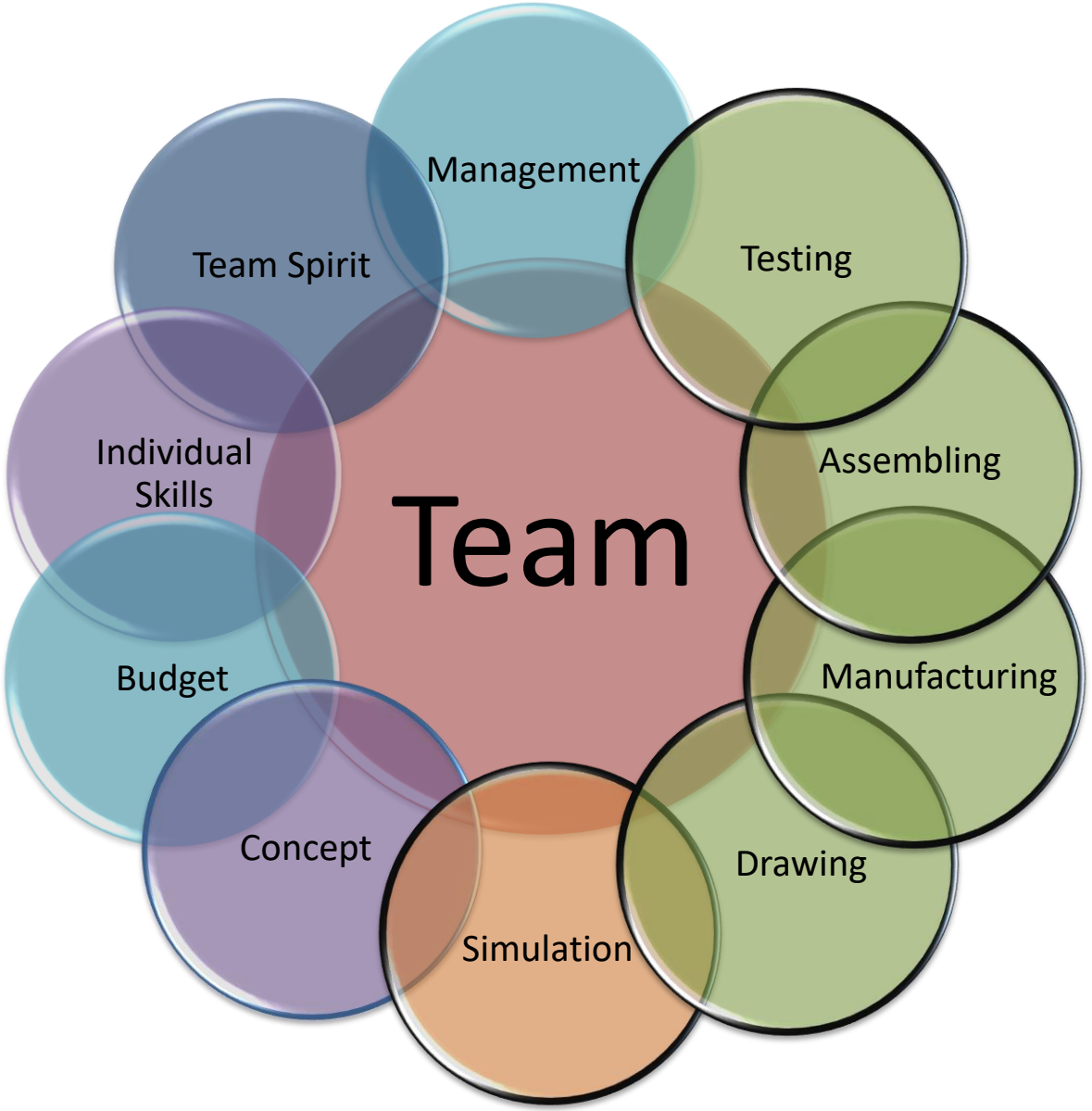
Formula Student Car Design Process

From concept to success, step by step tasks to design a competitive Formula Student car

Formula Student Team



Tips for New Teams

People > Machine

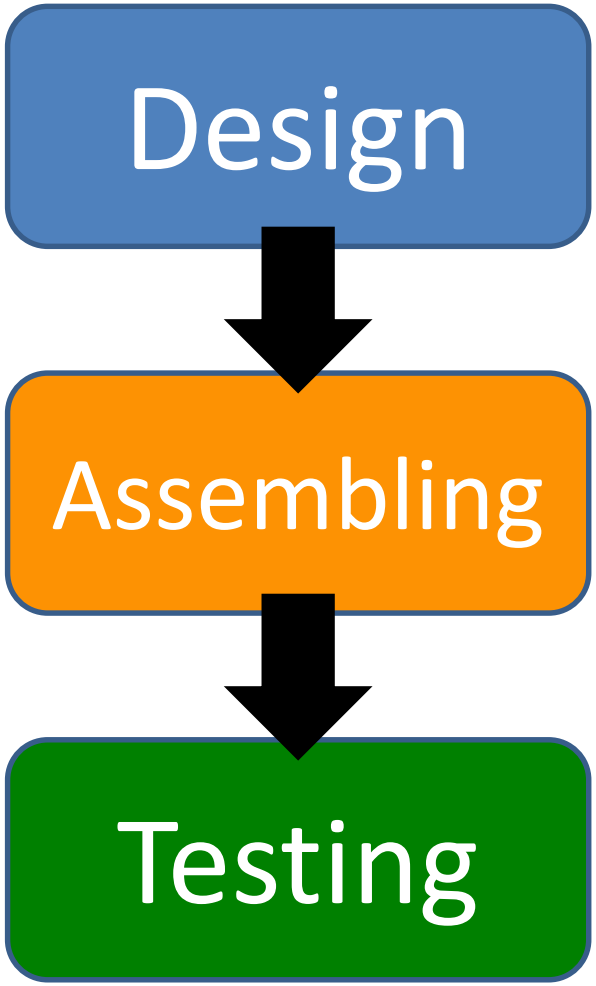
People > Money

Year 1:	*A*	*Team*	*C Car*
Year 2:	*A+*	*Team*	*B Car*
Year 3:	*A++*	*Team*	*A Car*

Tips for New Teams

- FS success ≠ well designed car
- FS success = 1. Team
  = 2. Project Management
  = 3. Engineering
- A good team and a well managed project are both based on *people*!

Year Schedule



4-5 months

1-2 months

4-6 months

Year Schedule

Design

- General Concept
- Specific Goals
- Interdependence between subsystems

Assembling

- Manufacturing
- Assembling

Testing

- Reliability
- Validation and Understanding
- Driver skills
- Performance Optimization

Goals

- You should define goals for all three phases. Your goals should be dependent on:
  - Culture
  - Experience
  - Team size
  - Leadership and organizational skills
  - Available tools
    - Workshop
    - Industrial partners
    - Software
    - Professors
  - Budget

Design Phase

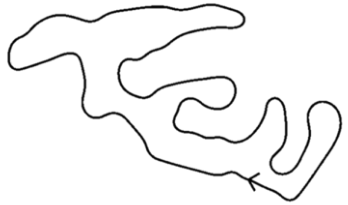
Initial Considerations

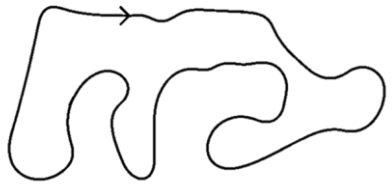
Before starting to design a new car, you should gather information/considerations from the following topics:

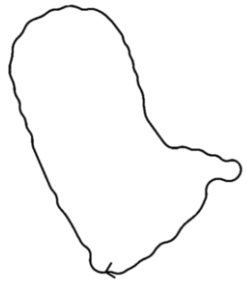
- Formula Student competition (rules, tracks, requirements, etc.)
- Previous cars
- Main problems and mistakes from previous years

Formula Student Competition

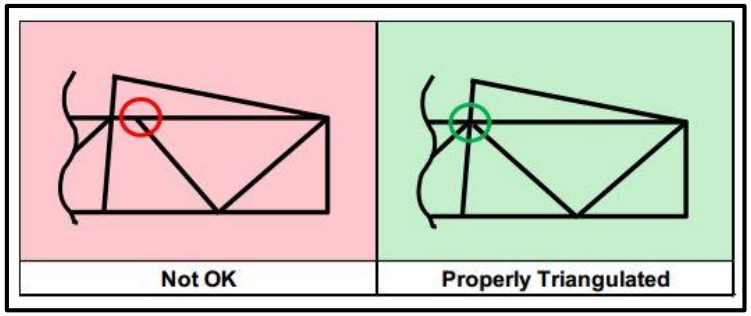
- **Rules**
- **Tracks**
  - **Speeds**
  - **Lateral and Longitudinal Sensitivity**
- **Competition**
  - **Performance**
  - **Access to data?**
  - **Access to older vehicles?**
- **What components do we have freedom with?**

