

Leading-Edge Motorsport Technology Since 1990

Racecar engineering™

Formula Student 2015 • www.racecar-engineering.com

DIGITAL SPECIAL

Formula Student 2015



Event report 2015
Delft does it again

Clipped wings
Dealing with aero rules

FSAE design tips
Mark Ortiz on new cars

VARLEY RED TOP™

THE ORIGINAL RACING BATTERIES



The Varley Red Top range has for many decades been the battery of choice for the professional and clubman in motorsport. These sealed lead acid batteries are compact and powerful enough to be used in all race series, however they are heavier than their modern counterpart, Lithium Ferrous Phosphate. Formula Student teams, using motorcycle engines of around 600cc, have until recently focussed their attention on the Varley Red Top 8, a small 12V 8Ah battery weighing only 3kgs.

VARLEY LITHIUM™

Recently we introduced the Varley Lithium range of Lithium Ferrous Phosphate batteries. First off was the Li-16, a 12V 16.1Ah battery the size of a Varley Red Top 15 but with the cranking capability of a 30, and weighing only 3.2kg. This was followed by two smaller versions, the Li-5, 5.5Ah weighing 1.1kg and the Li-3 2.4Ah at 0.5kg. The Li-3 has been proven with motorcycle engines up to 750cc and the Li-5 is gaining popularity in Formula Ford 1600 as it copes well with running without an alternator.





Formula Student is now an established part of the motorsport industry landscape, with an ever growing number of competitions around the world and a mind-boggling number of cars built every year. But to me, when reviewing the contenders in each of the main competitions – either in person or via that wonderful thing that has brought you this publication, the internet – it sometimes seems as if a lot of teams have forgotten the first principles of competition car design. And Indeed, one of the rules of thumb of engineering in general; keeping it simple.

We continue to see complex wheel designs, complex monocoques and devilishly tricky engines. I think too many teams get sucked in by the trendy and more glamorous designs routes open to them in many areas of the car and forget that simplicity is often the best solution. Often I even get the impression that teams include features in the design of the cars because they saw top teams doing it last year, despite the fact that they don't fully understand them.

It is not a new phenomenon this, indeed it is something that over the years has seen F3 become an almost exclusive Dallara class. The young drivers, lacking imagination, simply want to have the package that won last year, rather than thinking about the reasons why it won.

At the ImechE Learn to Win event in London recently many teams told me that they were looking to raise the budgets to build complex cars, but although I asked them why they wanted

to build a complex car? I don't think any of them really knew the answer.

The old timers in the motorsport engineering business tell me that they find that post digital revolution (yes there was a time before the internet) students and graduates are losing the skill of critical research. They struggle to go to the library to study literature of the past, and rely far too heavily on a quick Google search and the output of analysis software. They often forget to ask the simple question, *why*. Instead, I suspect they cut straight to, *how*.

The first question is a powerful weapon in car design, if you understand *why*, then the answer to *how* will probably present itself, and that answer will probably not be the one you were expecting in the first place. When you look at the designs of the cars that won Formula Student at Silverstone and Formula SAE, you will notice that they took unconventional routes with their projects. The reason for this is that both teams thought about the *why* for a long time before they thought about the *how*.

So, with that in mind, enjoy this free digital edition. If you do, then remember that there are others from previous years available on the *Racecar Engineering* website which are also free to download. But there are probably full printed issues of the magazine available in your university library, too. So I suggest you pay a visit if you have not already done so.

SAM COLLINS Editor

CONTENTS

4 FORMULA STUDENT REPORT

All the action from this year's Silverstone event with in-depth technical analysis

10 DELFT DOES IT AGAIN

How Dutch wonder-team once again proved to be the class of the field

12 AERODYNAMICS

Big changes in the aerodynamic regulations called for plenty of innovation at this year's event

16 THE CONSULTANT

Coping with tightening turns; Formula SAE differentials; and getting braking pedal pressures just right

21 TECHNICAL DISCUSSION

The big Facebook SAE debate

Many say that students and graduates are losing the skill of critical research

Splash and dash

Whether it's Formula 1 or Formula Student the same challenges are faced: new rules, new technologies and, of course, dealing with unpredictable weather...

By GEMMA HATTON



This year's Formula Student UK event was the most exciting by far

This year's drastic rule changes guaranteed Silverstone a weekend of dramatic racing, tough competition and some astonishing results. Some 135 teams turned up, but not all passed scrutineering, with teams such as Chalmers (2012 winners) not even making it through. Those that did pass were then faced with the brake, noise and tilt tests, which saw many of the big teams fail several times. They then had to spend hours fixing the cars before they could try again, pass, and be ready to compete.

Saturday morning came, and problems from the previous day's tests meant that many of the top teams were not ready to race at all. UH

Racing (Hertfordshire) was rebuilding its engine; Rennteam Stuttgart, TUfast Racing (Munich) and Ka Racing (Karlsruhe) were all queuing for re-scrutineering; Team Bath Racing was repairing broken wishbones and Oxford Brookes was fixing its suspension rockers. Even last year's winner, TU Delft, was cutting it fine, only giving itself a few hours to complete the acceleration event. The starting lines for the dynamic events were all looking rather empty.

One problem which had first manifested itself at Formula SAE a few weeks earlier related to the noise levels of some of the combustion cars. With the majority of the top combustion cars now using single cylinder engines, the 2015

rules aimed to reduce the noise of these engines by changing the maximum noise limit from 110dBA to 110dBC. This apparent minor change caused many of the top combustion teams to fail the noise test several times, causing such problems that the rules committee are now looking to modify this regulation for next year.

'We thought we were fine as we had done some tests back at our university and measured 104dBC but they measured 114dBC which is a big difference especially as dBC is a logarithmic scale,' Tom Pierson-Smith from Team Bath Racing said. 'It turned out that it was the direction of the silencer that was the issue as it was aimed at the rear wing and so the whole car was vibrating.'



Main picture: Typical English summer weather arrived at Silverstone just as the top cars were running the endurance test
Top: The tiny electric car from UAS Zwickau was a design finalist and finished second overall behind TU Delft – the Zwickau car was able to make the most of the dry running before the rain started to fall **Above:** The third element rear suspension layout of the combustion car from Stuttgart. Its original plenum (seen here) was destroyed early in the event leading to a hasty repair and the team missing two dynamic events. The car would have been a challenger for overall victory otherwise

Once we changed the direction we were legal, but this is definitely something we want to look at next year.'

Noise nuisance

LU Racing from Lund also failed noise despite extensive exhaust work. 'We use a Helmholtz resonator which kills one frequency, then we have two mufflers and separate them; one on the front and one the rear so we have half a wavelength between them which also kills the noise,' said a spokesperson. 'The final solution to decrease our design by 2dB to pass the test was to use smaller pipes to position the exhaust where it created the least sound.'

The first of the main events is acceleration, which is the time taken to complete the pit straight, worth 7.5 per cent of the overall available points. This is where the electric cars come into their own with instantly available torque. After each team had completed several runs, the top five run-off took place to equalise the track conditions. Unsurprisingly, the AMZ Racing car from ETH Zurich took the top spot with 3.72s, closely followed by TU Delft with 3.82s. One of the competition's big surprises was the fact that third place not only went to a combustion car, but to the heaviest car on the grid, with the 215kg, 4-cylinder beast from PWR Racing, Wroclaw clocking an astonishing 3.87s.

