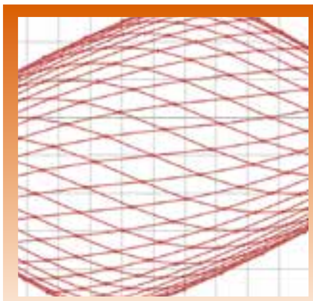

Slip Angle provides a summary of OptimumG's seminars

Formula Student 101

Building a Formula Student car? Then you need to read OptimumG engineer Claude Rouelle's 101 top tips for teams chasing FS glory. In Part 1 of this new mini-series he runs through his first 25 points

It's a mistake to study successful Formula Student cars before you start your design process; it could cramp your creativity

Besides his leading role at vehicle dynamics consultancy OptimumG, Claude Rouelle often offers his services as a design judge in many Formula Student competitions.

Rouelle started his 40-year racecar engineering career by designing and building a racecar and a wind tunnel. It was his engineering degree master thesis. The challenges he faced then were quite similar to those faced today by students building a first racecar. In this new mini-series Rouelle offers some advice on engineering and team building for Formula Student teams; though many of these tips are also applicable to professional race teams.

1. To finish first you must first finish. Think reliability before you think performance.

2. Accuracy, relevance, usefulness, meaningfulness, repeatability are five words that should be part of your everyday engineering vocabulary.

3. There are two rules with software use. Rule 1: You cannot make the software work unless you read the user manual/help file (and, ideally, some good case studies) from start to finish. Rule 2: Nobody reads the user manual. The same goes for the little sensor spec sheet.

4. The best way to predict the future is to look at the past. Often the best simulation and performance predictions are provided by the exploitation of previous data collected during previous races and on-track or in-labs tests.

5. There are three main goals you need to always keep in mind during your Formula Student concept phase: minimum weight, lowest centre of gravity, minimum yaw inertia.

6. A low inertia goes against stability but helps with control. The low limit of stability is mainly dependent on driver skills and speed. The reality is that inertia is always too big on a Formula Student car. Want proof? Look at the low mass and shorter wheelbase in karts. Besides, the best way to make a light car is to make a short car. I do not see any reason why you would not build a Formula Student car at the minimum legal wheelbase. Ergonomic and short cars are possible. I have seen many Formula Student cars with the minimum wheelbase

A low inertia goes against stability but it does help with control

where a 1.8m 90-kilo driver can easily sit and comfortably drive the car.

7. Ergonomics is fundamental. It plays a huge roll in the driver's ability to feel and control the car. Head, shoulder, ribs, hips, side, legs, heels, support is too often neglected. If, when you turn the steering wheel 180 degrees, the driver's hands rub his legs, or his elbows hit the chassis, he won't be able to get the most out of the racecar. You wear a cockpit like you wear a suit. A wood mock-up cockpit tested by your drivers will teach you more than any CAD software with dummy drivers.

8. If your steering torque is more than 5Nm, you will need to hire Arnold Schwarzenegger to drive your racecar. As a reference, most passenger car steering torques are in the 3Nm region. It is a pity that the majority of Formula Student teams do not simulate or measure the steering torque.

9. When you go to a job interview, you need to dress for the job you want, not the job you have. Same for design. Flip flops and dirty T-shirts are not the best clothes to impress design judges.

10. The gods of mechanical engineering are never with you. Mistakes keep being added to each other, and they do not cancel each other out. You must remove phrases such as 'this compensates for that' from your brain.

11. There are some numbers you should naturally know by heart, not because you memorised them but simply because you played with them so often: weight distribution, anti-roll stiffness distribution, wheelbases, tracks, motion ratio, damping ratio range, etc. If you must look for this kind of basic information in your binder during a conversation with a design judge, it sends a signal that you are not in control of your work.

12. In terms of project management, you must think about your racecar concept, simulation, drawing, machining, and assembly as an aeroplane that must land. If you keep flying your plane and run out of fuel, you crash. Similarly, a fantastic car design that is not finished on time won't help you. There must either be a dictator or a common agreement to have each car part finished on time. Winning starts at the workshop with on-time and on-target design achievements.

13. It is possible to create a car that is both stiff and light. The best way to achieve this is to keep in mind the lessons of Darwin: Form *follows* function. First, function and second, form, not the other way around.

14. Start any new Formula Student project with two separate brainstorming sessions that answer these simple questions; what makes a great team and what makes a great car. Make the wildest dream list of what defines an ideal team and a perfect car. Then, and only then, be reasonable and choose the goals that are within your team's means.

The three main goals you need to keep in mind during your Formula Student project's concept phase are keeping the car weight to a minimum, with the lowest possible centre of gravity and minimal yaw inertia

Cockpit ergonomics are a crucial part of the Formula Student design process. Your driver must be able to feel and control the racecar properly and it is important that no part of the chassis restricts movement

I do not see any reason why you would not build a Formula Student car at the minimum legal wheelbase

If you don't know why you win, you won't know why you lose

15. The worst thing that you could do when you start to design a Formula Student car is to look at other existing car pictures or videos on the Internet. Do not let pictures of other racecars influence you. Looking at other cars restricts your creativity and your ability to think function then form. Once your car has been designed, *then, and only then*, look at other racecar pictures, and if necessary, modify your own drawings.

