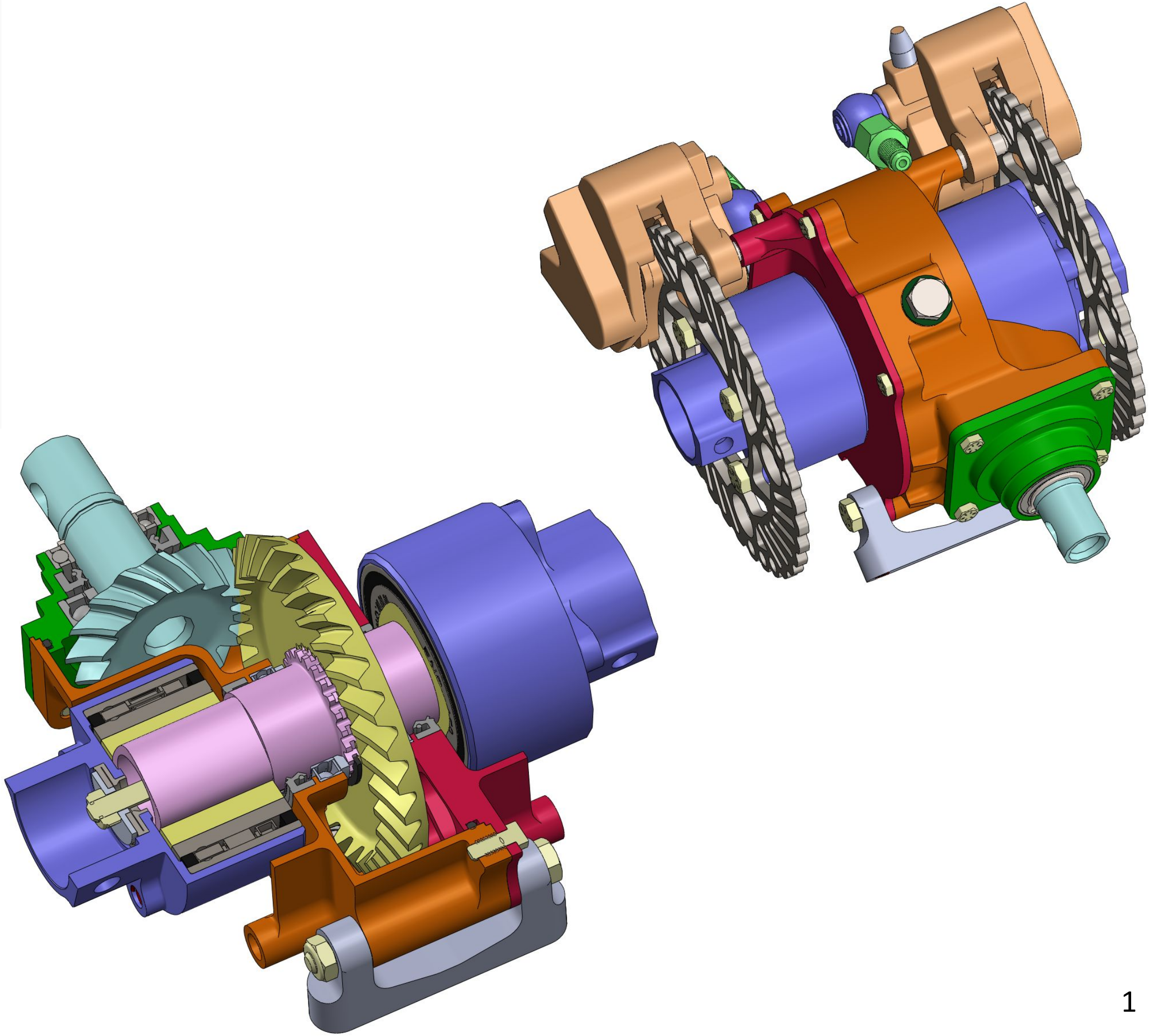
Front Differential

Armaan Bhojwani

The front differential acts as the forward power distribution gearbox in the four wheel drive Baja vehicle. It takes power from the driveshaft into the blue input shaft, and redirects it 90° into the front axles. It uses sprag clutches to allow the axles to overrun the drivetrain, improving vehicle dynamics while turning.

I was in charge of designing this component for the 2025 21XT vehicle.



Team Overview

Blue Jay Racing is the undergraduate Baja SAE Team at Johns Hopkins University. For the past 20 years, we've been developing our team's technical and problem solving skills by applying concepts taught in the classroom to the real-world. Each year, our members are tasked with designing, building, and racing a single-seat, four wheel drive off-road race car against 200+ teams worldwide.

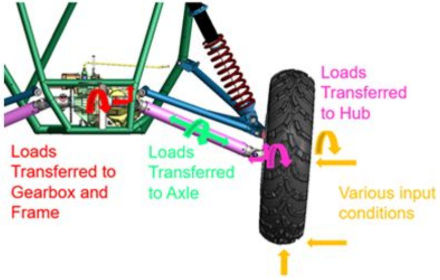
In the 2024 season, Blue Jay Racing placed **<u>5th overall out of 177 active teams worldwide</u>.**

Design Process Overview

Our team follows a strict design process to ensure design rigor. Some of these include:

- A centralized design sheet allowing designers to use consistent design factors and vehicle loads/parameters
- Component and subsystem level CDR and PDR design reviews through the course of the summer
- A formal design freeze process to ensure analysis validity, system integration, and manufacturability
- A custom drawing tree web portal to catalog the the vehicle and keep track of component statuses
- Component-level design sheets containing analysis documentation and hand calcs
- Thorough testing, both live on the vehicle and on the benchtop to validate analysis using a custom data acquisition system, allowing correlation of real vehicle performance and theoretical analysis

SYSTEM DESIGN AND FBD



6-DOF SOLVER FOR DERIVED LOADS

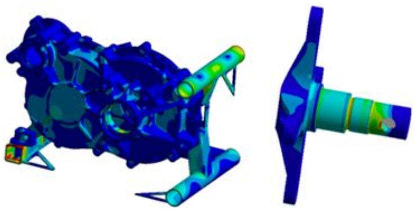
Upper A	Droop			Bump		
	Landing Jump	Cornering Rut	Front Impact	Landing Jump	Cornering Rut	Front Impact
Fx	179.1424	-47.436	-211.516	88.2929	77.318	-31.190
Fy	-522.0067	405.641	322.251	-552.1554	203.532	-107.159
Fz	1203.7201	-108.360	83.477	823.8615	629.152	179.711

