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music-ing
traveling
metal-cutting
Notion-ing

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Expected May 2027




Baja SAE: Continuously Variable Transmission

Shelley Wei
August 2025

Baja SAE (Society of Automotive Engineers)

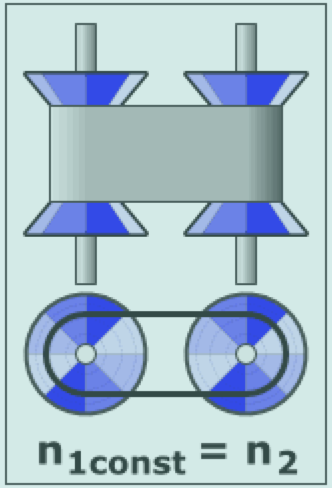
- Student-led teams who design and build cool off-road race cars

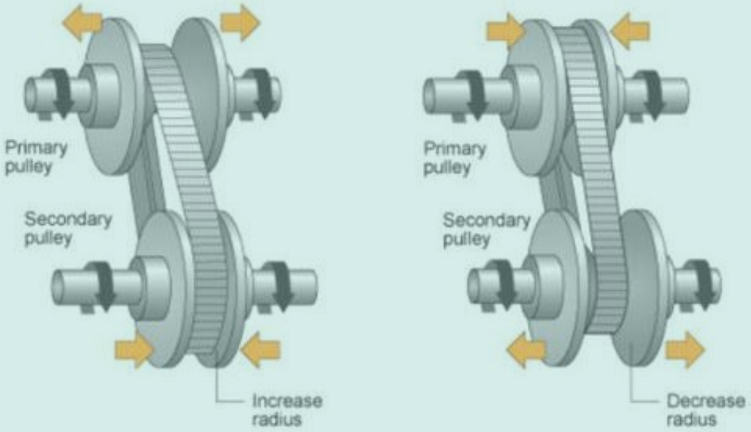
Events

- Dynamic
  - Acceleration, Hill Climb/Sled Pull, Maneuverability, Suspension & Traction
    - Points based on relative placement
- Static
  - Design Presentation, Business Presentation, Cost
    - Points based on judging
- Endurance (4-hour wheel-to-wheel race)
  - Points based on number of laps completed

What's a continuously variable transmission (CVT)?

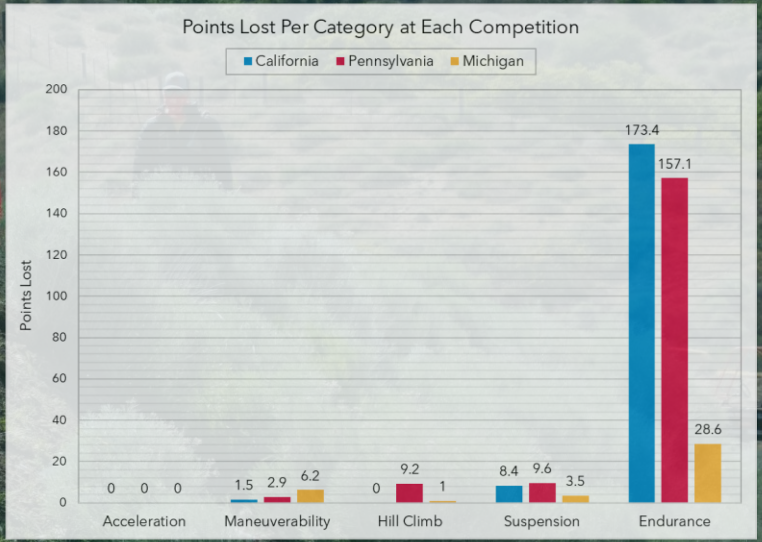
- Used in some road cars, ATVs, and snowmobiles (and Baja SAE cars)
- Consists of input pulley, output pulley, belt
- No discrete gearings
- Purpose: accelerate vehicle at engine peak power (P = mav)





Setting Requirements

Vehicle Requirements	Cascaded Requirements
3.8-second acceleration time over 100 feet	CVT must shift at engine peak power (3000 RPM)
Top speed of 38 MPH within 300 feet	Shift to max CVT ratio (0.639:1) within 300 feet
Ability to clear endurance obstacles at a minimum of 75% of top speed	CVT must backshift from ratio at 20 MPH to low ratio in 0.5 seconds
Lap times to increase no more than 6% after 4 hours of continuous runtime	CVT acceleration times don't increase more than 5% after 4 hours of runtime



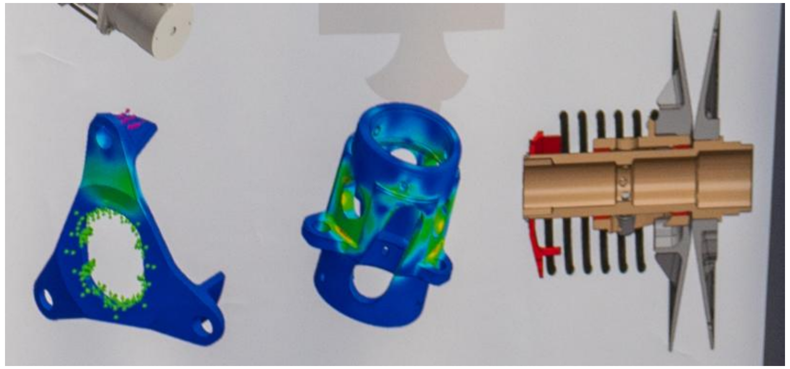
Early June 2024

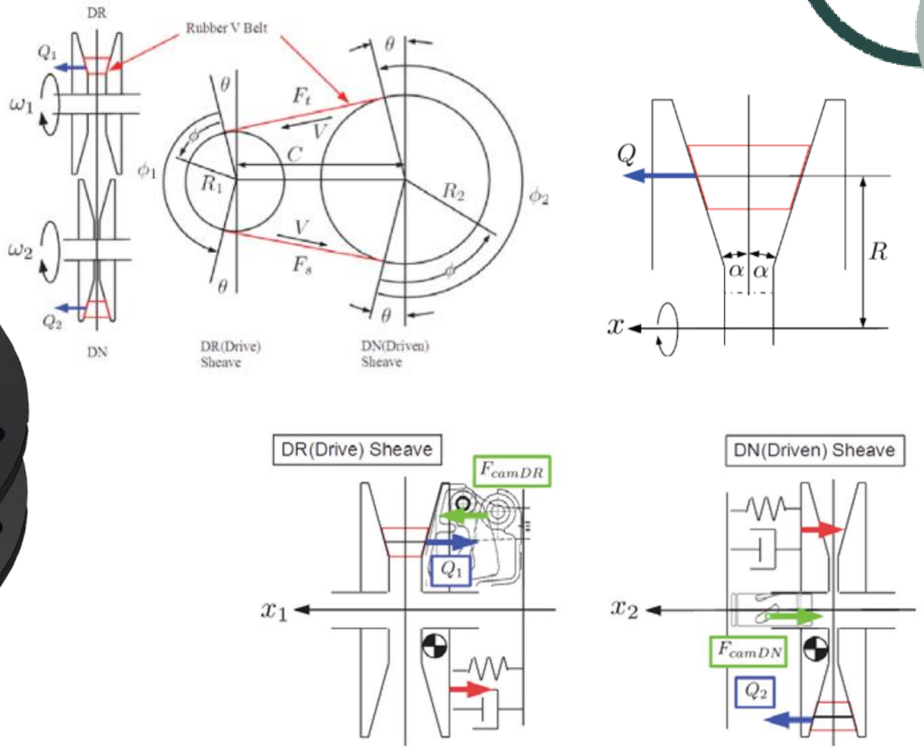
Decision Matrix

Rating	Value
Unsatisfactory	0
Just Tolerable	1
Average	2
Good	3
Very Good	4

	Importance Weight	**Custom Secondary Pulley**		**Modified Gaged Secondary Pulley**		**Gaged Secondary Pulley**	
Criteria		Rating	Weighted Value	Rating	Weighted Value	Rating	Weighted Value
Cost	0.125	4	0.5	2	0.25	1	0.125
Weight	0.1	4	0.4	2	0.2	1	0.1
Manufacturability	0.05	2	0.1	3	0.15	4	0.2
Reliability	0.2	3	0.6	2	0.4	1	0.2
Integration	0.125	3	0.375	4	0.5	4	0.5
Serviceability	0.05	3	0.15	2	0.1	1	0.05
Complexity	0.05	2	0.1	3	0.15	3	0.15
Risk	0.15	2	0.3	3	0.45	4	0.6
Performance	0.15	4	0.6	3	0.45	2	0.3
Weight Total	1	Regular Value	Weighted Value	Regular Value	Weighted Value	Regular Value	Weighted Value
Total		27	3.125	24	2.65	21	2.225

Research + Inspiration





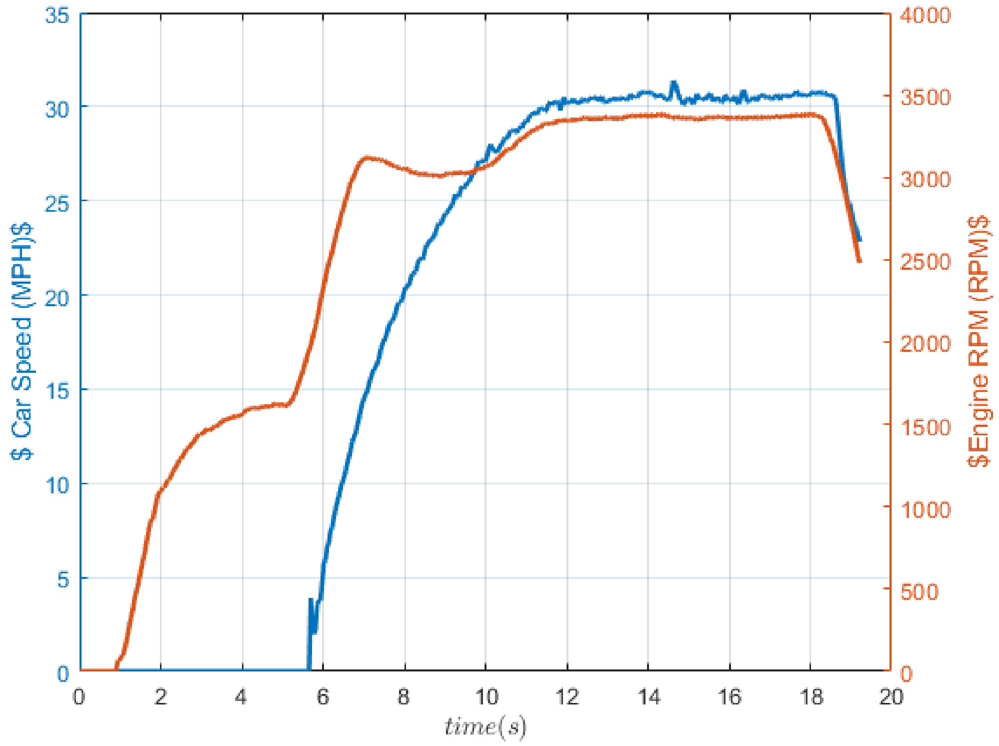
Acceleration Performance Analysis for Rubber V-Belt CVT with Belt Tension Clutching, SAE International Journal of Engines , Vol. 9, No. 1 (April 2016), pp. 417-422

