

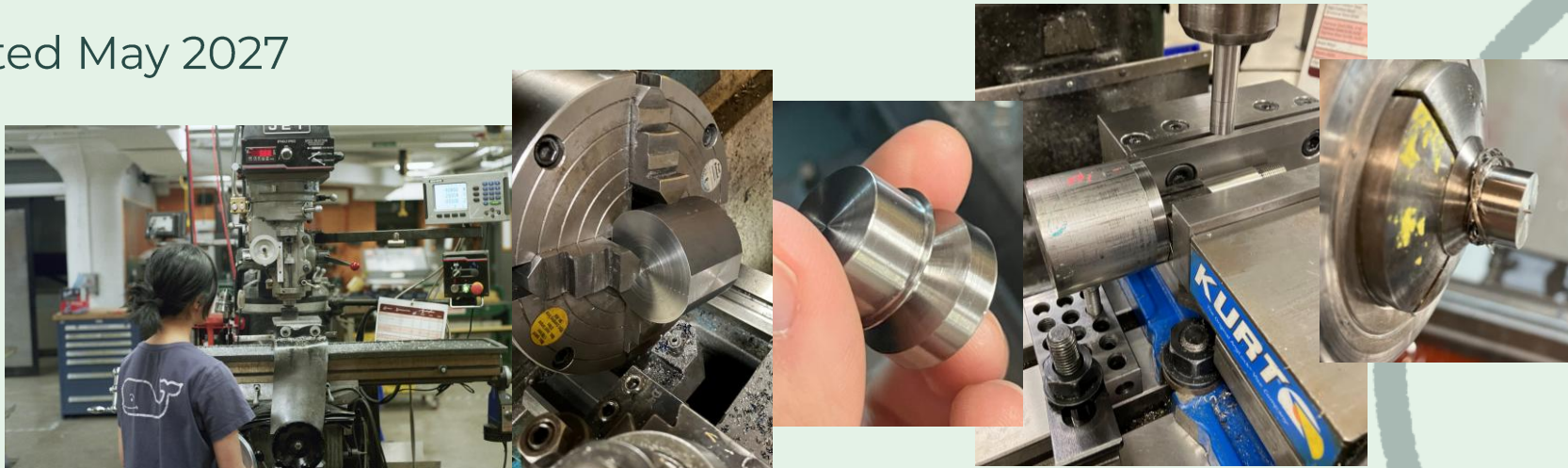
baja-ing art-ing
traveling music-ing
notion-ing metal-cutting

Shelley Wei

B.S.E. Mechanical Engineering

Case Western Reserve University

Expected May 2027





Baja SAE: Continuously Variable Transmission

Shelley Wei

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



Hill Climb



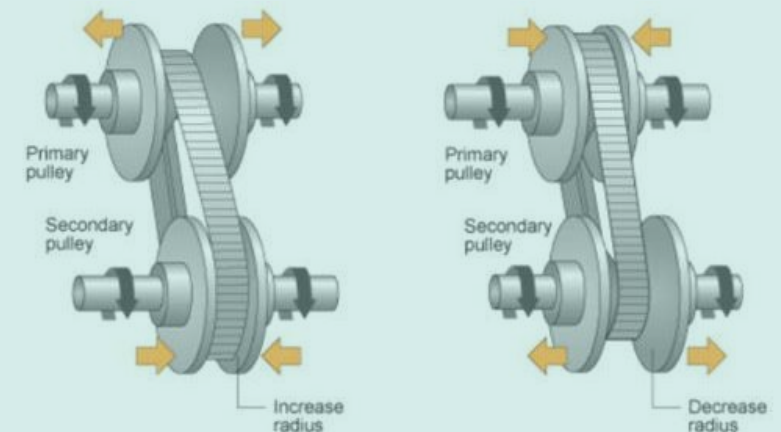
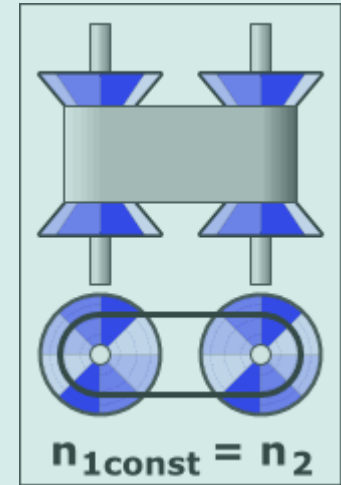
Suspension & Traction



Endurance

What's a continuously variable transmission (CVT)?

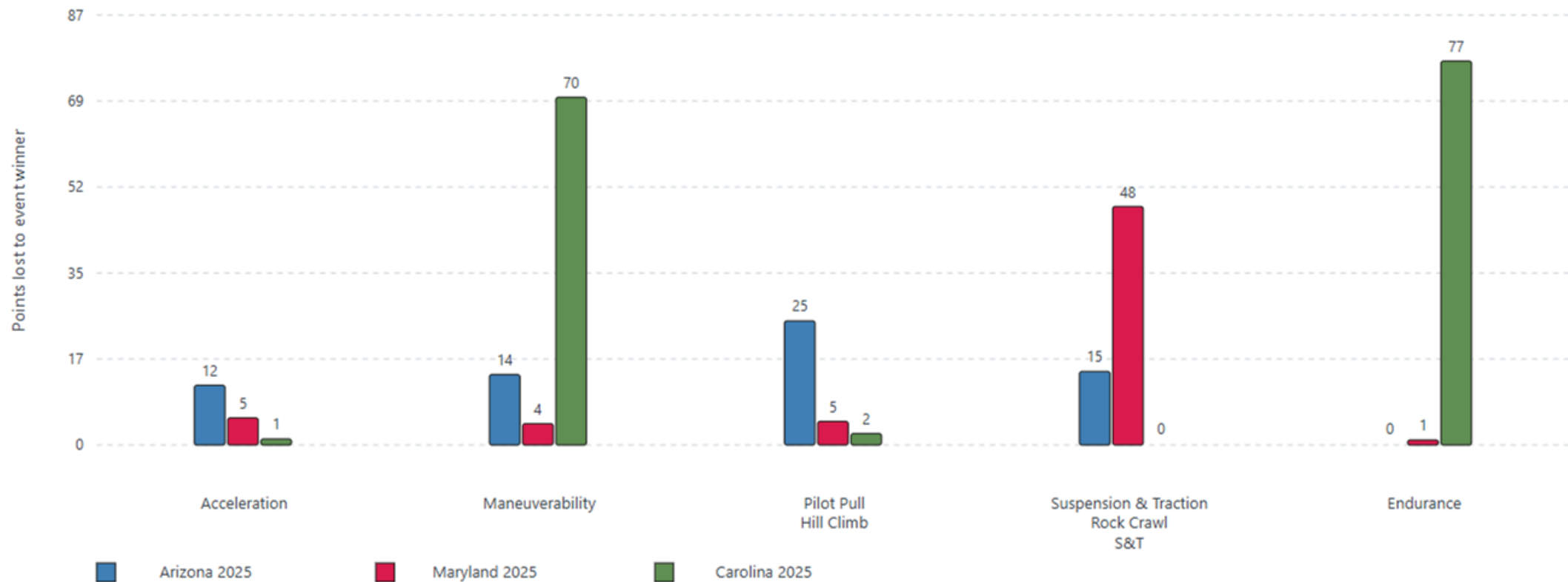
- Used in some road cars, ATVs, and snowmobiles (and Baja SAE cars)
- Consists of input pulley, output pulley, belt
- No discrete gearings
- Purpose: accelerate vehicle at engine peak power ($P = mav$)



Setting Requirements

2025 Season: Points Lost by Dynamic Event

Each bar is the event winner's posted points minus CWRU Motorsports' posted points for that competition.

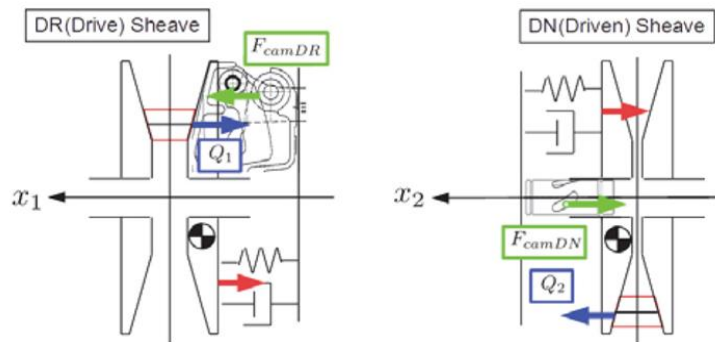
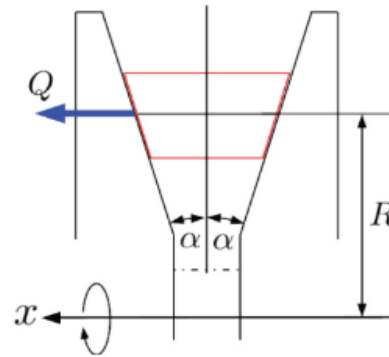
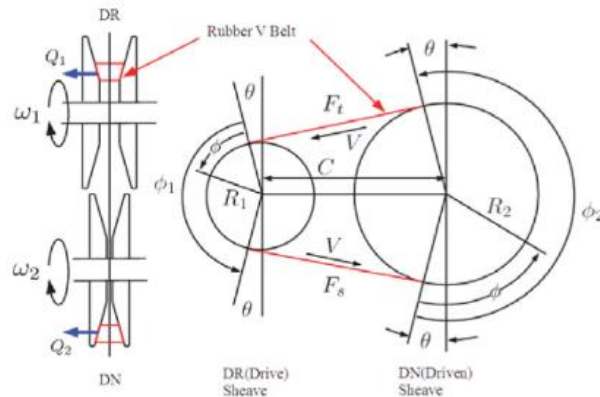


