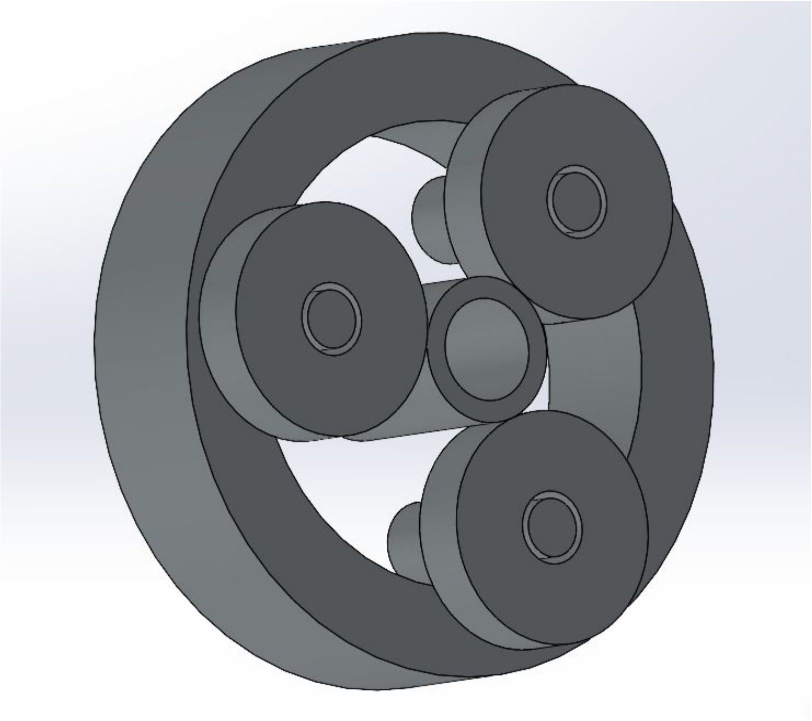
Outboard Gearbox

Autumn 2025 Progress

Toy gearbox/intro to cad

- Hands-on CAD project to introduce new members to SOLIDWORKS
- Modeled a simplified compound planetary gearbox to learn core components and relationships between the sun, planet, and ring gears
- Practiced part modeling, mates, assemblies, and basic design intent
- Built intuition for how planetary systems move and package in real designs



Research Projects

- Materials and heat treatment options
  - Research gearbox's material and heat treatment options
  - Find pros and cons of current choices, suggest alternatives
- Planet pin retention options
  - Currently both sides are location clearance fit, but other potential options are one or both sides being press fit
  - With one side press fit, need to evaluate if retaining rings are necessary for axial retention
  - With both sides press fit, need to evaluate the effect of the planet pin surface finish pressing all the way through the carrier
- Parametric gear macrogeometry
  - Create a MATLAB script for sizing gear macrogeometry, and to calculate both flank and root stress on all gears

Research Projects

- Floating members
    - Study the effect of floating members such as planet pin, sun gear, or ring gear on load sharing, gear sizing, and gear strength
- Outboard gearbox justification
    - Find out if an outboard drivetrain improves performance
    - Evaluate a 2 motor RWD configuration, along with a 4 motor AWD configuration

Floating Members

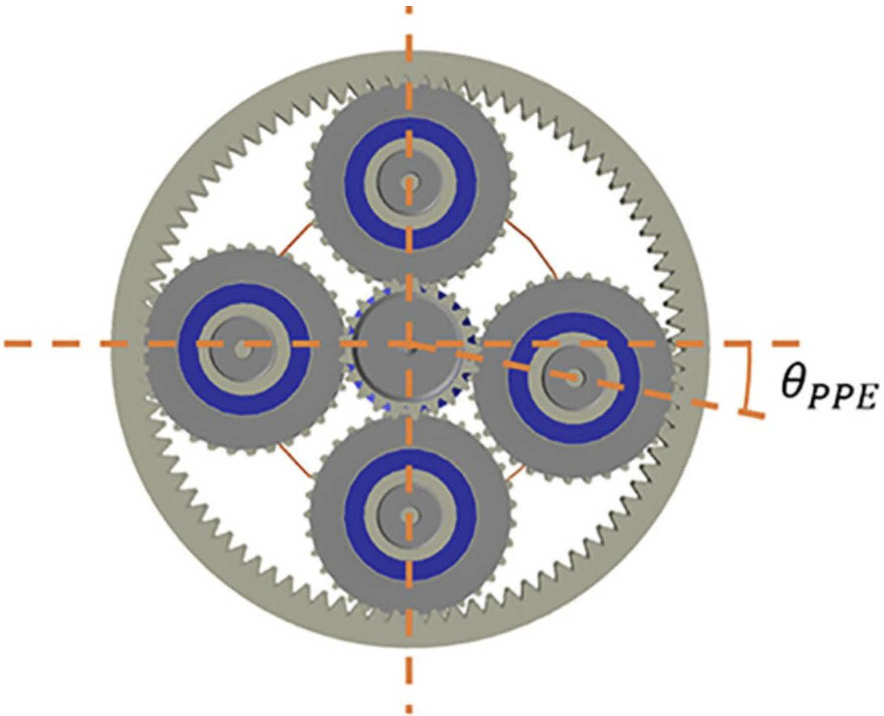
In a planetary gearbox "floating" member - typically the sun gear, ring gear, carrier or planet pins - are designed to allow for controlled radial freedom rather than a rigid fixation

Load Distribution

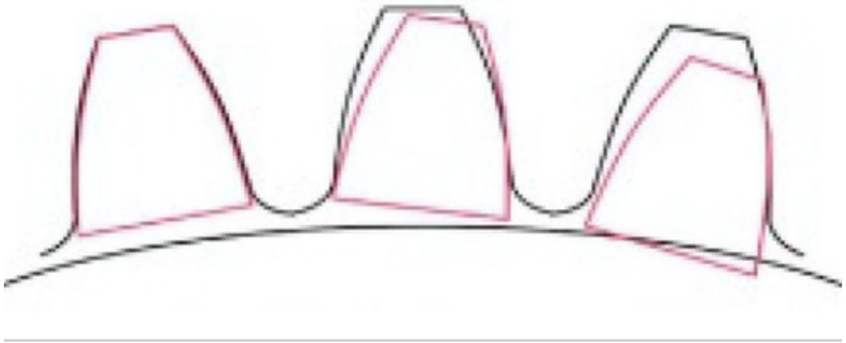
- The floating elements are able to self center themselves under load, which helps provide equal torque/force to all gears and their teeth

Accounting for Manufacturer Errors

- Floating members adjust for manufacture tolerances, assembly misalignment, and runout



Planet Pin Error



Gear Runoff

Floating Members

Floating the Sun Gear

Ways to float the sun gear:

- Connect Sun Gear to Shaft by a Spline/Gear Coupling with Backlash
- Support Input Shaft with Spline

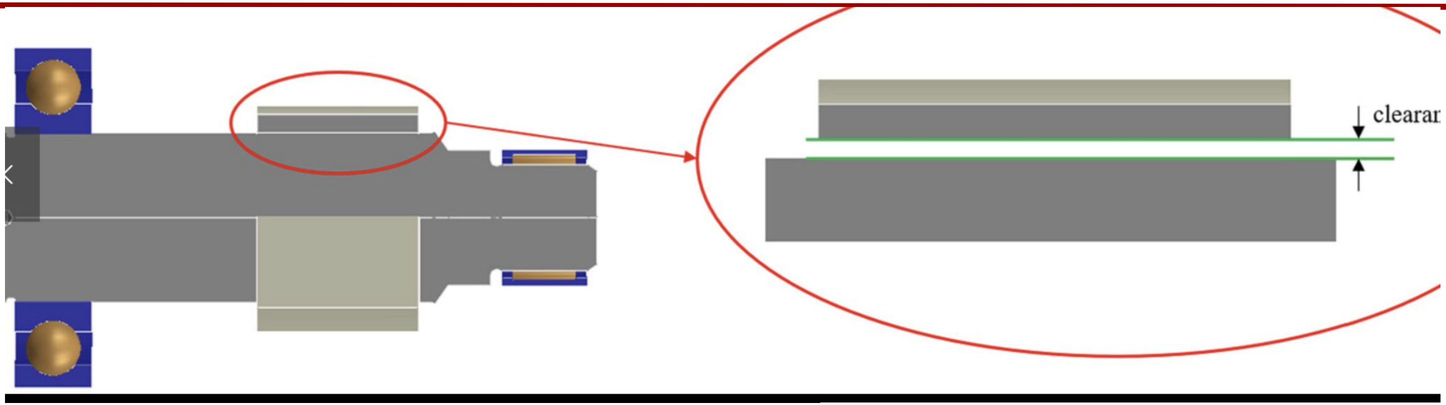
Benefits of Floating Sun Gear

- Improved Load Sharing(Planet to Planet)
- Improved Sun to Planet Mesh
- Easier to Avoid Resonance Frequency

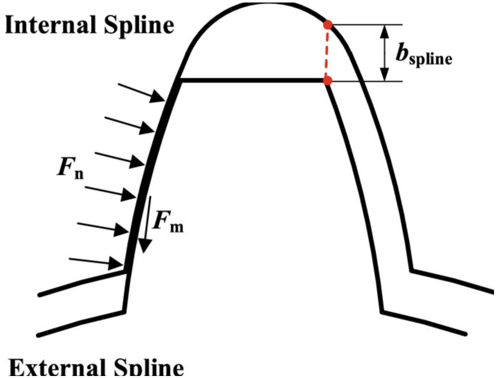
Cons:

- Increased Noise and Vibrations

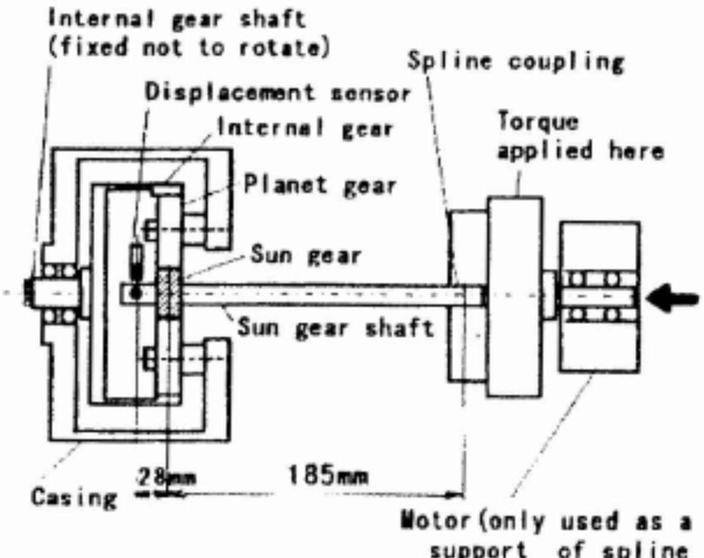
Radial Clearance



Spline/Gear Coupling with backlash



Input shaft with spline



Floating The Ring Gear

Ways to Float the Ring Gear

- Radial Clearance between ring gear and housing with pins
- Connect Ring gear to housing using single or double gear coupling(spline)
- Make the Ring Gear Flexible
- Bind Ring Gear to Elastomer Layer(Rubber)

Benefits

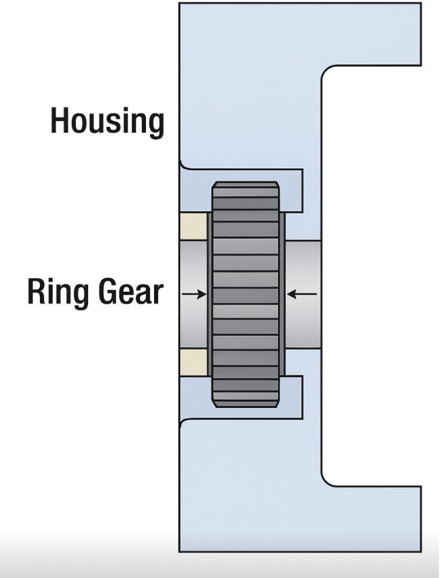
- Improved Load Sharing(Planet to Planet)
- Weight Reduction (Flexible Ring Gear)
- Lower Mesh Stiffness between planets and ring

Floating Both Ring and Sun Benefits

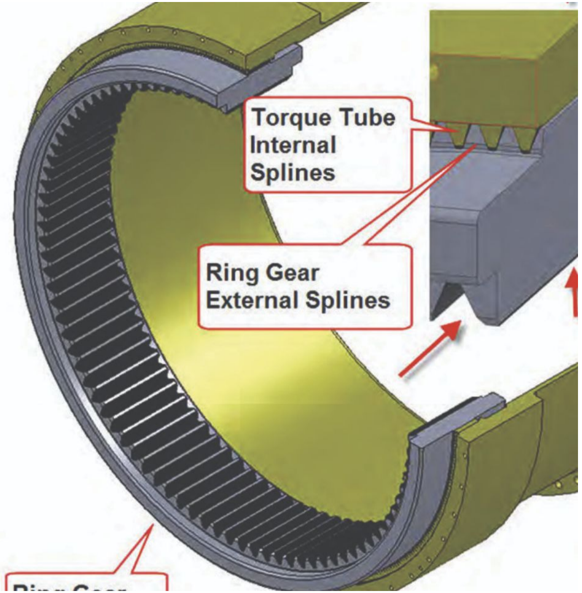
- Both Planet to ring and Planet to sun mesh improves
- Increase in gear safety factor

Cons

- Flexible: stress concentration where it flexes, reduced torque capacity, bad durability
- Elastomer layer: layer decay, higher friction, limited torque
- On all: Vibrations



Radial Clearance between ring gear and housing



Spline used to connect ring gear to housing

Floating Planet Pins

Ways to Make the Planet Pins Float

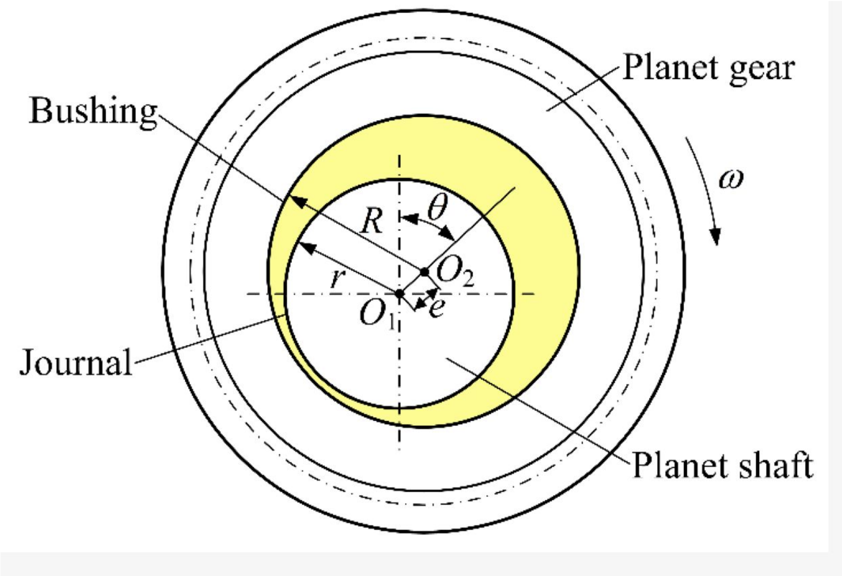
- Use a bushing or bearing with radial clearance
- FlexiPin

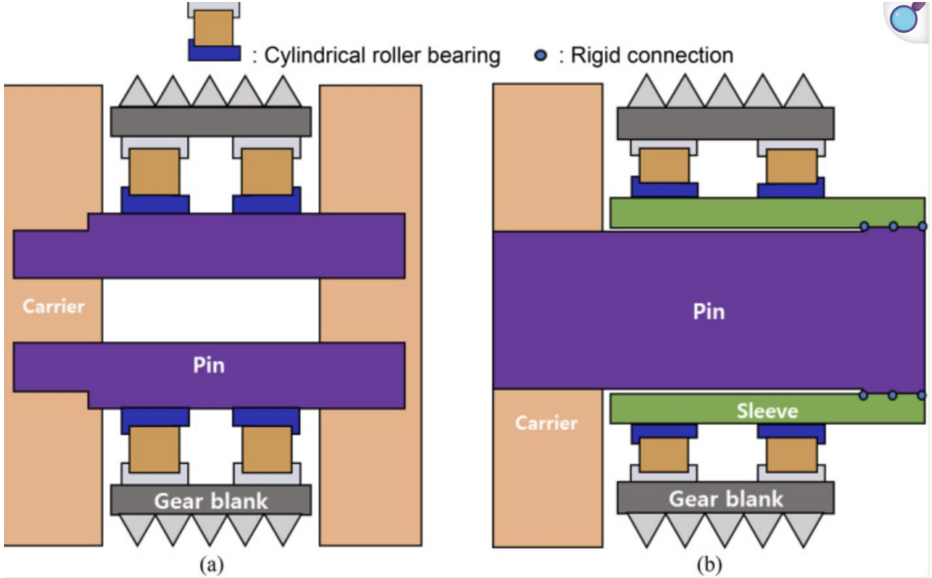
Benefits

- Better Load Sharing Among Planets
- Better life Span
- Increased Power Density

Cons

- Contamination Risk if Journal Bearing are present
- Bearing or Bushing: Bad for low speeds, bearing stiffness become a variable
- Flexipin: Sun to planet and planet to ring meshes, difficult optimization





Bushing/Bearing with Radial Clearance

Flexipin

Parametric Gear Macrogeometry

MATLAB program that gives us estimates for gear geometry based off inputs and constraints.

```
Inputs:
  maxRingDPD : maximum Ring pitch diameter (mm)
  ratioRange : [Rmin Rmax] target overall ratio (ring-output)
  huntingFlag: 'y'/'n' (also accepts yes/no/true/false/1/0; default = 'n')

Constraints:
  - Min Sun PD: Ds >= 17.6 mm
  - Planet PDs: Dp1 >= 26.6 mm, Dp2 >= 26.6 mm
  - Modules: M1 in 0.80:0.02:1.00, M2 in 0.80:0.02:1.00, with M2 >= M1
  - Integer teeth; D = module * teeth
  - Compound closure: Dp2 = Dr - Ds - Dp1 > 0 (then quantize Np2)
  - Center alignment: |(Ds+Dp1) - (Dr-Dp2q)|/2 <= tol (mm), tol = 0.05
  - 3-planet phasing: mod(Ns + Nr, 3) == 0
  - Optional hunting: gcd(Ns,Np1)=1 and gcd(Nr,Np2)=1
  - Stage-1 max OD cap: Stage1OD = 2*Dp1 + Ds <= 140 mm
```

We also include safety factors for all computations

Parametric Gear Macrogeometry

The outputs give us a different configurations of estimated gear geometry so we can continue to make new versions in SolidWorks with appropriate dimensions, keep the designs more realistic.