16. You need to think SMART goals, an acronym that stands for Specific, Measurable, Attainable, Relevant, and Time-bound.

17. If you don't know your strengths, you don't know your weaknesses. You get your car out of the truck and you are the quickest all weekend. Good. Then two weeks later, conditions are different: it rains, or the circuit is bumpier. You get lost. If you do not know *why* your car was that good two weeks ago, you won't know *how* to fix it when it under performs. To put it another way; if you don't know why you win, you won't know why you lose.

18. A design judge will be expecting you to demonstrate how you chose your suspension rod ends and tube sizes, hub and upright shape and material, etc. with load case studies from tyre to chassis starting with simplified tyre load in longitudinal acceleration (braking and acceleration), lateral acceleration (cornering), vertical load and acceleration (mass, weight transfer, aerodynamic forces and moment, and bumps), and then a combination or all of any of these, and finally with track replay. Without this, you take the risk that any designed part will be either over engineered (too heavy) or under engineered (too weak).

A common error with Formula Student teams is not simulating or measuring steering torque, making the car hard to drive on the handling tests. This needs to be no more than 5Nm; road cars are around 3Nm

All parts need to be lightweight and the only part that is too light is the one that breaks. You need to figure this out with intelligent design and FEA. Go lighter until it breaks and then go one step back

19. Formula Student teams cannot use the same safety factors as in the passenger car industry. Do not compare cars that are run 2000km a year (for the most organised team running several competitions) and cars that are supposed to be reliable without any major issue for 100,000km.

20. There is only one definition of a 'too light' part: that's when it breaks. Do the best you can with intelligent design and FEA. Go lighter until it breaks, then go one step backwards.

21. You need to look at your racecar assembly as well as each car part and wonder 'if something breaks, what will it be?' If you know the answer and you don't do anything about it, that is just insanity, because there is a great chance that once you are on the race track that part will break. Analysis. Awareness. Communication. Action.

22. If something broke on your car and you do not do anything about it because you do not know why it broke, there is a big chance that part will break again. Worse, if you know why that part broke and you don't do anything about it, that is laziness.

23. Not having a Plan B, and ideally a Plan C, for any car part failure during its development phase demonstrates a lack of either imagination, objectivity, or preparation. Example: you test your new racecar and after a few laps, your front wheel hub breaks. You will now do a failure analysis, redesign, reordering the material if you do not have it in stock, re-machining … You could lose several weeks during which your engine and your aero are not developed. Now, imagine having a Plan B: you can mount last year's uprights on the new car. During that time, you can at least continue the other car parts' reliability tests.

24. Einstein said that 'Intelligence is the ability to find a solution to a problem you never encountered before. Insanity is doing the same thing over and over again and expecting different results.' I am also convinced that the biggest thing that slows down our ability to develop our intelligence is our inability to control our emotions. Control, not suppress.

25. 'We cannot solve our problems with the same thinking we used when we created them' (again Einstein). No more comment needed.

Next month: *Don't miss points 26 to 50*

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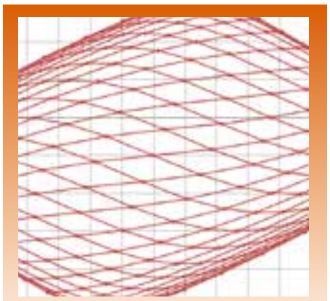


Slip Angle provides a summary of OptimumG's seminars

Formula Student 101

OptimumG engineer Claude Rouelle's 101 top tips for Formula Student teams continues with some thoughts on dampers, chassis rigidity, and even finding sponsorship for your FS project

Formula Student is really a project management and engineering design competition based on a racecar, rather than a true motorsport discipline

Besides his leading role at renowned vehicle dynamics consultancy OptimumG, Claude Rouelle also offers his services as a design judge in Formula Student competitions. Which means he's well-placed to advise those looking to take part in Formula Student events …

26. Let's start off where we finished last month, with a quote from Albert Einstein: 'We cannot solve our problems with the same thinking we used when we created them'. No more comment needed here.

27. There are two kinds of people: People who win and people who make excuses. Choose what kind of person you want to be.

28. What makes a car perform is tyre grip. The first thing that influences a race tyre's grip is its temperature. The first thing that influences tyre temperature is damping. Sometimes an over-damped car makes the car half a second slower because it is more difficult to drive, yet one second faster because you can generate more lateral and longitudinal accelerations.

29. The ideal damping in heave is not the ideal damping in roll and pitch. In heave, the dampers control the chassis movement and the tyre deflection against the forces acting on suspended and non-suspended masses. In roll, the springs and the anti-roll bars control the chassis and tyre movements against the forces and moment acting against these masses *and their inertias*. It is difficult to get the most from heave and roll control unless you decouple heave and roll stiffness and damping.