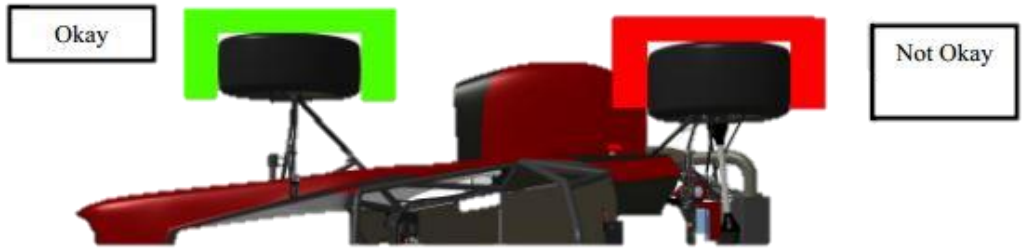






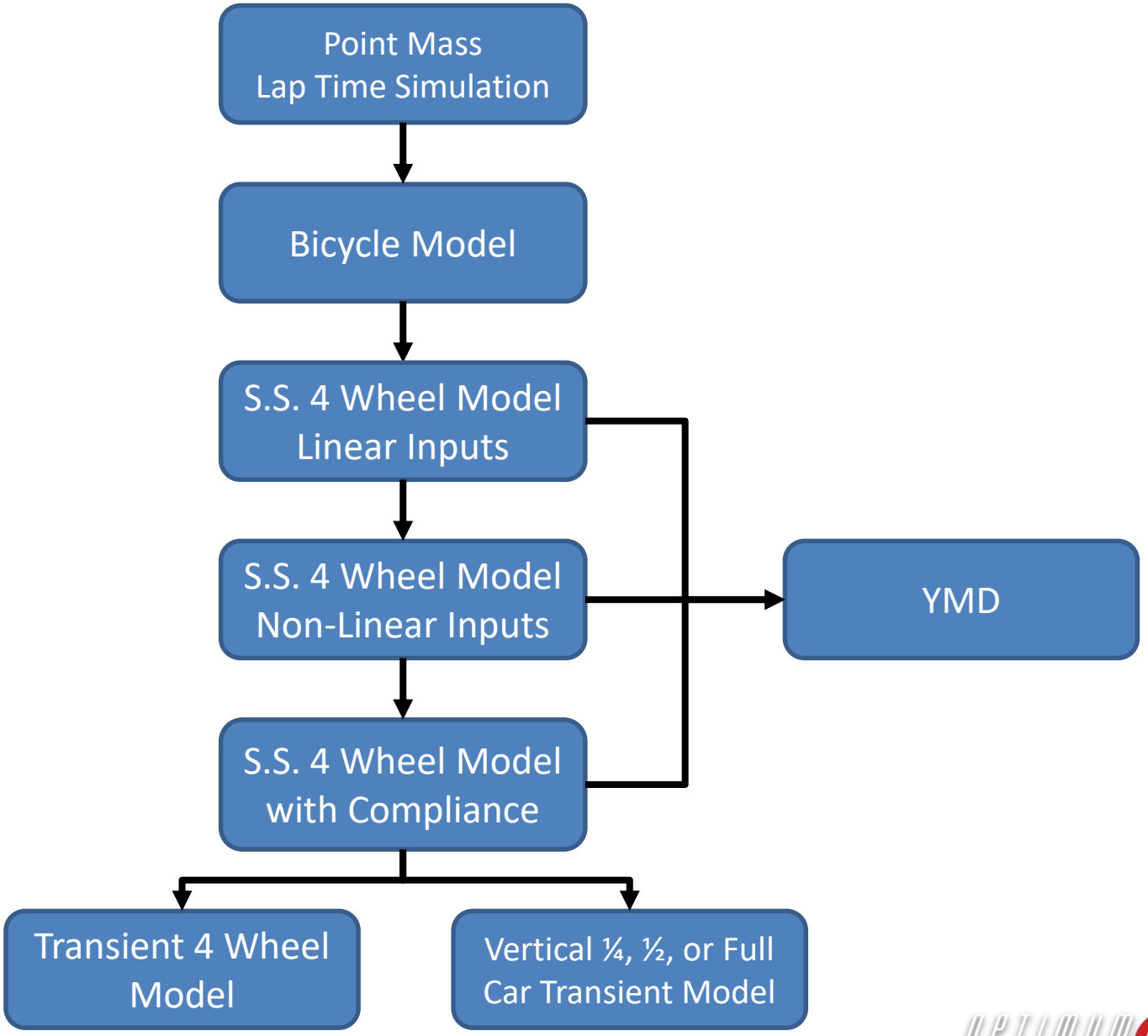
Rules





- The rules define the boundaries for your design
- Must be read completely by all team members
- The rules should be constantly revisited along the design process and along the year

Simulation Type Flowchart



Simulation

Before starting a specific simulation type, guarantee that you have all the necessary tools and information:

- The necessary software (commercial or self-made) and the knowledge on how to use it
- The necessary information from your design/car (examples: kinematics, aeromap, compliance from FEA or measurement)
- A clear list of the desired outputs and conclusions when performing a simulation

Point Mass - Lap Time Simulation

Inputs

- Mass
- Basic tire model
- Basic engine model
- Aerodynamic coefficients
- Transmission ratios
- Circuit

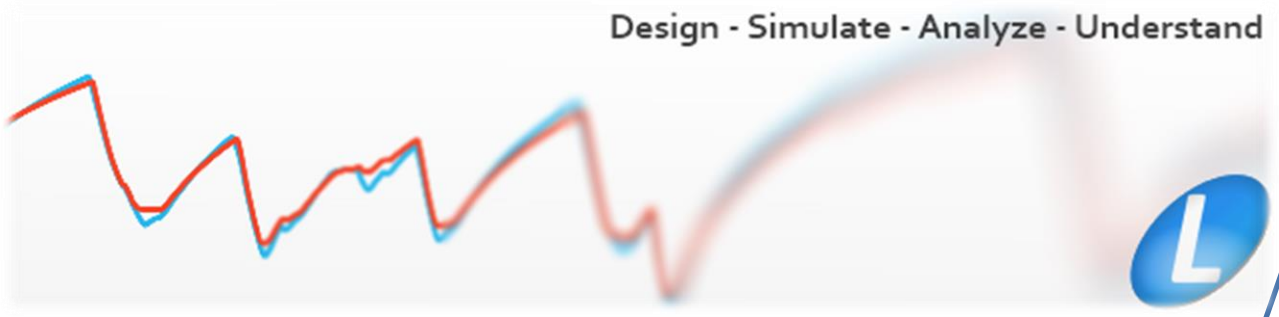
Outputs

- Lap time
- Speed/acceleration profile along the circuit
- Energy Consumption

Conclusions/Decisions

- Most important parameters among mass, grip, power, and aerodynamics
- Lap time sensitivity for each of the parameters
- Lateral/longitudinal grip sensitivity