Also Give strength estimates based on ISO 6336

Outputs

Module Stage 1 and Module Stage 2 (mm)
Sun Tooth Count, Ring Tooth Count, Planet 1 Tooth Count, Planet 2 Tooth Count
Sun Pitch Diameter and Ring Pitch Diameter (mm)
Planet 1 Pitch Diameter and Planet 2 Pitch Diameter (mm)
Overall Ratio, Stage 1 Ratio, and Stage 2 Ratio
Center Alignment Difference (mm)
Stage 1 Outer Diameter (mm)
Ring Diameter (mm)
Stage 1 Outer Diameter (mm)

Planet Pin Retention Options

Design Goal: Achieve **rotational retention** of planet pins while balancing manufacturability, cost, serviceability, and packaging constraints.

Options considered

1. Snap Rings + Clearance Fit (Current)

- Simple & fully serviceable
- **No rotational retention** → pin can spin/fret carrier
- Not adequate for high-load racing use

2. One-Side Press Fit + Snap Ring

- **Friction-based anti-rotation**
- Only one interference bore required
- Fully removable; low added cost
- Sensitive to interference tolerance

3. One-Side Press Fit + Retainer Bolt

- **Most secure:** friction + mechanical lock
- Prevents axial movement even if press fit relaxes
- Requires tapped hole + safety wire

4. Cross-Pin / Set Screw

- Positive mechanical lock
- Adds stress concentration; fatigue risk
- Moderate machining complexity

5. Keyed Pin / Retention Plate

- **Geometric anti-rotation**
- Very robust
- Higher machining cost; packaging constraints

Planet Pin Retention Recommendation

Final Recommendation: One-Side Press Fit + Retaining Feature (Snap Ring or Bolt)

Why This Strategy

- Provides **reliable rotational retention**
- Maintains **full serviceability** (critical for inspection/rebuild)
- Fits within FB27 machining capabilities
- Matches motorsport best practices
- Redundant retention possible (press + bolt)

Methods Not Recommended

- **Press Fit Both Sides** → Not serviceable
- **Welding/Staking** → Permanent; fatigue/cracking risk
- **Cross-Pin Alone** → Stress risers; less predictable under shock loads

Implementation options

Option A — Press Fit + Snap Ring

- Lowest complexity
- Reliable for moderate torque
- Minimal added parts and machining

Option B — Press Fit + Half Shaft Bolt *(Preferred)*

- Highest retention reliability (tolerance of 3 microns)
- Handles torque cycles well
- Bolt engages pin recess/flat; safety-wired
- Best performance-to-risk ratio for high-load racing

Materials and Heat Treatment Options

Gearbox Components	Gears (Sun, Planet, Ring)	Planet Pins	Carrier	Housing
Recommended Material	8620 Steel	8620 Steel	4140 Alloy Steel	7075-T6 aluminum
Recommended Heat Treatment	Carburized	Carburized	Quenched and Tempered	**Optional:** hard anodizing for durability
Alternatives Considered	**9310 steel:** higher fatigue strength but 15–20% higher cost, marginal gain **Full nitriding:** low distortion but case too shallow for gear bending fatigue	**Tool steel (O1/A2):** hard but brittle and difficult to machine **Nitrided 4140:** shallower case, reduced wear life	**4340 / 300M:** stronger but unnecessary for loads and more expensive **7075 aluminum:** too weak for torque and bearing loads	**6061-T6:** cheaper but ~50% weaker **Magnesium:** corrosion-prone, lower strength, machining fire hazard
Why Chosen	Best balance of fatigue resistance, wear life, machinability, and cost	Carburized 8620 provides optimal wear resistance and core toughness	4140 Q&T offers ideal strength, toughness, and manufacturability	Best stiffness-to-weight ratio and durability for gearbox housing

Gear Material Decision Matrix

Option	Machinability	Cost	Procurement Feasibility	Strength / Fatigue Resistance	Weight (qualitative)	Overall Assessment
8620 + carburized (Chosen)	Good	Low	Very High	Best (for case-hardened gear)	Baseline	Best overall balance
9310 + carburized	Good-Fair	Higher	High (but specialty)	Slightly Better	Similar	Marginal gain for higher cost
Through-harden + nitriding	Fair	Moderate-High	Moderate	Good	Similar	Shallower case, less ideal — not chosen

Planet Pin Materials Decision Matrix

Option	Machinability	Cost	Procurement Feasibility	Strength / Wear Resistance	Weight	Overall Assessment
8620 + carburized (Chosen)	Good	Low	Very High	Best for wear & toughness	Baseline	Recommended
Tool steel (O1/A2) through-hardened	Poor-Fair	Moderate	High	Good	Similar	Machining & brittleness issues — less desirable
4140 nitrided	Good	Moderate	High	Good	Similar	Less proven for pin wear — not chosen

Carrier Materials Decisions Matrix

Option	Machinability	Cost	Procurement Feasibility	Strength / Toughness	Weight	Overall Assessment
4140 Q&T ~40-45 HRC (Chosen)	Good	Low	Very High	Best fit for loads	Baseline	Strong choice
4340 Q&T	Good	Higher	High	Slightly Better	Similar	Cost increase not justified
Aluminum Alloy (7075)	Excellent	Moderate	Very High	Much Lower	Lighter	Strength trade-off too great — not chosen

Housing Materials Decision Matrix

Option	**Machinability**	**Cost**	**Procurement Feasibility**	**Strength / Stiffness**	**Weight**	**Overall Assessment**
7075-T6 (Chosen)	Good	Moderate	High	Best for lightweight high-stress	Baseline	Best for FSAE application
6061-T6	Excellent	Lower	Very High	Much Lower	Slightly Higher (if thicker)	Weight/strength trade not acceptable
Magnesium alloy	Fair	Higher	Moderate	Low/Moderate	Lower	Too many trade-offs — not chosen

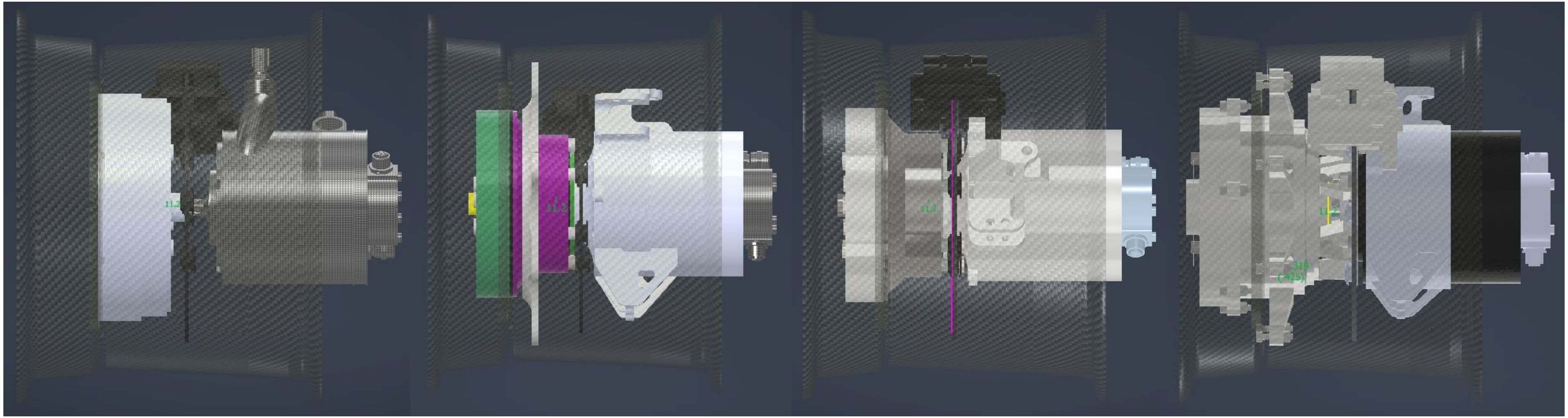
Outboard Gearbox Design

Goals:

- Create a parametric design compatible with RWD or AWD covering optimal gear ratio range [12.0:1 , 14.0:1].
- Minimize unsprung mass.
- Optimize assembly.
  - Ease of access to each component, minimize complex disassembly to replace parts.
- Allow for design variance for components not inside gearbox.
  - Gearbox Mounts, Spindle, Upright, Brake Rotors, Cooling jacket, Suspension Rods, Turn Rods, Mounting rods.
- Eliminate/Optimize Components.
  - Driveshaft components, Wheel Center, Spindle, Cooling Jacket
- Simulate dynamic/static stability and strength.
- Comply with FSAE rules.

