Auburn’s 2011 Formula SAE team pulled out a creditable 16th place finish in a sold-out field of 120 teams from 13 countries. We were the 9th U.S. finisher in this increasingly international contest. We departed from our three-year adventure in advancing FSAE powertrain development (pioneering the longitudinally-placed super motard engine with shaft drive) to return to a less risky arrangement (transverse sportbike engine with chain drive), and emphasized project management to achieve an early design freeze (1 October) and early prototype completion (26 February). Even this level of deliberate progress didn’t entirely shield us from disaster – a shattered differential three hours before our Endurance run threatened to spoil the season. But the team’s skill was sufficient for the challenge, and a solid spool was designed and fabricated from the wreckage of the diff in time to start and finish a good Endurance run.

FSAE Background

Almost every major North American engineering college fields a Formula SAE team for competition in either Michigan or California, or in the related Formula Hybrid competition in New Hampshire. Overseas competitions are held in Australia, Austria, Brazil, England, Germany, Italy, and Japan. Approximately 500 teams worldwide compete in Formula SAE, making it the largest motorsports series in the world. The Michigan competition, now held at Michigan International Speedway in Brooklyn (an hour west of Detroit) has by far the longest history and the caché of the “World Series of Intercollegiate Engineering”. FSAE-MI is the premier event in engineering student design competition. Michigan entries are limited to 120, and these usually sell out within a day or two (the record is 11 minutes). The 2010 Michigan competition included entries from 32½ U.S. States, as well as 36½ cars from 12 other countries: Austria (2), Brazil (1), Canada (17), England (1), Germany (5½), India (1), Japan (1), Mexico (1), Puerto Rico (1), Singapore (1), South Korea (2), and Venezuela (3). [The ½ car represents cooperation between Oregon State University and the Duale Hochschule Baden-Württemberg-Ravensburg (DHBW-R - Germany) in a single entry.]

Each college starts every year from a blank sheet of paper to design and build a single-seat, open-wheel road-racing car, the lightest ones getting to below 400 pounds curb weight. The teams are subject only to a 610 cc engine displacement limit, a 20 mm diameter intake restrictor, and absolute adherence to the letter and spirit of a thick set of safety rules. The goal of the Competition is to design and build a prototype for the weekend autocross enthusiast. The teams must demonstrate their prototype cost and manufacturability and sell their design to an investment audience, as well as proving their machine’s abilities on the racetrack. Designs are judged by a who’s who of race engineering professionals, with strong support from top engineers in the racing and automotive manufacturing industries. Although FSAE cars do bear a certain resemblance (due to requirements for: open-wheel architecture; at least four wheels; minimum wheelbase; minimum wheel size), design judges and qualified automotive engineers
never fail to express surprise at the design diversity from team to team and from year to year. Apparently, the perfect design in this ultra-competitive discipline has yet to be identified. Or perhaps it is that each design is only an expression of each team’s goals and philosophy, and success can come in many different forms.

FSAE competitions are 3½ day affairs, beginning with an opening half day for the very exacting Technical Inspection. Cars not passing Tech that day may try again, throughout the competition, but suffer from getting further and further behind on the rest of the schedule. The next day presents additional inspection issues: checking tilt (no leaks at 45°, no rollover at 60°); noise (110 dB max); and brakes (four wheel lockup from speed). Also on this day are the static events that make up 32.5% of the points: Design (explanation of the car and design process to a judging panel); Presentation (selling the merits of the design to an investment panel); and Cost (proving the reported manufacturing cost estimate). The second full day sees the cars running in: Acceleration (time to 75 m); Skid Pad (time on a 50 ft. diameter circle); and autocross (what the cars are made for – usually a 1 km course) – another 27.5% of the points. The final day is reserved for Endurance, 22 km of lapping on a course similar to the Autocross course, with one stop for a driver change. Endurance includes a measurement of fuel consumption, and finishing time plus economy comprise the last 40% of the points (30% for speed, 10% for fuel consumption). Only about one third of the entries are typically able to complete the Endurance Race, and thus get any Endurance/Economy points.

Although stirring race results are the immediate goal of any FSAE team, the real product is the teamers themselves. They learn the hard project engineering lessons of teamwork, metric-based overall design, devil-in-the-details machinery design, project planning and scheduling, financial control, supplier interface, communication (written and oral), and how to enhance each ability to make the whole greater than the sum of its parts. Most importantly they learn (and prove that they have) that special moxie that it takes to get a real running product out the door on time, under budget, and up to a demanding – and rigorously measured - performance specification. They learn that a prototype design is just that – a prototype. It isn’t ready to race until they learn a whole lot more about how to get the most from what they have just built.

