FINAL REPORT FOR THE YOUTH PARALYMPIC HANDCYCLE

Introduction to the Design of Mechanical Systems

MCG 2101[A]

Project Deliverable #7

Group 18

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Department of Mechanical Engineering

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2.0 Introduction

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3.0 Design Description and Rationale

3.1 Drivetrain - [redacted]

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3.2 Steering - [redacted]

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3.3 Braking - Ian

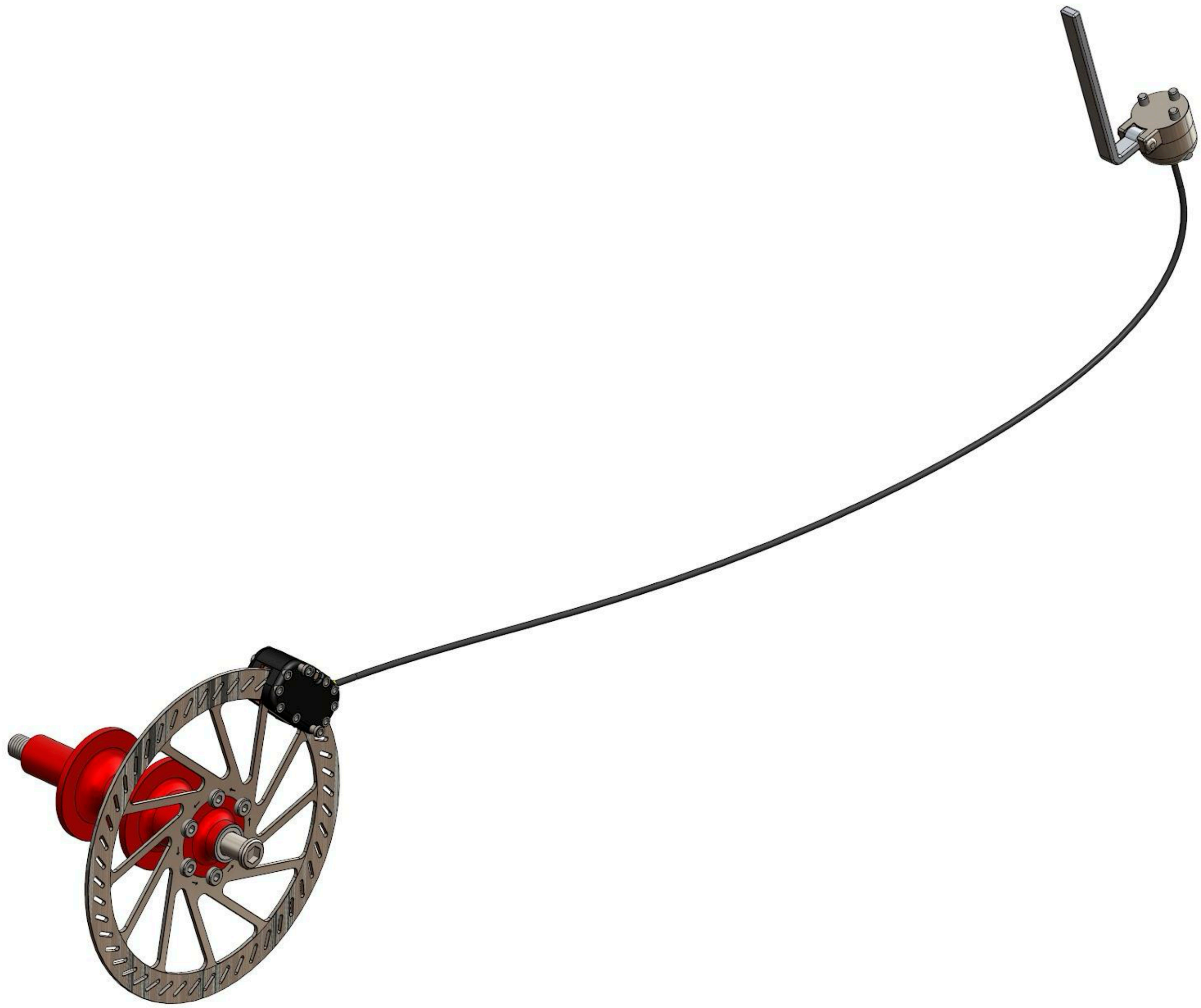

Fig. 3.3-1 View of the entire braking system in its assembly positioning.

The braking system is composed of three main subassemblies: the hub and rotor assembly, the pad and calliper assembly, and the brake lever assembly. Additionally there is a hydraulic tube and hose crimps that connect the brake lever assembly to the calliper assembly (see Fig. 3.3-2). When the user pulls the brake lever with their left hand, hydraulic fluid is forced out of the bottom of the brake lever assembly, through the hose, and into the brake calliper assembly. Subsequently, the four pistons in the brake calliper evenly squeeze the brake pad assembly against the brake rotor, resulting in a braking force.

The brake rotor is mounted to the front hub, which also accommodates for the front wheel and the drivetrain (see 3.1 Drivetrain). The brake calliper is mounted to the front forks using two bolts at opposite corners of the calliper (see 3.2 Steering and Fig. 3.3-2). Finally, the brake lever assembly is mounted to the aft end of the handle using three bolts that skewer the entire assembly (see 3.1 Drivetrain and Fig. 3.3.5-4).

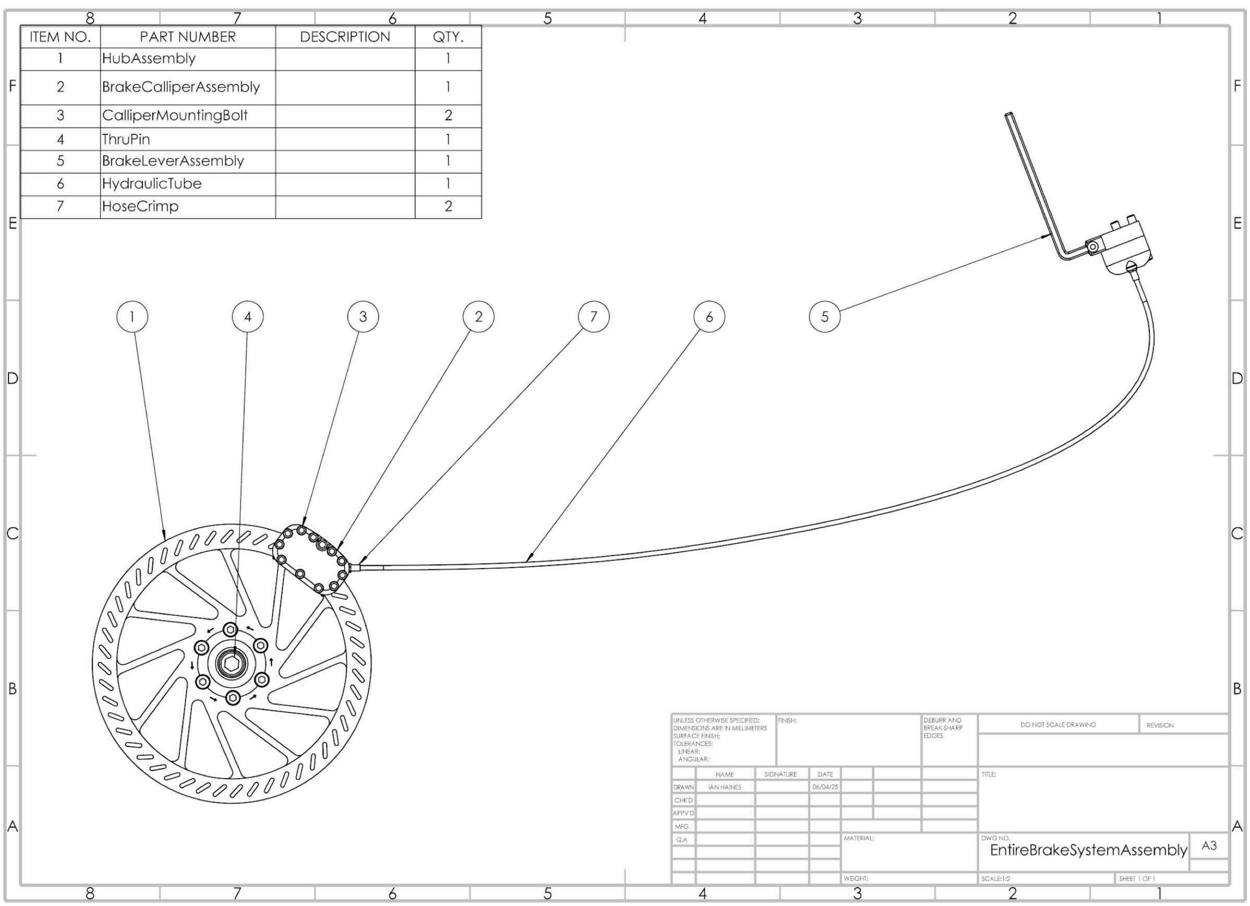

Fig. 3.3-2 Assembly drawing of the entire braking system.