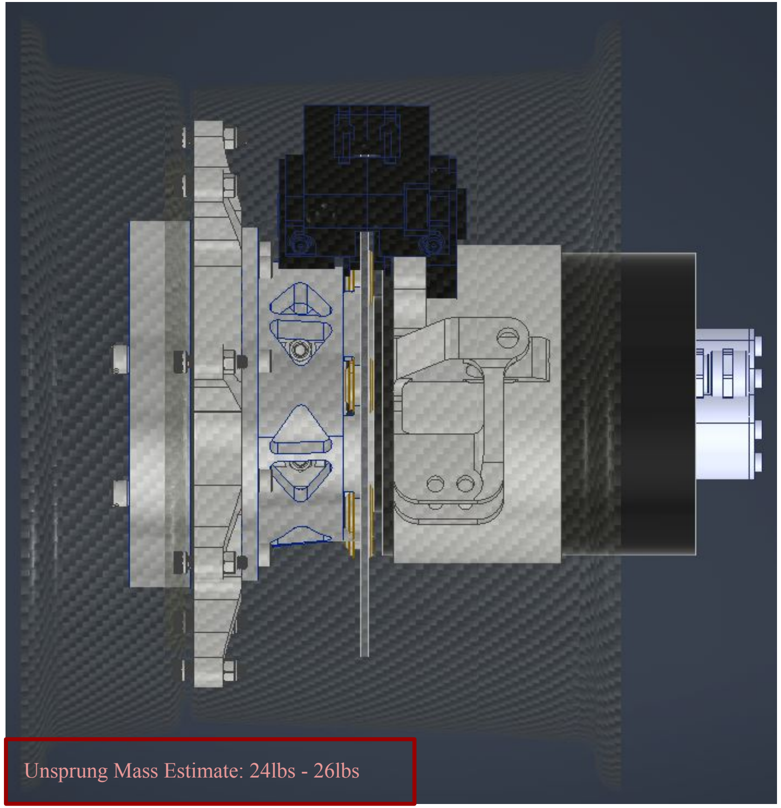
Outboard Design

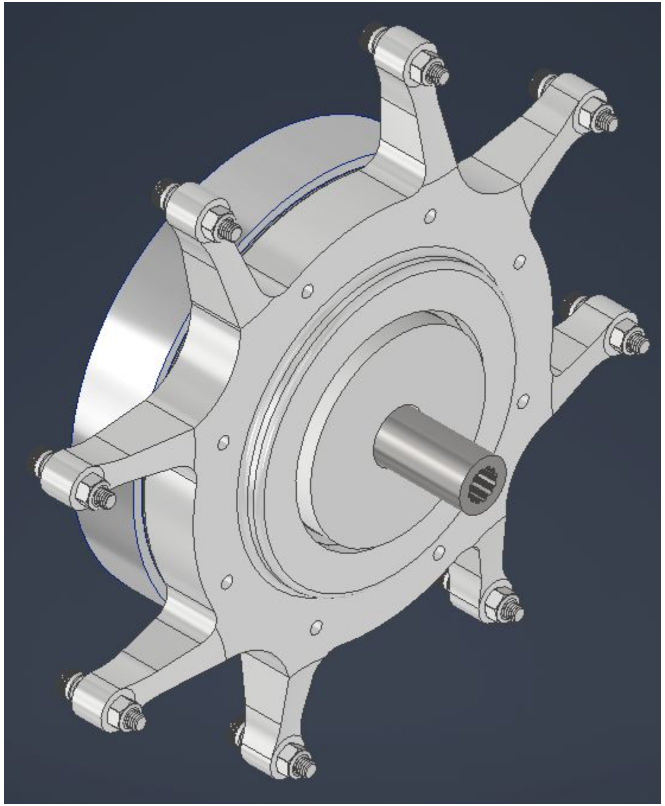
V1 V2 V3 V4

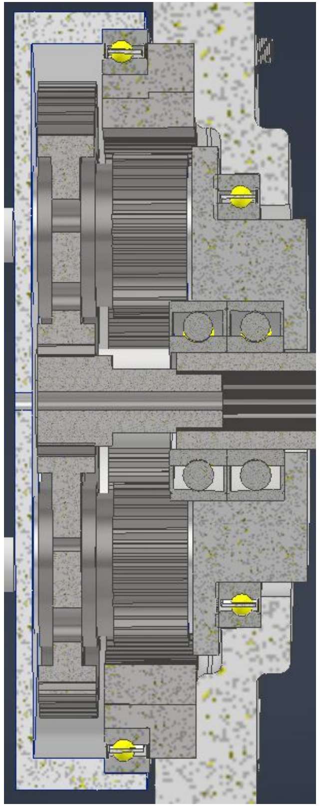


V5: Parametric V4,
Due to complexity, and questionable manufacturability, it was left unfinished.

Outboard V6







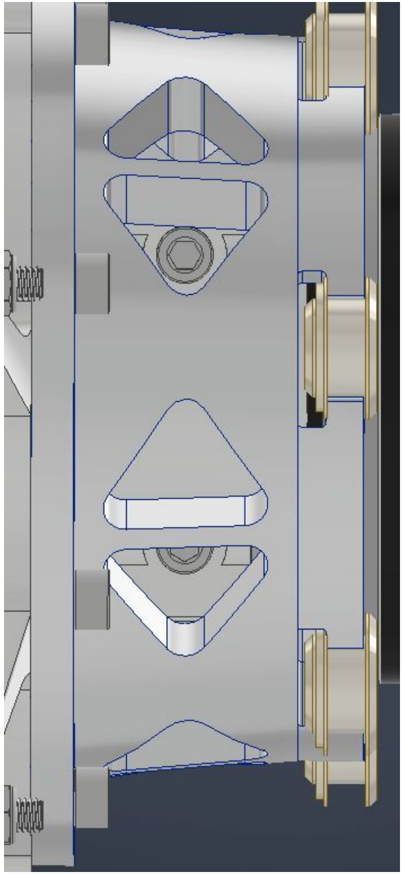
Outboard V6 - Videos

[Disassembly]

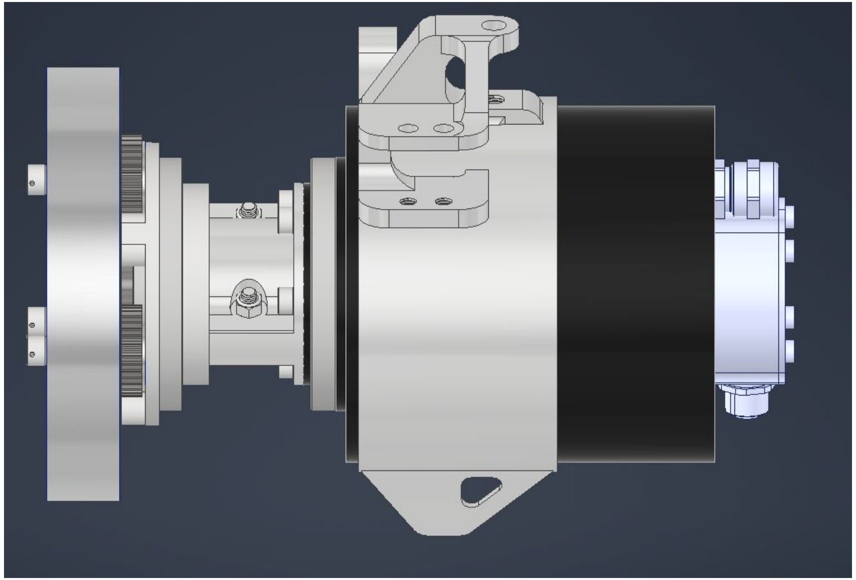
[Disassembly-With-Hidden-Components]

[System-in-motion]

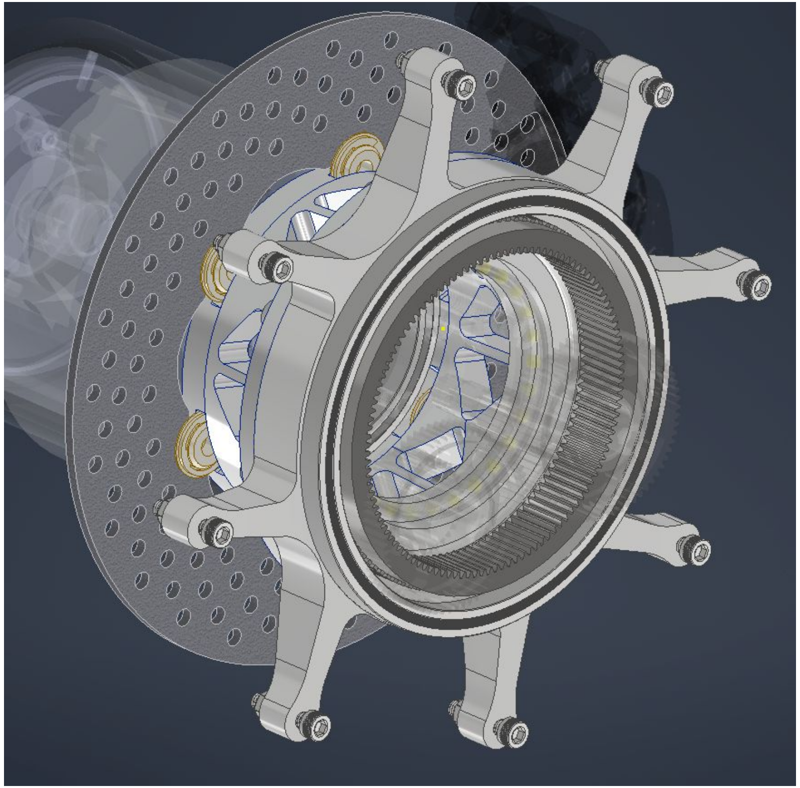
- Please don't hate me for quality of video, my computer cant take much more.