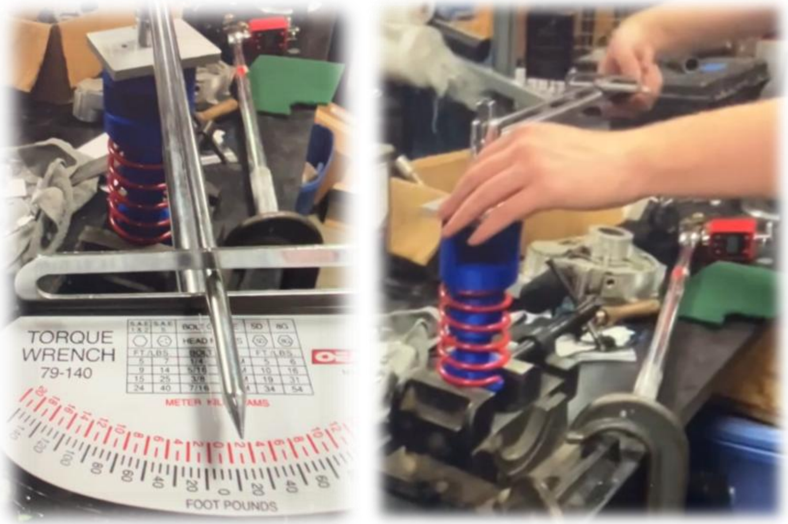
Early July 2024

Data Collection

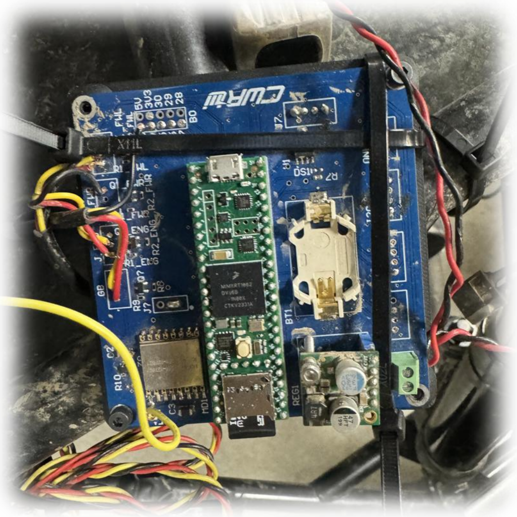
Engine RPM vs Wheel Speed: SR24 Data

Data used as reference for ideal shifting conditions for SR25, measured with hall sensor