3.3.1 Rotor

Table 3.3.1-1 Braking analysis.

Property	Magnitude	Units
Total Mass	95.00	kg
Linear Momentum	1055.56	kg*(m/s)
Kinetic Energy	5864.20	J
Approx. Front Wheel Normal Force	465.98	N
Max Linear Braking Force	372.78	N
Min Stopping Distance	15.73	m
Max Braking Acceleration	3.92	m/s^2
Min Stopping Time	2.83	s
Required Maximum Heat Power	2071.00	W
Required Moment on Wheel and Rotor	102.51	N*m
Required Calliper Braking Force	1139.05	N
Required Calliper Normal Force	1265.61	N
Rated Maximum Heat Power	3106.50	W
Rated Moment on Wheel and Rotor	153.77	N*m
Rated Calliper Braking Force	1708.58	N
Rated Calliper Normal Force	1898.42	N

***Note** The following assumptions were made. The rider mass is 80 kg. The handcycle mass is 15 kg. The top speed is 40 km/h. The wheel diameter is 550 mm. The rotor diameter is 180 mm. The wheel's coefficient of static friction with the ground is 0.80. The brake pads' coefficient of static friction with the rotor is 0.45. The factor of safety is 1.5.*

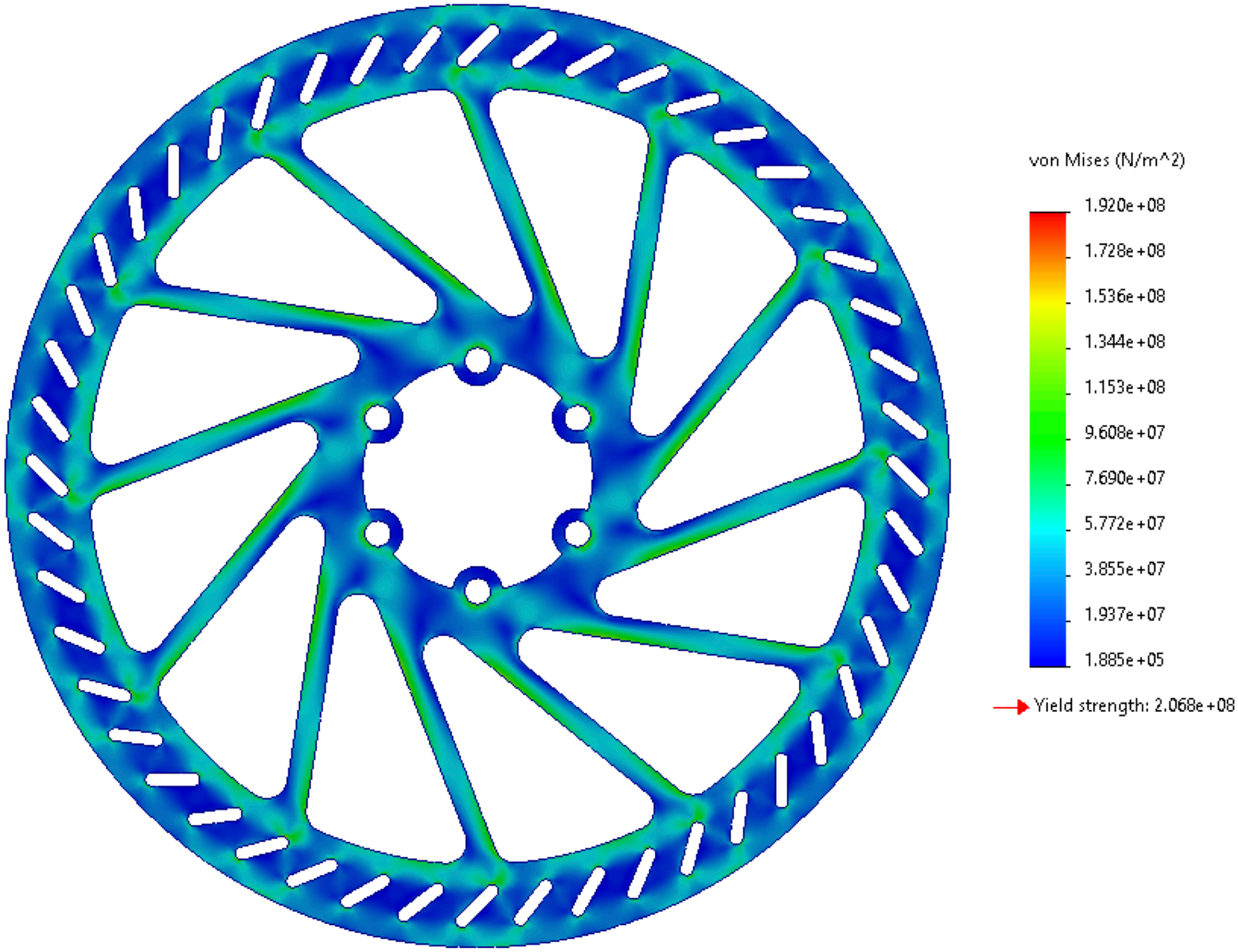

Fig. 3.3.1-1 Von Mises stress plot for the rotor under a moment of 153.77 N*m

The brake rotor was designed to withstand the estimated maximum moment of 153.77 N*m (see Table 3.3.1-1). Thus, it has rotational symmetry, and its features were designed to be in multiples of six. There are six bolt holes, twelve cutouts, and forty-eight ventilation holes. This design proved to be viable when tested using FEA—the maximum stress of 192 MPa was well below the yield strength of the chosen stainless steel, 206 MPa (see Fig. 3.3.1-1).

Additionally, the elastic displacement of the rotor was found to be tolerable, with the maximum displacement being 148.5 μm at the outer diameter (see Fig. 3.3.1-2).