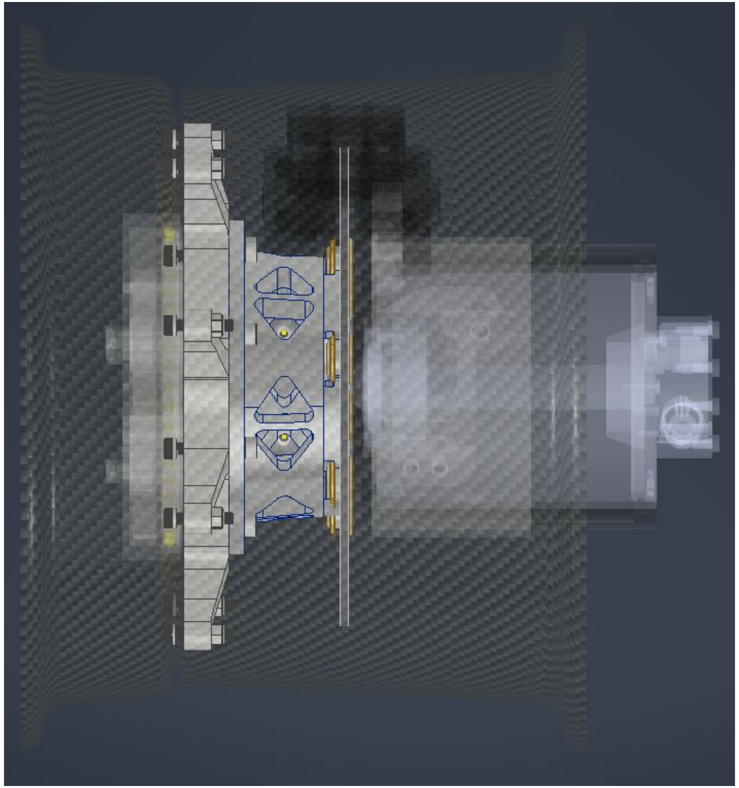


Static Components - not gears

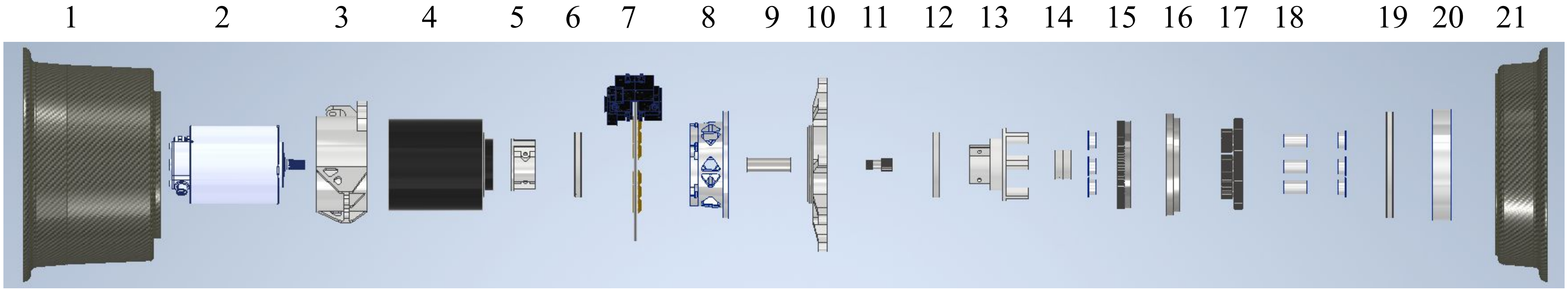


Dynamic Components - Driving System





Outboard V6 - Exploded View



1: Carbon barrel
2: AMK motor
3: Upright
4: Cooling jacket
5: Motor mount
6: Spindle bearing
7: Brakes
8: Spindle
9: Coupling
10: Wheel center
11: Sun gear
12: Inner ring gear bearing
13: Carrier with mount
14: Sun gear bearing
15: Ring gear
16: Ring gear housing
17: Planet gears
18: Planet pins
19: Outer ring gear bearing
20: Back housing
21: Carbon lip

Assembly Methods:

Planet Pins, pressed onto carrier and retained by half shaft bolts.

Inner ring gear bearing, pressed onto carrier.

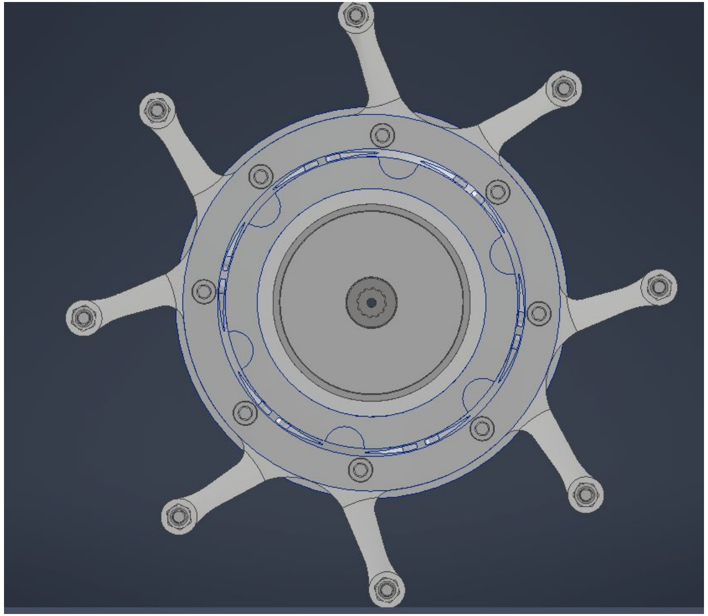
Outer ring gear bearing, pressed onto ring gear housing.

Spindle Bearing, pressed onto cooling jacket or upright.

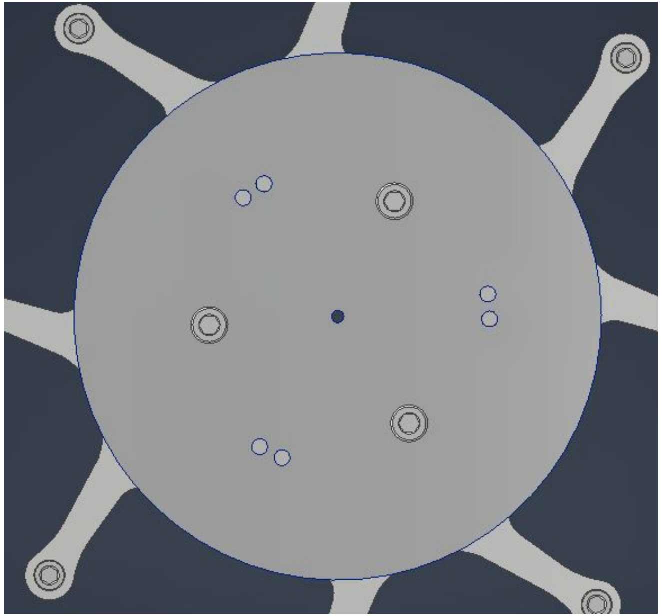
Splined ring gear attachment to ring gear housing, retained by wheel center.

Safety Wire - yay

Front View - Safety Wire

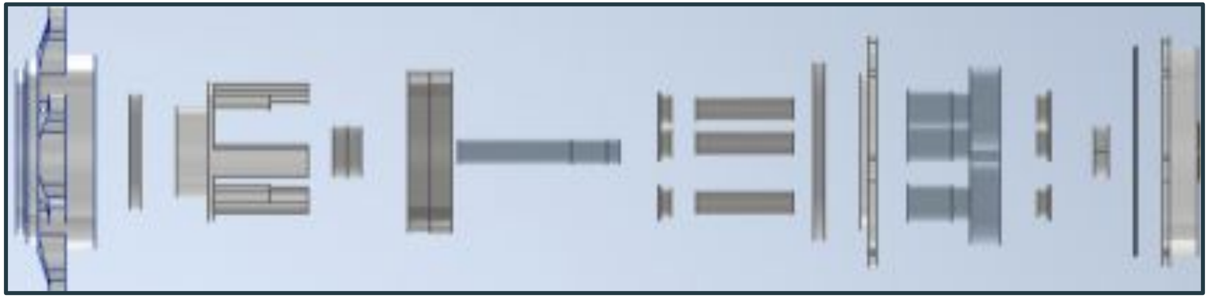


Back View - Safety Wire

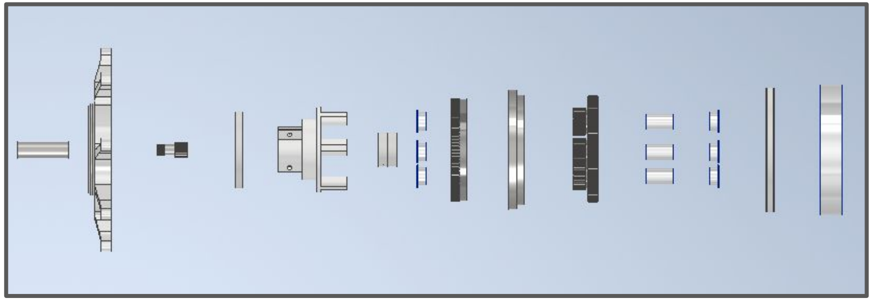


Design Changes V4 - V6

V4



V6



Coupling:
The sun gear is separated into a coupling and sun gear which mounts the sun gear to the motor. The addition of the coupling reduced the minimum sun gear pitch diameter from 17.6mm to 14.4mm

Removed Retaining Plate:
Due to the relocation of the outer ring gear bearing (Moved from inside the ring gear housing to the outside) we can now eliminate the retaining plate as the bearing can now be retained by the back housing.

Carrier Simplification:
Due to the removal of the retaining plate the carrier can now be manufactured. Previously the retaining plate required a complex geometry for the carrier in order to be mounted.

Separated Ring Gear Housing:
The Ring gear housing has now been separated into a wheel center and ring gear housing, allowing the wheel center to retain the splined ring gear.