30. Formula Student competition is *not* motorsport. It is good training if you want to work in motorsport, but it is not motorsport. It is a project management and engineering design competition based on a racecar. The best proof is that a so-so car can get a pretty good result with a very good driver. Formula student is about preparing future engineers for their career. Focusing on car performance only is

There are two kinds of people: the people who win and the people who make excuses. Choose what kind of person you want to be

The good race engineers know what the ideal tyre temperature is – it is simply the one they had when they were winning races

good but not enough. You need to explain, with an engineering approach, *why* your car is good and what could make it better.

31. Put your steering wheel straight. Is your rack centred? Do you have a tool to lock your steering rack in its centred position? Now measure your left and right wheelbase. Are they the same? If you have more than 1.5mm of difference (that is about one per cent of the wheelbase), you have real issues with your jigs or your manufacturing process, or both.

32. No two dampers are the same. Put the same bump and rebound damper setting on two different dampers and test them on a dyno. You will most probably see big differences. To have two dampers giving the same force *vs* velocity curve, you could need different bump and rebound settings. That is the very reason you need to use a damper dyno.

33. Many water coolers are way too big and, consequently, too heavy. They also create unnecessary aerodynamic drag. With good inlet and outlet ducts inside your sidepods, you can significantly increase your cooler efficiency.

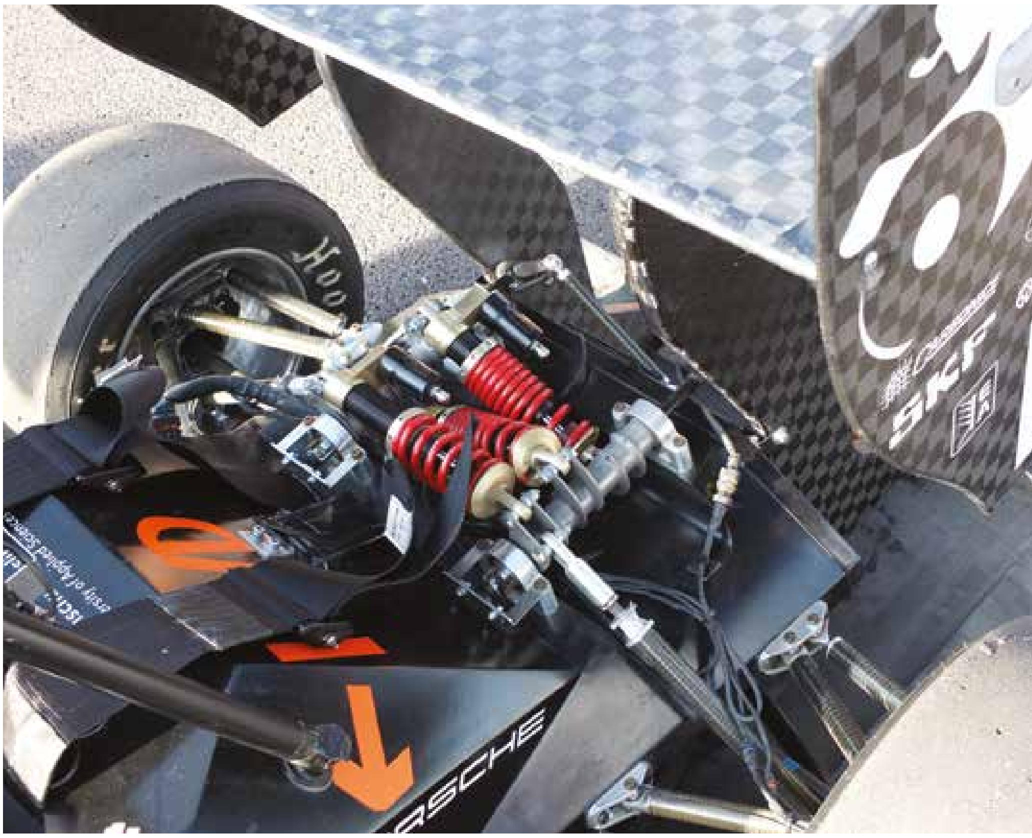
34. Here's a recipe for tubular chassis design: Minimum of tube, minimum of nodes (ideally three tubes per node), and maximum of triangulation. That is how you can get both high chassis stiffness and low mass.

35. Most students do not understand, or they simply underestimate, the importance, of chassis and suspension compliance. Nothing is rigid; 0.2mm of deflection here and 0.3mm of deflection there, and suddenly your front camber or you rear toe is far, far away from what you thought it was. From the driver input (steering wheel, brake pedal, throttle) to the tyres' contact patch, there are dozens of non-linear springs, dampers, and hysteresis that compromise the racecar's response to that driver input. Compliance is the biggest enemy of your driver's control and confidence.

