Project: Custom FTC Differential Swerve Drive

Abstract

Over four competitive seasons on FIRST Tech Challenge (FTC) team #19823, I iteratively designed and fabricated a series of custom holonomic drive modules. This document details the engineering evolution of my final Differential Swerve architecture. Unlike standard coaxial systems, this design couples two motors to a single wheel, utilizing software-based mixing to achieve higher torque density and a 30% reduction in vertical packaging. This project required solving complex challenges in tribology and Design for Manufacturing (DFM) within strict size and weight constraints.

Software Attribution: *Kinematic path planning and control loop implementation were developed by my teammate, Connor Sherwin. Mechanical design, fabrication, and hardware integration were executed by myself.*

1.0 Engineering Constraints & Objectives

The final design was engineered to meet four strict performance criteria derived from previous failures in past seasons:

- **Reliability:** Zero mechanical failures during matches under any circumstances (validated over 25 official matches).
- **Agility:** Surpass 8 ft per second max translational velocity.
- **Strength-to-Weight:** Be a structural body of the robot chassis itself while being under 10 pounds for total drive train mass.
- **Serviceability:** Complete module swap-out capability in under <3 minutes.

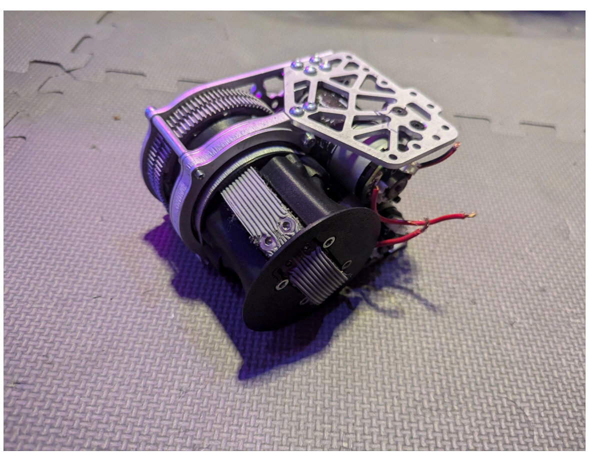
2.0 Architectural Selection: Why Differential?

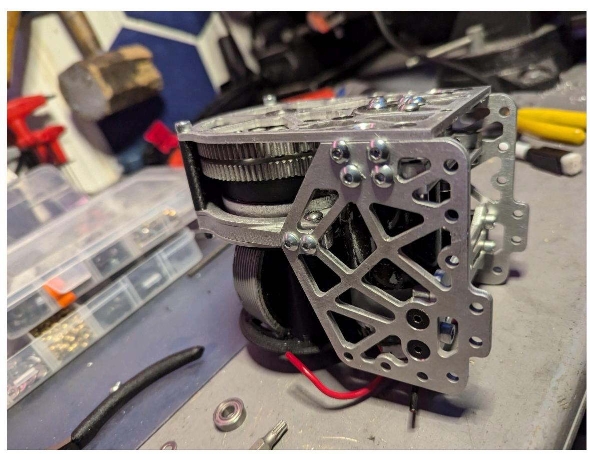
Standard FTC swerve modules typically utilize a Coaxial architecture, where one motor drives the wheel and a second drives the module rotation. While simple, this creates a "dead weight" inefficiency: during straight translation, the steering motor sits idle.

I selected a differential architecture to maximize power density within the FTC motor limit (With that limit being 8 DC motors and 12 servo motors, the swerve drive needs to use the minimum so other mechanisms can have increased DOF) In this configuration, both motors input into a shared differential bevel gear.

Because both motors contribute to wheel torque during acceleration, this doubles the driving force compared to coaxial equivalents. So instead of 4 coaxial swerve modules, (one driving and one steering motor per module) we can instead use 2 differential swerve drive modules (2 driving motors per module) and achieve the same driving power density while cutting 4 steering servo motors and 2 whole entire modules, saving motors, weight, and space.