Possible Gear Configs for parametric V7 (Matlab)

Inputs Parameters / Gear ratios:

Cfg	Inputs Parameters		Diameters	Gear ratios	CtrDiff	Stage1OD	Dr_des	OD1_des	DesignDiff
Cfg 1:	M1=0.80 M2=0.80	Ns=19 Nr=119 Np1=66 Np2=34	Ds=15.20 Dr=95.20 Dp1=52.80 Dp2=27.20	R=12.158 (S1=3.474, S2=3.500)	CtrDiff=0.0000	Stage1OD=120.80	Dr_des=111.20	OD1_des=126.40	DesignDiff=7.60
Cfg 2:	M1=0.80 M2=1.00	Ns=19 Nr=95 Np1=66 Np2=27	Ds=15.20 Dr=95.00 Dp1=52.80 Dp2=27.00	R=12.222 (S1=3.474, S2=3.519)	CtrDiff=0.0000	Stage1OD=120.80	Dr_des=111.00	OD1_des=126.40	DesignDiff=7.70
Cfg 3:	M1=1.00 M2=1.00	Ns=15 Nr=96 Np1=53 Np2=28	Ds=15.00 Dr=96.00 Dp1=53.00 Dp2=28.00	R=12.114 (S1=3.533, S2=3.429)	CtrDiff=0.0000	Stage1OD=121.00	Dr_des=112.00	OD1_des=127.00	DesignDiff=7.50
Cfg 4:	M1=0.80 M2=0.80	Ns=18 Nr=120 Np1=67 Np2=35	Ds=14.40 Dr=96.00 Dp1=53.60 Dp2=28.00	R=12.762 (S1=3.722, S2=3.429)	CtrDiff=0.0000	Stage1OD=121.60	Dr_des=112.00	OD1_des=127.20	DesignDiff=7.60
Cfg 5:	M1=0.80 M2=1.00	Ns=18 Nr=96 Np1=67 Np2=28	Ds=14.40 Dr=96.00 Dp1=53.60 Dp2=28.00	R=12.762 (S1=3.722, S2=3.429)	CtrDiff=0.0000	Stage1OD=121.60	Dr_des=112.00	OD1_des=127.20	DesignDiff=7.60
Cfg 6:	M1=0.80 M2=0.80	Ns=18 Nr=120 Np1=68 Np2=34	Ds=14.40 Dr=96.00 Dp1=54.40 Dp2=27.20	R=13.333 (S1=3.778, S2=3.529)	CtrDiff=0.0000	Stage1OD=123.20	Dr_des=112.00	OD1_des=128.80	DesignDiff=8.40
Cfg 7:	M1=0.80 M2=0.80	Ns=18 Nr=123 Np1=68 Np2=37	Ds=14.40 Dr=98.40 Dp1=54.40 Dp2=29.60	R=12.559 (S1=3.778, S2=3.324)	CtrDiff=0.0000	Stage1OD=123.20	Dr_des=114.40	OD1_des=128.80	DesignDiff=7.20
Cfg 8:	M1=1.00 M2=1.00	Ns=15 Nr=96 Np1=54 Np2=27	Ds=15.00 Dr=96.00 Dp1=54.00 Dp2=27.00	R=12.800 (S1=3.600, S2=3.556)	CtrDiff=0.0000	Stage1OD=123.00	Dr_des=112.00	OD1_des=129.00	DesignDiff=8.50
Cfg 9:	M1=0.80 M2=0.80	Ns=19 Nr=122 Np1=68 Np2=35	Ds=15.20 Dr=97.60 Dp1=54.40 Dp2=28.00	R=12.475 (S1=3.579, S2=3.486)	CtrDiff=0.0000	Stage1OD=124.00	Dr_des=113.60	OD1_des=129.60	DesignDiff=8.00
Cfg 10:	M1=0.80 M2=0.80	Ns=18 Nr=123 Np1=69 Np2=36	Ds=14.40 Dr=98.40 Dp1=55.20 Dp2=28.80	R=13.097 (S1=3.833, S2=3.417)	CtrDiff=0.0000	Stage1OD=124.80	Dr_des=114.40	OD1_des=130.40	DesignDiff=8.00
Cfg 11:	M1=1.00 M2=1.00	Ns=15 Nr=99 Np1=55 Np2=29	Ds=15.00 Dr=99.00 Dp1=55.00 Dp2=29.00	R=12.517 (S1=3.667, S2=3.414)	CtrDiff=0.0000	Stage1OD=125.00	Dr_des=115.00	OD1_des=131.00	DesignDiff=8.00
Cfg 12:	M1=0.80 M2=0.80	Ns=19 Nr=122 Np1=69 Np2=34	Ds=15.20 Dr=97.60 Dp1=55.20 Dp2=27.20	R=13.031 (S1=3.632, S2=3.588)	CtrDiff=0.0000	Stage1OD=125.60	Dr_des=113.60	OD1_des=131.20	DesignDiff=8.80
Cfg 13:	M1=0.80 M2=0.80	Ns=19 Nr=125 Np1=69 Np2=37	Ds=15.20 Dr=100.00 Dp1=55.20 Dp2=29.60	R=12.269 (S1=3.632, S2=3.378)	CtrDiff=0.0000	Stage1OD=125.60	Dr_des=116.00	OD1_des=131.20	DesignDiff=7.60
Cfg 14:	M1=0.80 M2=0.80	Ns=18 Nr=123 Np1=70 Np2=35	Ds=14.40 Dr=98.40 Dp1=56.00 Dp2=28.00	R=13.667 (S1=3.889, S2=3.514)	CtrDiff=0.0000	Stage1OD=126.40	Dr_des=114.40	OD1_des=132.00	DesignDiff=8.80
Cfg 15:	M1=0.80 M2=0.80	Ns=18 Nr=126 Np1=70 Np2=38	Ds=14.40 Dr=100.80 Dp1=56.00 Dp2=30.40	R=12.895 (S1=3.889, S2=3.316)	CtrDiff=0.0000	Stage1OD=126.40	Dr_des=116.80	OD1_des=132.00	DesignDiff=7.60
Cfg 16:	M1=0.80 M2=0.80	Ns=20 Nr=124 Np1=69 Np2=35	Ds=16.00 Dr=99.20 Dp1=55.20 Dp2=28.00	R=12.223 (S1=3.450, S2=3.543)	CtrDiff=0.0000	Stage1OD=126.40	Dr_des=115.20	OD1_des=132.00	DesignDiff=8.40
Cfg 17:	M1=1.00 M2=1.00	Ns=16 Nr=98 Np1=55 Np2=27	Ds=16.00 Dr=98.00 Dp1=55.00 Dp2=27.00	R=12.477 (S1=3.438, S2=3.630)	CtrDiff=0.0000	Stage1OD=126.00	Dr_des=114.00	OD1_des=132.00	DesignDiff=9.00
Cfg 18:	M1=0.80 M2=0.80	Ns=19 Nr=125 Np1=70 Np2=36	Ds=15.20 Dr=100.00 Dp1=56.00 Dp2=28.80	R=12.792 (S1=3.684, S2=3.472)	CtrDiff=0.0000	Stage1OD=126.40	Dr_des=116.00	OD1_des=132.80	DesignDiff=8.40
Cfg 19:	M1=0.80 M2=1.00	Ns=21 Nr=99 Np1=69 Np2=27	Ds=16.80 Dr=99.00 Dp1=55.20 Dp2=27.00	R=12.048 (S1=3.286, S2=3.667)	CtrDiff=0.0000	Stage1OD=127.20	Dr_des=115.00	OD1_des=132.80	DesignDiff=8.90
Cfg 20:	M1=1.00 M2=1.00	Ns=15 Nr=99 Np1=56 Np2=28	Ds=15.00 Dr=99.00 Dp1=56.00 Dp2=28.00	R=13.200 (S1=3.733, S2=3.536)	CtrDiff=0.0000	Stage1OD=127.00	Dr_des=115.00	OD1_des=133.00	DesignDiff=9.00
Cfg 21:	M1=1.00 M2=1.00	Ns=15 Nr=102 Np1=56 Np2=31	Ds=15.00 Dr=102.00 Dp1=56.00 Dp2=31.00	R=12.284 (S1=3.733, S2=3.290)	CtrDiff=0.0000	Stage1OD=127.00	Dr_des=118.00	OD1_des=133.00	DesignDiff=7.50
Cfg 22:	M1=0.80 M2=0.80	Ns=18 Nr=126 Np1=71 Np2=37	Ds=14.40 Dr=100.80 Dp1=56.80 Dp2=29.60	R=13.432 (S1=3.944, S2=3.405)	CtrDiff=0.0000	Stage1OD=128.00	Dr_des=116.80	OD1_des=133.60	DesignDiff=8.40
Cfg 23:	M1=0.80 M2=0.80	Ns=20 Nr=124 Np1=70 Np2=34	Ds=16.00 Dr=99.20 Dp1=56.00 Dp2=27.20	R=12.765 (S1=3.500, S2=3.647)	CtrDiff=0.0000	Stage1OD=128.00	Dr_des=115.20	OD1_des=133.60	DesignDiff=9.20
Cfg 24:	M1=0.80 M2=0.80	Ns=20 Nr=127 Np1=70 Np2=37	Ds=16.00 Dr=101.60 Dp1=56.00 Dp2=29.60	R=12.014 (S1=3.500, S2=3.432)	CtrDiff=0.0000	Stage1OD=128.00	Dr_des=117.60	OD1_des=133.60	DesignDiff=8.00
Cfg 25:	M1=0.80 M2=1.00	Ns=20 Nr=100 Np1=70 Np2=28	Ds=16.00 Dr=100.00 Dp1=56.00 Dp2=28.00	R=12.500 (S1=3.500, S2=3.571)	CtrDiff=0.0000	Stage1OD=128.00	Dr_des=116.00	OD1_des=133.60	DesignDiff=8.80
Cfg 26:	M1=1.00 M2=1.00	Ns=16 Nr=101 Np1=56 Np2=29	Ds=16.00 Dr=101.00 Dp1=56.00 Dp2=29.00	R=12.190 (S1=3.500, S2=3.483)	CtrDiff=0.0000	Stage1OD=128.00	Dr_des=117.00	OD1_des=134.00	DesignDiff=8.50
Cfg 27:	M1=0.80 M2=0.80	Ns=19 Nr=125 Np1=71 Np2=35	Ds=15.20 Dr=100.00 Dp1=56.80 Dp2=28.00	R=13.346 (S1=3.737, S2=3.571)	CtrDiff=0.0000	Stage1OD=128.80	Dr_des=116.00	OD1_des=134.40	DesignDiff=9.20