36. Chassis torsion stiffness FEA analysis does not mean a thing unless it has been compared with workshop measurement. If the two numbers are not the same, that's okay, providing you can explain why that's the case.

37. If you simulate or measure the chassis torsion stiffness, you need to apply realistic loads at suspension pickup points instead of irrelevantly at the front and rear bulkhead.

38. A soft spring in series with a stiff spring is still a pretty soft spring. There is no point in having a very stiff chassis and compliant suspension wishbones.



The first thing that influences a race tyre's grip is its temperature and the first thing that affects this is damping. It's also worth remembering that no two dampers are quite the same, so damper dynos are vital

To achieve both high chassis stiffness and low mass with a tube frame there is a simple recipe to bear in mind: minimum of tube, minimum of nodes (ideally three tubes per node) and maximum of triangulation

You can't solve engineering problems without engineering inputs

39. Camber compliance from rims can easily be 0.7-degree per *g*. If your car takes 3*g* in lateral, your dynamic camber calculation is already wrong by two degrees compared to a simplified kinematics software simulation. That is from the rim only.

40. Designing a suspension with rod ends in bending is simply criminal.

41. The same goes for suspension linkages axis that do not pass through a chassis node.

42. Single shear is a bad idea. Toe link rod end attachment on an upright is an example of this. Another example is a rocker axis on the chassis. One of the biggest sources of compliance that makes the real, measured wheel versus the spring motion ratio different than the one calculated without FEA is the deflection in the region of attachment of the rocker axis on the chassis.

43. The last thing you should be drawing is the chassis. The chassis is nothing more than a big bracket that holds everything.

44. Good race engineers know what the ideal tyre temperature is – it is the one they had when they were winning races. Pretty much the same can also be said for the tyre pressure.

45. You can't solve engineering problems without engineering inputs. That is why, for example, you need tyre force and moments models. Unless you use extensive and expensive trial and error (but then that is not what Formula Student is really about) I don't know how you can design suspension without a relevant tyre model.

A single tyre is in itself a complex system that's subjected to a multitude of variables, from driving styles to track conditions, which is why a tyre model only gives you an indication and not a perfect prediction

There are plenty of stickers on this car but gaining a proper sponsorship deal for Formula Student is tough and a team needs to persuade a company it will be getting more than just decals in return for its support

46. A tyre is a complex system that includes many different sciences, it is part engineering and part black magic. Track and ambient conditions that could change lap after lap, car set-up, driver's style, etc. That is why a tyre model only gives you an indication, not a perfect prediction of what the tyre forces and moments will be on the track.

47. You should be spending as much time testing and developing your racecar as designing and manufacturing it, especially if you are a new team. The two most common Formula Student weak points that I see are the driver's lack of skill and a lack of car reliability. How do you train your drivers and improve your car reliability if you do not test it? Professional teams with zillions of dollars and hundreds of people still manage to break things during races. How can the members of a little, inexperienced Formula Student team believe their car will be reliable without testing? Three to five months and 500 to 1000Km of efficient testing before the competition is an absolute minimum. You will reduce your lap time much more by testing your car one month earlier than by spending one more month designing it.

48. Some students can't give design judges a precise number on testing time and distance. You need to carry a notebook all the time which contains your test run sheets that show all the test data: the start and end set-up, start and end time of each run, numbers of laps ran, lap time, tyre temperature, pressure and temperature, atmospheric conditions, track temperature, driver comments, set-up change, and so on.

49. Unless your design decisions are backed up by in-lab tests and on-track validation, you won't impress anybody. Remember, this is a design competition, not a simulation competition.

50. You just can't ask for money from a sponsor so that you 'can put his company stickers on your car and have fun building and running your mini Formula 1'. Ask yourself what is the win-win situation for both you and your sponsor.

Next month: *Don't miss points 51 to 75*

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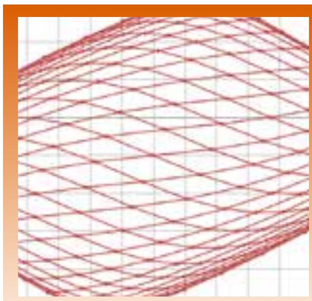

Slip Angle provides a summary of OptimumG's seminars

Formula Student 101

OptimumG engineer Claude Rouelle's 101 top tips for Formula Student teams continues with some thoughts on budgets, aerodynamics and racecar set-up

Claude Rouelle plays a lead role at renowned vehicle dynamics consultancy OptimumG. On occasion he also offers his services as a design judge in Formula Student competitions, which means he's in an ideal position to offer advice to those looking to take part in these events.

51. Let's begin where we left off with point 50 last month, discussing sponsorship. Sponsors do not buy your project; they buy into what you believe in. So it's all about selling your emotions.

52. There are only two kinds of sponsorship: with and without television. If you can have your racecar shown on local or even national TV, it will also be easier to get sponsors. Invite a professional racing driver to drive your car. Not only will he or she share with you many observations about your racecar ergonomics and its on-track behaviour, but they might also attract the TV reporters.

