The Ohio State University

Car: #128

Contact Information

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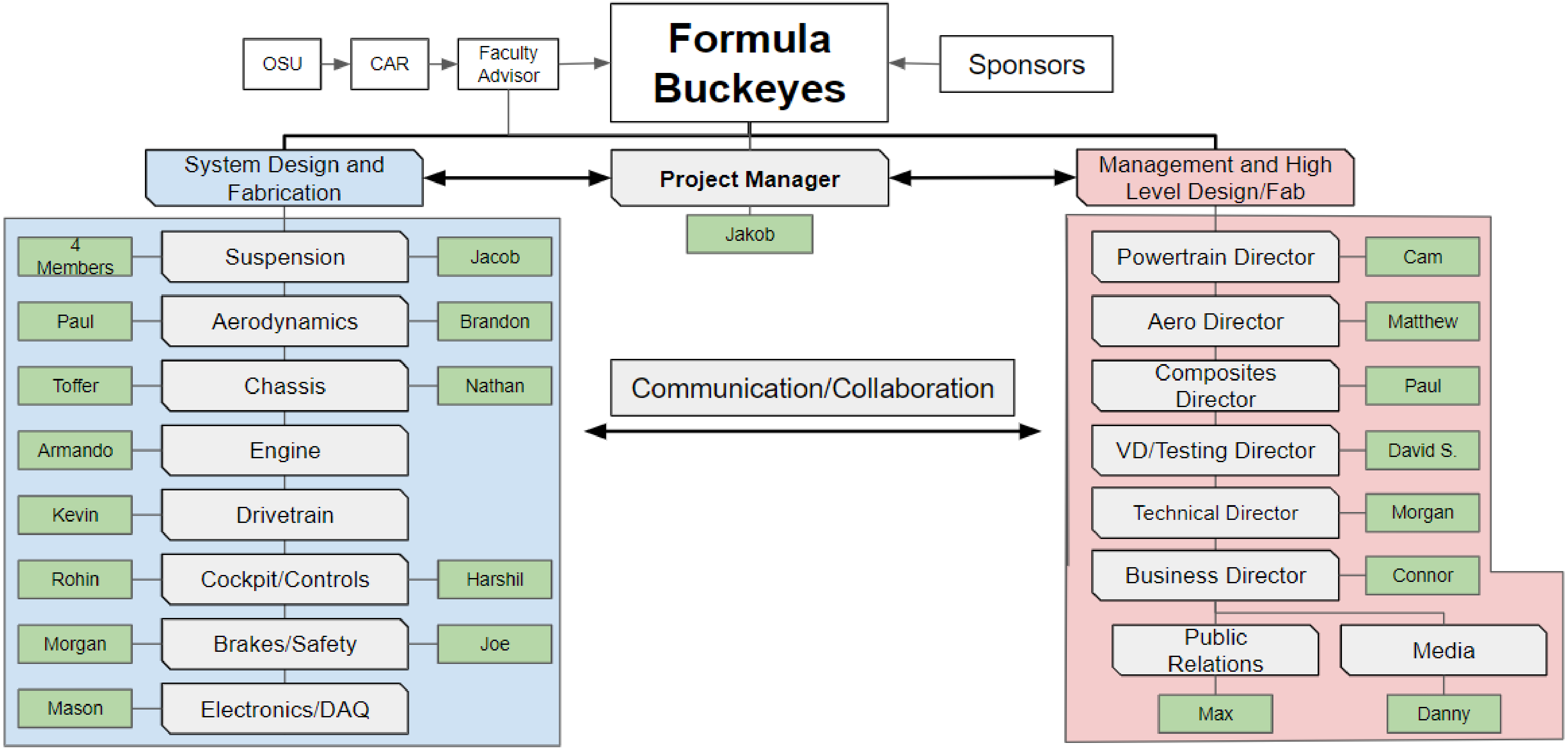
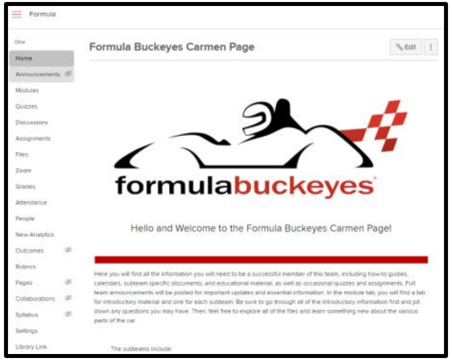
Team Update

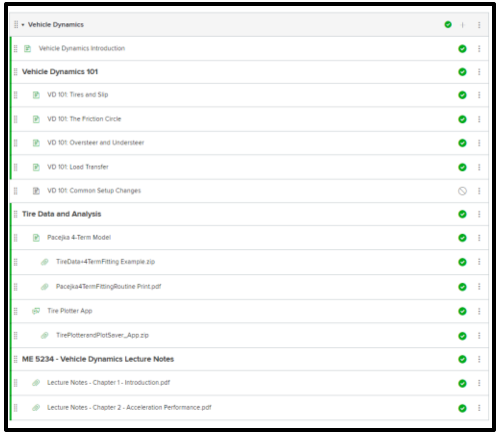
Team Structure

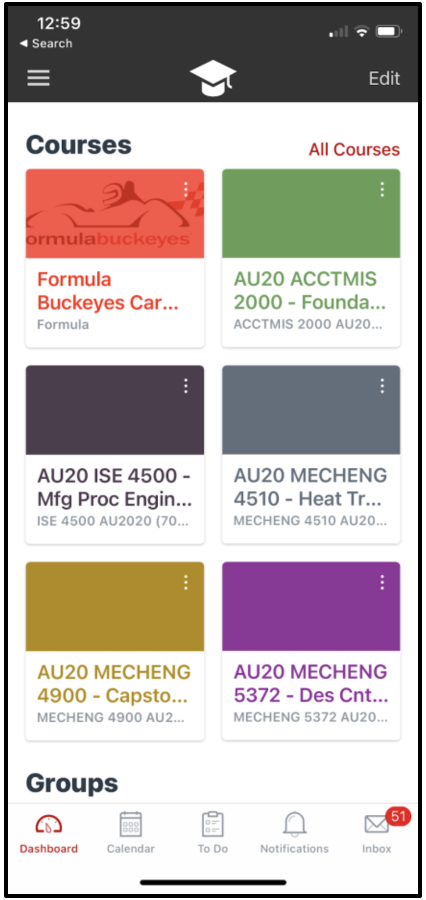


Team Update (2 of 3)

1. 25 Person Roster for Shop. 5 Allowed in at a time.
    1. 1-2 General Members per subteam
    2. Giant restriction on knowledge transfer and shop skills
2. To react, the leadership on the team is focusing on developing a Canvas page (university learning resource)
    1. Knowledge Transfer
        1. Tutorials
    2. Member Development
        1. Presentations on Design and Manufacturing
        2. Zoom Meetings







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COLLEGE OF ENGINEERING

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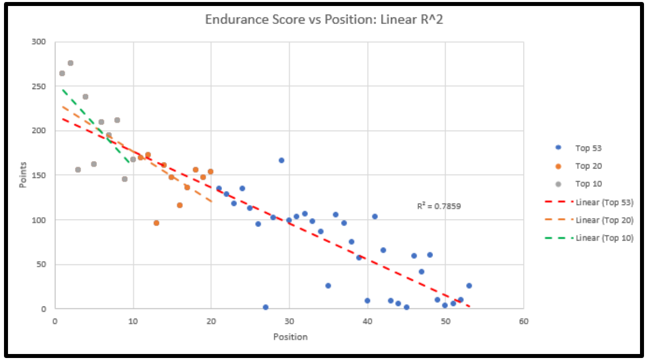
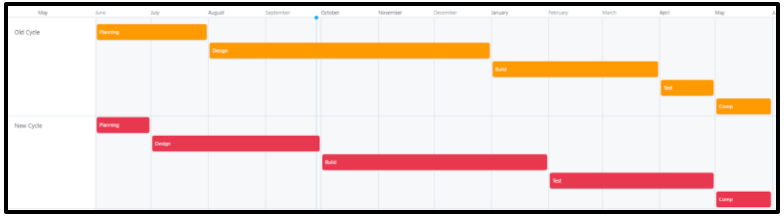
Team Update (3 of 3)

1. Determine what are the most important factors in the FSAE Competition
   1. Comp and Score Analysis
   2. Timeline Analysis
2. Understand our resources as an FSAE Team
   1. Time
   2. Knowledge
   3. Money/Sponsorship
3. Apply the most important factors of winning an FSAE Competition to our Team and its resources to come up with goals and a plan for the year.
4. Enforce Project Management to stay on plan and achieve our goals.

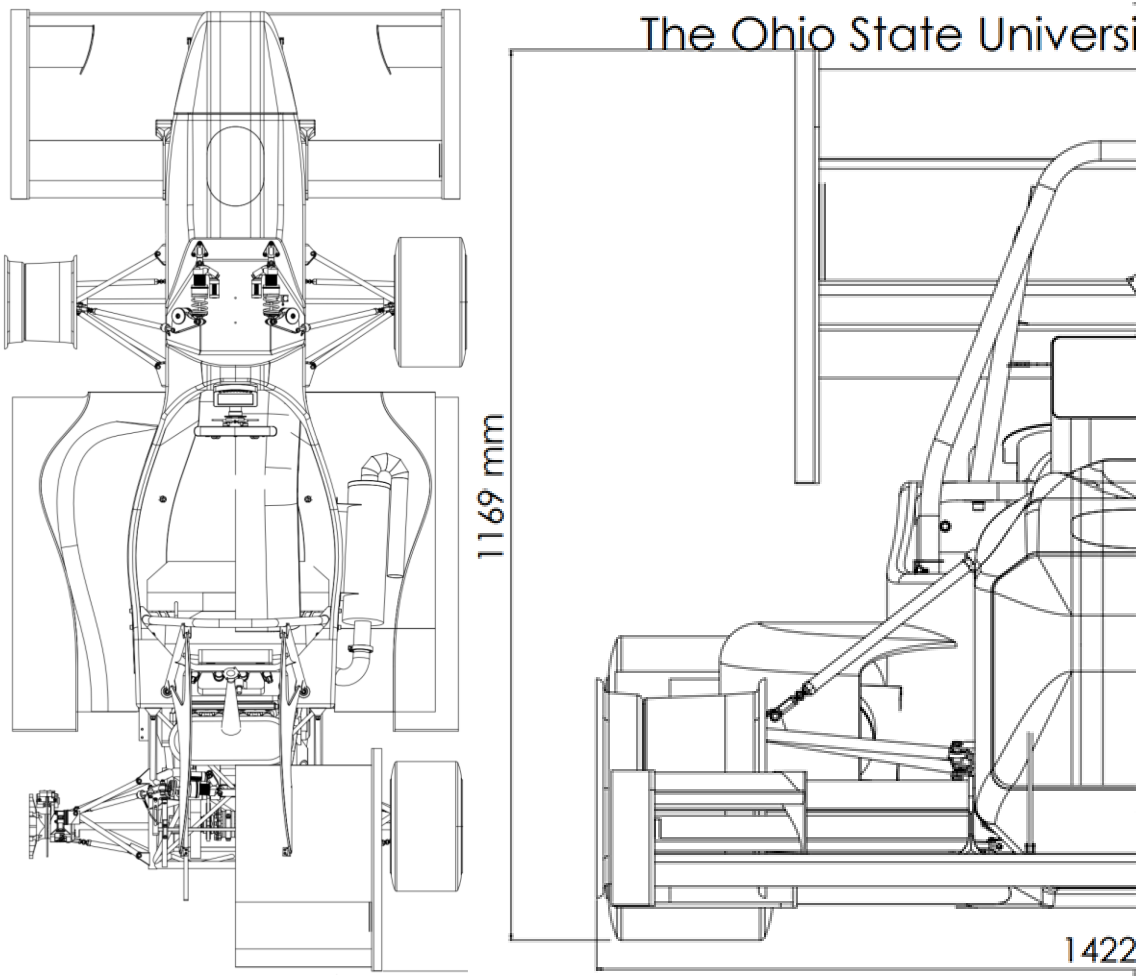




Overview

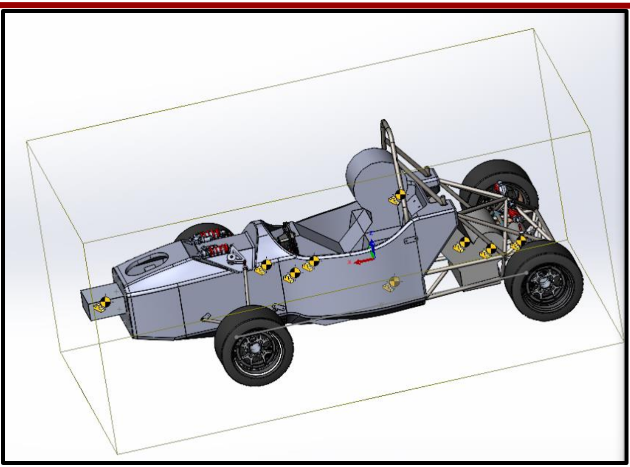
Vehicle Overview

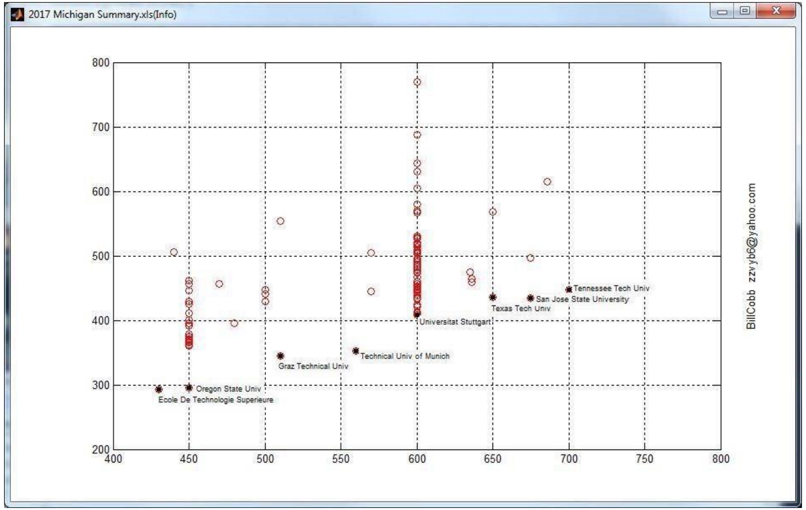
1. Basic Specifications
    1. Wheelbase: 1616 mm
        1. Front Track: 1200 mm
        2. Rear Track: 1175 mm
2. Tires and Rims
    1. Hoosier 16x7.5-10 R25B
    2. 8 Inch Wide Carbon Rim
3. Engine
    1. Honda CBR600rr
    2. Power 87 HP
4. Aerodynamics
    1. Front and Rear Wings
    2. Single Midwing+Diffuser
    3. Cl*A = -4.81



Vehicle Weight Breakdown

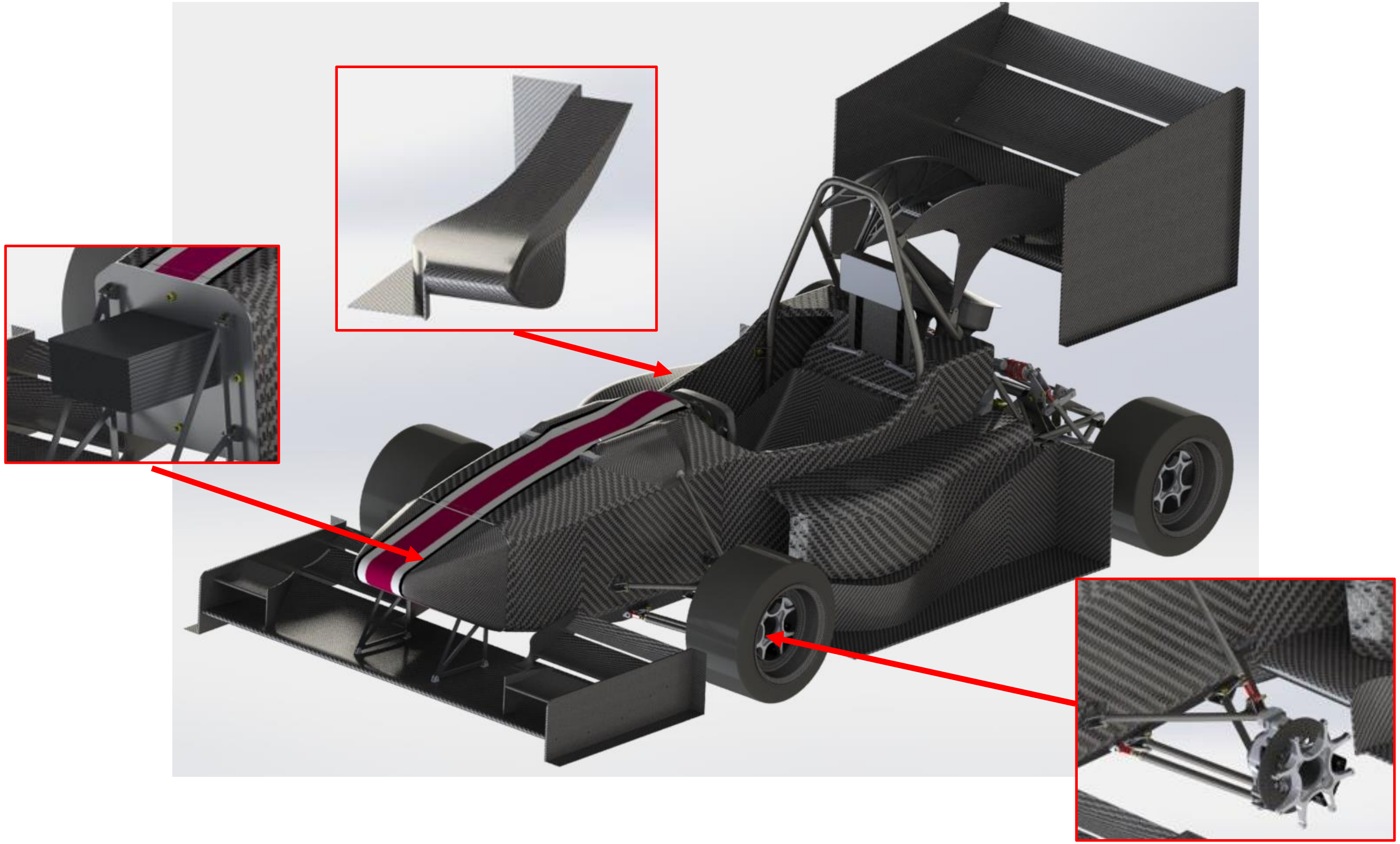
1. 80/20 Analysis on Major Systems
    1. Approximate Floor on 600cc Engine Car Weight at 400 lbs
    2. Weight Target
        1. Weight: 420 Lbs
    3. Propagated Weight Reqs to SubAssemblies