Cfg 28:	M1=0.80 M2=0.80	Ns=19 Nr=128 Np1=71 Np2=38	Ds=15.20 Dr=102.40 Dp1=56.80 Dp2=30.40	R=12.587 (S1=3.737, S2=3.368)	CtrDiff=0.0000	Stage1OD=128.80	Dr_des=118.40	OD1_des=134.40	DesignDiff=8.00
Cfg 29:	M1=0.80 M2=0.80	Ns=21 Nr=126 Np1=70 Np2=35	Ds=16.80 Dr=100.80 Dp1=56.00 Dp2=28.00	R=12.000 (S1=3.333, S2=3.600)	CtrDiff=0.0000	Stage1OD=128.80	Dr_des=116.80	OD1_des=134.40	DesignDiff=8.80
Cfg 30:	M1=0.80 M2=1.00	Ns=19 Nr=101 Np1=71 Np2=29	Ds=15.20 Dr=101.00 Dp1=56.80 Dp2=29.00	R=13.015 (S1=3.737, S2=3.483)	CtrDiff=0.0000	Stage1OD=128.80	Dr_des=117.00	OD1_des=134.40	DesignDiff=8.70
Cfg 31:	M1=0.80 M2=1.00	Ns=19 Nr=104 Np1=71 Np2=32	Ds=15.20 Dr=104.00 Dp1=56.80 Dp2=32.00	R=12.145 (S1=3.737, S2=3.250)	CtrDiff=0.0000	Stage1OD=128.80	Dr_des=120.00	OD1_des=134.40	DesignDiff=7.20
Cfg 32:	M1=1.00 M2=1.00	Ns=15 Nr=99 Np1=57 Np2=27	Ds=15.00 Dr=99.00 Dp1=57.00 Dp2=27.00	R=13.933 (S1=3.800, S2=3.667)	CtrDiff=0.0000	Stage1OD=129.00	Dr_des=115.00	OD1_des=135.00	DesignDiff=10.00
Cfg 33:	M1=1.00 M2=1.00	Ns=15 Nr=102 Np1=57 Np2=30	Ds=15.00 Dr=102.00 Dp1=57.00 Dp2=30.00	R=12.920 (S1=3.800, S2=3.400)	CtrDiff=0.0000	Stage1OD=129.00	Dr_des=118.00	OD1_des=135.00	DesignDiff=8.50
Cfg 34:	M1=1.00 M2=1.00	Ns=17 Nr=100 Np1=56 Np2=27	Ds=17.00 Dr=100.00 Dp1=56.00 Dp2=27.00	R=12.200 (S1=3.294, S2=3.704)	CtrDiff=0.0000	Stage1OD=129.00	Dr_des=116.00	OD1_des=135.00	DesignDiff=9.50
Cfg 35:	M1=0.80 M2=0.80	Ns=18 Nr=126 Np1=72 Np2=36	Ds=14.40 Dr=100.80 Dp1=57.60 Dp2=28.80	R=14.000 (S1=4.000, S2=3.500)	CtrDiff=0.0000	Stage1OD=129.60	Dr_des=116.80	OD1_des=135.20	DesignDiff=9.20
Cfg 36:	M1=0.80 M2=0.80	Ns=18 Nr=129 Np1=72 Np2=39	Ds=14.40 Dr=103.20 Dp1=57.60 Dp2=31.20	R=13.231 (S1=4.000, S2=3.308)	CtrDiff=0.0000	Stage1OD=129.60	Dr_des=119.20	OD1_des=135.20	DesignDiff=8.00
Cfg 37:	M1=0.80 M2=1.00	Ns=18 Nr=102 Np1=72 Np2=30	Ds=14.40 Dr=102.00 Dp1=57.60 Dp2=30.00	R=13.600 (S1=4.000, S2=3.400)	CtrDiff=0.0000	Stage1OD=129.60	Dr_des=118.00	OD1_des=135.20	DesignDiff=8.60
Cfg 38:	M1=0.80 M2=0.80	Ns=20 Nr=127 Np1=71 Np2=36	Ds=16.00 Dr=101.60 Dp1=56.80 Dp2=28.80	R=12.524 (S1=3.550, S2=3.528)	CtrDiff=0.0000	Stage1OD=129.60	Dr_des=117.60	OD1_des=135.20	DesignDiff=8.80
Cfg 39:	M1=0.80 M2=0.80	Ns=19 Nr=125 Np1=72 Np2=34	Ds=15.20 Dr=100.00 Dp1=57.60 Dp2=27.20	R=13.932 (S1=3.789, S2=3.676)	CtrDiff=0.0000	Stage1OD=130.40	Dr_des=116.00	OD1_des=136.00	DesignDiff=10.00
Cfg 40:	M1=0.80 M2=0.80	Ns=19 Nr=128 Np1=72 Np2=37	Ds=15.20 Dr=102.40 Dp1=57.60 Dp2=29.60	R=13.110 (S1=3.789, S2=3.459)	CtrDiff=0.0000	Stage1OD=130.40	Dr_des=118.40	OD1_des=136.00	DesignDiff=8.80
Cfg 41:	M1=0.80 M2=0.80	Ns=19 Nr=131 Np1=72 Np2=40	Ds=15.20 Dr=104.80 Dp1=57.60 Dp2=32.00	R=12.411 (S1=3.789, S2=3.275)	CtrDiff=0.0000	Stage1OD=130.40	Dr_des=120.80	OD1_des=136.00	DesignDiff=7.60
Cfg 42:	M1=0.80 M2=0.80	Ns=21 Nr=126 Np1=71 Np2=34	Ds=16.80 Dr=100.80 Dp1=56.80 Dp2=27.20	R=12.529 (S1=3.381, S2=3.706)	CtrDiff=0.0000	Stage1OD=130.40	Dr_des=116.80	OD1_des=136.00	DesignDiff=9.60
Cfg 43:	M1=1.00 M2=1.00	Ns=16 Nr=101 Np1=57 Np2=28	Ds=16.00 Dr=101.00 Dp1=57.00 Dp2=28.00	R=12.850 (S1=3.562, S2=3.607)	CtrDiff=0.0000	Stage1OD=130.00	Dr_des=117.00	OD1_des=136.00	DesignDiff=9.50
Cfg 44:	M1=0.80 M2=0.80	Ns=20 Nr=127 Np1=72 Np2=35	Ds=16.00 Dr=101.60 Dp1=57.60 Dp2=28.00	R=13.063 (S1=3.600, S2=3.629)	CtrDiff=0.0000	Stage1OD=131.20	Dr_des=117.60	OD1_des=136.80	DesignDiff=9.60
Cfg 45:	M1=0.80 M2=0.80	Ns=20 Nr=130 Np1=72 Np2=38	Ds=16.00 Dr=104.00 Dp1=57.60 Dp2=30.40	R=12.316 (S1=3.600, S2=3.421)	CtrDiff=0.0000	Stage1OD=131.20	Dr_des=120.00	OD1_des=136.80	DesignDiff=8.40
Cfg 46:	M1=0.80 M2=0.80	Ns=18 Nr=129 Np1=73 Np2=38	Ds=14.40 Dr=103.20 Dp1=58.40 Dp2=30.40	R=13.768 (S1=4.056, S2=3.395)	CtrDiff=0.0000	Stage1OD=131.20	Dr_des=119.20	OD1_des=136.80	DesignDiff=8.80
Cfg 47:	M1=0.80 M2=0.80	Ns=18 Nr=132 Np1=73 Np2=41	Ds=14.40 Dr=105.60 Dp1=58.40 Dp2=32.80	R=13.057 (S1=4.056, S2=3.220)	CtrDiff=0.0000	Stage1OD=131.20	Dr_des=121.60	OD1_des=136.80	DesignDiff=7.60
Cfg 48:	M1=1.00 M2=1.00	Ns=15 Nr=102 Np1=58 Np2=29	Ds=15.00 Dr=102.00 Dp1=58.00 Dp2=29.00	R=13.600 (S1=3.867, S2=3.517)	CtrDiff=0.0000	Stage1OD=131.00	Dr_des=118.00	OD1_des=137.00	DesignDiff=9.50
Cfg 49:	M1=1.00 M2=1.00	Ns=15 Nr=105 Np1=58 Np2=32	Ds=15.00 Dr=105.00 Dp1=58.00 Dp2=32.00	R=12.688 (S1=3.867, S2=3.281)	CtrDiff=0.0000	Stage1OD=131.00	Dr_des=121.00	OD1_des=137.00	DesignDiff=8.00
Cfg 50:	M1=0.80 M2=0.80	Ns=19 Nr=128 Np1=73 Np2=36	Ds=15.20 Dr=102.40 Dp1=58.40 Dp2=28.80	R=13.661 (S1=3.842, S2=3.556)	CtrDiff=0.0000	Stage1OD=132.00	Dr_des=118.40	OD1_des=137.60	DesignDiff=9.60
Cfg 51:	M1=0.80 M2=0.80	Ns=19 Nr=131 Np1=73 Np2=39	Ds=15.20 Dr=104.80 Dp1=58.40 Dp2=31.20	R=12.906 (S1=3.842, S2=3.359)	CtrDiff=0.0000	Stage1OD=132.00	Dr_des=120.80	OD1_des=137.60	DesignDiff=8.40
Cfg 52:	M1=0.80 M2=0.80	Ns=21 Nr=129 Np1=72 Np2=36	Ds=16.80 Dr=103.20 Dp1=57.60 Dp2=28.80	R=12.286 (S1=3.429, S2=3.583)	CtrDiff=0.0000	Stage1OD=132.00	Dr_des=119.20	OD1_des=137.60	DesignDiff=9.20
Cfg 53:	M1=1.00 M2=1.00	Ns=16 Nr=101 Np1=58 Np2=27	Ds=16.00 Dr=101.00 Dp1=58.00 Dp2=27.00	R=13.560 (S1=3.625, S2=3.741)	CtrDiff=0.0000	Stage1OD=132.00	Dr_des=117.00	OD1_des=138.00	DesignDiff=10.50
Cfg 54:	M1=1.00 M2=1.00	Ns=16 Nr=104 Np1=58 Np2=30	Ds=16.00 Dr=104.00 Dp1=58.00 Dp2=30.00	R=12.567 (S1=3.625, S2=3.467)	CtrDiff=0.0000	Stage1OD=132.00	Dr_des=120.00	OD1_des=138.00	DesignDiff=9.00

