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BELOW The Rn.10, the first complete design from Radon Sport, sent shockwaves through the Formula Continental community

APPLAUSE FOR THE BANNED

Whatever the outcome of the dispute raging over its legality, **Peter Elleray** believes the innovative construction of Radon's Formula Continental chassis offers the industry valuable lessons

IN THE second part of our look into chassis materials and construction, we made reference to the Radon Formula Continental car, which has created some controversy in the Sports Car Club of America's championships with its hybrid tubeframe/composite panel construction.

I have been fortunate enough to be able to follow this up with a long and very informative conversation with the Radon designer Nathan Ulrich, and can now present here in Race Tech what we believe to be the first in-depth description of the car, and the background to how it came about.

It is both Nathan's wish and my own that we focus on the technology used and the engineering, and so for those who wish to follow the ongoing politics within the SCCA and their members, we once again refer you to the appropriate thread on apexspeed.com. Search for 'Radon' and remember to wear a flak jacket…

WE CAN DO BETTER THAN THAT!

Radon Sport came about as a result of Ulrich visiting the SCCA Winter Nationals at Sebring in January 2009, at the invitation of racer Chris Camadella. There he was reintroduced to Formula Continental. The SCCA's 'F.C' series runs what we in the UK would once have recognised as FF2000 cars, in other words Formula Ford with wings and slicks. The original series was based around the venerable Ford Pinto single overhead cam engine, familiar to a generation of those of us who owned and drove Cortinas, Capris and Escorts. In the mid-1990s the option of using the newer twin overhead cam 16-valve Zetec unit was offered, and the field is now split roughly 50/50 between the two. Ulrich was both surprised and also a little perturbed to see that the technology on the cars was basically the same as it had been 20 years earlier. The late 1990s series of Van Diemen models ruled the roost.

What followed was not quite a case of, "We can do better than that," but it was not far away from it.

A separate company – Radon Sport LLC – was formed, and having decided that the Van Diemen was well developed mechanically but not so impressive aerodynamically, it initially looked at offering some aero upgrades for that car. To do this a full car CAD model of the wetted surfaces was reverse-engineered and CFD employed. A front wing, diffuser and upper rear wing package was produced that used the standard Van Diemen beam wing for structural reasons. Radon also diversified into producing a bespoke 4-pot aluminium brake calliper that offered a stiffer and lighter replacement for the widely used LD20 series that had been around for many years. Ironically, when the time came to design their own car, these were set aside and a partnership formed with Alcon in the UK to use its products instead.

RIGHT The base tubular frame ready to accept the carbon inner panels

That a complete car did eventually emerge

> *“He was surprised and a little perturbed to see that the technology on the cars was basically the same as it had been 20 years earlier”*

BELOW The tubeframe is still central to the chassis function. Here the cockpit ‘inner’ panels are fitted to the far side. Note that the frame runs right through the engine bay

BELOW Once clothed with inner and outer cockpit panels, the tubeframe is effectively hidden

owed as much to Ulrich’s perception that the structural integrity of the regular tubeframe car could be improved in an accident by the use of modern composite materials, as it did to the desire to continue the aerodynamic work that had already been started in the wing package developed for the Van Diemen. Since the first prospective customers were also personal friends a central part of the design concept specified composite front and rear crash structures, lateral crush structures and side impact protection panels. The potential problem was that around 30 lb would be added to the all-up weight in doing so.

Initially it was thought that perhaps the goals could be achieved by maintaining the Van Diemen suspension geometry, which obviously worked well with the tyres available, and designing a new frame and body. It was soon realised that this would compromise other important design goals. So, with what one imagines must have been a very deep breath, the newly-established company and its first-time racecar designer plunged head first into a clean sheet of paper design. What emerged 18 months later was to send shockwaves through the Formula Continental community in the USA.

Perhaps, given Ulrich’s background and his experience with both composite construction and CNC-machined component design, that should not come as a great surprise. After many years of CAD design work for Technique Applied Science he had gained a deep understanding of how to design complex machined structures which could be made in such a way that a profit could be returned. Without this accumulated experience it is difficult to believe that something as intricately detailed as the Radon ▶

