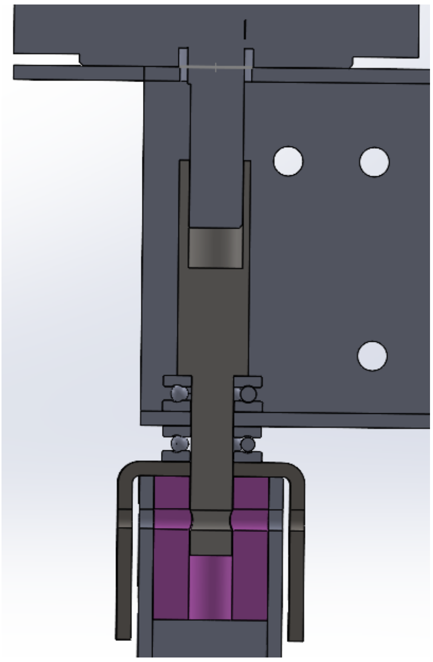
# Turning System

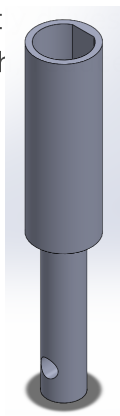
The turning system provides active steering for the front and rear wheel assemblies. To ensure high reliability during operation, the subsystem uses a direct-drive arrangement engineered to withstand heavy vertical static loads while eliminating mechanical play and plastic material deformation. It was desinged in a way to provide rotation while preventing vertial load transfer to the stepper motor as their axial load limit is much lower than the load of an individual turning system.

## System Architecture & Components

The finalized design (Version 2) replaces indirect mechanical transmission with direct motor drive to simplify the assembly and maximize torque transfer efficiency.



- **Stepper Motor:** Direct the steering shaft without intermediate reduction gears. This eliminates backlash es total part count, and removes gear-tooth wear as a potential failure point.



- **Custom Interface Shaft:** Machined shaft tapped at the side and secured to the stepper motor shaft via a set screw. It translates the rotational output of the motor shaft into a rigid mechanical connection for the turning core. It was designed in such a way that for some reason the interface shaft was pushed upwards it would not load the axial direction of the stepper motor shaft. (Note: In this image the set screw is not present as that was an addition made during manufaturing as the creation of D-bore with the chosen material was deemed not possible with the equiment at Cube.)
- **Lower Core Block (Plastic Cube):** Connected securely to the upper interface shaft it aids in a more even tranfer of torque form the shaft to the vertial square tubes, provides support for the screws connecting the U-shaped bracket to the vertical square tubes and interface shaft, and supports the U-shaped bracket in the center where the thrust bearing load is.
- **Vertical Square Tubes:** Act as the primary load-bearing rotating columns for both the front and rear steering assemblies. The vertial load is carried upwards with this tube and then trasnferred to the U-Bracket, which transfers it to the thrust bearings which then trasnfers it to the suspension system.
- **U-Shaped Steel Brackets:** Mounted to the exterior of the vertical square tubes. They provide a flat, rigid metal surface that prevents localized plastic crushing under heavy structural loads.
- **Thrust Bearings:** Positioned flush against the steel brackets. They isolate the vertical forces caused by the weight of the rover  enabling smooth rotational motion under full payload.

# Design Rationale

**Version 1:** The initial concept attempted to use a 3D-printed gear (30 mm diameter) driven by an M6 60 mm bolt and hex nuts pressed into embedded cutouts inside the plastic cube. This was was the first idea that came to mind when thinkning of not exceeding the axial load limit of the stepper motor.

- **Primary Failure Mode 1 (Gear Shear):** The main probelm foreseen with this concpet was that under high torque the gear could bend causing jumping/slipping whihc would not be ideal. Another probelm was the gear would degrade quite quickly.
- **Primary Failure Mode 2 (Interface Stripping):** High torque from the stepper motor concentrated immense torsional forces onto the sharp corners of the embedded hex nuts. Because plastic yields easily under point loads, the nuts quickly stripped out their plastic pockets, causing total loss of rotational control.
- **Primary Failure Mode 3 (Nut loosening):** Since the system relies on two nuts that are screwed into each other to create a lock; under high amounts of torque and continuous vibration, these nuts would eventually loosen making the turning system useless.

**Version 2 (Current Production Design):**

- **Direct Drive Integration:** Eliminating the printed gears entirely removed the primary shear risk. Driving the turning column directly ensures 100% torque transmission from the stepper motor without intermediate mechanical loss.

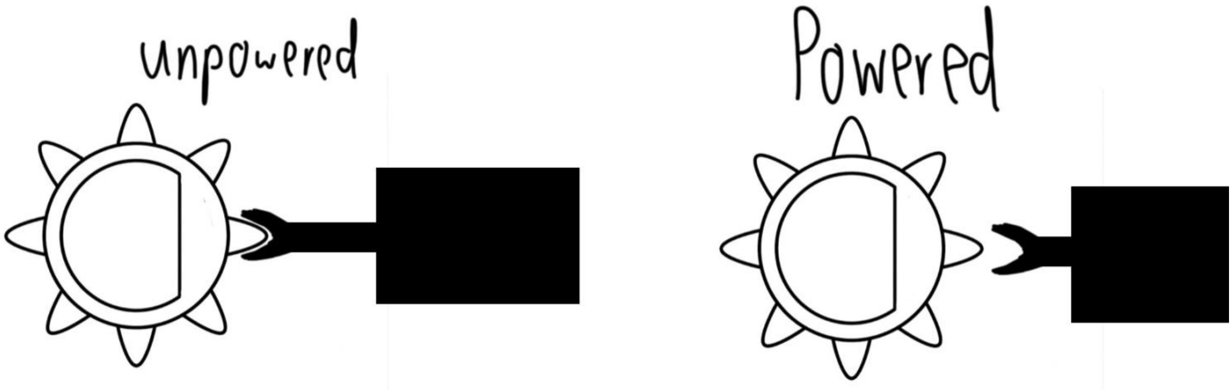
- **Metal-on-Metal Fastening:** Switching to a tapped metal interface block with set screws distributes clamping pressure evenly across the flat of the motor shaft. This prevents the rounding and stripping experienced in plastic cutouts.
- **Axial Load Isolation via Thrust Bearings:** Standard radial bearings or plain plastic bushings degrade quickly when subjected to heavy vertical loads down the steering axis. Placing thrust bearings against rigid U-shaped steel brackets creates a dedicated path for vertical forces to pass through the frame. This protects the internal stepper motor bearings from dynamic impacts during travel and maintains low rotational friction.