53. Be realistic: you will not make a competitive Formula Student car with a budget of $10,000.

54. The best sponsors are not necessarily the ones giving you money. You will get more benefit from technical partners who give you material or parts free of charge; you might also be able to engage in fruitful engineering conversation with them, too.

55. Never say to a judge that you 'did not have the money'. The money is there. If you do not get it, it is because you do not know how to find it. Similarly, never say to a judge 'we did not have the time'. If you do, you are presenting yourself as a victim. Instead, say 'we did not take the time'. *You* are the one overseeing your project, deciding your goals and priorities within your means.

56. It's worth including in your upright and chassis design some adjustability in suspension pick up points. A difference of just a few millimetres of suspension pick up points coordinates can sometimes give you major performance increase. Of course, you won't have the possibility to test different suspension kinematics if your racecar is finished just a few weeks, let alone a few days, before the competition starts.

57. On any circuit, even street courses with a lot of braking and acceleration, a five per cent increase in

A five per cent lateral grip increase will give you three to five times the lap time gain of a five per cent increase in longitudinal grip

While sponsorship of any type is always welcome it's often the companies that supply parts and advice rather than cash that prove the most useful of backers

Of all the car set-up parameters the rear toe adjustment has by far the biggest influence on the racecar's control and stability

lateral grip will always give you three to five times the lap time gain given by a five per cent increase in longitudinal grip. That is why camber control in roll is more important than camber control in heave.

58. I have seen slow motion videos of in-lab tests of Formula Student cars (four- or seven-post rigs) where, at some frequencies, the wheel moves versus the chassis but the damper-spring unit doesn't! Indeed, in one case, I saw the edge of the rocker axis moving on a circle of about 12mm of diameter. Sometimes your compliance *is* the suspension. It's worth performing some FEA with frequency, as all good aircraft engineers will do.

59. I would expect a good team to show design judges each wheel toe and camber compliance (in deg/KN or deg/KNm) graph versus separate or combined inputs of tyre *Fx*, *Fy*, *Mx*, *My* and *Mz* in simulation and from workshop measurements. That implies building a simplified K&C test rig. Of course, such workshop measurements are not worth anything unless you explain how they helped you to validate (or not) your FEA simulation, to design this year's car (or will help you to design a better next year car), and how you included these numbers in your vehicle dynamics simulation.

60. Good drivers can feel the difference of a 0.1-degree of rear toe adjustment. That gives you an idea of the importance of the accuracy and the repeatability of the rear toe adjustment. In fact, within all the car set-up parameters, the rear toe adjustment (and compliance) has by far the biggest influence on the car's control and stability.

61. If a design judge with his hands on the front and rear part of your wheel simulates a self-alignment *Mz* torque and he can see or feel a toe angle variation your suspension has unacceptable toe compliance. Back to the drawing board. The *Mz* that even a strong human being will be able to produce is smaller than the *Mz* created by your tyre.

62. The two best ways to avoid toe compliance is to make sure you design your upright with a large distance between the toe link pick up points and the wheel centre while also having the toe link (or the steering arm) as perpendicular as possible to the chassis longitudinal axis.

63. The fishing string is simply not an accurate enough tool for measuring toe.

64. If you want to play aero, play aero. A good aero design judge will want to see your downforce, drag, side force, aero-balance, aerodynamic roll, pitch, and yaw moments numbers in 5D; front and rear ride height, yaw angle (with as much as

It's worth including some adjustability in suspension pick up points in both your upright and your chassis design. A difference of just a few millimetres can sometimes reward you with a major performance gain

Extreme aerodynamic packages are part and parcel of Formula Student competition. But you will need to ensure you have all the relevant figures at your fingertips if you want to impress a good aero design judge

CFD numbers are usually 20 per cent too good compared to reality

180-degree yaw angle when your racecar spins and goes backwards), steering angle, and roll angle. Of course, they will also want to see how you use an aeromap in your vehicle dynamics simulations.

65. Bear in mind that CFD numbers are usually 20 per cent too good compared to reality.

66. Do not even consider playing with CFD unless you simulate a moving floor and rotating wheels.

67. A few years ago, we were asked by a journalist to predict the lap time of a Formula 1 car on the Austin circuit before the first visit of F1 to the COTA (Circuit of the Americas) race track.

We were wrong by six tenths of a second, which in Formula 1 is a pretty big gap. But the reality was that two weeks before that first grand prix took place we did not know what the tarmac temperature was going to be and in which direction the wind would be blowing, and that's to name just two of the parameters that influence the lap time. There are too many parameters (the racecar, the driver, track, environmental conditions, etc.) to be spot on in your predictions. What is important is to evaluate the lap time *variation* (much more than the absolute value) versus the amount of fuel, or the front wing angle or the static rear ride height. We really need to work in delta, trends and sensitivities more than in absolute value.