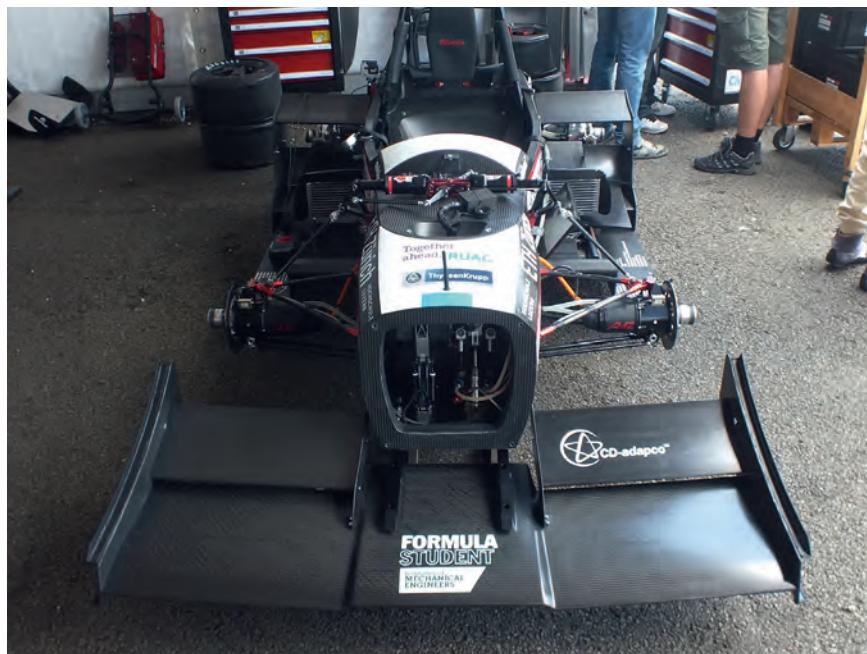
Next up was the sprint event, an 800m tight course that tested the cars' manoeuvrability and handling, and which was worth 15 per cent of the overall points. No clever strategies had to come into play during this test as the weather unusually remained at a consistent 18degC ambient air temperature, resulting in consistent track conditions. Therefore, the top 10 consisted of the usual suspects; the combustion Stuttgart car coming first having completed the course in 49.05s, followed by its electric brother finishing in 49.31s. Only three hundredths behind was the Zurich car, which was followed by Delft, TU Graz Racing and TUfast Racing.



Design finalist ETH Zurich headed into endurance separated from Delft by just two points but ground to a stop about 1km from the finish line, costing Zurich a strong overall result

Results

| Overall Class 1 | |
|--|--|
| 1st | TU Delft |
| 2nd | UAS Zwickau |
| 3rd | Stuttgart (combustion) |
| Overall Class 2 | |
| 1st | Team Bath |
| 2nd | Bristol |
| 3rd | Aristotle University of Thessaloniki |
| Cost, Manufacturability & Sustainability | |
| 1st | Aberdeen |
| 2nd | Surrey |
| 3rd | Strathclyde |
| Design | |
| 1st | ETH Zurich |
| 2nd | Oxford Brookes |
| 3rd | Norwegian University of Science and Technology |
| Business | |
| 1st | TU Delft |
| 2nd | Aberdeen |
| 3rd | Liverpool |
| Efficiency | |
| 1st | KTH – Royal Institute of Technology |
| 2nd | UAS Cologne |
| 3rd | TU Delft |
| Skidpad | |
| 1st | ETH Zurich |
| 2nd | TU Graz |
| 3rd | OTH Amberg-Weiden |
| Acceleration | |
| 1st | ETH Zurich |
| 2nd | TU Delft |
| 3rd | Wroclaw |
| Sprint | |
| 1st | Stuttgart (Electric) |
| 2nd | Stuttgart (Combustion) |
| 3rd | ETH Zurich |
| Endurance | |
| 1st | Team Bath |
| 2nd | TU Delft |
| 3rd | Birmingham |



The ETH Zurich car is driven by four student-designed hub motors and boasts a neat composite monocoque

Sunday hosts the main event of the competition, and is by far the toughest challenge for both the cars and teams: endurance. This event, worth 300 points, is a 22km course, including a driver change and a hot restart. Every year, both reliability and weather cause havoc with the teams, with many either failing to restart or simply finishing their weekend stopped on the side of the track. This year, as teams tried to implement so many new rule changes into their designs, many arrived at Silverstone with a lack of testing, so reliability was even more of an issue. Of the 52 cars that started, only 25 crossed the finish line. That means that only 38.5 per cent of the cars took part in the main race and less than half of those actually finished. Then, of course, the rain came, which completely shook

up the results of those who had not finished. The Silverstone Formula Student competition once again proving why it is the toughest in the world.

Teams spent the morning before the race analysing and discussing weather patterns, the chance of rain and which tyres should be used. At this point in the competition, AMZ Racing from Zurich were first, with TU Delft less than two points behind – it was all down to the final race. Both were on different strategies; TU Delft were the only team to have developed its own tyres with their new dry tyres approximately a second a lap faster around a 20 second course compared to last year. Unfortunately for them, these tyres weren't ready for Silverstone, and so they only had wets to run on. However, as these were also uniquely developed, they were

actually faster than last year's drys, but to maximise their performance further obviously they were hoping for rain, and so continued their rain dancing. AMZ Zurich knew this, and also knew that its only hope to secure an overall competition win was for it to remain dry so they could finish with a competitive time. Sadly, the surrounding black clouds had other ideas.

Battle of Britain

The first exciting racing of the day was the battle for the top UK spot as both Oxford Brookes and Team Bath took to the track at the same time. Usually this is a three-way fight but with UH Racing's (Hertfordshire) continuing engine problems, it was out of the running. As Oxford Brookes completed its first stint and successfully re-started, Bath continued to lap faster and faster until the inevitable happened and Oxford Brookes was overtaken. Although somewhat irrelevant as points are allocated for overall race time rather than track position, that didn't stop the cheers from Team Bath. Even though its drivers took out 24 cones, its total race time including penalties was an impressive 1484.1s, securing the top position, while Oxford Brookes completed the course in 1577.5s. 'The moment I turned the ignition off, I could feel the rain and I knew we were in a great position,' beamed Ryan Marsh, Team Bath's test manager – and he was right. As LU Racing from Lund and the Ka Racing's electric car battled through the downpour on track the rain got heavier, and within minutes the race was red flagged.

Back on track

After the monsoon was over and the track was cleared the cars could begin running again, and only the top teams were left. However, with teams such as TU Graz, Rennteam Stuttgart combustion, TUFast and Ka Racing all experiencing problems, only TU Delft and ETH Zurich would challenge Team Bath's time. The rain played into the hands of TU Delft who were extremely fast on their wets, yet remained a total of 14s slower than Team Bath, and in second place. Next up was ETH Zurich, but with only two laps to go a safety switch in the high voltage system triggered and the car ground to a halt on the side of the track. Team Bath Racing had not only completed endurance, which its previous teams had always struggled with, but had won it with their brand new KTM engine, and so were the first UK team to win since 2009. The rest of the top 10 was made up of cars that had run in the dry, meaning teams such as Loughborough, John Moores and UAS Zwickau capitalised on some major points.

Of course, ETH Zurich's endurance woes handed the overall competition win to TU Delft, who were once again crowned Formula Student Silverstone Champions for the second year running by over 116 point to UAS Zwickau, who were then followed by Rennteam Stuttgart. Team Bath came in at fourth and claimed top

Bath Innovations



Team Bath Racing had its most successful UK event, finishing first in endurance, securing an overall fourth place in the competition, making it the top UK team. It achieved this with a radical new concept. After four years of using an Aprilia RXV550, 552cc, 2-cylinder V twin that caused them numerous problems and resulted in three DNFs in endurance, the team finally decided it was time for a change. 'Although last year's team finally got the Aprilia to complete the endurance, we decided to move away from this engine,' explained Tom Pierson-Smith, project manager for Team Bath Racing. 'From our dyno testing, we were getting around 70hp with our new KTM 500 EXC single cylinder compared to 48hp from last year for a very similar powertrain weight. This is also our first year of using E85 [ethanol fuel blend], which [helped] with our endurance score.'

One interesting aspect of this car is the fact it has been designed with pre compressor injection. 'We are the only team running a turbo without an intercooler to try and reduce turbo lag, and we also have two injectors; one before and after compression to improve charge cooling.' Although this system wasn't in full swing at Silverstone, the hardware is ready and it will be implemented in the Austrian and Spanish Formula Student events, in which Bath will also be competing.

The talk of the paddock at Silverstone was Team Bath's wheel hub and suspension design. The wheels consist of two pieces; a 3D printed steel centre wrapped with carbon fibre to make the spokes and a carbon fibre rim. 'Splitting the rim into two skins of carbon fibre and having a Rohacell foam core really



Team Bath's wheel design (top) was the subject of much debate. The wheel is made up of a 3D printed steel centre wrapped in carbon fibre (above), which forms the spokes, fitted inside a carbon fibre rim which itself is split into two skins of carbon fibre. The core is Rohacell foam

helped to reduce the weight of the wheel further.'

