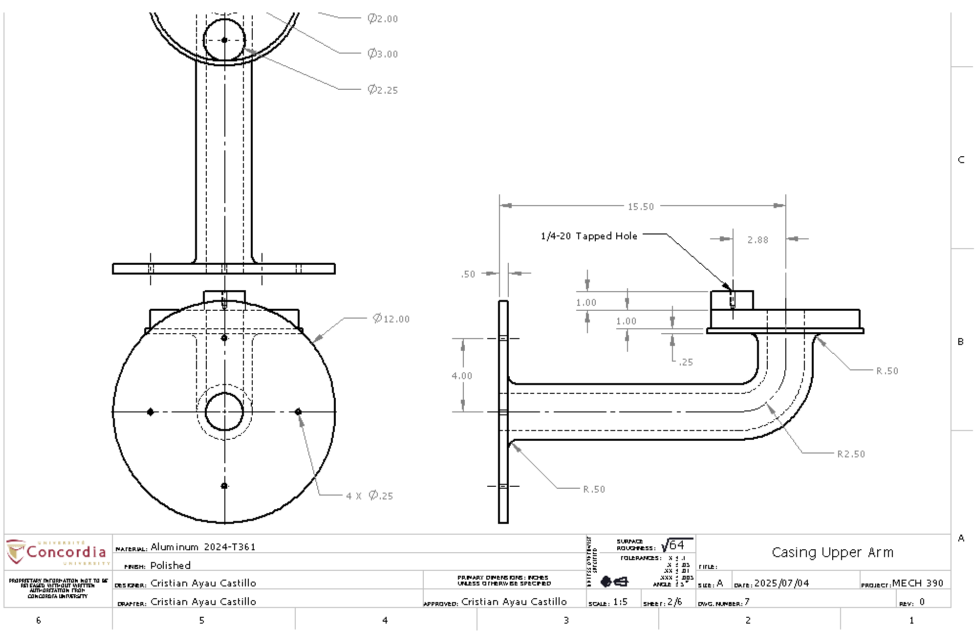


Figure 28: Upper Arm Drawing.

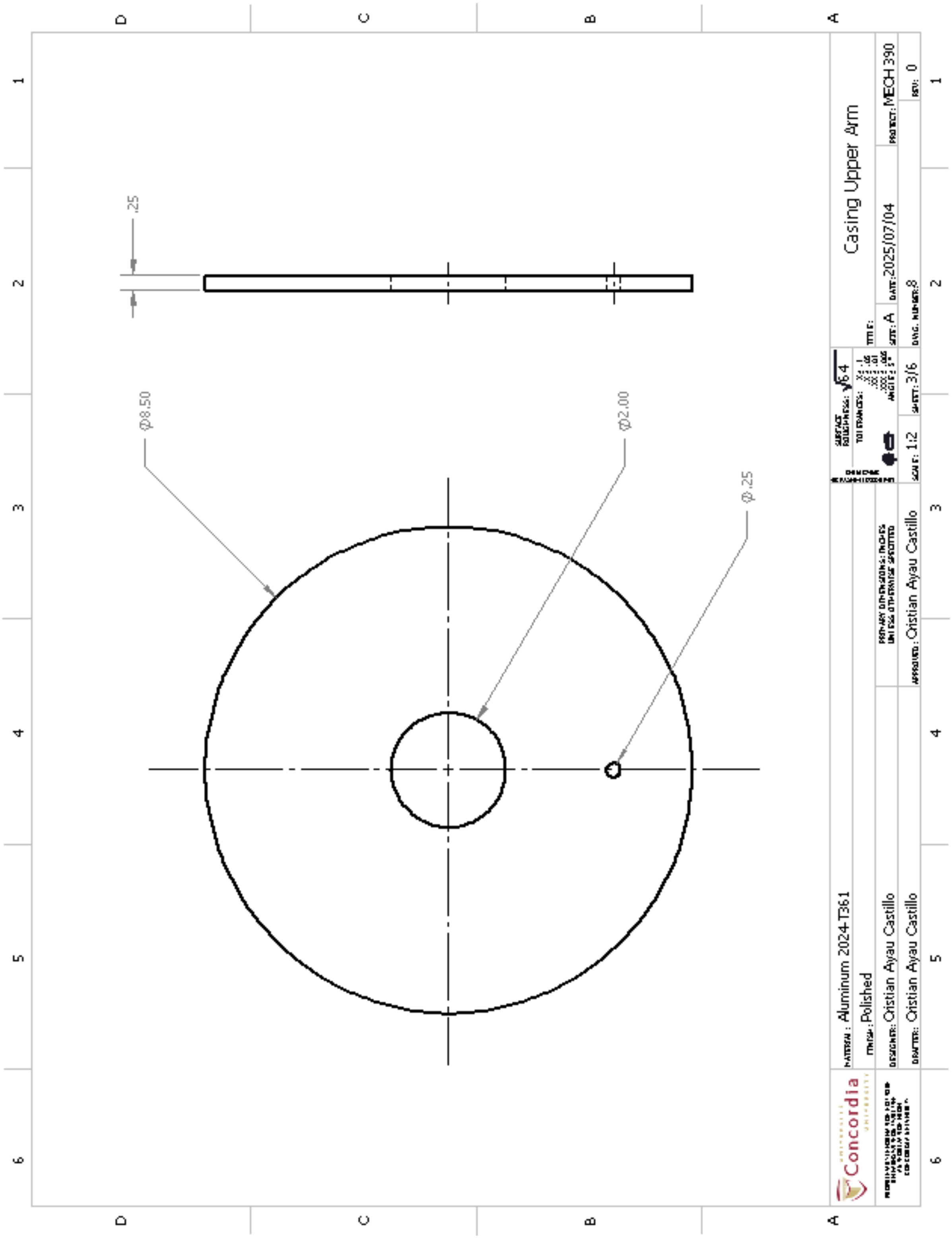


Figure 29: Upper Arm Casing Drawing.

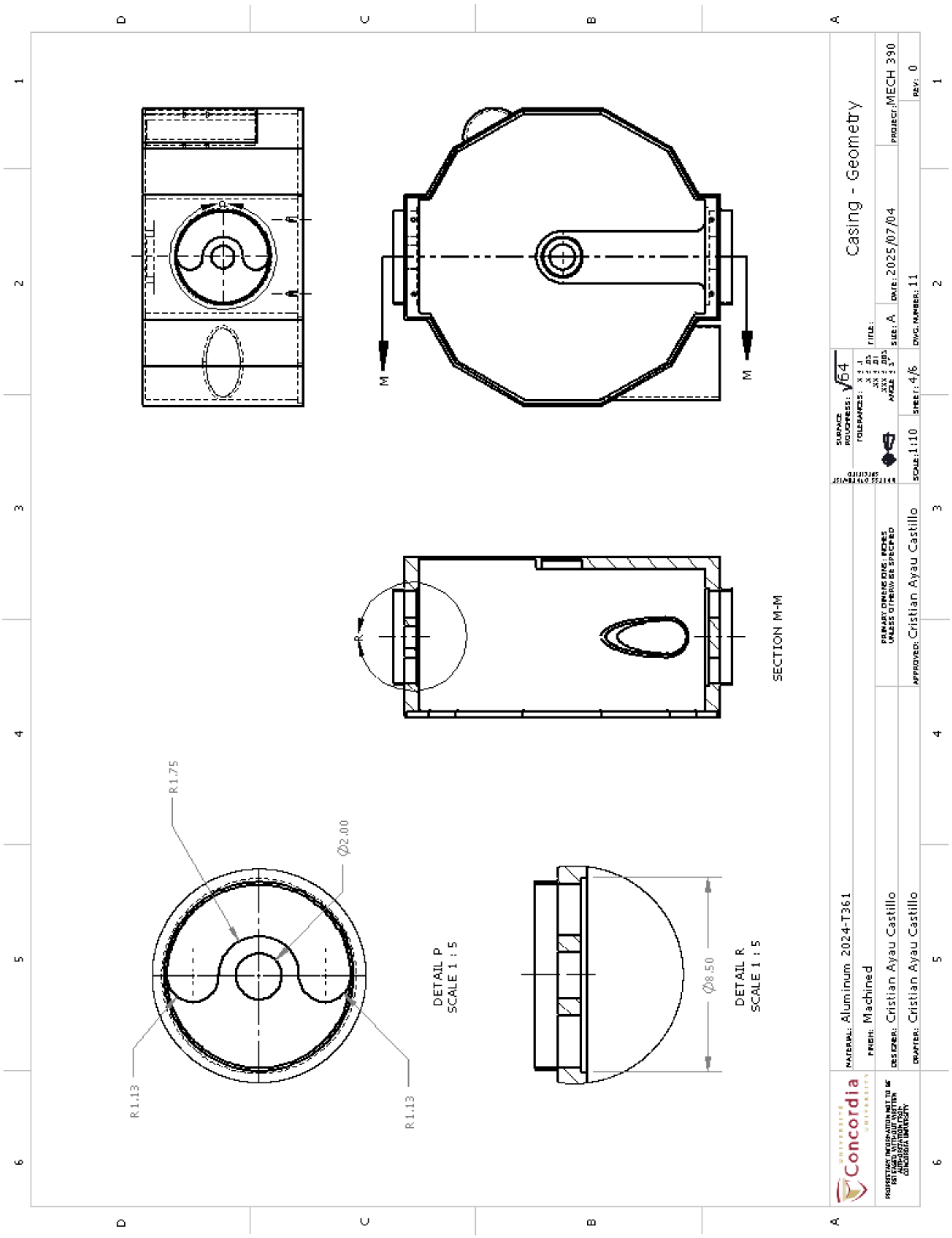


Figure 30: Casing Locking Mechanism Drawing.

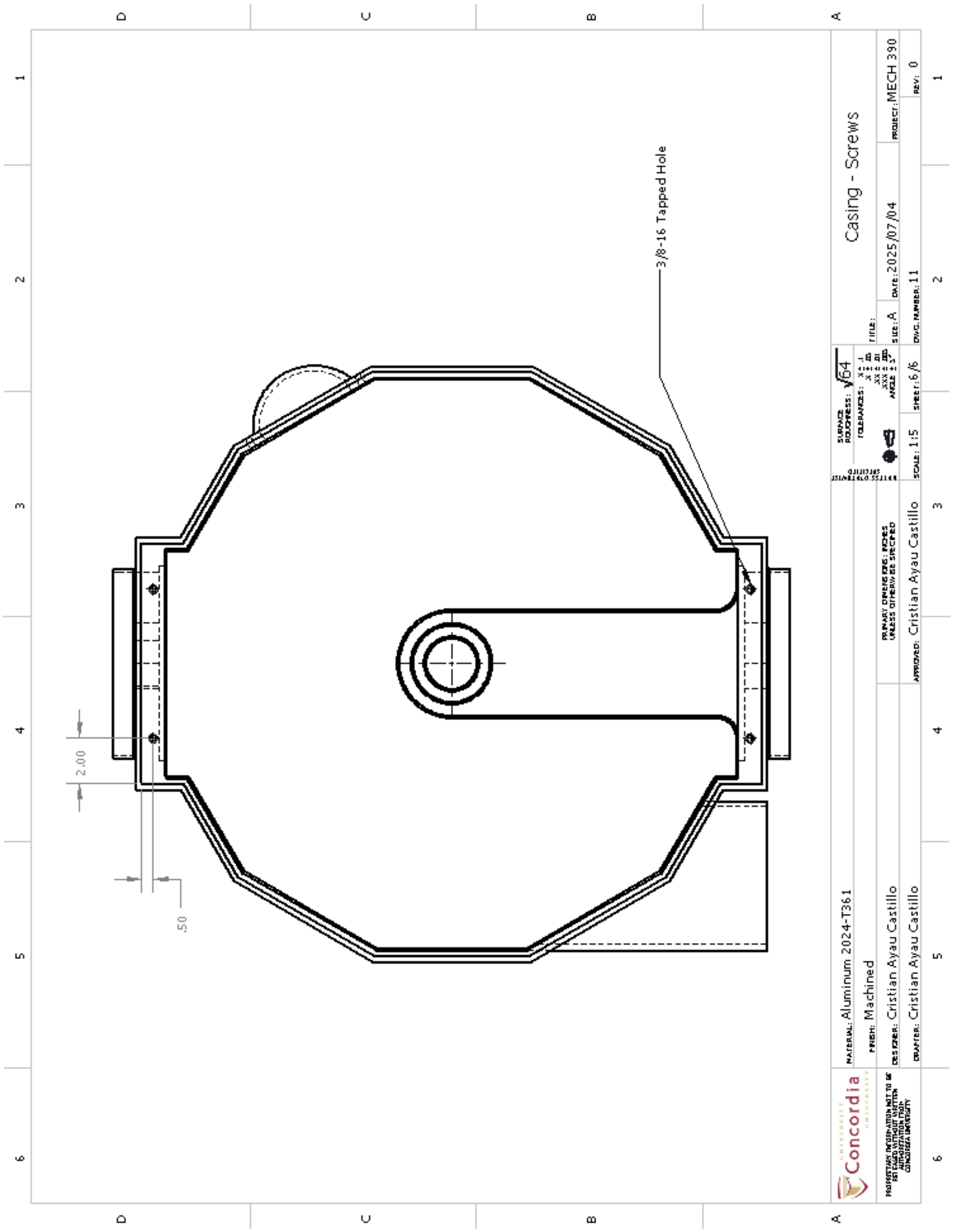


Figure 31: Casing Tapped Hole Drawing.