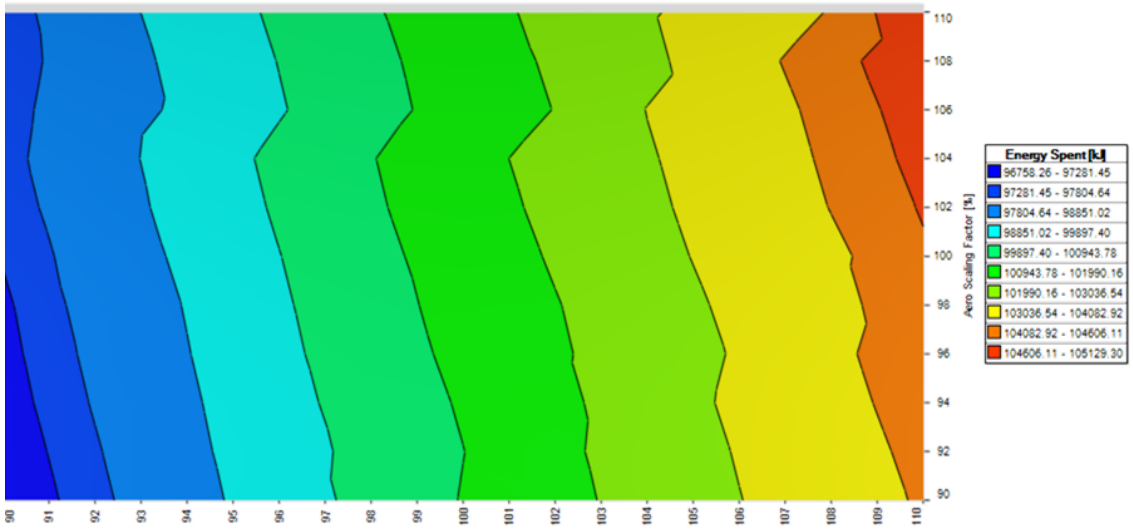
Point Mass - Lap Time Simulation



Point Mass Simulation

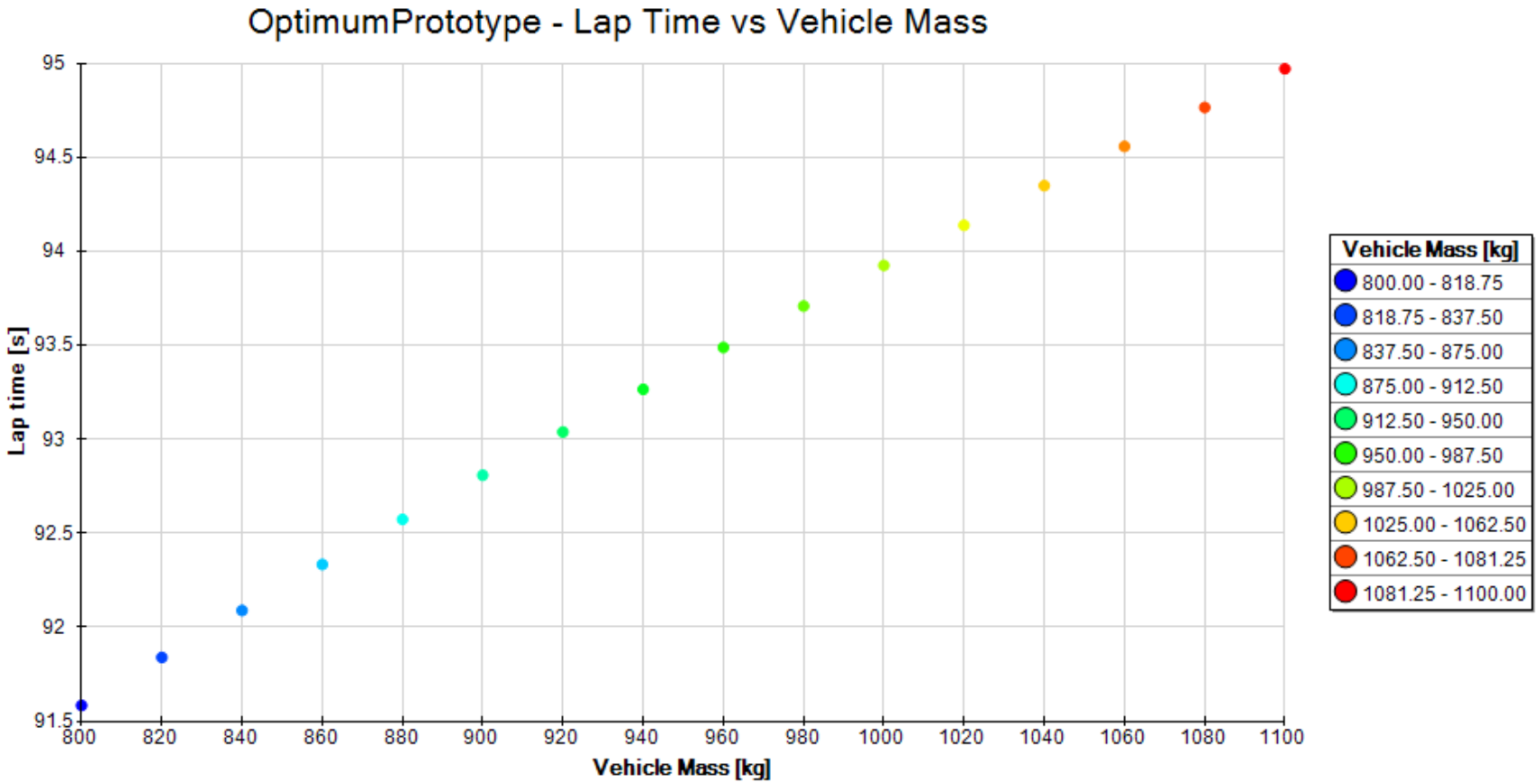
Sensitivities

- **Mass**
- **Grip**
- **Power**
- **Aero (Downforce and Drag)**
- **Energy Consumption**



Point Mass - Lap Time Simulation

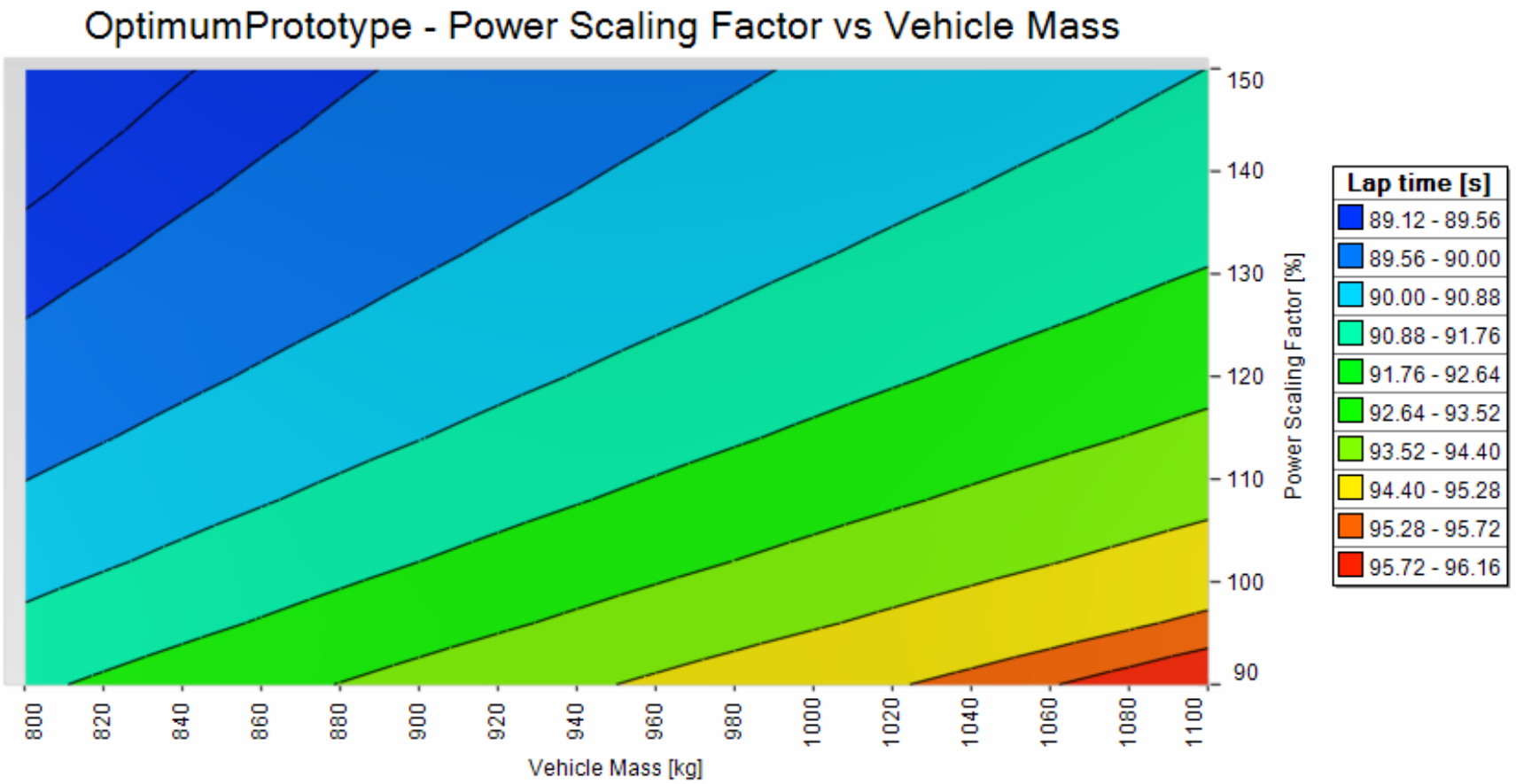
Mass Sweep



- How influent is mass reduction?
- What is our mass reduction limit?
- How much would it cost?

Point Mass - Lap Time Simulation

Mass and Power Sweep

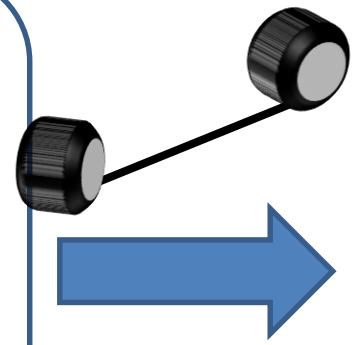


- What is more influent, mass or power?
- Where should we invest our money?