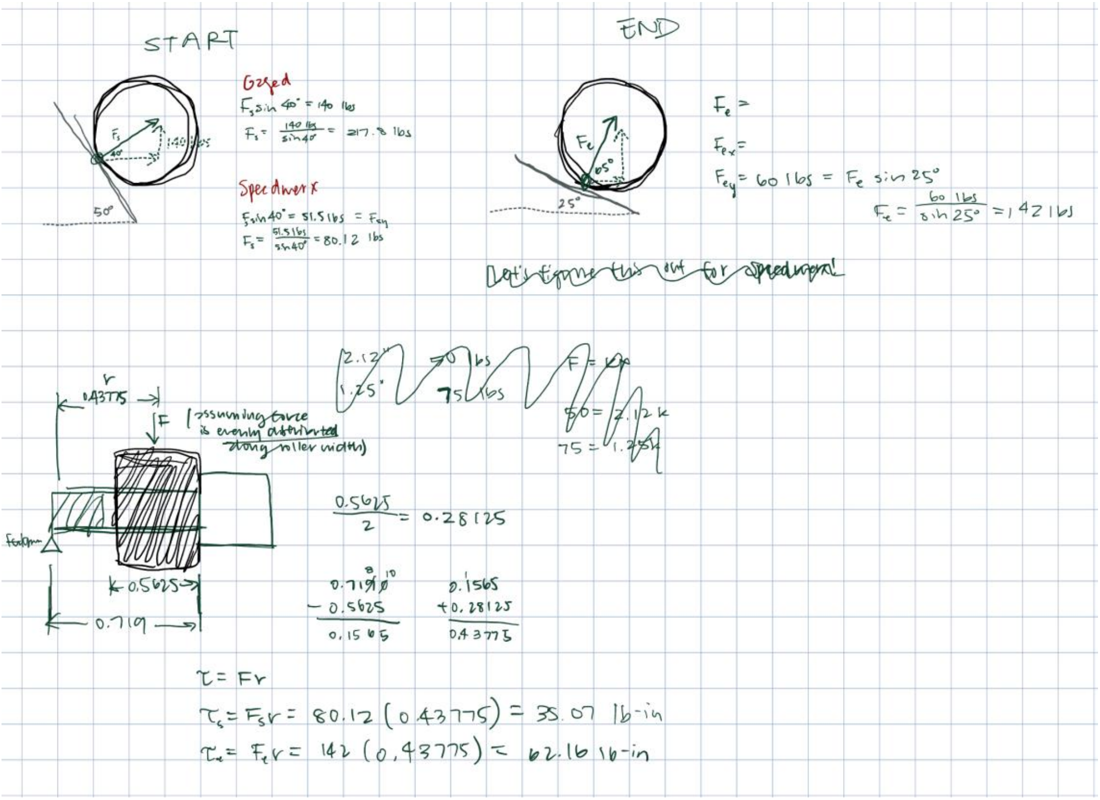


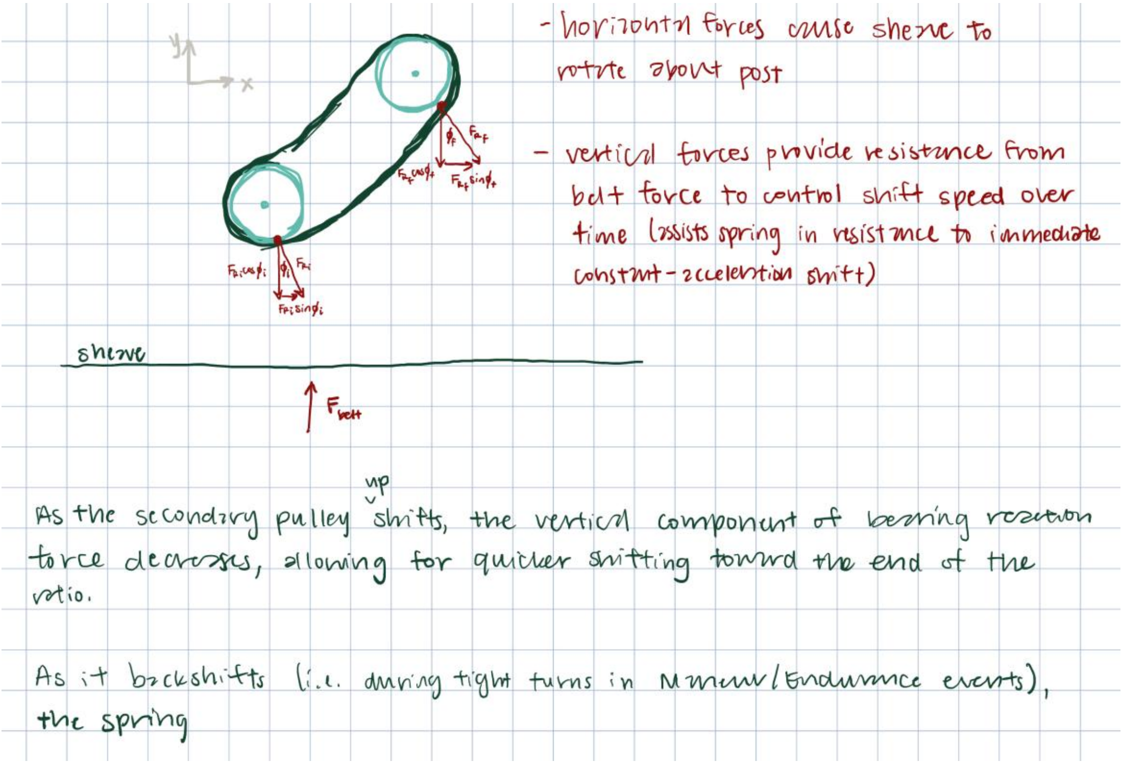
Torsion Testing of Secondary Spring



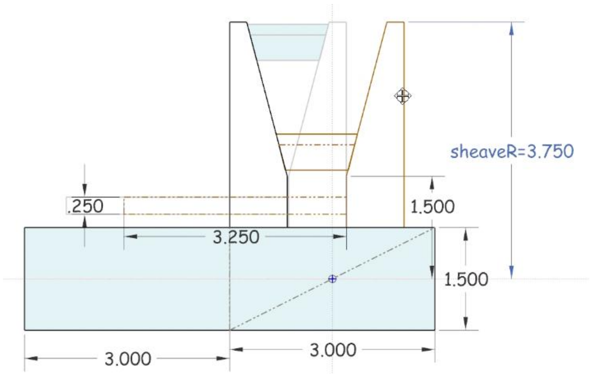
Hall Monitor Unit PCB

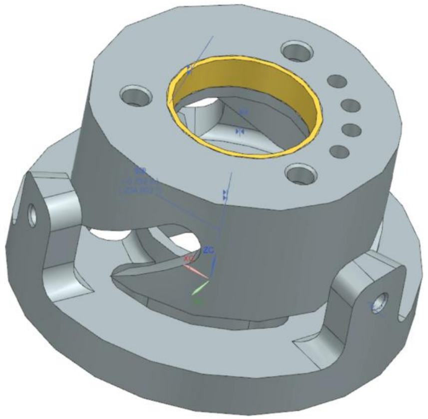
Free-Body Diagrams

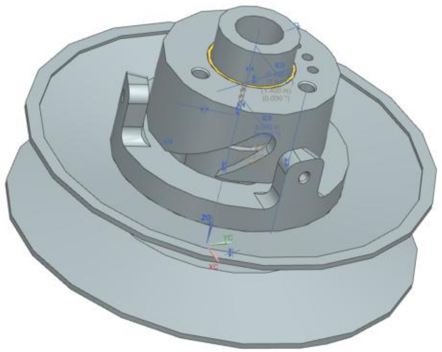


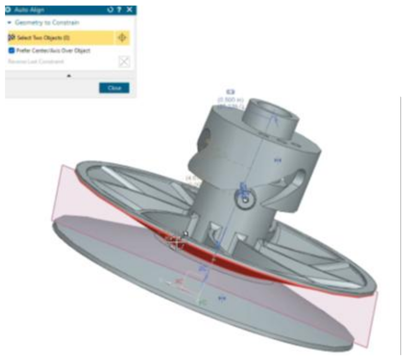


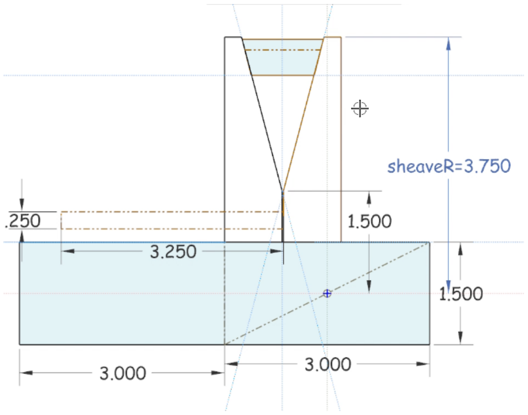
Generating Concepts

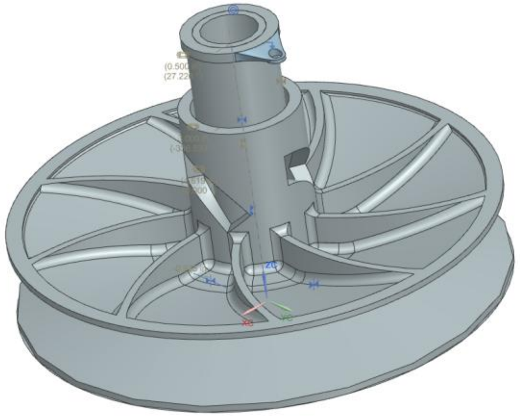


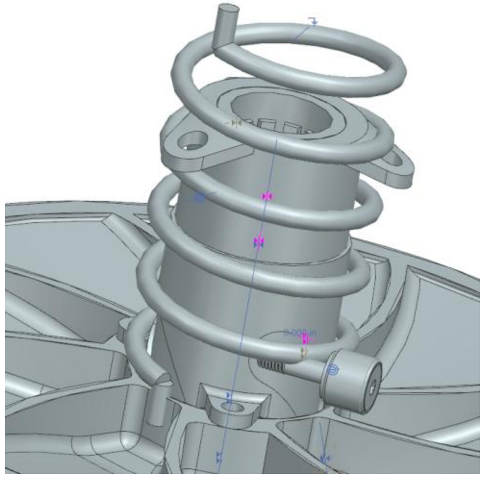


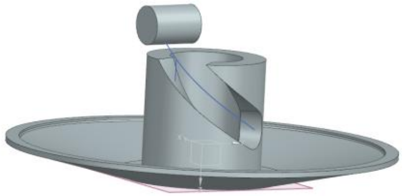








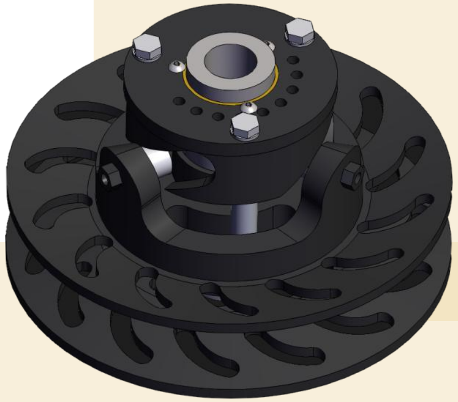


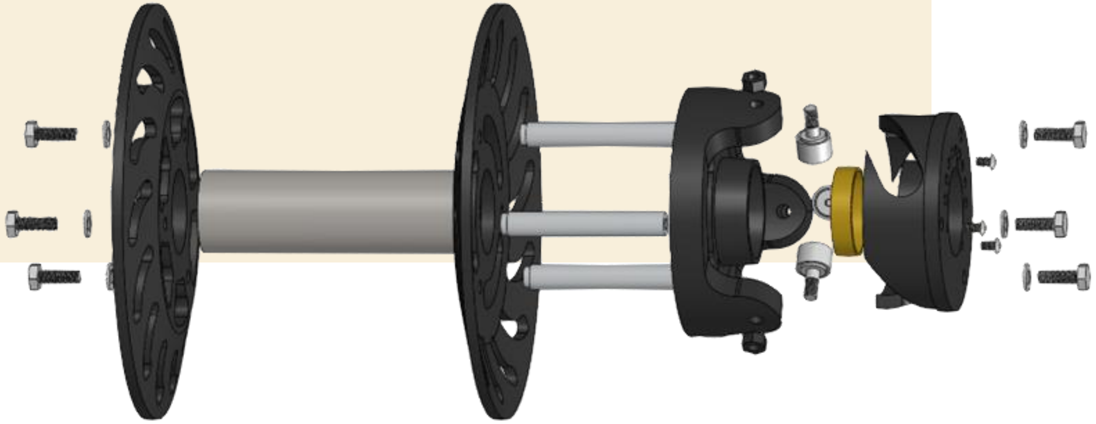


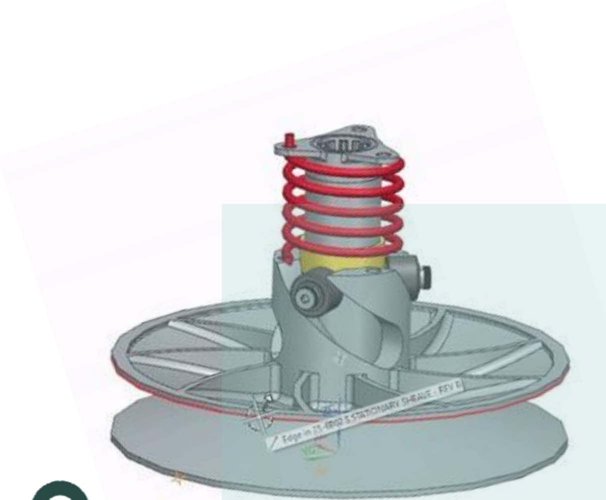
Early July to August 2024

SR24 vs SR25

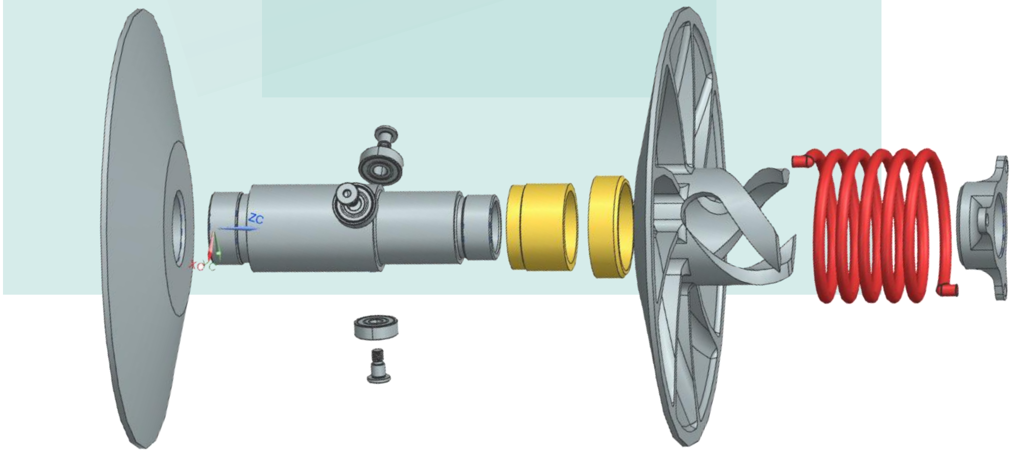
Gaged Secondary (OEM)