68. If two numbers (for example, performance prediction from simulation and recorded test data) are not the same, at least one of them is wrong. It could be your simulation input or algorithm is wrong, or it could be your sensor is not properly calibrated, or it might be both. However, if two simulations give you the same results it doesn't necessarily mean they are correct. In any case, all simulations are wrong, but some are useful.

69. There is no useful measurement without another kind of number: the degree of uncertainty.

70. You cannot get realistic and useful anti-dive, anti-lift and anti-squat numbers unless you have a relevant tyre model, a good knowledge of your brake balance distribution and, in the case of combined lateral and longitudinal accelerations, a relevant differential model.

71. Any bodywork part (sidepods, engine cover, nose, panel to access the pedal box, etc.) should be able to be removed and then attached back on to the car in less than 30 seconds. If not, you need to go back to the drawing board. Similarly, any toe or camber or ride height adjustment should not take more than two minutes. If it takes longer, again, back to the drawing board.

72. Do not start to manufacture any car part or jig unless *all* drawings are complete. If you do so, you should be able to manufacture and assemble your car in six weeks with no surprises, and you will know the complete list of materials and parts to purchase.

73. Brake fluid is hygroscopic. The boiling temperature point goes down significantly with the humidity percentage. Flush and replace the brake fluid after a test or a race in the rain.

74. Brake fluid is incompressible, right? Then why is there a brake pedal stroke? Put a dial gauge right where the brake master cylinders are mounted on the chassis, or on the brake caliper. Push on your brake pedal and look at your dial gauge. You will get a good example of what compliance is here.

75. Performance is like a volume. That is, *Volume = Surface x Height*. But the surface here is your starting conditions: the size and experience of your Formula Student team, the strengths of your teacher, the software you have access to, etc. You cannot blame yourself for the things you have no influence on, such as the team state at the time you joined it. However, you can influence the height of the volume – and that is your input.

Next month: *Don't miss points 76 to 101.*

Competing in the wet is about more than simply considering the reduced grip – for instance, brake fluid is hygroscopic and so this needs to be flushed out and replaced after the racecar is taken out in the rain

Bodywork pieces such as sidepods and engine covers need to be removed and then replaced within 30 seconds. Similarly, any toe, camber or ride height adjustment should not take more than two minutes

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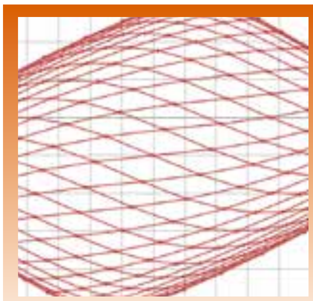


Slip Angle provides a summary of OptimumG's seminars

Formula Student 101

OptimumG's 101 top tips for Formula Student success concludes with Claude Rouelle's final 26 pearls of wisdom – including advice on bump-steer, stability and communicating with drivers

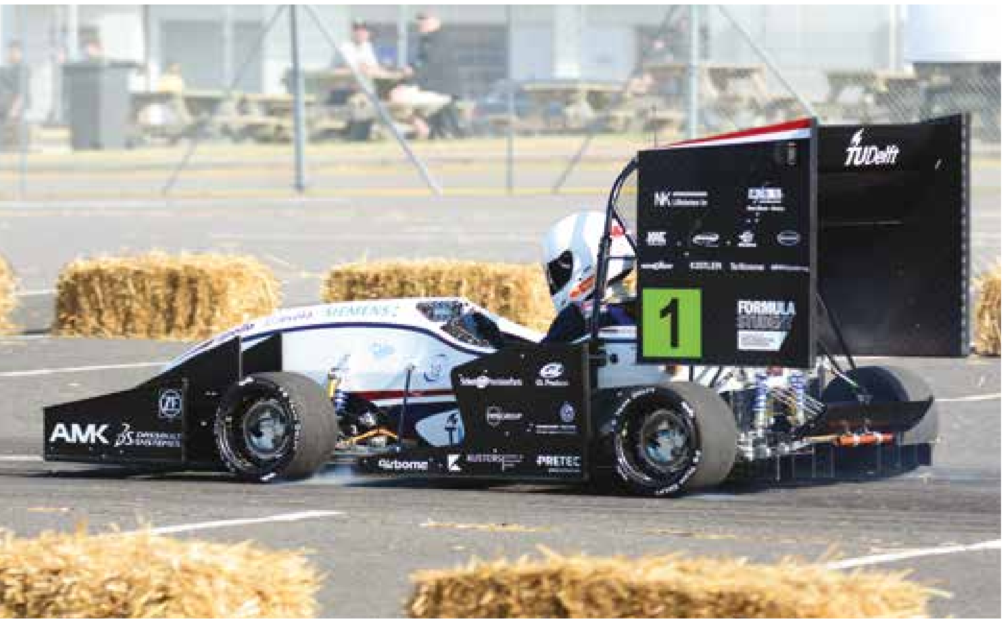
Besides his leading role at OptimumG, Claude Rouelle also often offers his services as a design judge in many Formula Student competitions. He started his 40-year racecar engineering career by designing and building a racecar and a wind tunnel; it was his engineering degree master thesis. The challenges he faced then were similar to those faced today by students building a first car for Formula Student competition. He is then, ideally placed to offer his advice. Below are his final 26 short engineering and team building tips (see the last three issues for the first 75). And if you're not a student? Well many of these gems are also applicable to professional race teams.