Early June 2025

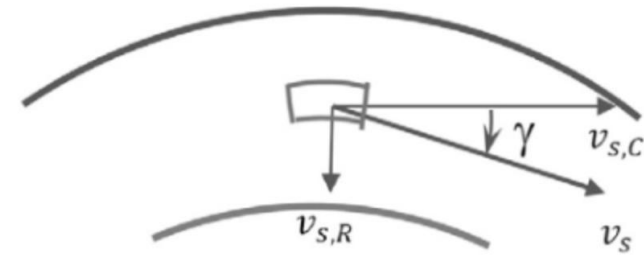
Setting Requirements

Vehicle Requirements	Cascaded Requirements
Components must perform consistently for 16 hours in Endurance conditions	Drivetrain components must meet the 95% confidence interval and maintain a minimum FOS of 1 for at least 16 hours of runtime
Able to maintain 90% of entry speed through any obstacle.	Drivetrain must be able to climb benchmark concrete wall obstacle from standing start on dirt
100-foot acceleration time of 3.85 seconds on a dirt surface straightaway	• Drivetrain mass shall not increase more than 2% from SR25 • Drivetrain efficiency shall be at least 77% • CVT shall shift at engine peak power
Complete 300-foot dirt surface straightaway in 9 seconds	Gearbox/CVT ratio must enable a top speed of 40 MPH
Lap times must not increase more than 5% after 5 hours of runtime	Acceleration times must not increase more than 5% after 5 hours of runtime
Complete a benchmark figure-8 course within 6 seconds on a dirt surface	CVT must be able to shift from highest ratio achieved during a benchmark figure-8 to 75% of ratio (or lower) in 0.2 seconds

Research



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



$$\frac{dT}{T - qv^2} = \left(\frac{f_c}{\sin\theta + f_R \cos\theta} \right) d\alpha = f_v d\alpha$$

$$T - qv^2 = Ce^{f_v \alpha}$$

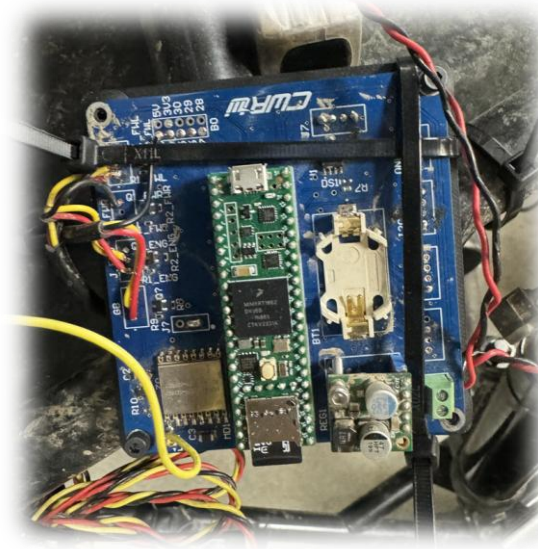
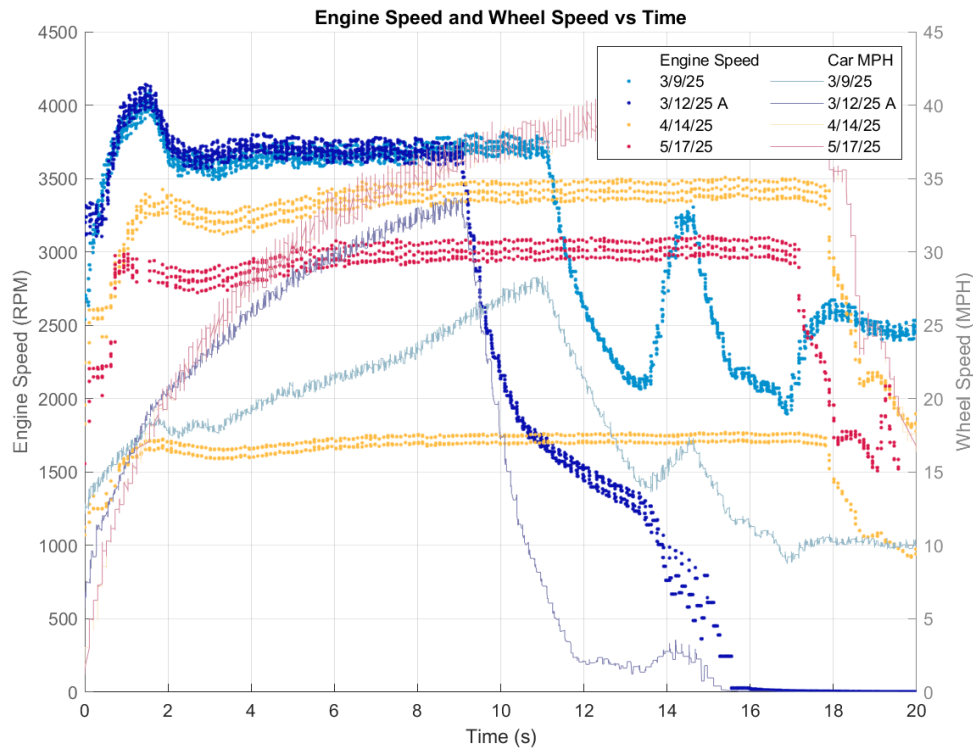
Analytical model for the power losses in rubber V-belt continuously variable transmission (CVT), Mechanism and Machine Theory, Vol. 78, No. 1 (2014), pp. 289–306.

- Derives equation for **belt tension**
 - Important factors for efficiency include **belt tension**, belt wrap angle, COF, and sheave angles

Data Collection

Engine RPM vs Wheel Speed: SR25* Data

Data used as reference for ideal shifting conditions for SR26*, measured with hall effect sensor



Hall Effect Sensor PCB



Spring Coefficient Testing of Primary Spring

* Our car models are named SRXX, where XX is the number car. SR25 was our 2024-2025 vehicle, while SR26 is our 2025-2026 vehicle.

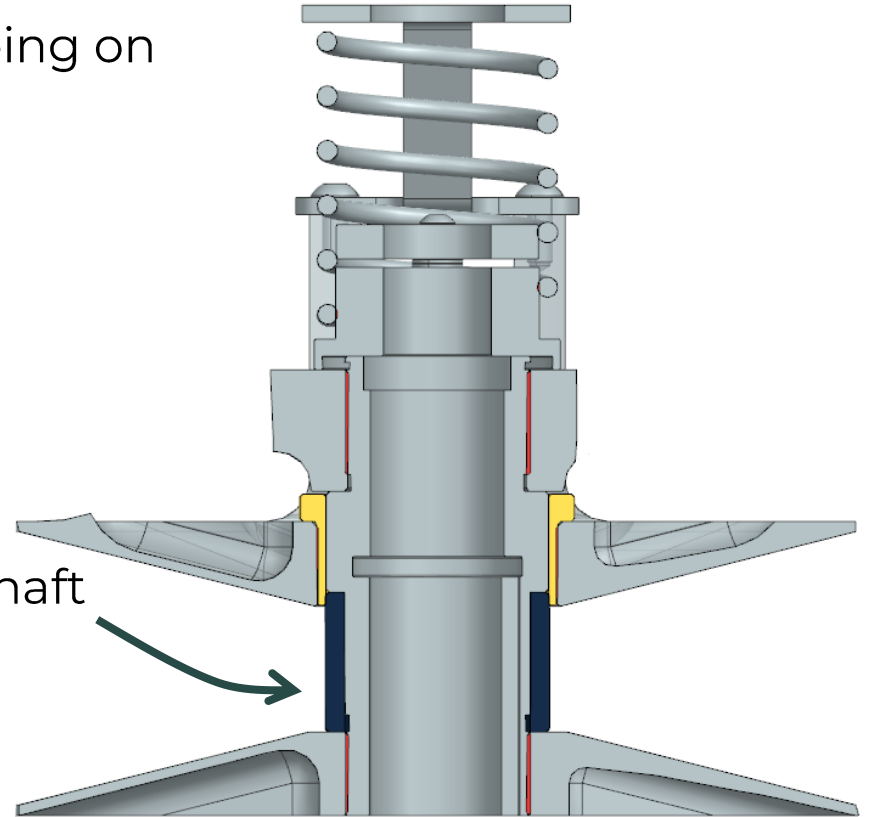
Bearing on Shaft

- First attempt at using in team history
- Allows for increase in belt tension without belt rubbing on shaft while spinning
 - Increasing belt tension increases efficiency
- Industry standard