'Last year's team looked at prototype uprights and we knew that reducing the unsprung mass was a crucial area of performance, because it brings our dampers into play. Therefore, if we have a lighter unsprung mass, then we have less mass to control further away from the car, which will improve our handling,' explained Pierson-Smith. 'We were quite aggressive to secure sponsorship from a new research company, but it meant we saved 30 per cent weight of the uprights from last year. They also have camber adjustments at the top which makes it a lot quicker and easier to adjust. Overall, our wheels are an impressive 50 per cent lighter than last year.'

Electronics

Electric cars seem to be becoming the norm, but the engineering challenges of designing and building such machines should never be underestimated. Not only do teams have to understand and design the battery and motor layouts but all the necessary related electrical systems have to be implemented as well. With a competition as specific as Formula Student, it is rare to find systems that meet team's requirements and so they have to invest in the technology and build it themselves.

The biggest headache for most teams is the Battery Management System, which monitors the current, temperature and voltage of the cells as well as the overall state of charge to ensure that the battery remains in a safe operating range. The biggest danger with electric cars is the risk of thermal runaway of the battery. Particularly in lithium-ion cells, when the temperature is high, the internal resistance is low, so any residual current is then drawn to the cell with the lowest resistance, which warms that cell up. As its temperature increases, its resistance drops further, and so the current once again is drawn to that cell, generating a positive feed loop as the battery essentially self-feeds itself, which initiates thermal runaway. 'The Battery Management System is the single worst thing,' explains Johannes Tornell, lead design expert at Chalmers, which developed an electric car for this year for the first time. 'We have been trying to find one that fits our car but it is difficult due to communication issues and the noise generated by the converters. We also decided to use a carbon fibre casing, and fixing the cells to this was also challenging.'

The team from NTNU who reached the design finals also developed a bespoke BMS. 'We decided to make it from scratch so that we could monitor the current and temperature of each cell pair. Our 7.45kWh battery runs 144S2P, and after last year's

reliability problems, we decided to add laser welds, which improved the reliability and therefore we could complete much more testing,' explained Roy Andreas Iversen, project manager.

Another area that teams such as NTNU decided to develop was the motor controllers and the inverters. 'We bought our own IPT's (Inductive Power Transfer), control cards, completed all the calculations, identified the motor regulations and torque control,' continues Iversen. 'By developing components from scratch, we can get the exact requirements we want.'

Cool solution

NTNU's batteries are air cooled by the ramps besides the driver's shoulders and a fan that pushes the air through the battery. 'By laser welding the mechanical connections we have a lot less internal resistance so we generate less heat to start with. Low resistance in the battery results in less heat, which improves efficiency and therefore the car can be driven for longer and faster throughout the race,' Iversen says.

An issue when developing your own systems is that when something goes wrong you have to re-tune them, and this is precisely what happened to NTNU. 'Four hours before FSUK, nine out of the 20 magnets in the motor came loose due to some misalignment between the stator and the rotor of the motor, which resulted in some grinding and heat. So we sent a guy from Norway to Lithuania to knock on the door and buy new motors. Of course these were a little different, so we have had to do some tuning because the new motor is aligned and so the flux field needed to be modified to the new motor.' Although a shame that the full potential of bespoke electrical systems could not be fully demonstrated at Silverstone for NTNU, it is still impressive. For maximum performance, self-developed electronics is definitely the future.

UK team, with Munchen in fifth, and Oxford Brookes in sixth place.

This year's event was by far the most exciting, not only from a racing point of view but also from an engineering point of view. As Formula Student competitions worldwide continue every year, teams and cars become more refined and more reliable. The big development steps from combustion to electric, spaceframe to monocoque and now the inclusion of an aero package, have already been made, and so designs arguably become less interesting. However, the variety of approaches taken to comply with this year's new regulations resulted in some truly fascinating innovations, some of which took the interest of world class engineers such as Ross Brawn and Paddy Lowe.

But with Silverstone and Hockenheim out of the way and memories of it merely a blur of presentations, judging, dynamics, success and failure and perhaps a little bit of 'flunkypal', the thoughts now turn to the 2016 event, and another round of rule changes.

Rule changes

The FSAE rules committee announced its plans for coming seasons at Silverstone but has decided that after the substantial aerodynamic rule changes for 2015 it would only make minor rules tweaks in 2016. Some rules will be reworded and clarified, and though it has not been revealed which these are the controversial 'weekend racer' rule may well be among them. With all bar one of the cars in the design final featuring composite monocoque chassis (Oxford Brookes used an aluminium monocoque) some believe that the judges had overlooked the fact that none of these cars were really suitable for weekend racers.

Professional drivers

Andrew Deakin, chairman of the FSAE rules committee explained that following FSAE and the events at Silverstone that the noise limit may have been 'too aggressive' and that the situation is being monitored. 'We will have to wait until they've gathered data from other events before we can make an informed decision,' he told gathered team representatives.

For 2017 more changes are set to come, including moves to prevent 'professional' drivers with significant racing experience from taking part in dynamic events, though it seems that this will be hard to police. More significant from a design standpoint may be the introduction of a fifth percentile driver template as well as the existing 95th percentile template. The cost event may also change substantially, as it's felt that some teams do not take it seriously.

It is expected that more changes will come for 2017, so teams will have to keep on innovating to stay ahead.



Bespoke electronics packages seem to be a growing trend in Formula Student. The NTNU car featured a team-built Battery Management System (BMS) which enabled it to monitor the current and the temperature of each cell pair

There are to be moves to prevent 'professional' drivers taking part

If you want to **win at racing**, then you can't lose any time in the workshop.



LISTA drawer cabinets offer the ideal basis for creating flexible workstations. The mobile drawer cabinets are fully integrated and can be removed as needed in order to have tools at your side when working. In the racing division the workbench combination with power unit cabinets allows permanent access to tools, compressed air and power supply. We support you with practise-experienced solutions and decades of experience. Contact us.



www.lista.com

Flying Dutchmen

Team Delft from the Netherlands once again took top honours at Formula Student UK – we took a close look at its winning design

By GEMMA HATTON



Founded in 2000, Team Delft has a rich history in Formula Student. It is currently the second best electric Formula Student team in the world, having won overall at eight competitions, five in Formula Student Germany, and now three in FSUK. So, what is the secret to its great success? The answer is continuous innovation and pushing the boundaries in both engineering and the rules.

Wheels and tyres

One of Delft's most iconic engineering achievements is the unique inner-wheel design, which was first developed for the DUT14 and combined a one-stage transmission with a spoke-less wheel design. This year the concept was developed further and parts of the brake caliper were integrated with the upright, which not only reduced the number of parts but also the length of the load path and thus, the mass. 'Our motor is inside the hub and we have a one stage planetary gear system which is integrated inside the upright as well as one half of the caliper,' explains Stijn Pennings, team manager. 'This means our drivetrain is only 3 to 4cm wide.'

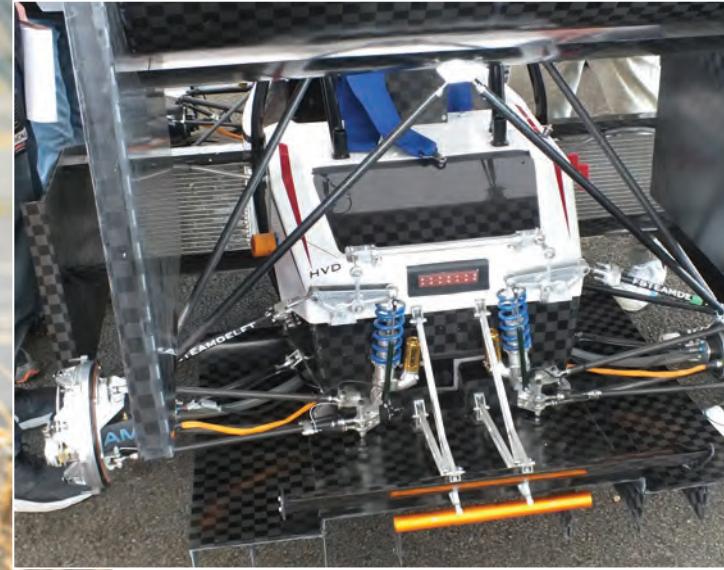
Something else that makes Delft so unique is that it has been developing its tyres with Apollo since 2013, and this year worked on the size and the compound structure. Delft student Daniel van den Berg explained: 'The goal of the vehicle dynamics department is to maximise both car and driver performance in the competitions. The tyres of any car form the only contact the car has with the road. Thus, all forces which accelerate the vehicle in both longitudinal and lateral direction are generated by the tyre. Up to and including the year when the DUT14 was made, the team always used pre-designed tyres. They were a black box, a slip went in and a force came out accelerating the car. Generally speaking not a lot was known about the essentials of tyre dynamics, and how to maximise the performance of the tyres.'