Design Constraints:

```
M1_range        = 0.8:0.2:1.0;
M2_range        = .8:.2:1;
tol             = 0.05;
minSunPD        = 14.4;
minPlanetPD     = 26.6;
tinyPitchTol    = 1e-9;
MAX_STAGE1_OD   = 132;
odTol           = 1e-9;
MIN_DESIGN_DIFF = 7.1;
```

If Ds >= 17.6 Coupling is not required

Applicable Face Width Range: 8mm : 50mm

Outboard V5 only had 8 working configs with a max ratio of ~12.36:1

Moving Forward?

FBD - Determine all forces that act on the outboard system and analyze a FBD, in order to move forward with simulations.

Ansys simulations - Simulate Static and Dynamic Forces to ensure strength in the system.

- Limit load on gearbox caused by axial forces From turning - Axial retaining washer may be required

Ensure manufacturability for V6 - Assume 3 axis CNC, 4 axis if necessary, reduce cost

Ensure the gearbox is sealed - Research additional sealing methods and prove the design is sealed.

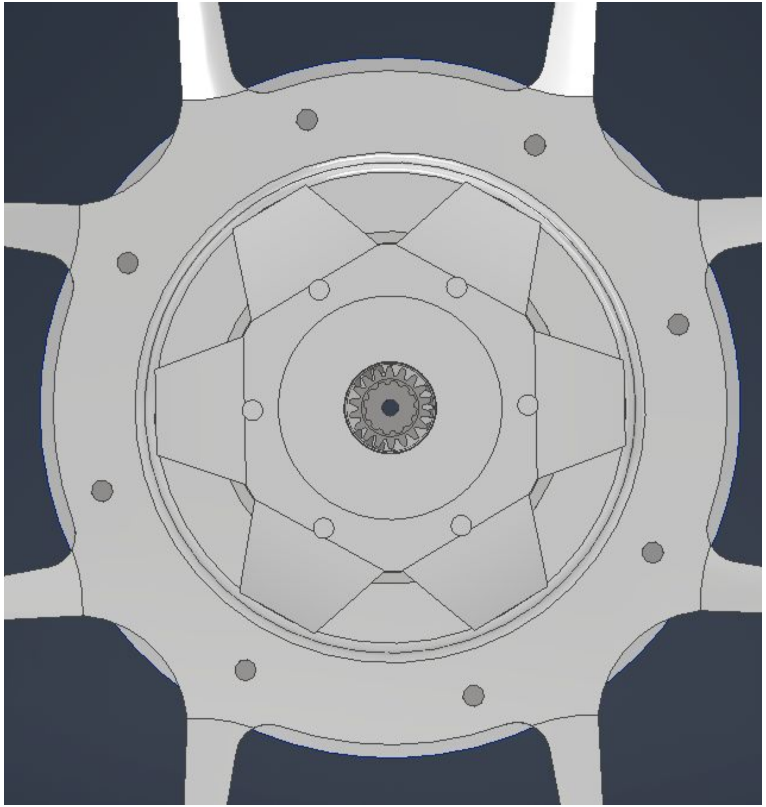
Parametric V7 - Adin will complete over winter break

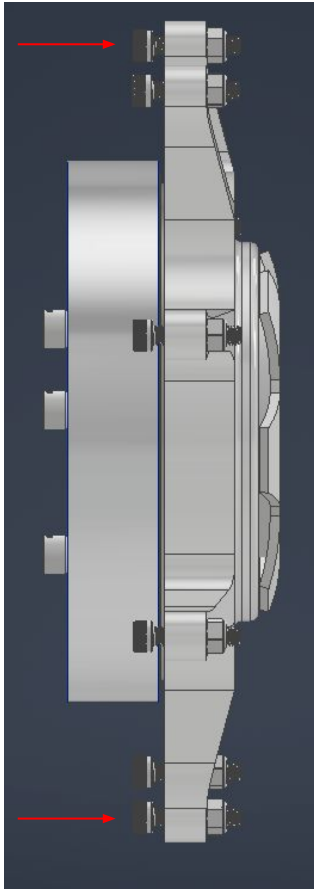
Kisssoft - When arjun returns, work on creating a modified Kissoft model.

Work closely with Powertrain, Suspension & Brakes subteams - With V7 outboard gearbox design, there are very few additional design requirements to the already existing system, however with an increased unsprung mass, and the upright now housing the cooling jacket and motor, redesigns are required.

Cost - Limit the cost for the newly added bearings (SKF Sponsor???)

Axial Retaining Washer





Some form of Axial retaining washer may be required to reduce the load on the gearbox seen from the wheel center. The current design already allows for the Output System to shift +-1.5mm in the axial direction.

The 3mm tolerance can be removed, although it is in place due to load concerns.

Final Design Process

Matlab → Kissoft → Parametric Model → Simulate → Finalize

Matlab

Determine optimal gear ratio from vehicle dynamics team, for AWD or RWD.

Pick from the 54 available configs that best suits the optimal gear ratio.

Kissoft

From the chosen gear ratio use kissoft to optimize gear geometry.

Parametric Model

Input the 6 Values from matlab to automatically generate a new gearbox.

Input the Gear geometry from kisssoft.

Simulate

Using the created dynamic and static simulation, simulate the housing system for the new gearbox to ensure the designs structural integrity.

Make necessary changes if needed.

Finalize

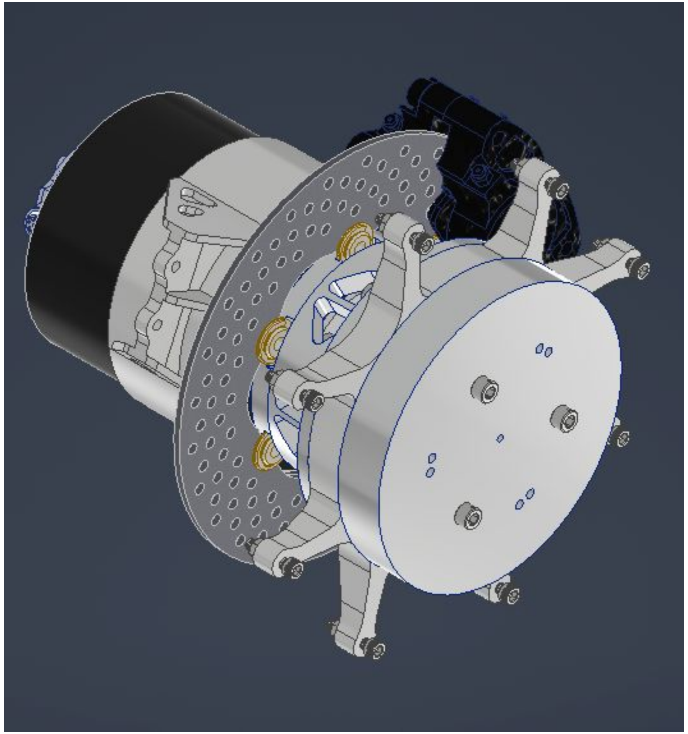
Suspension: Spindle, Upright

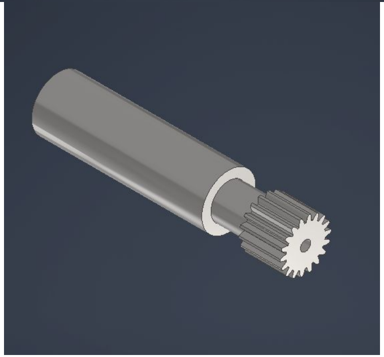
Brakes: Brake Rotor, Brake Caliper

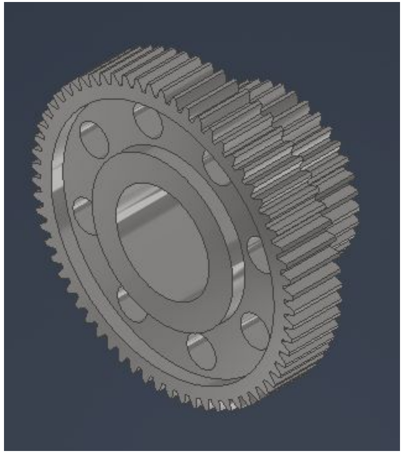
Powertrain: Cooling Jacket, Gearbox Mount.

Drivetrain: Gearbox, Wheel Center.

Additional Photos







Thank you!

Questions?