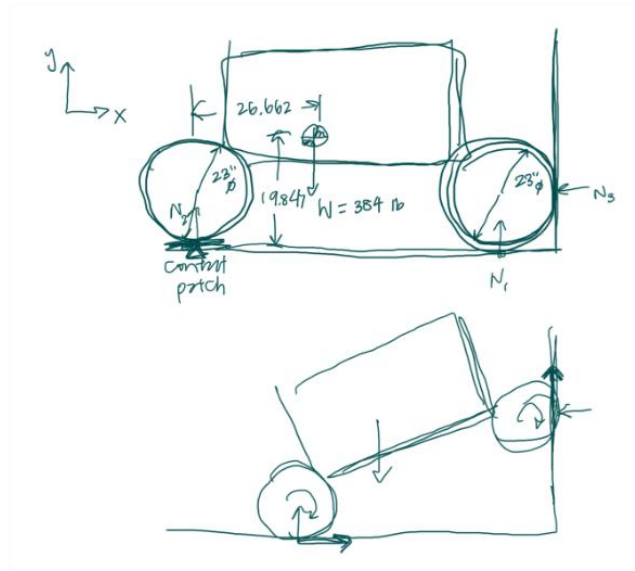


Polaris clutch

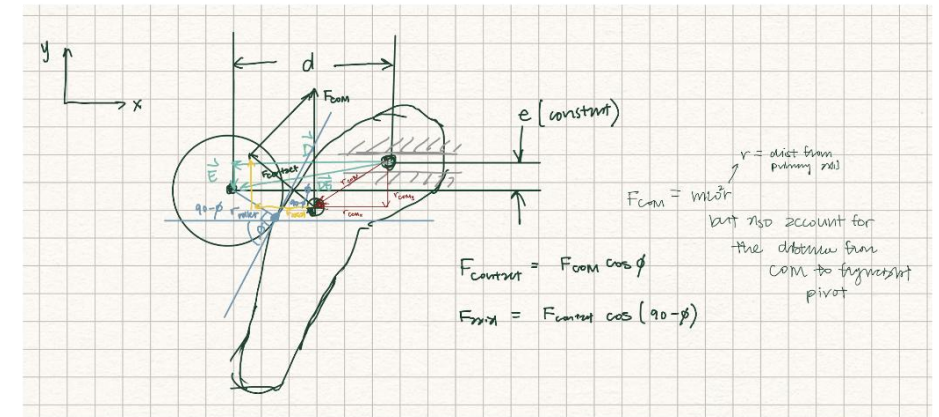
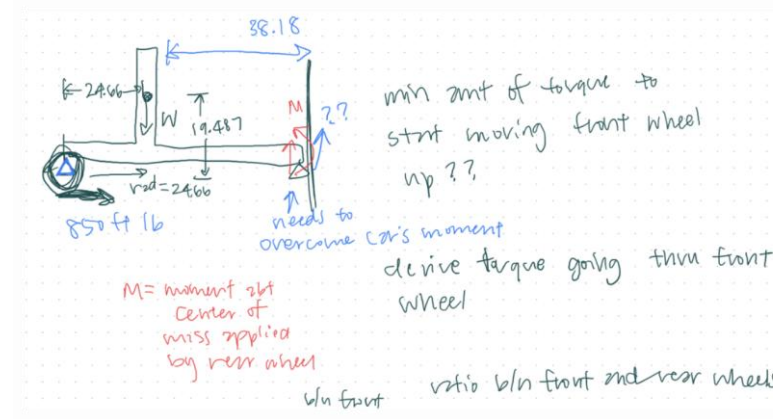
Bearing on shaft



Free-Body Diagrams

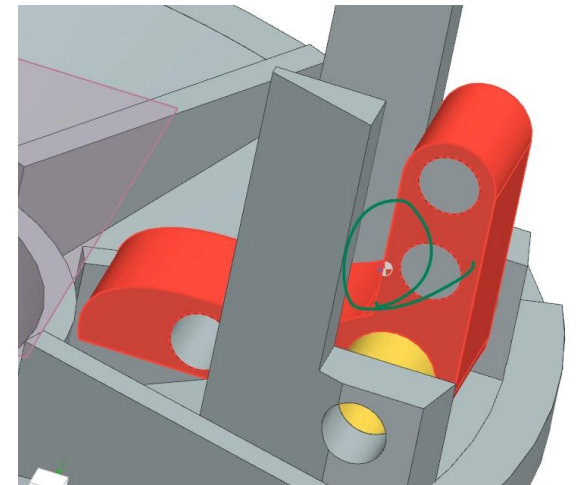
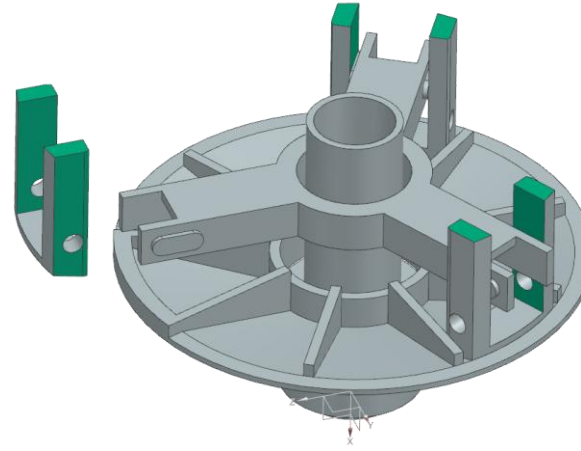
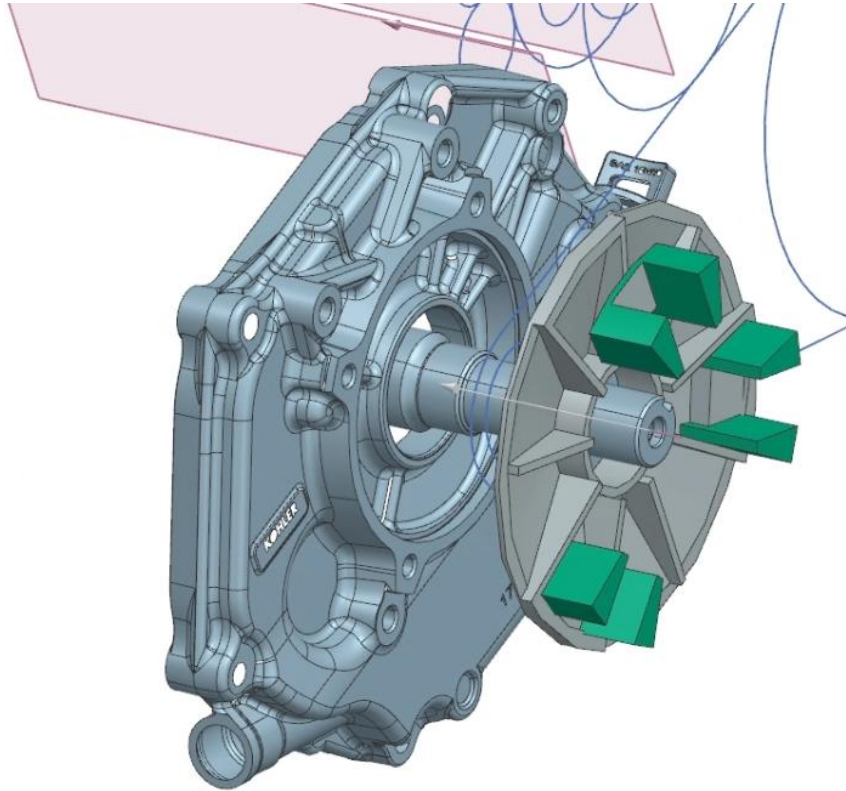


Torque needed to climb wall from standstill $\rightarrow$ CVT ratio



Primary pulley flyweight forces

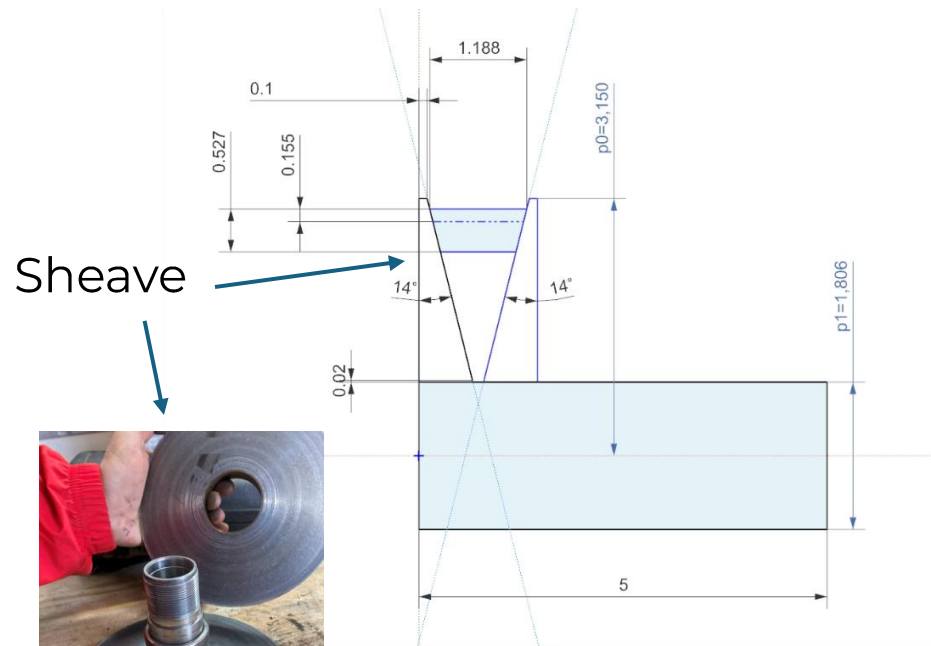
Generating Concepts



Late July to August 2025

Custom Belts from Sponsor

Match sheave angle, customized belt geometry (width, height, etc.) to optimize packaging and grip between belt and sheaves

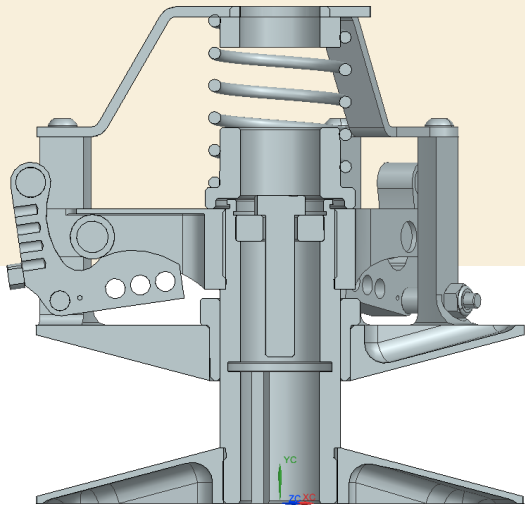
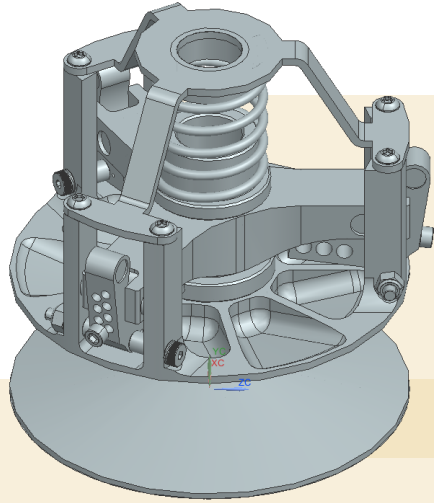