Bicycle Model - Steady State

Additional Inputs

- Wheelbase
- CG height
- Mass distribution
- Downforce distribution



Outputs

- Maximum lateral acceleration
- Balance metric
- Control & Stability metrics
- Longitudinal weight transfer
- Pitch
- Slip angle / slip ratio
- Sideslip angle

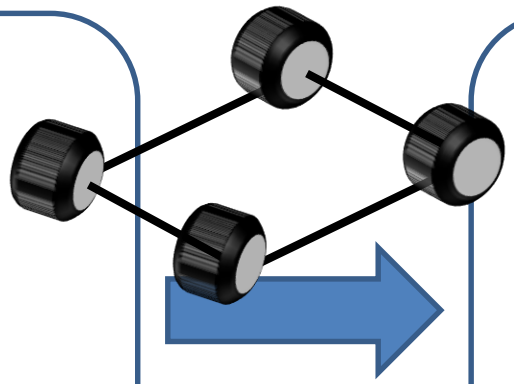
Conclusions/Decisions

- Match mass distribution, downforce distribution, and tire selection to achieve the desired car balance
- Understand how mass distribution, downforce distribution, and tire selection influences grip, balance, control, and stability

4 Wheel Model - Steady State

Additional Inputs

- Wheel Track
- Suspended and non-suspended mass
- Spring, ARB, and tire stiffness
- Static camber and toe
- Compliance (optional)



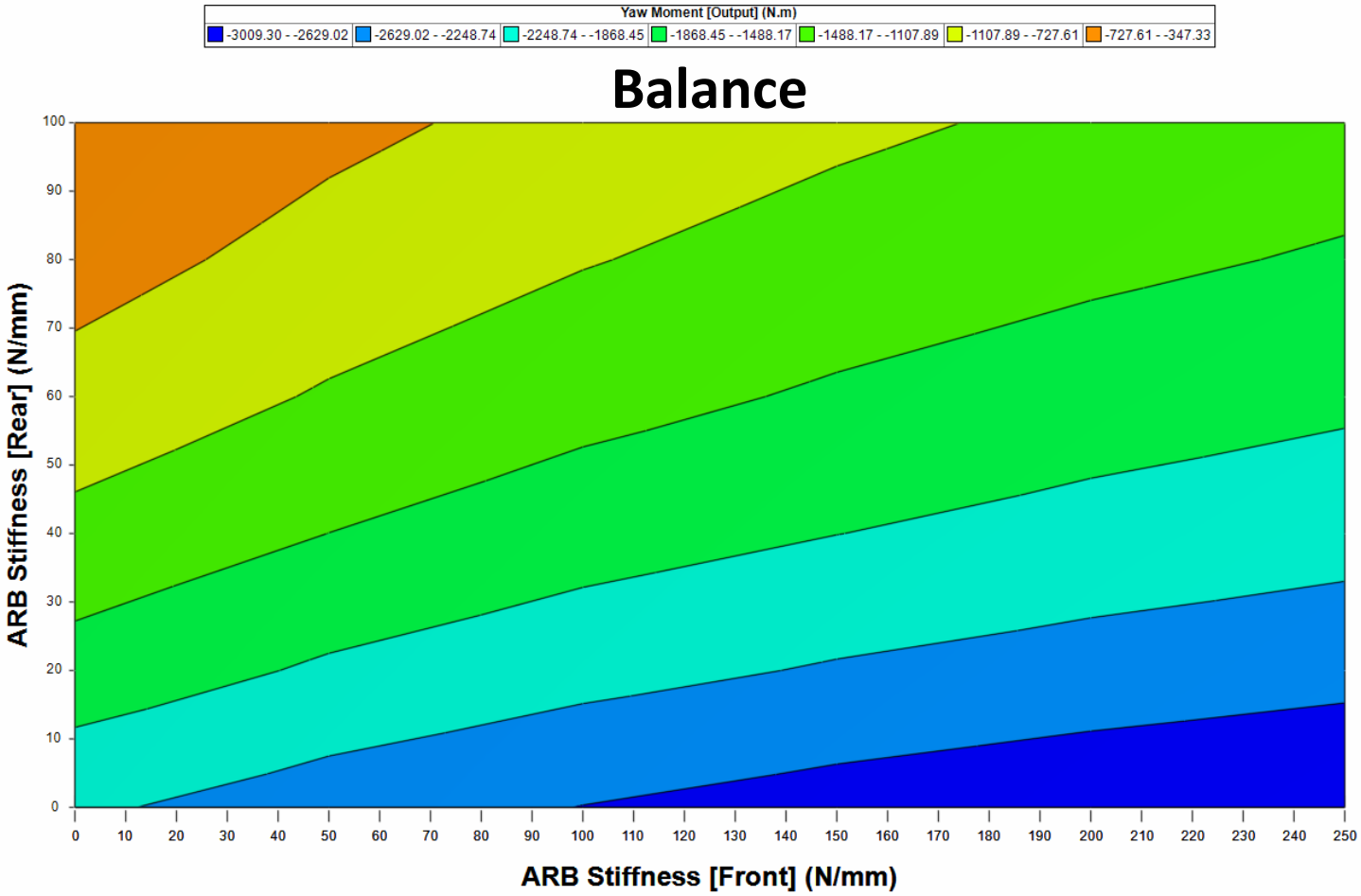
Outputs

- Lateral load transfer distribution
- Roll and pitch angles
- Lateral and longitudinal accelerations

Conclusions/Decisions

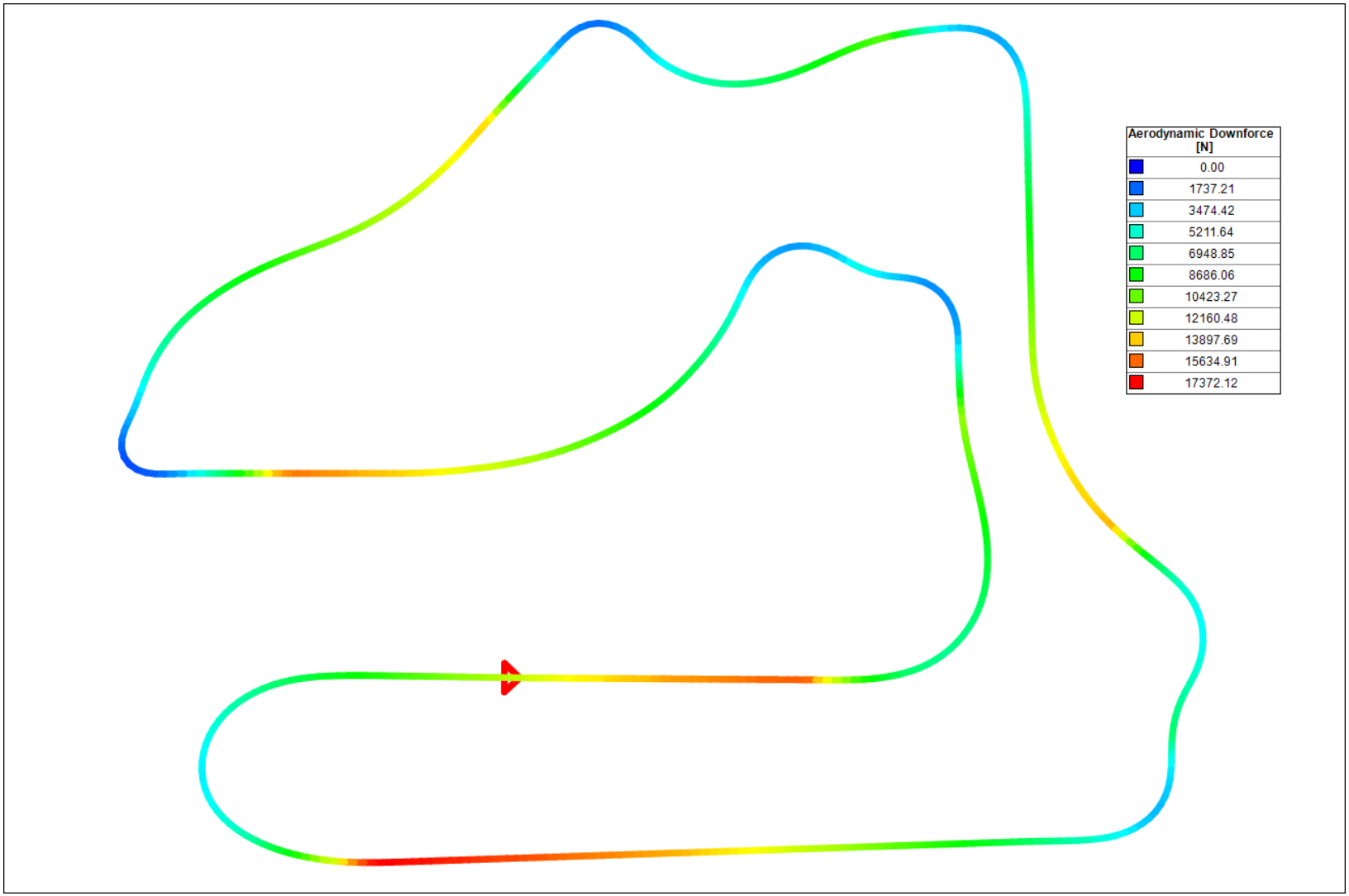
- Match spring, ARB, and tire stiffness to achieve the desired car balance with lateral load transfer distribution included
- Decide spring, ARB, and tire stiffness to provide the desired roll gradient

4 Wheel Model - Steady State



4 Wheel Model - Steady State

Downforce – Track Replay



Non-Linear Kinematics 4 Wheel Model

Additional Inputs

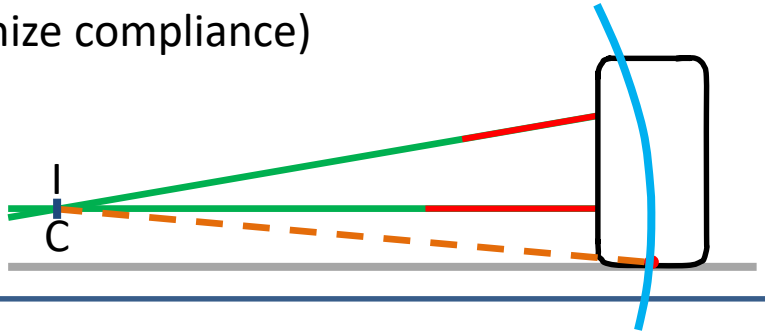
- Pickup points

Outputs

- Camber variation
- Toe variation
- Caster/kingpin variation
- VSAL (front and side view)
- Motion ratios
- Etc.