FSAE has been running since 1981. Auburn has competed since 1996, placing 3rd in 2004 and 5th in 2003. Team members tend to be mechanical engineers, though a spectrum of other engineering and non-engineering disciplines are also represented. Team alumni are widely sought after, with racing, the automotive manufacturing industry, and SpaceX working hard to retain first dibs.

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FSAE Michigan 2011

The combination of Oregon State University and Duale Hochschule Baden-Württemberg-Ravensburg (branded “Global Formula Racing” – GFR) won the 2011 FSAE competition using a concept similar to OSU’s 2010 winner – full carbon fiber tub; minimum allowed wheel size; single cylinder 450 cc engine [Note: the car was designed for a full aerodynamic package, and wore this in its winning effort at 2011 Formula Student Germany, but ran without the appendages in Michigan]. Munich, Stuttgart, Graz University of Technology, and Wisconsin all made the top five, with Michigan, Zwickau, Akron, Kansas, and University of Applied Sciences Graz completing the top ten. Slipping in front of Auburn’s 16th place finish were Amberg-Weiden, Purdue, Colorado State, Cornell, and Michigan State. [That makes Auburn 9th in the U.S., or 10th if one counts GFR – ed.]
Auburn FSAE 2011

AU/FSAE 2011 was led by Captain Chris Nau. Using a new organizational structure, the next level of management was: Chassis Chief Engineer Nick Durant; Powertrain Chief Engineer Brian Keyser; and Business Manager Michael Gay. Lead Designers included: Sean Baker (electrics); Adam Clay ( drivetrain); Roy Crump (composites); Austin Gurley (suspension); Sherrod James (tire application); Michael Nunnelly (structure); Greg Olin (fluids); David Paulk (intake tract); Chase Reynolds (fluids); Kurt Wagner (aerodynamics); and Ben Williams (brakes). The vital jacks-of-all-trades were: John Clay; Jake Fredrick; Dana Sisk; Marcus Thompson; and Zach Woollen.

From 2008 to 2010, AUFSAE pursued an innovative concept in FSAE powertrain – a lightweight, wide vee, super motard racing engine of 550 cc, placed compactly with its crankshaft longitudinal to the car, leading to a shaft drive to a ring gear. Design judges took notice, and the powertrain was a key element that landed us in design semi-finals twice. But the racing engine is tricky, and repeatable, reliable performance was elusive. In the three years of the super motard program, we had one good overall (15th) and two endurance DNF’s. After the 2010 competition, the decision was taken to return to the reliable power of the I-4, 600 cc sportbike engines. The Yamaha variant (R6) was chosen.

The most important development by the 2011 team was project scope and schedule. Since FSAE is a design competition, the team tends to design each entry from scratch. This is a pretty steep mountain for the new team to climb every year, and we have noticed that most of our competitors use a multi-year development cycle. We chose to adopt this style, incorporating our past best practices, and limiting the amount of original design in each new car. 2011’s concept was pulled from many features of our past high-placers, but most closely resembles the 2006 car in overall appearance. On schedule, we resolved never again to finish the car so late that there was not enough time to respond if it didn’t work as planned. The mantra all year was ‘ready for testing by E-Day’ (25 February). [We came close – the car started, idled, and rolled on the 25th, and commenced driving trials one day later.] To finish fabrication early, the design must be complete. A hard freeze of 1 October was imposed on design, and this was met (if the design does not appear to be likely to complete by 1 October, then the design scope is reduced).

We did allow ourselves one major design indulgence – an aerodynamic groundplane with tunnel diffusers. This is our most complete aero analysis effort to date, and is the first time our aero design and fabrication effort has actually made it onto the car. The flat groundplane covered the space between the wheels, and created the necessity for design compromise between suspension roll stiffness and aerodynamic downforce. With no limit on diffuser tunnel height (as limits most racing series), the nozzles extended high and far behind the car.