'In 2013 this was changed as the team got the opportunity to develop our own tyres. We were able to do this with the support of Apollo Tyres. Daniel Muusers, now chief vehicle dynamics, embarked on this journey to both understand the underlying dynamics as well as design our first very own tyres. The striking results of this year-long research can be seen

on the DUT14. The reduction in size meant that the DUT14 could go back to the essence of our team, a lightweight design,' said Berg.

Pennings added: 'In 2014 we made a lap simulator to identify the crucial car parameters, and of course one of the most important is the friction coefficient. We designed four different compound variations, two of which were effective and two that were not. We had to choose between the two effective designs, but this was difficult because one showed significant graining, and the other looked promising but only came to temperature after five laps which was too slow for us. However, these tyres were tested at 5degC which is not realistic. So once we tested at a more representative temperature of 20degC we found that the tyre that was graining at the lower temperature was not at the higher temperature and so we chose this one. We still ordered the other alternative, however, to complete different structure tests on. There is approximately a three per cent increase in performance by just changing the structure of the tyre.'

Another benefit of developing your own tyres is the flexibility in size: 'We also wanted to



Main picture: The Delft DUT15 ran with an unsprung wing for the first time this year while it also used sidewings **Top right:** The accumulator was re-designed for this year, and can now store 12 per cent more than previous example **Right:** Detail work on car was impressive

make the wheels as small as we could to make them as light as possible. There is a little less compound on each tyre, and 1mm less rubber around the entire circumference of the tyre quickly adds up to a large weight saving; each tyre is 1kg lighter than last year,' says Pennings.

Sadly these newly developed tyres were not ready in time for Silverstone, and so Delft could only compete using its wet tyres – however, this year's wet tyres were actually faster than last year's dry tyres due to their unique development process, and as it turned out the British weather played into their hands. 'During the first two laps last year's slicks were faster, but over the whole race distance of the endurance event, this year's wets are actually faster because the dry tyres degraded quicker,' Pennings says.

Accumulator

In accordance with this year's rules, Delft also had to re-design its accumulator, which provides the energy to its four electric motors at each wheel. This year's design can store 12 per cent more energy than DUT14, reaching 7.2kWh. Although this led to a weight increase, the team's simulation demonstrated that the

increased energy capacity was more desirable as it results in a higher average velocity throughout the endurance event.

Aerodynamics

This year was the first time the team ran with unsprung wings. This means that the wings are mounted directly on to the wheels instead of the chassis so that the angle of attack of the wings remains as constant as possible, because it is not affected by the movement of the car. The new aero rules reduced the width of the rear wing, and so to ensure it was still effective, the front wing had to remain low. Another consequence of a narrower rear wing is that sidewings could be used, as the turbulence from the sidewings no longer disturbs the flow onto the rear wing because the rear wing simply isn't there. Although Pennings says this was only a rough concept as the team ran out of time to refine it. Main rivals ETH Zurich also ran sidewings, so it seems that this could be a step in the right direction.

Much of the DUT15's aero package was designed in CFD using Open FOAM software. Here Delft has made a big step. In the past its

CFD projects were reliant on a privately owned cluster made up of 36 computers, all of which were old university cast-offs. Using this system, solving a case would take around 24 hours which limited the amount of optimisation that could be done. So with this bottleneck in the design process identified the DUT Racing students went looking for another solution and ended up using a cloud based system.

You may think that teams such as Delft with their many students, resources and sponsors, have little more to do than refine their designs each year. However, there is always plenty to work on and Pennings still feels that there is much potential to come from the 4wd system: 'We need to do a lot more control testing and this is something I would recommend for next year's team. This is our fourth year with 4wd where we can independently control all the wheels and we still haven't really exploited the torque vectoring capabilities and so on. The only way to do this is to finish the car early to allow for substantial testing so that you can tune the acceleration, so the driver feels like the electrical systems are actually helping him rather than slowing him down.'



Wings clipped

Big changes to aerodynamic regulations for 2015 ensured there was plenty of innovation on show in the Silverstone paddock

By GEMMA HATTON

One of the first Formula Student cars to feature an aerodynamic package was the 2002 entry from Monash University, and ever since it has been a pioneer in the field of generating downforce. Although it only enters the Silverstone competition every couple of years, there is no question that its monster wings, some of which generated up to 3460N of downforce at 115kph, set a trend.

By 2013, nearly every top team featured large front and rear wings along with large diffusers and undertrays. 'We opened up the regulations about five years ago to allow much bigger aerodynamic wings, but they are probably getting too big now,' said Andrew Deakin, vice chancellor of Formula Student and chairman of the International Rules Committee. 'Having spoken to the design judges it seems that there are quite a few teams that just have a

big wing without understanding how efficient it is and how much downforce it generates.' Which is why 2015 saw the most dynamic aero rule changes to date.

The first main change was restricting the width of the rear wing, which can now only be as wide as the inside of the rear tyres as opposed to the outside of the rear tyres as the rules were last year. The next was reducing the plan view size of both front and rear wings, with the front wing now only able to extend 700mm further from the front tyres when it used to be 762mm, and the rear wing reduced from 305mm to 250mm rearward from the rear tyres.

One of the toughest rules by far for this year was the deflection test. If any aero device deflected by a 'significant' amount then the scrutineers could apply a 200N force at any point, in any direction, and the resulting deflection could be no more than 25mm.

Although this was rarely implemented, it definitely resulted in teams having to reconsider the stiffness of their designs and is also the reason behind why some teams decided not to run underbody aero. 'To meet those rules with an underbody that doesn't add a lot of weight is very difficult,' highlighted Cole Pearson, chief aero designer at Oxford Brookes Racing.

Sidewings

By reducing the width of the rear wing, several teams such as ETH Zurich, TU Delft and TU Munich designed an undertray combined with a sidewing concept. 'The undertray is an aerofoil shape which we also ran last year,' explains Jonas Abeken, chief executive officer at 2013 FSUK winner, ETH Zurich. 'We gain more downforce with this combination of undertray that extends out the back and the sides of the car, along with the sidewings. These are new for this year's

Karlsruhe once again went for some very neat looking wings on its pair of 2015 cars, but the design had some unintended consequences, including robbing the front brake discs of air. Also, it seemed that the drivers in both cars struggled to see the leading edges and spent a lot of time collecting cones in both the Sprint and Endurance events





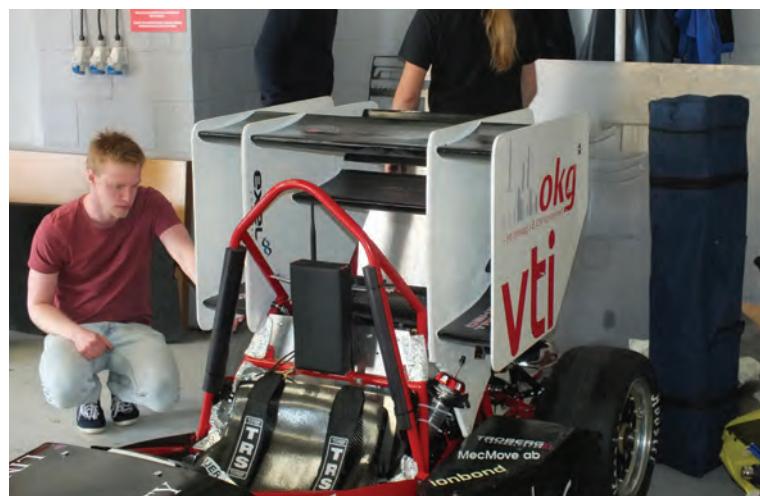
TU Munich was one of a number of teams who attempted to recapture lost downforce via the use of sidewings – overall winner TU Delft also used these



The level of complexity of the aerodynamic packages on the 2015 cars went beyond anything seen before as teams tried to claw back aero lost to new rules



Swan neck rear wing supports were used by some teams but derided by others, a number of teams also opted to use these very delicate lattice-like swan necks



Linkoping arrived with perhaps the most wing elements ever seen on a FSAE car. We lost count at 11 in the rear wing alone. Team claims to have optimised wings

rules as last year this would not have been a good solution. The flow onto the rear wing would have been disturbed from the effects of the sidewings, and it would not have worked effectively. But now that the rear wing is no longer in the way, it's an effective solution.'