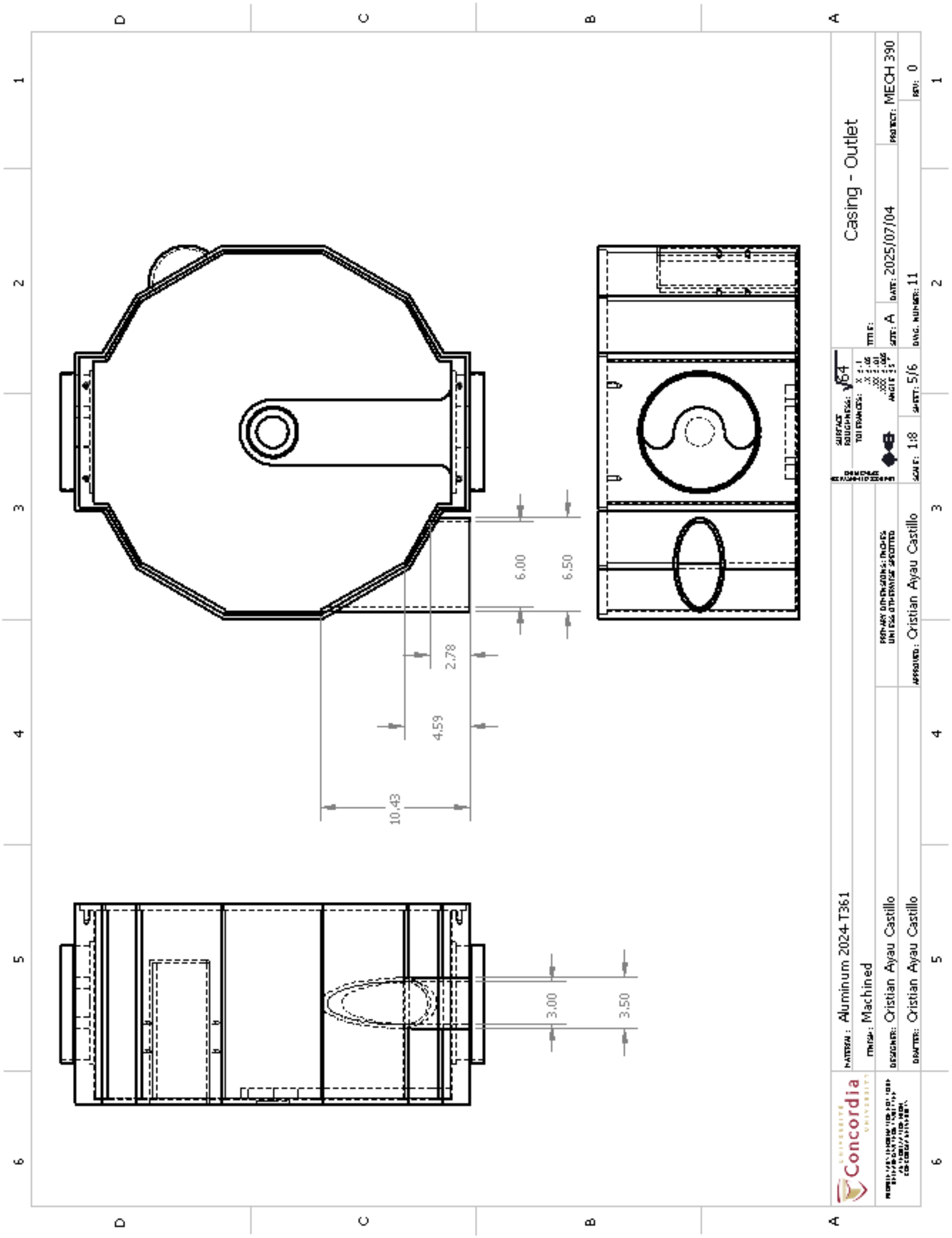


Figure 32: Casing Outlet Drawing.

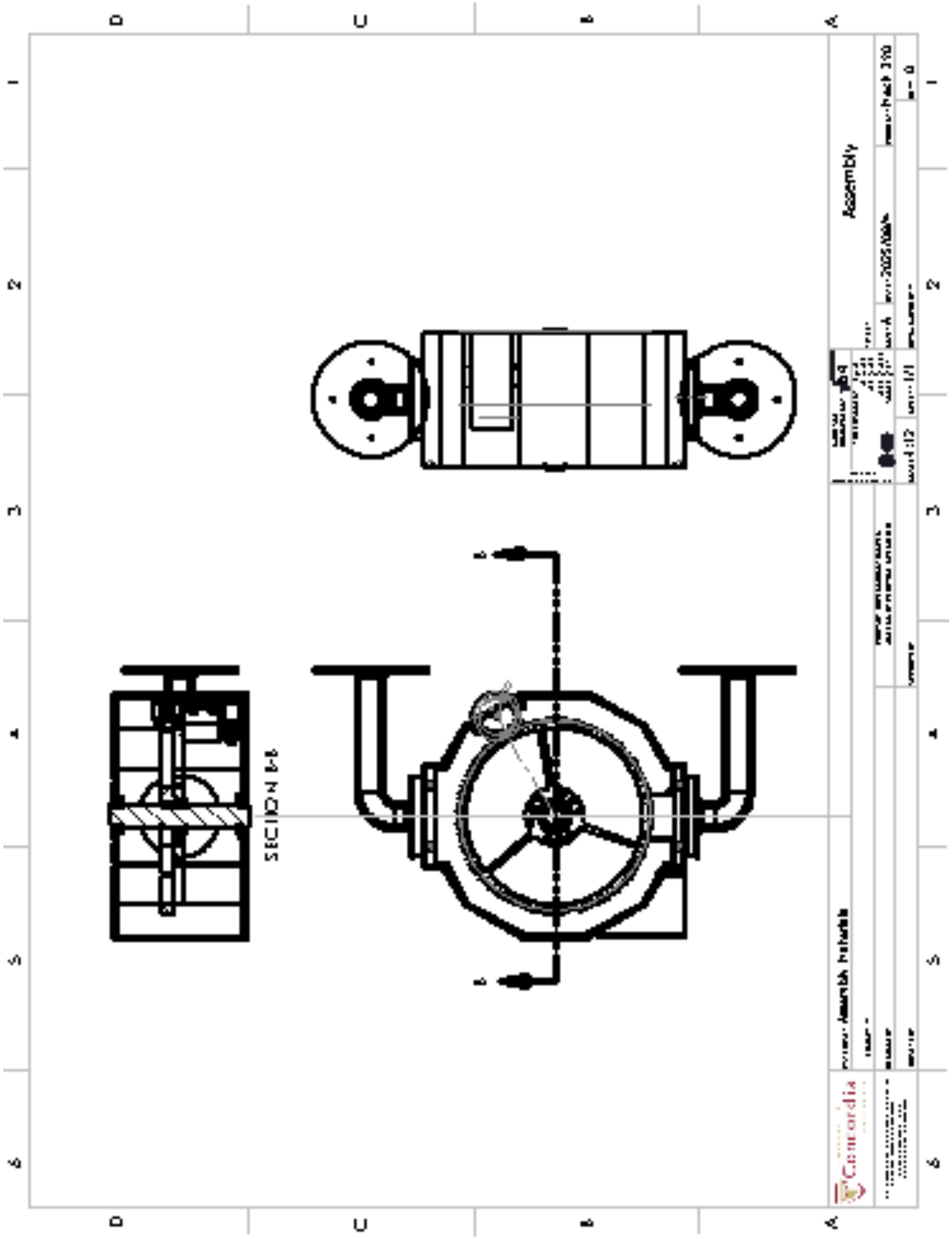


Figure 33: Assembly Drawing.

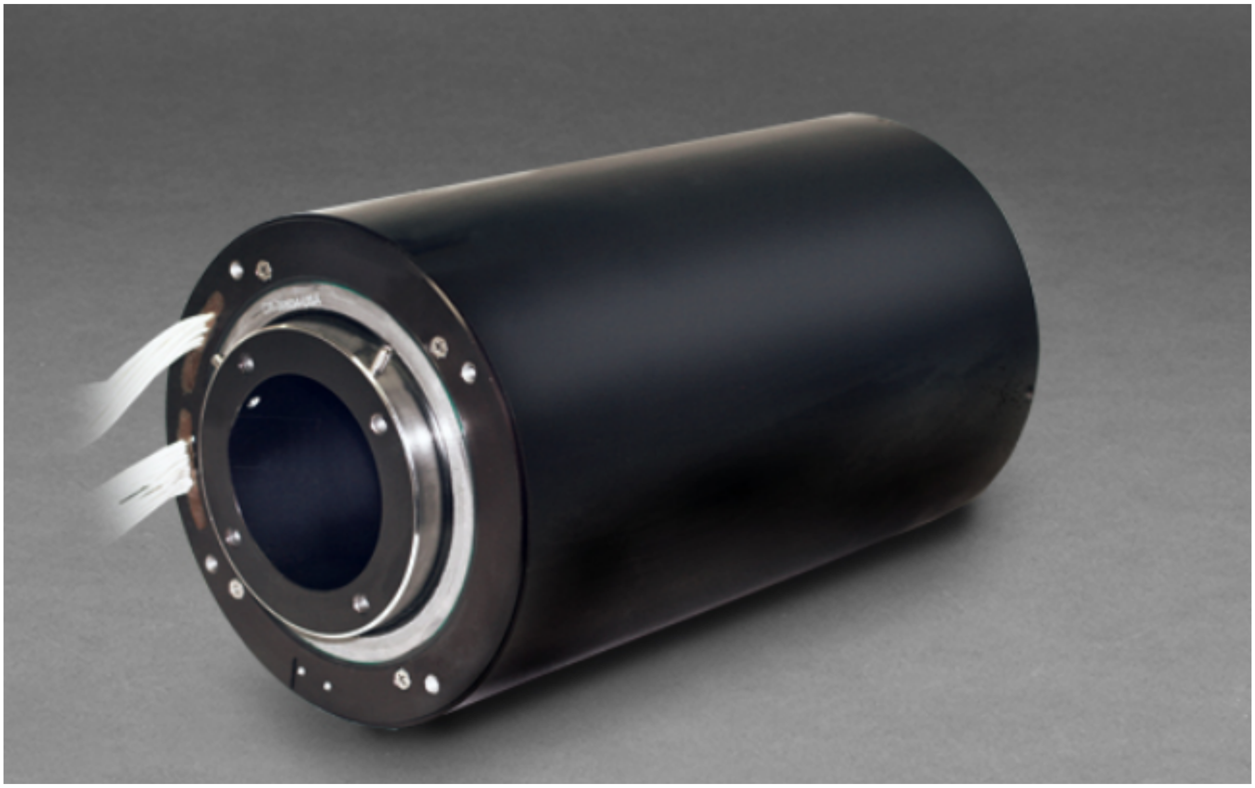


Figure 34: Slip Ring Model AC6275

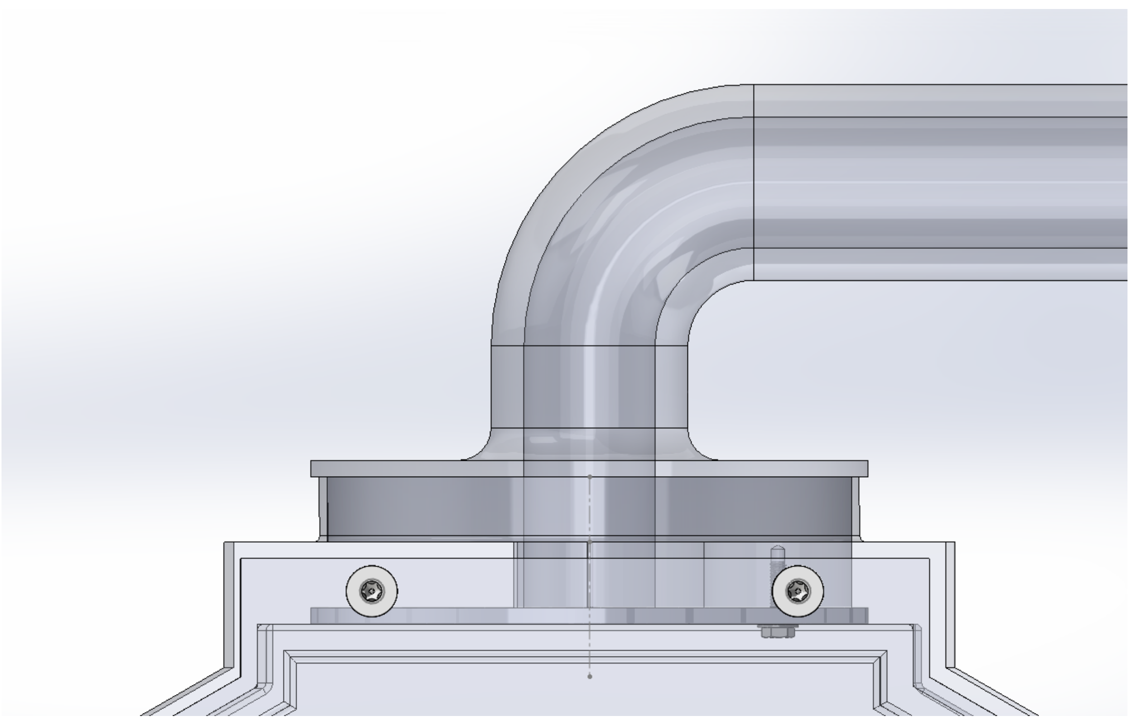


Figure 35, Arm and Frame Mating.