Lower A	Droop			Bump		
	Landing Jump	Cornering Rut	Front Impact	Landing Jump	Cornering Rut	Front Impact
T/C	620.3902	-1257.042	300.806	594.3782	-935.978	26.427
Fx	-148.0569	-23.257	1152.128	-143.8317	4.796	908.760

	Droop			Bump		
Tie Rod	Landing Jump	Cornering Rut	Front Impact	Landing Jump	Cornering Rut	Front Impact
Point Based	-30.8188	44.819	-667.622	-29.4030	44.588	85.241

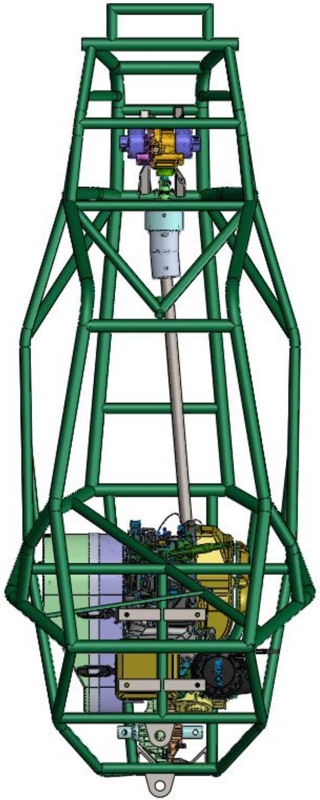
H-Arm	Droop			Bump		
	Landing Jump	Cornering Rut	Front Impact	Landing Jump	Cornering Rut	Front Impact
Fx	223.79	-625.41	900.53	152.03	-202.75	887.61
Fy	-595.99	997.95	-63.44	-1059.95	746.03	-76.01
Fz	1348.23	-581.38	39.53	813.47	674.38	-11.72
Halfshaft	737.03	-2059.69	78.46	1083.19	-1444.62	77.66
My	375.91	1698.58	-6402.09	-556.97	780.86	-5322.78
Mz	662.52	-1282.53	-2032.27	186.95	-235.20	-3321.89

FINITE ELEMENT ANALYSIS



Off-center Driveshaft

20XT (2024)



21XT (2025)

Overview

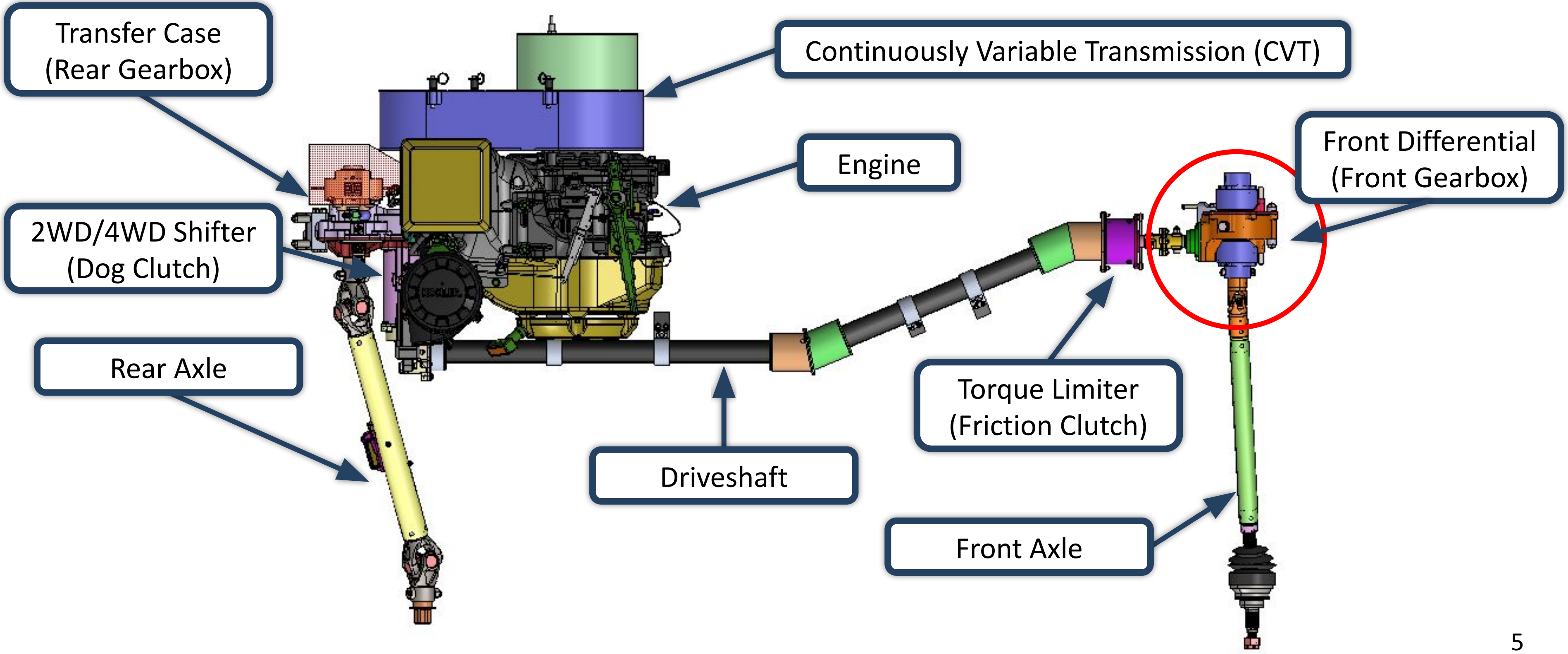
The driving high-level change in the design of the 21XT is the implementation of an off-center driveshaft.

Previously, the driveshaft has been routed directly under the drivers seat, however this year, we are routing it to the side of the driver which allows us to drop the seat by 2.5 inches, significantly lowering the vehicle’s center of gravity, and allowing the frame to be 5 lbs lighter.