Conclusions/Decisions

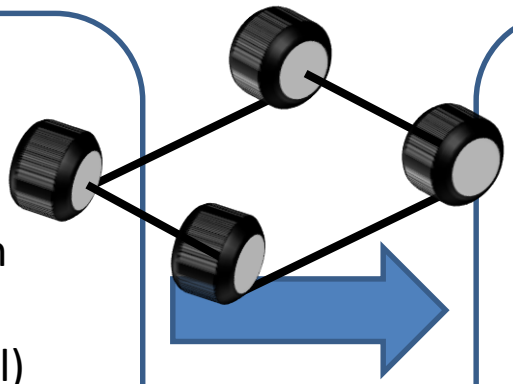
- Decide all pickup points of the suspension to provide the desired kinematic gains and motion ratios
- Iterate with chassis design to guarantee that all pickup points have enough support from chassis (minimize compliance)



Transient Bicycle / 4 Wheel Model

Additional Inputs

- Yaw inertia
- Damper curves
- Tire relaxation length (optional)
- Compliance (optional)



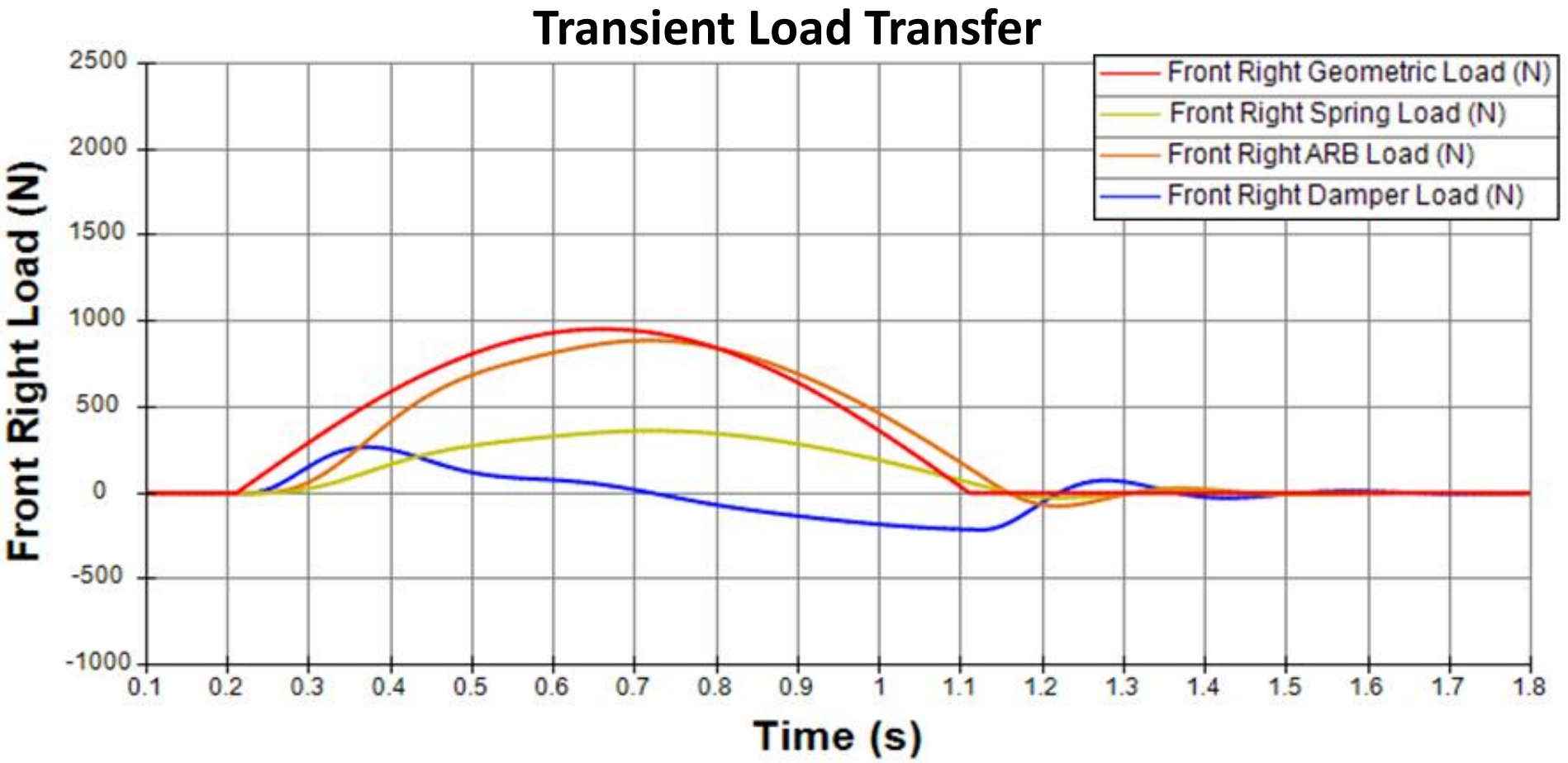
Outputs

- LART
- YART
- Yaw velocity damping
- Control and stability
- Transient roll and pitch behavior

Conclusions/Decisions

- Understand how different parameters influence the car transient response for lateral, longitudinal, and yaw accelerations
- Understand how the dampers are controlling roll and pitch

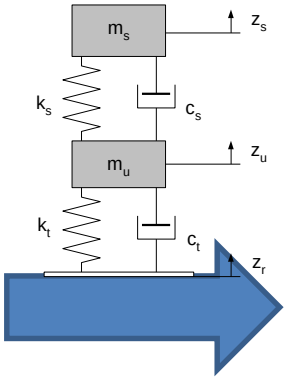
Transient 4 Wheel Model



Vertical ¼, ½, or Full Car Transient Model

Additional Inputs

- Tire damping (optional)

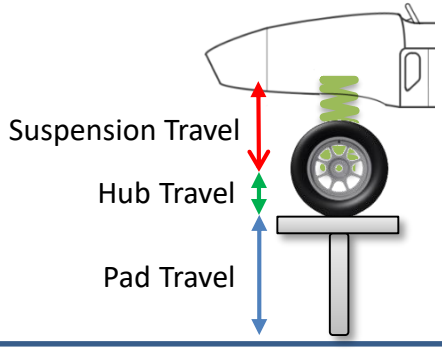


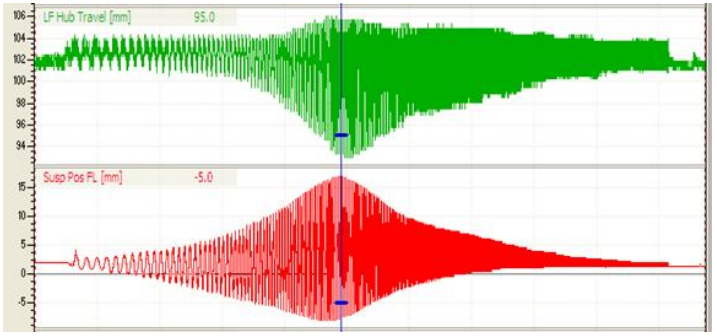
Outputs

- Transmissibility
- Load variation
- Heave/pitch coupling
- Damper speed histogram
- Body control