# Failure Modes and Future Work

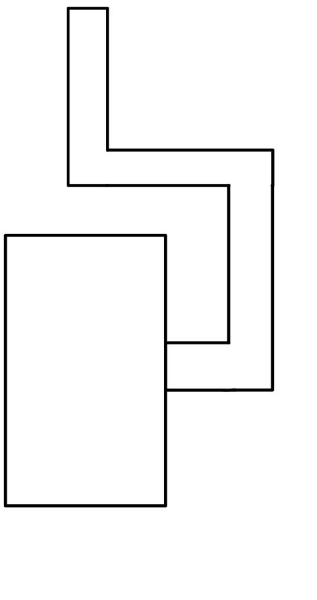
The turning system is one of the more intrecate parts of the drive system, but in this case it was one of the more rushed systems as time was running out and the main focus was getting a subsystem that worked for now and could be improved on in the future.

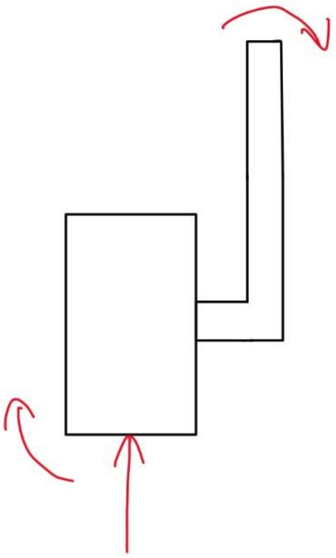
- **U-Shaped Bracket Tolerancing:** Since the U-shaped bracket relies on bending to create it, it sufferes from multiple steps that are quite inaccurate. One must first score the original plate, then line up the scored line by eye in the bending machine, and then bend the plate. This must be done for both sides as the machine can only do one side at a time. This process is very inaccurate and causes that the holes do not line up well, the dimensions to be off, etc. This is why in the current rover they do not exist. They were replaced with washers. This combined with other oversights caused quite some problems with the lower part of the suspension system.
    - **Improvement:** Either find a way to produce these brackets with more accuracy or find extruced channels that achieve the same goal. Ideally a system that is much improved from this would be prefered.
- **Interface Shaft Under Constrained:** Currently the interface shaft only has one hole that connects the stepper motor to the vertical tube. This means that at it only connects the lower part of the suspension system to the upper part through this hole. This has 2 probelms. The first being the reliance on one sigular M3 screw that holds the turning and therefore that part of the suspension system together. The other being that it does not contrain all the degrees of freedom, as in if the vertical tube was not pressup against the main suspension part it would be able to wiggle and rotate around that point. While the singular M3 screw is fine (it only needs to carry a load if that specifc wheel is in the air), it could pose a probelm if an irreguar force acted on it which could break it.
    - **Improvement:** Create interface shafts that are longer as to include more through holes in order to increase the amount of screws.
- **No Rigid Hold when Unpowered:** According to the rules of the ERC the rover needs an emergency shutoff button. Currently the wheels can only hold their currect angle while powered. In the event that the button needs to be pressed, the stepper motor becomes unpowered and the wheels will then proceed to turn in thier own, unpredictable way. This can cause a probelm in the case the wheel sharply turns perpendicular to the motion of the rover, potentially causing damage to the suspension system as there is quite a lot of momentum when needing to quickly stop.

- **Improvement:** Add a physical stop that is only activated when the unpowered. First rough idea would be including a gear like structure mounted on the stepper motor or interface shaft with a solanoid with a negative gear like piece attached to the end that is extended when inpowered and retracted when powered. An example is given below. This could be hidden away in the horizonal memebrs of the suspension system.




- **"L" Shaped Turning System Causes Unwated Moment:** With the way the motor subassembly is currently mounted the entire turning system creates an "L" shaped system. The leftmost picture picture describes how this moment is created when the systme is loaded. This comined with the problems seen in the first two failure modes compounds the unwated camber of the vertial part of the suspension system. The reason this was done was that when faced with the "making everything modular" probelm, another system such as a "U" shaped system seen on actual mars rovers was seen to be more complex to figure out. In hindsight this could have been solved quite simply, such as creating 90° brackets similar to the ones used for the main members of the suspension system.
    - **Improvement:** For the reveal event, a rudementary "U" shaped system was fashioned. This is not a complete system as there is no connection to the stepper motor responsible for the turning. an example can be seen on the rightmost image.





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Revision #9
Created 2026-07-20 14:55:01 UTC by Ludwig Franz Kumpf
Updated 2026-07-30 16:13:21 UTC by Ludwig Franz Kumpf