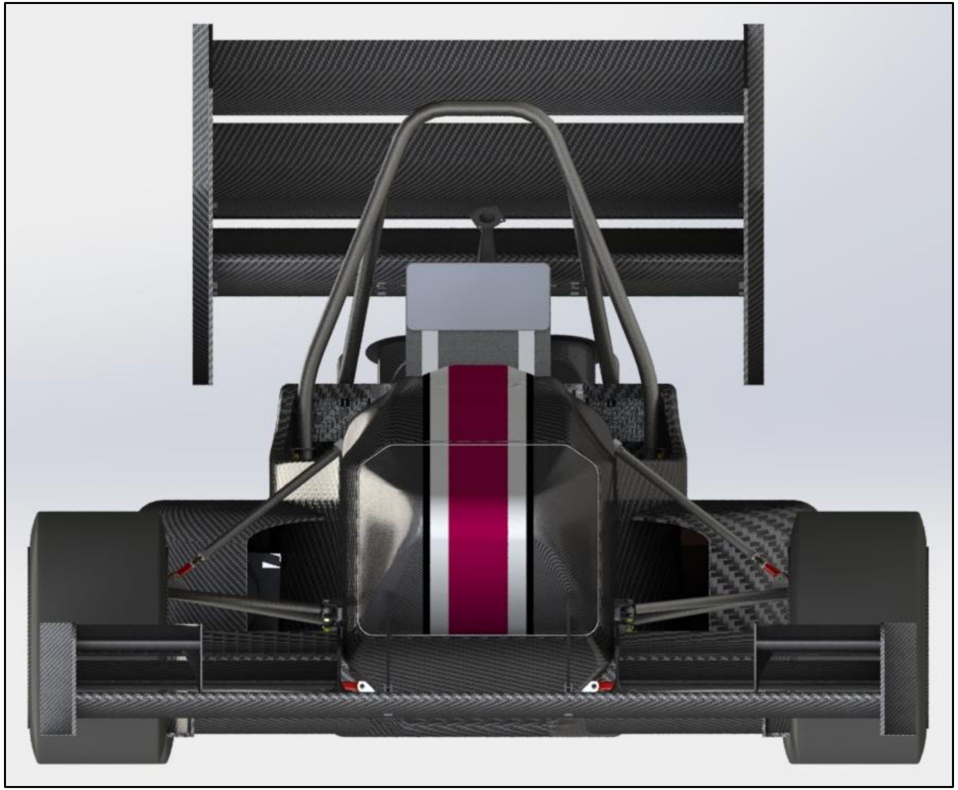


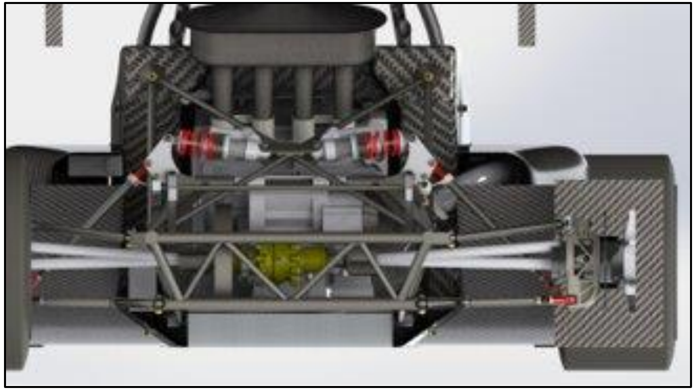
	Components	Mass (kg)	Center of gravity (m)		
			xi	yi	zi
Primary Indicators (80% of Total Mass)	Front Tub	20	0.34	0.00	0.29
	Rear Frame	7	1.40	0.00	0.20
	Driver	0	0.58	0.00	0.34
	Engine	57	1.32	0.00	0.28
	Diff	2.6	1.616	0.00	0.20
	IA+IA Plate	2	-0.63	0.00	0.00
	Full Fuel Tank	6.5	0.86	0.00	0.00
	Front Hoop	1.823	0.20	0.00	0.00
	Main Hoop	3.859	0.98	0.00	0.00
Secondary Indicators (15% of Total Mass)	Muffler	4	1.79	0.00	0.00
	Front + Rear Shocks	4	0.81	0.00	0.00
	Water Radiators	2	0.81	0.00	0.00
	Oil Res	5	1.50	0.00	0.00
	Oil +Water Resivors	2	1.30	0.00	0.00
Third (5%)	Misc	37	0.74	0.00	0.00
	TOTAL SUSPENDED MASS	154.782			
	FL Wheel + Arms	8.16466	0.00	0.60	0.20
	FR Wheel + Arms	8.16466	0.00	-0.60	0.20
	RL Wheel + Arms	7.71107	1.62	0.59	0.20
	RR Wheel + Arms	7.71107	1.62	-0.59	0.20
	TOTAL NON SUSPENDED MASS	31.75146			
	TOTAL	186.53346			
	Goal:	265			
	Total Weight Accounted For:	70.39		Percent Rear:	59.41

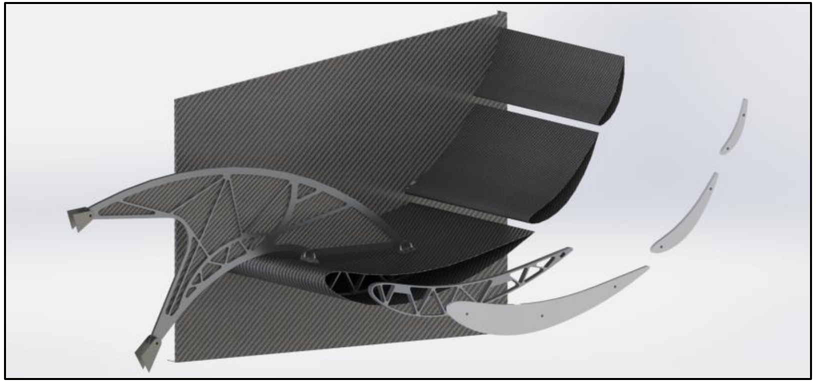
Isometric View



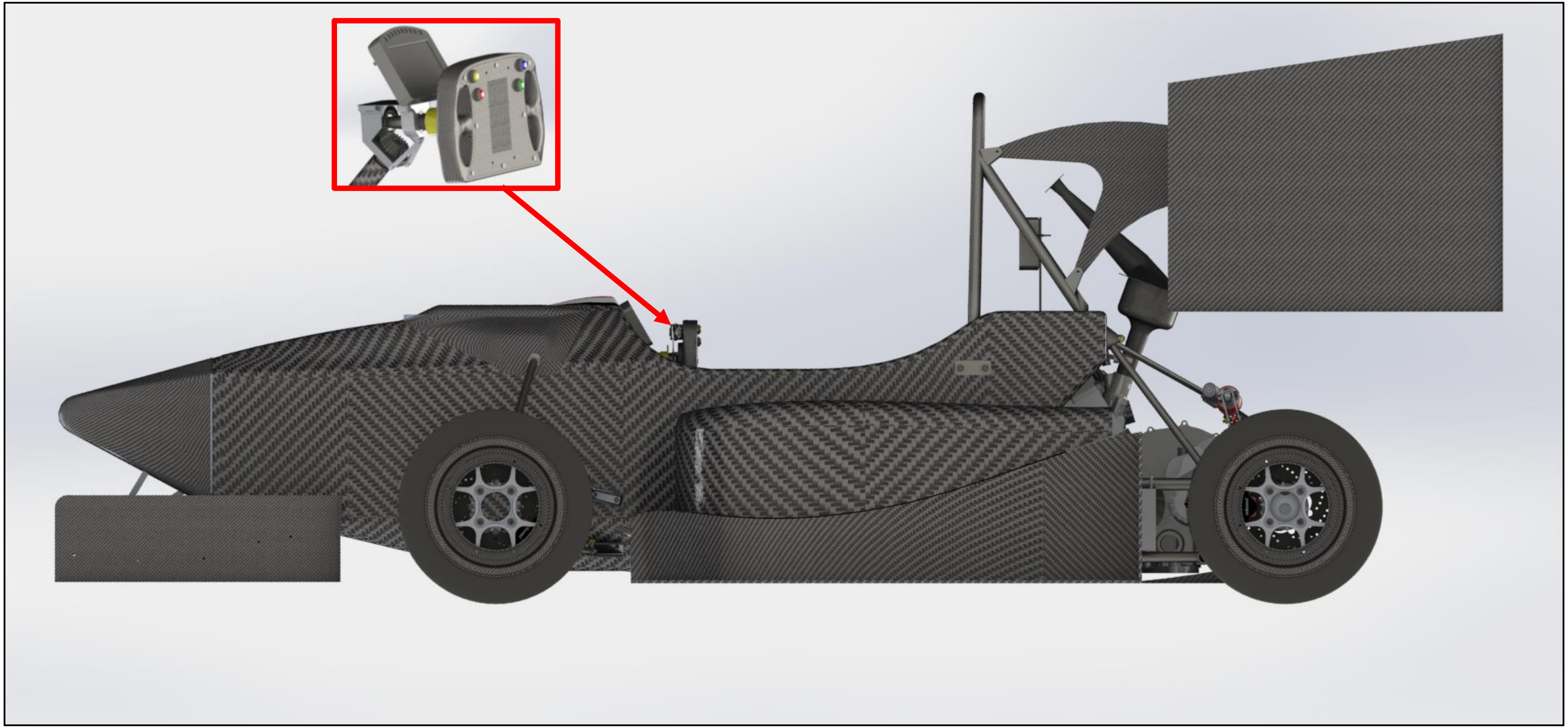
Front View



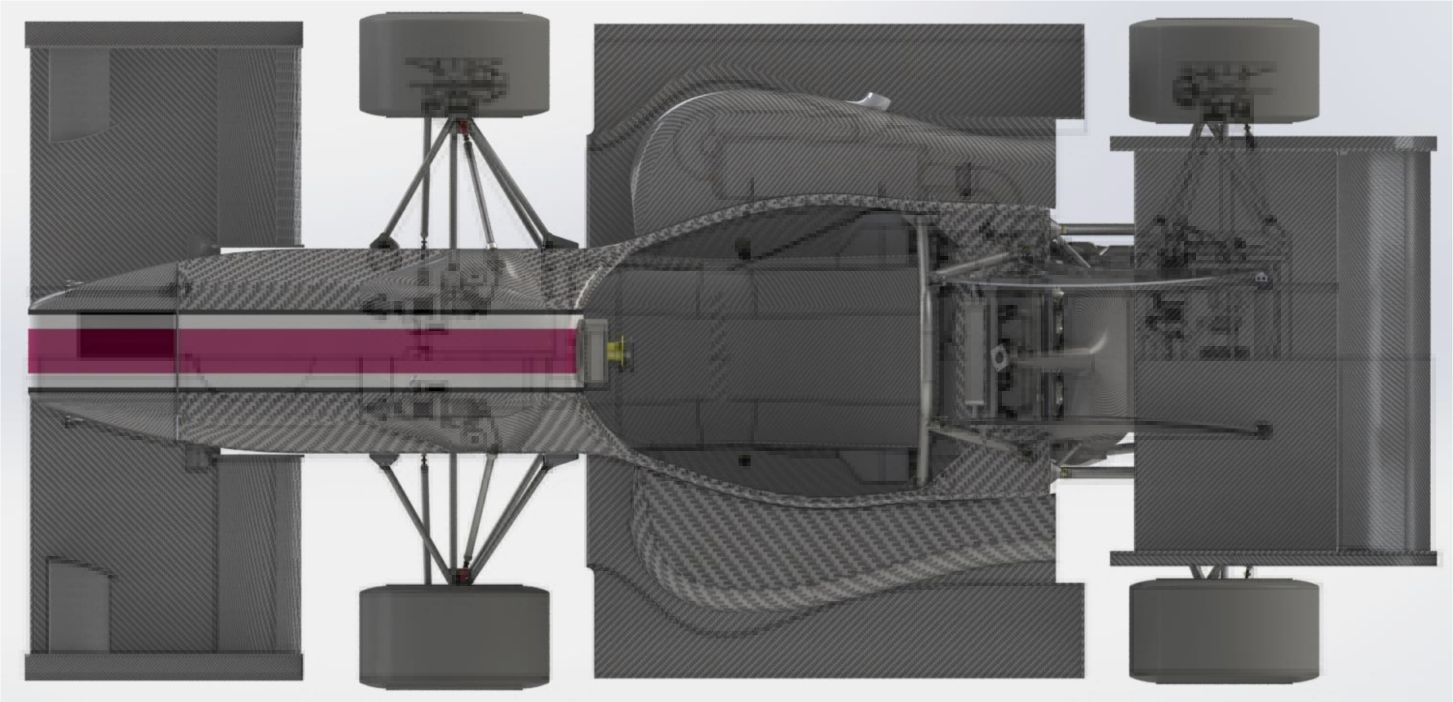




Side View

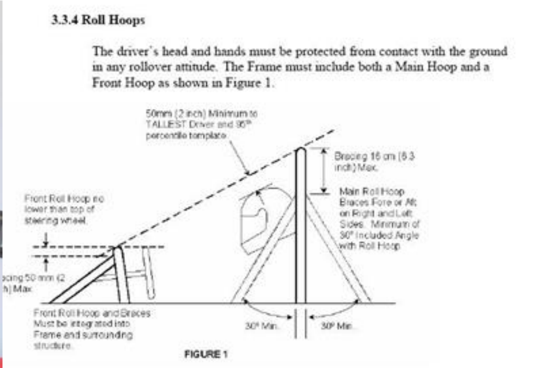


Top View

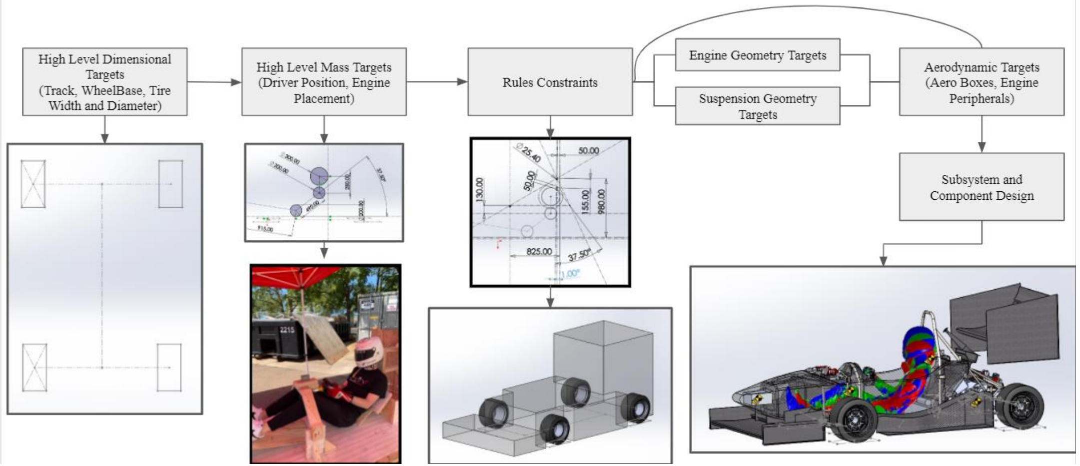


System Goals

1. 1^{st} Iteration Vehicle
    1. Focus on Increasing Ceilings
2. Rules Compliance
    1. Easily Passing Tech for more dynamic event time
3. Manufacturing Diversity
4. Maximizes Team Member Engagement
    1. Minimizes Risk
    2. Component Complexity Reduction
5. Take advantage of time given by COVID and Senior Team Member Knowledge


3.3.4 Roll Hoops

The driver's head and hands must be protected from contact with the ground in any rollover attitude. The Frame must include both a Main Hoop and a Front Hoop as shown in Figure 1.



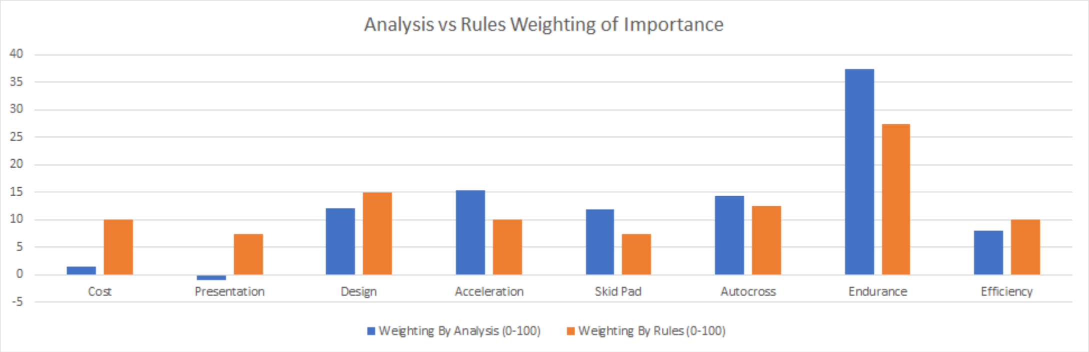
Shop Capabilities

- Full Machine Shop
  - 3 Axis CNC Machine
  - 3 Axis CNC Lathe
  - Manual Mill and Lathe
- Waterjet
- Plasma Cutter
- 2.8ft^3 3D Printer
- Fabrication Hot Room

Points Goal

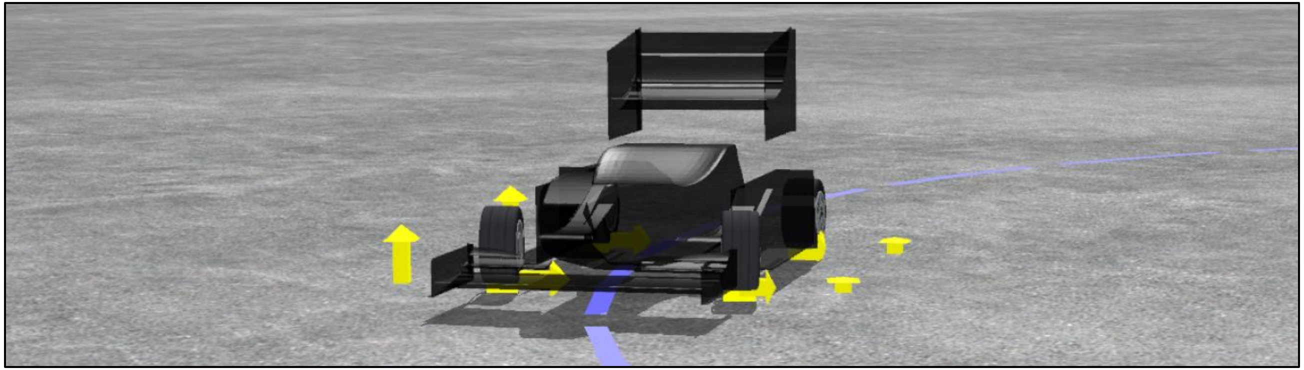
Points Goal by Event	
Autocross	87.81
Endurance	176.35
Accel	75.28
Design	103.67
Marketing	61.08
Cost	62.87
Economy	71.94
Skidpad	47.78
Overall:	686.78

- After performing extensive analysis on 2019 Michigan results. The graph below displays (in blue) the point spread of top 50 teams, vs. The points spread of the rules (in orange)
- Table values are a result of this, show the point values of a top 10 team based on linear regressions of the top 50 teams in each event



Highlights— CarSim Integration

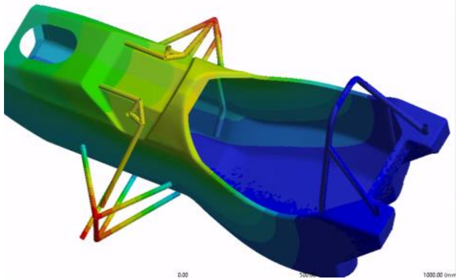
- Ground-Up Approach
  - While functional, previous year's model was known to be relatively inaccurate
    - FB20 model was based off existing model from 2016-17 season
  - 2021 model was built from scratch using model verification methods along the way
- Available Design of Model
  - Team can easily create and/or modify any previous car’s model to compare
  - New CarSim model architecture will allow for adaptability through more intelligent organization of databases/datasets



Highlights – Full Vehicle Load Case

1. All Part and System Load Cases Derived from either
   1. Stress Loading Case
      1. Max Braking
      2. Max Combine
   2. Specified Corner Loads
      1. Can Calculate Desired Wheel and Lateral Loads

Stress Loading



Stress Testing (FOS of 1.2)				
	Left Wheel (Newtons)		Right Wheel (Newtons)	
Full Braking:	Fx	5300	Fx	5300
	Fy	0	Fy	0
	Fz	2400	Fz	2400
Max Combined:	Fx	675	Fx	2150
	Fy	-75	Fy	-5500
	Fz	1000	Fz	3000
Boundary Conditions	1. Apply Force at Front Uprights			
	2. Fix Rear Suspension or Rear Frame			

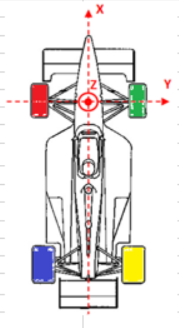
Torsion Testing				
Torisonal Stiffness	Fz	1000	Fz	-1000
Boundary Conditions	1. Apply Force at Front Uprights			
	2. Fix Rear Frame Mounting points on Tub.			