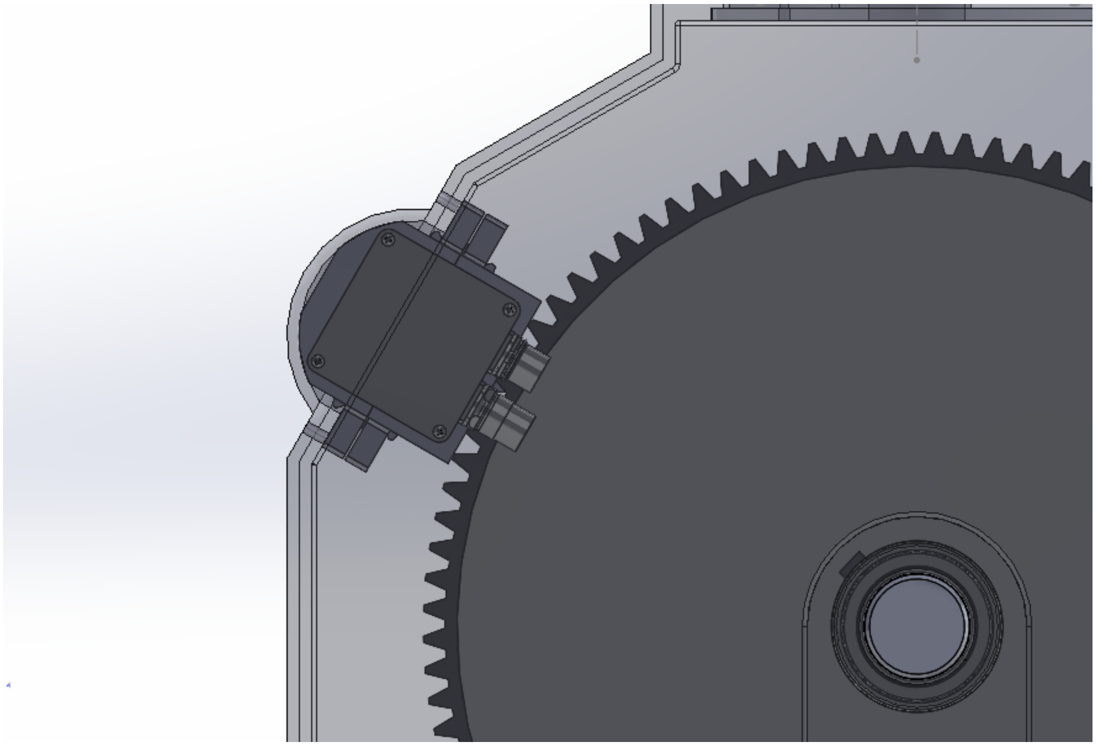


Figure 36, Motor Placement.

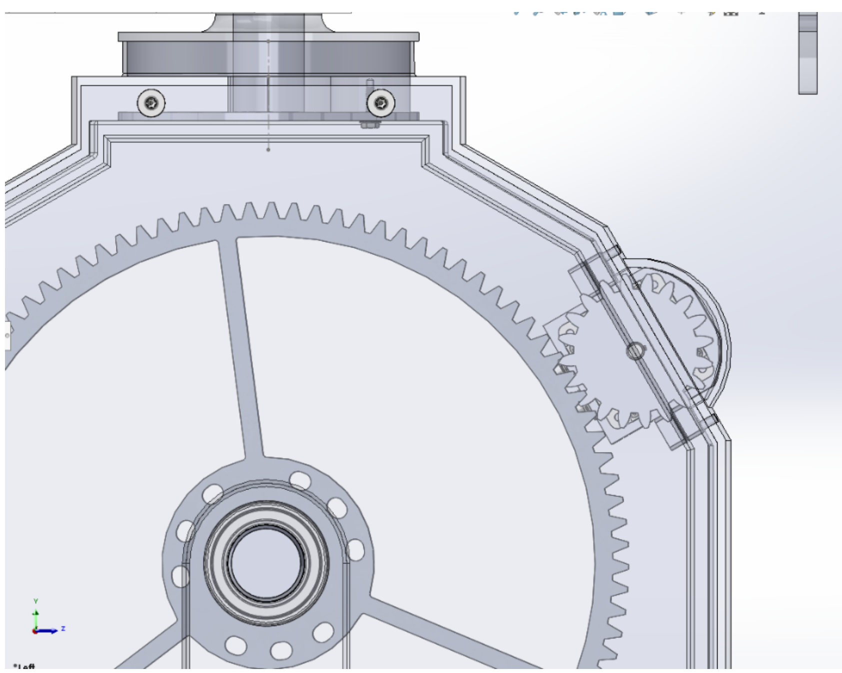


Figure 37, Gear Meshing.

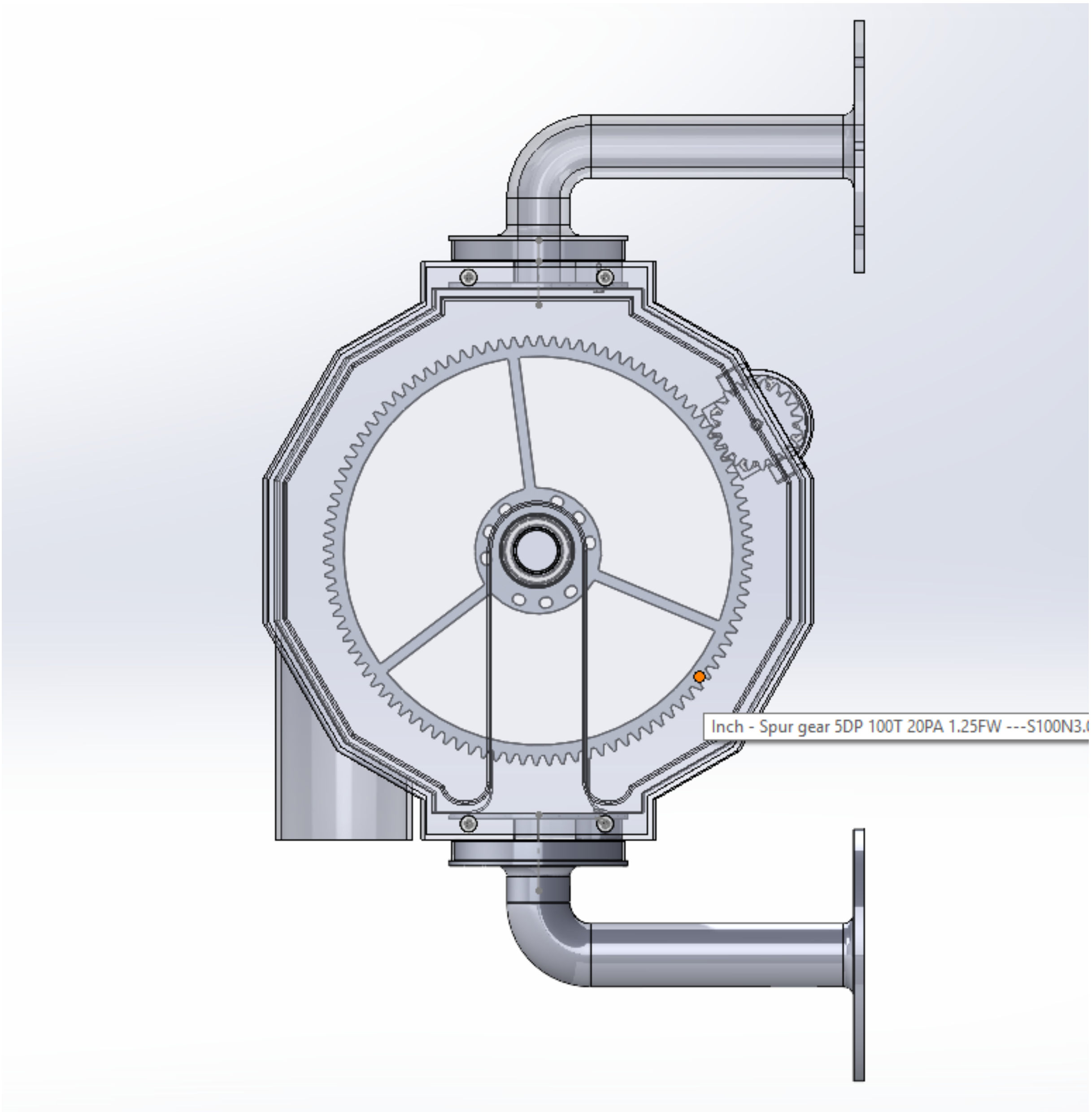


Figure 38, Assembly with Cover Removed.

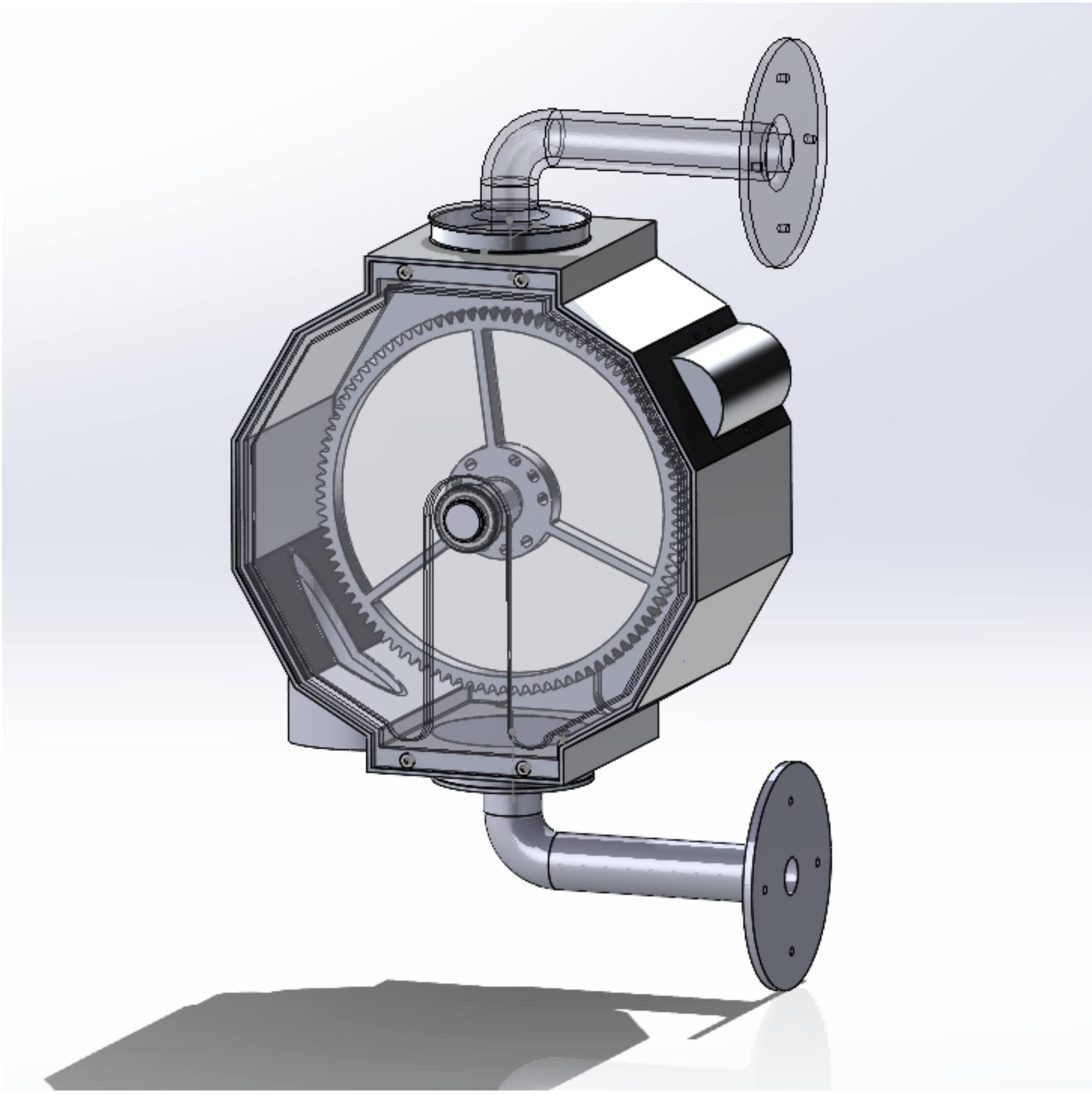


Figure 39, Full Assembly with Cover and Top Arm Translucent.