Cooling Issues

With so much emphasis on the aerodynamic rules, this certainly was the main focus this year. Teams such as Chalmers spent over 50,000 CPU hours in CFD, trying to optimise the airflow around its car. However, some teams optimised their designs too much, which resulted in some highly effective front wings that unfortunately caused problems. 'We found out during the testing phase of our car that the front wing takes too much air away from the front wheels and therefore the brakes,' explained a spokesperson for Ka Racing, Karlsruhe. 'We had to find a solution and integrating a brake cooling fan was the best and fastest. We have now validated this with over 600km of testing.'

Arguably the fact that Karlsruhe's car is a high power concept did not help its brake cooling issues, as this not only means it is heavier (at 200kg), but maximum downforce was the aim. To add to its problems it was running the smaller 10 inch wheels.

Either way, the overall driveability and reliability of the car has to be the main priority. One team that didn't fall into this trap was Norwegian University of Science and Technology (NTNU). 'We specifically designed our front wings not to eat up all the air, as we knew this may be a problem,' Roy Andreas Iversen, project manager said. 'We could have gained much more downforce by having a larger front wing but we wanted a stable car, that was neutral and handled well, so we prioritised the balance of the car.'

This seemed to be another trend for this year. Several teams highlighted that their focus was purely on the aero balance of the car to give their drivers the most predictable and driveable machines. 'The front wing has been

limited by the rear wing, as the front can take a lot more downforce, so we tried to get the same downforce at both the front and the rear,' said Iversen. 'Therefore we took a little hit on the maximum downforce we achieved to increase the overall feel of the car.' This was similar to both Team Bath and Oxford Brookes who both worked closely with lap time simulations and the suspension department to achieve a 50-50 aerodynamic balance.

Swan neck mountings

One controversial area that saw many different approaches was the mounting of the rear wing, and a large proportion of the top teams run with 'swan neck' like rear wing mountings, which attach to the upper side of the rear wing. However, the teams say this was not a direct consequence of the rules (and other teams completely disagree that it is an effective solution). 'Essentially, you want to keep the low pressure side, the underside of the wing clear because that produces approximately

'The front wing takes too much air away from the brakes'



The Karlsruhe car sported an apparently Benetton B193 inspired rear wing with a forward element – the German team was one of a number of competitors to opt for this style of wing



The Karlsruhe car also needed to use cooling fans on the front brakes as a consequence of the front wing reducing the air flow over the disc and caliper



Linkoping's front wing was perfect for collecting up the cones – problem was the event was not over

two thirds of the overall downforce of the rear wing,' explains Abeken. 'The moment you mount from the underside, you are creating an obstruction which causes separation and therefore a loss of downforce. We found that there was much less loss of downforce by mounting on the top of the rear wing, rather than on the underside.'

Another team that utilised this technique, and one of the few teams implementing it last year, was Oxford Brookes. 'Compared to a lot of

teams we run relatively small mounts. Last year we wanted to mount on the upper surface of the rear wing because it's much more efficient than underneath, so we ran a design that used carbon tubes and joints,' says James Durham, head of aerodynamics for Oxford Brookes Racing. 'Although this gave us much better flow under the wing, it meant we were seeing quite a lot of deflection through the whole assembly and therefore this year we decided to go for a solid carbon swan neck and use a nomex core. It's extremely lightweight and we use the geometry of the roll part to give us an angle to ensure that for side deflection we still have substantial strength throughout the system.' The further advantages of this type of mounting is the fact that it is a single component which is relatively easy to lay up and it remains lightweight. 'The weight of our total aerodynamics package, including the mounting system, is only 10kg and this is helped by the use of hollow carbon fibre wings with an internal C bracket,' says Durham.

Oxford Brookes' upper cascade

There are always some bizarre wing designs throughout the competition, some of which may not have been entirely thought through. However, one interesting element on the Oxford Brookes car which had been thought through was the upper cascade on the rear wing. 'It helps us generate more upwash and allows us to run higher angles of attack on the upper flaps,' explains James

Durham. 'It is something we have seen before and, because we are front limited, we really focused on getting a good balance front to rear because that was an issue last year. Even though the regulations have reduced the working area of the wings, by adding a high mounted cascade, we can gain more working area.'

Cole Pearson, chief aero designer says: 'As long as you keep the separation between the

'The correlation between CFD and reality is a well-known problem, but teams try to mitigate this by conducting correlation studies, to improve the accuracy of their simulations,' says Pearson. 'We worked with wool tufts and flow vis during track testing to compare the results with CFD. We use damper potentiometers to the spring rates of the vehicle from which we can read the corner loads. We do both constant speed testing, which models a static vehicle at speed so we can measure the vehicle's lift and front to rear balance, and we do coast down testing where all the forces are taken off the car apart from the aero and tyre drag which we can read through the velocity trace as well as accelerometers.'

All this work amounts to a correlation of five per cent between the team's CFD and its on track testing. Although this still shows CFD's inaccuracies, it is impressive to see teams focusing on such areas and is something they need to work on to continually improve.'



Upper cascades on the rear wing of the Oxford Brookes entry were to help balance out the front-limited racecar

Unsprung wings

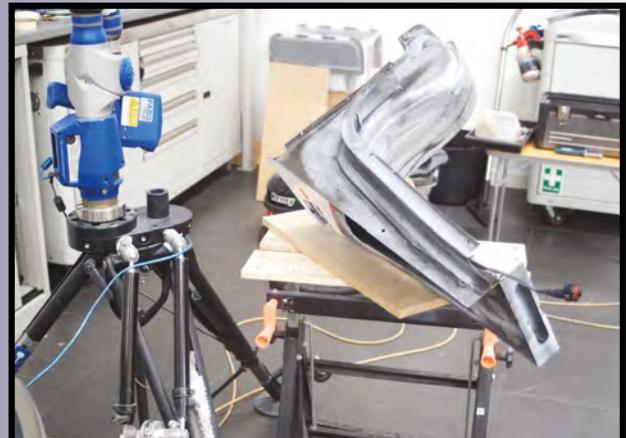
Other teams decided that the optimum approach was to have unsprung wings. 'We ran swan necks two years ago, but I am not a fan,' says Tom Pierson-Smith, team leader of Team Bath Racing. 'To me, the load path needs to go straight into the tyres, so my favourite mounting solution is the unsprung wings that Delft run. If we had had another month we probably would have run that. Instead, we have tried to transfer all the load through the four pillars underneath the main plane and hopefully as much of that into the tyres.'

These swan neck designs are primarily benefiting the airflow on the underside of the rear wing, which may be a result of teams using optimisation software such as CFD. The question is whether this benefits the overall handling of the car, or are unsprung wings ultimately the best way to go? It will be interesting to see which solutions teams decide to develop for next year's competition.