Specified Corner Loads

Input				
Dim.	Wheel base		1616	mm
	Front track		1200	mm
	Rear track		1175	mm
Mass and Inertia	Total mass		263.0	kg
	Total Mass distribution		48.96	% Fr
	Front non suspended mass (per wheel)		8.0	kg
	Rear non suspended mass (per wheel)		8.0	kg
	Non suspended mass weight distribution		50.00	% Fr
	Total mass CG height		280	mm
	Front non suspended mass CG height		203	mm
	Rear non suspended mass CG height		203	mm
	Suspended mass		231.0	kg
	Suspended mass weight distribution		48.82	% Fr
	Suspended mass CG coordinates	X	825	mm
		Y	0	mm
		Z	290.7	mm
	Suspended mass roll inertia (ref SM CG) - I_{xx}		33.875	kg.m²
Spring ARB Tire	Front spring stiffness		60.000	N/mm
	Rear spring stiffness		60.000	N/mm
	Front ARB stiffness		0.000	N.m/°
	Rear ARB stiffness		1.500	N.m/°
	Front tire stiffness		117.000	N/mm
	Rear tire stiffness		117.000	N/mm
M.R.	Front spring motion ratio		1.000	-
	Rear spring motion ratio		1.000	-
	Front anti roll bar motion ratio		1.000	-
	Rear anti roll bar motion ratio		0.143	-
Roll	**Front** roll center	Z	10.000	mm
	Rear roll center	Z	20.000	mm

Results			
Roll	Suspended mass roll stiffness	0.4028	°/g
	Roll angle	0.6041	°Roll
Frequency & Damping	Front NSM frequency (per wheel)	19.25	Hz
	Rear NSM frequency (per wheel)	19.25	Hz
	Front NSM Critical damping (per wheel)	1934.9	N/(m/s)
	Rear NSM Critical damping (per wheel)	1934.9	N/(m/s)
	Front suspended mass frequency	**5.19**	**Hz**
	Rear suspended mass frequency	**5.07**	**Hz**
	Front SM critical damping (per corner)	3678.6	N/(m/s)
	Rear SM critical damping (per corner)	3766.7	N/(m/s)
	Front total SM frequency (with tire)	3.95	Hz
	Rear total SM frequency (with tire)	3.87	Hz
	Front total critical damping	3195.9	N/(m/s)
	Rear total critical damping	3263.1	N/(m/s)
	Roll natural frequency of SM	6.62	Hz
M.N.	First magic number	48.11	kg/kg
	Second magic number	47.46	kg/kg
	Third magic number	46.60	kg/kg

Dynam. Mass (Kg)	
20.2	108.5
18.2	116.0



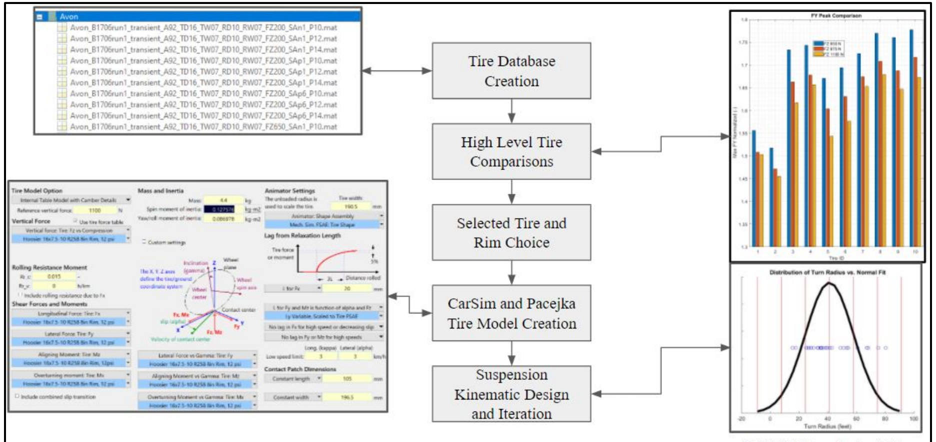
Case to simulate		
Lat G	1.50	G
Long G	1.00	G
Speed		MPH
CL		-
CD		-

Error message box

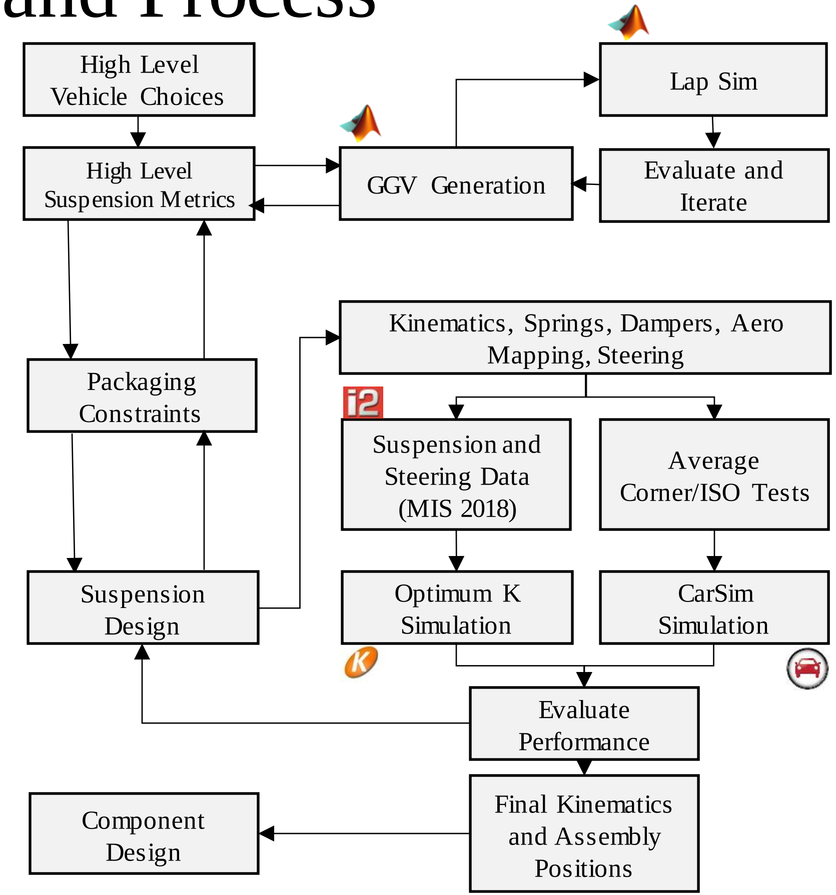
Suspension

Suspension (1) – Philosophy and Process

1. Philosophy
   1. Take the chosen High Level Vehicle Choices and maximize the performance of the vehicle.
2. Process
   1. Create a Sensitivity Analysis using Lap Sim
   2. Set High Level Suspension Metrics in CAD
   3. Balance Packaging Constraints with other Sub-Systems
   4. Design Suspension and Iterate based off simulation results



MIS 2019 Turn Radius Dist

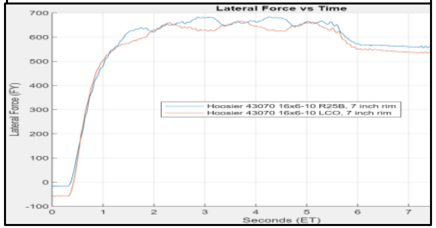


Suspension (2) – Tire and Rim Choice

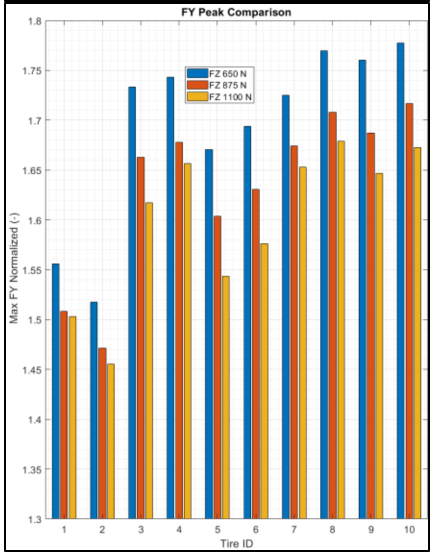
1. Tire Choice
    1. Team did a High Level Analysis on 10 Tire and Rim Combos to Select the best performing tire
        1. 10 Inch OD rim chosen
            1. Camber Stiffness, Inertia, and Experience
2. Hoosier R25B 16x7.5-10
    1. Highest Performance Ceiling
    2. Good Degradation (Reduced Long Run Cost)
3. 8 Inch Rim Width
    1. Fastest Responding Combination

1. Avon A92 - 7 Inch Tread Width - 7 Inch Rim Width
2. Avon A92 - 7 Inch Tread Width - 8 Inch Rim Width
3. Hoosier LCO - 7.5 Inch Tread Width - 7 Inch Rim Width
4. Hoosier LCO - 7.5 Inch Tread Width - 8 Inch Rim Width
5. Hoosier LCO - 6 Inch Tread Width - 6 Inch Rim Width
6. Hoosier LCO - 6 Inch Tread Width - 7 Inch Rim Width
7. Hoosier R25B - 7.5 Inch Tread Width - 7 Inch Rim Width
8. Hoosier R25B - 7.5 Inch Tread Width - 8 Inch Rim Width*
9. Hoosier R25B - 6 Inch Tread Width - 6 Inch Rim Width
10. Hoosier R25B - 6 Inch Tread Width - 7 Inch Rim Width*

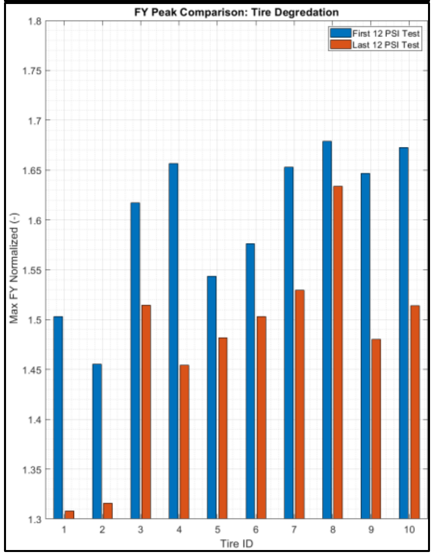
Transient Performance



Steady State Performance

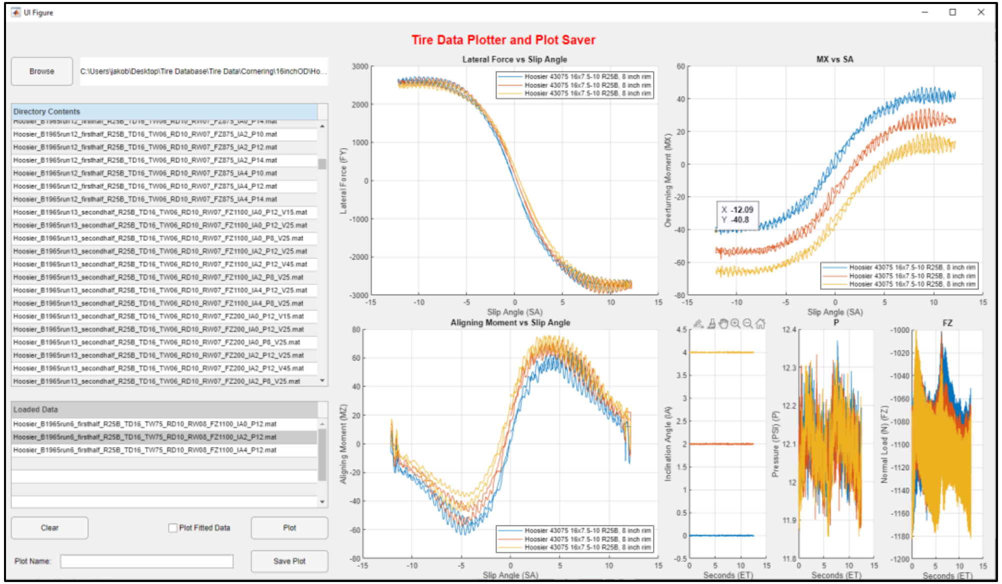


Degradation Performance



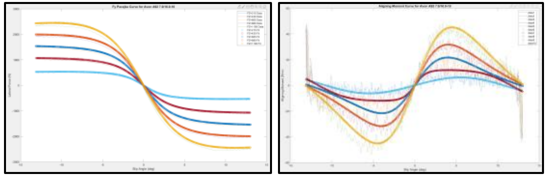
Suspension (3) — Tire Analysis Tools

1. MATLAB Application software utilized to make a more user-friendly, graphically based interface
    1. Tire Database Created - .mat files of each individual load
        1. Hoosier_B1965run2_firsthalf_R25B_TD16_TW75_RD10_RW07_FZ200_IA0_P10
    2. Fitted Data and Raw Data Options
    3. Easily Configurable for All TTC Data Plotting (Transient, Lateral, Drive/Brake)
2. Tire Temp vs Friction Data Compiled for Camber Analysis
3. MX Analysis for Camber vs SA/Load
4. Pacejka4 Model Generation for LapSim/GGV Generation

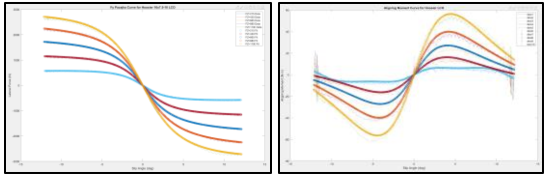


Suspension (4 Combine) — Tire Analysis

- Based off of previous research, Hoosier was once again selected as tire supplier for 2021 season

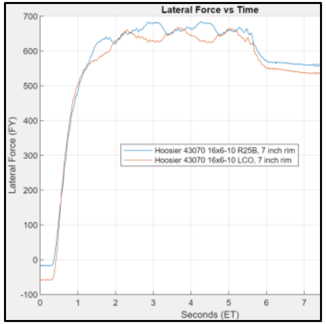


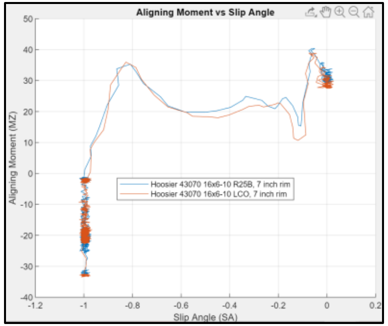
Avons



Hoosiers

- Focus shifted to choice of compound
  - Hoosier offers R25B and LCO in all FSAE-spec tire sizes
    - R25B compound is harder than LCO
- R25B tentatively chosen as competition compound
  - Tire modelling shows small loss of performance for large gain in cost savings with tire life
  - Plan to test both compounds on the finished car; temperature effects not considered in simple modelling

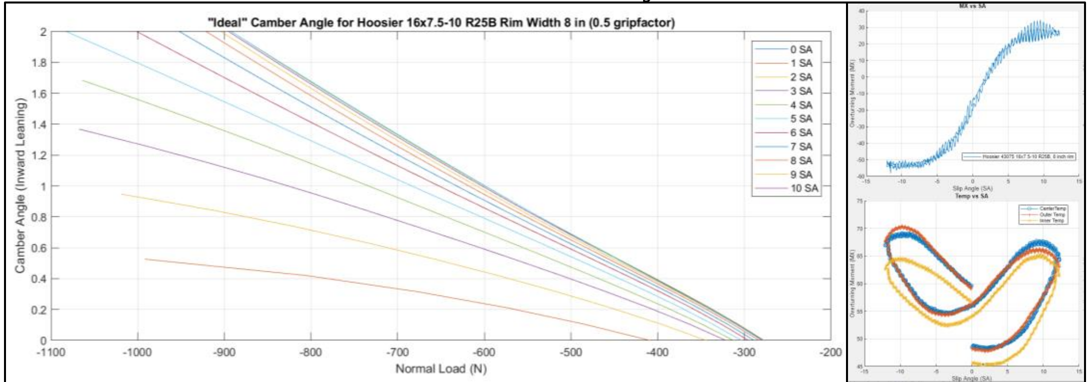




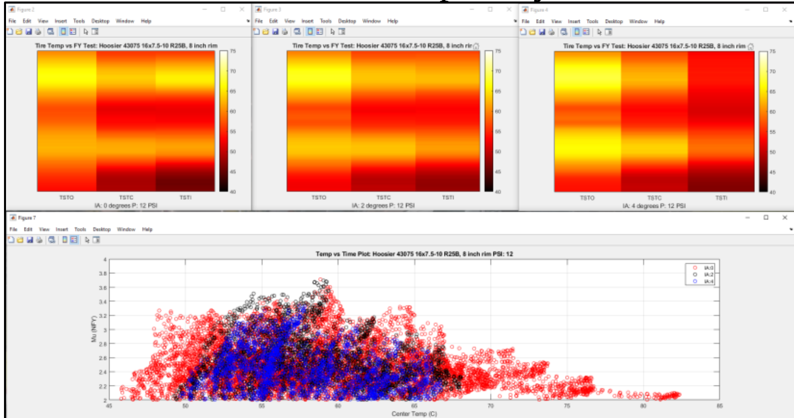
Suspension (5) — Tire Analysis Camber Curve Gen

1. To generate suspension camber kinematics requirements two studies were conducted.
   1. Camber vs SA MX Analysis – For what camber angle at each slip angle does the tire produce 0 MX. Should hint at optimum tire ground contact and wear.
   2. Camber vs Temp Analysis – Looked at heat distribution vs camber angle on various runs as well as all the applicable data.
2. Results and Takeaways
   1. Target Temperatures between 55 and 60C during testing
   2. The 7.5 inch tread width with an 8inch rim causes a very rectangular profile tire. This lead to some counterintuitive results of the MX study. Heavy camber induces large temperature gradients with this profile and unlike narrower/taller profile the MX=0 theory does not seem to hold
      - 0-2 degrees of camber seem to produce the best wear and performance

Camber vs SA MX Analysis

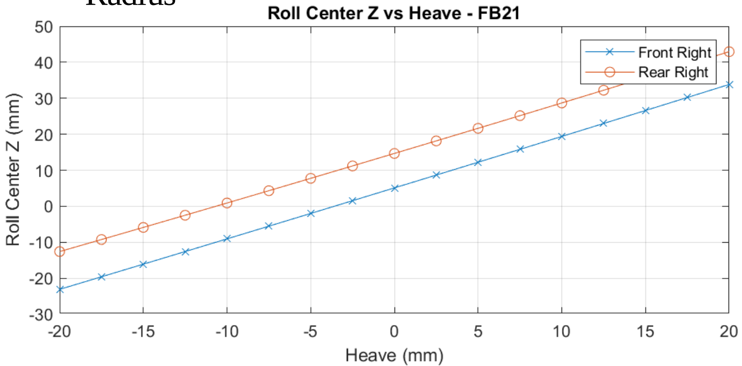


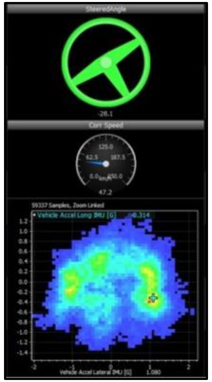
Camber vs Temp Analysis

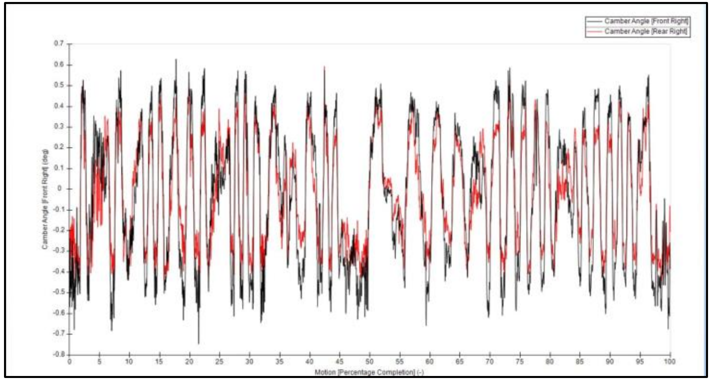


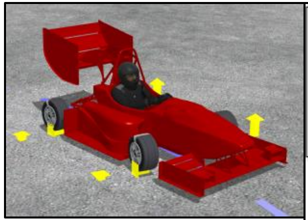
Suspension (6) – Kinematics Design Overview

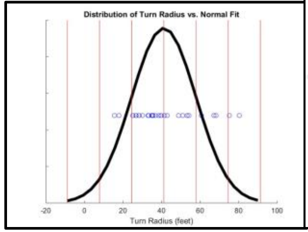
1. Purpose
   1. Control Wheel Movement and Chassis Movement
2. Goal
   1. Maximize Tire Performance
   2. Communicate Vehicle State to Driver
   3. Mitigate Instability Characteristics
3. Take into account compliance effects
   1. Legacy Data
   2. Ansys Compliance Simulations
4. Simulate Final Iterations in CarSim to verify intent and performance
5. Design for ISO Tests and Average 2019 Corner Radius