Part	Slab ID	Position	Pitch Length (mm)	Cord Position (mm)	Top Width (mm)	Pitch Width (mm)	Thickness (mm)	Angle
3	CWRU	8326LKNN	15	883.7	4.4	26.7	24.4	14.1
	CWRU	8325LKNN	6		26.7	24.4	14.2	27.9
2	CWRU	8325LKNN	18		26.9	24.6	14.2	28.0
	CWRU	8325LKNN	21		26.9	24.6	14.2	27.5
	CWRU	8325LKNN	36		27.1	24.9	14.1	27.4
	CWRU	8325LKNN	42		27.2	24.9	14.1	26.2
	CWRU	8325LKNN	24	884.1	4.5	27.2	24.8	14.3
1	CWRU	8326LKNN	27	883.7	4.4	27.3	25.0	14.1
5	CWRU	8325LKNN	45		27.3	25.0	14.2	27.1
6	CWRU	8325LKNN	33		27.3	25.0	14.2	27.3
	CWRU	8325LKNN	9	883.5	4.3	27.3	25.0	14.2
	CWRU	8325LKNN	39	884.0	4.4	27.3	25.0	14.0
	CWRU	8325LKNN	30		27.3	25.0	14.2	27.9
	CWRU	8325LKNN	48		27.4	25.0	14.1	27.8
	CWRU	8325LKNN	12		27.4	24.9	14.1	27.6
	CWRU	8325LKNN	89		27.8	25.3	14.1	28.8
4	CWRU	8325LKNN	77		27.7	25.3	14.2	28.0
	CWRU	8325LKNN	56		27.7	25.3	14.1	28.5
	CWRU	8325LKNN	80	884.1	4.5	27.7	25.3	14.1
	CWRU	8325LKNN	83	884.0	4.4	27.7	25.3	14.1
	CWRU	8325LKNN	53		27.8	25.4	14.1	28.6
	CWRU	8325LKNN	59		27.8	25.4	14.1	28.2
	CWRU	8325LKNN	65		27.8	25.4	14.3	28.6
	CWRU	8325LKNN	62	884.3	4.5	27.9	25.4	14.2
	CWRU	8325LKNN	74	884.2	4.5	27.9	25.6	14.2
	CWRU	8325LKNN	68			27.9	25.6	14.2
	CWRU	8325LKNN	71					28.0

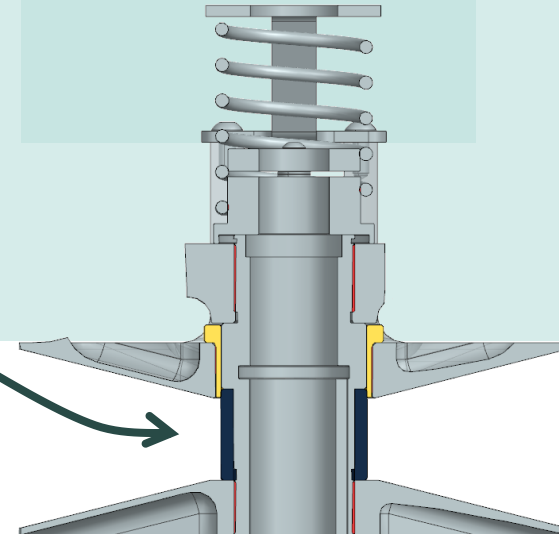
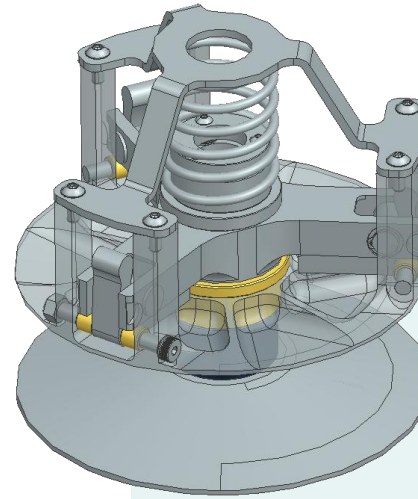
A variety of belt profiles to test

SR24 vs SR25

Custom
Primary
(2nd in team
history)



Custom Primary
(3rd in team history)



Bearing on shaft

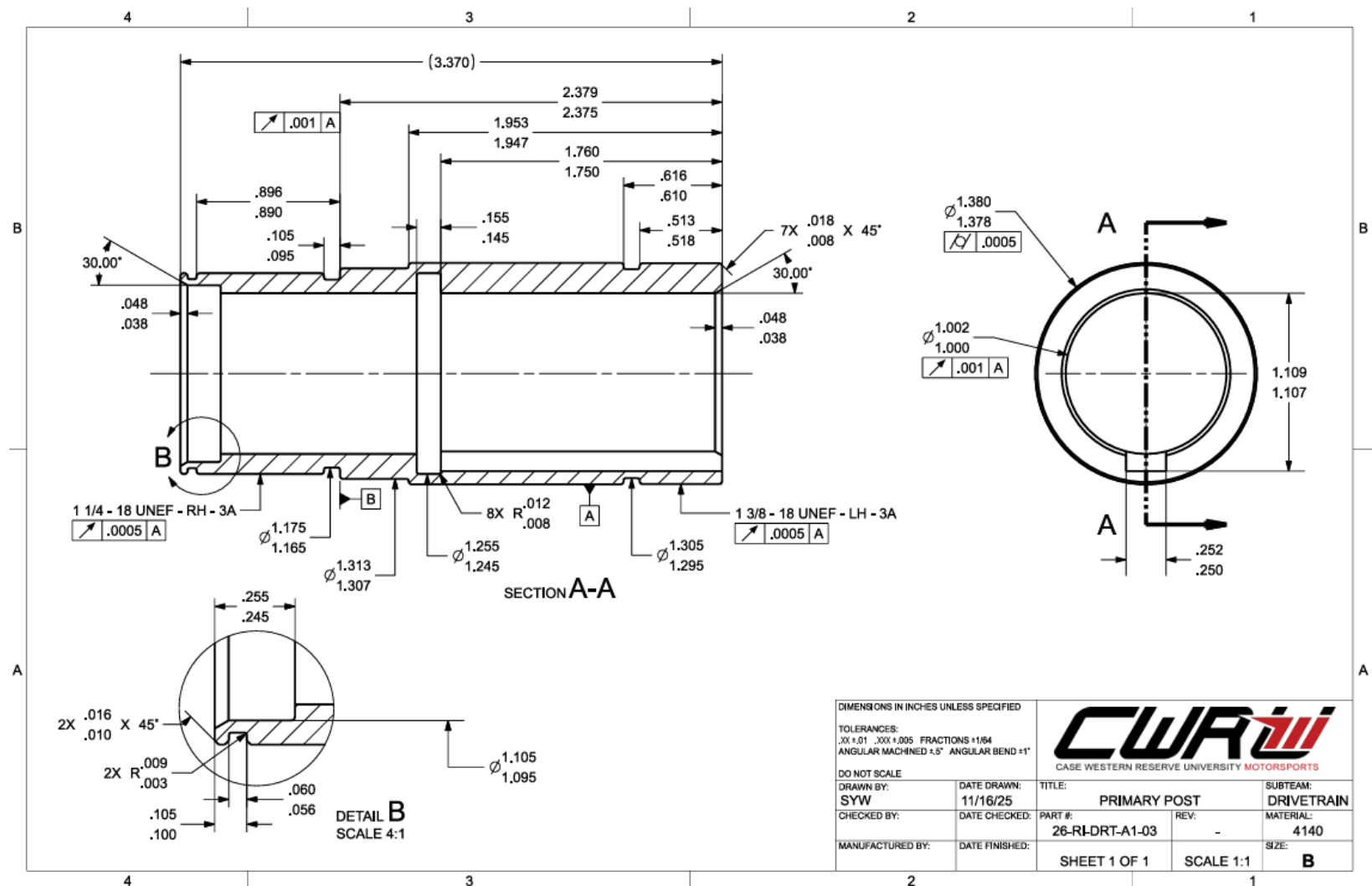
August to October 2025

Finding a Shaft Bearing

Name	Price	# ID	# OD	# Length	Seal?	URL	Notes
Caltric One-Way Primary Clutch Bearing Compati	\$21.97	1.33	1.75	1.24	☐	amazon.com/CaL...YYCnN4	
Polaris Sportsman	\$59.95		2.01		☐	a.co/d/0TS0MtF	no dims tbh
Caltric One-Way Primary Clutch Bearing Compati	\$21.97	1.33	1.75	1.24	☐	a.co/d/53XMF47	might be the same as first one
Caltric 1520836 Primary Clutch One Way Bearing	\$28.99	1.29	1.74	2.01	☐	ebay.com/itm...vD_BwE	has inner race?
Caltric Primary Clutch One Way Bearing Kit Comp	\$48.50	1.33	1.74	2.02	☐	a.co/d/eg7CeBW	honestly not sure of dims, this comes w a bushing and wa
Primary Clutch Bearing Needle And Washer Fits Pt	\$39.90				☐	a.co/d/4Xuxopf	no dims listed
SuperATV Up & Running Polaris RZR Primary Clutch	\$44.95		3	2	☐	a.co/d/dS7ua8t	dk if this is the actual dims
Dokili Primary Drive Clutch Needle Bearing 35146	\$25.75	1.38	1.73	1.22	☐	a.co/d/gB1fSua	
Primary Clutch Bearing And Washer Fits Polaris R2	\$44.90	2	2.2	1.5	☐	a.co/d/fWtlpnf	might just be package dims
RCB162117 One-Way Needle Bearing/Clutch 1x1	\$14.99	0.3125		1.0625	☐	vxb.com/pro...pt.com	
P90 Primary Clutch One Way Roller Bearing 15211	\$50.00				☐	gilomeninnovations.com/p90...%20mph	
1521172 1521667 fits for Polaris Sportsman RZR R	\$19.67				☒	a.co/d/fakCbDs	no dims
HK 3520.2RS		1.378	1.6535	0.7874	☒	skf.com/us/...20.2RS	
FJTT-3524					☐		NSK, they no longer produce it tho
HK3524					☐	vxb.com/pro...630955	
HK3526					☐	a.co/d/1U6xXBj	