Drivetrain Subsystem Implications

- Rear gearbox had to be restructured to transfer power all the way across the car
- Driveshaft needs a universal joint pivot in the middle
- Differential design priorities changed to best support this new architecture

Front Differential: Drivetrain Assembly Context



Front Differential: Design Criteria

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Requirements

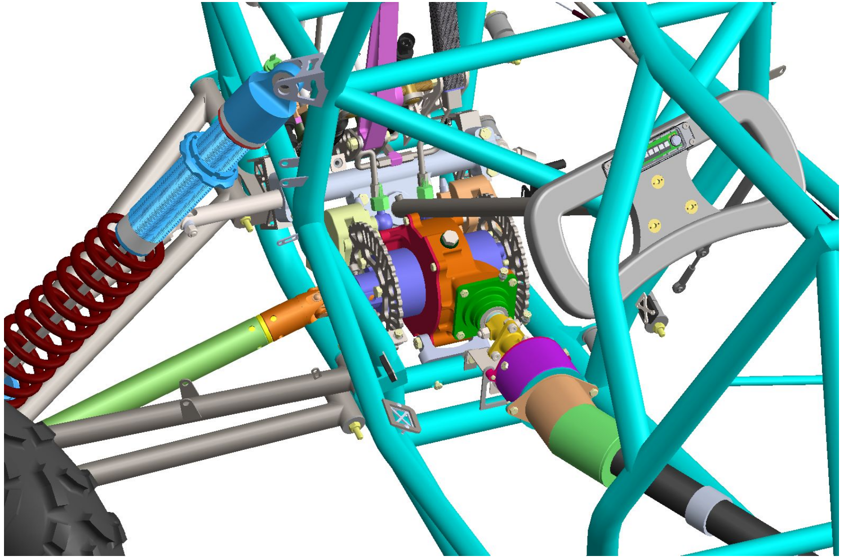
- Redirect driveline power 90° to the front axles
- Gear down the power output to desired final drive ratio
- Allow front wheels to overrun drivetrain power
- 3% underdrive as determined by vehicle dynamics requirements (suspension subteam)

Constraints

- Brake components mounting/loads
- Driveshaft torque (1546 in-lbs as limited by friction clutch)
- Front axle output
- Footbox packaging

21XT Goals and Results

- Shrink axially for better brakes packaging
  - Achieved: **<u>14% narrower</u>** (8” -> 6.9”)
- Accommodate off-center driveshaft
  - Achieved: moved input shaft off-center by **<u>1.06”</u>**, significantly reducing torque factor on driveshaft
- No significant mass/moment of inertia increase
  - Achieved: slightly heavier as necessitated by above goals. **<u>4% heavier</u>** (6.857 lbs -> 7.148 lbs)