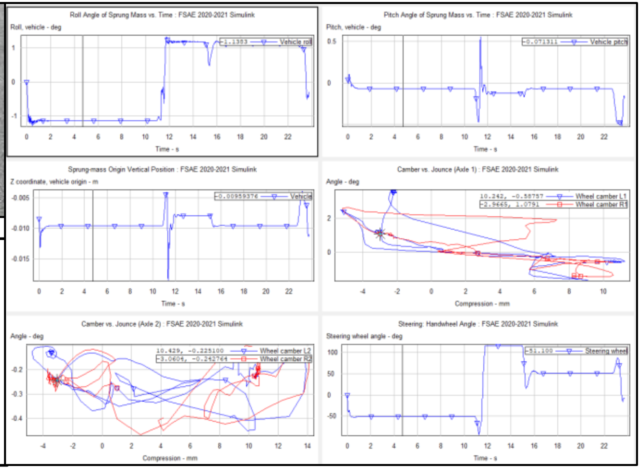












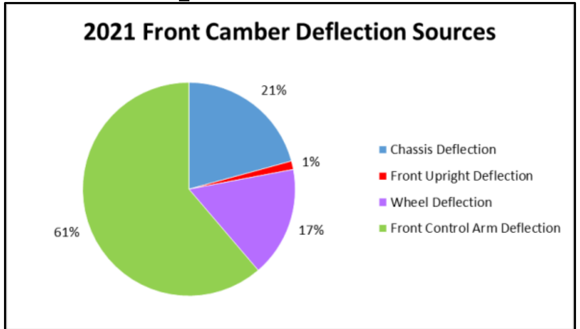
Suspension (7) – Kinematics Design Camber

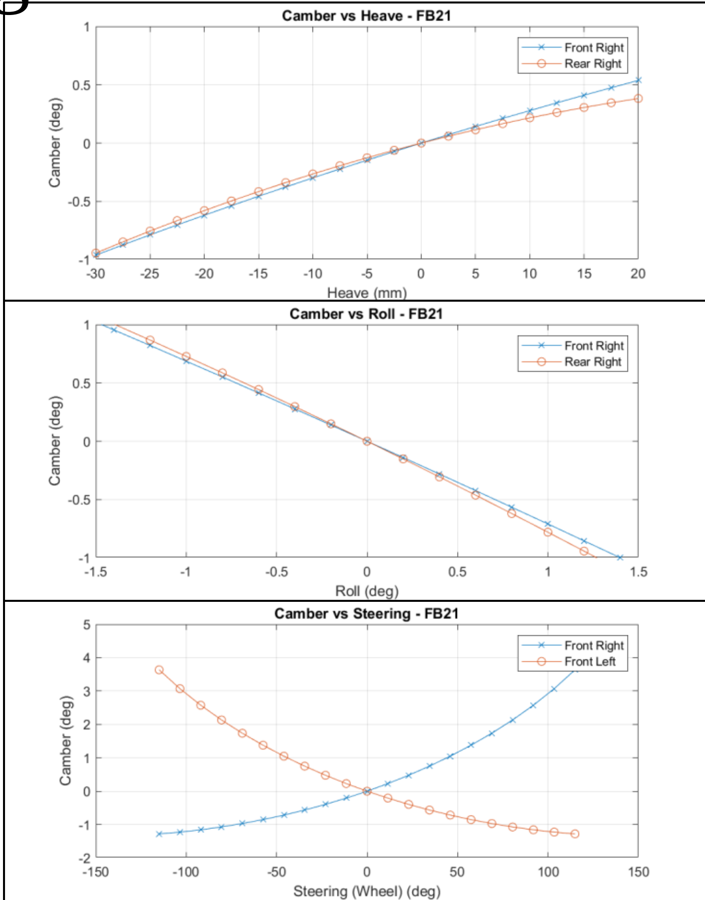
1. Camber Curve Target Operating Ranges Determined by Tire Analysis
2. Compliance data estimated and confirmed on previous iteration vehicle
    1. This was accounted for in CarSim Model to set static cambers

K&C Data

Car Sim Inputs	Front		Test Direction
Toe/Fx	9.68E-06	deg/N	Parellel
Steer/Fy	2.92E-03	deg/N	Opposed
Steer/Mz	6.54E-03	deg/N-m	Opposed
Camber/Fx	1.48E-04	deg/N	Parallel
Inc/Fy	2.86E-04	deg/N	Opposed
Inc/Mz	0.00E+00	deg/N-m	Opposed
Long/Fx	4.44E-04	mm/N	Parallel
Lateral/Fy	3.76E-06	mm/N	Opposed
Dive/MyBk	0.00E+00	deg/N-m	Opposed

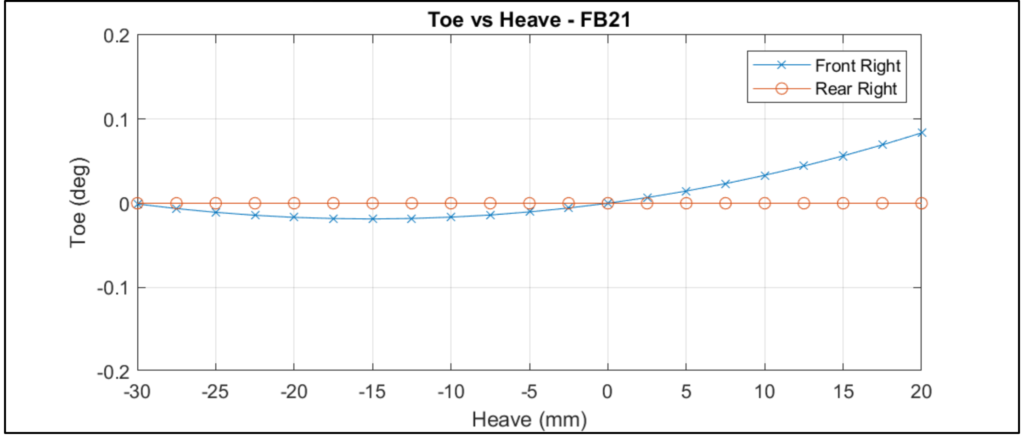
Compliance Estimates

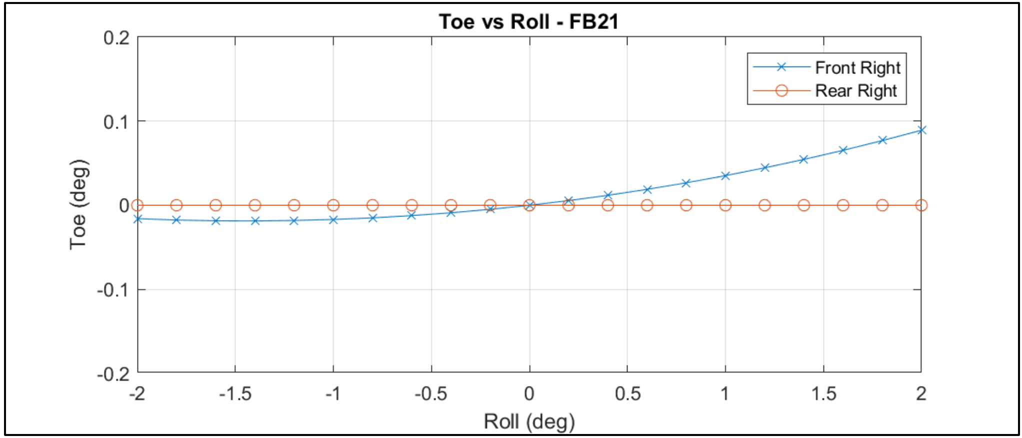




Suspension (8) – Kinematics Design Toe

1. Ensuring No Bump/Roll Oversteer in the front end of the car for Stability
2. Toe used as tuning parameter during vehicle testing
    1. Static Toe In Pre-Tensions
    2. Static Toe Out Loosens Rear End
        1. Skid Pad -1 to -2 Degrees
3. Compliance Data Accounted for in CarSim Model



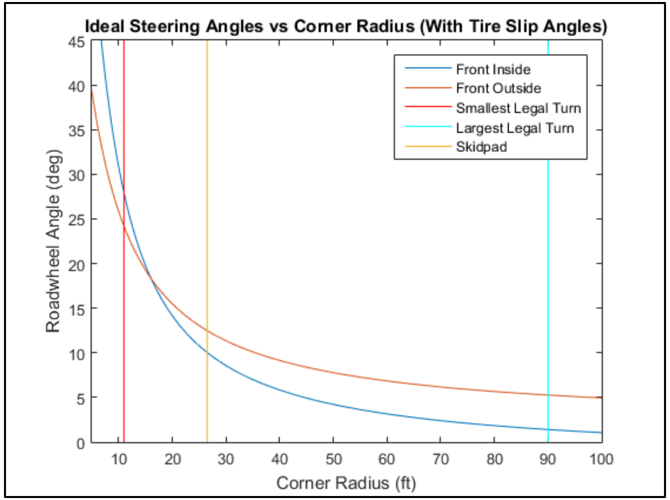


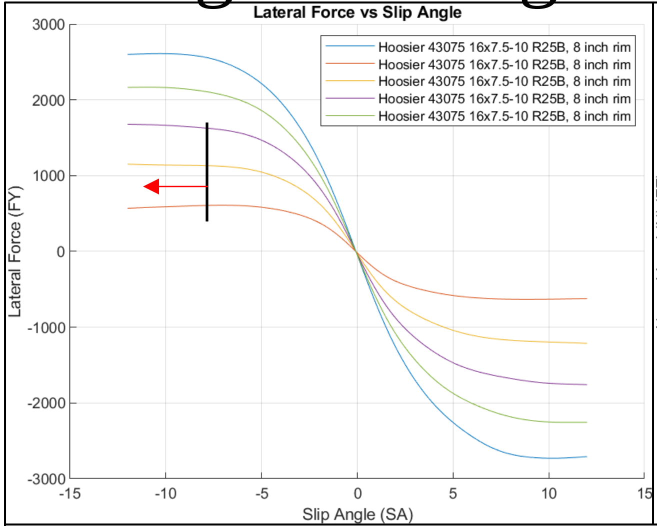
K&C Data

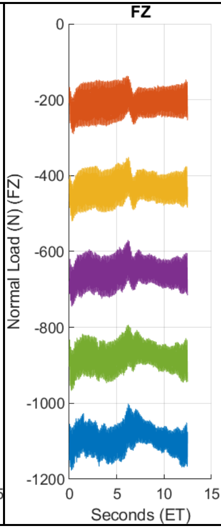
Car Sim Inputs	Front		Test Direction
Toe/Fx	9.68E-06	deg/N	Parellel
Steer/Fy	2.92E-03	deg/N	Opposed
Steer/Mz	6.54E-03	deg/N-m	Opposed
Camber/Fx	1.48E-04	deg/N	Parallel
Inc/Fy	2.86E-04	deg/N	Opposed
Inc/Mz	0.00E+00	deg/N-m	Opposed
Long/Fx	4.44E-04	mm/N	Parallel
Lateral/Fy	3.76E-06	mm/N	Opposed
Dive/MyBk	0.00E+00	deg/N-m	Opposed

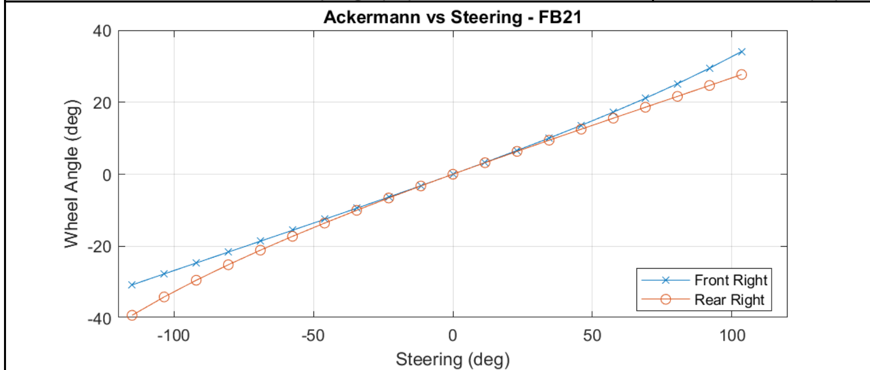
Suspension (10) – Kinematics Design Steering

1. Pro-Ackermann Steering Chosen
   1. 86% Static
   2. More Slip Angle at low loads will always reach peak faster.
   3. With these tires, Pro-Ackermann will speed up turn-in response at any normal load.
2. Steering Ratio – 3.563



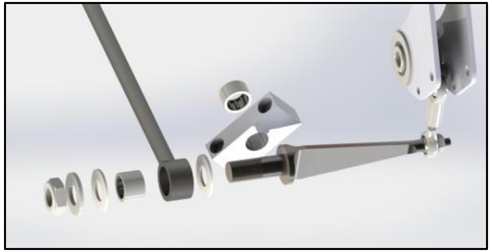


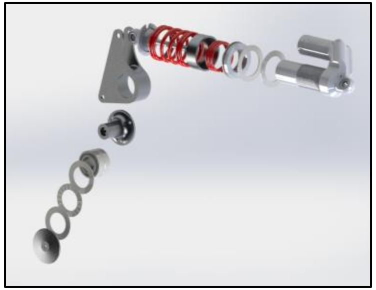


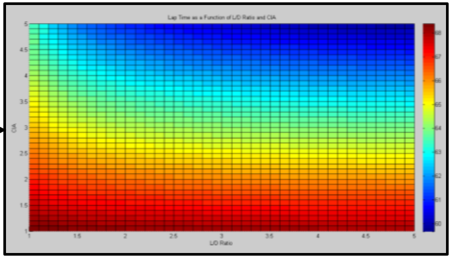


Suspension (11) – Spring and Dampers Overview

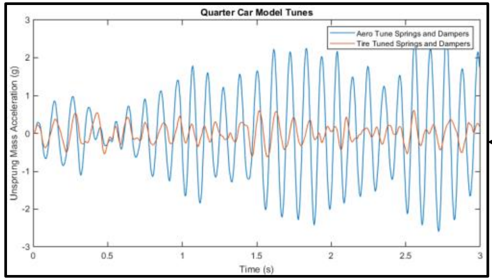
1. Many Setups and Designs considered for FB21
    1. Conventional Corner Spring, Damper, and ARB.
    2. Conventional + Heave Spring/Damper
    3. Roll and Heave Decoupled
2. Roll and Heave Decoupled was highly desired/researched
    1. Low undulation tracks remove a heavy need for individual wheel control.
    2. Axle Control and Body Control Much More Important especially with Aero
    3. Decoupled Roll Damping Tuning would be very nice
3. Conventional Corner Spring, Damper, and Rear ARB was chosen
    1. Simplistic Design and Packaging
    2. All necessary LLTD targets can be hit
    3. Lightest Option and Least Complexity in Simulation

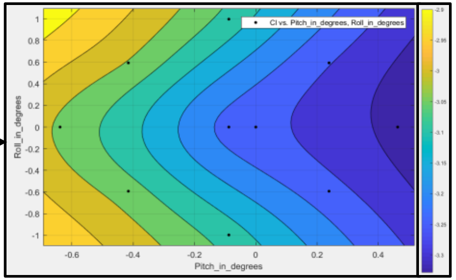






Quicker Lap Times



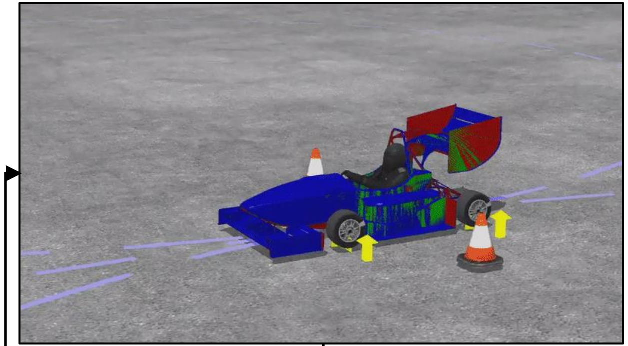


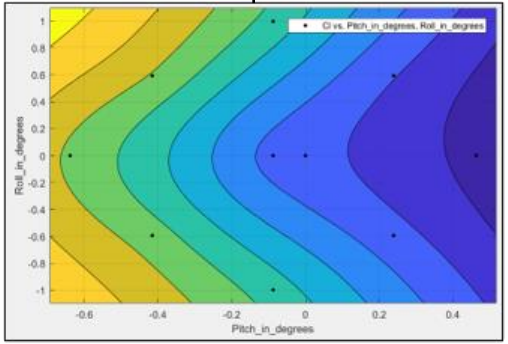
Quicker Lap Times

Suspension (12) – Spring and Dampers + Aero

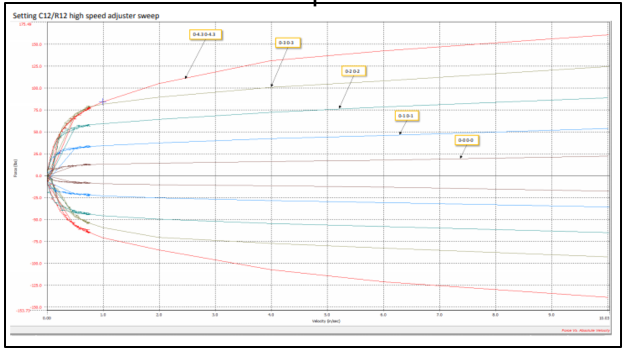
1. Tradeoffs in Suspension and Aero Design
   1. Low Spring Rates and Favorable UnSprung Mass Tuning Decreases Aero Performance
   2. High Spring Rates and Sprung Mass Tuning Decreases Aero Performance

CarSim





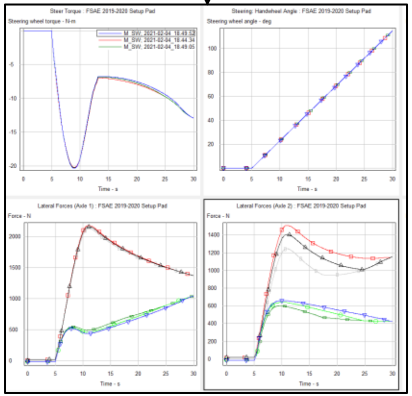
Aero Map Data



Damper Dyno Data

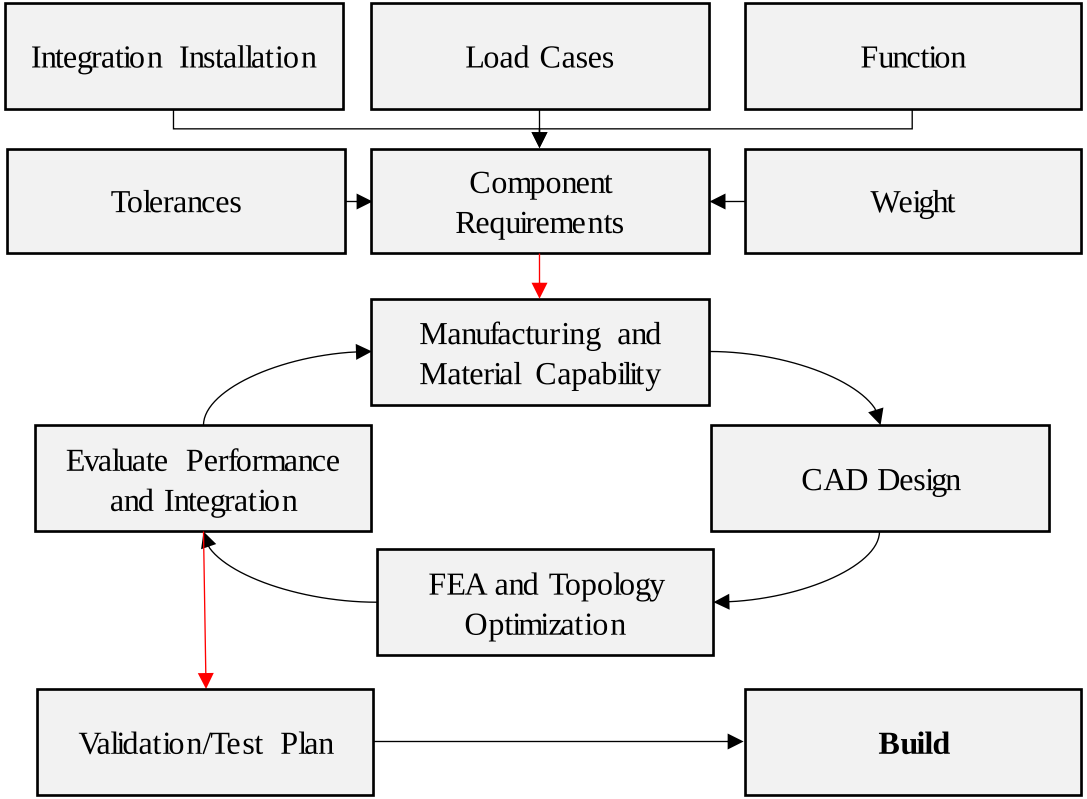
Spring Data

Profit



Suspension (13) – Component Design Overview

1. Suspension Components Require insurance of installation and clearance as well as strict adherence to compliance requirements to ensure good vehicle performance.
2. Validation Equipment:
   1. Wheel Stiffness Tester
      1. Supported Carbon Fiber Rim Development
      2. Used for Outboard Camber/Toe Compliance Measurements
   2. In-House Shock Dyno
      1. Damper Build Verification
      2. Spring Assembly Rates
3. Propagated Stiffness Requirements from Compliance Suite