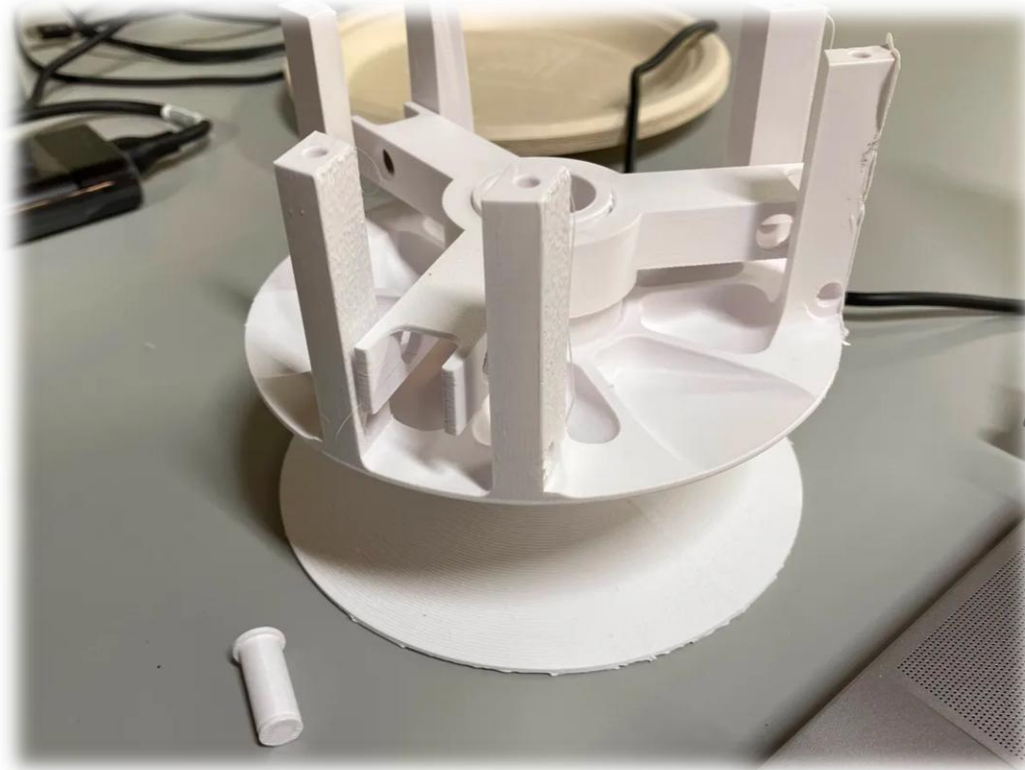
- Difficult to find smaller needle-roller bearings that are sealed
- Ended up going with an unsealed needle roller bearing and attempted to use COTS O-rings to seal in between race and needles, but was unsuccessful due to fit issues
- After testing with CVT on-car, found that the bearing was still rolling with enough force