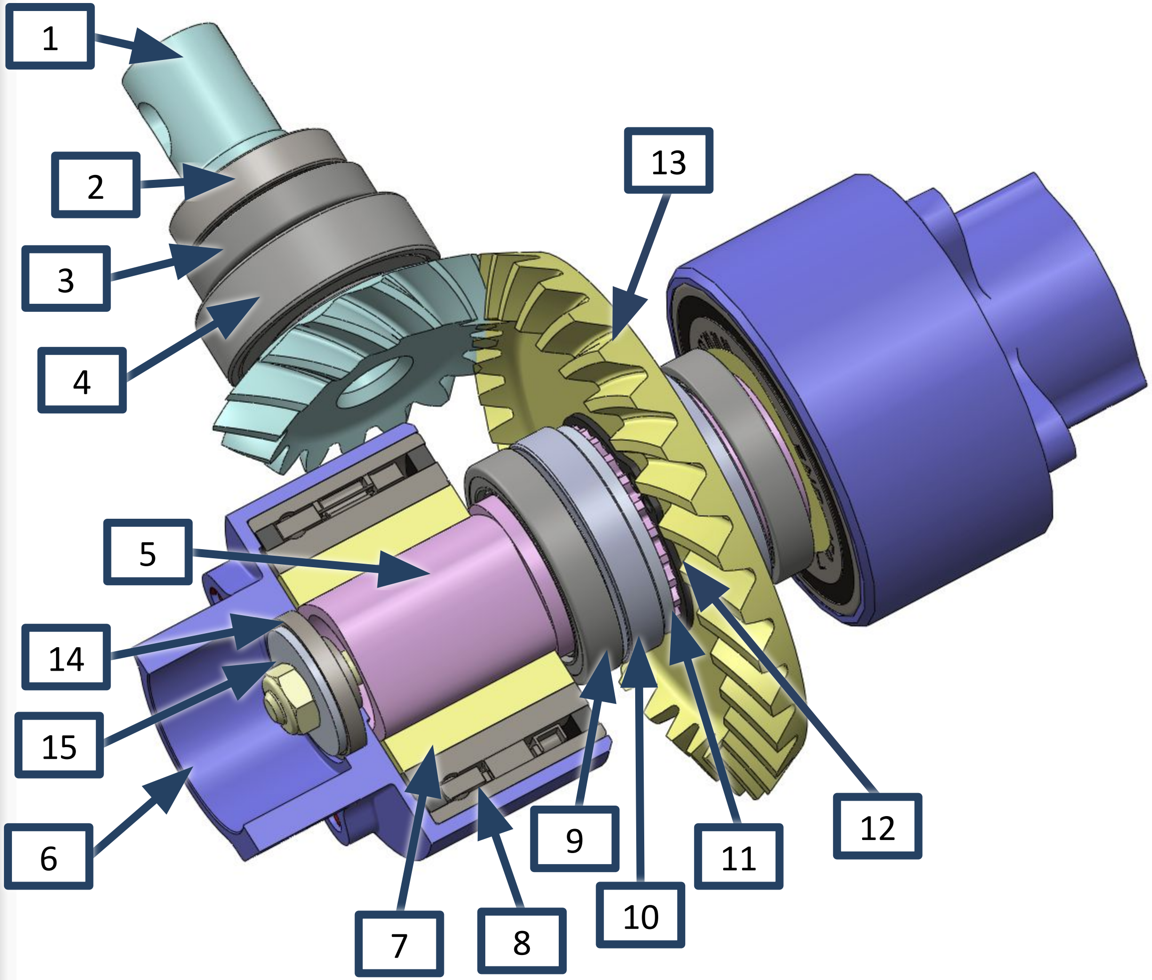


Front Differential

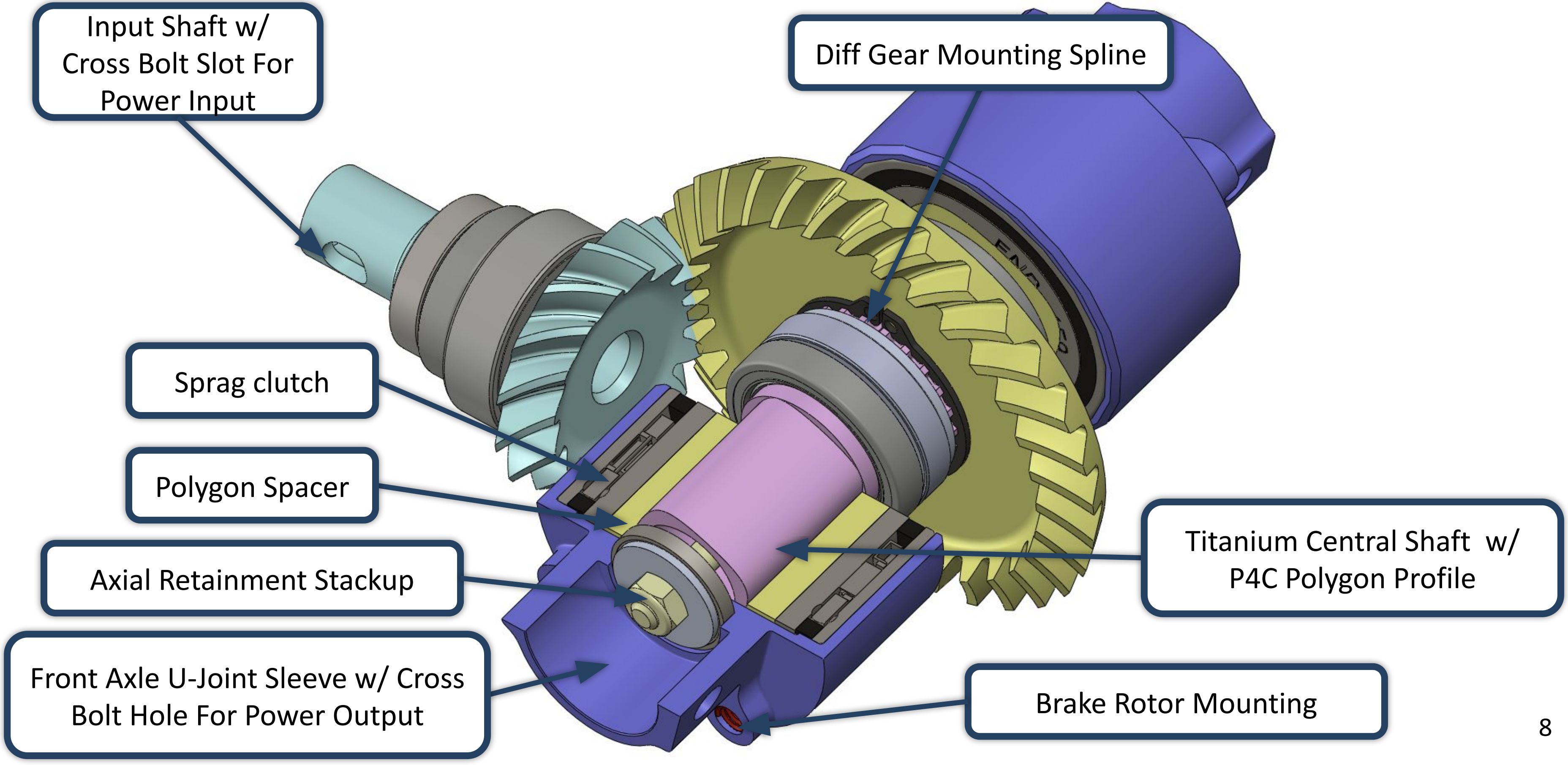
Internal Component Overview

1. 2104M-00207 Diff Pinion
2. 2104M-002-5972K279 Small Pinion Bearing
3. 2104M-002-1199N314 Pinion Seal
4. 2104M-002-6661K88 Large Pinion Bearing
5. 2104M-00201 Central Shaft
6. 2104M-00205 Cup
7. 2104M-00213 Polygon Spacer
8. 2104M-00212-FND459Z Sprag
9. 2104M-002-1199N317 Central Shaft Seal
10. 2104M-002-5972K282 Central Shaft Bearing
11. 2104M-00243 Central Shaft Bearing Spacer
12. 2104M-002-97633A380 Diff Gear Retaining Ring
13. 2104M-00206 Diff Gear
14. 2104M-002-AXW_10 Cup Thrust Bearing
15. 2104M-00241 Axial Retainment Bushing

Every component except for bearings, shaft seals, and fasteners is fully custom and has been designed and analyzed in-house.