Suspension (14) – Control Arms

1. Control Arm Construction
    1. 5/8 OD 4130 Tube – 0.035, 0.049, 0.065 Wall
    2. Best Tradeoff between weight and stiffness properties
2. Control Arm Tube Dimensions Specified from max loading conditions with a FOS of 2 for any peaks
    1. 2.2 G Braking
    2. 1.9 G Lat

Load Case

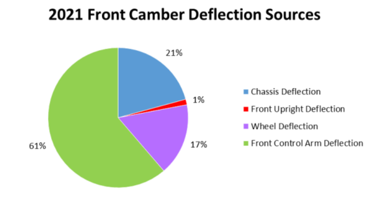
Cornering	(Right Turn)				total cornering force (lb)		
					1131.7		
Front			force in z (lb)			Force in y (lb)	
normal force (lb)	Force in z (lb)	load transfer	outside	inside	total front force (lb)	outside	inside
279	375	128	316	59	524.8	442	83
Rear			force in z (lb)			Force in y (lb)	
normal force (lb)	Force in z (lb)	load transfer	outside	inside	total rear force (lb)	outside	inside
321	434	151	368	65	606.9	515	92

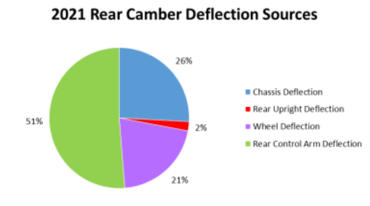
Braking					total braking force (lb)		
					1586.7		
Front			force in z (lb)			Force in x (lb)	
normal force (lb)	Force in z (lb)	load transfer	outside	inside	total front force (lb)	outside	inside
279	524	316	420	420	1176.6	588	588
Rear			force in z (lb)			Force in x (lb)	
normal force (lb)	Force in z (lb)	load transfer	outside	inside	total rear force (lb)	outside	inside
321	609	-316	146	146	410.1	205	205

Tube Dimension Calc (FOS:2)

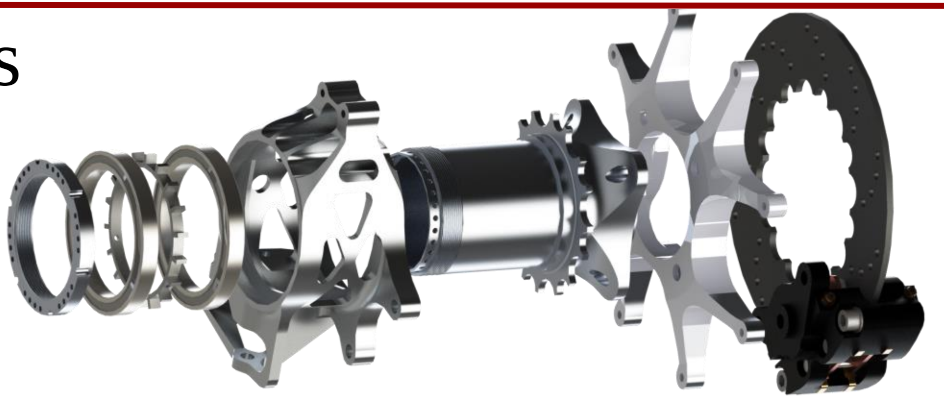
Global FOS	Arms	Lengths (in)	Critical Load Accel (lb)	Critical Load Braking (lb)	Critical Load Cornering(lb)	Buckling Load (lb)	Tensile Load (lb)	Min Moment of Inertia (in^4)	Required Area
2	FLL	14.82	2094.78	-2094.78	712.75	4189.55	4189.55	3.14E-03	0.0599
MoE (psi)	FLT	16.23	-2294.18	2294.18	116.63	4588.36	4588.36	4.12E-03	0.0655
29700000	FUL	12.65	563.85	-563.85	182.46	1127.69	1127.69	6.15E-04	0.0161
Yield Strength (psi)	FUT	11.85	-525.57	525.57	238.43	1051.14	1051.14	5.03E-04	0.0150
70000	RLL	12.85	1450.04	-1450.04		2900.09	2900.09	1.63E-03	0.0414
	RLT	11.21	-928.61	928.61	924.62	1857.23	1857.23	7.96E-04	0.0265
	RUL	13.04	727.13	-727.13	74.03	1454.25	1454.25	8.44E-04	0.0208
	RUT	7.61	-424.05	424.05	522.71	1045.42	848.10	2.06E-04	0.0121

Arm	OD (in)	Req Wall (Buckle)	Req Wall (Tensile)	Required Wall
FLL	0.5	0.12	0.035	0.12
	0.625	0.035	0.028	0.035
FLT	0.5	0.12	0.035	0.12
	0.625	0.049	0.035	0.049
FUL	0.5	0.028	0.028	0.028
	0.625	0.028	0.028	0.028
FUT	0.5	0.028	0.028	0.028
	0.625	0.028	0.028	0.028
RLL	0.5	0.035	0.028	0.035
	0.625	0.028	0.028	0.028
RLT	0.5	0.028	0.028	0.028
	0.625	0.028	0.028	0.028
RUL	0.5	0.028	0.028	0.028
	0.625	0.028	0.028	0.028
RUT	0.5	0.028	0.028	0.028
	0.625	0.028	0.028	0.028





Suspension (15) – Uprights



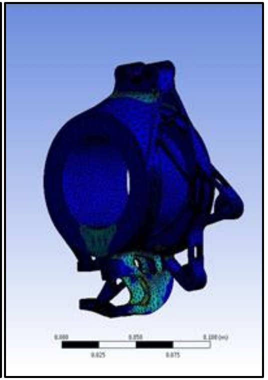
1. Front Uprights – Billet 7075 Manufactured in-house
2. Rear Uprights – 3D Printed Ti-64
3. Ansys Topology Optimized
4. Focus on Camber and Toe Stiffness Minimization

Stiffness Comparison on FEA

		2018 Baseline		2019 r2		2019 r3		2019 r4		2019 r5		2019 r6	
		Front	Rear	Front	Rear	Front	Rear	Front	Rear	Front	Rear	Front	Rear
	Weight (lbs)	0.89	0.83	0.99	2.06	1.88	2.09	1.01	1.2	0.988	1.14	0.966	1.14
		0%	0%	11%	148%	111%	152%	13%	45%	11%	37%	9%	37%
	Tire Radius (in)	7.86	7.86	7.86	7.86	7.86	7.86	7.86	7.86	7.86	7.86	7.86	7.86
Camber Stiffness	TCP Displacement (in)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Load Generated (lbf)	2178	1785	2197	1616	8883	2163	3797	2163	3210	2872	5130	3747.565
	Overturning Moment (lbf-in)	17119.08	14030.1	17268.42	12701.76	69820.38	17001.18	29844.42	17001.18	25230.6	22573.92	40321.8	29455.86
	Deflection (deg)	0.07289535	0.072895	0.072895	0.072895	0.072895354	0.072895	0.072895354	0.072895	0.07289535	0.072895354	0.0728954	0.072895
	Camber Stiffness (lbf-in/deg)	234845	192469	236893	174246	957817	233227	409415	233227	346121	309676	553146	404084
	Change from Baseline	0%	0%	1%	-9%	308%	21%	74%	21%	47%	61%	**136%**	**110%**
Toe Stiffness	TCP Displacement (in)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Load Generated (lbf)	198	634	203	633	1279	633	900	410	792	817	427	755
	Overturning Moment (lbf-in)	1556.28	4983.24	1595.58	4975.38	10052.94	4975.38	7074	3222.6	6225.12	6421.62	3356.22	5934.3
	Deflection (deg)	0.07289535	0.072895	0.072895	0.072895	0.072895354	0.072895	0.072895354	0.072895	0.07289535	0.072895354	0.0728954	0.072895
	Toe Stiffness (lbf-in/deg)	21350	68362	21889	68254	137909	68254	97043	44209	85398	88094	46042	81408
	Change from Baseline	0%	0%	3%	0%	546%	0%	355%	-35%	300%	29%	**116%**	**19%**
	Notes					BaseLine Ti				Gutted to the most im comfortable with		Keep top continous and gutted	

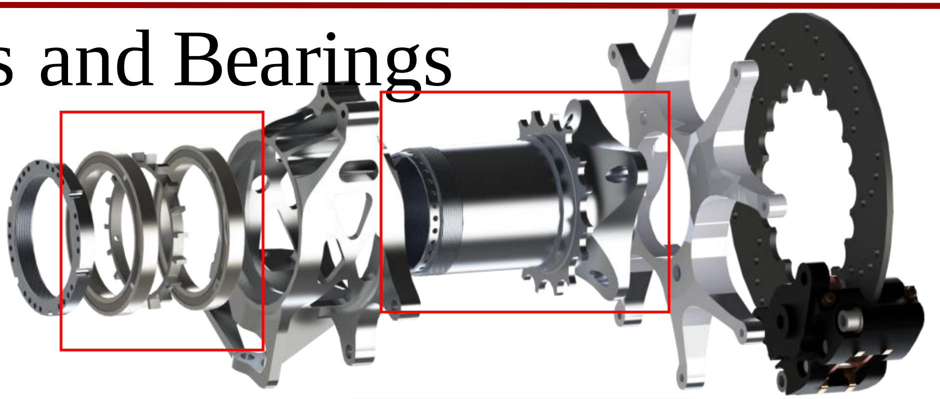
Load Case

Results

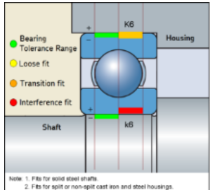


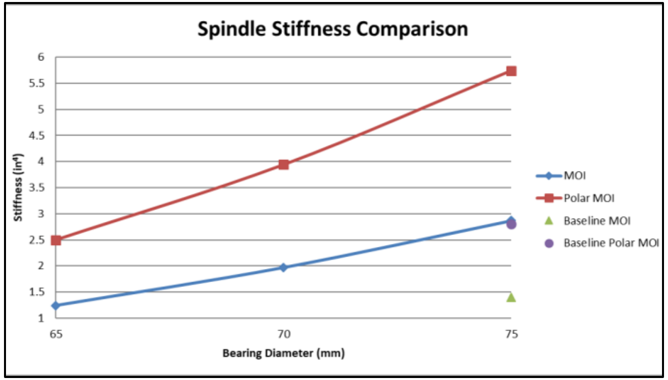
Build

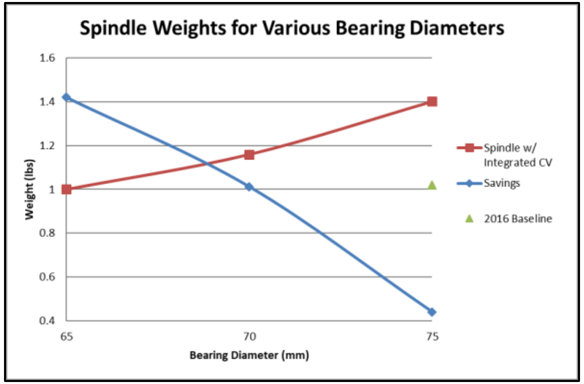
Suspension (16) – Spindles and Bearings

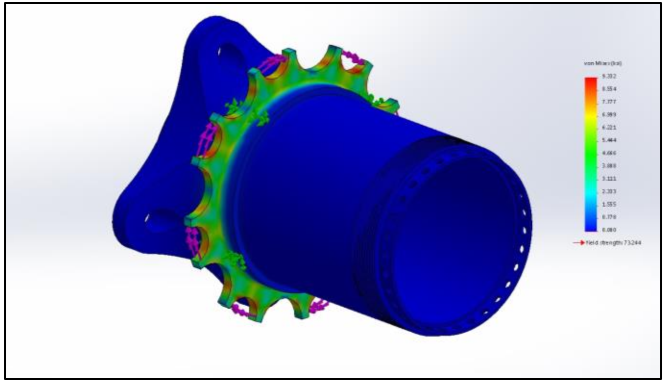


1. Spindles Designed with Integrated CV
    1. Reduces Mass by 0.98 lbs compared to Bolt in CV
2. 70mm single row ball bearing is the best compromise between stiffness and weight savings







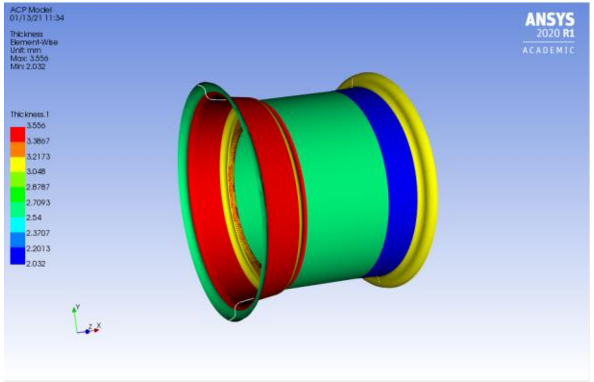


Suspension (17) – Wheels

1. 3 Piece Carbon Fiber Wheel Design 10”x8”
    1. 7075 Al Wheel Center
    2. Outer Wheel Lip
    3. Inner Wheel Barrel
2. Ease of Assembly when doing Tire Swaps
3. 40% Weight Reduction over OZ Wheels

Stiffness Comparison

Layup Schedule



Test

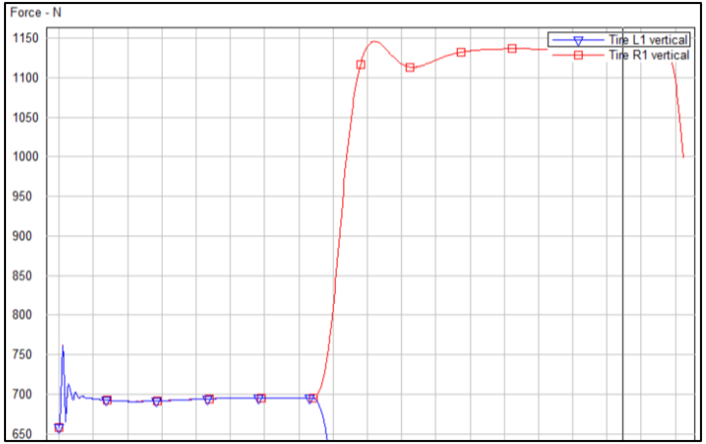
Suspension (18) —Simulation Goals

- Integration
  - Integrate our vehicle as much as possible into the CarSim space for continual validation and allows for more educated design choices in the future
  - Responsibly organize results in a format to be compared to in future years
  - Find trends between all levels of simulation, from steady-state to driver-in-the-loop
- Reusability
  - Create models and scripts that can be reused from year to year so that future cars can be designed around simulation data
  - Properly transfer general vehicle dynamics knowledge across the entire team so that our data can be usable for any subteam

carSIM®

Suspension (19) — CarSim Model Verification

- Lack of testing/competition prevented any reliable comparison to real-world results
  - Model can best be verified by comparison to hand calculations
    - E.g. steady-state load transfer, roll gradient via wheel/spring rates, downforce generated @ 60 mph
  - Expect results to be within ~10% ballpark of calculated values
    - Both simulation and hand calcs will have a degree of error compared to on-track results



$$LLT = \frac{a_y * h_{CG}}{t} = \frac{1.4 * 0.271}{1.171} \sim 32\%$$

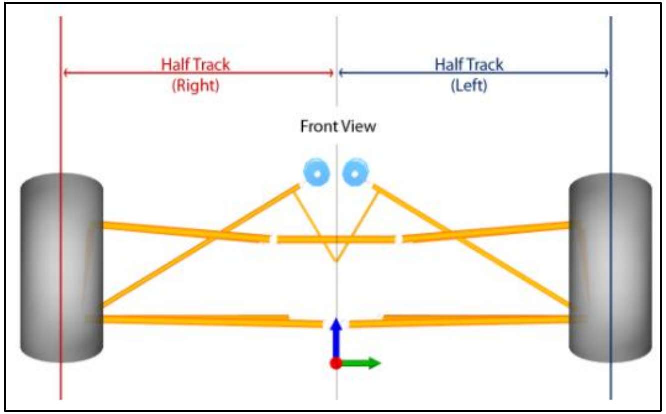
theoretical

$$\frac{1150 - 700}{2 * 700} \sim 32\%$$

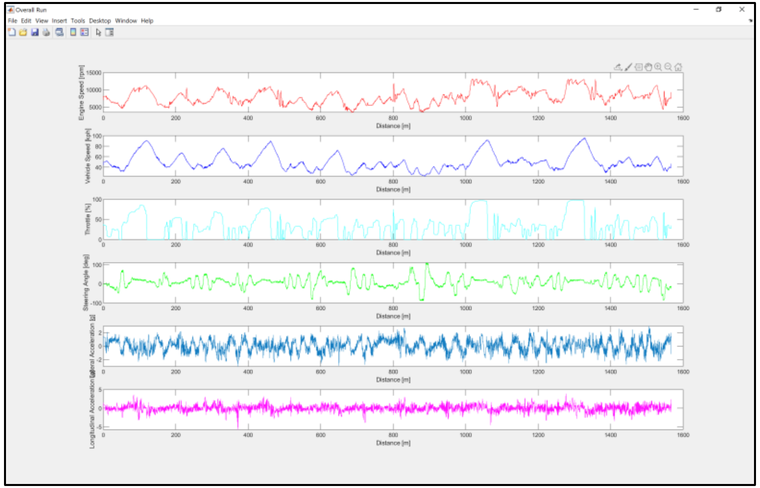
empirical (based off simulation)

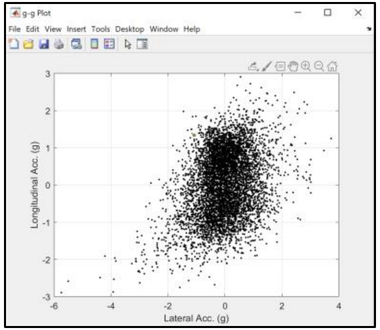
Suspension (19) — CarSim Simulation

- Sets up good benchmark to hit once we get on track
  - All results we obtain from early simulation will give the team a good idea of how close the pure model is to a given car
    - This information can be passed down to future car generations in the design phase
- Allows for design changes on the fly
  - Early mistakes can be avoided if ran in the model and the results are poor
    - Much of suspension design for 2021 season was verified using CarSim modeling



Suspension (20) — Simulation and Testing



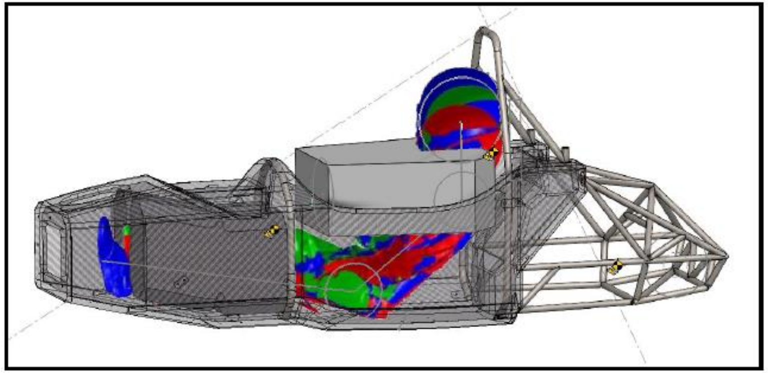


- Proper utilization of CarSim results requires the architecture to directly compare to on-track results
  - Current post-processing techniques were laborious and often led the team to only working within DAQ platform
- Decision made to create DAQ processing software in MATLAB for multiple inputs
  - Capable of using results both from simulation and real-world data, allowing for the easy direct comparison of vehicle performance
    - Drivers and the final car can now be held to the standard of their theoretical best
    - Advanced vehicle dynamics calculations can be performed within MATLAB to give more context into vehicle performance

Frame | Body | Aero

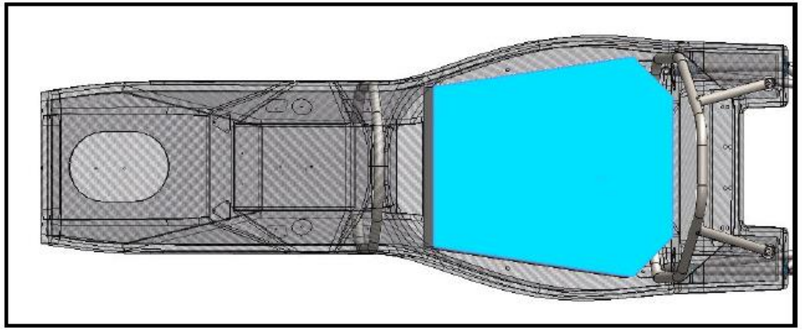
Design Goals

- Lightweight chassis
- Designed for safety and comfort of the driver
- Designed together with suspension
  - Optimal loading, stiffness, and dimensional accuracy
- Monocoque and engine packaging shape allows for minimal aerodynamic interference
- Allows for future engine conversion to single cylinder design
- Optimal hoop mounting and integration
- Passes all rules and templates with room to spare