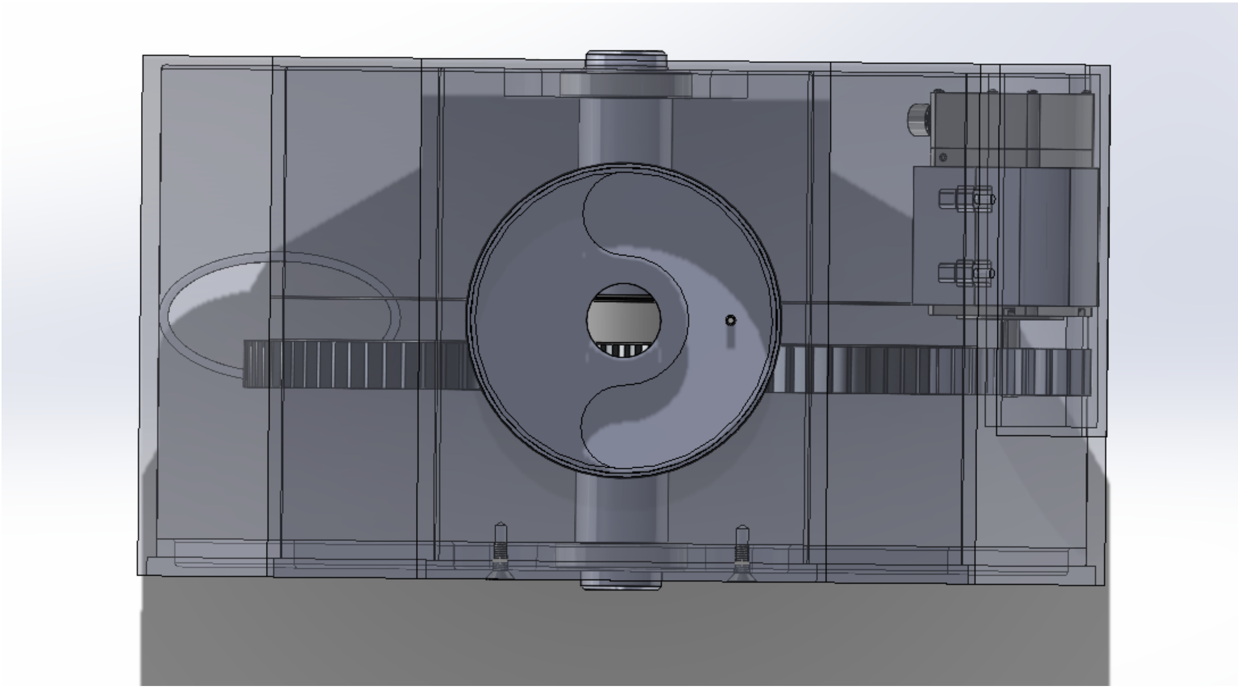


Figure 40, Bottom View of Swivel Locking Mechanism.

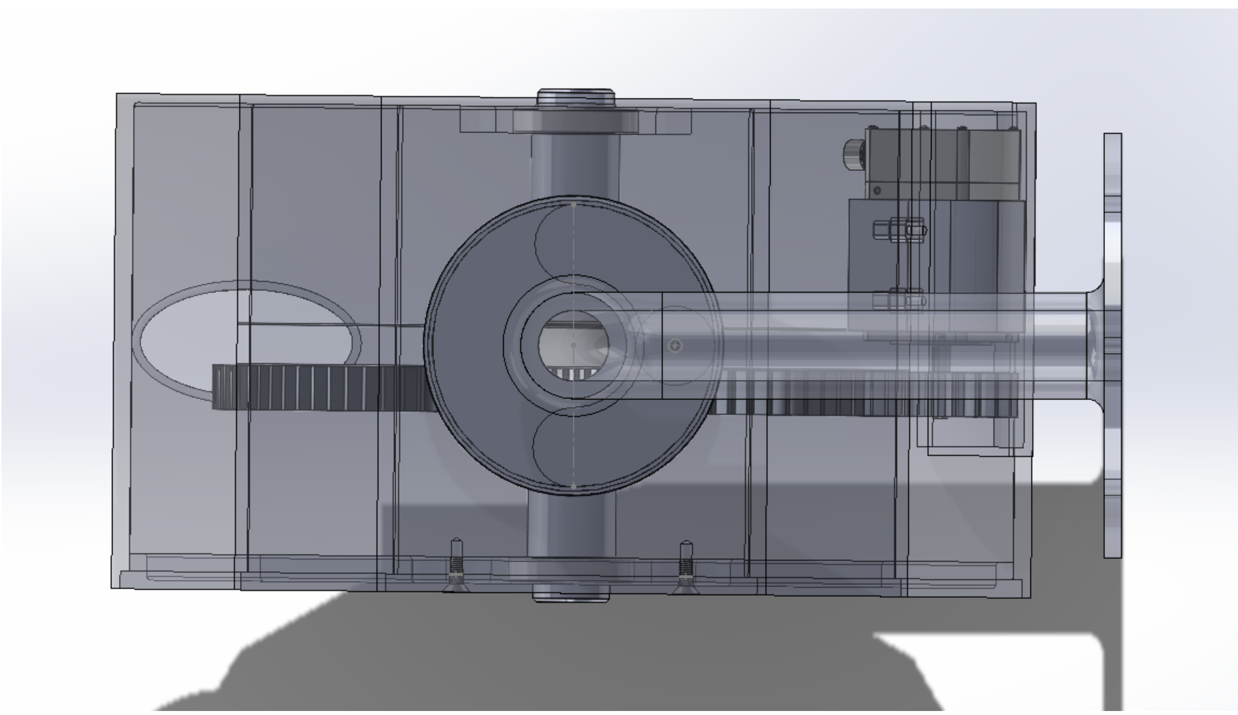


Figure 41, Bottom View of Swivel Locking Mechanism with Arm.

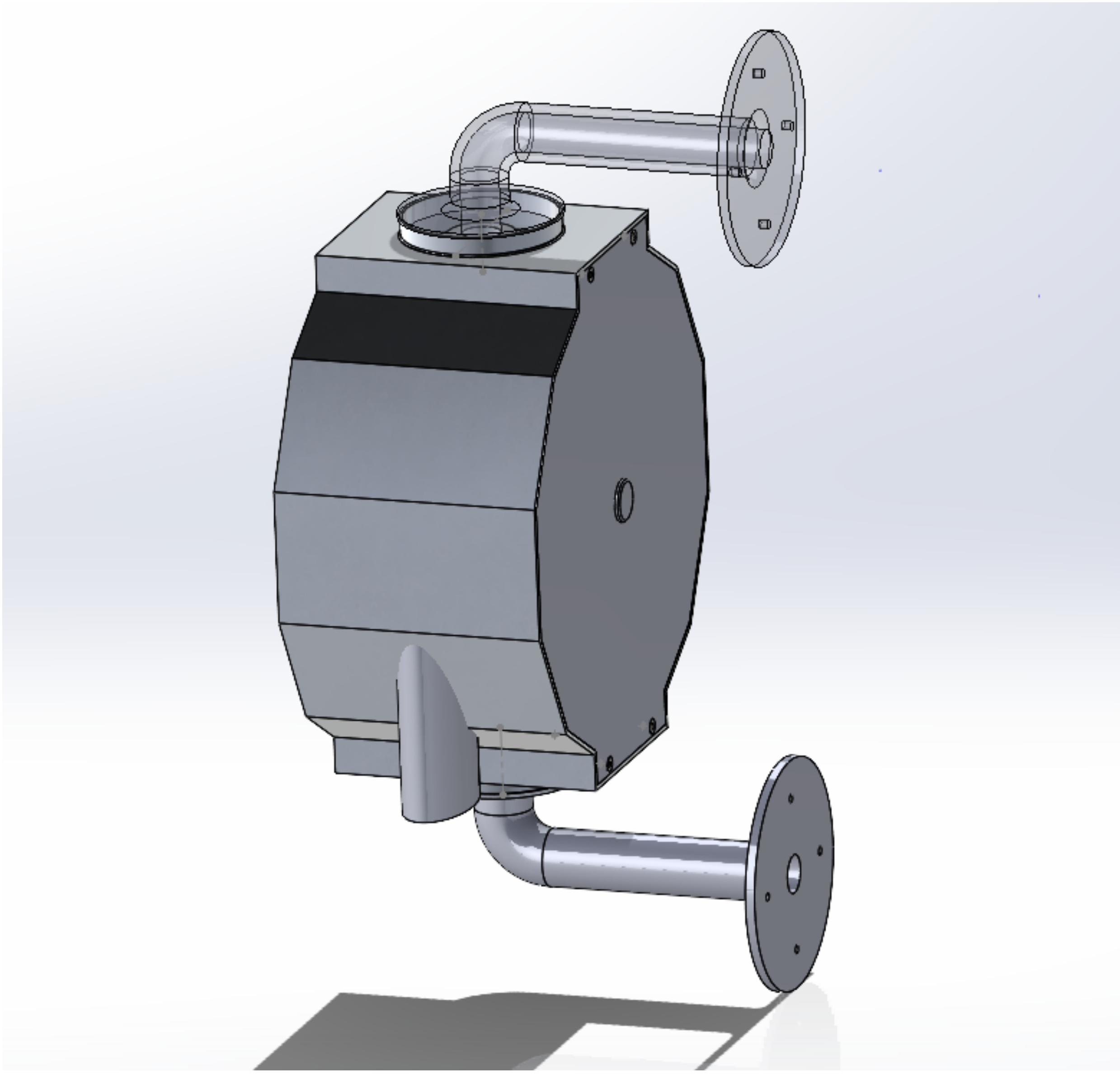


Figure 42, Case with Covers Attached.