Front Differential: Internal Anatomy

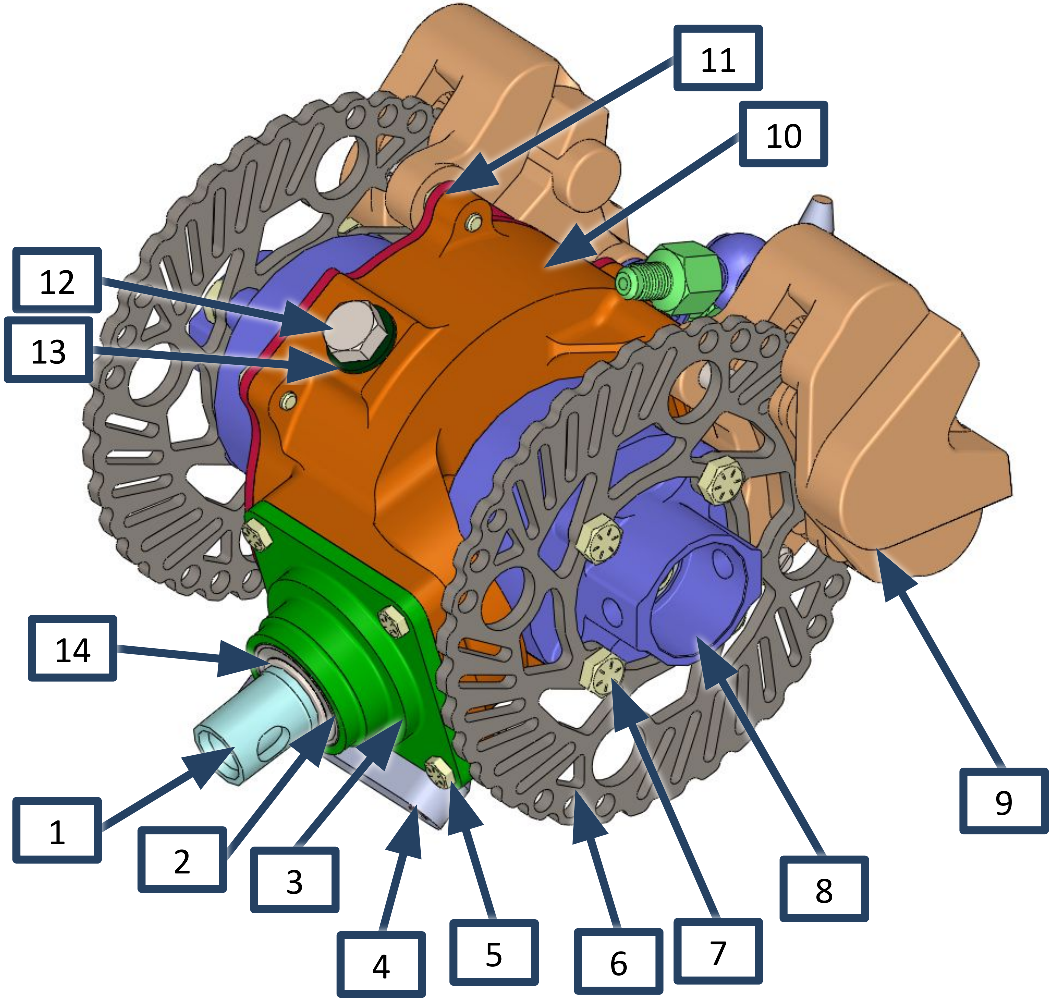


Front Differential

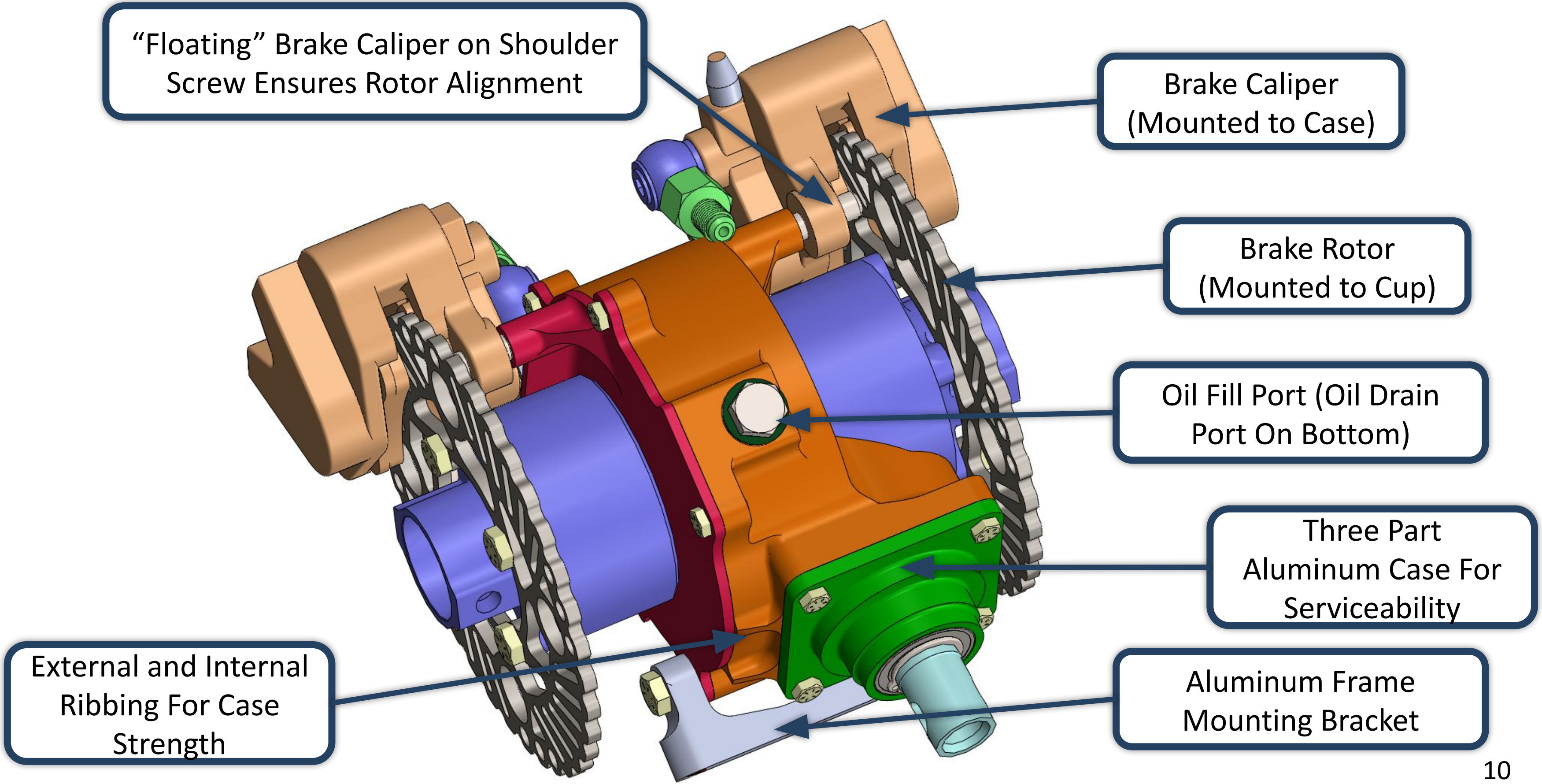
External Component Overview

1. 2104M-00207 Diff Pinion
2. 2104M-002-5972K279 Small Pinion Bearing
3. 2104M-00223 Pinion Case
4. 2104M-00227 Frame Bracket
5. 2104M-002-92620A416 Case Bolt
6. 2103M-00105 Rotor
7. 2103M-001-92620A535 Front Rotor Mounting Bolt
8. 2104M-00205 Cup
9. 2103M-001-120-5453 RH Caliper
10. 2104M-00203 Main Case
11. 2104M-00202 Left Case
12. 2104M-002-92240A617 Oil Bolt
13. 2104M-002-93303A106 Oil Sealing Washer
14. 2104M-002-90967A235 Pinion Retaining Ring

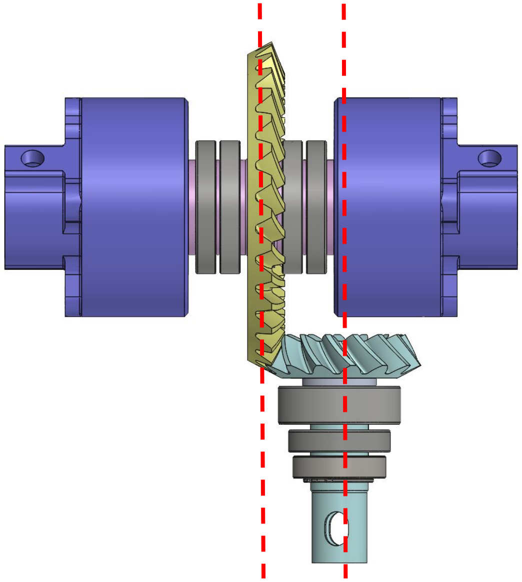
Every component except for bearings, shaft seals, and fasteners is fully custom and has been designed and analyzed in-house.