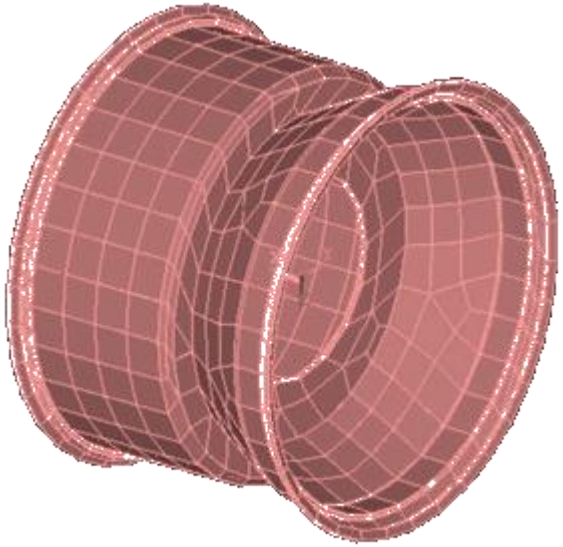
Conclusions/Decisions

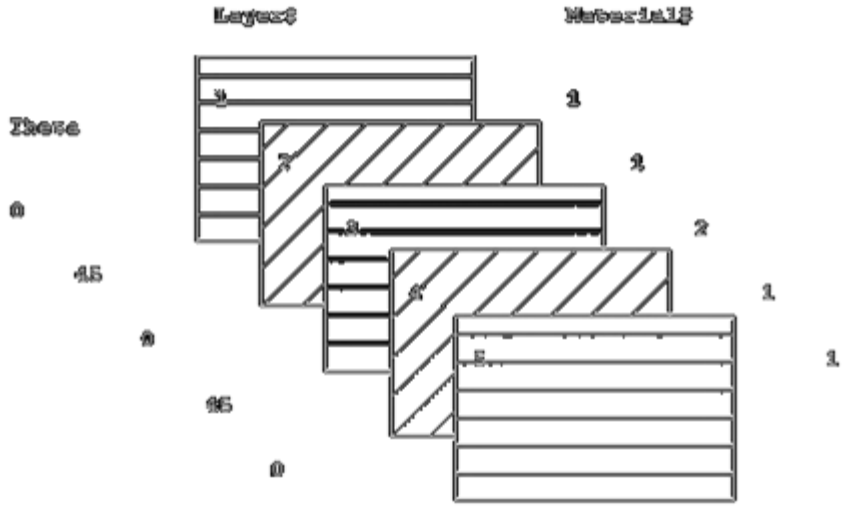
- Match spring, tire, and damper stiffness to achieve the desired body control, load variation, and ratio between suspension and tire compression.





CAD




Layers
Materials
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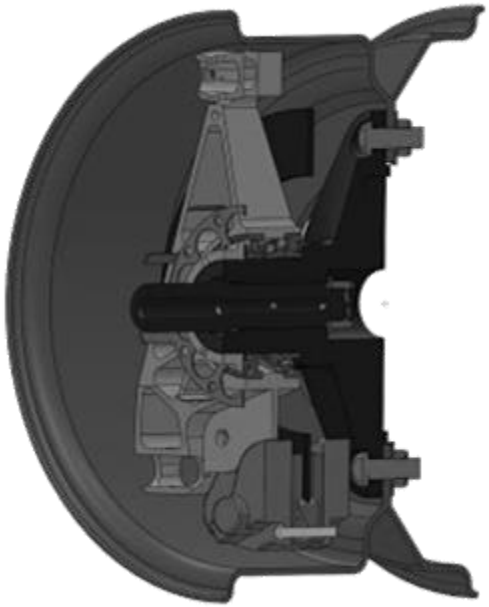
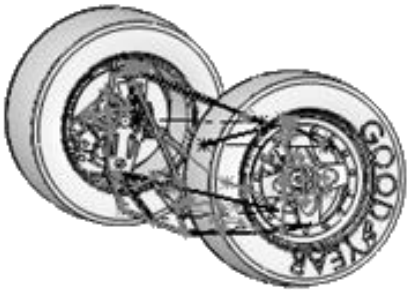
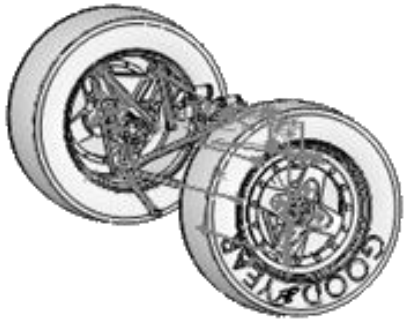



GOODYEAR


GOODYEAR

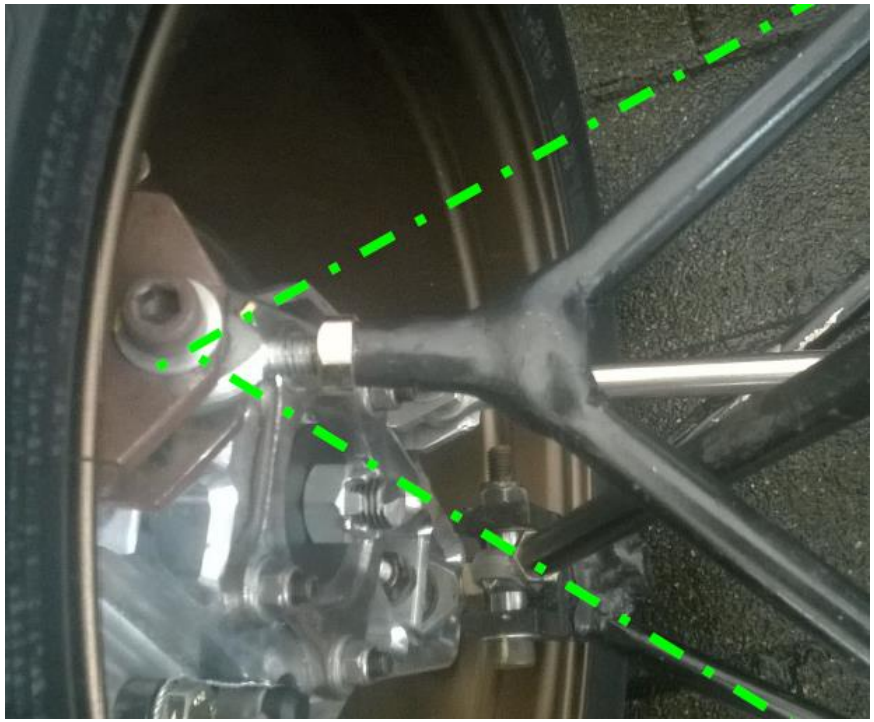
General Advice

General advice for a formula student car design:

- Low mass
- Low yaw inertia
- Low CG height
- Small car
- Low compliance
- Respect of engineering best practices (no rod end in bending, suspension linkage axis going through chassis node, etc.)

General Advice

Rod end in bending



Suspension linkage axis in the middle of a tube

Testing Phase

Testing Goals

- Reliability
- Validation and understanding of the car
- Driver training

- Performance optimization (setup)

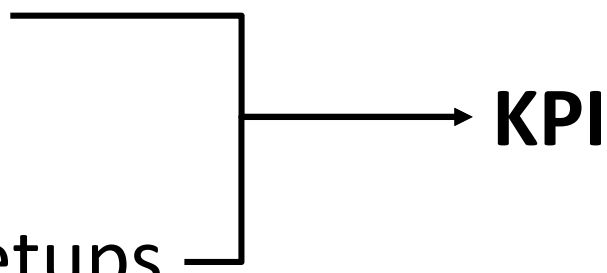
Testing

- Testing – phase with the highest potential for improvement of your car's performance
- Breaking – you will break things if you test enough
- Failure Analysis
- Repair

Data Acquisition

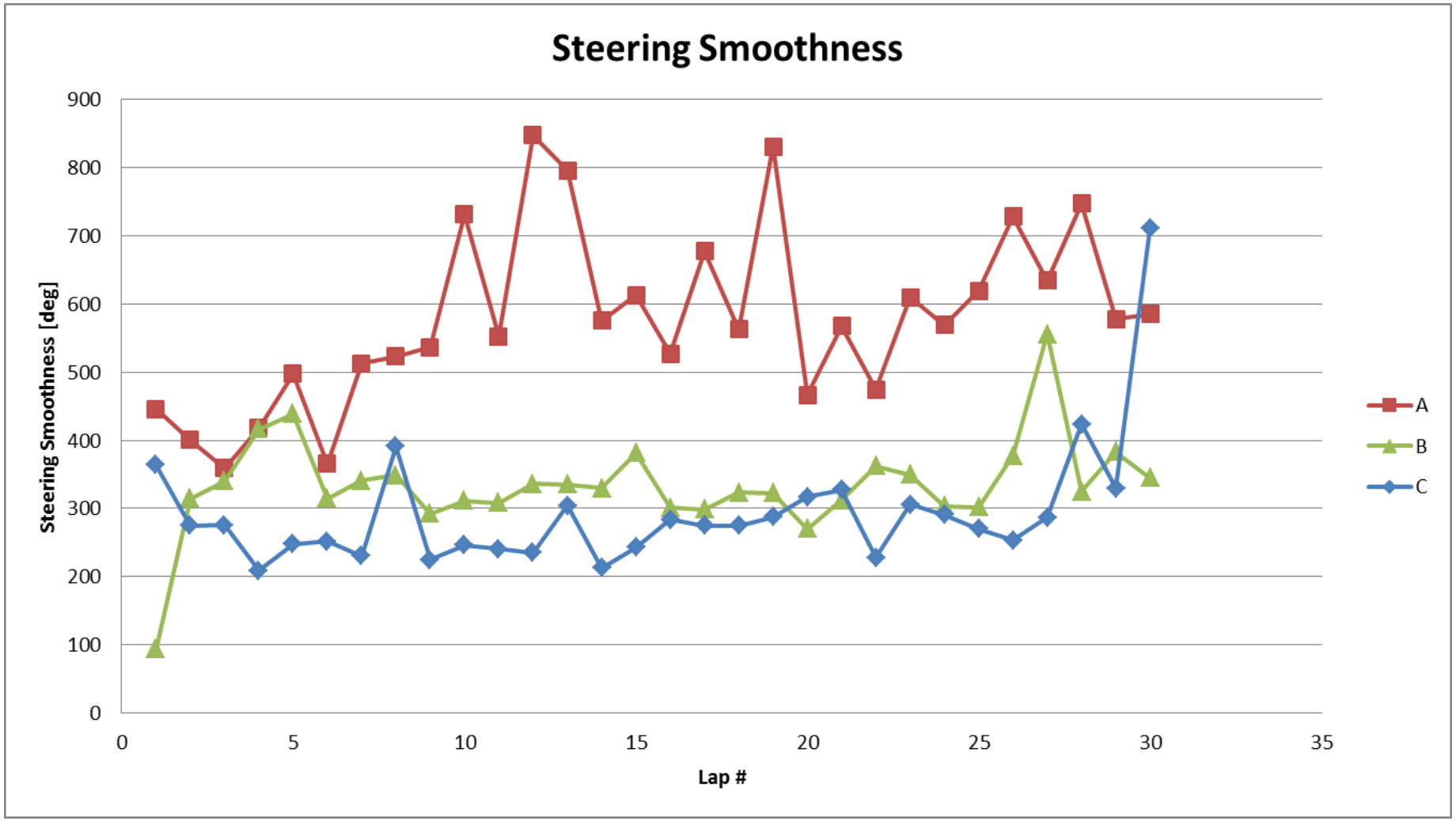
You should not only acquire the data, but use it to:

- Validate and correlate with simulations
- Understand your vehicle behavior
- Improve driver skills
- Compare different setups



Data Acquisition

KPI Example – Driver Comparison



Before Going to the Track

Using dummy dampers

Before Going to the Track

Using dummy dampers

1. Setup with dummy damper at designed eye-to-eye length
2. Install dummy dampers
3. Connect suspension linear (or rotary) potentiometer
4. Do your car setup
5. Zero suspension potentiometers
6. Remove dummy dampers
7. Put real spring and damper unit.
8. Reconnect suspension linear (or rotary) potentiometer
9. Turn spring platform to come back to same reference length read from the potentiometers

Before Going to the Track

Setup pad methodology

1. Is the chassis and suspensions straight? Symmetrical?
2. Install dummy dampers
3. Fuel and driver ballast.
   Same corner weights as without dummy dampers
4. Setup Tire @ hot pressure
   (unless dummy wheels are used)
5. Disconnect ARB
6. Min Shock setting
   (unless dummy dampers are used)
7. Adjust Ride Height
8. Adjust Caster
9. Adjust Camber
10. Adjust Toe
11. Make sure tire pressure are still on target
12. Go to 7
13. Adjust Corner Weight
14. Go to 7
15. Check Bump Steer using dummy dampers adjustments
16. Place damper and adjust length with spring platform until same as dummy dampers 's length (if using dummy dampers)
17. Reconnect ARB. Adjust ARB droop link length to get the same corner weight
18. Damper setting
18. Wings setting

Before Going to the Track

Know your car adjustments

Dummy damper length (mm)				Ride Height				Motion ratio				Corner weight (kg)				Toe (mm)				Caster (deg)				Camber (deg)			
LF	RF	LR	RR	LF	RF	LR	RR	LF	RF	LR	RR	LF	RF	LR	RR	LF	RF	LR	RR	LF	RF	LR	RR	LF	RF	LR	RR
245	245	305	305																								
250	250	305	305																								
255	255	305	305																								
260	260	305	305																								
265	265	305	305																								
270	270	305	305																								
275	275	305	305																								
280	280	305	305	42.5	42.5	79.0	79.0					50.0	50.0	55.0	55.0	-2.0	-2.0	1.0	1.0	6.7	6.7	4.9	4.9	-3.0	-3.0	-1.4	-1.4
285	285	305	305																								
290	290	305	305																								
295	295	305	305																								
300	300	305	305																								
305	305	305	305																								
310	310	305	305																								
315	315	305	305																								

- By filling up this sheet you will have a good idea of:
  - Motion Ratio
  - Camber variation in heave
  - Bump steer
  - Caster variation in heave
- It will help you to notice and trace any possible dissymmetry
- Be aware that these measurements do not take into account the tire and chassis compliance
- Worth to validate your kinematics software

Before Going to the Track

Check List

Steering	Yes	No	Comments
Wheel centered and secured			
Shaft to pinion bolt nut tight			
Rack mount bolts tight			
Rack end clevises tight and locked			
Rack length checked			
Track rod jam nuts tight			
Rack end clevis bolts tight			
Steering arm bolts tight			
Steering free lock to lock			
Rack roller adjustments locked			
Pinion hold down tight			
End play checked			

Front Suspension	Yes	No	Comments
Hub bearings checked for play			
Hub retaining bolts torque			
Upper and lower ball joints checked			
Upper and lower ball post nuts tight			
Upper wishbone attach bolts tight			
Lower wishbone attach bolts tight			
Upper and lower shock bolts tight			
Sway bar attach bolts tight			
Sway bar link bolts tight			
Sway bar centered			
Shocks adjusted in bump			
Shocks adjusted in rebound			
Spring locked			
Front wing adjusted			
Race tire mounted and pressure set			
Wheel nuts tight and double checked			

Front Brakes	Yes	No	Comments
New pad sign on steering wheel			
Race pads installed			
Caliper bolts tight and wired			
Discs centered			
Discs checked for cranks and run out			
Brakes bleed, bleeders tight and dry			
Seals and unions checked under pressure			
Master cylinder bolts tight			
Reservoirs full, caps tight, rag in place.			

Cockpit	Yes	No	Comments
Fire extinguisher charged, mounting tight			
Safety harness bolts secure			
Throttle cable attach to chassis and pedal secure.			
Throttle cable jam nuts secure			
Throttle stop adjusted and locked			
Clutch stop adjusted and locked			
Bias bar stop nuts locked, bearing free			
Master cylinder rods free, jam nuts locked			
Pedal bolts secure			
All instruments/switch lines secured and insulated			
Shift linkage adjusted, lubed and secured			
Mirrors adjusted and secure			
Seat secured and locked			

Electrical	Yes	No	Comments
Battery fully charged			
Battery connections secure and insulated			
Battery hold down secure			
Electric pumps functioning			
Tail/brake lights functioning and secure			

Rear suspension	Yes	No	Comments
Rear substructure attach bolts secure			
Ball joints checked for play, jam nuts tight			
Hub bearings checked for play			
Hub retaining bolts torque			
Upper and lower ball joints checked			
Upper and lower ball post nuts tight			
Upper wishbone attach bolts tight			
Lower wishbone attach bolts tight			
Upper and lower shock bolts tight			
Sway bar attach bolts tight			
Sway bar link bolts tight			
Sway bar centered			
Shocks adjusted in bump			
Shocks adjusted in rebound			
Spring locked.			
Front wing adjusted			
Race tire mounted and pressure set			
Wheel nuts tight and double checked			

Before Going to the Track

Setup Sheet

Sponsor BEST ***EXACT RACING***

SET UP NO. FINAL ISSUED ON: '########

EVENT	RACE	CIRCUIT	VANCOUVER			DATE	SEPTEMBER 1 ST 2000				
DRIVER	Mr DRIVER	LAP DIST	1.648			CHASSIS	T00/20-28	? miles			
DIFF	HEWLAND SALISBURY	ENG. NO / MILES	080	358	REV LIM 7390	FUEL	10 GALLONS				
PLATES	2 PLATES	M/C FRONT	Ft .750		Rr .750	RACK	6 TEETH				
RAMPS	45 / 80	DISCS	AP Solid	PADS	CM 93	RAD INLET	FULLY OPEN				
PRE-LOAD	none	BRAKE BIAS	T from full front								

RATIOS	1st	15 : 31	2nd	18 : 30	3rd	21 : 29	4 th	22 : 25	5th	23 : 24
					CWP	10 : 31				

FRONT WING

26.00 °					ANGLE	27.00 °					
out.	.750	.750	in	none	in	GURNEY	none		in.	.750	.750	out.
Ft			Rr			SKIRTS	Ft		Rr			

LEFT FRONT

TOE	.060	ins	OUT
CASTER	5.50 °	Trail	STD
CAMBER	- 3.50 °		
TIRE PRESS.	C 12.5	H	19.0
DUCTS	50 % open		

TILT 0.00				
Low RC	No antidive	GEOMETRY	Low RC	No antidive
	1.225 ins	RIDE HT	1.225 ins	
500 lb/in		SPRINGS	500 lb/in	
		ROLL BAR	.590	
fixed .250	**90** °	BLADE	.250 x .150	90 °

