Formula Student Car Design Process

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

- Design: 4-5 months
- Assembling: 1-2 months
- Testing: 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

Performance

Competition

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

- Point Mass Lap Time Simulation
  - Bicycle Model
    - S.S. 4 Wheel Model Linear Inputs
      - S.S. 4 Wheel Model Non-Linear Inputs
        - S.S. 4 Wheel Model with Compliance
          - Transient 4 Wheel Model
          - Vertical 1/4, 1/2, or Full Car Transient Model
          - YMD
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

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

Design - Simulate - Analyze - Understand
Point Mass - Lap Time Simulation

Mass Sweep

How influential 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

Balance

ARB Stiffness [Front] (N/mm) vs. Yaw Moment (Output) (N.m)
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

Transient Load Transfer

![Graph showing transient load transfer for different load types over time.](image)
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.

[Diagram showing suspension travel, hub travel, and pad travel]
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

KPI
Data Acquisition

KPI Example – Driver Comparison

Steering Smoothness

[Graph showing steering smoothness over laps for three drivers labeled A, B, and C]
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’ 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

<table>
<thead>
<tr>
<th>Dummy damper length (mm)</th>
<th>Ride Height</th>
<th>Motion ratio</th>
<th>Corner weight (kg)</th>
<th>Toe (mm)</th>
<th>Caster (deg)</th>
<th>Camber (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>RF</td>
<td>LR</td>
<td>RR</td>
<td>LF</td>
<td>RF</td>
<td>LR</td>
</tr>
<tr>
<td>245</td>
<td>245</td>
<td>305</td>
<td>305</td>
<td>250</td>
<td>250</td>
<td>305</td>
</tr>
</tbody>
</table>

- 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
# BeforeGoing to the Track

## Check List

### Steering
- 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
- 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 centering
- 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
- 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
- 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
- Battery fully charged
- Battery connections secure and insulated
- Battery hold down secure
- Electric pumps functioning
- Tail/brake lights functioning and secure

### Rear Suspension
- 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 centering
- 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

<table>
<thead>
<tr>
<th>EVENT</th>
<th>RACE</th>
<th>CIRCUIT</th>
<th>VANCOUVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVER</td>
<td>Mr DRIVER</td>
<td>LAP DIST</td>
<td>1.648</td>
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### EXACT RACING

<table>
<thead>
<tr>
<th>DIFF</th>
<th>HEWLAND SALISBURY</th>
<th>ENG. NO./MILES</th>
<th>080</th>
<th>356</th>
<th>REV LIM</th>
<th>7300</th>
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<tbody>
<tr>
<td>PLATES</td>
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<td>IPADS</td>
<td>CM</td>
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### Ratios

<table>
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<tr>
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<th>15</th>
<th>31</th>
<th>2nd</th>
<th>18</th>
<th>30</th>
<th>3rd</th>
<th>21</th>
<th>22</th>
<th>4th</th>
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<th>24</th>
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</tbody>
</table>

### Front Wing

<table>
<thead>
<tr>
<th>ANGLE</th>
<th>26.00°</th>
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<tbody>
<tr>
<td>out.</td>
<td>.750</td>
</tr>
<tr>
<td>in.</td>
<td>.750</td>
</tr>
</tbody>
</table>

### Left Front

<table>
<thead>
<tr>
<th>TOE</th>
<th>0.88 ins OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASTER</td>
<td>5.00°</td>
</tr>
<tr>
<td>CAMBER</td>
<td>-3.50°</td>
</tr>
<tr>
<td>TIRE PRESS.</td>
<td>C</td>
</tr>
<tr>
<td>DUCTS</td>
<td>50% open</td>
</tr>
</tbody>
</table>

### Right Front

<table>
<thead>
<tr>
<th>TOE</th>
<th>0.88 ins OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASTER</td>
<td>5.00°</td>
</tr>
<tr>
<td>CAMBER</td>
<td>-3.00°</td>
</tr>
<tr>
<td>TIRE PRESS.</td>
<td>C</td>
</tr>
<tr>
<td>DUCTS</td>
<td>50% open</td>
</tr>
</tbody>
</table>

### Rear Wing

| HOLE | .875 |

### Miscellaneous Notes

- New FWEP

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**Low RC**

**No anti-dive**

**No antidive**

**Low RC**

**No anti-dive**

---

**Rake**

| LFT | 0.725 |

### Rear Shocks

<table>
<thead>
<tr>
<th>Type</th>
<th>P D 10</th>
<th>D14</th>
<th>5 deg</th>
<th>Std</th>
<th>4.0</th>
<th>A+</th>
<th>-6.0</th>
<th>C</th>
<th>-0.5</th>
<th>150</th>
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</table>

### Front Shocks

<table>
<thead>
<tr>
<th>Type</th>
<th>P D 10</th>
<th>D14</th>
<th>5 deg</th>
<th>Std</th>
<th>4.0</th>
<th>A+</th>
<th>-6.0</th>
<th>C</th>
<th>-0.5</th>
<th>150</th>
</tr>
</thead>
</table>