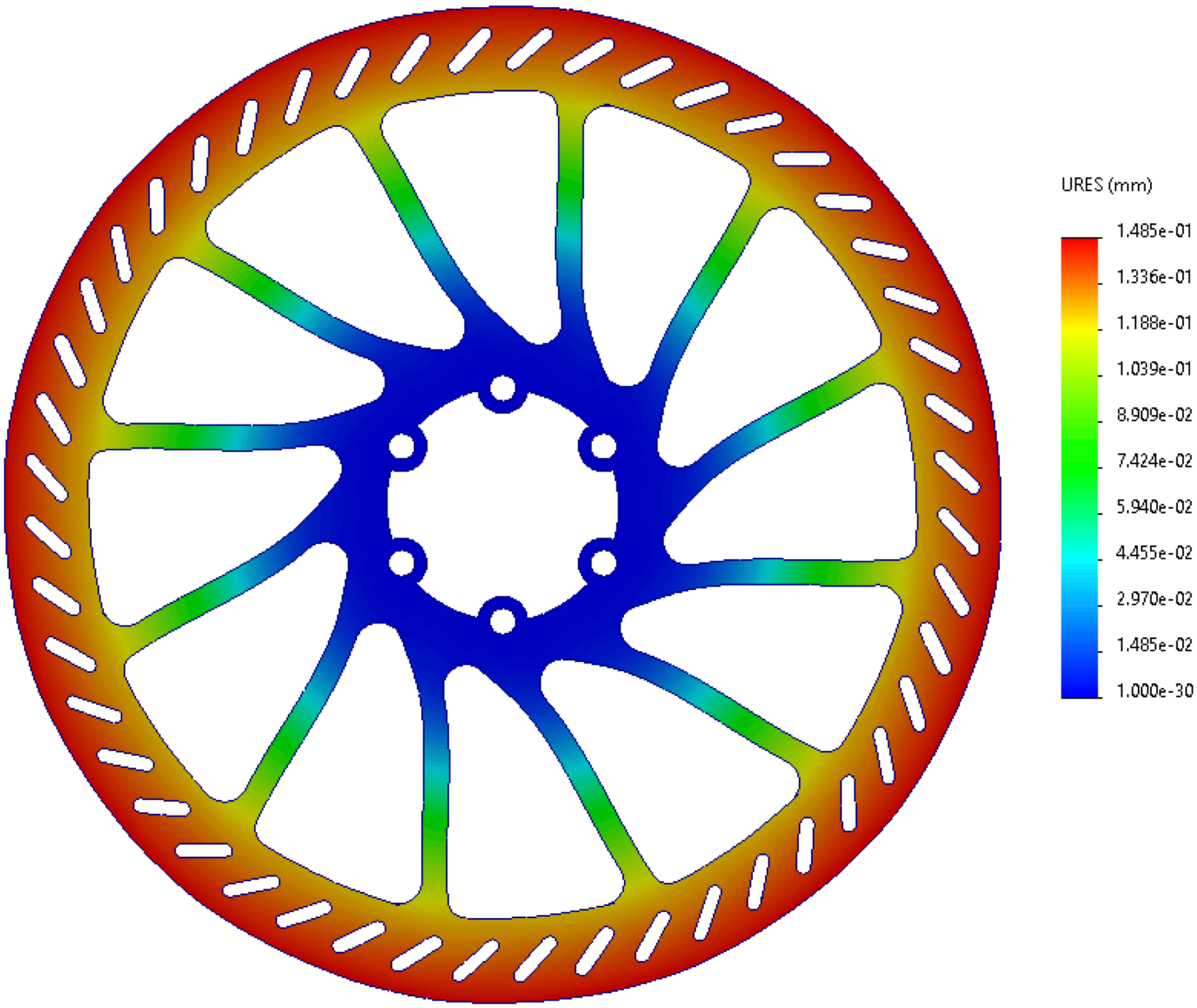

Fig. 3.3.1-2 Displacement plot for the rotor under a 153.77 N*m moment (121.233x def.).

3.3.2 Hub and Rotor

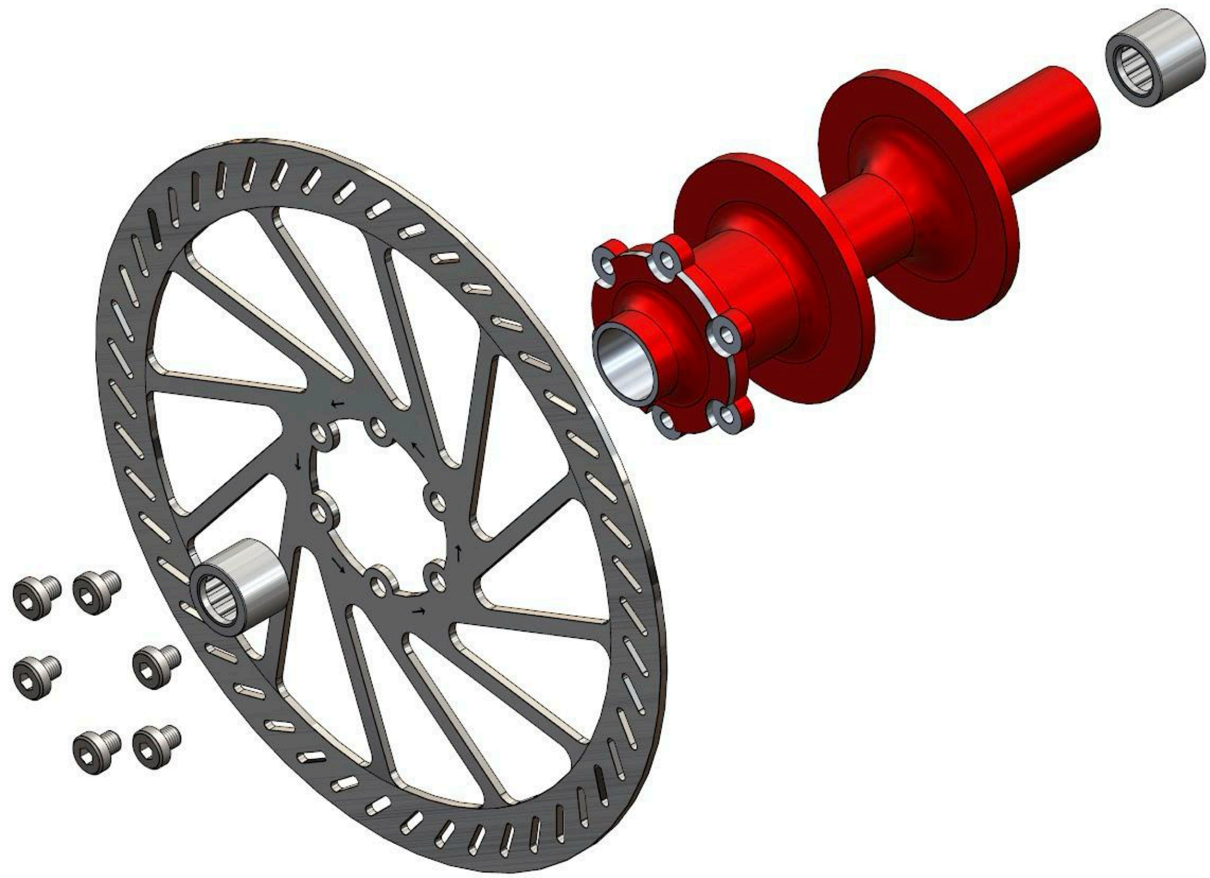

Fig. 3.3.2-1 Isometric exploded view of the rotor and hub assembly.

The rotor and hub assembly is composed of two major components: the rotor and the hub. The geometry of the rotor and hub allows for the two to mesh together, such that the rotor is self-locating. There are six hex socket bolts that further secure the rotor to the hub. Additionally, there are two needle roller bearings [5] that are press fitted into either side of the hub and transmit the front wheel load from the hub to the thru pin (see Fig. 3.3.2-2).

During braking, the moment in the rotor is transmitted to the hub and the connected wheel. As a result, there is a backward angular acceleration on the wheel, slowing the handcycle.