Manchester Metrology LTD

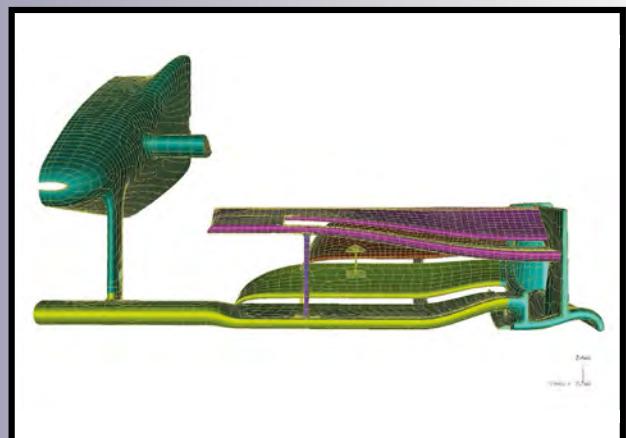
Portable Measurement Solutions

ONSITE INSPECTION AND NON CONTACT LASER SCANNING SERVICES



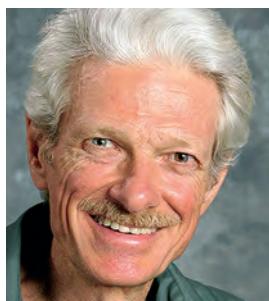
FARO ARM INSPECTION

HIRE AND LEASING OF FARO ARMS, GAGES, LASER TRACKERS AND LASER SCANNERS.
ACCESSORIES, PROBES, MAGMOUNTS, LEAPFROG CONES AND MUCH MORE.



WWW.MANCHESTER-METROLOGY.COM

Manchester Metrology Ltd, Unit 12 Greenside Lane Industrial Estate
Greenside Lane, Droylsden, Manchester M43 7AJ
Tel: 0161 637 8744 • Fax: 0161 425 0944
info@manchester-metrology.com



Coping with tightening turns

Decreasing radius turns and slaloms in autocross

Autocross places demands on good handling rather than engine power and outright speed. A good setup is crucial



Question

I see that your speciality is oval-track and road racing, but I get the sense that a few cursory minutes of your thoughts on autocross might be as good as some experts in this smaller field of interest.

Do you have any thought on shock absorbers when the driving is to keep control during all quick large steering movements and sharp transitions between off-throttle and/or trail-braking into tightening slaloms and other no-rest decreasing radius turns, and powering out of tight corners?

The consultant says

I'll actually advise on any kind of vehicle. Right now I'm mentoring a team at UNC Charlotte who are designing a human-powered vehicle. US-style autocross is basically road racing

(asphalt surface; car turns both ways) in a parking lot, one car at a time, around traffic cones. Usually the turns are tight and the straights are very short. Well maintained parking lots tend not to be very bumpy, but they can be quite wavy, since they cover a lot of area and are generally intended to be used at very low speeds.

I've driven a few autocrosses, and the turns and gates come at you so fast that the steering wheel is in nearly constant motion and the car spends very little time in steady state.

The event also rewards aggressiveness. You get a time penalty for every cone you knock down, and if you miss a gate your run is not counted, but on the other hand there is usually not much to hit except cones, and you are scored only by your best run.

Because most of the turns are tight and of short duration, the car is generally undergoing large yaw accelerations for a substantial portion of the run. The usual challenge in very tight turns or slaloms is to overcome understeer when initiating the turn and oversteer when concluding the turn. My usual recommendation for this is to use more low-speed damping, both compression and rebound, at the rear than at the front. That tends to de-wedge the car (unload the inside rear and outside front and load the other two

wheels) when it's rolling outward and add wedge when it's de-rolling or rolling inward.

This is not without some disadvantages as the rear wheels will tend to unload more than the fronts over any crests. Using compression damping, not just rebound, at the rear can help calm things down. This may call for more than a simple adjustment on a single-adjustable shock, however.

The questioner asks about decreasing-radius turns and slaloms. The courses I've driven didn't have these, but I can easily imagine course designers including them to add a driving and setup challenge. When we're trying to slow down during sustained cornering, we are most often worried about oversteer rather than understeer. If we've adopted setup tricks that are geared to tossing the car entering tight turns, especially extra rear brake, a steady turn of decreasing radius can catch us out.

Barring elaborate active suspension and braking systems, we can't really expect the car to know whether we're trying to toss it or slow it without spinning it. However, if we use rear low-speed damping to free the car up on entry rather than using rear brake, that will have relatively great pro-oversteer effect entering abrupt turns, and relatively little effect in sustained braking and turning.

CONTACT

Mark Ortiz Automotive is a chassis consultancy service primarily serving oval track and road racers. Here Mark answers your chassis setup and handling queries. If you have a question for him, get in touch.

E: markortizauto@windstream.net

T: +1 704-933-8876

A: Mark Ortiz

155 Wankel Drive, Kannapolis, NC 28083-8200, USA

Formula SAE differential differences

A look at some of the many types of diff now available

Question

There seems to be a bewilderingly wide variety of differentials used in FSAE. What are the pros and cons of each type?

The consultant says

I have at least some experience with the following options, in chain-drive FSAE cars:

1. Worm gear diff (Quaife, Zexel)
2. Clutch pack diff (Drexler)
3. Viscous diff (adapted from Mazda Miata)
4. Face cam diff (Suretrac, which is from a Honda ATV)
5. Spool

The problem with the worm gear design is that it doesn't provide much locking effect when the inside rear wheel is very lightly loaded. This can be helped by preloading the gears, but the preload is highly wear-sensitive. The result is that when cornering near the limit, the car cannot be throttle steered; the inside wheel spins.

The Drexler comes preloaded. When the preload is right, the car can put enough torque through the diff to get some further locking, even with the inside wheel very light. There is, however, an inevitable compromise between torque transfer when it's needed and the tendency of the preload to produce understeer. In the 2015 UNC Charlotte FSAE car, the team found it best to reduce preload torque to about half the value the unit had as supplied.

It should be noted that this was a very light single-cylinder car with 10in wheels. The car, with driver, is around 500lbs, compared to more like 650lbs for a typical 4-cylinder car. The tyres have about 18in outside diameter, versus about 21 for a typical 13in tyre. This means that for a similar effect on car behaviour, that car would theoretically need the preload reduced by a factor of $(18/21)(500/650)$, or to about 2/3 as much, compared to a 4-cylinder car on 13s. The amount of preload reduction actually used was the result of cut-and-try.

The team also had a car with an adapted Mazda Miata (MX5) viscous LSD. This type of diff has the advantage of having negligible locking torque when there is little speed difference, and still generating locking torque when one wheel spins, even if the

wheel that's spinning is transmitting very little torque. It is entirely velocity sensitive.

The UNCC car with the viscous didn't perform as well as hoped. I attribute this to two factors. First, there was no way to adjust the aggressiveness of the viscous unit. Second, the team insisted on using traction control. The viscous unit works by allowing some wheelspin but generating a locking torque roughly proportional to the square of the amount of wheelspin, and also related somewhat to temperature. When

either overrun or underrun the carrier, and the average of the two output shaft speeds will not necessarily equal the carrier speed. The paper does not include information relating locking torque to input or output torque. The team used this unit because it seemed promising, was able to put some power down with one wheel very light, and was available at a much lower price than a Drexler. I am not sure what degree of success the team had with this unit, but they went to a Drexler for the next car.

There was no way to control the aggressiveness of the unit, and the team insisted on traction control

the engine management won't allow any significant wheelspin, the viscous diff can't work as intended. According to the students responsible for tuning the ECM, the abruptness of traction control intervention could be adjusted, but the trigger point, in terms of slip value where intervention began, could not.

The face cam unit remains a bit of a mystery to me, even after reading an SAE paper about. It appears to me to be a kind of soft locker, rather than a true differential. That is, it will allow one wheel but not both to

One car had a spool. A car with a spool requires a driver who can deal with its properties. Drivers with karting experience tend to be good candidates. This particular car never was developed to the point where it was reliable. One problem was that it kept breaking driveshafts. I still think somebody should try a locker – either a face dog locker like a Detroit locker, or a roller clutch locker like the Weismann. I would appreciate hearing from anybody who is aware of anything like either of these being tried in FSAE. R



Drexler manufactures a clutch pack differential that comes preloaded; Charlotte FSAE team reduced preload by half

Pedal of honour: the big brake out

All you need to know to sort brake pedal pressure for FSAE

Question

How do you calculate line pressure and pedal force for a brake system? If the line pressure or pedal force is too high, what can you do?