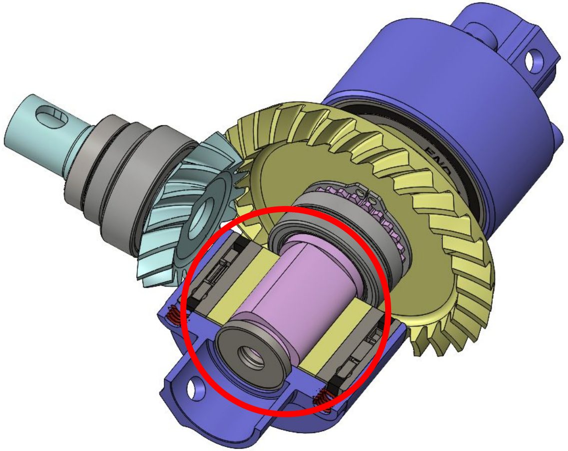


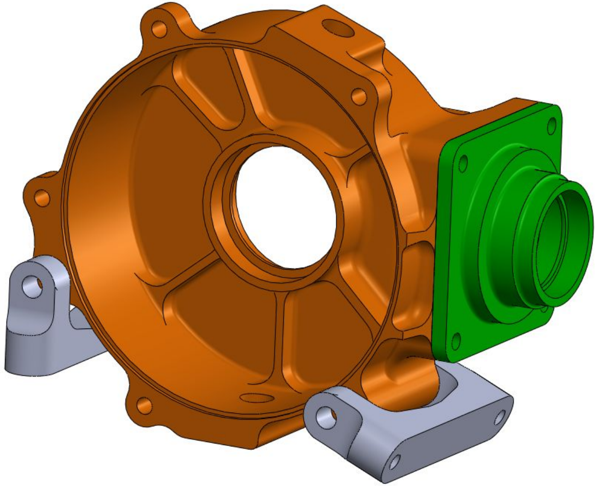
Front Differential: External Anatomy



Front Differential: Design Highlights





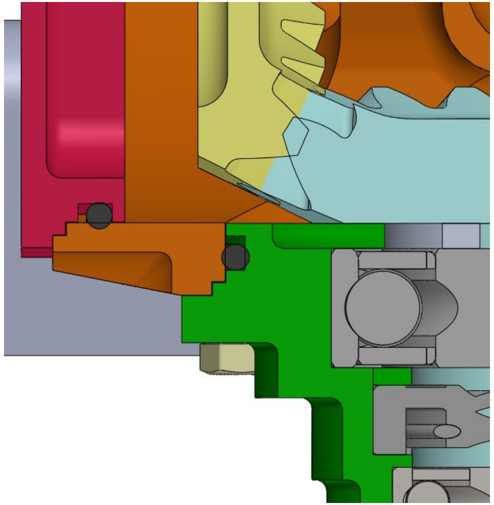


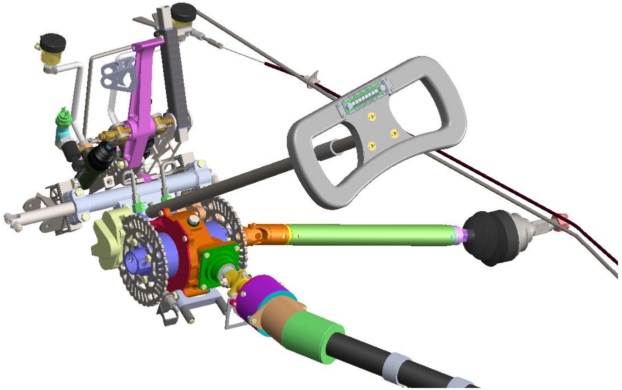
Off-center input shaft reduces U-Joint misalignment in the driveshaft, lowering its max torque and thus allowing it to be lighter, which is beneficial to the overall system, although at the expense of missing the weight reduction goal for the differential

DIN P4C polygon torque transfer profiles on the Ti-6Al-4V shaft were analyzed and chosen over splines, keyways, P3G, and hex profiles to ensure easy manufacturability, serviceability

Structural 7075-T651 aluminum case and frame tabs were extensively analyzed with FEA in ANSYS to react internal gear loads as well as brake system loads while being lightweight

Front Differential: Design Highlights





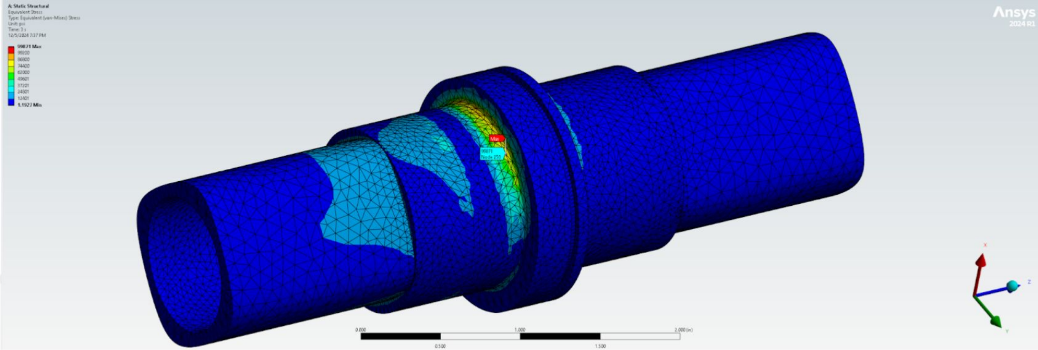
Fully custom spiral bevel gears, created and analyzed using KISSsoft. They were optimized for drive ratio, weight, and strength, but also for geometry, allowing the output bearing to fit into the diameter of the driven gear