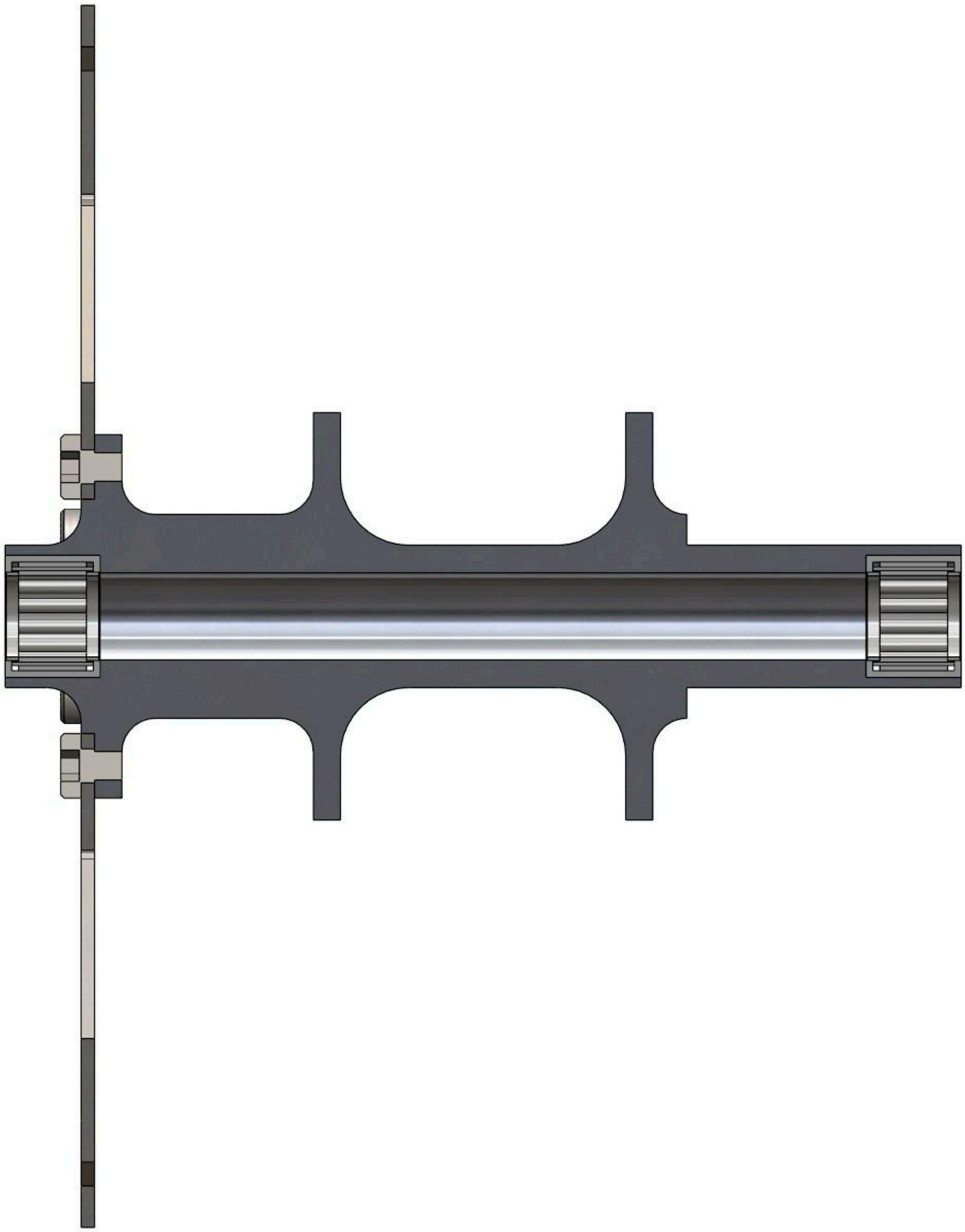

Fig. 3.3.2-2 Section view of the rotor and hub assembly.

Note *The 5905K85 Needle-Roller Bearings were adapted from McMaster Carr [5]*

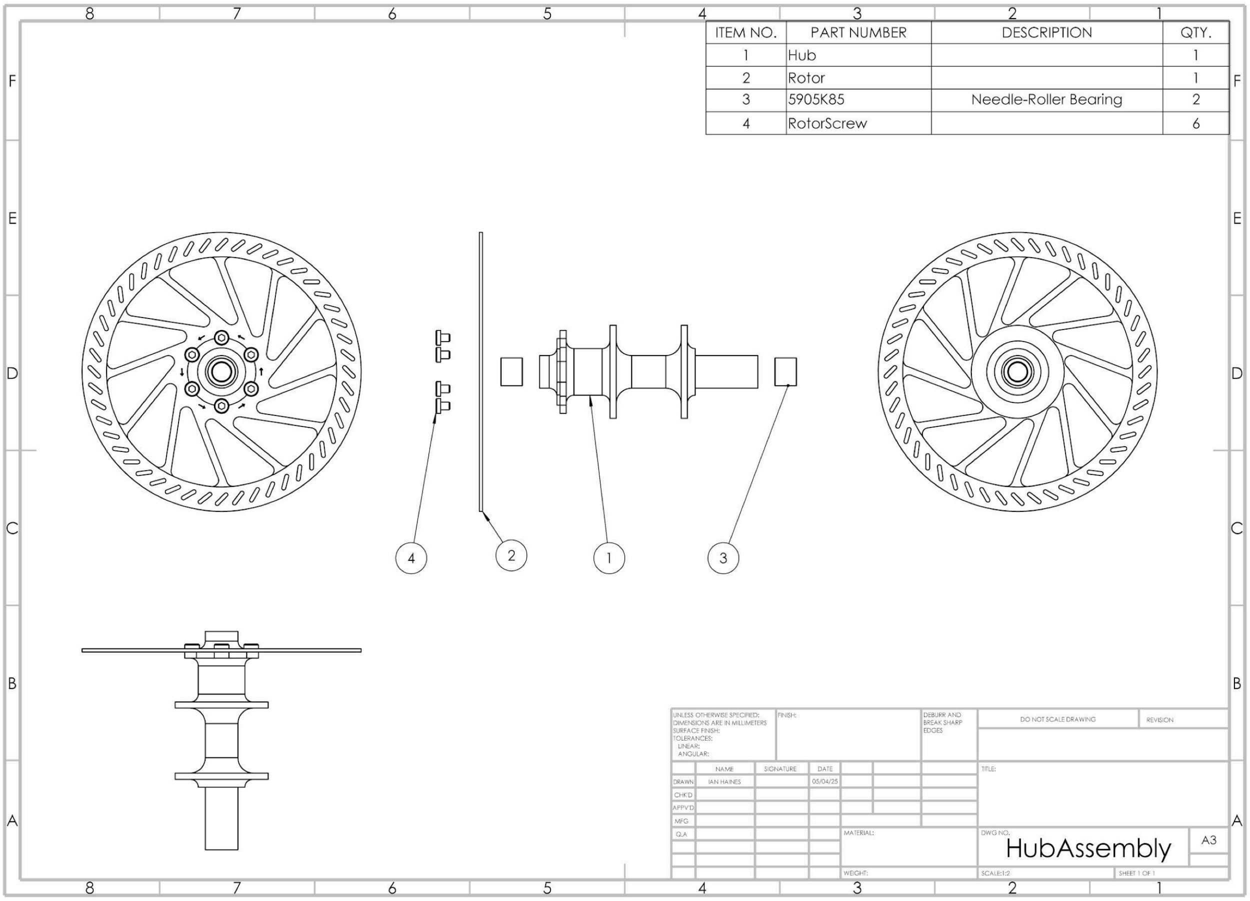

Fig. 3.3.2-3 Assembly drawing of the hub and rotor assembly.