### Rear Wing

| HOLE | HOLE | .755 |

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**Low RC**

**Angisquat**

**High RC**

**Antisquat**

**High RC**

**Antisquat**

---

**Rear Shocks**

<table>
<thead>
<tr>
<th>Type</th>
<th>P D 16</th>
<th>L2</th>
<th>5 deg</th>
<th>Std</th>
<th>5.0</th>
<th>B</th>
<th>-6.0</th>
<th>D</th>
<th>-18</th>
<th>180</th>
</tr>
</thead>
</table>

### Front Shocks

<table>
<thead>
<tr>
<th>Type</th>
<th>P D 16</th>
<th>L2</th>
<th>5 deg</th>
<th>Std</th>
<th>5.0</th>
<th>B</th>
<th>-6.0</th>
<th>D</th>
<th>-18</th>
<th>180</th>
</tr>
</thead>
</table>

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**MISCELLANEOUS NOTES**

- New FWEP
Before Going to the Track
Set Down

<table>
<thead>
<tr>
<th>EVENT</th>
<th>DATE</th>
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</thead>
<tbody>
<tr>
<td>DRIVER</td>
<td>TIME</td>
</tr>
<tr>
<td>KIUEL</td>
<td>CIRCUIT</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>WEIGHT WITH BARS</th>
<th>WEIGHT WITH BARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEIGHT NO BARS</td>
<td>WEIGHT NO BARS</td>
</tr>
<tr>
<td>RIDE HEIGHT</td>
<td>RIDE HEIGHT</td>
</tr>
<tr>
<td>SPRINGS</td>
<td>SPRINGS</td>
</tr>
<tr>
<td>CAMBER</td>
<td>CAMBER</td>
</tr>
<tr>
<td>FRONT TRACK</td>
<td>FRONT TRACK</td>
</tr>
<tr>
<td>FRONT TOE</td>
<td>FRONT TOE</td>
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<tr>
<td>REAR TOE</td>
<td>REAR TOE</td>
</tr>
<tr>
<td>REAR TRACK</td>
<td>REAR TRACK</td>
</tr>
<tr>
<td>WING ANGLE</td>
<td>WING ANGLE</td>
</tr>
<tr>
<td>GURNEYS</td>
<td>GURNEYS</td>
</tr>
<tr>
<td>ARB &amp; POS</td>
<td>ARB &amp; POS</td>
</tr>
</tbody>
</table>

| CHANGES | \_ | \_ | \_ | \_ | \_ |
| WEIGHT WITH BARS | \_ | \_ | \_ | \_ | \_ |
| WEIGHT NO BARS   | \_ | \_ | \_ | \_ | \_ |
| RIDE HEIGHT      | \_ | \_ | \_ | \_ | \_ |
| SPRINGS          | \_ | \_ | \_ | \_ | \_ |
| CAMBER           | \_ | \_ | \_ | \_ | \_ |
| FRONT TRACK      | \_ | \_ | \_ | \_ | \_ |
| FRONT TOE        | \_ | \_ | \_ | \_ | \_ |
| REAR TOE         | \_ | \_ | \_ | \_ | \_ |
| REAR TRACK       | \_ | \_ | \_ | \_ | \_ |
| WING ANGLE       | \_ | \_ | \_ | \_ | \_ |
| GURNEYS          | \_ | \_ | \_ | \_ | \_ |
| ARB & POS        | \_ | \_ | \_ | \_ | \_ |

<table>
<thead>
<tr>
<th>NOTES</th>
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<td>_</td>
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Before Going to the Track

Tear Down

<table>
<thead>
<tr>
<th>EVENT</th>
<th>DRIVER</th>
<th>DATE</th>
<th>CIRCUIT</th>
</tr>
</thead>
</table>

**Tear Down**

**Front**

- **Front Left Shock**: 
- **Front Right Shock**: 
- **Front Left Wheel Hub**: 
- **Front Right Wheel Hub**: 
- **Front Left Pushrod**: 
- **Front Right Pushrod**: 
- **Total Front Camber Shim Thickness**: 
- **Front Left Spring Platform**: 
- **Front Right Spring Platform**: 
- **Front Left Spring Spacers**: 
- **Front Right Spring Spacers**: 

**Rear**

- **Rear Left Shock**: 
- **Rear Right Shock**: 
- **Rear Left Wheel Hub**: 
- **Rear Right Wheel Hub**: 
- **Total Rear Camber Shim Thickness**: 
- **Rear Left Pushrod**: 
- **Rear Right Pushrod**: 
- **Total Rear Camber Shim Thickness**: 
- **Rear Left Spring Platform**: 
- **Rear Right Spring Platform**: 
- **Rear Left Spring Spacers**: 
- **Rear Right Spring Spacers**: 

**Notes:**

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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
Thank you!

Claude Rouelle
Founder and President

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