RIGHT FRONT

TOE	.060	ins	OUT
CASTER	5.50 °	Trail	STD
CAMBER	- 3.00 °		
TIRE PRESS.	C 13.5	H	19.0
DUCTS	50 % open		

X WEIGHT	

X WEIGHT	+20

FRONT SHOCKS

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 10 D14	5 deg	Std	**4.0**	a+	**-6.0**	C	**-0.5**	150

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 10 D14	5 deg	Std	**4.0**	A+	**-6.0**	C	**-0.5**	150

LEFT REAR

TOE	.120	ins	IN
CAMBER	- 2.20 °		
TIRE PRESS.	C 12.0	H	18.0
DUCTS	50 % open		

RAKE 0.725				
High RC	Antisquat	GEOMETRY	High RC	Antisquat
	1.950 ins	RIDE HT	1.950 ins	
800 lb/in		SPRINGS	800 lb/in	
Double Adjustable		ROLL BAR	x	
.350 x .250	**45** °	BLADE / ADJ	.350 x .250	**90** °

RIGHT REAR

TOE	.080	ins	IN
CAMBER	- 1.80 °		
TIRE PRESS.	C 12.0	H	18.0
DUCTS	50 % open		

REAR SHOCKS

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 16 L 2	5 deg	Std	**5.0**	B	**-6.0**	D	**-18**	180

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 16 L 2	5 deg	Std	**5.0**	B	**-6.0**	D	**-18**	180

REAR WING

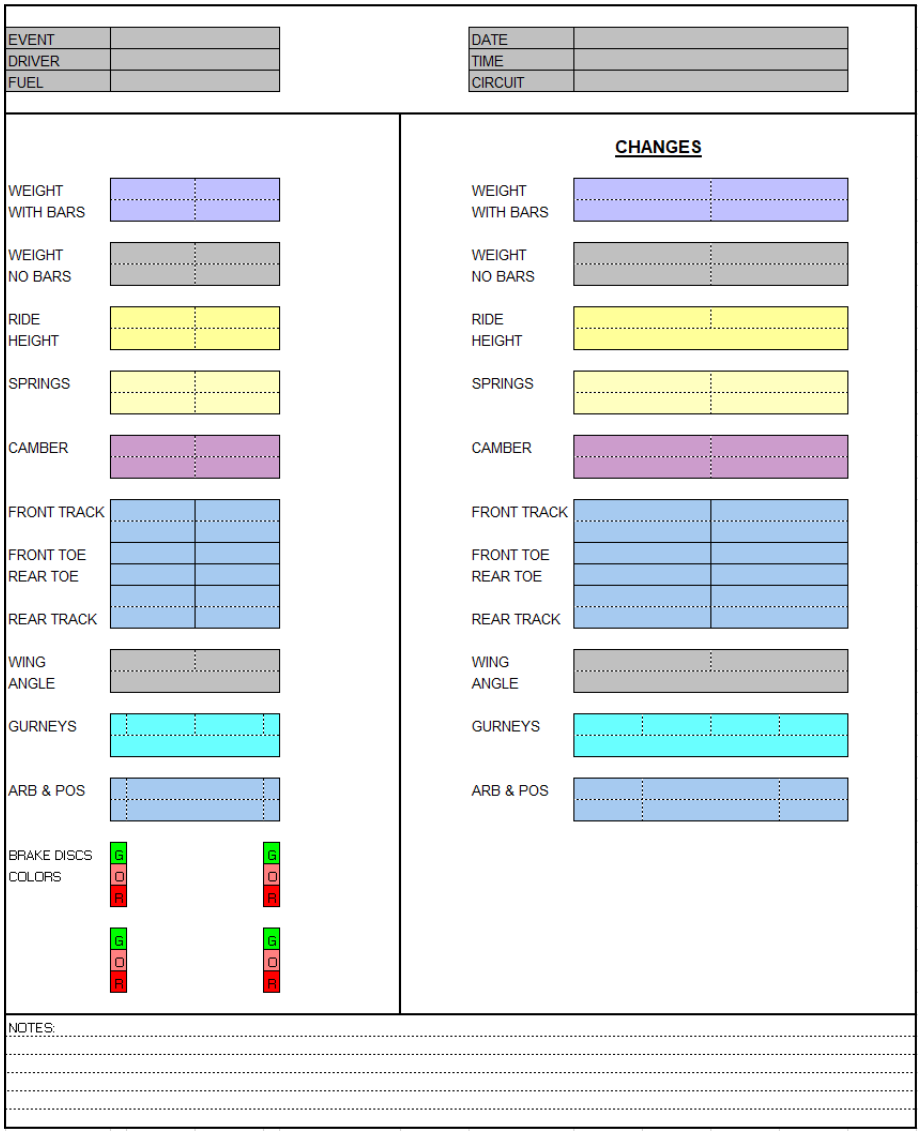
HOLE	HOLE 11
GURNEY	.875

MISCELLANEOUS NOTES

New FWEP

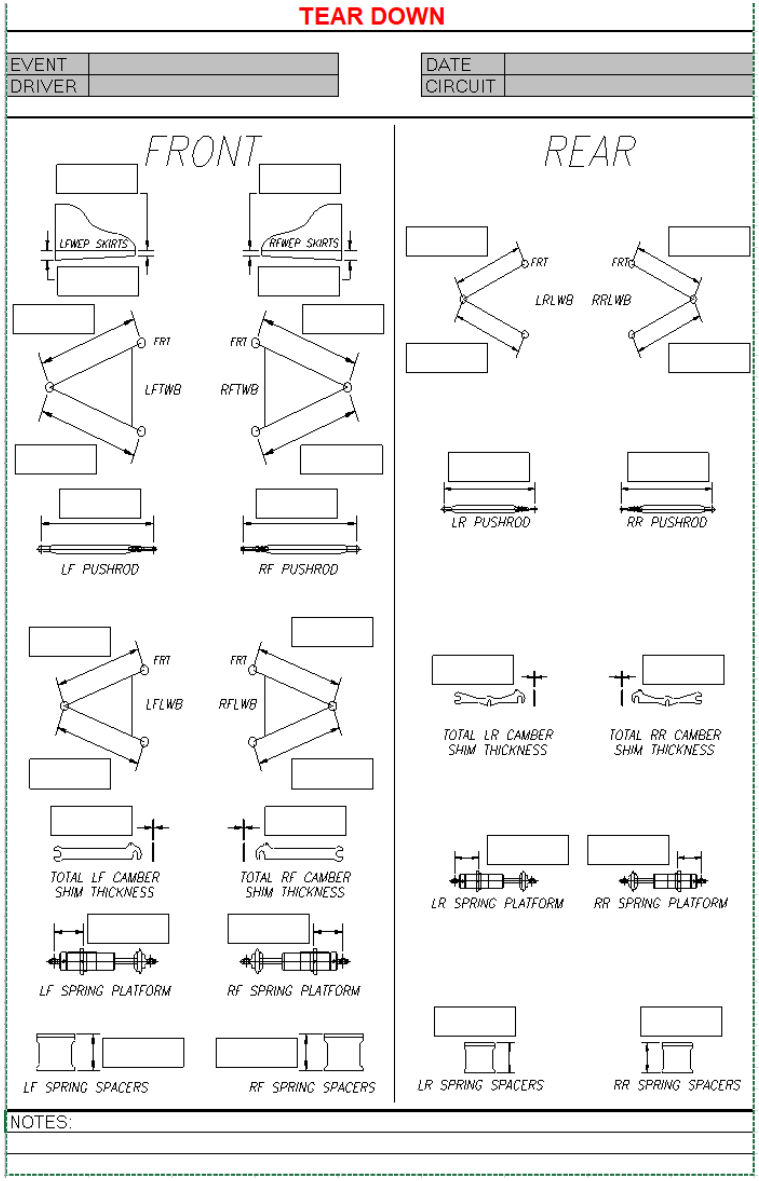
Before Going to the Track

Set Down



Before Going to the Track

Tear Down



On the Track

Setup

Suggested order of parameters to adjust and test on the track:

- Tire Pressure
- Ride Height
- Engine Tuning
- Brake Balance
- Camber/toe/caster
- Springs
- ARBs
- Damper
- Aerodynamics
- Differential
- Different pickup points
- …

Iterate!

Competing

Competing

- Study all documents provided by the competition organization ahead of time
- Develop a time plan for all activities during the competition days. Examples:
  - When and who is going to each event (design and business presentation, skid pad, acceleration, autocross, endurance)
  - When to setup the car for each event
- Leadership and organization are extremely important

Emotion is your #1 Enemy and #1 Friend

There is nothing wrong with being happy about good results.

There is nothing wrong with being sad about bad results.

There is nothing wrong with emotions. But don't let them influence your decisions, judgment and actions.

Dealing with Ups and Downs

Success

- Why did it work?

- Identify factors for success

- Celebrate

Failure

- Why didn't it work?

- Identify factors for failure

- Regroup and redefine

Suggested Video

WOT Films: Claude Rouelle, Advice for SAE Teams

https://youtu.be/c1n-rgqSTyY

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