3.3.3 Calliper

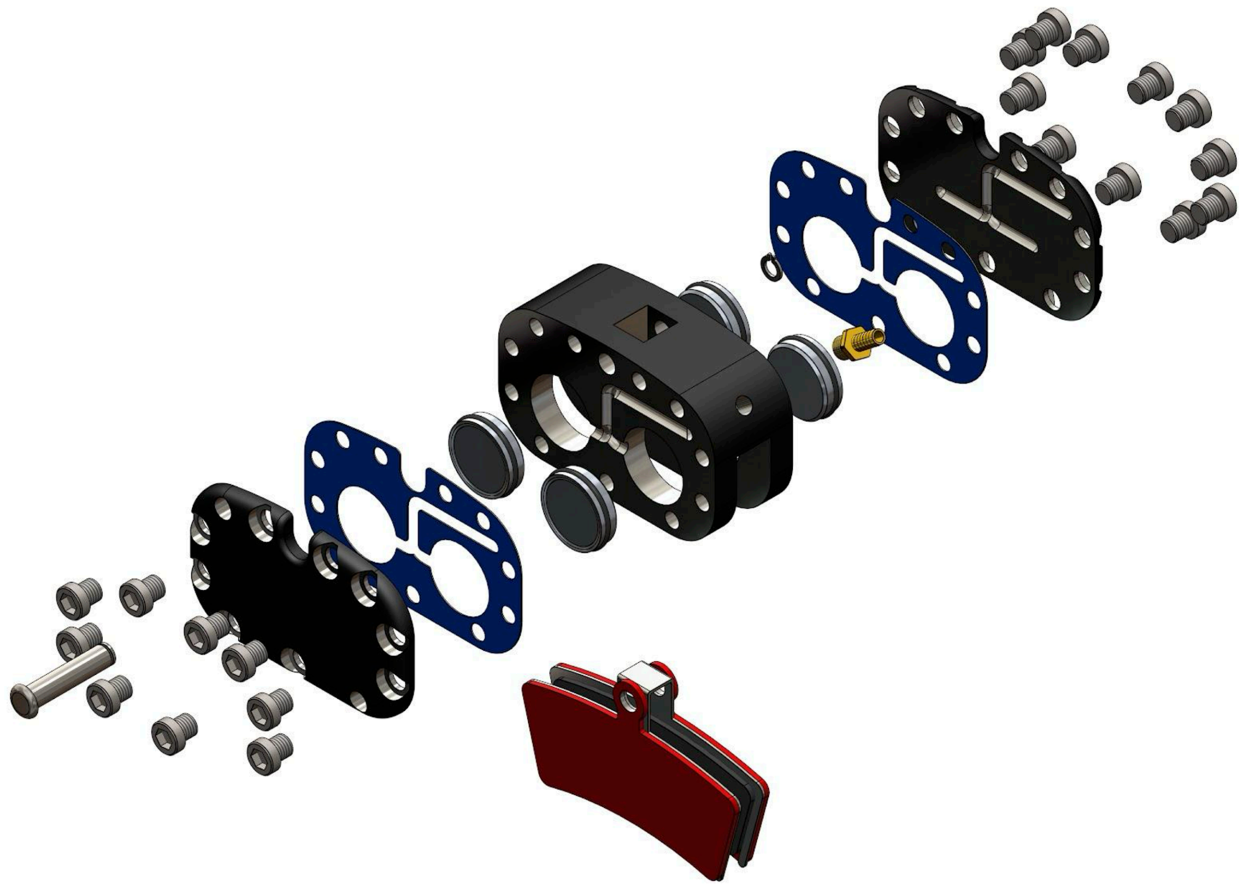

Fig. 3.3.3-1 Isometric exploded view of the brake calliper.

Hydraulic fluid enters the calliper through the hydraulic fitting before flowing through the channels in the calliper housing and caps to the four cylinders. As a result, the pistons are pushed inwards such that they squeeze the brake pad assembly against the rotor. The hydraulic fluid communication between the rotors ensures that equal forces are applied by each piston.

The brake pad assembly nests into the brake calliper and is fastened to the assembly using the brake pad pin and its accompanying circlip (see Fig. 3.3.3-3). Gaskets between the calliper housing and the caps ensures that the hydraulic fluid stays contained in the assembly during operation. On the passive side, eleven hex socket bolts fasten the cap to the housing. On the mounting side, nine hex bolts fasten the cap to the housing, while two mounting bolts on opposing corners mount the assembly to the brake calliper bracket on the forks (see 3.2 Steering and 4.0 Design Ensemble).

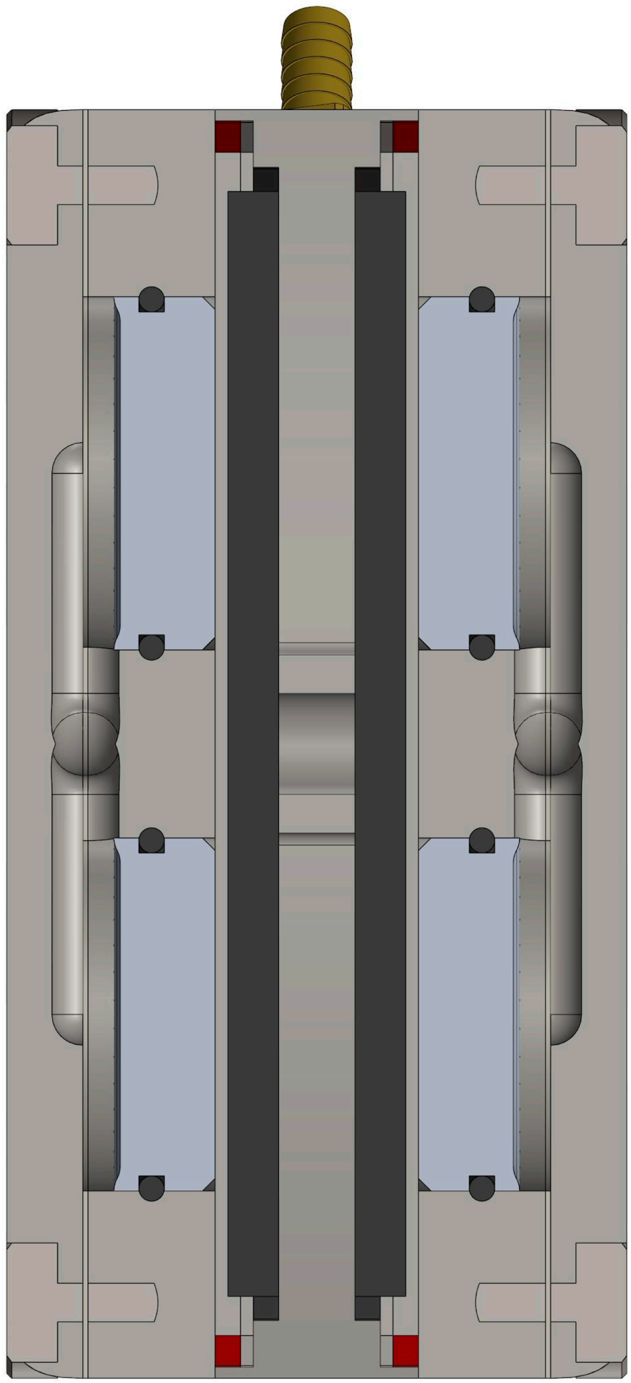

Fig. 3.3.3-2 Section view of the brake calliper.