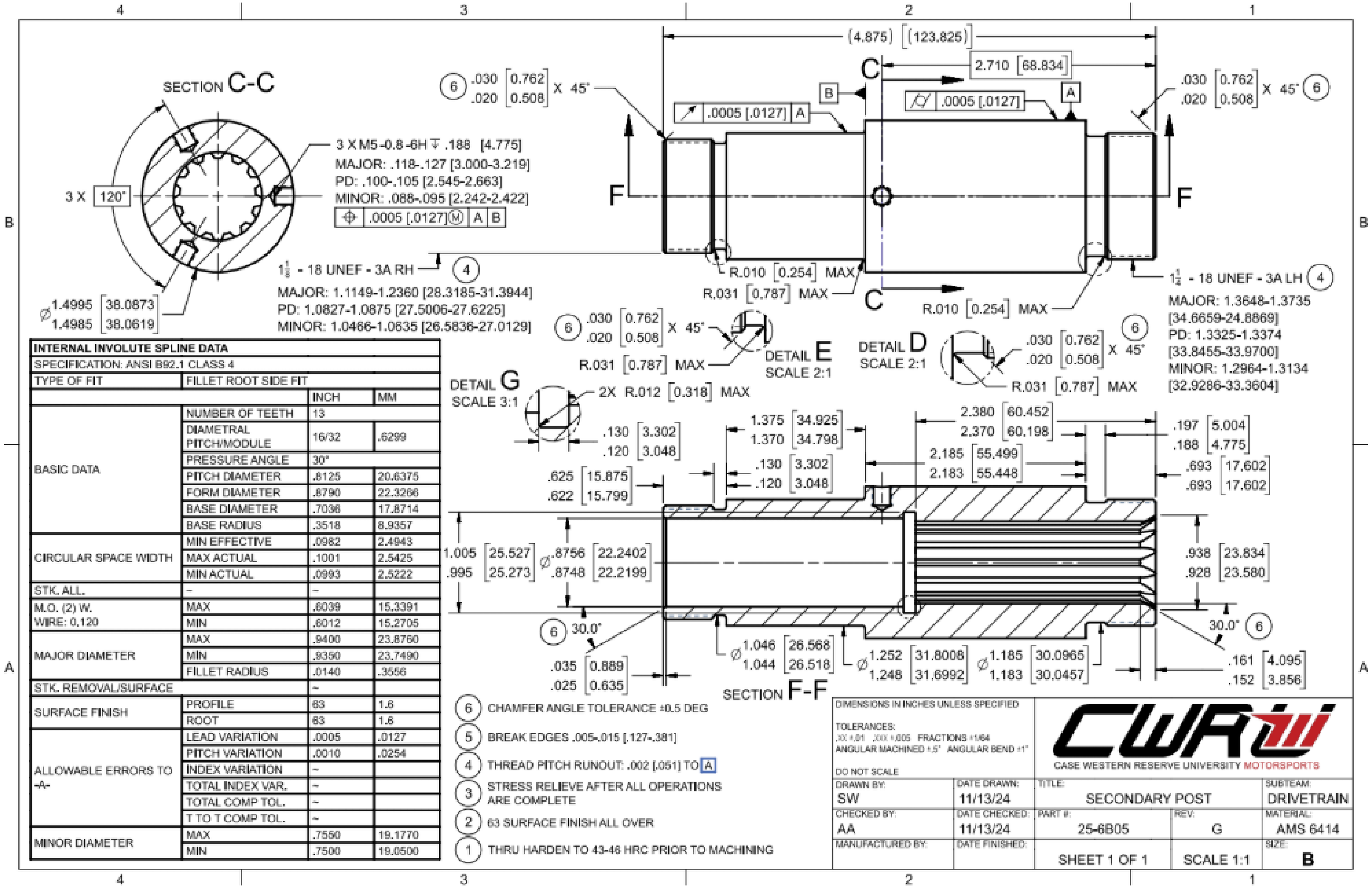


Early Versions of Custom Secondary



August to October 2024

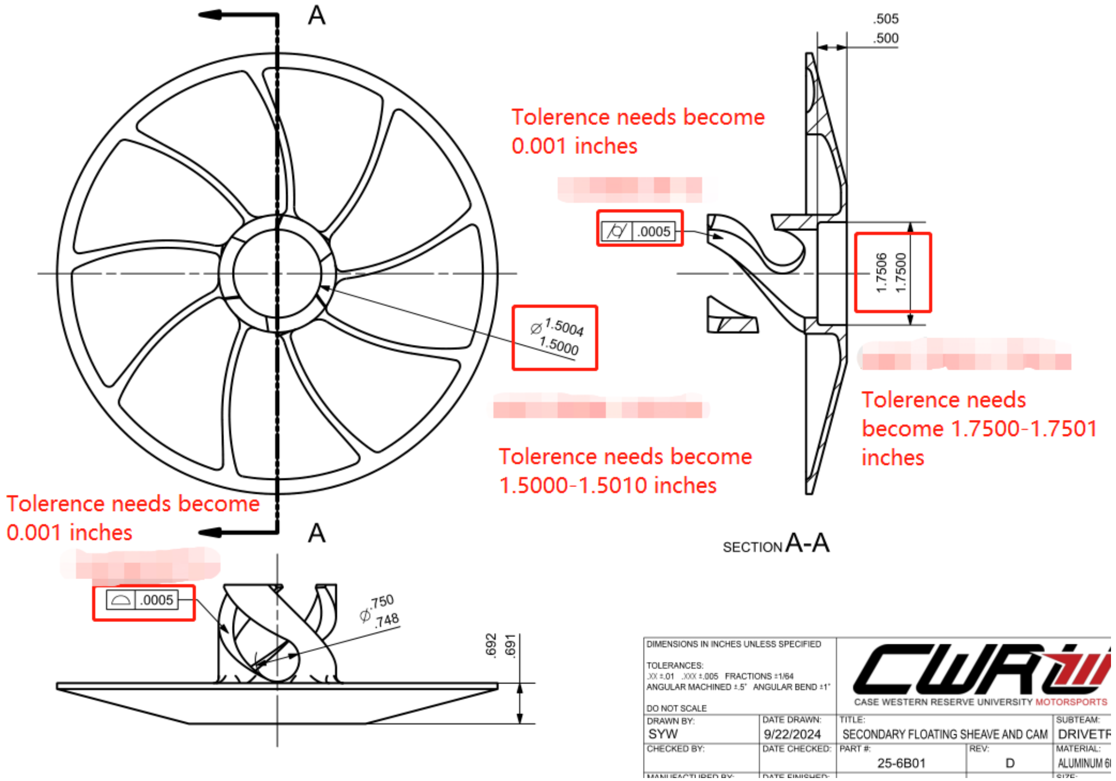
Spline Drawing for Sponsor



August to November 2024

Complex CNC Components

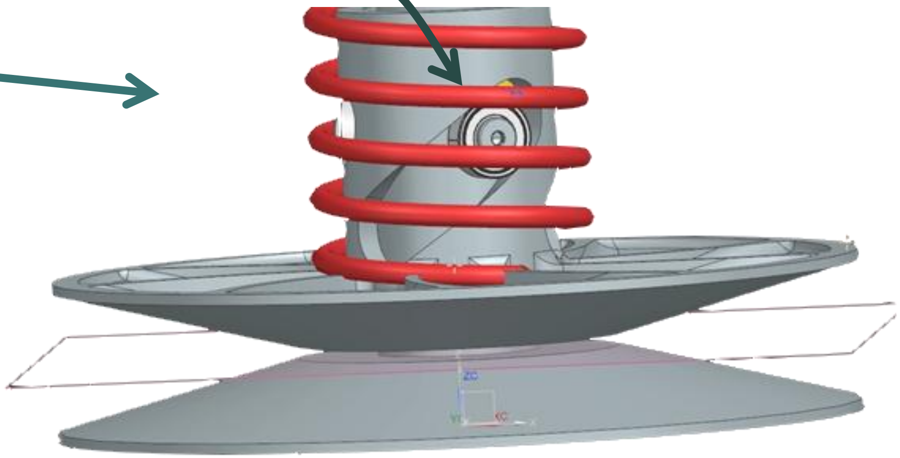
- Manufacturer required looser tolerances
  - Would the tolerances still allow for proper assembly and fits?
- Catalyst for thinking about a more manufacturable design



Late September 2025

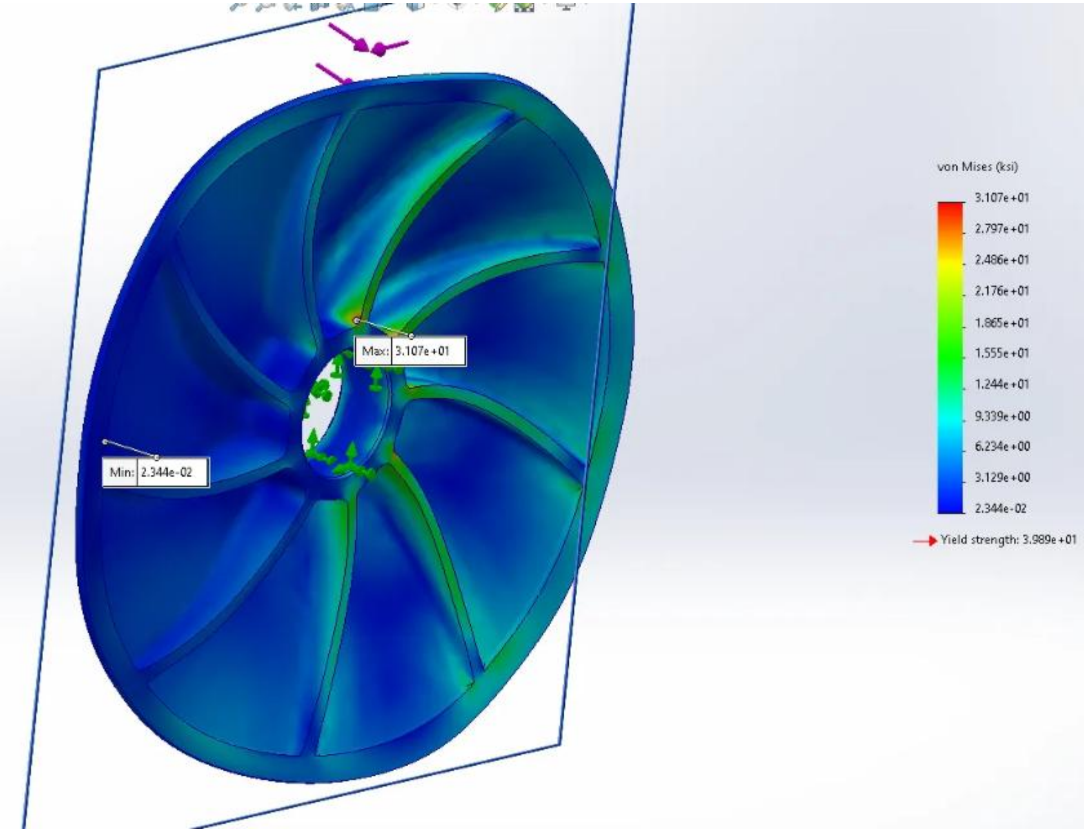
Iteration + Prototyping

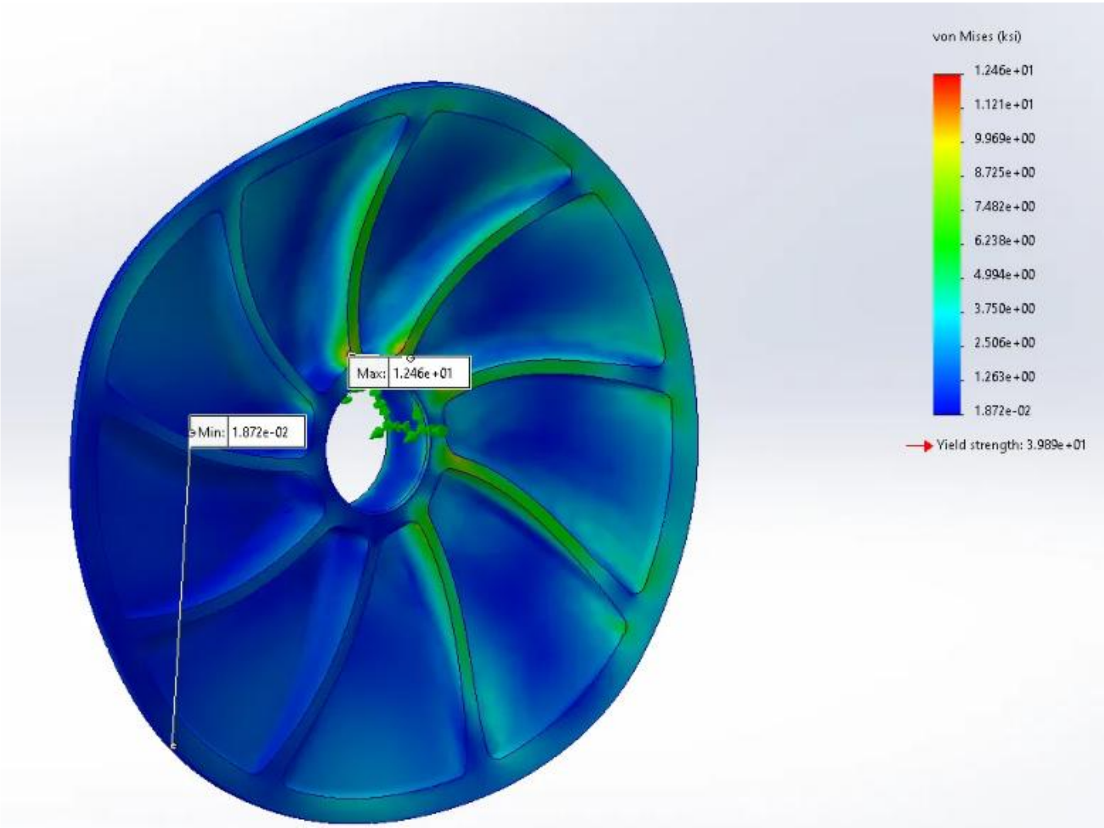
Closed helix for structure due to smaller radius taking more load from bearings