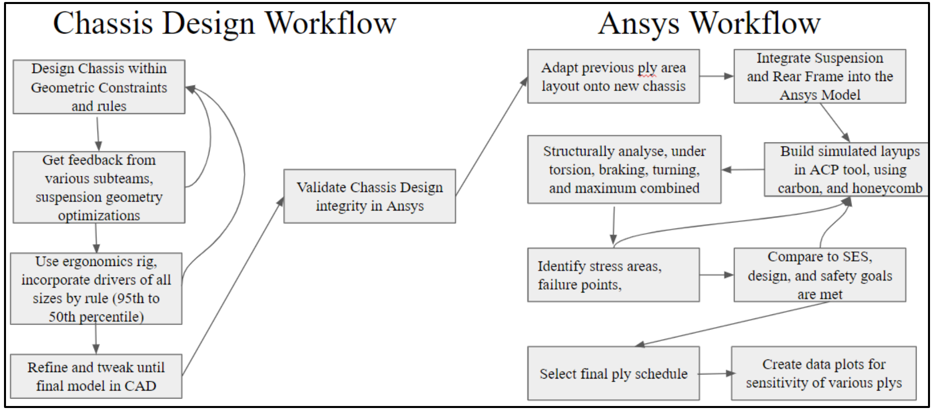
Subteam Goals

- Focus on knowledge transfer
  - Have had issues with composite knowledge loss
- Manufacture chassis efficiently and on time
- Increase testing time
  - Reduce manufacturing time
  - Meet critical deadlines
- Merge aero and chassis workforce
  - Dissipates more skills to more people
  - Gets more people chassis experience



Design Process and Decisions

- Design matrices for various choices
  - Materials, Processes, Coring, Layups
- Completely new design process for 2021 Chassis
  - Other sub teams specifically designed for, focus on Suspension and Aerodynamics integration
  - More rules compliant, room to adapt and conform to future rules and sub team adjustments
- Further material research allows for better manufacturing
  - Inlayed dowel pins in molding to locate holes and hardpoints
  - Mixed mold material to ease complex mold geometry construction



Fiber Type	2x2 twill	Unidirectional	Weight Multiplier
Cost	3	2	2
Layup difficulty	4	2	3
Weight	3	4	3
Strength	4	4	4
Time	4	3	3
Total	55	47	

Frame type	Monocoque	Space frame	Both	Weight Multiplier
Design Factor	4	3	4	4
Manufacturability	2	4	2	3
Cost	2	3	2	2
Weight	4	2	3	3
Servicability	3	4	4	3
Stiffness (Tor)	4	3	4	5
Accesibility	2	4	4	3
Total	73	75	79	

Core	Aluminium	Rohacell	Nomex	Weight Multiplier
Machinability	4	4	4	3
Cost	3	3	3	2
Risk	3	1	2	2
Weight	3	4	4	4
Strenght	4	2	2	4
Total	52	44	46	

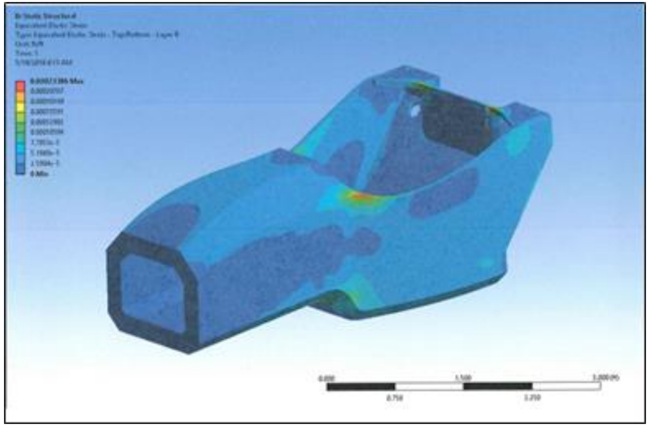
Hardpoint type	Carbon	Phenolic	None	Weight Multiplier
Weight	4	3	5	2
Machinability	2	3	0	3
Strenght (Shear)	3	4	0	4
Total	26	31	10	

Layup Process	Autoclave	Roomtemp	Weight Multiplier
Cost	3	4	2
Time	3	3	3
Weight	4	2	4
Difficulty	3	4	3
Total	40	37	

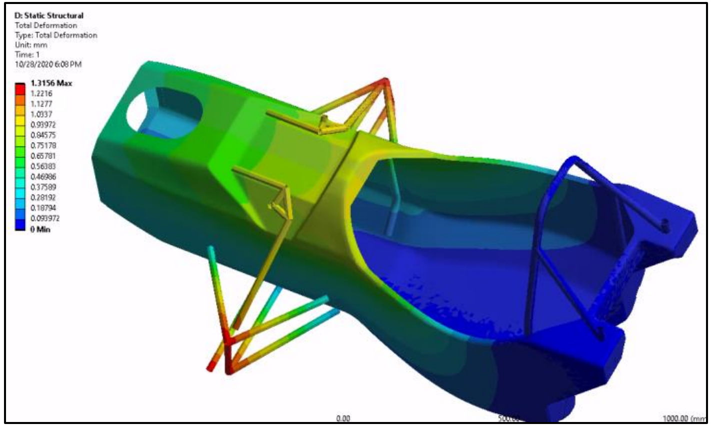
FEA and Torsional Simulation

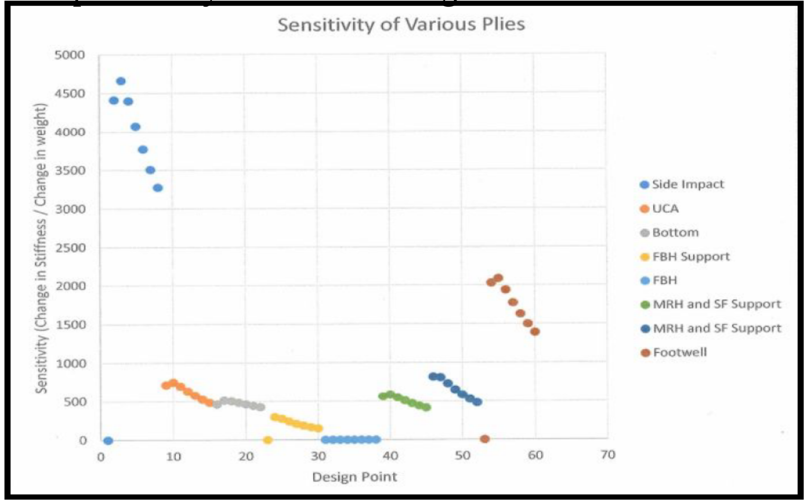
- Composites modeling and simulation way ahead of previous years
  - Includes full suspension, tubing, and frames, allowing for proper torsion axis and moments, helps confirm strength of mounting solutions
- Suspension is key addition, as the mountings to the wall and upper tub are extremely important for hardpoint location and sizing
- Rear frame is also included and used as support for all loads simulated. Ensuring there is not a random weak spot anywhere, and provided good initial iterations of its design
- While the torsional test shown in the bottom right has arbitrary values, we were getting stiffness values in the range of 1800 Nm/Deg, expecting a value much lower. As we could easily optimize for this case, and use reinforcements for the areas most stressed by the specifically torsional loading

2018-2020 FEA



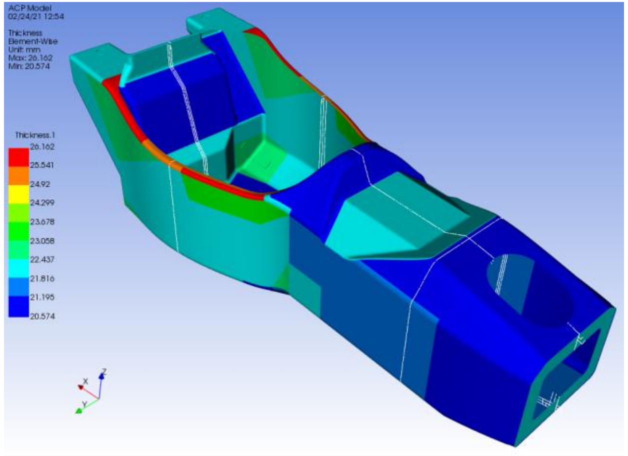
2021 FEA



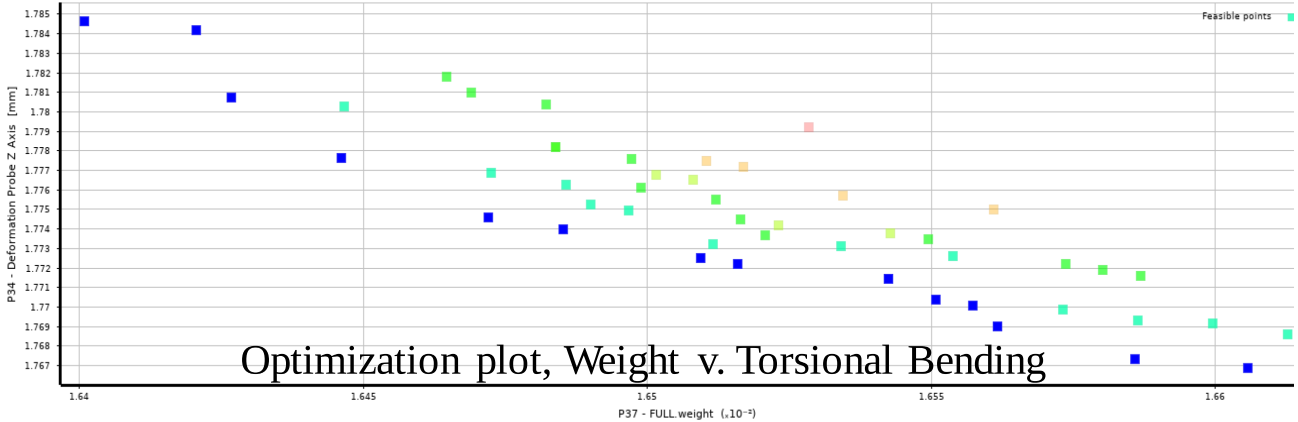


Layup Schedule and Optimization

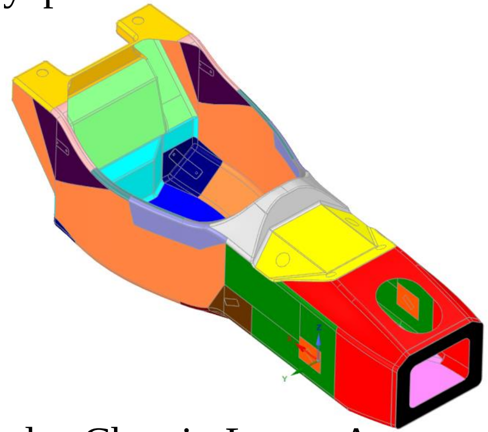
- Starting with a base layer of 2, running optimizations to test plausible layer numbers for all zones
  - Referring to other years data and continuing to iterate from there
  - Specific optimizations done on the front half, and back wall of the chassis to ensure compliance in the torsional case
- Nearly double the number of areas of previous years
  - Including inner skin reinforcement zones on traditionally high stress area such as corners, the cockpit lining, and suspension points



ACP Layup Thickness Contour Plot



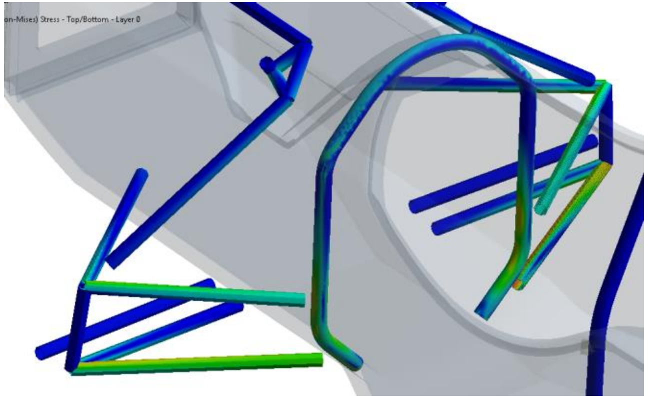
Optimization plot, Weight v. Torsional Bending



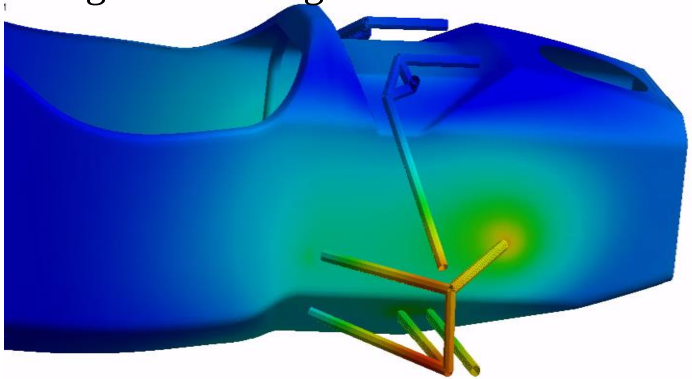
Color Chassis Layup Areas

FEA Integrated Simulation

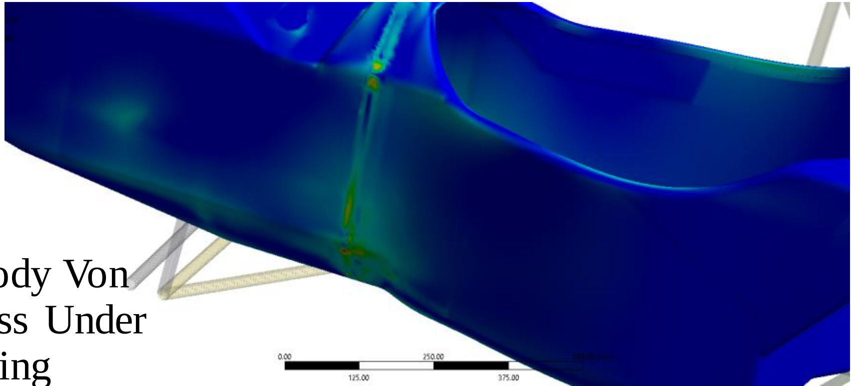
- Various predetermined loaded scenarios to confirm validity
  - Based on real car suspension load cells from previous years
  - Shows all simulated joints, connections, tubes, layup zones work as intended
  - Includes max braking, torsional testing, and cornering scenarios
- Eventually, practical torsional test will be conducted on the final tub upon completion, to check validity of the model, allowing for more precise optimizations while still being sure about safety
- This development also lets us see how the front hoop interacts with suspension and chassis better than ever before, opening opportunities to improve this system which has been generic previously



Integrated Tubing Von Mises Stresses

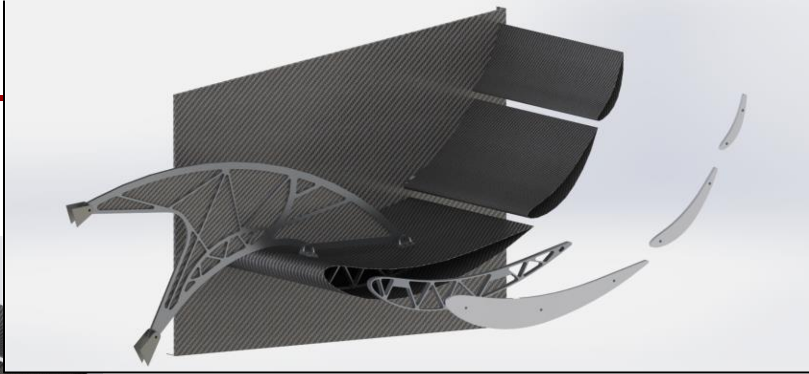


Combined Deformation Loading Into Tub



Chassis Body Von Mises Stress Under Max. Braking

Isometric View



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COLLEGE OF ENGINEERING

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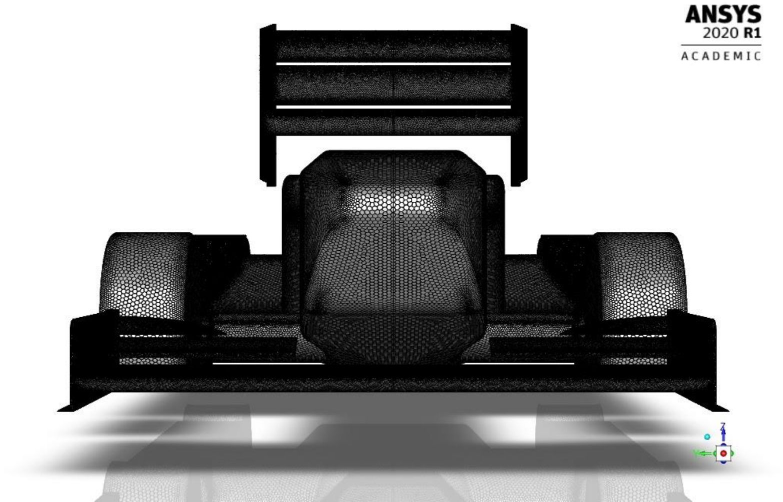
Frame | Body | Aero (6 of 20)

Design Goals

•Maximize downforce while maintaining a lift to drag ratio of 2.5
•Adjustable center of pressure of 50% with little to no migration
•Side force center of pressure of 40%
•Performs within 10% error to CFD.
•Combined weight of front and rear wing < 20 lbs
•Create a strong aero platform to build on.



Subsystem Overview

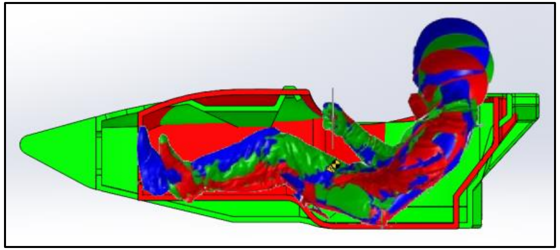
• Features an adjustable front wing, rear wing, nose, ducted sidepods, and undertray.
•Tested in CFD in a full-car simulation with rolling wheels and road. (TotalSim U.S. and ANSYS Fluent)
•The aero package includes front wing cascades for flow control.
•All mounting structures have been optimized for weight reduction.