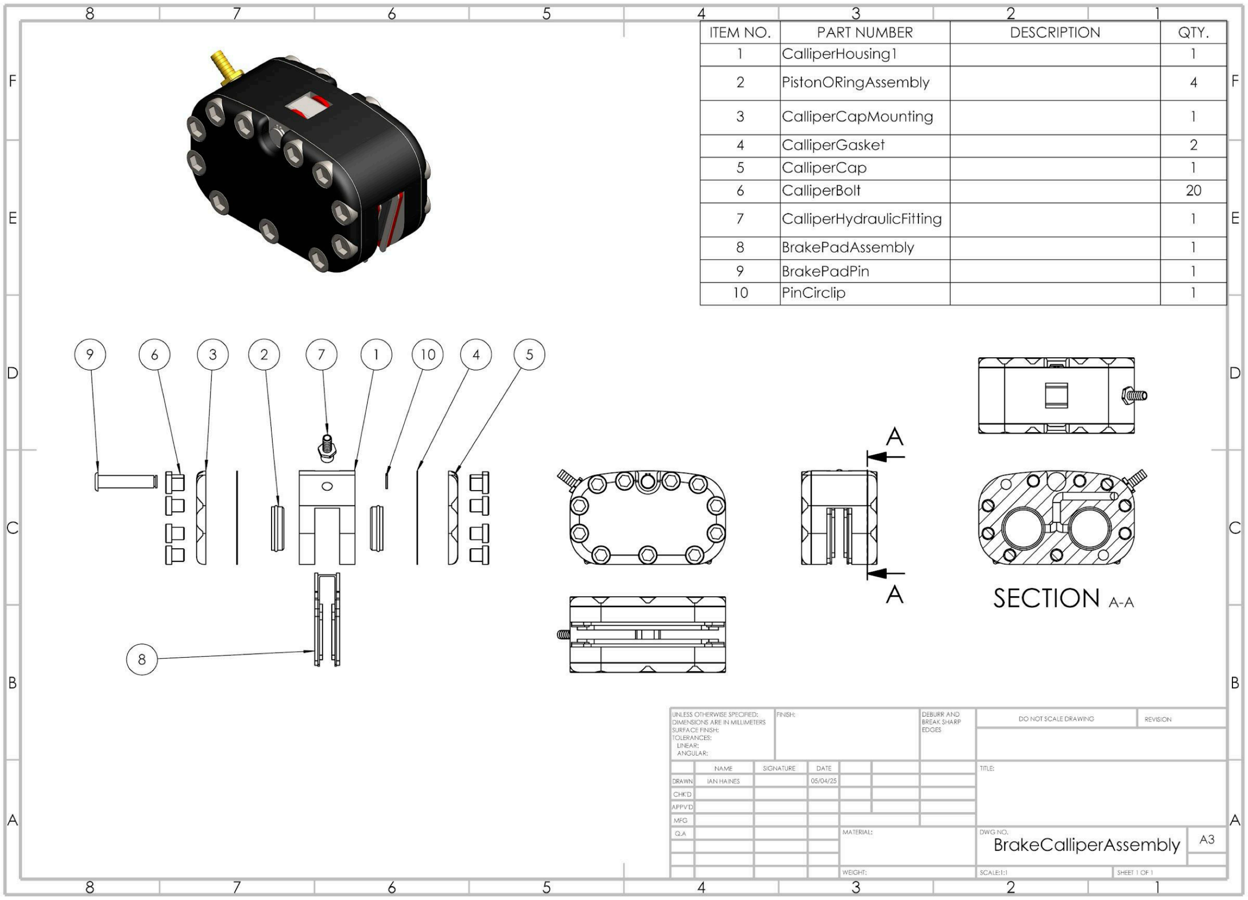

Fig. 3.3.3-3 Brake calliper assembly drawing.

3.3.4 Brake Pad

Fig. 3.3.4-1 Exploded view of the brake pad assembly.

The brake pad assembly is composed of the brake pads, brake pad backings, and a brake pad spacer. Depending on the user's preference, the brake pad material could be composite, or primarily polymeric. The top radius of the assembly and the brake pad pin holes properly locate the assembly inside of the calliper (see Fig. 3.3.3-3). When the user applies the brakes, the calliper squeezes the brake pad assembly, reducing the distance between the brake pads until they contact and squeeze the rotor's braking surface. When the pressure is removed, the brake pad spacer springs back to its original position, ensuring that the brake pads do not contact the rotor when they are not intended to.

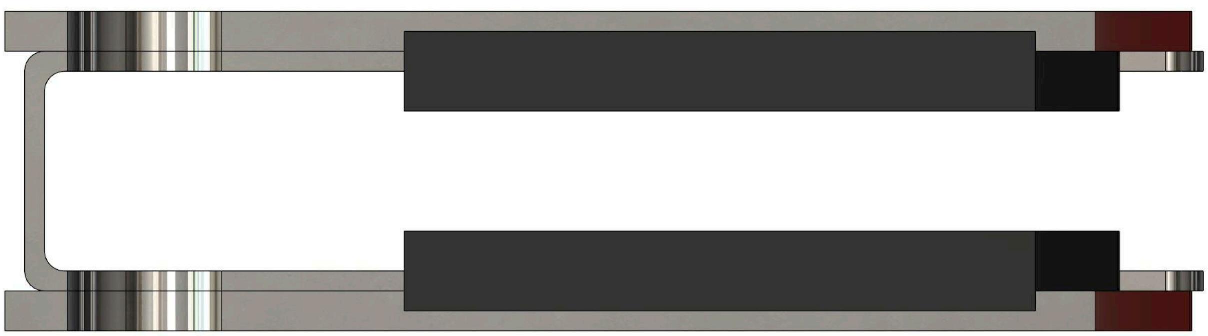

Fig. 3.3.4-2 Section view of the brake pad assembly.

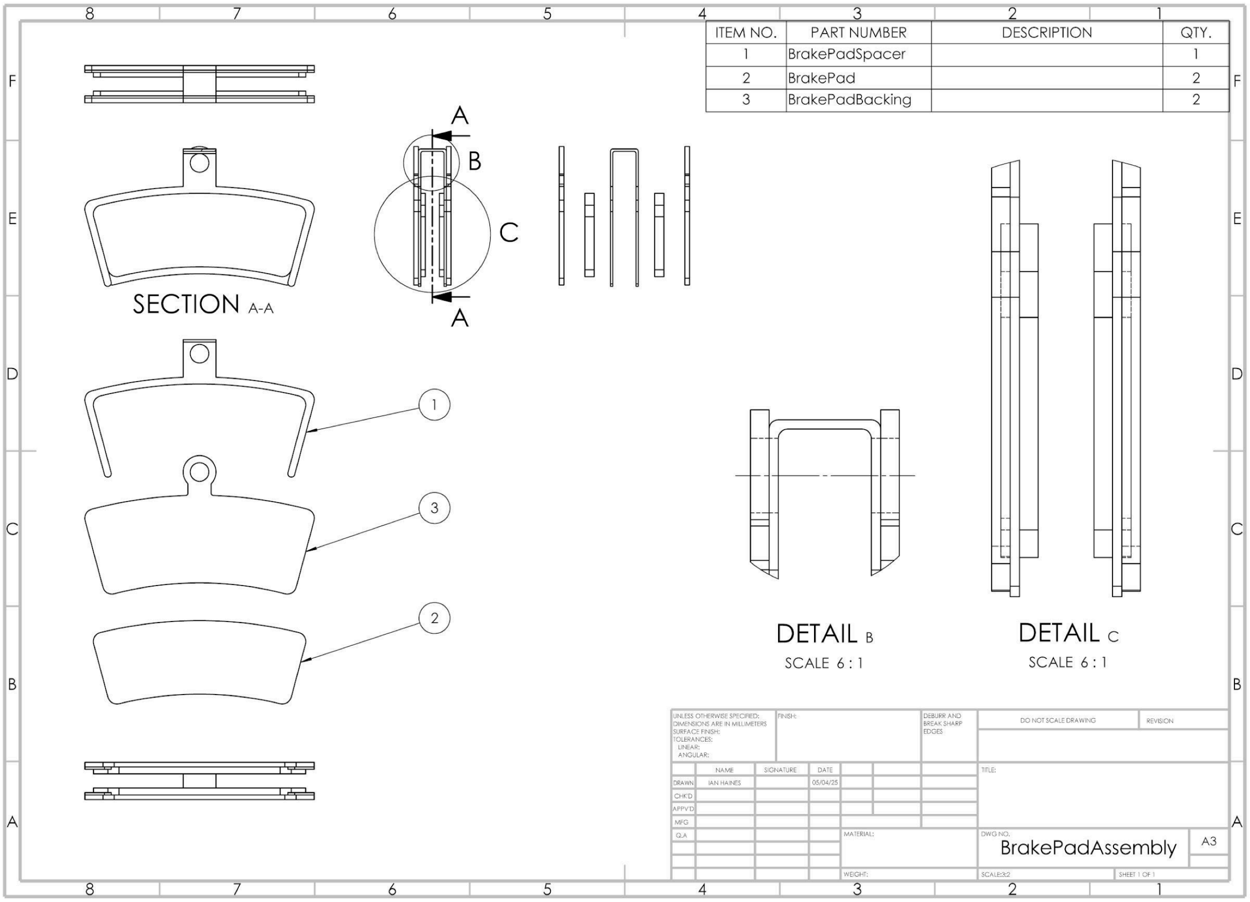

Fig. 3.3.4-3 Brake pad assembly drawing.