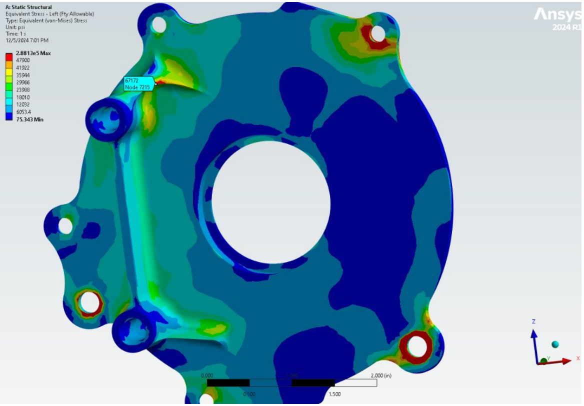
Alignment feature between case halves ensures o-ring engagement and radial positioning as long as the case is axially retained

Intricate integration with brakes system and rest of drivetrain, which necessitated significant communication and coordination between designers and subteams

Front Differential: Analysis

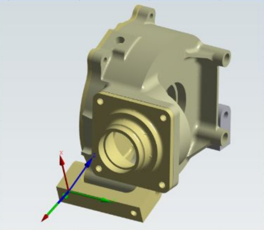
I thoroughly analyzed all components in the assembly using hand calcs, finite element analysis in ANSYS, and specialized industry tools like Gleason KISSsoft to ensure that their design was optimized for maximum weight savings while being strong enough to withstand the predicted loads.



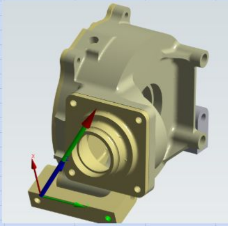


Frame Bolt Calcs			
Given	Value	Unit	Notes
F1			Ignored NX, PY bolt bc forces enveloped by F3,F4
F2			Ignored NX, NY bolt bc forces enveloped by F3,F4
F3	1333.35	lbf	Magnitude of X and Y forces; Timestep 1; PX, PY bolt
F4	1293.94	lbf	Magnitude of X and Y forces; Timestep 1; PX, NY bolt
DF	1.35	-	Largest for case-related DF's
d_minor	0.156	in	minor diameter of 10-32 bolt
Fty	150000	psi	
Calculation	Value	Unit	Notes
F	1800.0225	lbf	
A	0.0191134497	in^2	
sigma	94175.69972	psi	Shear stress
Fails?	NAH, PASSES	-	
Margin	59.3	%	100*(Allow/Max-1)

NX, PY bolt



PX, NY bolt



	NX, PY bolt X	Y	Z	PX, NY bolt X	Y	Z
Time 1	55.66	-19.139	-19.139	1145.8	681.89	769.98
Time 2	48.581	-15.354	-418.79	1115	656.56	781.33

KISSsoft

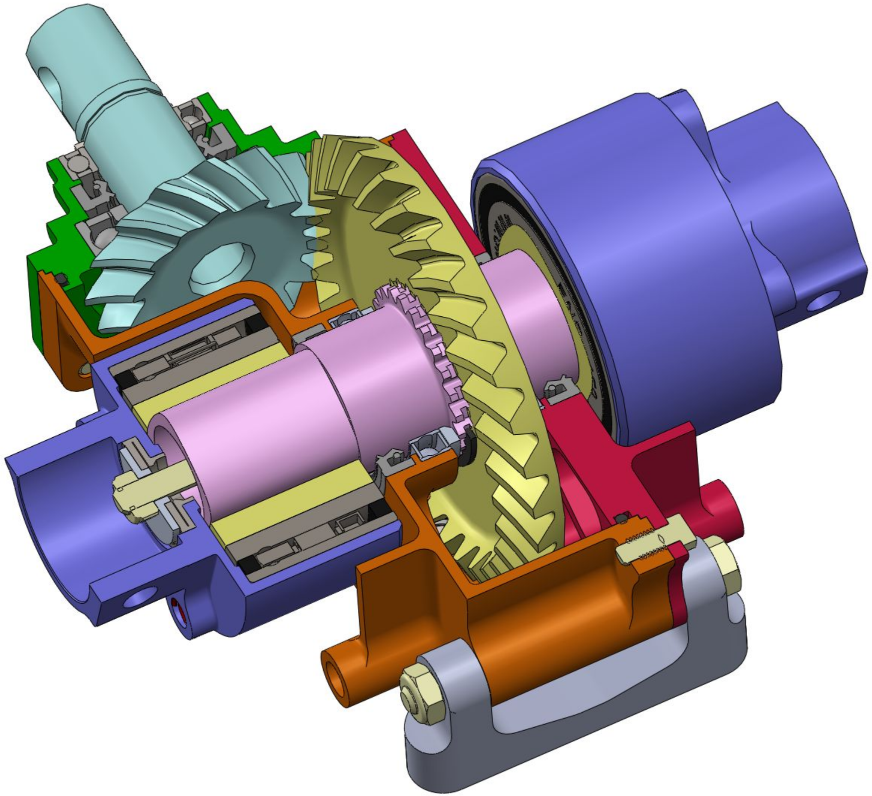
Auxiliary values for the tooth root:				
Distance from center (in)	[ft,fm,fr]	0.3181	0.0331	-0.2519
Length of contact line (in)	[lbt,lbm,lbr]	0.0000	0.4096	0.0446
Angle of contact lines (°)	[βB]		0.0000	