Our 2011 car weighed in at 489 lbs. (curb). The weight split is 49/51, slightly rear-heavy (desirable) for light drivers, but 50/50 with heavier drivers. Wheelbase is 64.7 in. on 49.9 in. and 49.3 in. front and rear tracks. The Chromoly space frame was covered
by carbon fiber body panels (with a chined shape that avoided loss of newbies to the infinite mold-sanding process!). The Yamaha R6 engine, breathing through the FSAE 20 mm restrictor, tested at 35 ft·lb. We ran the FSAE-specific Michelin radials, and our electro-pneumatic, spark retard shift-without-lift system. Solid state relays with fault-detection capability enhanced electrical reliability.

Day One.5 – Static Events

In Michigan, the car slid easily through Technical Inspection, checking off Wednesday evening. Thursday morning, we had no problems with Tilt, Brake, and Noise.

Design begins with the Design Report, turned in a month early, and read by the judges who will judge the car. The report is non-scored, but gives that vital first impression to the judges, and serves to settle the judging order (better cars are usually judged first). Our time was 9 am. The Event seemed to go well, though we only scored 80 points out of 120 (30 more points are available to cars selected for design finals). Post-event feedback was fairly clear that although we are in the hunt with a well-reasoned and well-built car, the bar is climbing on fit, finish, and design integration. We need to improve our sports car magazine impression. Better quantitative reasoning and analysis to make a supporting case for the design choices would also have helped. Our score put us in a tie for 37th place. The eventual winner of Design (after finals on Saturday) was GFR, with the full 150 points. Other finalists were Graz (both of them), Stuttgart, Munich, and RIT.

The Cost Event includes 40 points for the actual prototype cost, 40 for evaluation and inspection at the event, and 20 for the team’s on-the-spot solution to cost reduction in a system of the judges’ choosing. We did well on discussion on-event (36.1 of 40), and made the full 20 on our cost-reduction solution. But our prototype cost of $15,906 gave us only 14.8 points out of 40, for a total Cost score of 70.96, good for 51st place. Kookmin University won cost with a score of 96.9. The lowest prototype cost was Centro Universitario Da FEW with $9,775. Of course, within the FSAE common-item costing structure, the secret to low reported cost is not sleight of hand, but rather to design for cost from the initial concept on, instead of finding the cost out later, after the prototype is built.
The Presentation Event has never been quite clear whether it is about content (the investment potential of the design) or about presentation values. The answer is that it is probably both. There has to be a good case, and it has to be convincingly and effectively presented. The case depends on revenue and cost – will the design gather enough of a market to generate revenue? Can the design be manufactured, marketed, and supported for a saleable price? What is the cash flow and rate of return? Michael Gay assembled a solid, marketing-oriented presentation with Chris Nau’s support, and pulled down 65.28 points (out of 75) to place 23rd. The top three teams in Presentation were Stuttgart, Singapore, and GFR. In a new effort to improve the breed and spread the education, these three gave their presentations a second time to the whole field. From that demonstration, one might say that spot-on answers and excellent showmanship are the order of the day.

Overall static events put us in 38th place with 216.3 points (out of a possible 325). GFR led the field with 304.8.

Day Two – Short Dynamic Events

We started the morning with Skid Pad, with Nick Durant and Chris Nau doing the driving – two attempts each on a course that does one circle right to settle in and then one for time, then one circle left and one for time. Scoring time is the average of right and left. We ran 5.348 s for 38.92 points and 23rd place. Grip and downforce were good, but throttle modulation through the R6’s characteristic low-rpm dip troubled our drivers a little. University of Applied Sciences Graz won Skid Pad in 5.154 s for the full 50 points.

Acceleration is also run in the morning. Marcus Thompson and Chris Nau still had to deal with that R6 dip, and would have been helped by launch control and smoother clutch engagement. Still, we made 4.370 s for 75 m on our new powerplant, good for 53.26 points out of 75, and 23rd place. Cornell won Acceleration in 3.945 s.

Autocross is everything – the low-end torque so necessary to a good launch in the Acceleration event, the high-lateral-g steady turning of the Skid Pad event, plus an additional metric, the ability to snap-turn quickly into a corner. To do this, we should have achieved a more rearward weight split, and could have enlisted a little more aid from the steering set-up. And then spent more time learning to drive the twitchier car that resulted. But as it was, in this year of overall concept stabilization, we put a premium on easy-to-drive and likely-to-finish. With Adam Clay and Michael Gay sharing the driving, we pulled a best time on the Autocross course of 54.796 s (over approximately 1 km) which put us in 35th place with 63.6 points out of 150. Kansas won the event with a time of 48.151 s.