3.3.5 Brake Lever

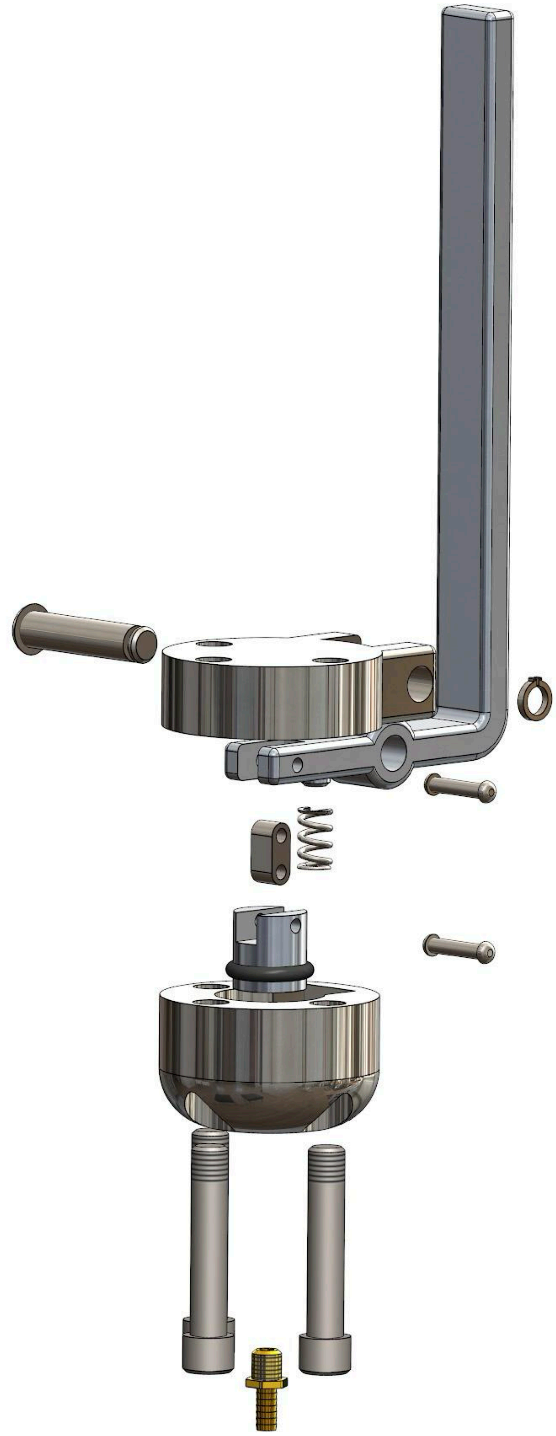

Fig. 3.3.5-1 Exploded view of the brake lever assembly.

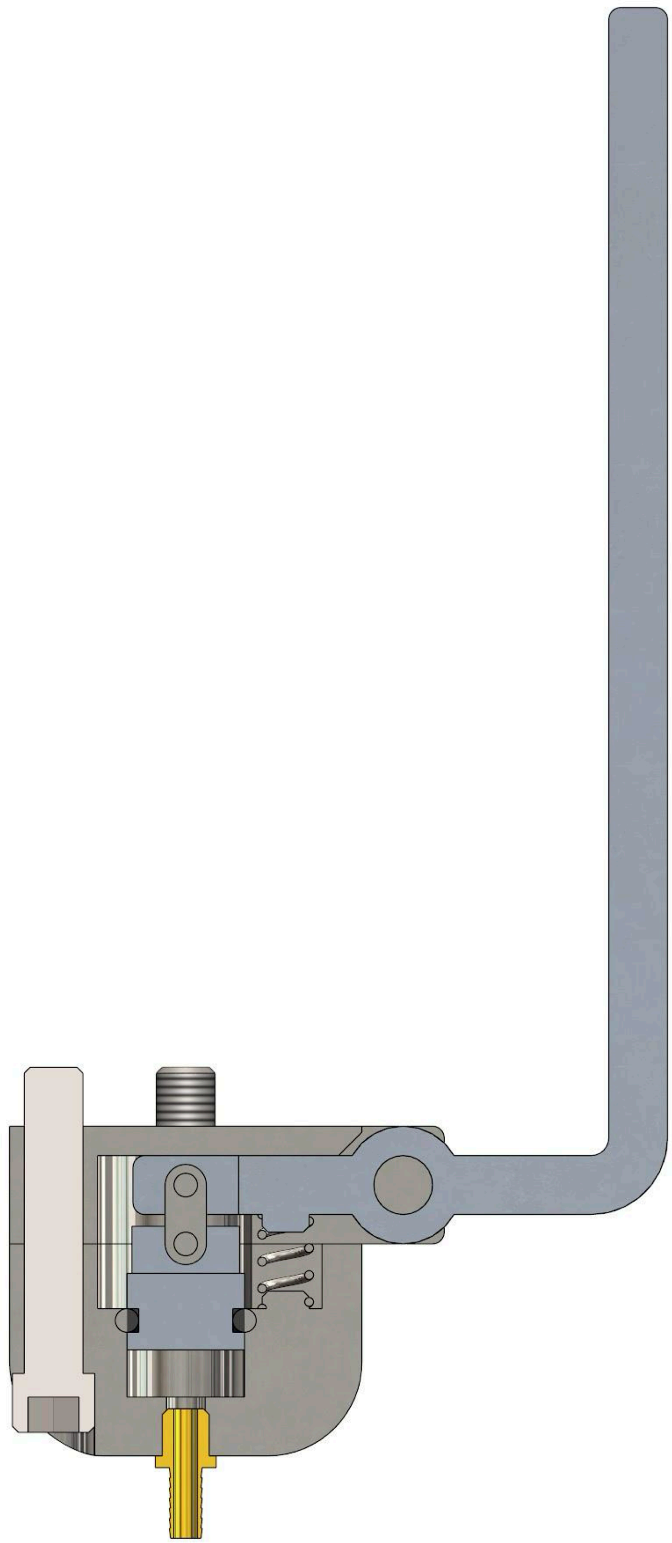

Fig. 3.3.5-2 Section view of the brake lever assembly.

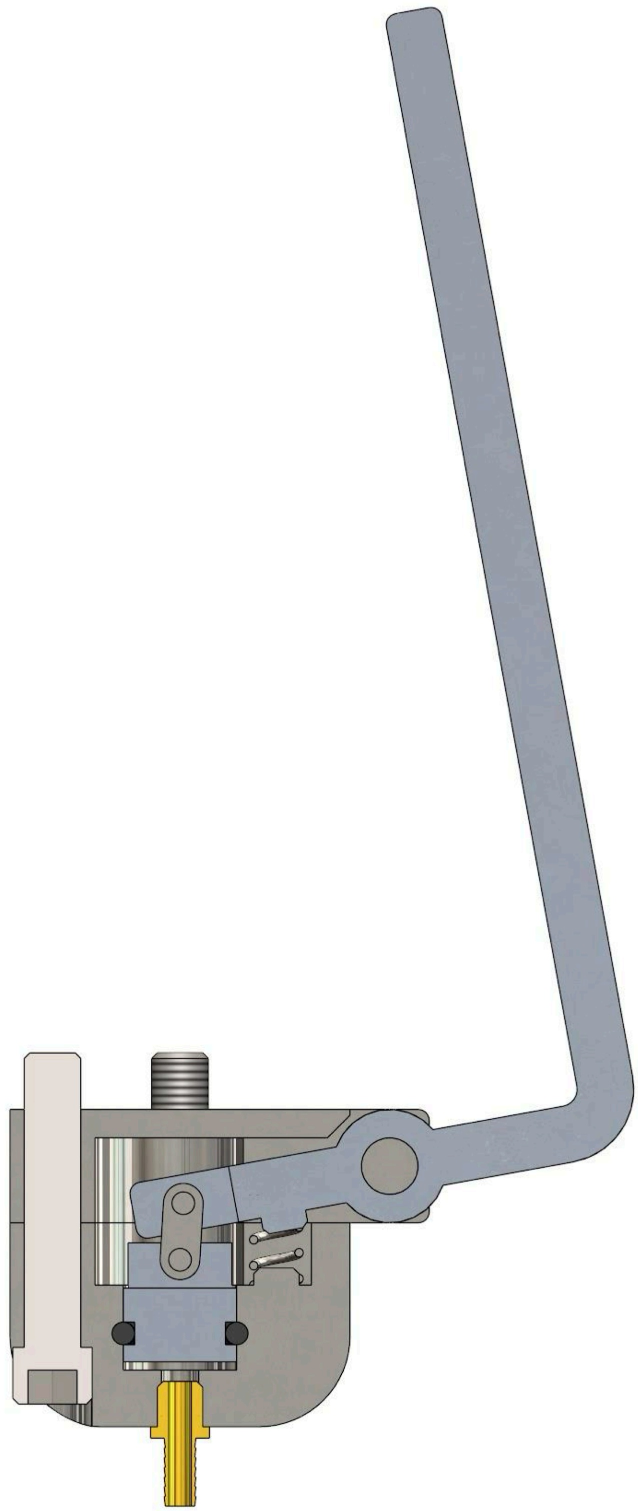

Fig. 3.3.5-3 Section view of the depressed brake lever assembly.