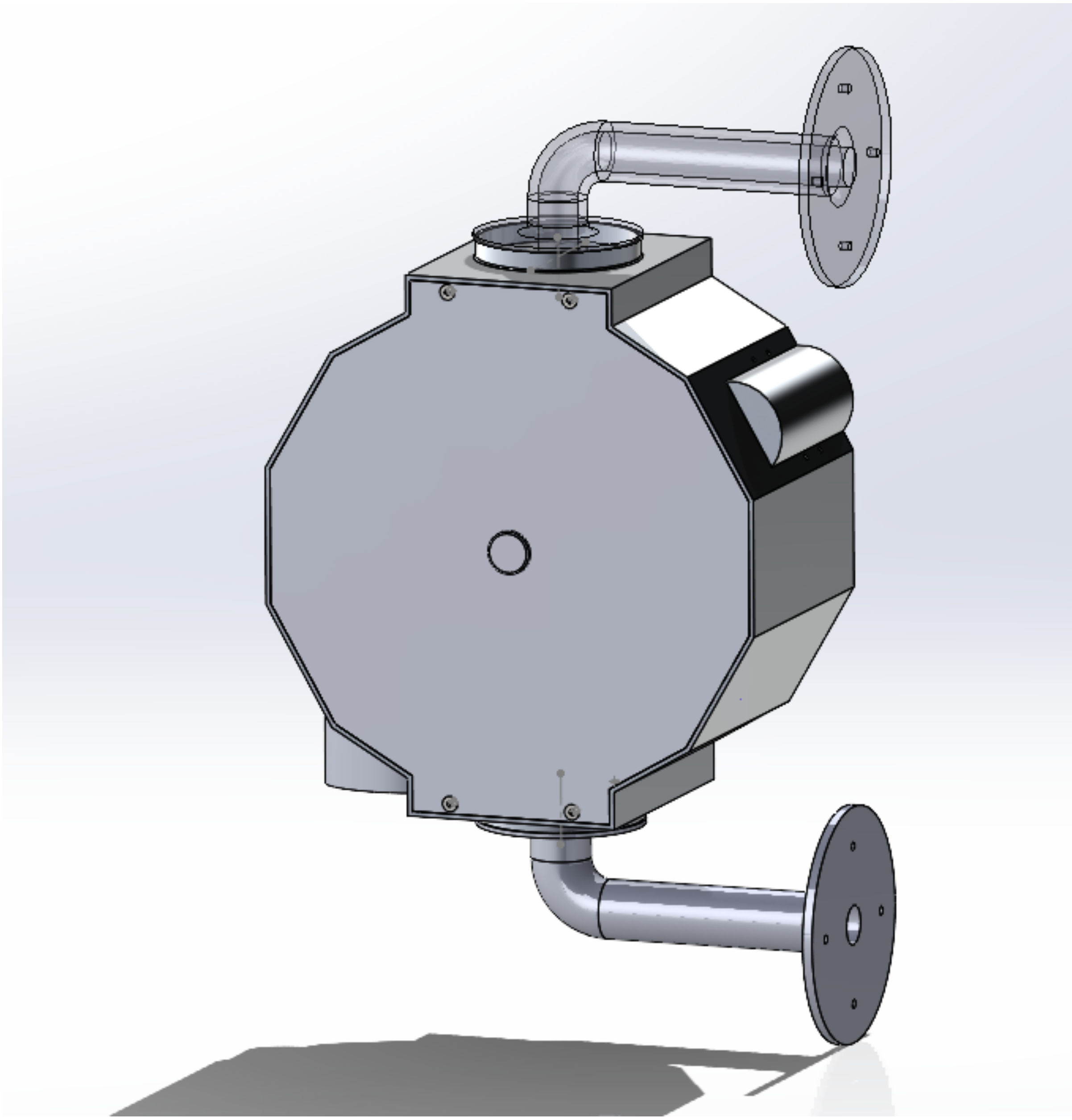


Figure 43, Case Front View.

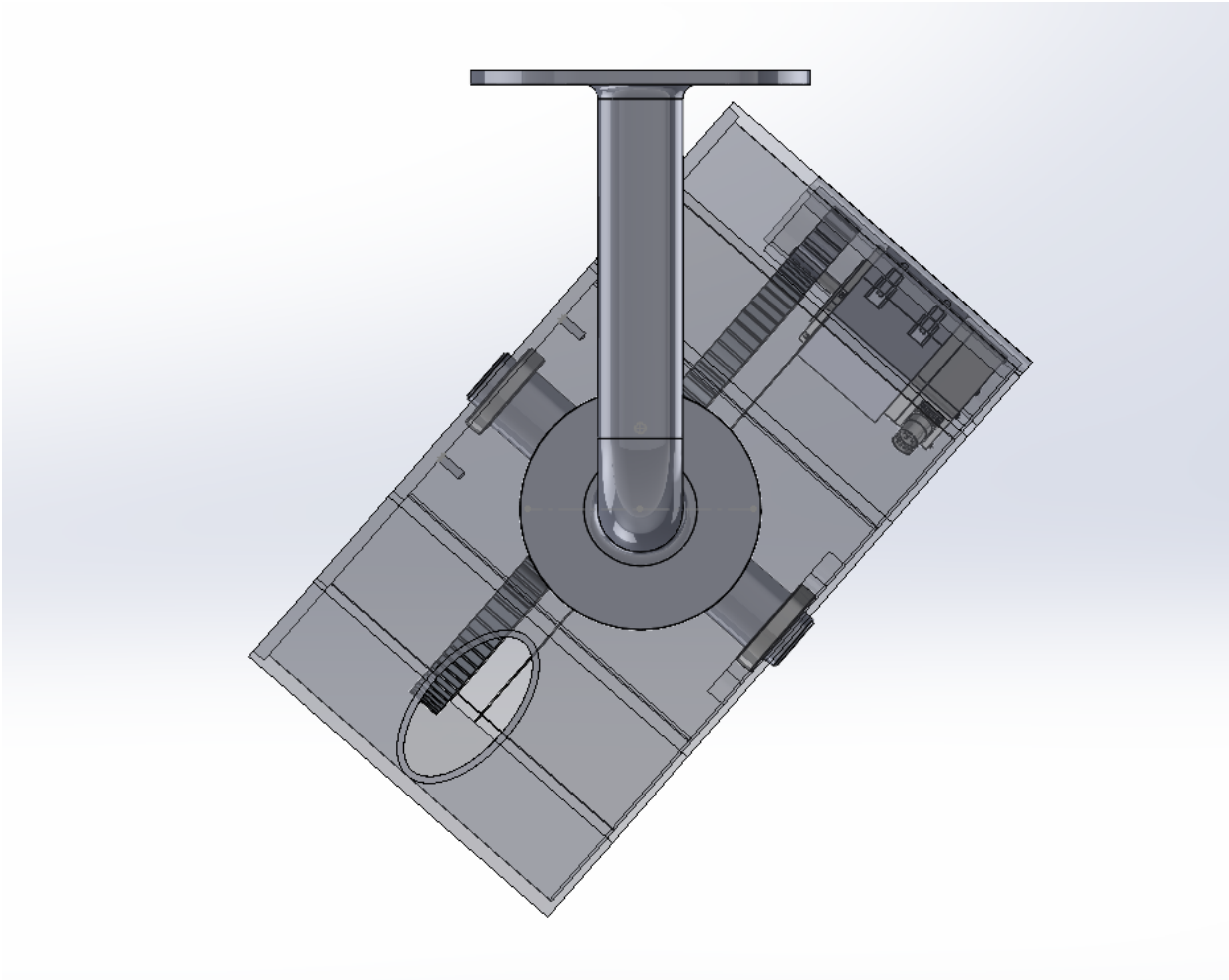


Figure 44, Bottom View of Assembly.

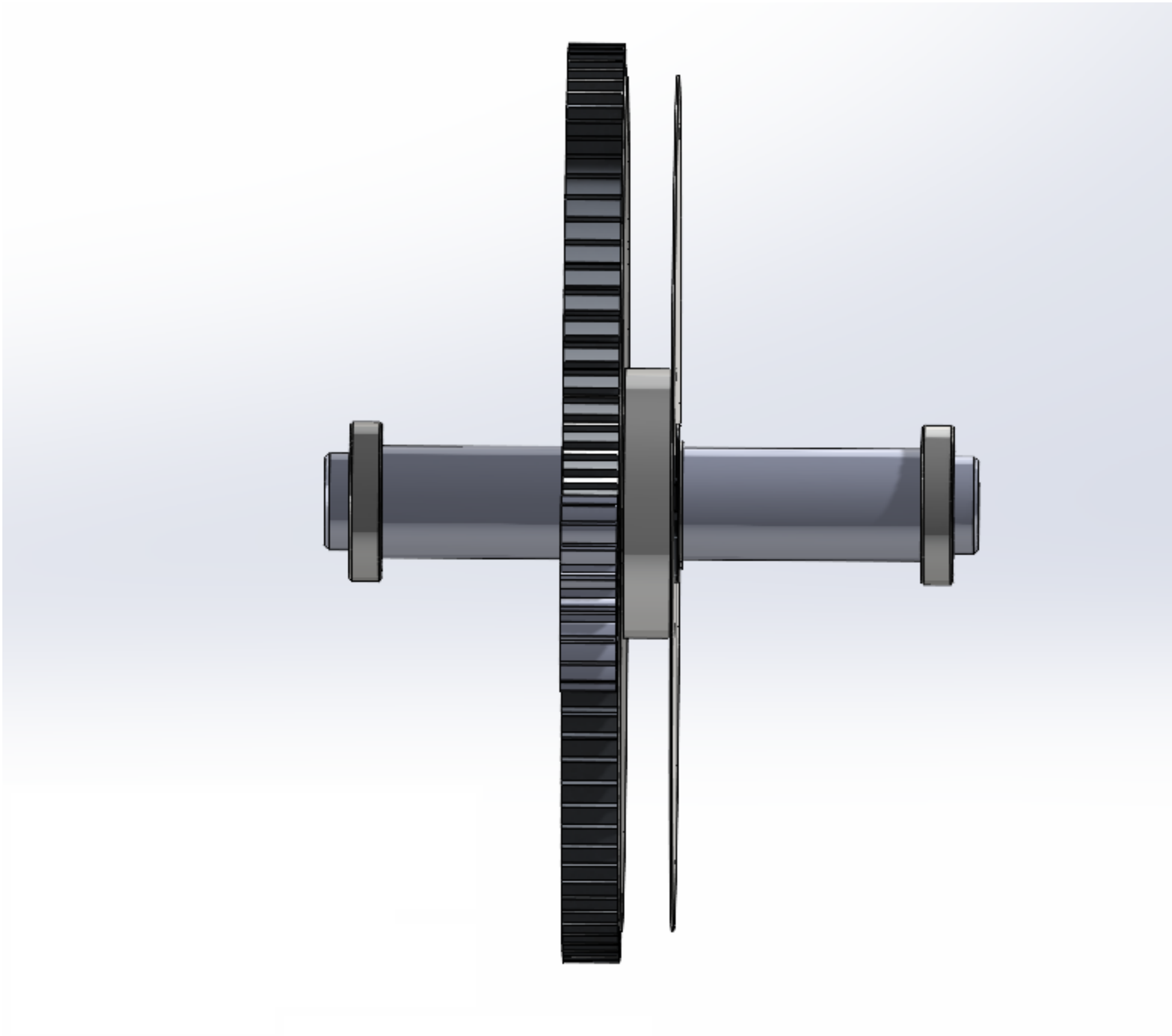


Figure 45, Shaft, Spool and Bearing Configuration.

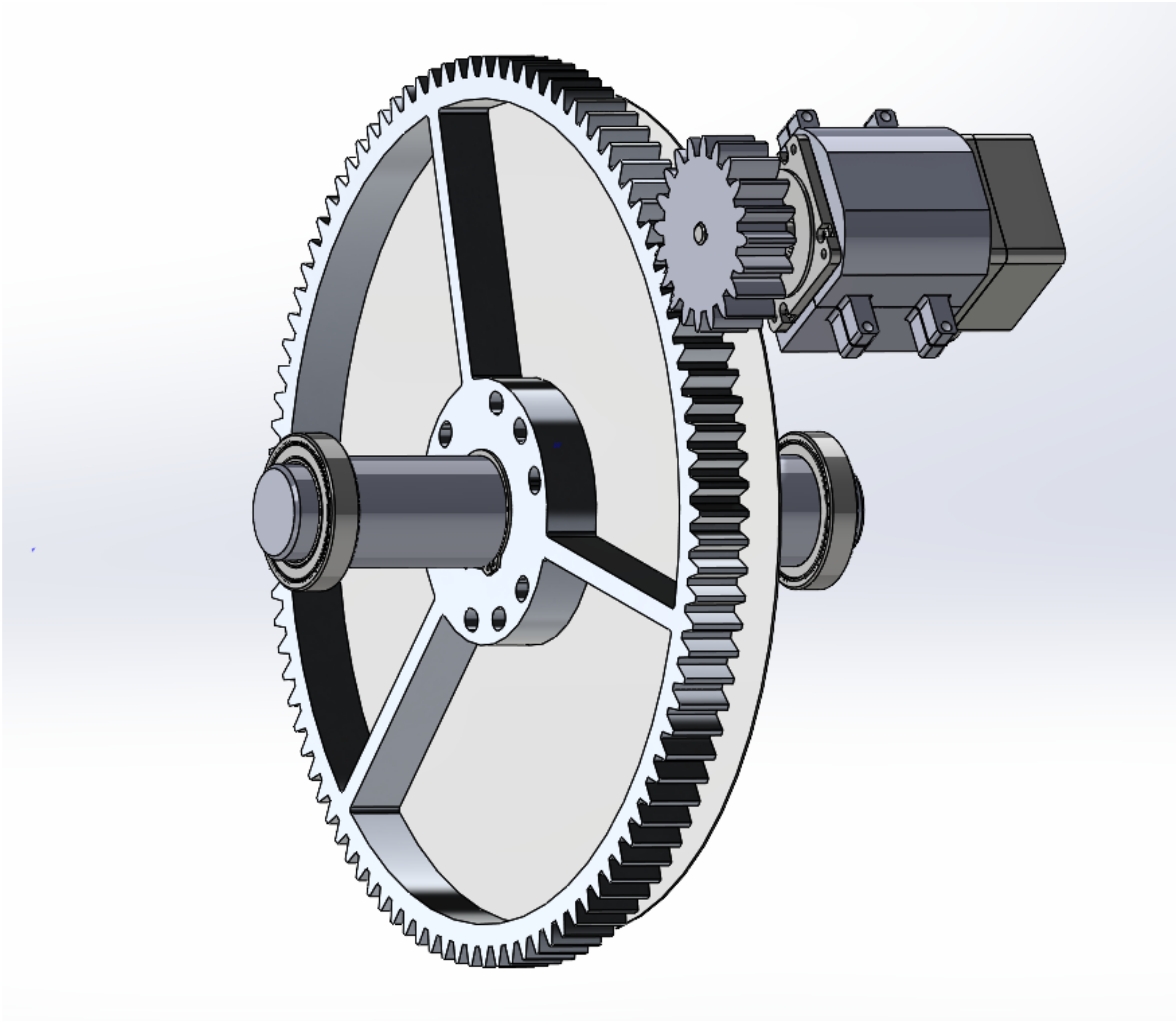


Figure 46, Rotating Body Assembly.