3.0 Phase 1: Validation Prototype (The "Test Bench")





Design Intent:

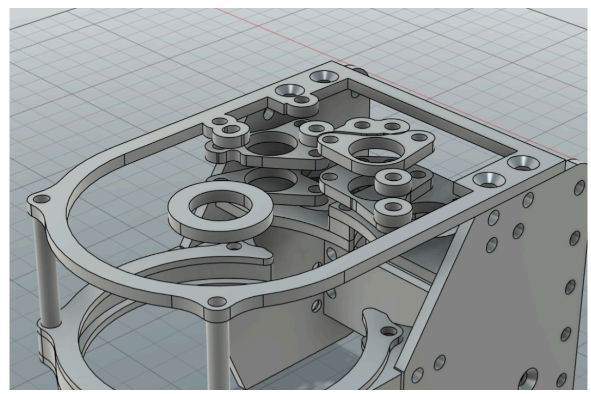
The primary goal of the first prototype was to validate the mechanical feasibility of the differential bevel interface and the accompanying software.

Mechanical Configuration:

- **Chassis**: Laser cut 6061 Aluminum side plates for rigidity.
- **Gearing:** COTS aluminum and steel spur/bevel gears (Avoiding plastic due to previous failures with plastic bevel gears)
- **Transmission:** Direct spur gear contact for maximum efficiency.

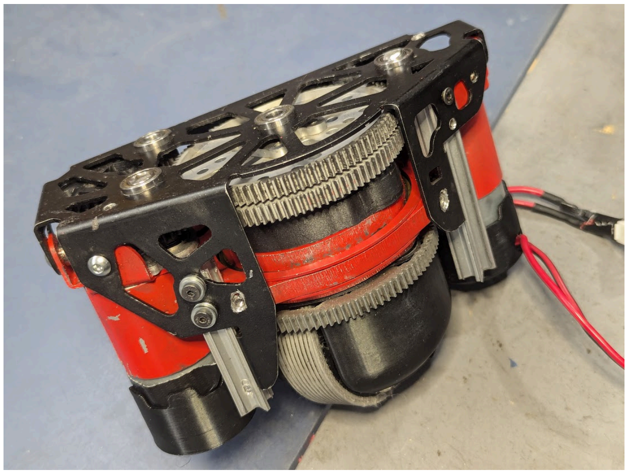
Failure Analysis & Learnings:

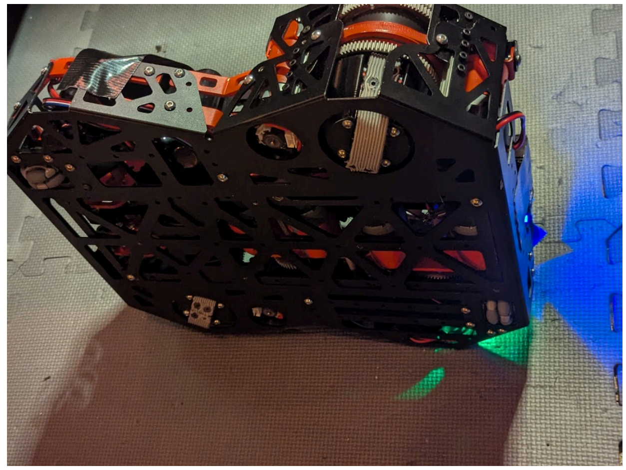
While this prototype successfully proved the differential mixing logic, it revealed critical flaws that informed the final design:



1. **Spur gear meshing:** The design of the top spur gear mounts proved to be unnecessarily complex as shown in the figure on the right. The multi layered design caused alignment issues with tooth profiles.
2. **No modularity:** This design, while compact, did not have the modularity I was looking for, attaching it to the chassis would require excessive screwing/bolting.
3. **Excessive Factor of Safety (Mass Optimization):** Destructive testing (drop tests, side-load impacts) revealed zero plastic deformation, indicating the chassis plates were significantly over-dimensioned. This highlighted an opportunity to optimize the strength-to-weight ratio by switching from 1/8th sheet metal construction to 1/16 sheet metal construction.