76. When you design your Formula Student car, think about the installation on the chassis of the tools that you will be using to measure each wheel's toe: fishing string or, much better, laser beam on a flag. The fixture of these tools on to your chassis should be part of your racecar design.

77. A bump-steer target should be part of your set-up sheet. You need to define how to measure the toe variation versus the ride height variation. Without compliance, the toe measured with step by step dummy damper length reduction on a set-up pad (or blocks of wood of different thickness between the set-up pad and the bottom of the chassis) versus the ride height variation will give you a bump-steer law that most kinematics software with no compliance will give you too. With compliance it is worth adding load (sandbags for example) to simulate the aero load and/or the longitudinal weight transfer. You do that with real springs and real tyres at hot pressure and measure the toe variation and the ride height variation. The ratio between these two measurements will give a more realistic motion ratio number. The other alternative could be, lucky you if so, putting your car on a K&C rig. But the usefulness of these K&C tests depends very much on the test preparation.

78. You can't perform serious tests without an accurate set-up procedure. You need a set-up pad with four scales that are perfectly horizontal. It is well worth making sure your measurement reference plane is, and stays, horizontal.

79. Car balance is very sensitive to the tyre static load variation. On an FS car 0.5kg of cross weight difference (LF + RR compared to RF + LR) statically with an asymmetric set-up, or dynamically, with for example an anti-roll bar adjustment, could change yaw moment (and hence car balance) by as much as 20 per cent: a huge difference in the car's behaviour.



Drivers are much more sensitive to the racecar's balance than they are to the amount of grip available

80. It is worth putting your car on the set-up pad and turning your steering wheel from full left to full right and return, and let's say every 30 degrees of steering wheel movement, measure your LF, RF, LR and RR ride heights, your corner weights, your cambers, your damper lengths, and your LF and RF steering wheel angle. It will give you camber, corner weight, ride height, motion ratio and Ackermann curves that will be worth comparing with your simulation curves. Moreover, if these curves are different from turning the steering wheel from full left to full right and full right to full left, you know there is an asymmetry in your car and it is worth investigating what the causes of this are.

81. In the same spirit, it is useful to load your Formula Student car step by step with sandbags and measure your dampers' length, your tyres' loaded radius, chassis ride heights, cambers and toes. It will give you very useful information that is worth comparing with your simulations. In any case, always believe more what you measure (if you measure accurately) than what you simulate. Simulation is for trends and sensitivities (the slope of the curve) not for absolute value.

82. There are four ratios that are, ideally, linked and which will determine your racecar grip and balance. These are the weight distribution, the tyre cornering stiffness distribution, the aero-balance and the anti-roll stiffness distribution.

83. In a rough estimation, the front and rear tyre cornering stiffness ratio is within a few per cent of the front and rear tyre width ratio. But that really is a rough estimation. Ideally, you will have to look at your front and rear tyre cornering stiffness from your non-linear tyre model. Beware: a tyre cornering stiffness (N/deg) is not the tyre lateral stiffness (N/mm). They are related though; a larger tyre will give you a bigger lateral stiffness and a bigger cornering stiffness but the ratio between the two stiffnesses is not necessarily linear.

84. On a rear-wheel drive car that has the same front and rear tyres your simulation will show that your best lap times are reached when your weight distribution is about 46 to 49 per cent. That is often the best compromise found between pure cornering (skid pad for example), pure braking or

Formula Student corners are so tight and so low-speed that stability is less of a concern than on more normal race tracks

acceleration (in a straight line) or a combination of both braking and cornering (in the corner entry) or acceleration and cornering (at the corner exit). If you are outside that percentage, you are probably compensating undesirable chassis and/or suspension wishbone and upright compliance with your springs and anti-roll bars.

85. I have no problem with a Formula Student racecar with a weight distribution of 40 per cent front and 60 per cent rear, but that car should necessarily have larger rear than front tyres.

86. Usually, on a good car with limited compliance, the weight distribution (front weight / front + rear weight) and the cornering stiffness distribution are within one or two per cent of each other.

87. The wheel rate is the spring rate divided by the square of the motion ratio. Motion ratios are rarely constant by design (and/or by compliance); for an aero car you want a decreasing motion ratio (increasing wheel rate) versus ride height as the downforce is square-of-the-speed sensitive.

88. Usually the front to total anti-roll stiffness (spring and anti-roll bars in parallel, themselves in series with the tyre wheel rate) distribution percentage (front Nm/deg / [front + rear Nm/deg]) is not far away from your weight distribution. If there is more than five per cent difference that means you compensate severe chassis or suspension compliances with your spring and anti-roll bar stiffness. Patches on patches: you could get a good balance (yaw moment) but not the best possible grip: less lateral acceleration than your tyres should give you.