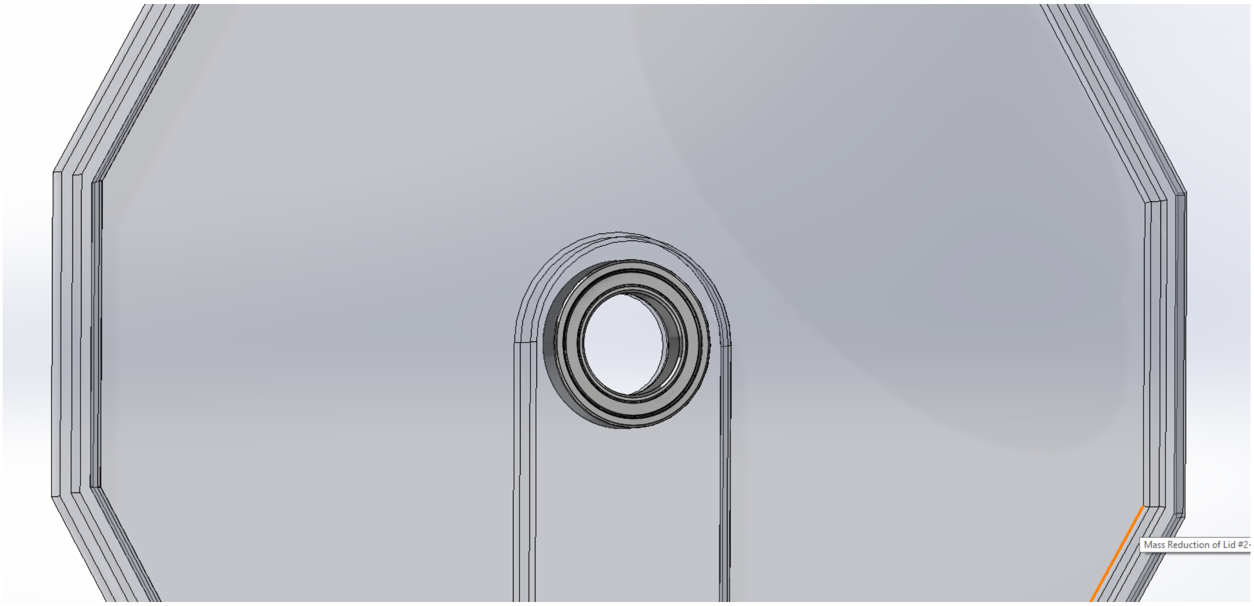


Figure 47. Bearing Placement.

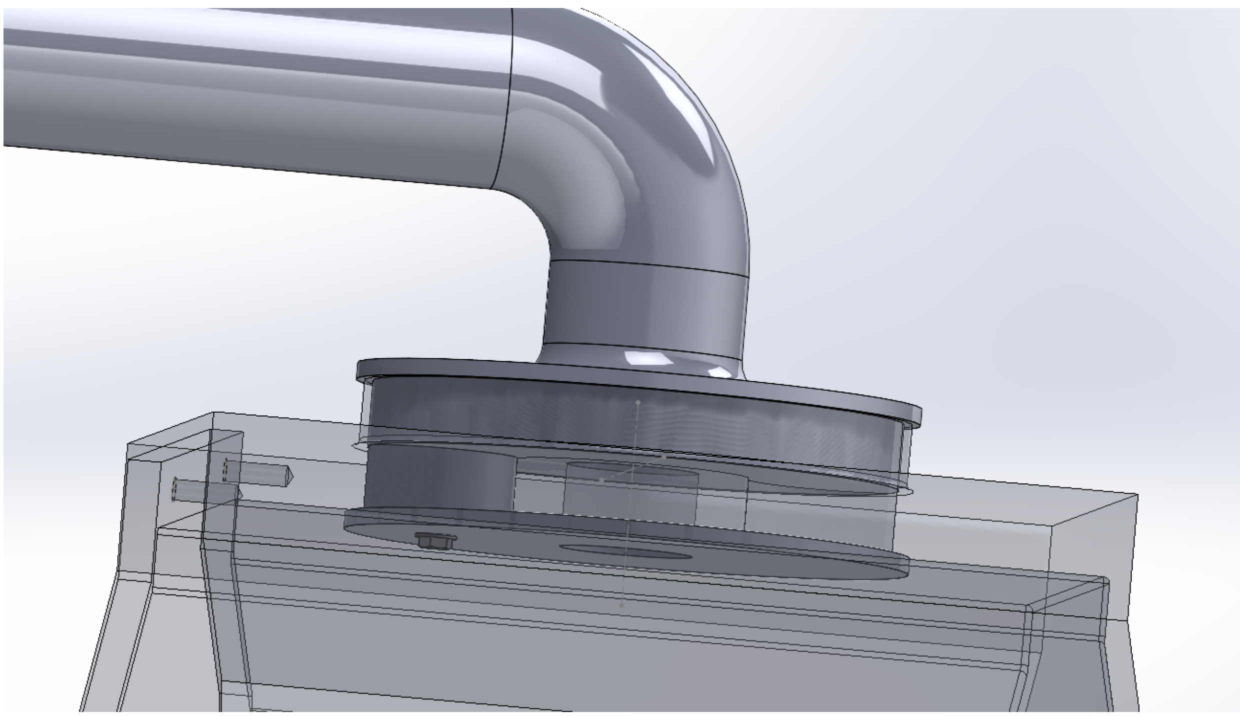


Figure 48, Swivel Lock Mechanism.

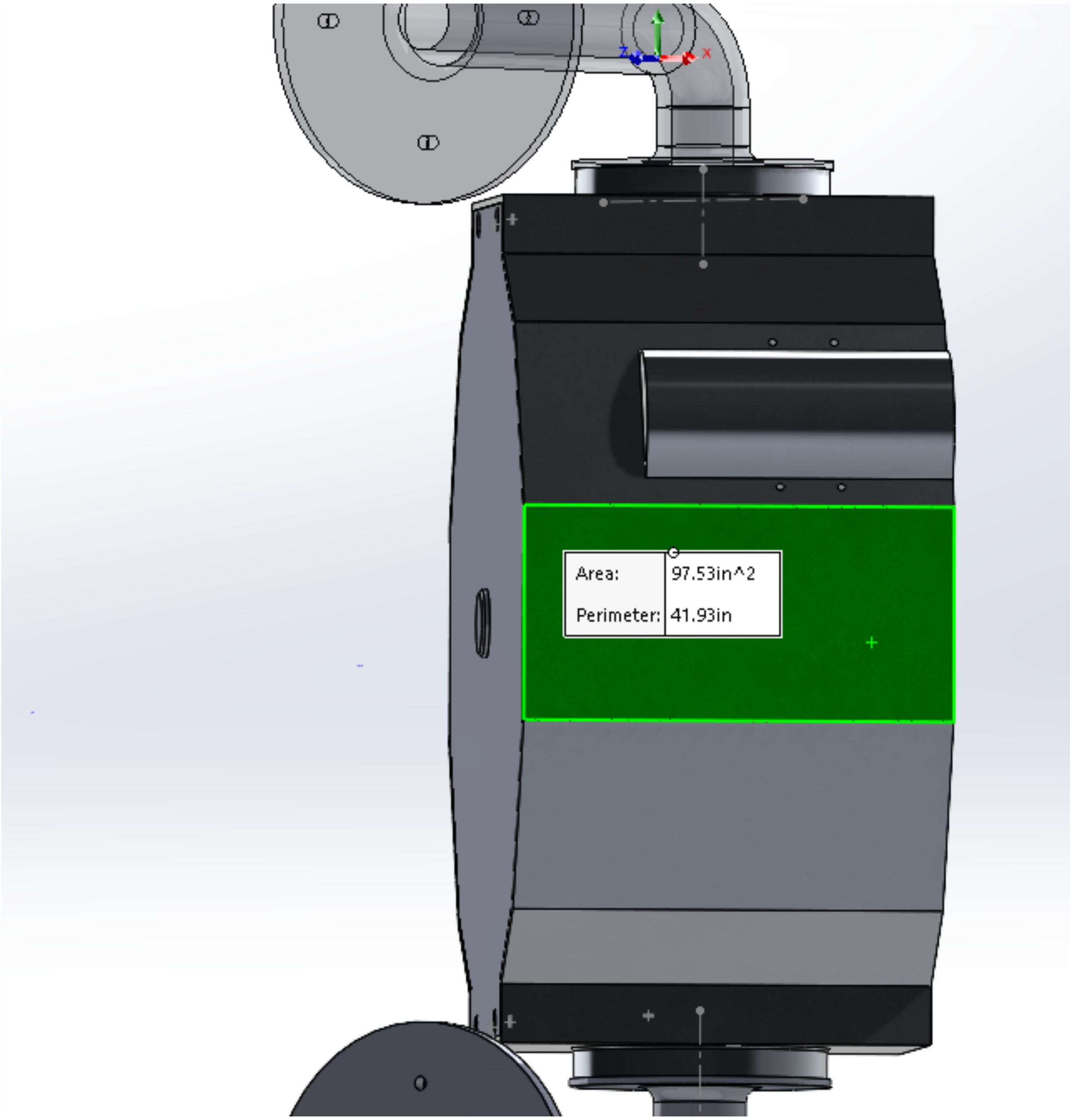


Figure 49, Area of Side Panel.

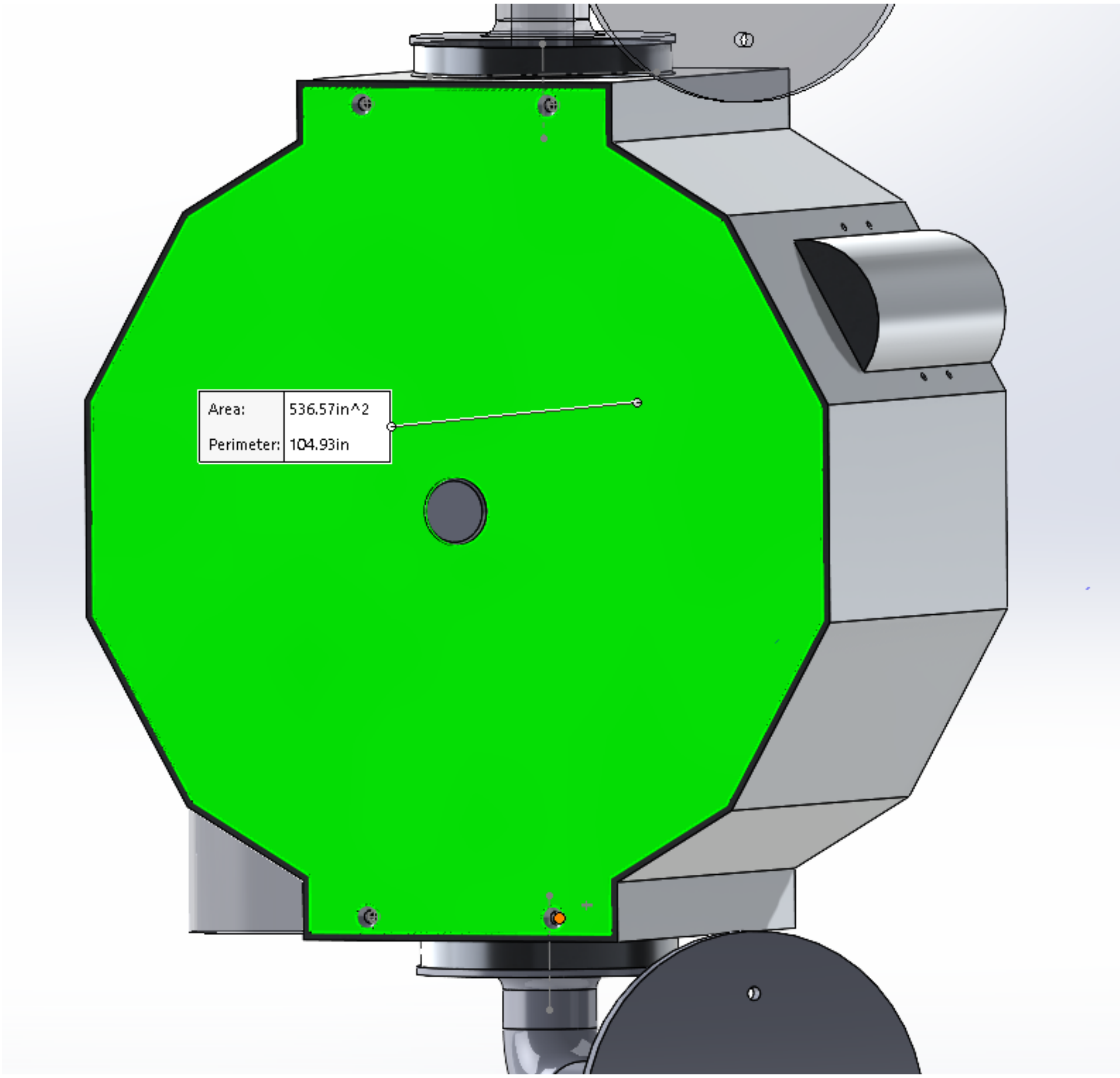


Figure 50, Area of Lid.