Early November to Mid-December 2024

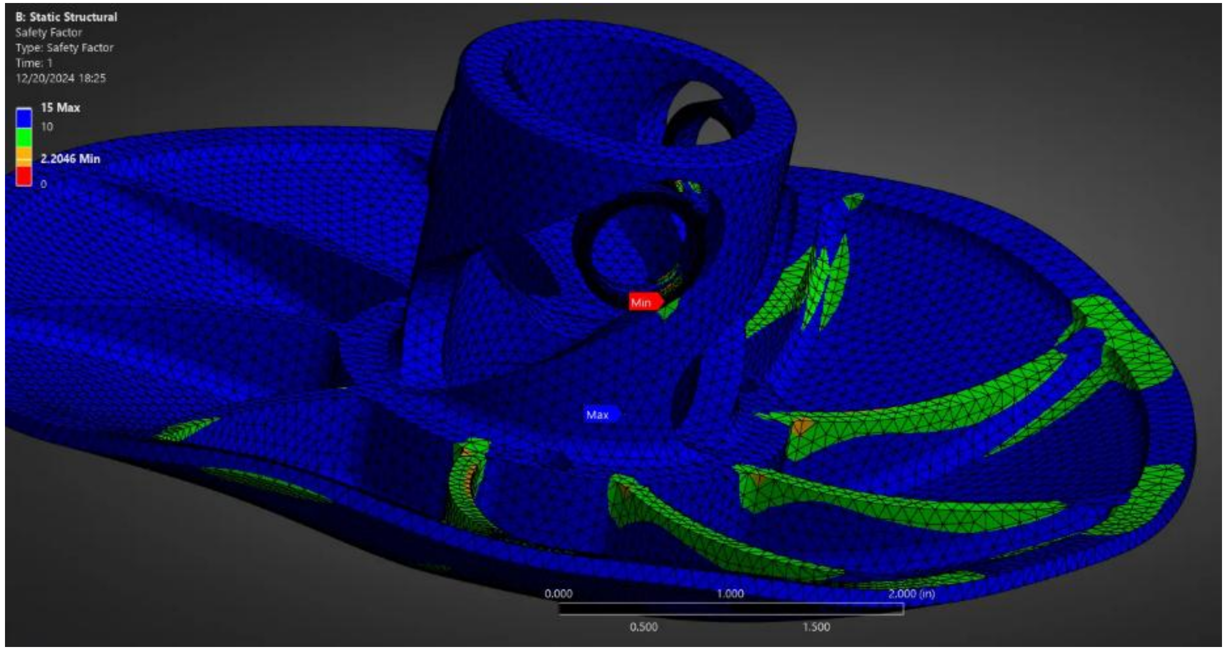
Finite Element Analysis

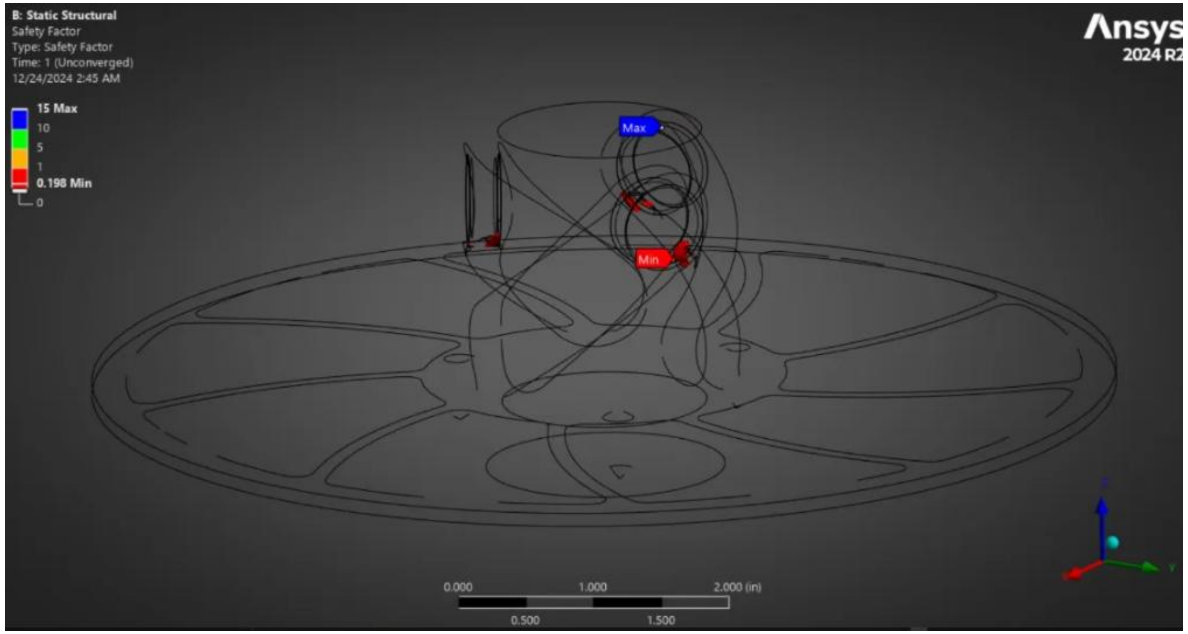




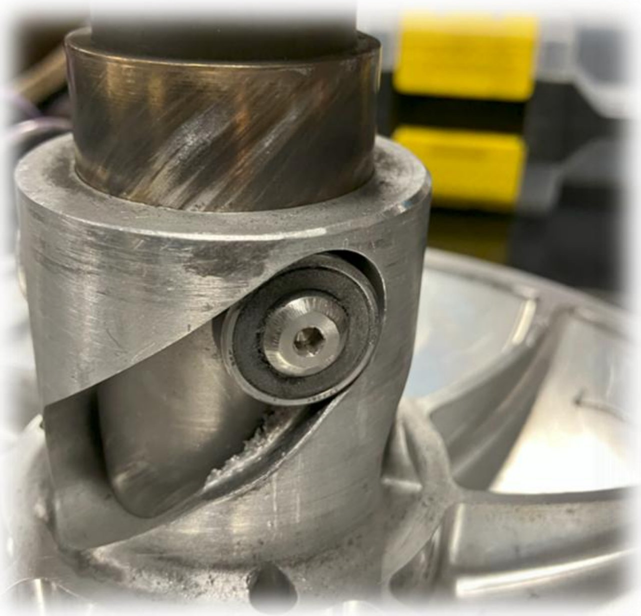
Late September 2024

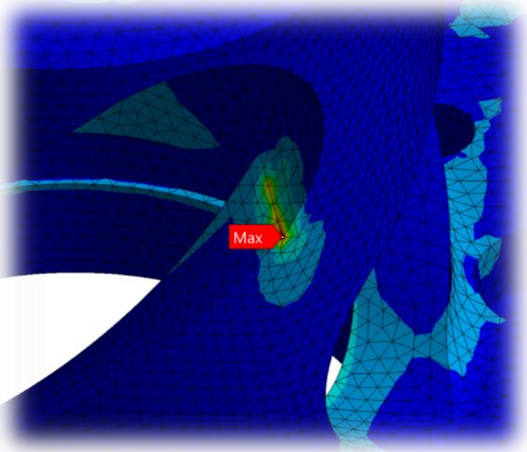
Finite Element Analysis

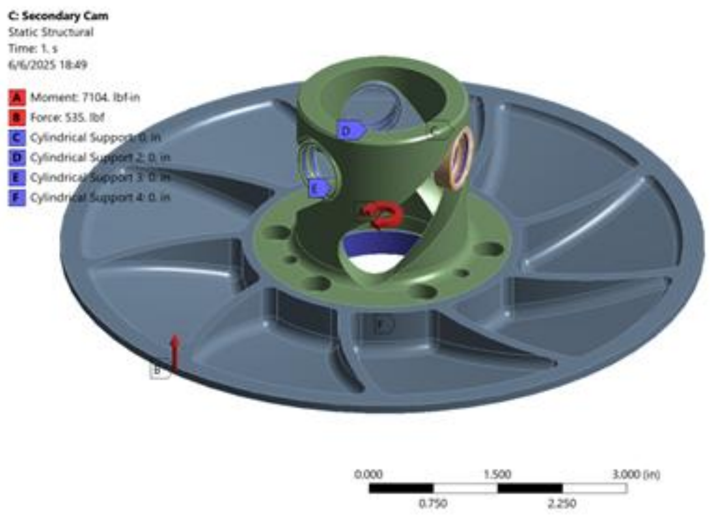


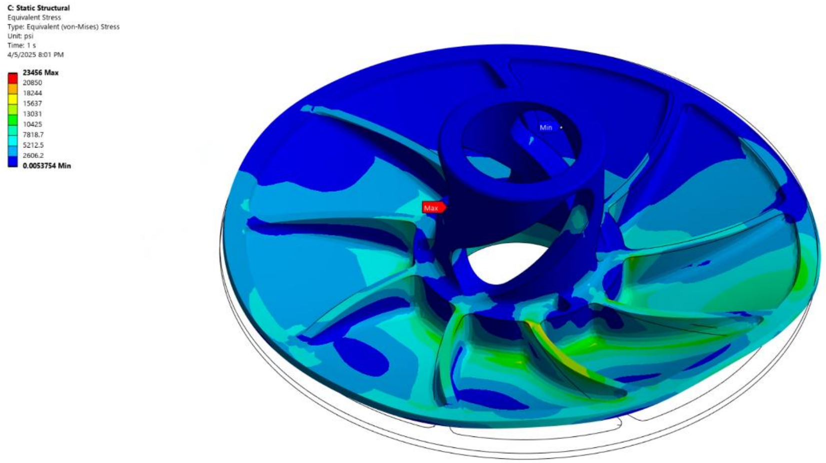


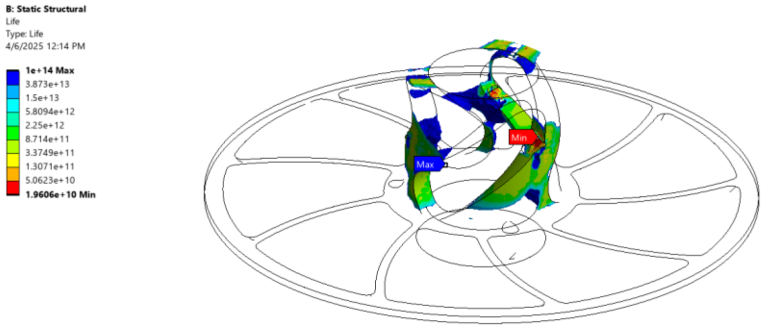
Finite Element Analysis











March to April 2025

Manufacturing

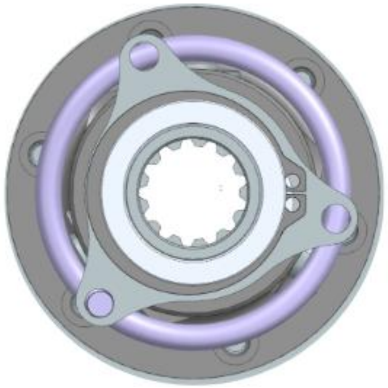
Machined bushings, allowing for control over concentricity and press/slip tolerances

Assembly

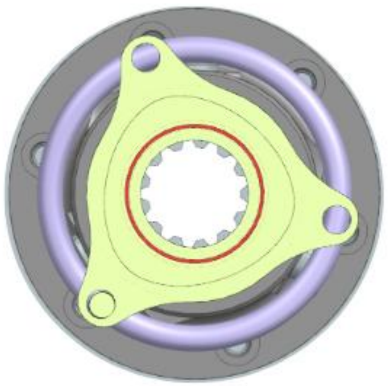
- Many threads and much Loctite → not design for assembly
- Looser tolerances are actually okay