The consultant says

This question comes from the UNC Charlotte Formula SAE team. The team is trying to run a legacy design, making the fewest possible changes. The legacy design, however, has a persistent brake problem which caused the car to DNF in the endurance event in 2015 due to the brake overtravel switch being tripped, shutting off the engine. This was also a problem in the brake test that is part of tech inspection. The brake system does not have a sufficiently firm pedal, and also gets some heat fade in protracted use. This, combined with the softness of the pedal, results in the pedal travelling far enough to trip the required overtravel switch. The switch can be tripped in limit braking with cool brakes, and it becomes easier and easier to trip it as the brakes fade.

The system has some problems that are immediately apparent. The master cylinders,

which are under the driver's heel beneath a removable panel, are mounted on their sides to reduce height. The banjo fittings through which the hoses from the remote reservoirs feed the master cylinders are at 3 o'clock and 9 o'clock, not 12 o'clock. That creates an unblended high spot inside the master cylinder. Two of the calipers are mounted with the bleed screws pointing down. These can be bled, but only by removing the calipers. The reservoirs are very nearly at the same height as the calipers; there are no residual pressure valves.

In sum, there are a number of ways that air in the system might be causing soft pedal. If we are willing to live with taking calipers off to bleed the brakes, all these potential sources of air in the system can be addressed at the master cylinders, pedal, and reservoirs.

But is that likely to be the whole problem? Can we deal with this by revising the layout of the pedal, master cylinders, and reservoirs? Can we keep the existing uprights, discs, and calipers? Or are there further problems relating to the brakes themselves? It is to answer this that we need to see if line pressures and pedal

forces are within reasonable limits.

The car is built very light. With the lightest driver in 2015, it weighed about 512lbs. It uses a single-cylinder engine and 10in wheels. Tyre outside diameter is about 18in. Front and rear brakes are identical. Calipers are the very light AP CP4226-2S0. These are popular in FSAE due to their small size and weight, but they are designed for use on the rear of racing motorcycles. In the original application they are intended to actually produce less rear braking force than stock calipers, and also provide a small weight reduction. The reason for wanting less braking is that motorcycles on road courses, at least in the dry, are limited in straight-line braking by rear wheel lift rather than grip. AP says that when these calipers are used in FSAE applications, there is a danger of fade, caliper flex and excessive line pressure. They also say that line pressure needs to be kept below 1000psi.

It should be obvious why caliper flex will cause soft pedal. High line pressure will also reduce pedal firmness because the fluid has some compressibility and the hoses have some compliance. AP's recommended guidelines are that if line pressure in any brake system exceeds 1000psi the system is undersized, and if it is less than 400psi the system is oversized. An oversized system works fine; it's just bigger and heavier than it needs to be. An undersized system is likely to have precisely the problems we are experiencing, especially with calipers optimised for lightness rather than rigidity.

So what line pressures should we expect our system to generate? First, we have to figure out what force the system has to generate at the contact patches. In our case, we have identical brakes front and rear, and roughly 50% rear statically. Some amount of the car's weight will transfer forward in braking. So we need to look first at the front brakes.

The team has not measured the car's c.g. height. It's probably somewhere in the 10 to 12in range. The wheelbase is 60in. How much of the car's weight will transfer forward? We can work this out with free body diagrams, but here's a shortcut: the portion of the weight that will transfer per g of rearward acceleration is the c.g. height divided by the wheelbase. For a 12in c.g. height, that's $12/60 = 1/5 = 20\%$

There are a number of ways that air in the system might be causing a soft pedal



It's a delicate task to get the brakes right on a small and light Formula Student racecar – Delft aced it with its DUT 15

per g. For a 10in c.g. height, it's $10/60 = 1/6 = 16.67\%$ per g. AP suggests assuming that the car brakes at 1.25g. That's perhaps a bit lower than FSAE cars will achieve on a good surface with no downforce. With downforce, the accelerations can be much larger. The current car has no wings or other downforce devices, but the team is considering adding some.

Normally we might start with a heavy driver and a high assumed c.g. But let's see what we get, given charitable assumptions: 512lb total weight, 10in c.g. height, 1.25g braking. The portion of car's weight that transfers is a sixth times 1.25. That's 20.83%. The front wheels have 70.83% of the 512lb weight on them. That's 362.6lbs for the wheel pair, or 181.3lbs per wheel. For simplicity, we'll assume that the coefficient of friction at the front contact patches equals the acceleration of the car in gs: 1.25. Friction force at each front contact patch is then 181.3×1.25 , or 226.7lbs.

The radius of the tyre is 9in. The brake disc is 7in diameter, and the pads sweep a surface on it about an inch wide. The acting radius is then about 3in; about a third of the tyre radius. Therefore the two brake pads combined have to generate a friction force roughly three times the contact patch force, about 675lbs.

The pads have a coefficient of friction of about .42 to .40. Using the .42 value, the two pads have to press on the rotor with a combined force of 675lbs divided by .42, or 1607lbs, or about 800 pounds each. The pistons are an inch in diameter. The area of each piston is the diameter squared times $\pi/4$, or .7854 sq.in each. The hydraulic pressure needed to generate 800lbss of force from a piston that size is 800lbs divided by .7854sq.in, or 1019lbs per sq.in. We're over the recommended limit, using the most charitable assumptions. With a lower pad coefficient of friction, a grippier road surface, a heavier driver, a higher c.g., and/or some downforce, we could easily see 1200psi or more.

We can conclude that the front brakes are seriously undersized. What about the rears? They only need to generate about 25 to 30% of the stopping force, so they will see at the most 30/70 or 43% as much pressure as the fronts. Even with a lot of downforce, they are within safe operating limits, provided that the master cylinders and pedal are sending them only as much pressure as is needed to have them lock at about the same pedal force as the fronts.

Although the front brakes are operating at higher than recommended pressure, there have not been any leaks or catastrophic failures. We just have a spongy pedal and some fade. We don't really know how much of the compliance is due to the high hydraulic pressure. We can reasonably predict that we won't get really good operation as long as the front brakes are undersized, no matter what we do with the pedal and master cylinders. On the other hand, we know that the



Many FSAE teams will use brakes designed for motorcycle racing, but these can create their own peculiar problems

current configuration doesn't permit proper bleeding, and we're bound to get a significant improvement just from correcting that.

We also know that we can shorten the pedal travel by going to bigger master cylinders and/or a smaller pedal motion ratio. We can't just let the pedal travel more, without changing the frame design. The overtravel switch is close to the front bulkhead now. Moving that forward means lengthening the frame, which in turn means the current nose won't fit. Having the pedal further rearward when the brakes are not applied is not an option either, because our tallest drivers can barely fit now, and the rules require us to accommodate a 95th percentile male. The only way to shorten the pedal travel via pedal or master cylinder changes is to add to the pedal force required, one way or another.

Pedal force

So where are we now on pedal force? The front master cylinder is 5/8in diameter. That's .307sq.in of piston area. 1000psi acting on that piston produces a push rod force of just over 300lbs. 1200psi produces just over 360lbs push rod force. The pedal motion ratio is 6.5:1, and there are two push rods. At mid-adjustment on the balance bar, force on each push rod is 3.25 times pedal force. Pedal force is then about 92lbs for 1000psi, or about 111lbs for 1200psi. Recommended pedal force for a 1.25g stop is 80lbs. 100 is heavy but not unmanageable. More than that may be tolerable.

The rear master cylinder is 3/4in. That means

that at mid-adjustment on the balance bar, the rear brakes are generating about 41% of the braking, not the 25 to 30% they would require if the front wheels are to lock before the rears. At around 1g, at mid-adjustment on the balance bar, the rear wheels lock. As further pedal force is added, the rear calipers continue to deflect, the fluids in the lines continue to compress, the hoses continue to swell, but none of the added pressure does anything to stop the car because the rear tyres are already contributing as much retardation as they can.