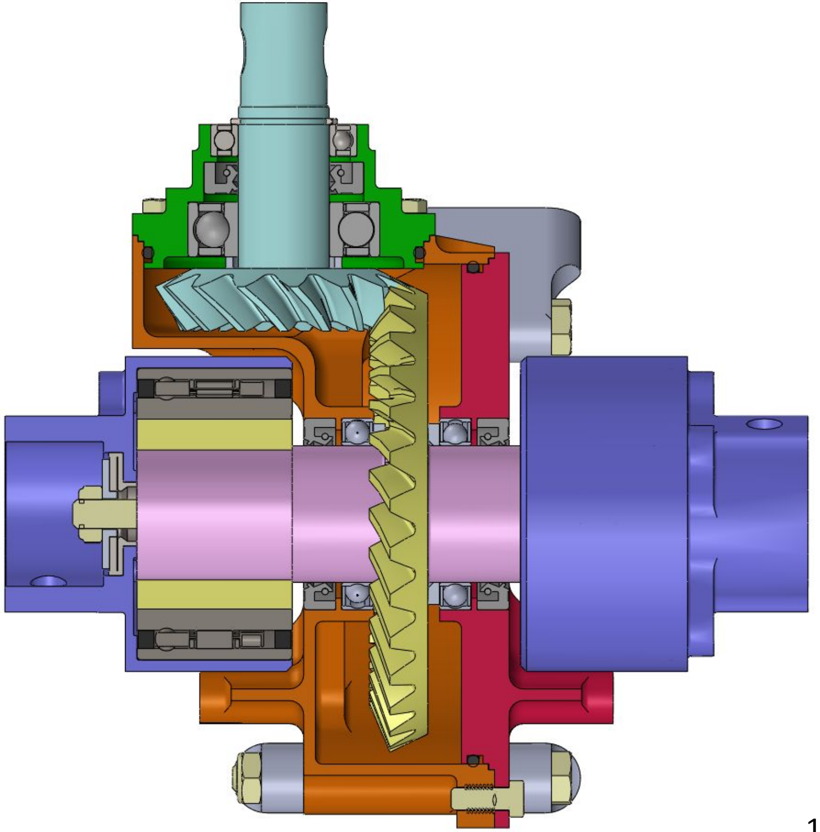
9 General influence factors

9.1 Forces and circumferential speed

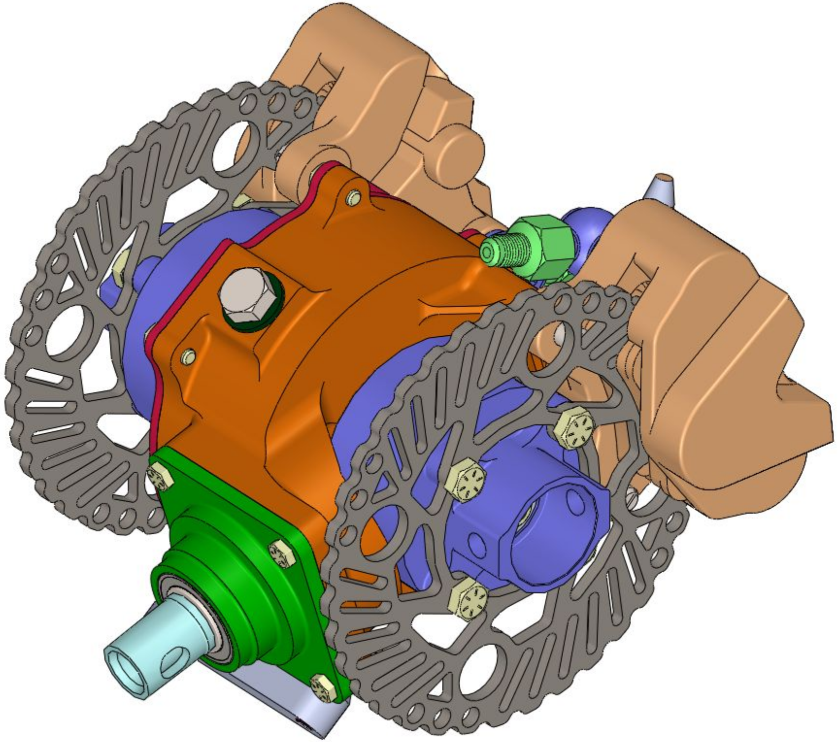
		------- Gear 1	----------------	Gear 2 -------
Nominal circum. force at pitch circle (lbf)	[Fmt]	1748.8		1748.8
Nominal circumferential force of virtual cylindrical gear (lbf)	[Fvmt]		1748.8	
Drive side				
Axial force (lbf)	[Fa]	1440.7		166.1
Radial force (lbf)	[Fr]	166.1		1440.7
Normal force (lbf)	[Fnorm]	2272.0		2272.0
Axial force (%)	[Fa/Ft]	82.383		9.498
Radial force (%)	[Fr/Ft]	9.498		82.383
Remarks:				
Forces if rotation goes in opposite direction (coast-sided):				
Axial force (lbf)	[Fa]	-763.8		1232.8
Radial force (lbf)	[Fr]	1232.8		-763.8
Normal force (lbf)	[Fnorm]	2272.0		2272.0
Axial force (%)	[Fa/Ft]	-43.677		70.495
Radial force (%)	[Fr/Ft]	70.495		-43.677
Normal circumferential force on reference circle per mm (lbf/in)				
	[w]		3974.64 *	
$w = F_{vmt}/b_v$				
Circumferential speed reference circle (ft/s)	[v]	8.31		8.31
Compound velocity in direction of tooth height (ft/s)	[vΣvert]		4.66	
Sliding velocity in direction of contact lines (ft/s)	[vgpar]		0.00	
Compound velocity (ft/s)	[vΣ]		10.61	
Sliding velocity (ft/s)	[vg]		0.00	

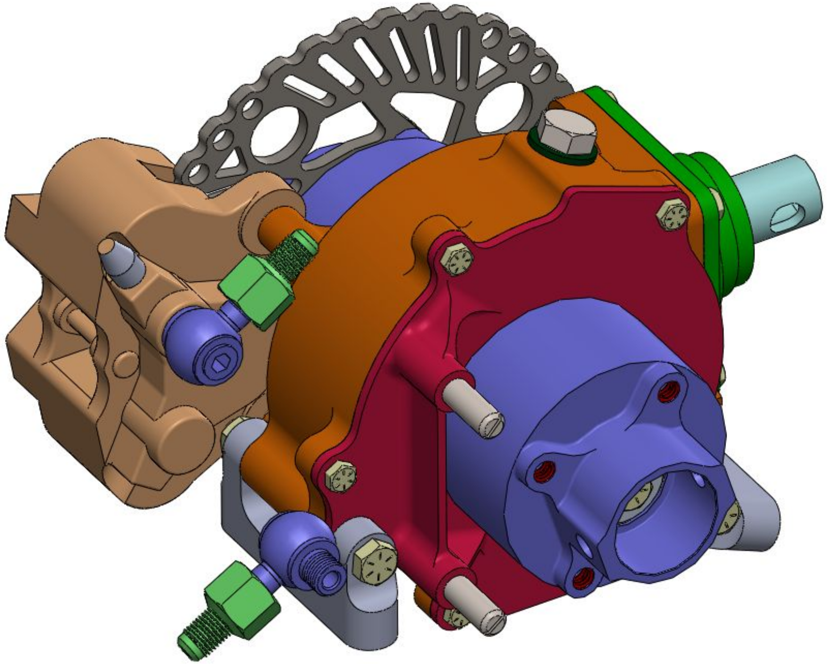
Front Differential: Design





Front Differential: Design





20XT Pictures

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