Iteration

Initial Version:
Threaded Spring Retainer

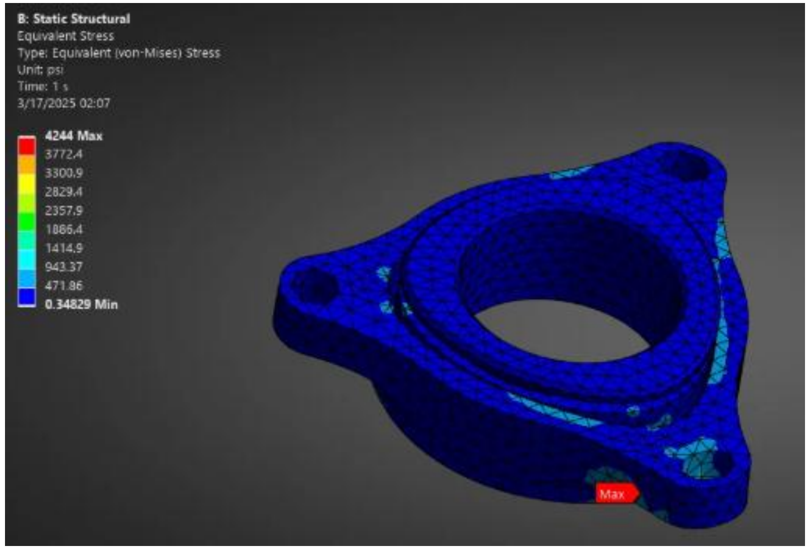


Top View



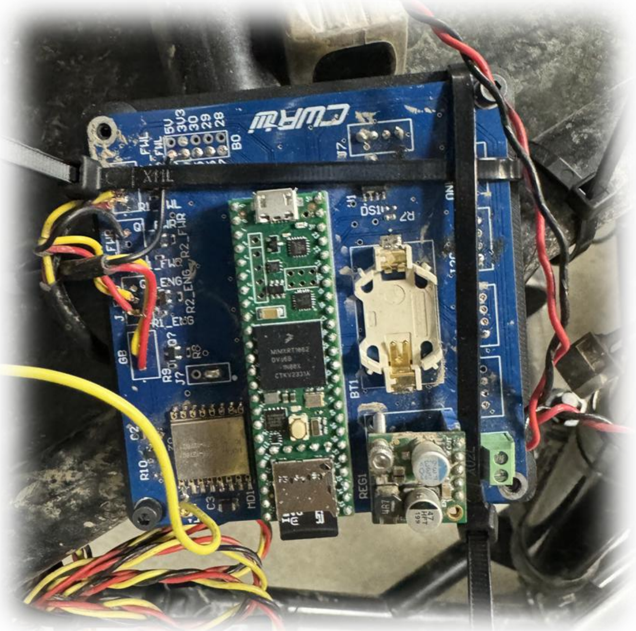
Section View
(Trilobe Profile)

Revision A:
Trilobe Spring Retainer

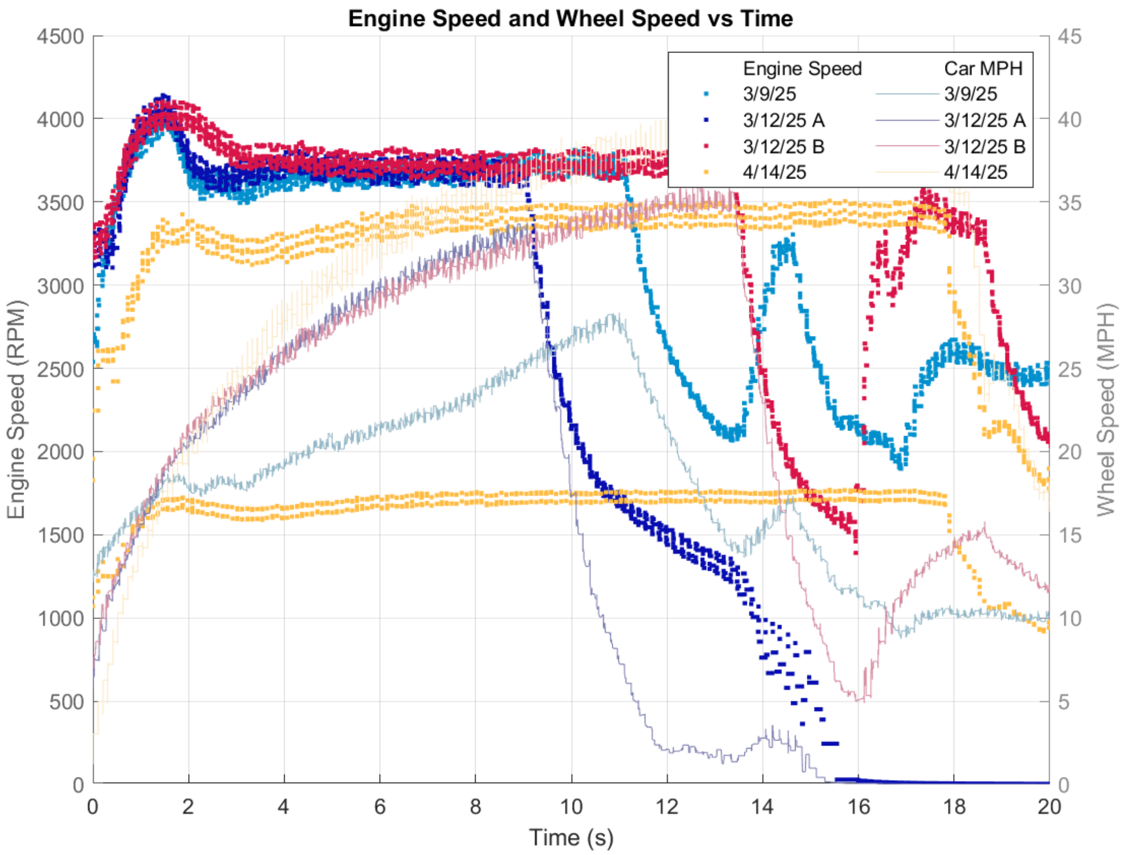


March to April 2025

Testing



Testing



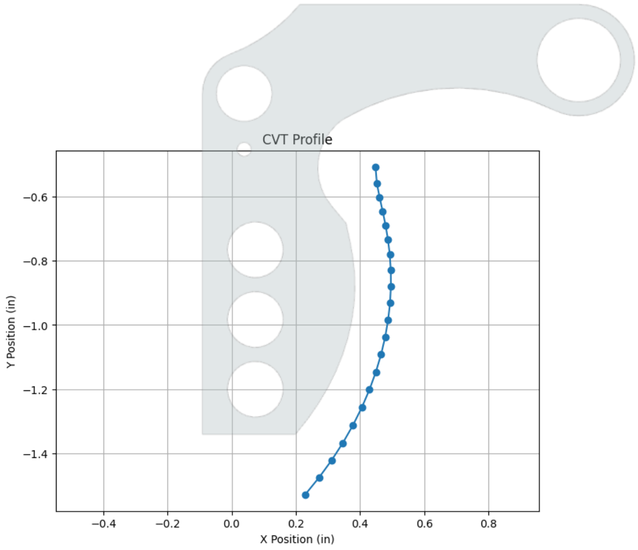
Discrepancies Between Analysis and Testing

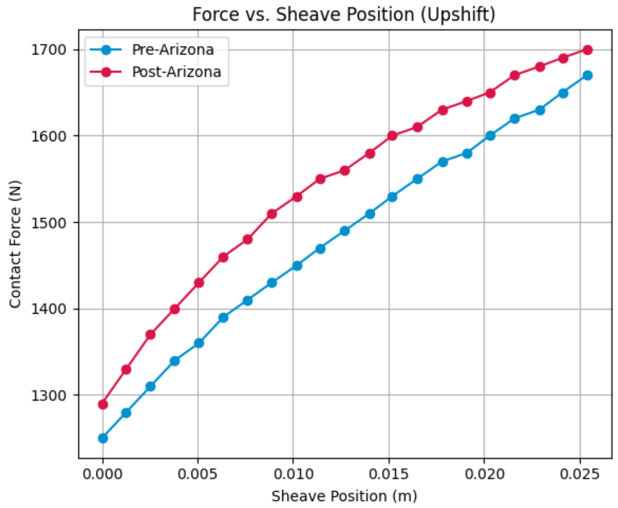
- Friction in system
  - I.e. bushings sliding on post, friction coefficient between belt and sheave material
- Flyweight COM position ineffective

Arizona Competition

- Belt slipping/skipping issues
  - Due to temperature differences
- Not shifting to full range
- Not shifting at peak power

Reflection + Testing + Iteration





Generating Flyweight Profiles and Masses/Center of Mass

- Python script
- Input desired contact angles based on desired shift RPM
- Variable profile as CVT shifts, lines up with engine RPM

Design Process Between Competitions

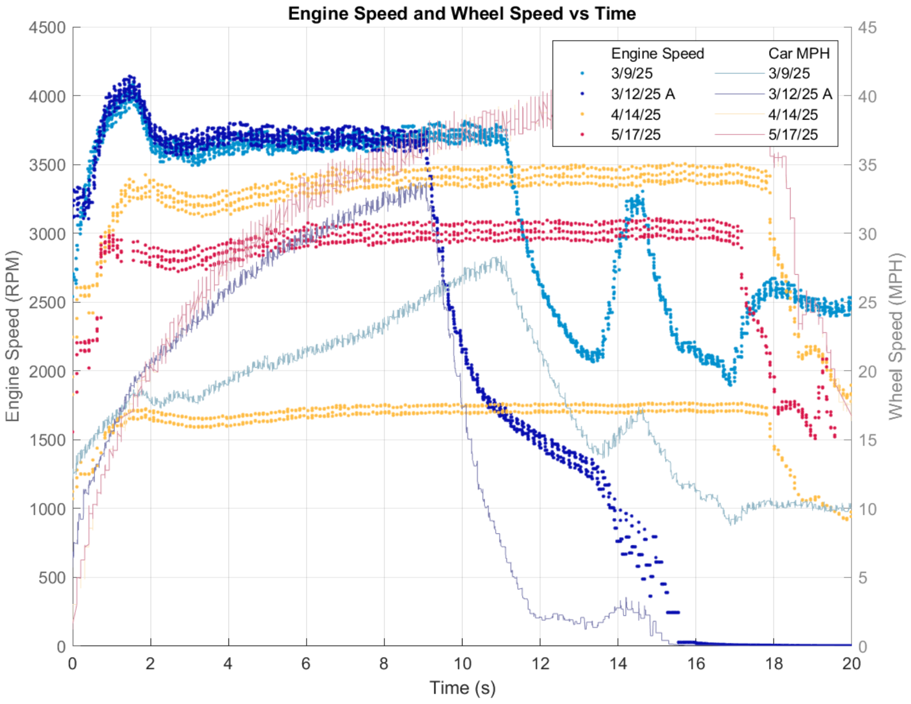
- Based on testing data before Arizona competition, new COM position with more acceleration force
- Secondary sheaves closer together to increase shift range