Drawing for Sponsor



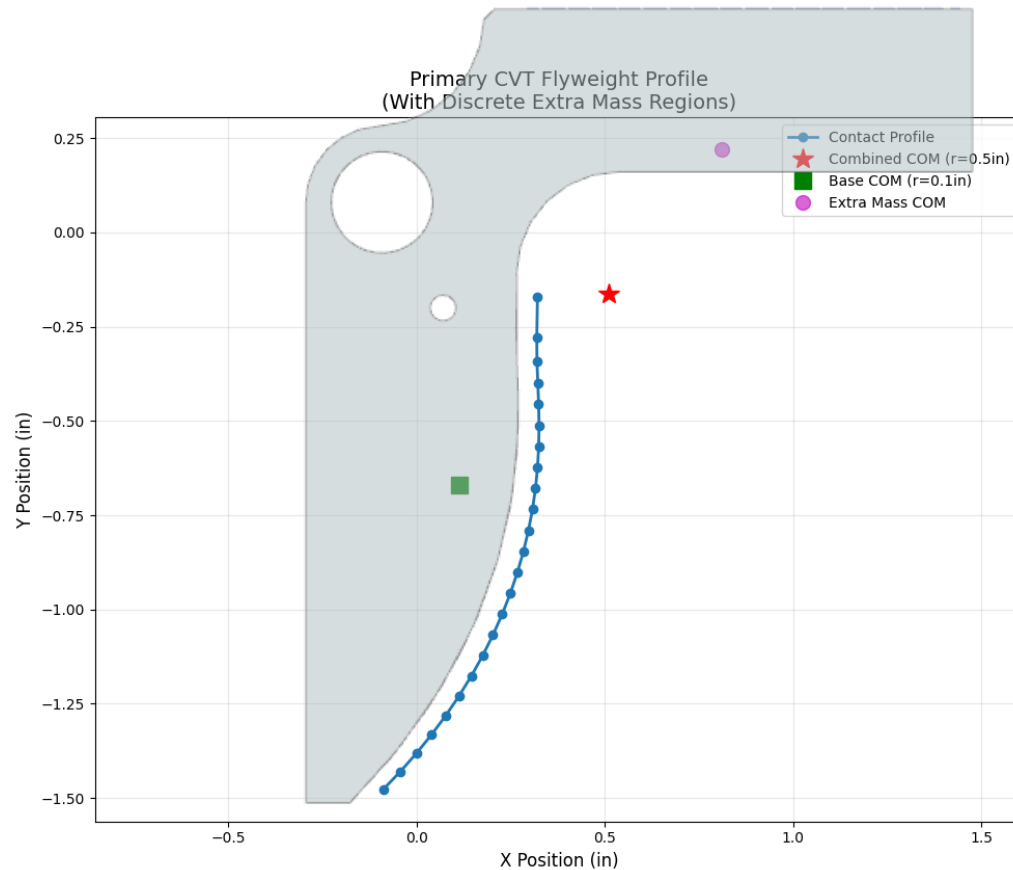
August to November 2025

Fit-Checking



Early November to Mid-December 2025

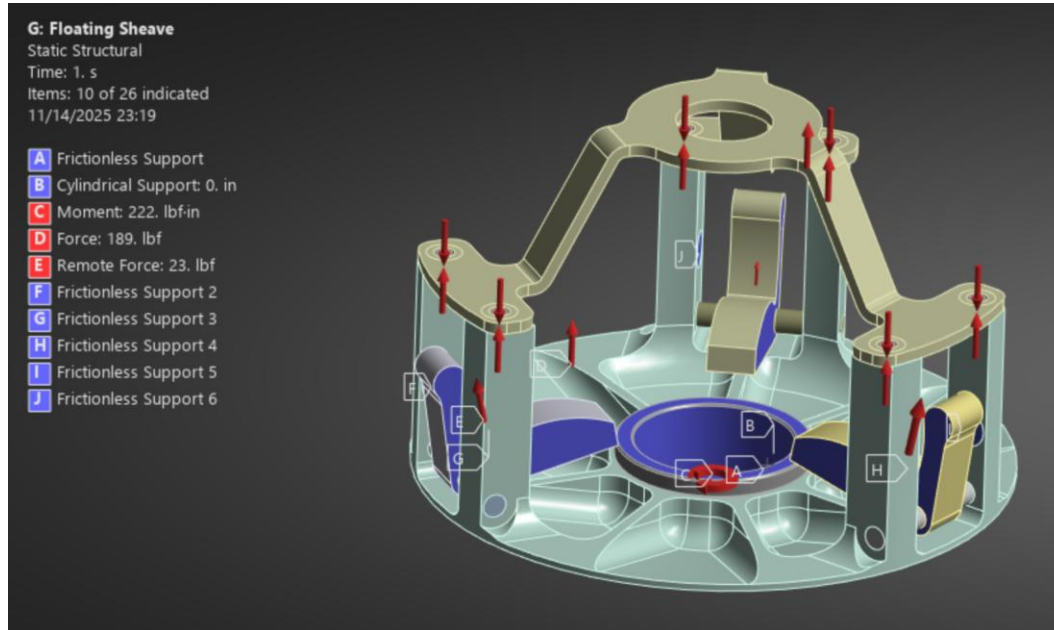
Performance Analysis



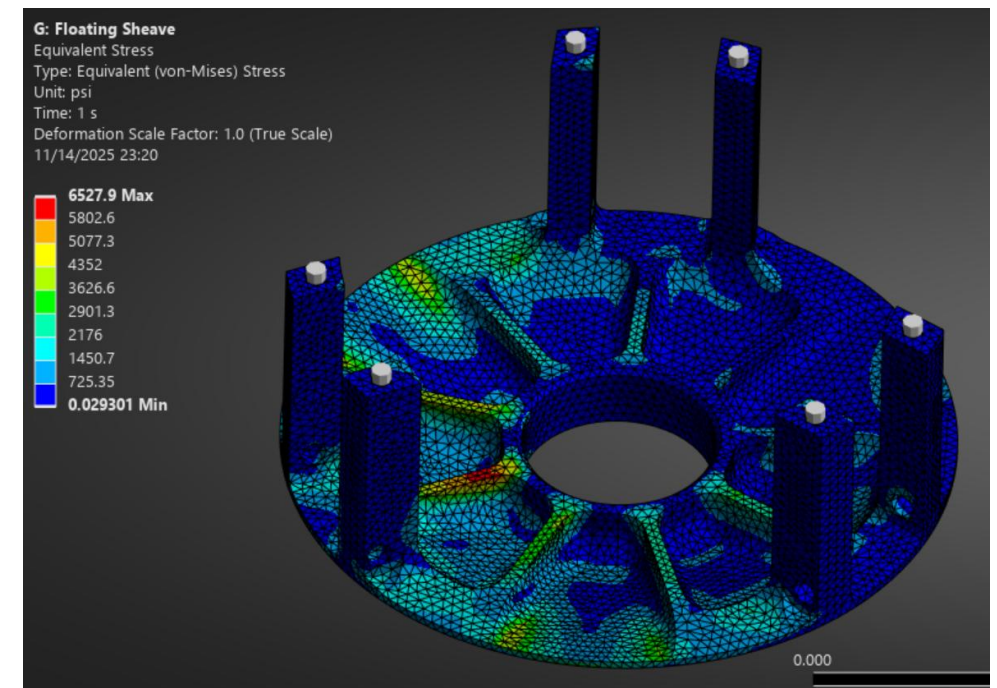
Generating Flyweight Profiles and Masses/Center of Mass

- Python script
- Input desired contact angles based on desired shift RPM
- Variable profile as CVT shifts, lines up with keeping engine RPM at peak power of 3000 RPM

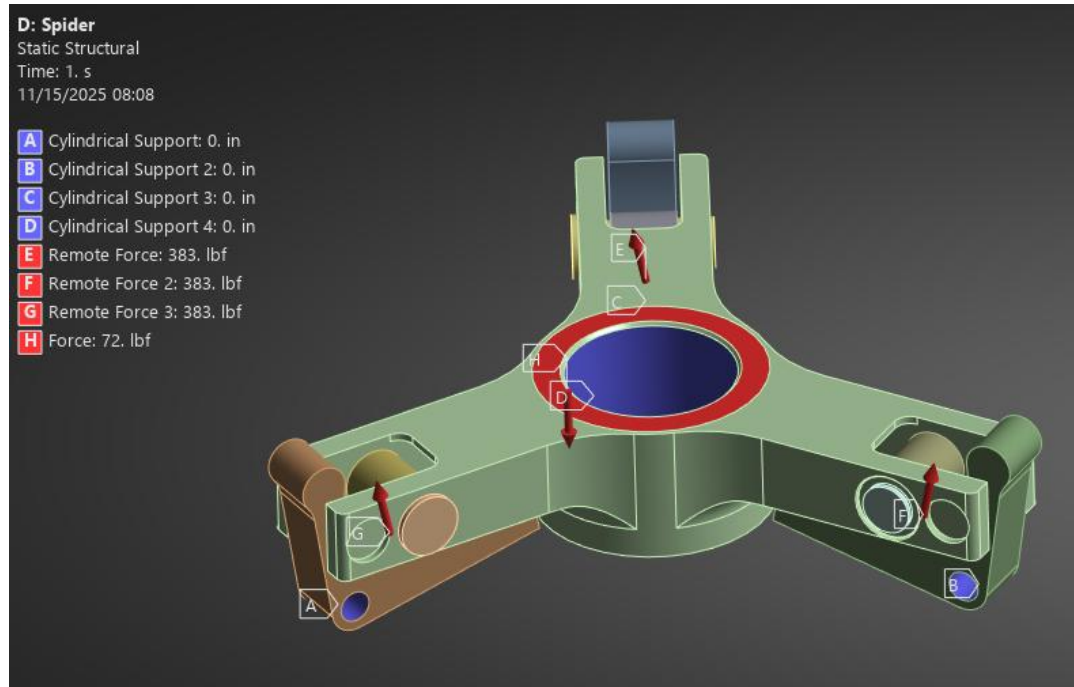
Finite Element Analysis



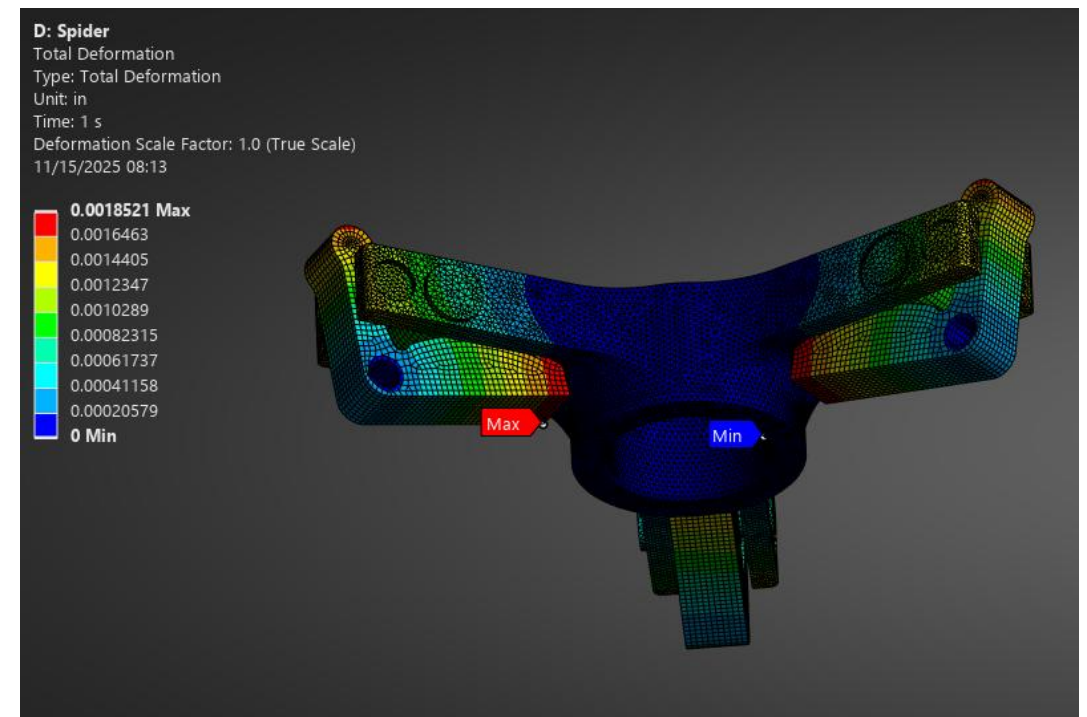
Static loading from spring, belt, flyweights



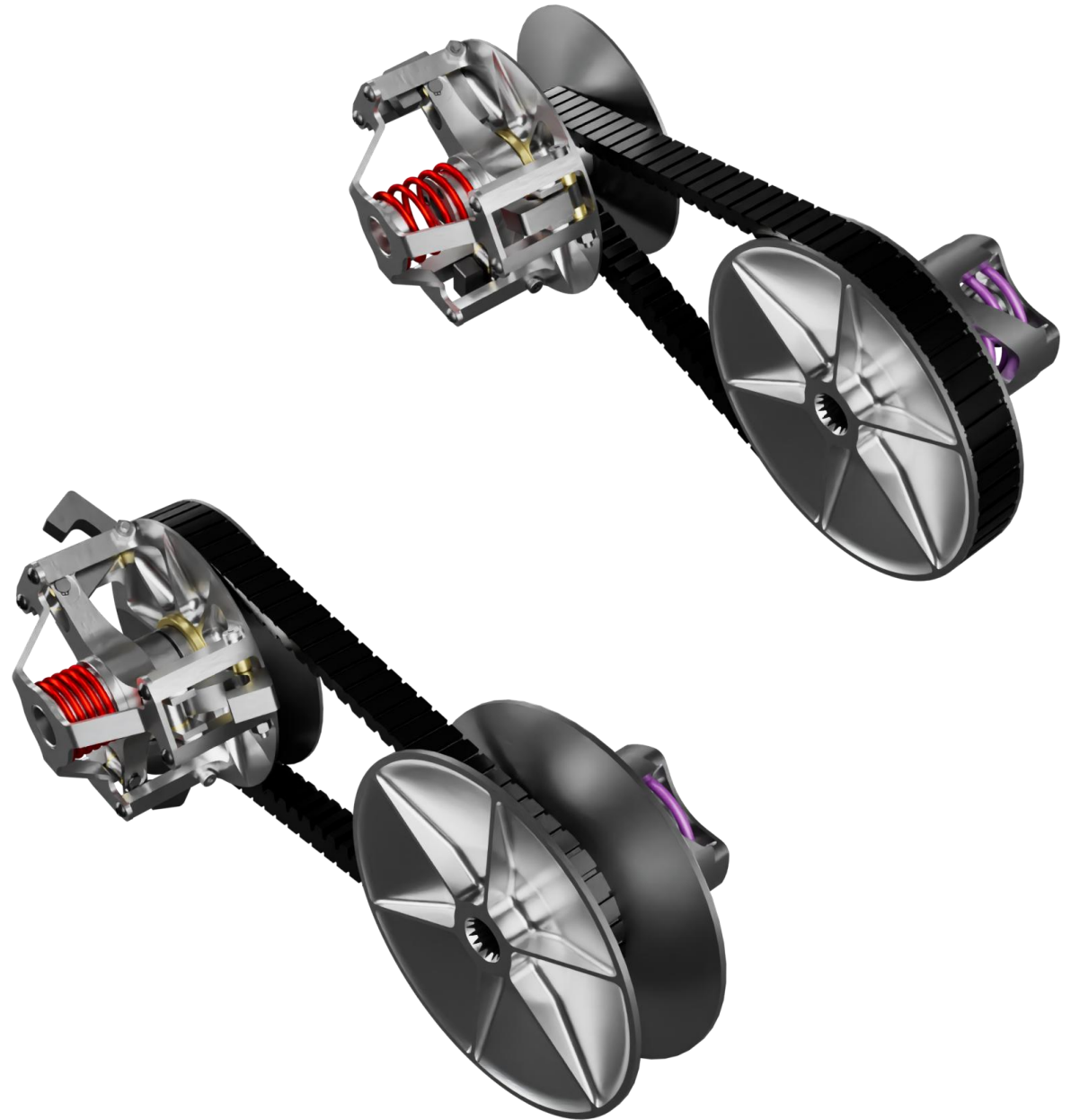
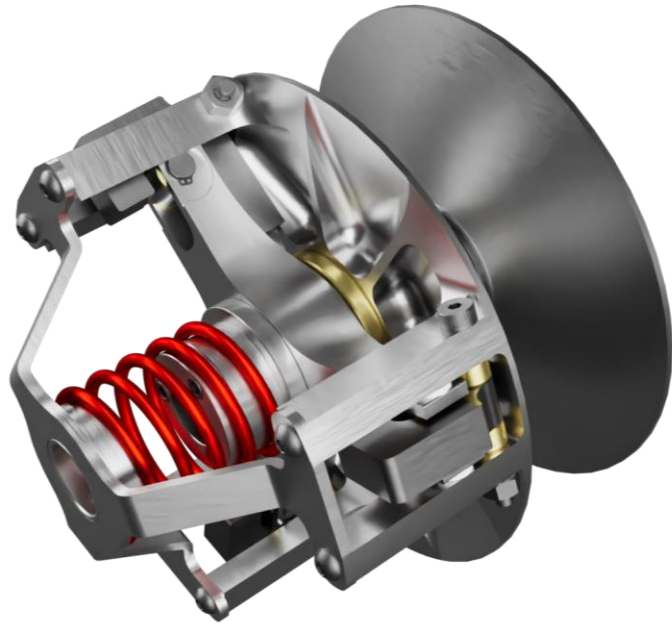
Finite Element Analysis