4.0 Phase 2: The Final Competition Architecture



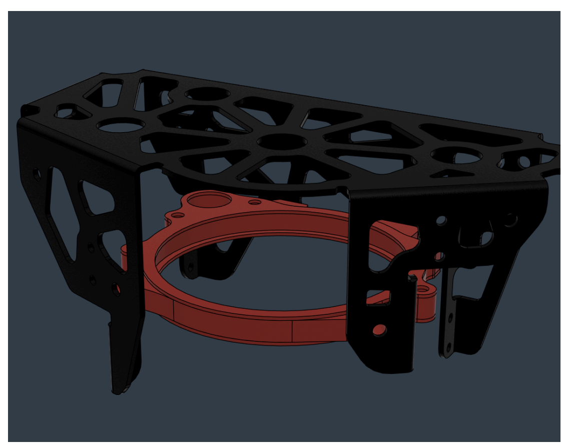


Design Intent:

Following the validation phase, the objective shifted from kinematic proof-of-concept to systems integration. The final design focused on miniaturization and modularity, treating the drive module not as a permanent fixture, but as a "Hot-Swappable" Unit.

Mechanical Implementation & DFM:

- **Material Selection** (5052 vs. 6061): To address the mass optimization issues of Phase 1, I transitioned the primary structural plates from 6061 Aluminum to 5052. While 5052 has a lower yield strength, its high formability allowed for a bent-flange architecture. This becomes the crucial strength factor, as the bent sheet metal designs allowed me to remove 90 degree mounting brackets while going from 1/8in thick to 1/16in thick plate. This drastically cut weight while maintaining ~90% of the original strength.

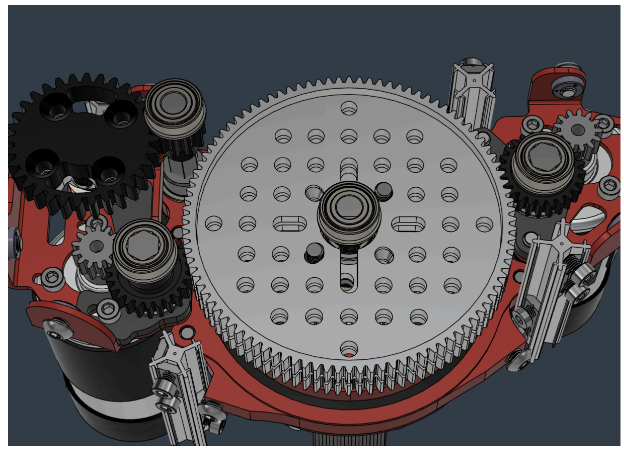


New Topology

- **Topology Optimization:** The pocketing on the new plates internally targeted struts at major screw hole mounting sections that would see the most stress on the module.

- **The "Pod" Modular Architecture:** To satisfy the <3 minute serviceability constraint, the entire module was designed as a self-contained "pod. It utilizes a quick-release rail system based on standard 15mm extrusion profiles, allowing for tool-less removal of the drive pod once the retention screws are loosened.

Tribology & Gearing:



- **Zero-Backlash Tensioning:** To mitigate the gear mesh alignment issues seen in Phase 1, the final design incorporates slotted motor mounts and simplified intermediary gear mounting. This allows for precise center-distance tuning between the pinion and the differential bevel gear, manually eliminating backlash to ensure the software PID loops remain stable without integral windup due to mechanical play.
- **Lubrication:** This version also includes bevel gear covers so grease stays inside the geartrain and dirt stays out, allowing for smoother motion and extended maintenance intervals which eliminates the need for inter-match lubrication.

5.0 Performance Validation

The final differential architecture was deployed in 25 official matches.

- **Torque Density Verified:** The 2-module configuration successfully accelerated the robot to 8 ft/s, validating the theoretical torque summing and gear ratios chosen for the design.
- **Durability:** The switch to the bent sheet metal architecture resulted in zero chassis warping despite heavy defensive play.
- **Reliability:** The module achieved the target of 100% mechanical uptime throughout all competition matches (My proudest achievement).