May to Early June 2025

Reflection + Testing + Iteration

Engine RPM vs Wheel MPH and Engine RPM + Wheel MPH vs Time: CVT Tuning Data

Data used to calculate new system tuning parameters

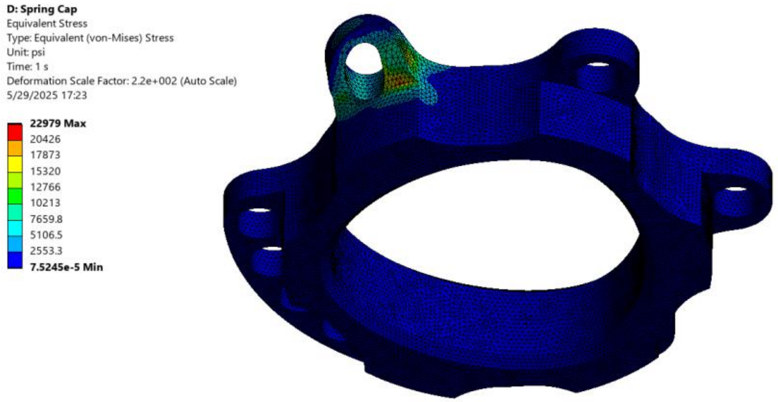


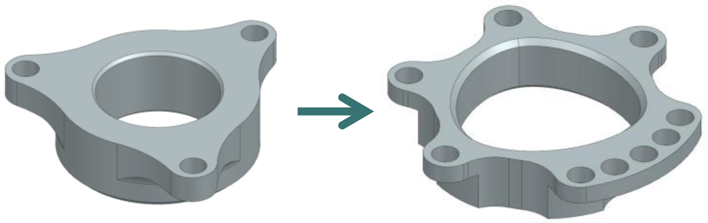
Correlation of Analysis and Testing

- Greater acceleration force from flyweights → stronger launch and faster acceleration
- Decrease distance between secondary sheaves → increase top speed

May to Early June 2025

New spring retainer design to prevent spring cocking and provide more pretension options





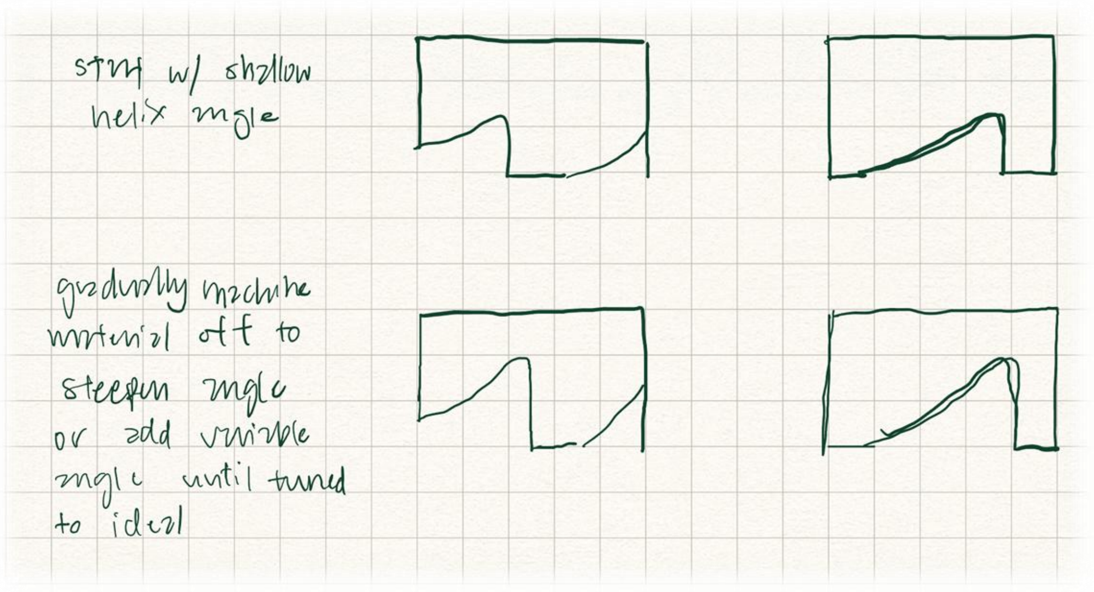
Maryland Competition

- Even wear on bushing
  - Less efficiency lost to friction from cam sliding on bushing
- Still not reaching top speed overall

Mid-June 2025

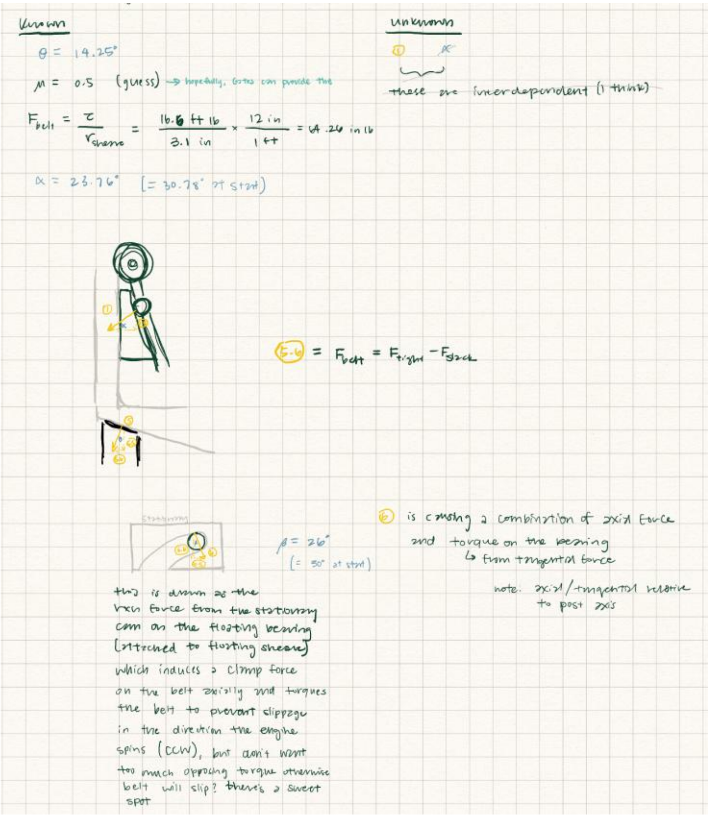
Improvements + Advice for Future Designers for Secondary CVT

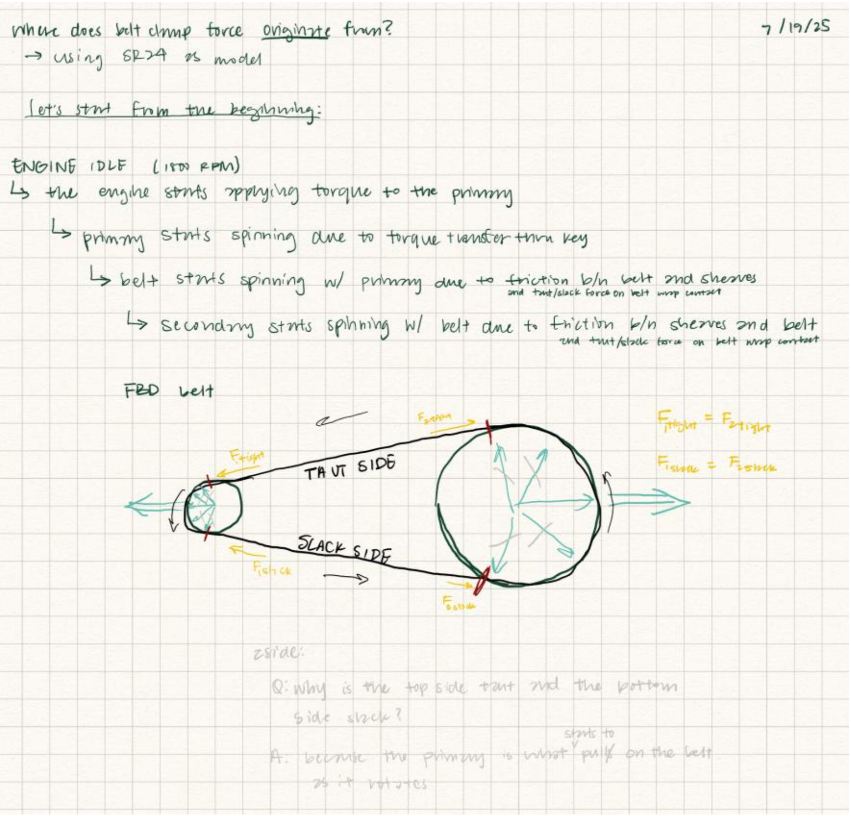
- Helix
  - Manufacturable
  - Tunable
- Spring
  - Finalize decision early-on
  - Test spring rates with higher granularity
- Spring retention
  - Prevent cocking of spring to maintain desired spring performance

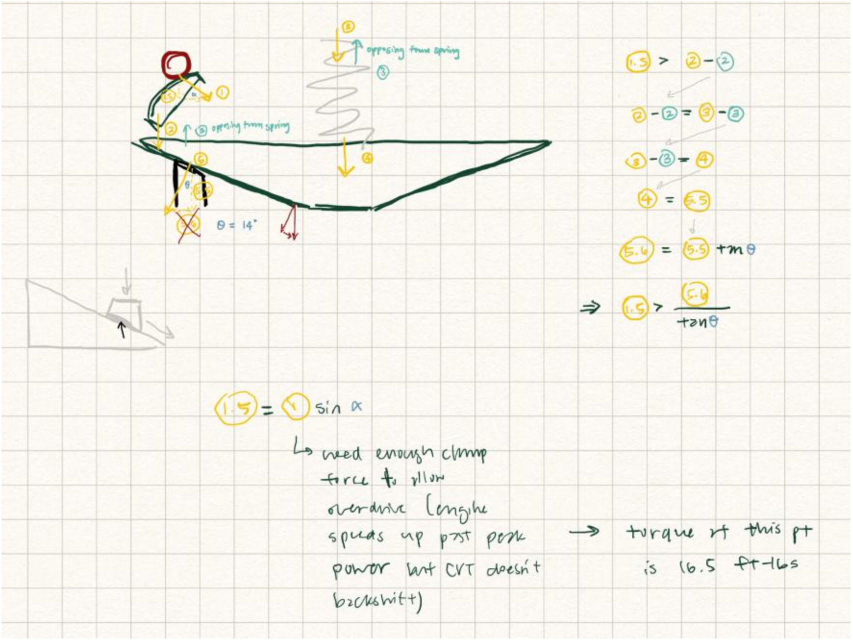


CVT Improvements for SR26 (2025-2026 Season)

Free-Body Diagrams
- Fully understand entire system
- Get an idea of what variables to tune