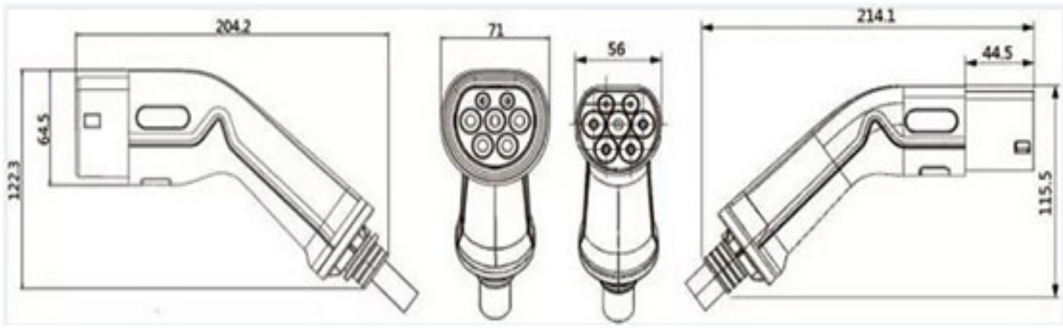


Figure 51: Charging Cable Handle Dimensions [12].

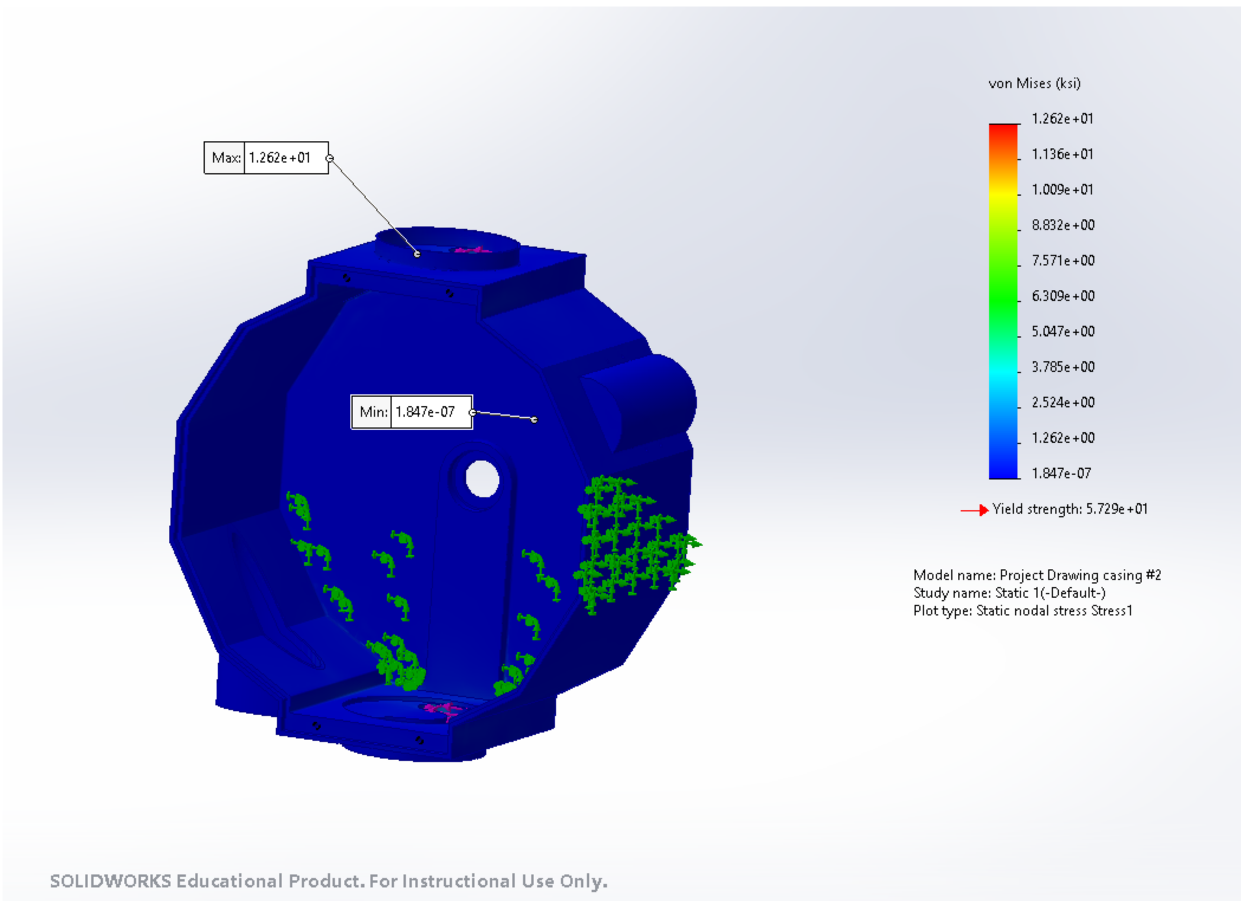


Figure 52: FEA for Casing Box.

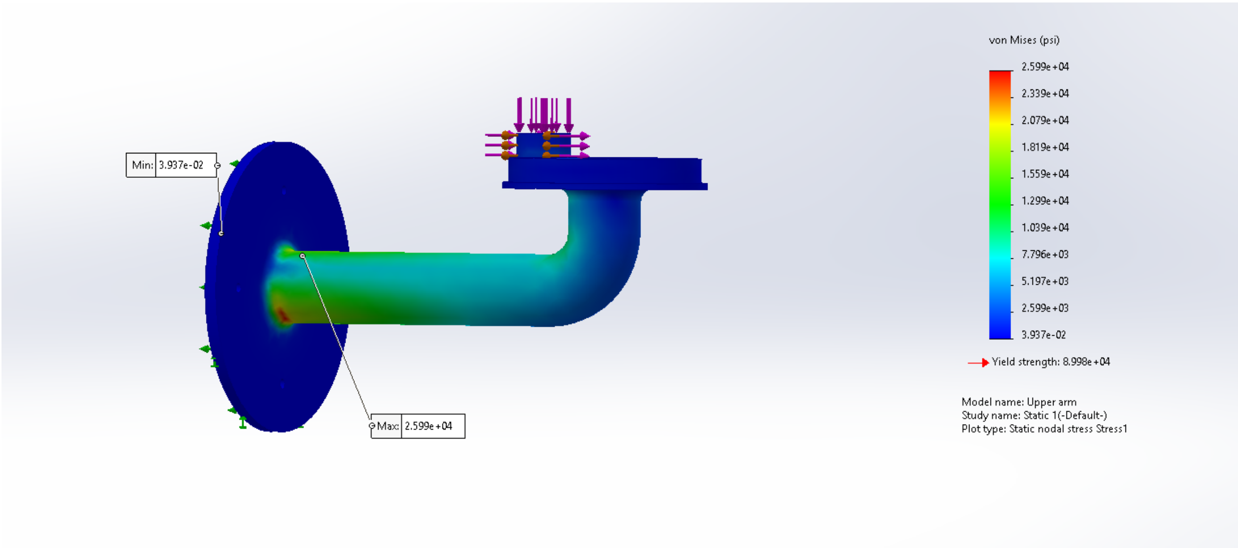


Figure 53: FEA for Casing Arms.

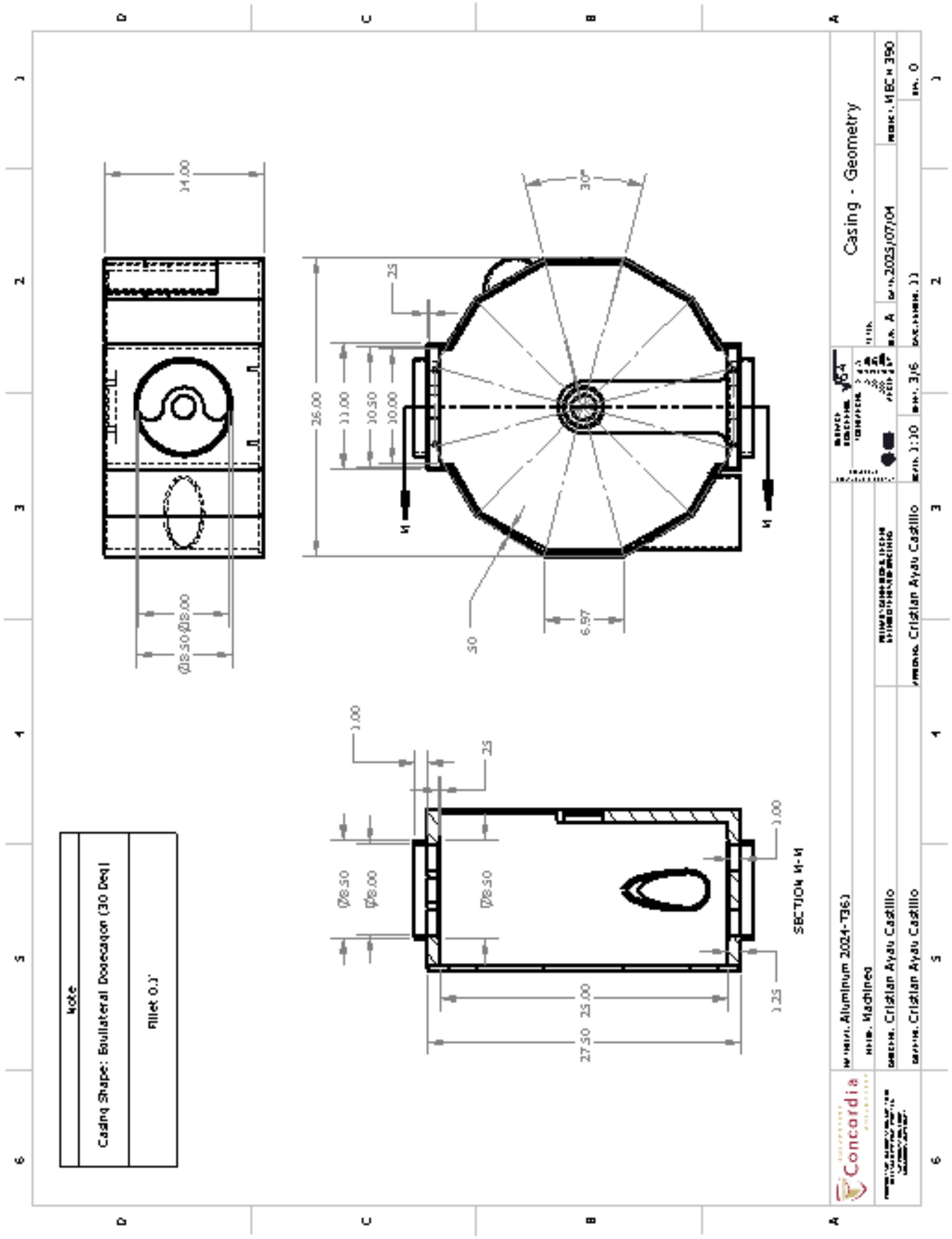


Figure 54: Casing Geometry.