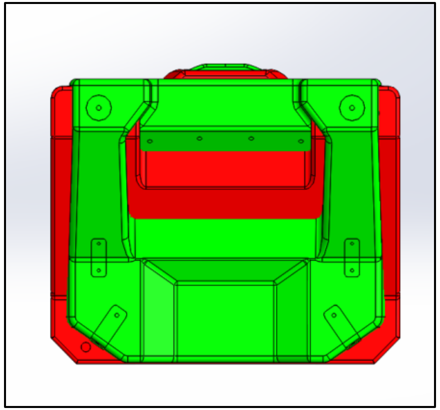
Downforce: -4.81 CL*A **-L/D: = 3.2**

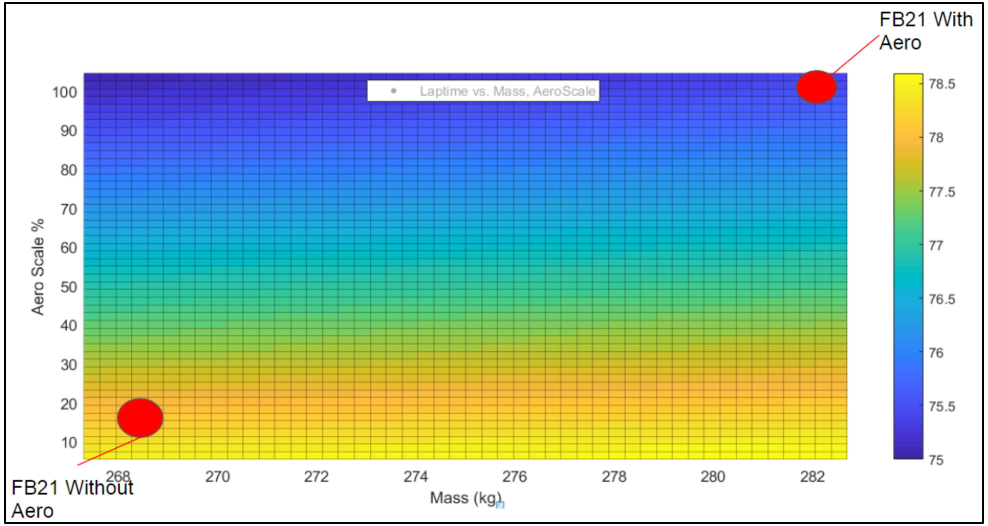
Center of pressure: 48%

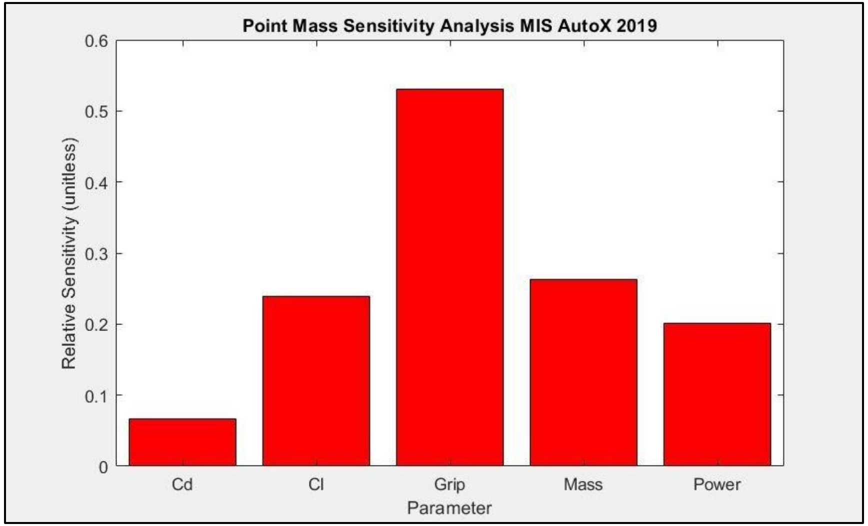
Frame | Body | Aero (8 of 20)

Lap time simulations were used to determine performance sensitivities. This data was used to create the new vehicle concept and vehicle architecture. The monocoque was made slimmer and the track width wider, which yields 13% more aerodynamic real estate to use on the side of the car. The engine peripherals were also repackaged to keep the airflow from the sidewings as smooth as possible. These changes allowed the team to design a new sidewing and underfloor assembly.



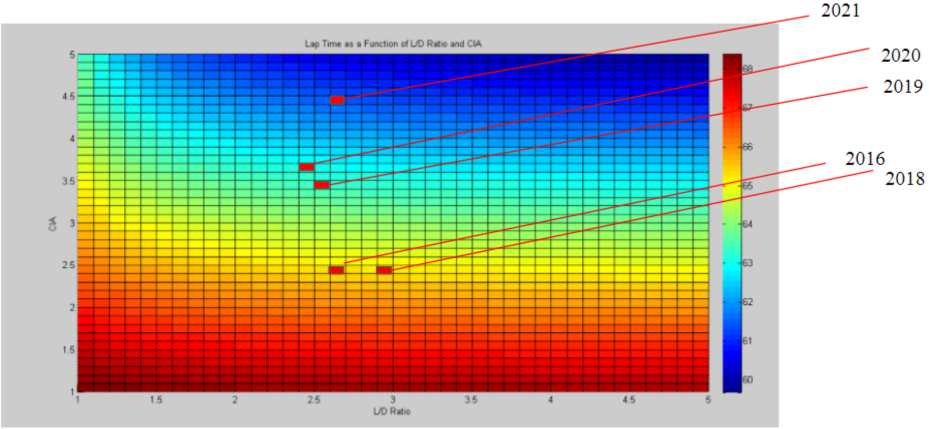


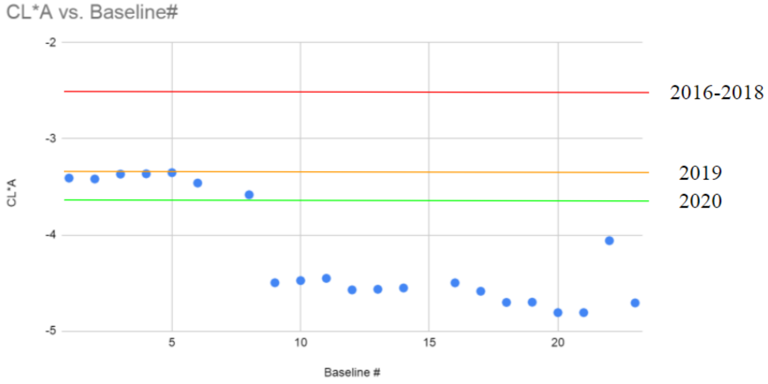




Frame | Body | Aero (7 of 20)

- The plot right shows laptime as a function of CL*A and L/D ratio at FSAE Michigan. As expected, laptime drops as downforce increases. However, an L/D higher than 2.5 yields no improvement in laptime. This suggests that any "dirty downforce" that is accumulated is worth the drag penalty if the L/D value stays above 2.5.



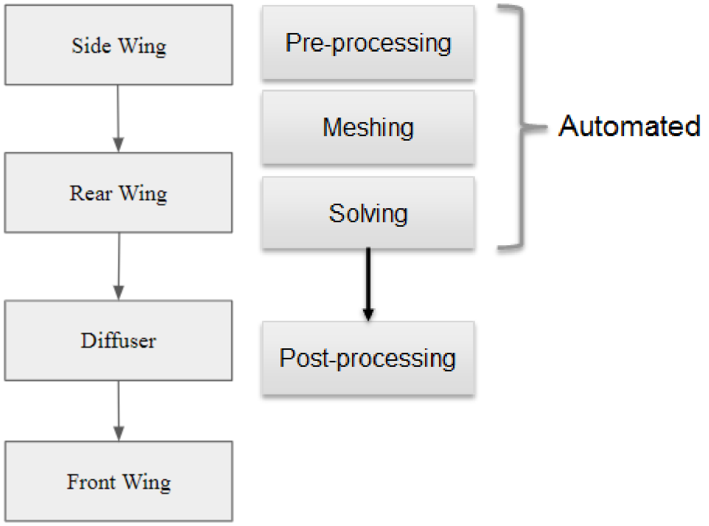


- The plot left shows the aerodynamic development throughout the year. The team saw dramatic improvement when the midwing and floor were redesigned.
- This plot helps to validate our knowledge transfer and design methods.

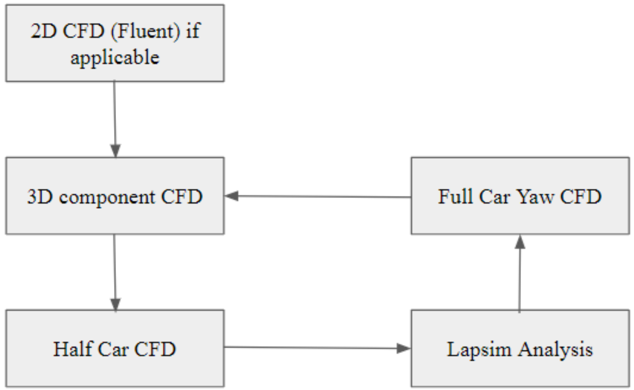
Design Process

- The rear wing and diffuser are designed after the sidewing because the upwash from the sidewings affect the downstream elements.
- Within one design cycle, the front wing is adjusted last to correct the aerodynamic balance.
- The CFD workflow increases in computational cost with each step.
- Pre-processig through solving has been automated; requiring less than 10 clicks per run.

Component Workflow



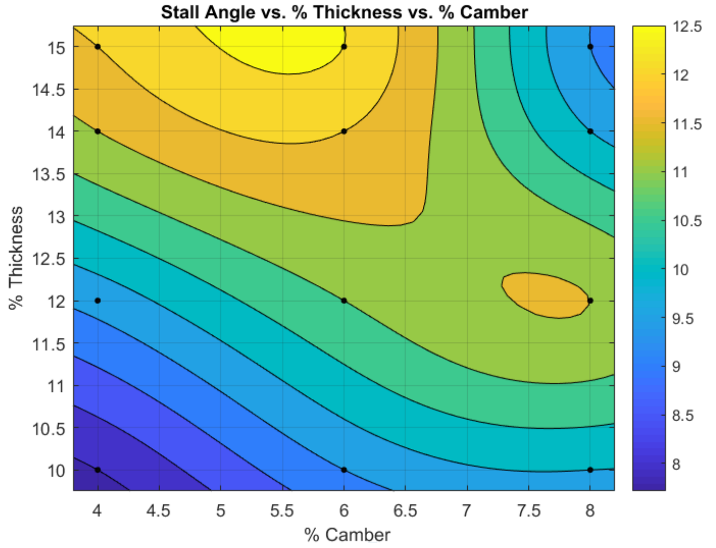
CFD Workflow

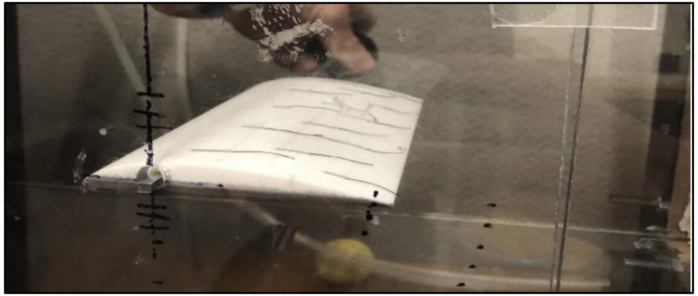


Airfoil Selection

- All non-ground effect wings use an Eppler 423 cross-section. The front wing main plane has an Eppler 385 cross-section.
- Using panel method code XFLR5, airfoils with varying thickness and camber were tested. It was determined that the Eppler 423 was ideal for most FSAE applications because of its high CLmax and soft stall tendencies.
- The Eppler 385 was chosen for its strong performance in ground effect. An airfoil with less camber was chosen because of the increased stall sensitivity in ground effect.

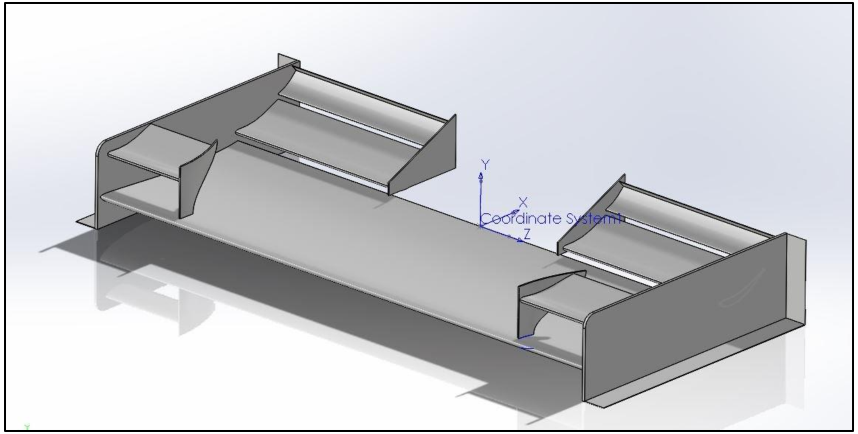
Airfoil Name	CL	CD	L/D
E174	0.21	0.03	7
E176	0.16	0.03	5.3333
E178	0.11	0.02	5.5
E180	0.06	0.02	3
E182	0.01	0.02	0.5
E193	0.14	0.03	4.6667
E195	0.09	0.03	3
E205	0.21	0.03	7
E207	0.16	0.03	5.3333
E210	0.12	0.04	3
E211	-0.04	0.02	-2
E216	0.19	0.03	6.3333
E221	0.08	0.02	4
E222	0	0.02	0
E385	0.35	0.04	8.75
E387	0.2	0.03	6.6667
E392	0.18	0.03	6
E393	0.14	0.03	4.6667





Front Wing

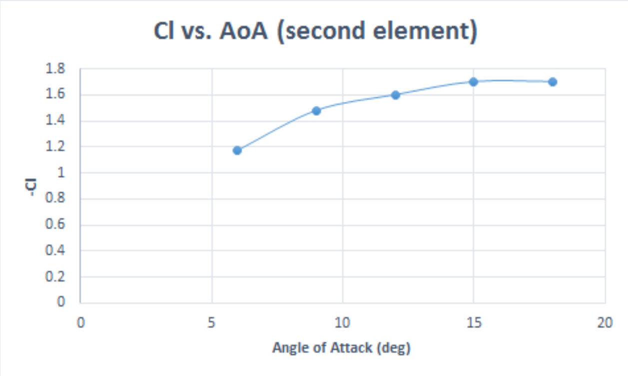
- The purpose of the front wing is to provide aerodynamic balance and to help remove front tire wake from the downstream aerodynamic devices.
- Features a single “main plane” that is designed to produce downforce in ground-effect, two flaps, and cascades to control tire wake.
- Maximize surface area to keep the downforce value high and induced drag low.
- Outboard-loaded design keeps inboard airflow clean for downstream components.
- Endplate flanges reduce inside tire wake.

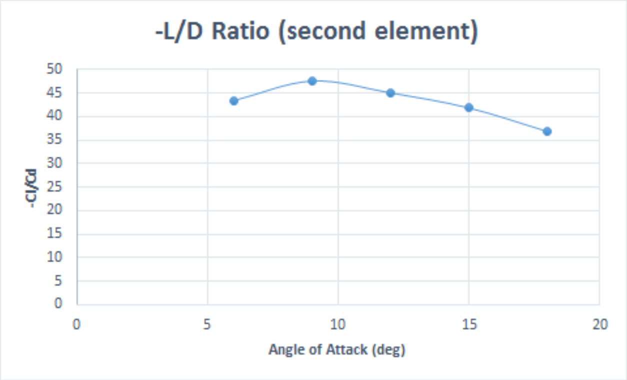


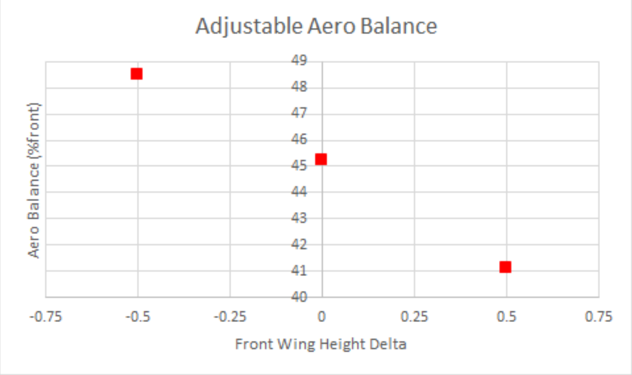
Front Wing layout			
	Multiplier	Outboard DF	Inboard DF
Downforce potential	0.5	6	9
Manufacturability	0.7	7	6
Corralation to CFD	0.85	7	8
Weight	0.6	7	7
Drag	0.5	8	5
Downstream effect	0.9	8	5
	Totals	4.875	4.45

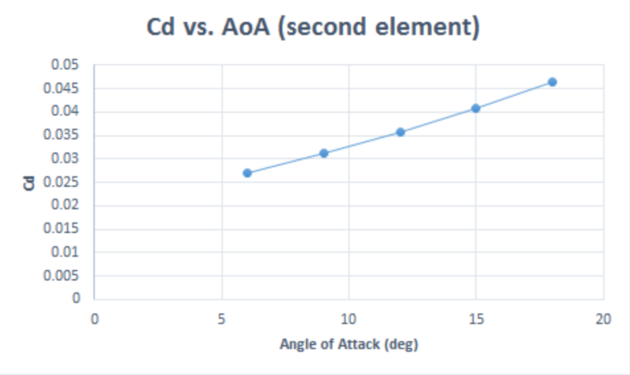
Front Wing Optimization

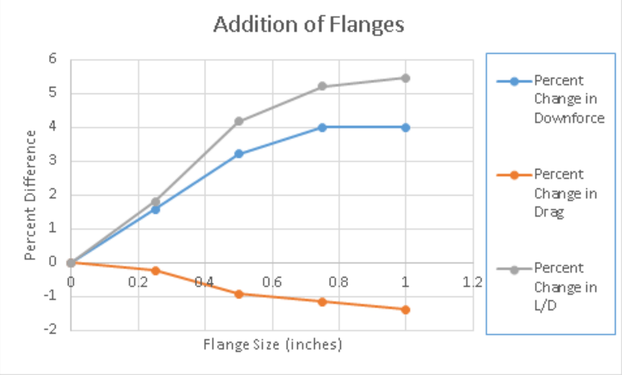
- Both the front and rear wings have been optimized using AoA and gap size sweeps.
- Front wing has been designed for all vehicle attitudes (ex. under braking) where stall could occur.
- Endplate flanges increase L/D by reducing front tire wake and endplate tip vortices.
- Adjustable front wing height helps to fine-tune CP location.





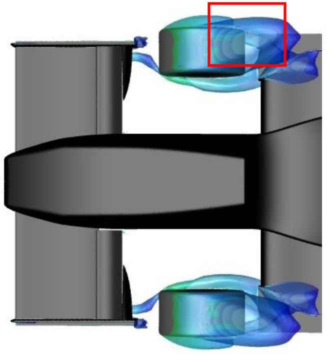




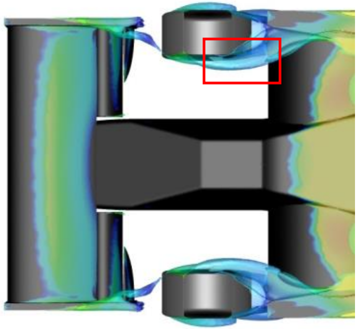


Tire Wake Management

- Both inside and outside tire wakes must be controlled to prevent losses from downstream aero devices.
- Cascades on the front wing throw air up and around the tire, pulling the outside wake away from the rear wing.
- Endplate flanges and an outboard loaded design helps to reduce the inside tire wake, improving midwing performance.