Some reduction in deflection can be had by not overpressuring the rear brakes. This can be accomplished by balance bar adjustment up to a point. Beyond that, either a larger rear master cylinder or a proportioning valve in the rear line could be used. Using a proportioning valve along with a balance bar makes sense because it allows us to have less rear brake percentage at high apply pressures, where forward load transfer is greatest, without having premature front lock-up in conditions of poorer grip, and still having enough rear brake to free the car up in trail braking. A rear proportioning valve would not reduce pedal force required and wouldn't reduce deflections occurring on the master cylinder side of the valve. However, it would reduce deflections occurring on the caliper side of the valve.

Hopefully, this discussion provides some useful info on how to calculate hydraulic pressures and pedal forces in brake systems, and an insight into the complexities. R

We can conclude that the front brakes are seriously undersized. What about the rears?



NATIONAL
MOTORSPORT
ACADEMY

APPLY
NOW!

BRITAIN'S FIRST *ONLINE* MOTORSPORT ENGINEERING DEGREE

Mosler GT. Winner
GT Cup, GTO Class
Championship



Learn Online and On-track with one of our Race Teams

College/School leavers – earn while you learn & gain practical motorsport experience

Mature Students – A second chance for a Motorsport Career, study flexibly alongside work & family

Foundation Degree (FdSc) Motorsport Engineering



BSc (Hons) Motorsport Engineering

Awarded by Staffordshire University.

The National Motorsport Academy, in partnership with Staffordshire University, is pleased to launch Britain's first online Motorsport Engineering degrees. In this competitive, global industry, Motorsport Engineers must have the broad range of skills demanded by the top teams. Working closely with the industry, we have designed our courses specifically to meet their requirements. Not only will our graduates be qualified Motorsport Engineers with practical experience, they will also be innovative, resourceful and commercially-focused. Making them highly sought after graduates.

Why study with us?

- Low Tuition Fees £5,500 per year/level
- Entry from 100 points
- Mature students welcome
- EARN while you LEARN
- Choose your own start date
- Your own personal tutor
- Unlimited tutor support, 5 days a week
- Stimulating, interactive, course content
- Online forum to meet other students
- Student loans available
- Free Autocad & industry software, NUS card
- Guaranteed work experience placement

How to apply

Please register on our website today at
<http://motorsport.nda.ac.uk/how-to-apply>

What you will study

- Mathematics for Motorsport
- Race Car Design & Preparation
- R & D Simulation and Analysis
- Fundamentals of Motorsport Technology
- Fluid Mechanics & Thermodynamics
- Engine Design, Development & Simulation
- Vehicle Dynamics, Physics & Data Acquisition
- Work Experience & Research Study
- Advanced Engine Development
- Aerodynamics
- Hybrid & Electric Vehicle
- Final Project



New for 2015 Lotus GTE (Le Mans). Over 30 races planned.

Facebook debate

Provoked by the current trend of FSAE teams staging elaborate and seemingly expensive launches, we asked on our Facebook page is Formula SAE/Formula Student getting out of control in terms of costs or are the rules too stable? Is the best engineering winning or simply the biggest budget?

This seemingly innocuous question provoked an ongoing debate. To read the full debate or to join in visit www.facebook.com/RacecarEngineering

Julian Hakkinen: I think the concepts have converged a bit over the last years (10in rims, single cylinder/4WD electric, as much aero as the rules allow), so therefore I think the overall costs for a car have not changed too much in recent seasons. Looking at FSAE Michigan, the performance of the University of Florida showed that you don't need the most fancy car to place on the podium, and get close to winning. Budget is not everything. Yes you can get yourself some nice unnecessary parts but that won't give you too much performance. Only in the electric class, I think, you cannot win if your budget is quite limited.

Some parts are really expensive and you cannot get them sponsored, so you have a big disadvantage, that you probably are not able to make up with

best engineering against teams like Delft, Zurich, Stuttgart or Karlsruhe.

Daz Wiese: I personally think the engineering rules are fine, as they promote innovative ideas. But how many of the cars are actually designed and built by the students these days? There should be a cost cap or containment, with harsh

penalties if any of the teams are found guilty of not adhering to it.

Robin Bailes: I think FSAE Michigan proved you do not need a large budget to be competitive. Gator Motorsports (Florida) were second in both Design and Endurance, finishing third overall. Comparing them to TU Graz, who finished less than 20 points ahead of them overall (finishing first), the budget difference is huge. Formula Student is more about the people involved, way more so than anything else, if you don't have the right people, you could have a budget of £1m, you still wouldn't win the competition.

Soren 'Kage' Kaae: The rules of Formula Student have been too stable for a long time. Especially engine regulations. Why have a maximum displacement and a restrictor? The only people who gain from this are those who sell spare parts for R1's and CB600RR's.

Pat Clarke: FS was started to complete the education of young engineers with an interesting practical project. It was to be an educational engineering competition with a motorsport theme, not the motorsport event it has mostly become. Part of the challenge set for teams is to raise funding and clearly some teams are better than others.

What the event really needs to get it back towards the original intent is to readdress the points split between the static and dynamic events. Clearly, an engineering design competition that awards less than 1/6 of the available points to design is one of the issues. If FSAE is a design comp', surely the designs should be assessed against their design criteria

(with cost an important factor). If we are supposed to be preparing young engineers for industry (as the original intent) then Industry needs cost savvy engineers and project managers, not race engineers and drivers.

Charlie Kniffin: It would definitely be worth paying more attention to manufacturing and cost effectiveness during Design judging. Either that,

or maybe revamp the cost of the event to make it better reflect real world cost. I'm working for a major jet engine manufacturer and some of the stuff I

see teams putting on cars is just so unrealistic in the real world at this time. I think it is a great way to get exposure to the technology, but it won't be hitting the automotive world for quite some time. There needs to be more of a trade off when it comes to putting these massively expensive parts on the car (the five figure electric motors being another example).

I'll also add that my team (UCONN) placed 19th this year with a very basic car: spaceframe, 4 cylinder, no aero. And that is with finishing dead last in skid-pad and no prep at all for Business. So I guess there are two sides to this argument. There are certainly some exorbitant parts going on to some of these cars, but going by the Gators and from what I have seen from my team you can go basic and still do well.

To meet and see the cars of some of the top British Formula Student teams visit the 2016 Autosport International show, where there is a section dedicated to universities and colleges involved in the motorsport industry 

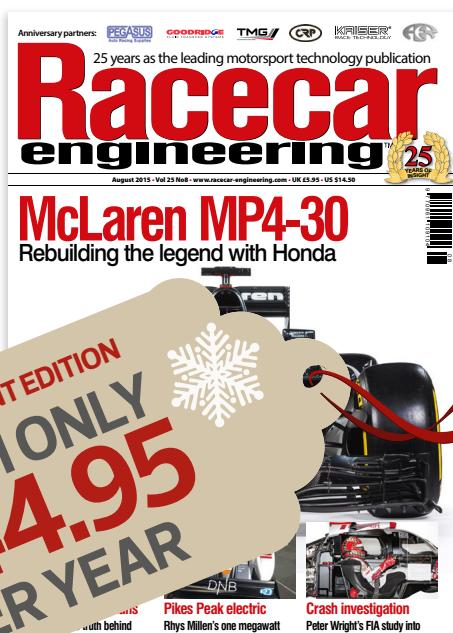


University of Florida, Gator Motorsports, showed at FSAE Michigan that you don't necessarily need a huge budget to be successful, coming second in Design and Endurance and finishing third overall. Some also say raising the budget is a part of the challenge when it comes to student engineering competitions like FSAE

THE PERFECT CHRISTMAS GIFT

SUBSCRIBE FOR FAMILY AND FRIENDS

Give the gift that lasts all year!



LUXURY PRINT EDITION
FROM ONLY
£44.95
PER YEAR

SAVE
OVER
£26



ALSO AVAILABLE IN
DIGITAL FORMAT

- Download to your computer, smartphone or tablet device
- Instant delivery worldwide
- Easy access anywhere, anytime!

ONLY £34.95 FOR 12 ISSUES!



www.chelseamagazines.com/racecar-RX5P for print



www.chelseamagazines.com/racecar-RX5PD for digital



+44 (0)1795 419 837 quote RX5P for print or RX5PD for digital