89. The need for stability increases with the speed. On most racecars the aero-balance percentage is one or two per cent smaller than your weight distribution. In other words, the centre of pressure (CoP) is always behind the centre of gravity (CoG). That number could go up one or two per cent at very high speed. But a Formula Student car is a different animal; the corners are so tight and so low-speed that stability is less of a concern than on more usual race tracks. It is very possible to have a five per cent, or even more, bigger aero-balance number than the weight distribution.

90. There's no such thing as understeer or oversteer. There is under yaw moment (or under yaw acceleration) or over yaw moment (or over yaw acceleration). The goal is to get the biggest possible lateral acceleration and the yaw moment you want when you want it. There are 12 causes of yaw moment: four tyres *Fy*, four tyres *Fz* and four tyres *Mz*. Good vehicle dynamics knowledge will help you to decide how to change your set-up and from there your tyres' forces and moments, and from there your balance (yaw moment). You will know the yaw moment you need at every part of the circuit if you have a good car, tyre aero model, and you know the shape of the trajectory.

With suspension you should always put far more faith in what you measure than in what you simulate

It is good practice to have a driver report car balance, grip etc on a sliding scale rising from zero to 10

91. All drivers are much more sensitive to balance than grip. I defy even good drivers to feel a difference between 2.1 and 2.2*g* lateral. If you remove the lap time from the dashboard they will not feel a 0.5s lap time difference, although the best ones will conclude they have a better car because at the corner exit they change gear earlier. But give them a touch of understeer or oversteer and they will complain, believe me!

92. Lap time simulation is good, but not good enough. Many students will use it, often randomly changing the set-up, and see improvement, but do not often understand, qualify and quantify the why and the *how* of the set-up change on performance.

Race engineers should 'translate' their simulation results or data analysis into a language that the car's driver can understand

93. It is a bigger priority to first understand how your racecar design and set-up parameters influence these six essential targets: grip, balance (yaw moment), control (yaw moment created by a given steering angle variation, in Nm/deg), and stability (yaw moment created by a given yaw angle variation, in Nm/deg) on corner entry and in the corner, and stability at the apex.

94. Let's go testing. Testing what? How? When? In which order? You can't go to a race circuit to test your racecar without a test plan.

95. A good mechanic is a clean mechanic. You should be able to work on your car all day long wearing a clean white shirt. If not, that means your car is dirty. This leads us to the next advice on the order in which you should perform the different tasks; you clean, you inspect and maintain and only then you set the car up. Cleaning the car helps you to inspect it in every detail. What is the point in adjusting the ride height with a 0.5mm accuracy if you have not seen a crack in an upright?

96. The goal of the racecar engineer is to correlate subjective feedback from the drivers as well as objective simulation/data results. Most engineers are not good drivers and good racing drivers are rarely good engineers. Race engineers should 'translate' their simulation results or data analysis in driver language. The driver involvement in the racecar design and set-up is valuable but has its limitations. His or her focus should be to get the best out of the racecar out on the track, whatever the car's strengths and weaknesses are, and get back to the engineers with the most accurate and detailed racecar behaviour description.

The driver's role in the build is valuable but has limitations, and they should concentrate on the driving

Every part of the car should be spotless. By cleaning it carefully before setting up you might spot issues

97. A good way to help each other as an engineer and driver is to create a correlation between subjective and objective measurements. Here is an example of how this can be done. The driver is asked to quantify the racecar stability from zero to 10. Based on previous debriefs, the race engineer knows that when the driver's happy (a 10) the stability number at corner entry is, for example, 4000Nm/deg. But today the driver is not happy and gives a four on the stability subjective quantification. The engineer sees the stability number is 2500Nm/deg. With good vehicle knowledge and a good simulation software and a bit of experience, the engineer will know what to change to go from 2500NM/deg to 4000Nm/deg.

98. A design judge will want to see your internal engineering reports, not only the eight-page design report that teams will submit a few weeks ahead of the competition. He will want to see the big binders with calculation methods, test reports, lessons learnt from success and failure, the 'if-money-and time-were-not-an-issue' dream to do list. It shows how well the knowledge is transmitted inside the team from one year to another.

99. There are two questions a design judge will ask himself when he looks at your racecar: 'If I had the opportunity would I like to drive that car?' and 'If I had to buy a Formula Student car, would I buy this one?' Some Formula Student cars could be fun to drive but not to buy because their maintenance cost and reliability are questionable.

100. If you have 100 teams at a competition you will only get one winner. Does that mean you have losers? No. There's always something to get from these events. What every student learns at a competition is teamwork and delivering on-time, on target performance, as well as leadership – and God knows this world needs leaders.

101. There is no need to panic in design judging. And remember, this is not about life and death. It's much more important than that!

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