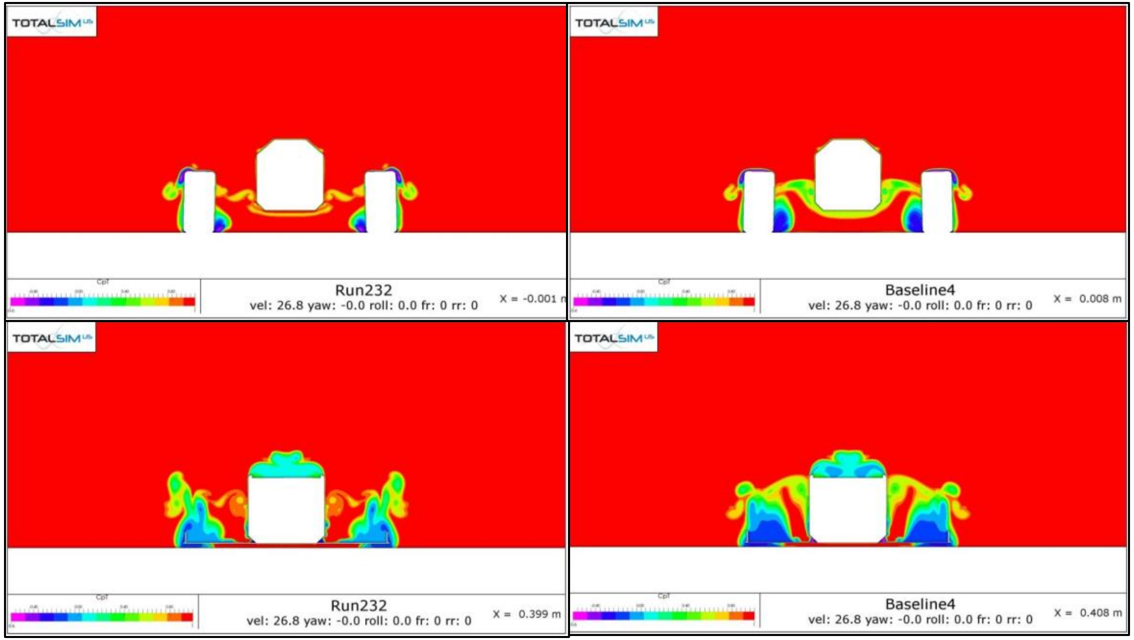
Outside Wake



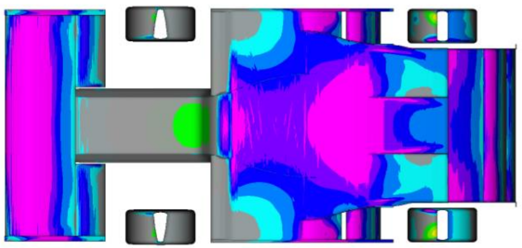
Inside Wake

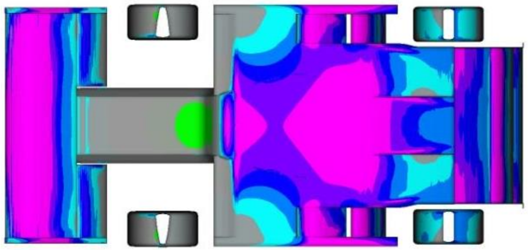
New Design Iteration

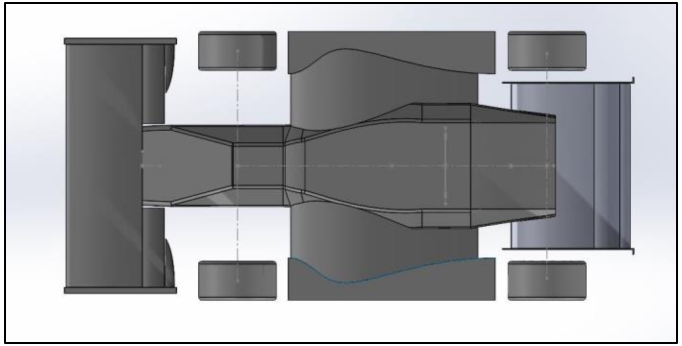
Old Design Iteration



Midwing Overview



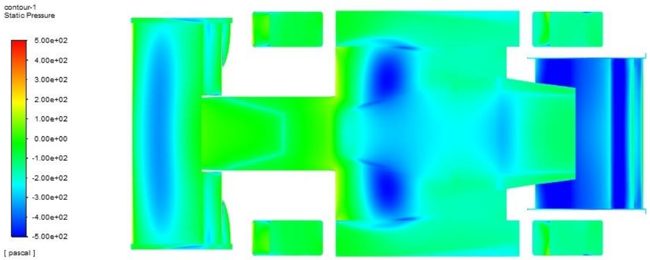


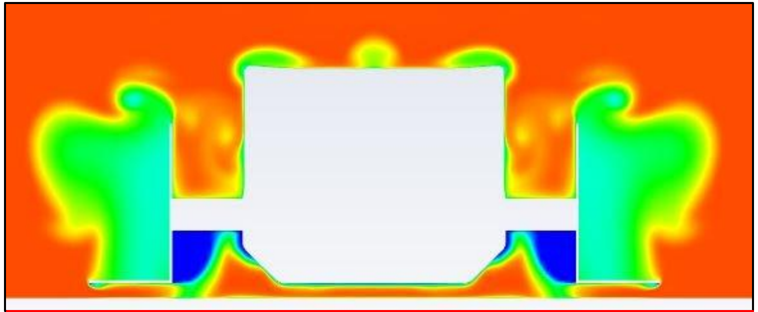


- Throughout development, the midwing was moving further inboard.
- This design decision yielded more surface area to seal the floor, and provided the midwing with cleaner airflow.
- Moving the midwing inboard also strengthens the interaction between the midwing and rear wing.
- Engine peripherals (oil reservoir, exhaust resonator), were repackaged to provide smoother airflow to the rearwing.

Midwing Developement

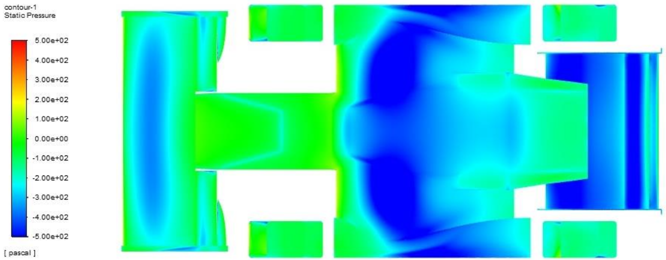
Baseline

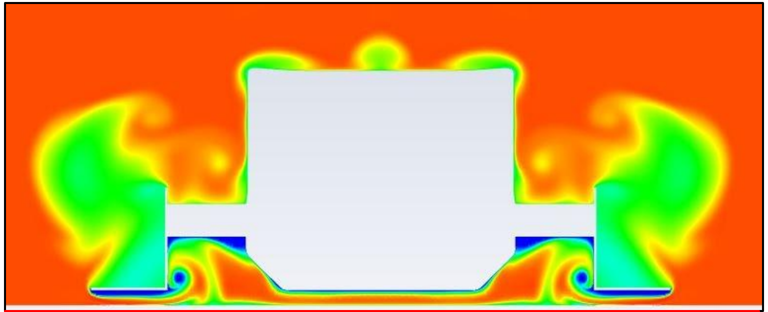




Flow separation occurs and propagates span-wise across the midwing.

Diverging-Converging Design

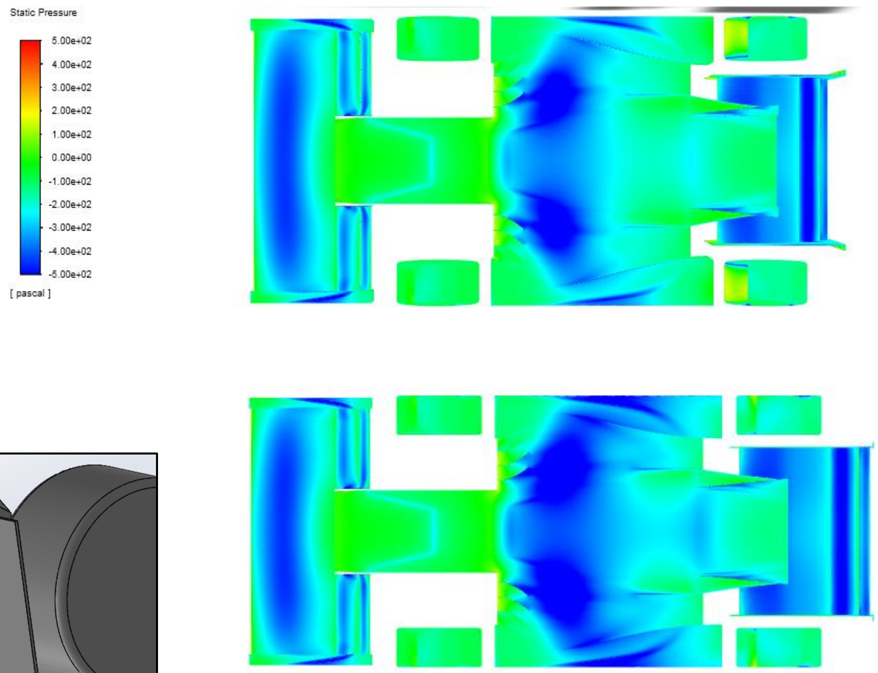




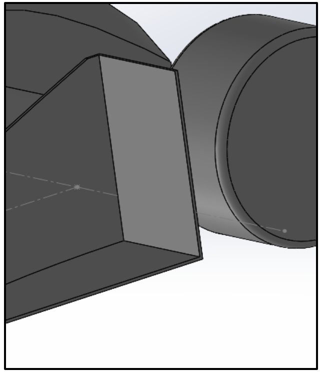
Adds and additional 110 points of downforce with a negligible increase in drag.

Rear Wheel Blockers

- Rear wheel blockers help reduce the static pressure at the midwing exit, improving undertray performance.
- Blockers also help reduce rear wheel lift and tire squirt, improving diffuser airflow.
- As shown in the table below, the blockers are efficient. Downforce is dramatically increased, while drag is impacted only slightly.

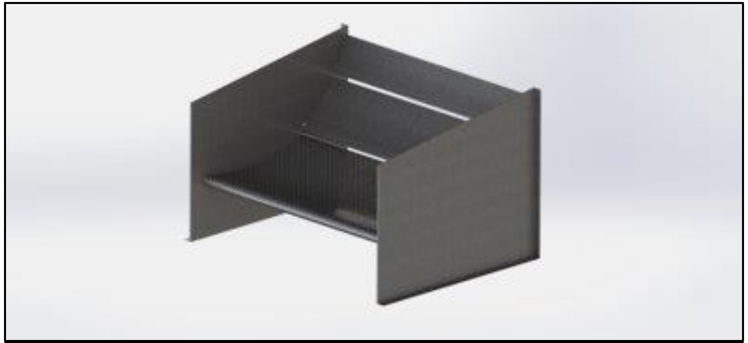


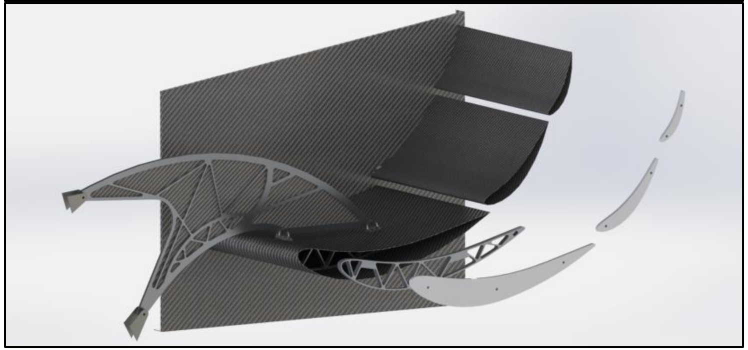
	With Blockers	Without Blockers
CL*A	-4.80	-4.06
CD*A	1.49	1.44

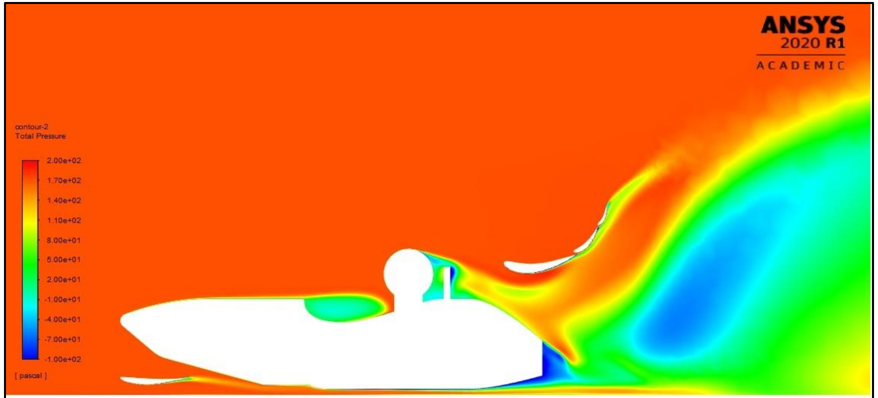


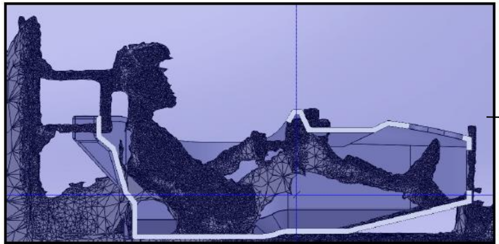
Rear Wing Development

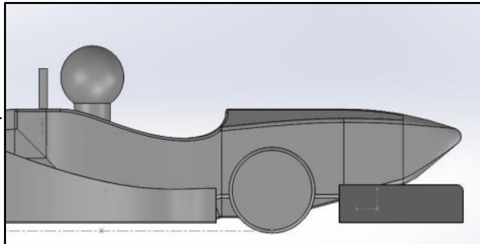
- Features 3 elements to prevent stall.
- Utilizes a trailing edge gurney flap and endplate flanges.
- Features "swan neck" mounting system
- The rear wing has been placed out of the wake of the driver's head and head rest, but low enough to interact with the diffuser.
- Driver was located in CFD CAD using photogrammetry.





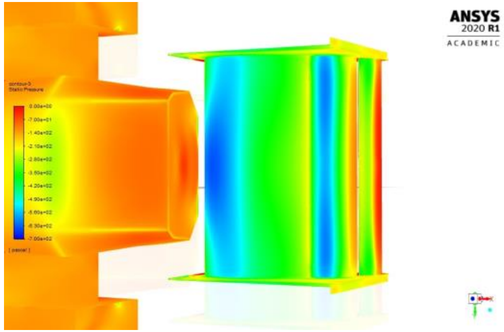




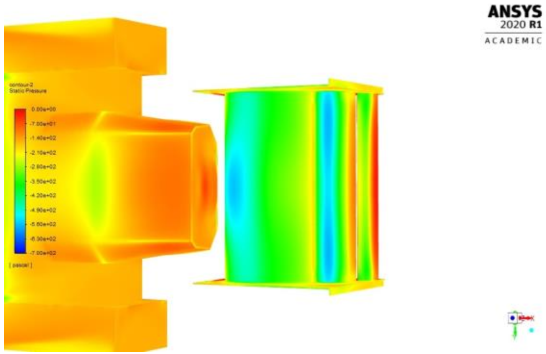


Rear Wing cont.

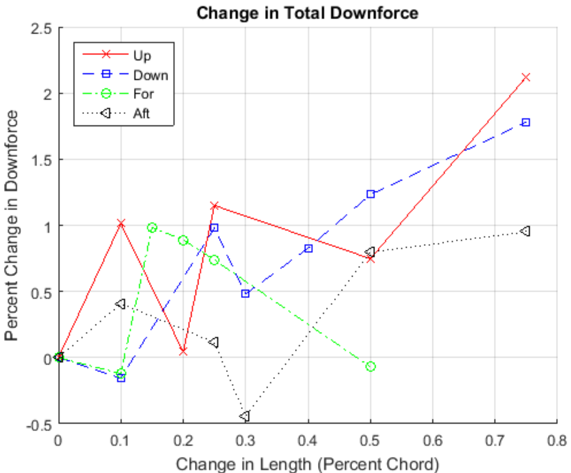
- As shown in the static pressure plots right, the upwash from the midwing lowers the effective AoA of the rear wing, reducing the downforce that is produced. The rearwing was further optimized in half car runs to mitigate this effect.
- An endplate sizing study has been conducted. Results are shown bottom right.
- Extending the rear endplates up and down both had significant effects on overall downforce.
- Extending the endplates up had the biggest effect on drag because the endplate tip vortices were reduced.

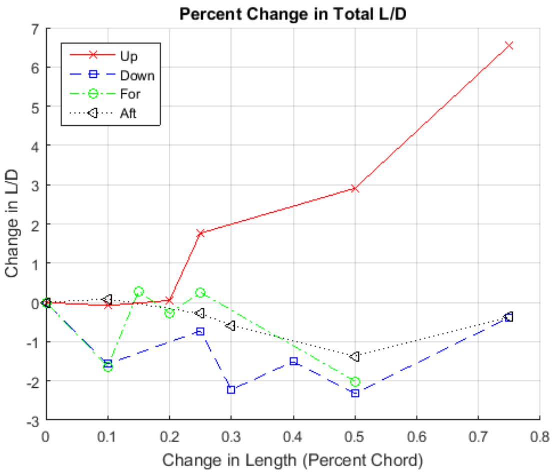


Midwing AoA: 5 degrees



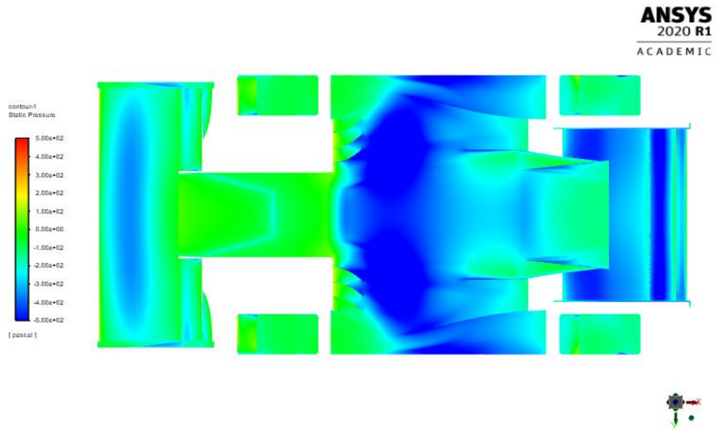
Midwing AoA: 13 degrees

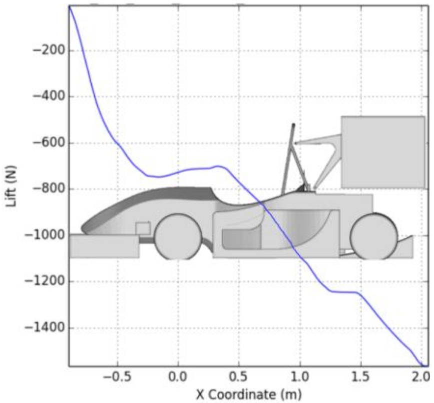


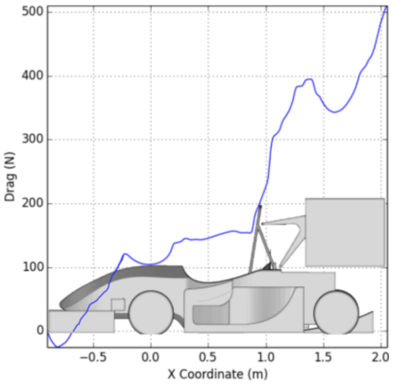


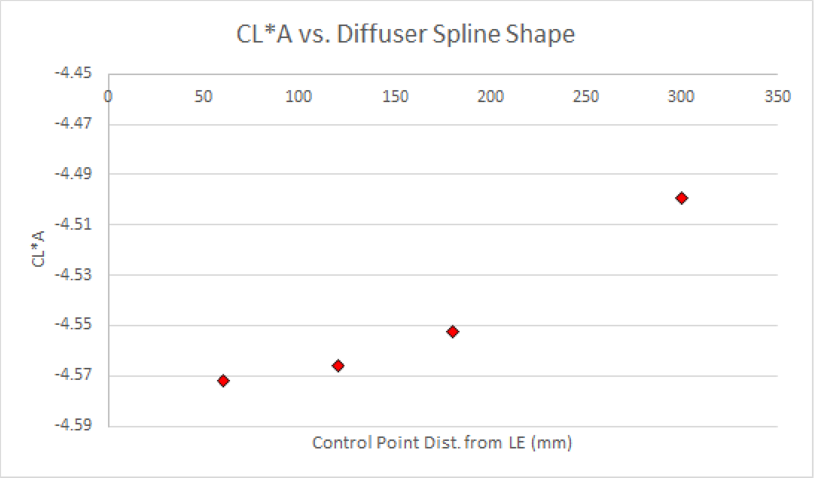
Diffuser Development

- The leading edge radius was optimized (shown bottom right). A diffuser with a sharper leading edge was selected. However, if the leading edge is too dramatic, the diffuser stalls.
- The lift and drag accumulation graphs show how efficient ground effect is. Lift is accumulated significantly along the floor, while the drag values remain relatively constant.
- Diffuser length was also optimized to strengthen the interaction between the rear wing and diffuser.

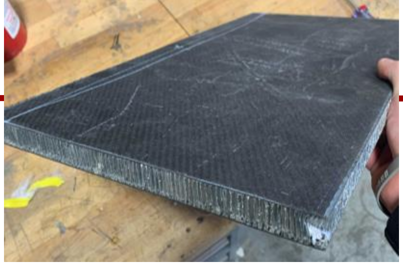
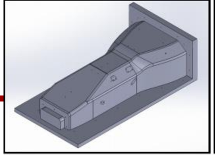
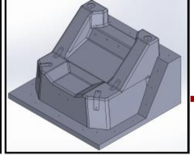
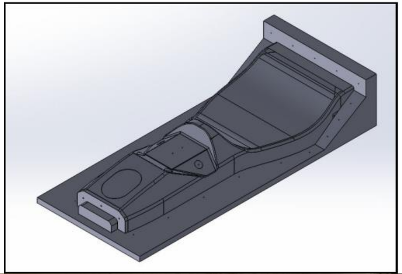
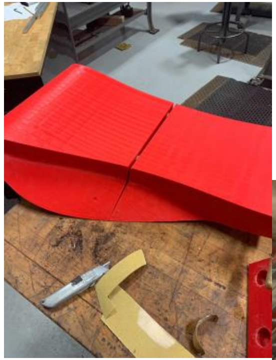








Manufacturing


- Chassis Build:
  - Alum honeycomb and Prepreg 2x2 twill Carbon Fiber
  - Cured for 5 hrs, with a 260 F soak at 80psi
  - 1 Piece mold for ease of manufacturing
- 3D Printed Molds/Bucks done In House
  - Rapid design and prototyping of geometries
  - Can go from CAD to part in ~3 days for most components
    - Design > Print > Paint > Layup
- Airfoils are 2x2 Twill or 3K Plain Weave Carbon
  - Bonded in female screws
    - Super easy to assemble
  - Inlayed nuts inside 3D printed pieces
  - Utilizing Wet/Room temp layups and resin infusion based on geometry and other complexity factors
  - In House waterjet allows for fast mounting solutions