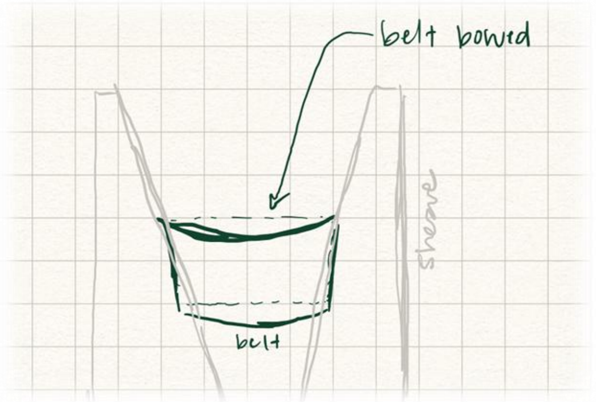


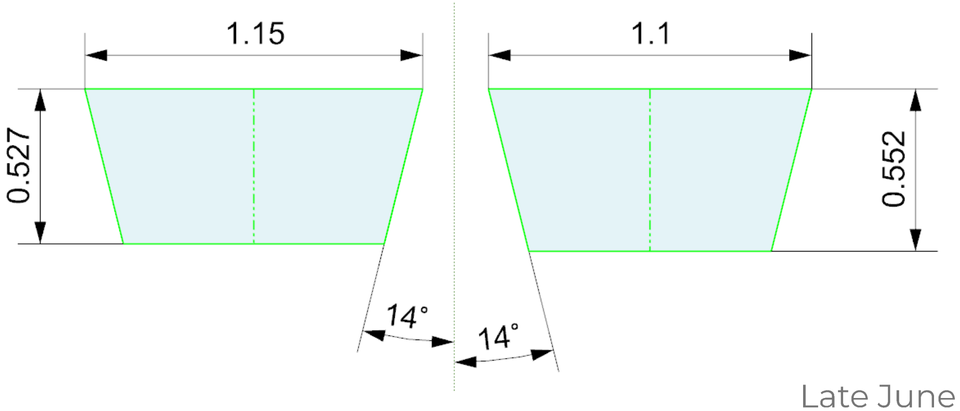


Mid-July 2025

CVT Improvements for SR26 (2025-2026 Season)

Problem	Solution
Belt slip on primary	More belt clamp force
Overheating system	Solve belt slip problem, integrated cooling
Didn't reach full shift range	Increase overall system efficiency, solve belt slip problem
Belt bowed (when looking at cross-section)	Increase height to width ratio by decreasing width





Late June to Early August 2025

CVT Improvements for SR26 (2025-2026 Season)

Problem	Solution
Wear and tear	Design for lower stresses by having greater contact areas and appropriate material pairings for contacting components
Uneven wear and tear	More controlled spacing of pulleys in shroud





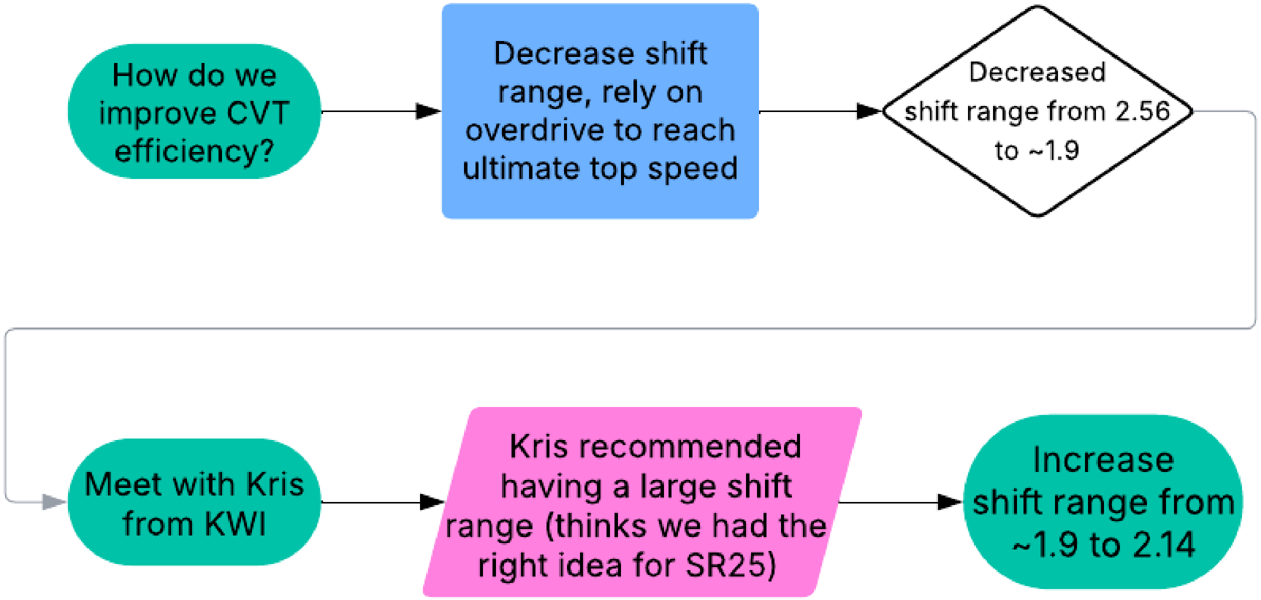
Late June to Early August 2025

CVT Improvements for SR26 (2025-2026 Season)

Ratio Decision-Making

Main Drivers:

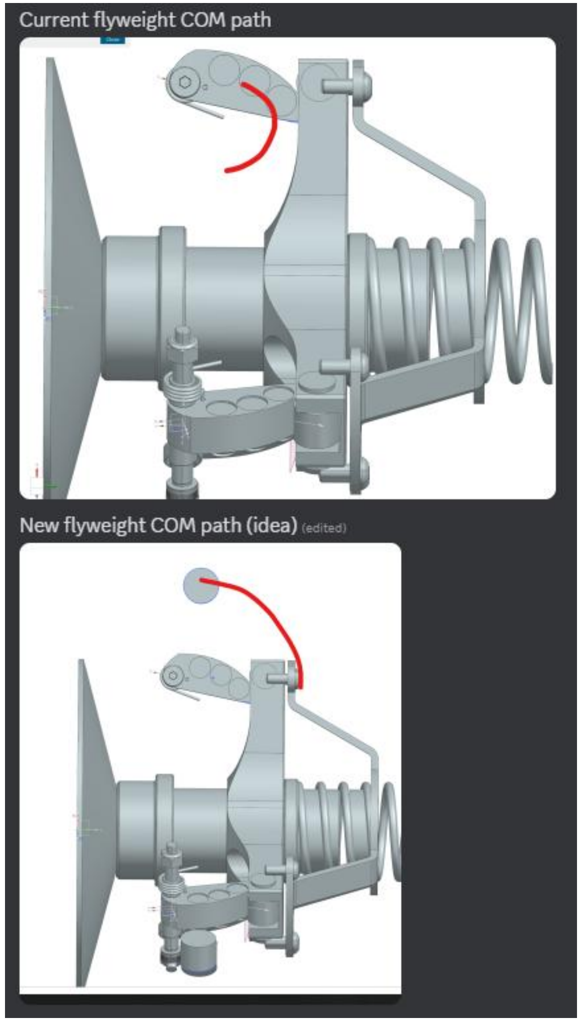
- Increase torque from SR25
- Rely slightly more on overdrive (empirically, efficiency is better that way)
- Primary post one-way bearing diameter



Late June to Early August 2025

CVT Improvements for SR26 (2025-2026 Season)

Problem	General Solution	Design Solution
Belt slip on primary	More belt clamp force	Flyweight COM position + spring rate
Sheave wear on primary	•Solve belt slip problem •Harder sheave material	•More clamp force •7075 sheaves (SR25: floating sheave was 7075, stationary was 6061)



Late June to Early August 2025

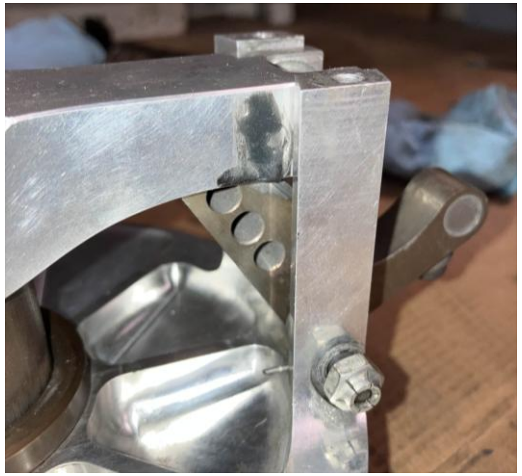
CVT Improvements for SR26 (2025-2026 Season)

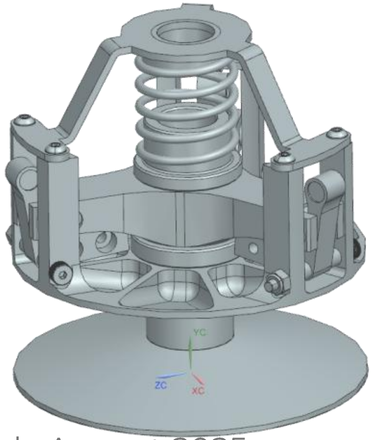
Problem	General Solution	Design Solution
Didn't reach full shift range	• Solve belt slip problem • Increase efficiency of overall system	• Flyweight COM position + spring rate • Increase minimum belt wrap radius
Heat build-up	• Solve belt slip problem • Increase efficiency of overall system • Extra cooling/more shroud ventilation	• Flyweight COM position + spring rate • Integrated fan/CFD • Increase minimum belt wrap radius

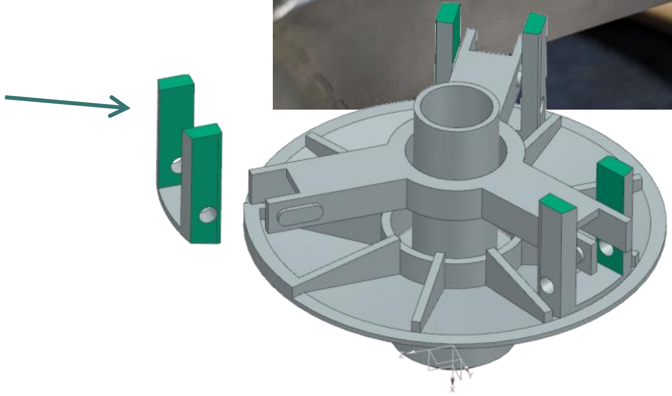
Late June to Early August 2025

CVT Improvements for SR26 (2025-2026 Season)

Problem	General Solution	Design Solution
Roller pins slipping out	Better retention of whatever component the roller is rotating about	Mini circlips on both inner ends
Flyweight/spider not maintaining positions clocked to each other	Prevent wear in mating components	• Press in one long piece that acts as both the spacers and a bushing to minimize wear on both the shoulder bolts and spacer" • Wider PTFE bushing on spider, break edges on floating sheave stands







Late June to Early August 2025