The brake lever assembly uses a simple crank slider mechanism to convert the lever’s rotational motion into linear motion for the piston. The lever rotates about the “lever arm pin” and is linked to the piston using the “lever linkage”. The components in this linkage series are pinned using two “lever piston pins” which are permanently affixed using an upset end.

The entire assembly is held together using three hex socket bolts that skewer the “hydraulic body” and the “attachment” parts and screw into the bottom of the left crank handle (see Fig. 3.3.5-4).

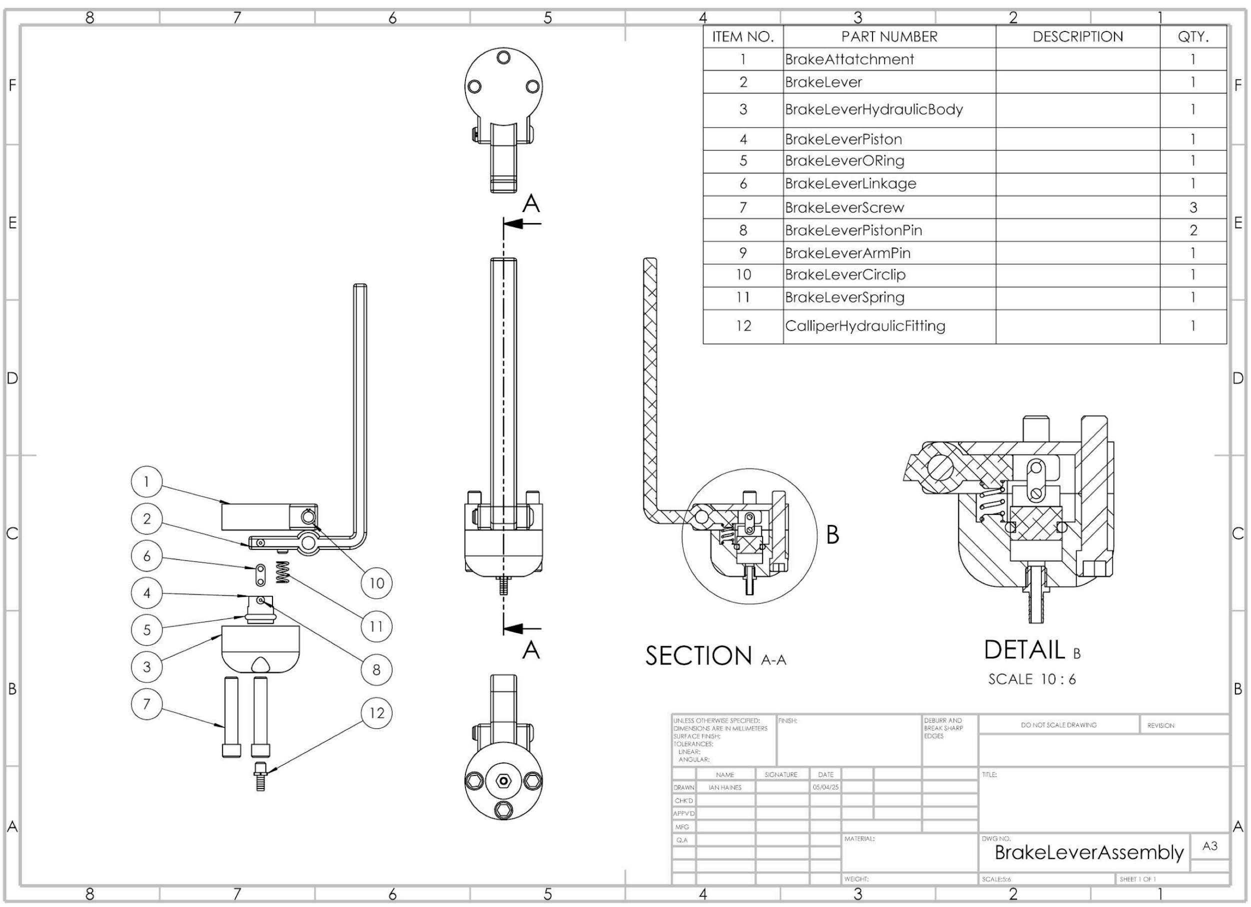

Fig. 3.3.5-4 Brake lever assembly drawing.

Fig. 3.3.5-5 Brake lever.

$$d_{calliperPiston} = 14 \times 10^{-3}\, m$$

$$d_{leverPiston} = 10 \times 10^{-3}\, m$$

$$A_{calliperPiston} = {\frac{d_{calliperPiston}}{2}}^{2} \times \pi = 1.539 \times 10^{-4}\, m^{2}$$

$$A_{leverPiston} = {\frac{d_{leverPiston}}{2}}^{2} \times \pi = 7.854 \times 10^{-5}\, m^{2}$$

$$F_{hand} = 230\, N$$

$$L_{handle} = 9.989 \times 10^{-4}\, m$$

$$w = \frac{F_{hand}}{L_{handle}} = 2303\, N/m$$

$$v(x) =- F_{hand}x + wx$$

$$M(x) =- 230x + \frac{wx^{2}}{2} + C_{1}$$

$$C_{1} =- (- 230L_{handle} + \frac{w(L_{handle})^{2}}{2})$$

$$M_{oment} = M(0) = 11.49\, N/m$$

$$L_{arm} = 3.739 \times 10^{-4}\, m$$

$$F_{leverPiston} = \frac{M_{oment}}{L_{arm}} = 307.2\, N$$

$$P = \frac{F_{leverPiston}}{A_{leverPiston}} = 3912\, kPa$$

$F_{calliperPiston} = P \times A_{calliperPiston} = 602.2\ N$

$F_{calliper} = F_{calliperPiston} \times 4 = 2.409\ kN$

$\eta_{mech} = \frac{F_{calliper}}{F_{hand}} = 10.47$

Therefore, the braking system has a mechanical advantage of about 10.47. For an applied squeezing force of 230 N, which is about the average peak squeezing force of a person over the age of 80 [6], a force of 2.409 kN will squeeze the brake rotor. This is greater than the required 1.898 kN (see Table 3.3.1-1) that was previously determined. Thus, the braking system will be easily operable by all youth paralympic athletes, and the given athlete will be able to reliably lock the front wheel with the braking system.

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3.5 Seat - [redacted]

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3.5.1 Structural Analysis Under Braking Loads

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4.0 Design Ensemble

SEE APPENDED DRAWING

5.0 Conclusion

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References

[1] M. Mozorov, “SRAM Rival XPLR ETap AXS Groupset,” *Grabcad.com*, Apr. 20, 2022. https://grabcad.com/library/sram-rival-xplr-etap-axs-groupset-1 (accessed Feb. 17, 2025).

[2] “Aluminum 6061 - A96061.” Diversified Specialty Metals. https://diversified-metals.ca/products/6061-aluminum-products (accessed April 2, 2025)

[3] “What Is Caster?” Suspension Secrets. https://suspensionsecrets.co.uk/caster/ (accessed March 22, 2025)

[4] M. Wilkinson. “The geometry of bike handling: It’s all about the steering.” VELO. https://velo.outsideonline.com/road/road-gear/the-geometry-of-bike-handling-its-all-about-the-steering/ (accessed April 2, 2025).

[5] *Needle-Roller Bearing, Sealed on One Side, for 12 mm Shaft Diameter*. (2022). McMaster Carr. Accessed: Apr. 06, 2025. [Online]. Available: https://www.mcmaster.com/catalog/131/1432/5905K85

[6] T. Nilsen, M. Hermann, C. Eriksen, H. Dagfinrud, P. Mowinckel, and I. Kjeken, “Grip force and pinch grip in an adult population: Reference values and factors associated with grip force,” *Scandinavian journal of occupational therapy*, vol. 19, pp. 288–96, Feb. 2011, doi: 10.3109/11038128.2011.553687.