Our short dynamic event total was 155.8 points (out of a possible 275), 27th best in the field. GFR had the best day with 257.1. Heading into Endurance, we were in 31st place with 372.1 points. GFR led with 561.9.
Day Three – Endurance and Fuel Economy

So far, so good. We could be sitting in a higher place, but to a team shocked with two elaborate powertrain failures in the last three competition years, it felt good that the car was running fine, we had no major bobbles, and were looking forward to a good Endurance Race. The weather was a bit of a concern, though. We had been surprised by not doing as well as we hoped in Autocross, and so had a starting time later in the day. The “spring” sky over Michigan was spitting a bit, and reports came in over the smart phones of worse to come. It was looking like we might have to run on rain tires. Not great news for our prospective Endurance time, but that’s racing – you make the best of it. To get some of that best, three hours before our probable start time (cars go in order, not on a schedule), we headed down to the practice track. The rain tires had not been scuffed in, and our intent was to do a few hard launches to get the grip up. Adam Clay was test pilot. He revved the engine, dropped (well, engaged) the clutch, and the differential shattered. Exploded would be a better word. The rear axle was spitting out chunks of steel and aluminum, the fragments plopping audibly on the ground. The team’s presence of mind was right on top of it. Gather up the pieces (they might have some use). Get back to the paddock. Get the car up on stands and stripped. Start the examination and formulate a plan. The way it came out is this: too much had broken to be able to reassemble the differential; too many fractures of machined parts that had to fit and slide and engage. And no thought of replacement. Our diff was a complete custom job, using parts from 13 year old ATV’s (as in, discontinued 13 years ago), added to our own full-shop fabricated pieces. No one else’s spare stock diff would fit into the car – certainly not within the time available. But the team leadership formulated a plan: there were just enough pieces left that they could be welded together, one fragment on top of another, with a few extra hand-drilled holes and some re-purposed bolts, that the diff remains could be cobbled into a serviceable solid spool. And that’s what we did. With every piece and step a question of “will this work?”, and dropping the car back to the ground while the announcer blared “Auburn University, Auburn University - last call for Auburn University!”, we got Michael Gay suited up and rolled to the starting line.

The drivers were a bit tense. No one knew if the repairs would hold. No one knew how the car would handle with a locked diff. Everyone wanted to finish the race at all costs. Cars that do not finish Endurance get no points, but cars that finish Endurance in too slow a time also get no points. Tricky. But Michael ran well. A little gingerly at first, but faster and faster, and then he started passing cars. Michael finished his 11 laps and handed over to Adam Clay at driver change. And the car restarted (never a given). Adam Clay came out fast, also working down the time as his experience and confidence went up. Soon Adam was making regular passes as well. And then it was over. Auburn had completed the Endurance Race. Smiles and hugs all around. A year of tension and three hours of stark terror had paid off.

We completed Endurance in 1696.875 s, adjusted up 14 s for our 7 cone strikes. That gave us 202.0 points out of 300, and 14th place in Endurance. GFR won Endurance in 1488.288, adjusted for cones to 1502.288. In the related Fuel Economy event, we were measured at 1.171 gal. fuel used (not as good as with the super motard engines, but better than we used to burn with our previous sportbike engine). That was worth 38.0 points.
out of 100 to place 20\textsuperscript{th} in Fuel Economy. Amberg-Weiden placed first, burning 0.619 gal.

**Conclusions**

Adding it all up, we made 612.0 points out of 1000 and placed 16\textsuperscript{th}. We have an overall concept that we like and want to refine, and we know which directions to go in to accomplish that refinement. An experienced team returns for 2012, to be led by Michael Nunnelly as Captain, Adam Clay as Chief Engineer, Powertrain, and Marcus Thompson as Chief Engineer, Chassis. We expect to fix the low-rpm dip with a variable runner length intake system, refine the aero package, and run a dead stock Drexler differential. Oh yes – on E-Day 2012, look to see us in a carbon fiber half tub (from the main hoop forward).

The pity is we can’t keep all the good ones. Chris Nau will be leaving the team, graduating in December, and on-track to earn the Certificate in Automotive Engineering to go with his BME. Nick Durant will finish his BME and Certificate in August [late flash – Nick will join Honda Racing Development in California]. Michael Gay will finish up in Economics at the end of the summer, and looks to continue his relationship with Barber Motorsports. Sean Baker graduates in Electrical Engineering, and Cassidy Horan in Biomedical Sciences. Fair wind and following seas to all of our distinguished alumni.