Appendix 14 – Tables

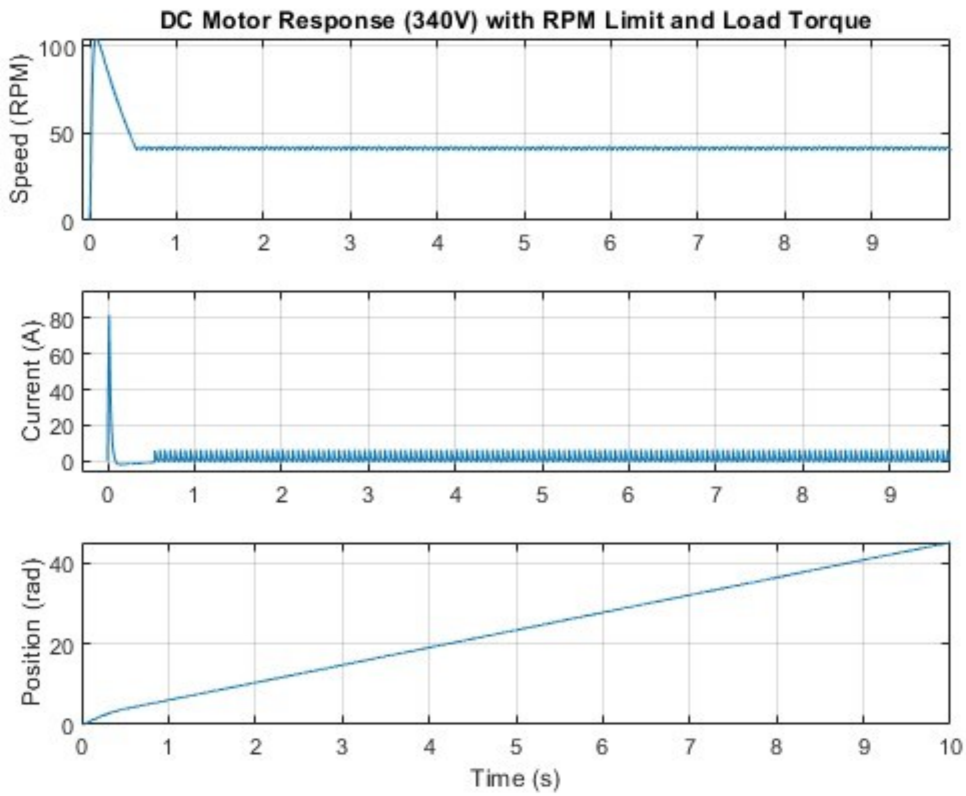


Table 1, Simulated motor at 40rpm with no PID control

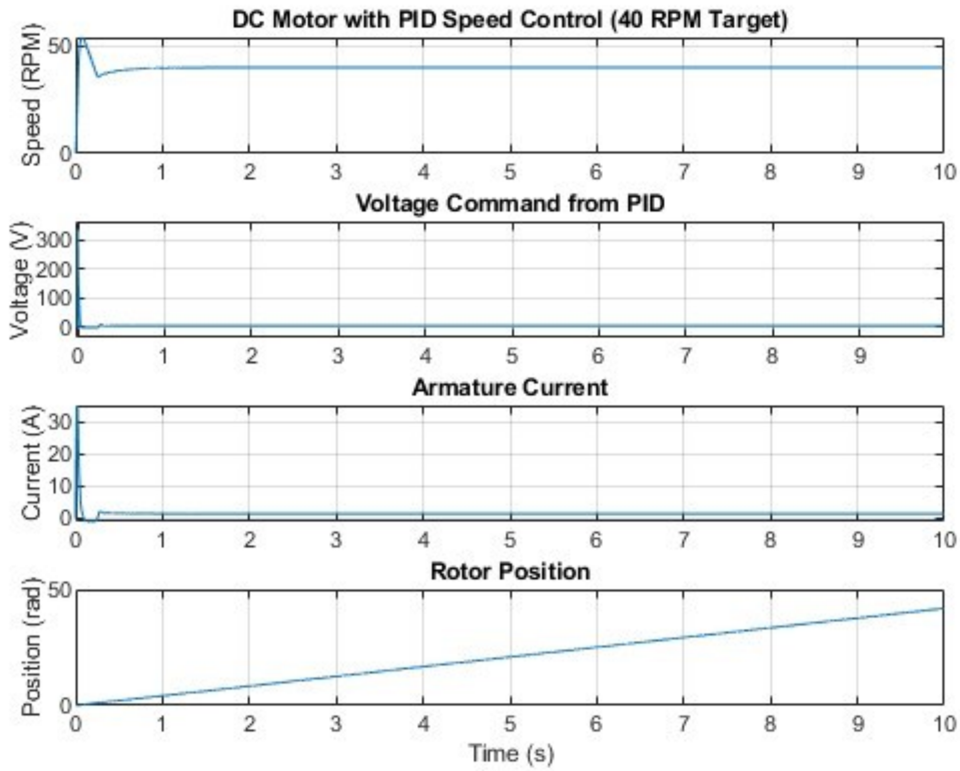


Table 2, Simulated motor at 40rpm with PID control

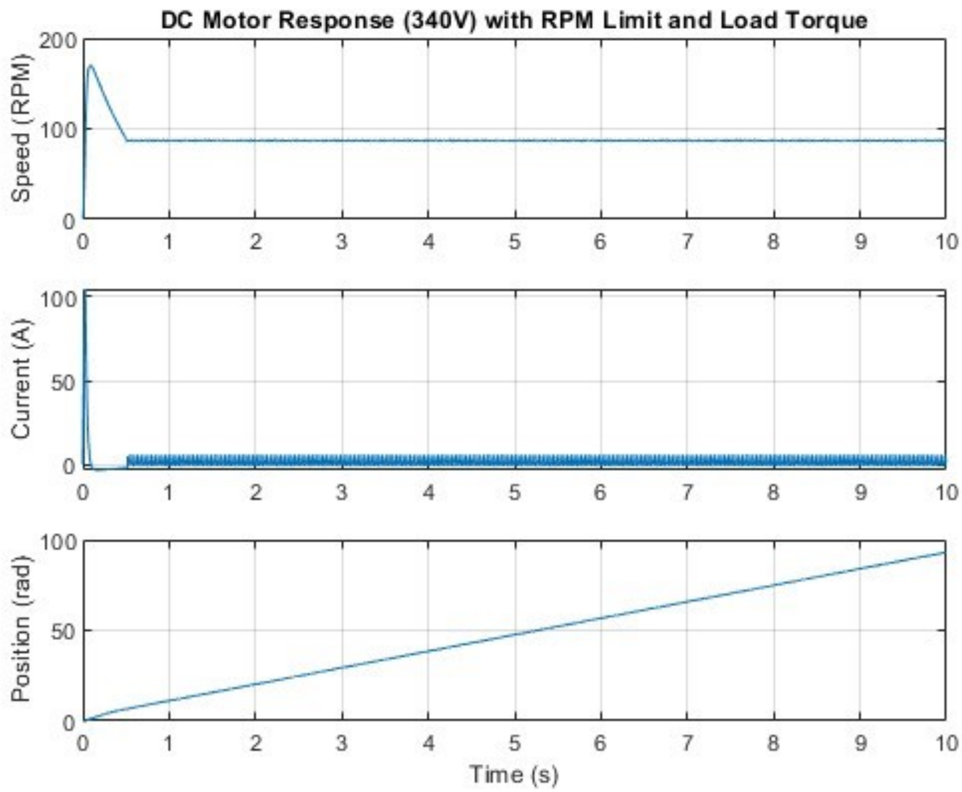


Table 3, Simulated motor at 86rpm with no PID control

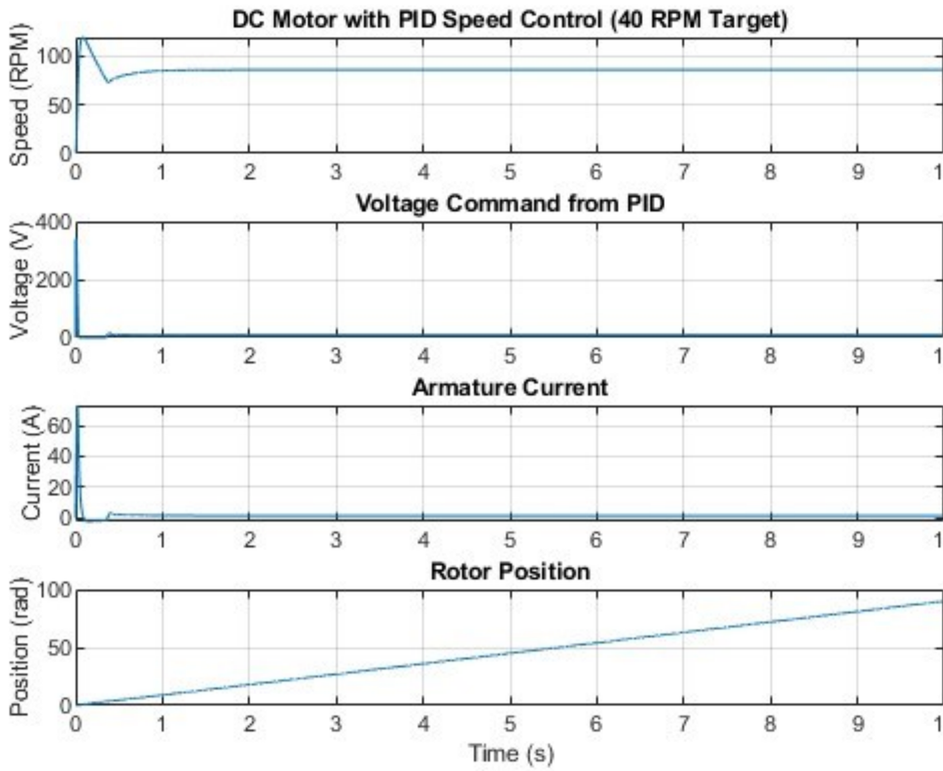


Table 4, Simulated motor at 86rpm with PID control

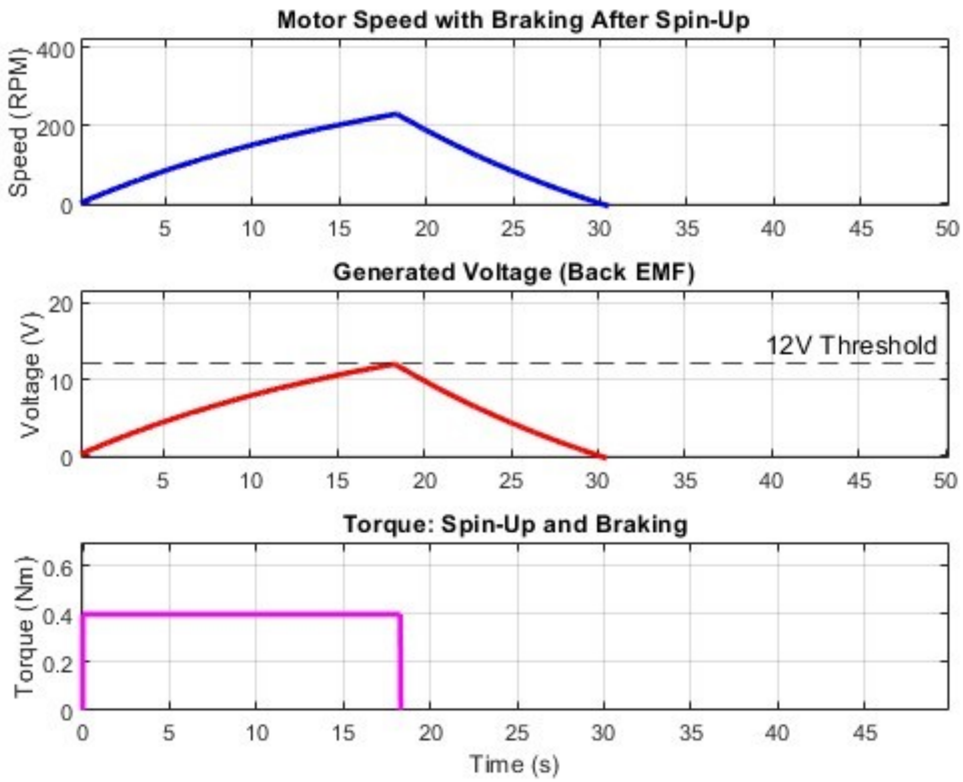


Table 5, Motor back emf when the brake is applied

	cable layer in ft	length used	weight removed	weight remaining	Torque at layer in lb*ft	equivalence in lb*in	
	0.325	2.041	0.67353	7.57647	2.46235275	29.548233	
	0.375	2.355	0.77715	6.79932	2.549745	30.59694	
	0.425	2.669	0.88077	5.91855	2.51538375	30.184605	max T
	0.475	2.983	0.98439	4.93416	2.343726	28.124712	
	0.525	3.297	1.08801	3.84615	2.01922875	24.230745	
	0.575	3.611	1.19163	2.65452	1.526349	18.316188	
	0.625	3.925	1.29525	1.35927	0.84954375	10.194525	
max stretch	0.675	4.239	1.39887	-0.0396	-0.02673	-0.32076	
Total	4	25.12	8.2896	-0.0396			

Table 6, spool torque algorithm table