Static loading from spring, flyweights



Final CAD



February 2026

Manufacturing

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

- Post-machined bushing ID after pressing into sheave



Assembly



March 2026

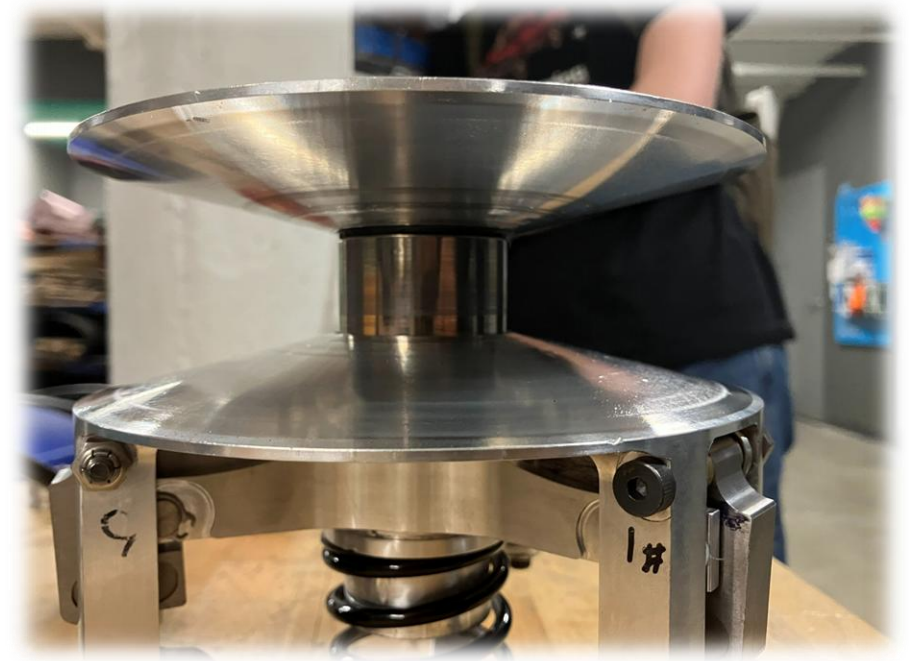
Testing



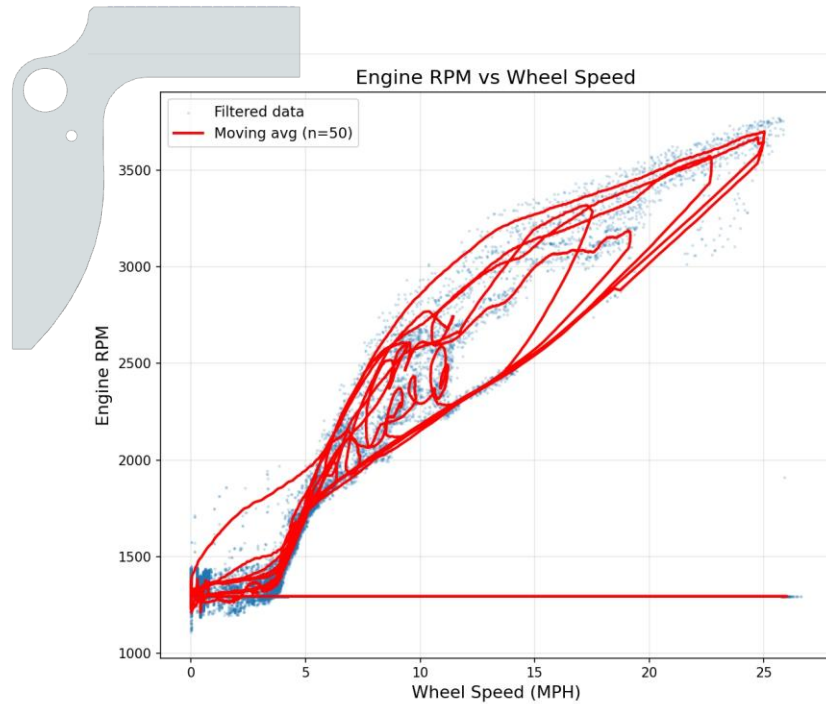
New hall sensor PCB



Wear rings from belt on sheaves indicate how far CVT shifted

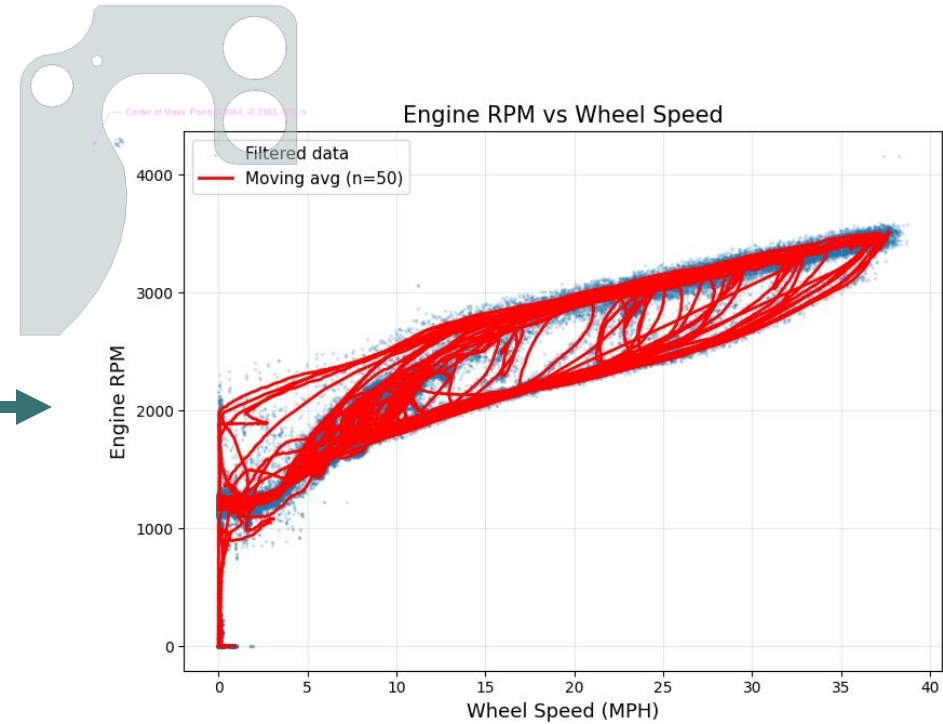


Testing



April 10th

Shifting above engine peak power (3000 RPM), top speed not close to 40 MPH → more shifting force needed



April 29th

Closer to 3000 RPM, but not flat at 3000 RPM → more shifting force needed at high end

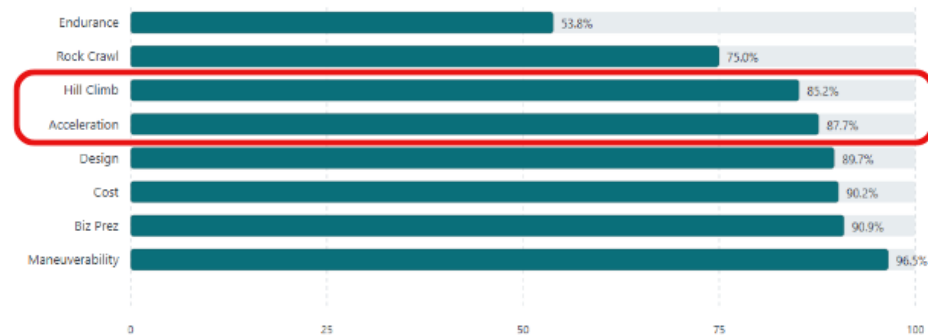
Oregon (1st) Competition

- Component failure (spider)
 - Propagated from stress concentration
- Not shifting to full range and not shifting at peak power → poor performance in Acceleration and Hill Climb
- Poor performance in Endurance due to getting rear-ended during 4-hour race



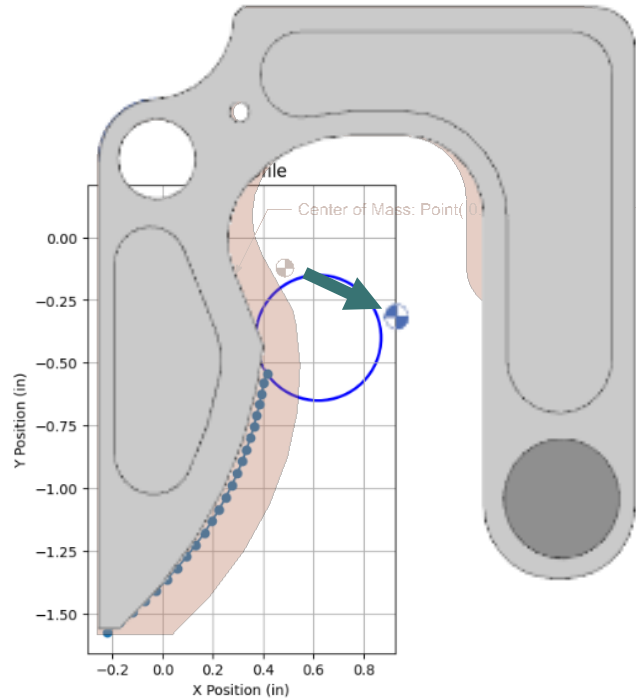
Oregon 2026: Percent of Winning Event Score

Sorted from weakest relative score to strongest. 100% means CWRU matched the top posted event score.



Early May 2026

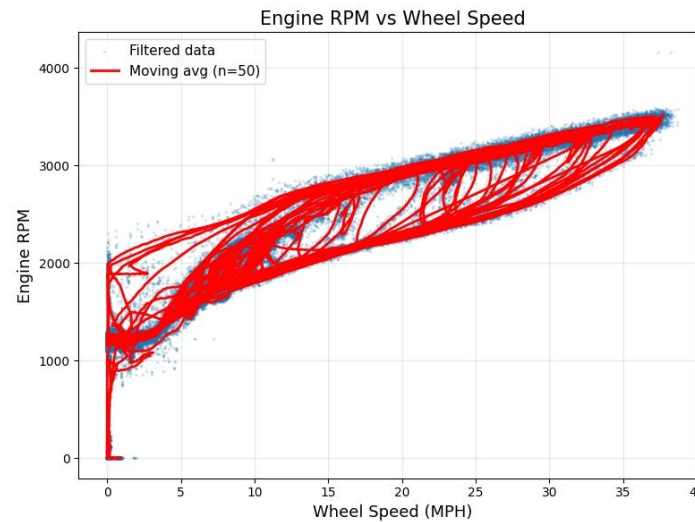
Iteration



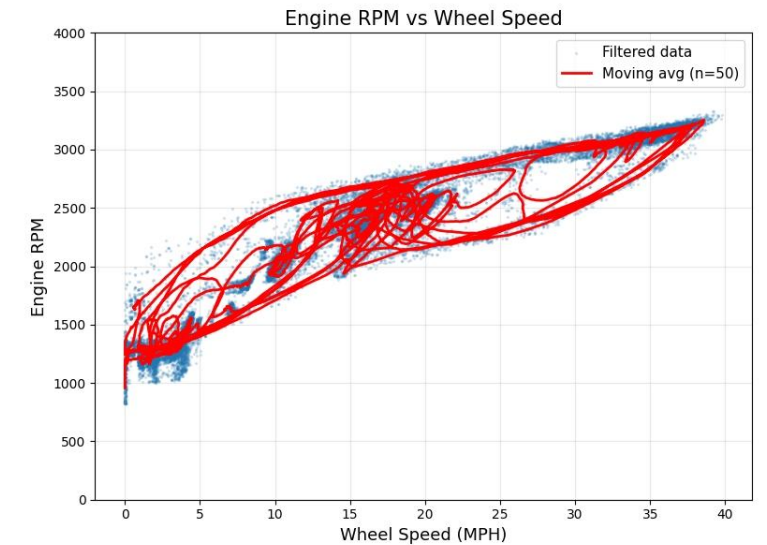
COM of flyweight moved radially outward relative to pulley rotation (red is pre-Oregon flyweight)

Flyweight Iteration Between Competitions

- Based on testing data before Oregon competition, new COM position with more acceleration force

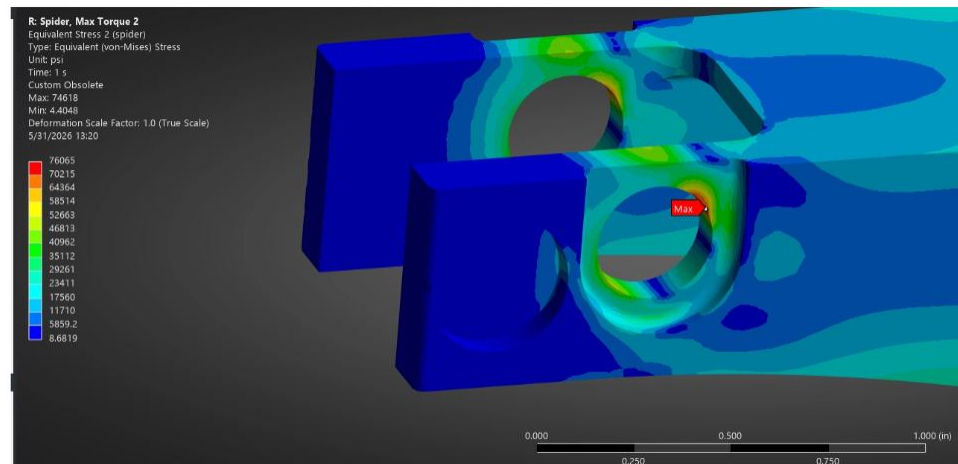
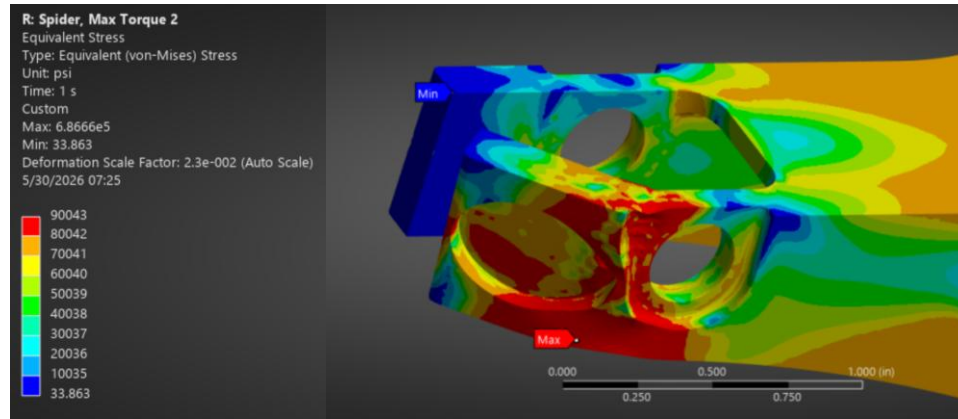


Pre-Oregon



Post-Oregon

Iteration



Spider Iteration Between Competitions

- Replicated failure in FEA
- Strengthened failed component (spider) and re-ran FEA, reduced stress concentration by changing shape of incised area

May to Early June 2026

New York (2nd) Competition

1st Competition

Oregon 2026: Percent of Winning Event Score

Sorted from weakest relative score to strongest. 100% means CWRU matched the top posted event score.



10th at Oregon competition

- Poor performance in Acceleration, Hill Climb, Endurance (due to crash)
- Component fracture in CVT

2nd Competition

New York 2026: Percent of Winning Event Score

Sorted from weakest relative score to strongest. 100% means CWRU matched the top posted event score.

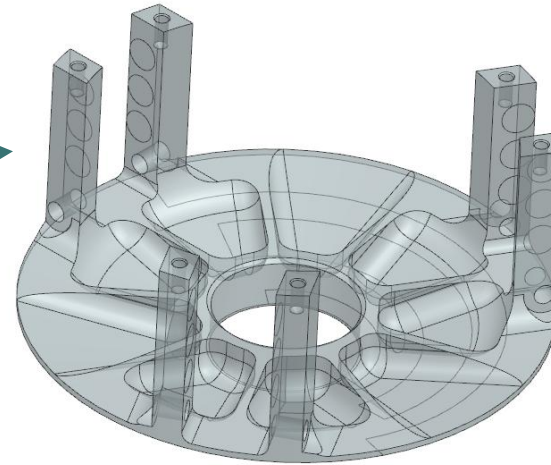


Won the entire New York competition

- Better performance in Acceleration, Hill Climb, and Endurance events
- No component failures in CVT

Improvements + Advice for Future Designers for Primary CVT

- Floating Sheave
 - Manufacturable
 - I.e. separate into multiple parts like other teams
- Shaft Bearing
 - Find a sealed bearing
 - Prevent belt dust from building up in needles and seizing bearing
 - Belt was rubbing on bearing



Improvements + Advice for Future Designers for Primary CVT

- Make more severe flyweight iterations
 - Iterated from Rev – all the way to Rev P
 - Over-adjust, like PID
- Finish design early, do not make too many changes
 - Leave many more months of tuning time to learn more about the system
 - I.e. how temperature affects performance, different belt geometries, etc.
- Test off-car
 - Make use of our custom CVT dynamometer (still in progress, but likely will be ready to use this upcoming school year)