In at the deep end

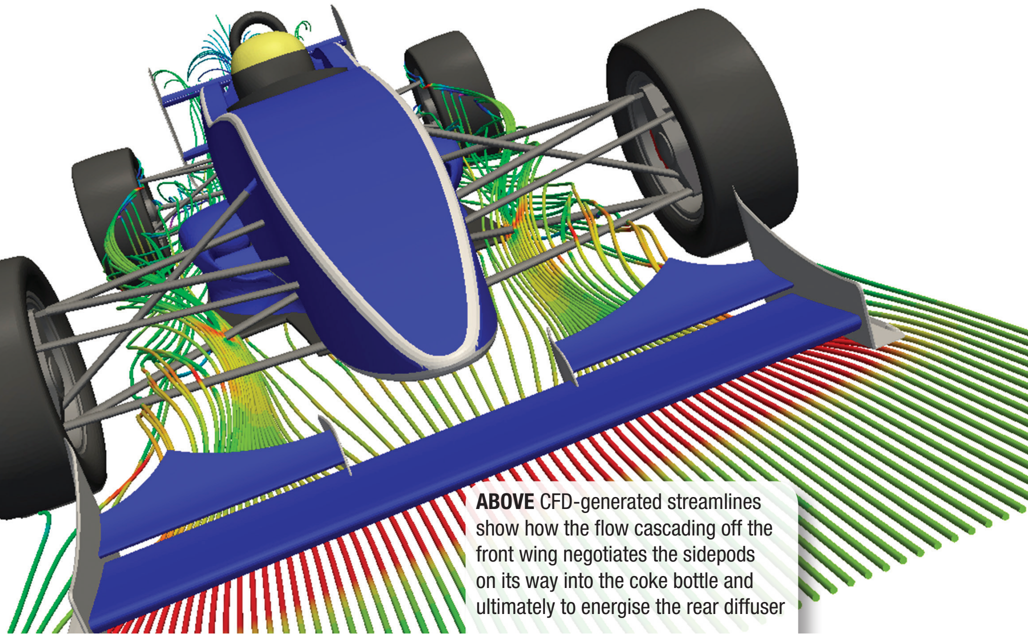
NATHAN ULRICH is both the majority shareholder in Radon Sport LLC and the chief designer. Educated at the University of Pennsylvania, he qualified as a mechanical engineer with both Master’s and Bachelor’s degrees, and then received a Graduate Research Fellowship and numerous academic awards on his way to becoming a PhD in the subject.

The majority of Ulrich’s professional life has been spent as a product designer, as opposed to a racecar designer. He did graduate work in robotics before starting his career at Woods Hole Oceanographic Institution, developing, testing, and operating deep ocean robotics. In 1994 he formed Technique Applied Science,

> **“Inventions ranging from deep sea robots to a power-assisted wheelchair”**

a product development firm, and has invented machines ranging from deep sea robots used for scientific research to consumer products such as kick scooters, electric motorbikes, a power-assisted wheelchair, and the robotic Penn Hand. He has won several awards, been issued many US patents, and has written 15 scientific and technical publications. Not your average route into racecar design, then.

Ulrich started racing with the SCCA in 1993, winning the NERRC and NARRC Championships in his first year. He then raced in World Challenge and IMSA (GTS2) in a Porsche 968 Turbo RS before retiring from driving. Both of these cars were self-built and, in addition to consultancy work in both IndyCar and in F1, represent his exposure to racecar design and engineering prior to the Radon. In fact, the Radon is his first complete racecar design.



ABOVE CFD-generated streamlines show how the flow cascading off the front wing negotiates the sidepods on its way into the coke bottle and ultimately to energise the rear diffuser

could be commercially viable at this level, for it raises the level of detail and execution well above that seen so far on this type of car.

The bigger surprise is that a vehicle that makes use in its major structure of both composite panels and machined aluminium bulkheads could be designed in such a way that it conforms to a set of regulations that were drawn up to mandate tubeframe racecars. That, of course, is the crux of the whole argument currently continuing within SCCA circles.

Ulrich is at pains to point out that the basis of what he was planning to do was submitted to the SCCA back in 2010 and was approved by them at that time. Carbon front and rear crash structures were already permitted, as were carbon cockpit inner panels providing they respected the six-inch centre rule on fasteners, to comply with the definition of a non-structural panel. The Radon complied with the letter of the regulation, but it is fair to say that at the time that the car was conceived nobody had actually envisaged that these inner cockpit panels could then be used in a structural manner. Regulations also specified side anti-penetration panels and the materials that they should use, with carbon not being allowed and some changes were made to the initial design to accommodate this.

Basically then, what Radon has done is to trade-off the additional weight taken up by the use of a structural carbon inner panel by deleting the diagonal members normally found on a tubeframe structure. Top and bottom frame rails are retained, the upper one performing the same job as the composite cockpit rim on a full carbon tub as well as forming the perimeter of the footbox roof. There is a complete hoop at the dashboard and another forming the seatback and main roll hoop to which we will return shortly. A second hoop directly behind the first forms a twin rear hoop. By itself, this twin hoop concept and the perimeter tubeframe meets the FIA rollover criteria without the carbon panels fitted. These are about three to five times more stringent than the minimum SCCA standard. By itself, the frame is fairly strong, but not very stiff in torsion.

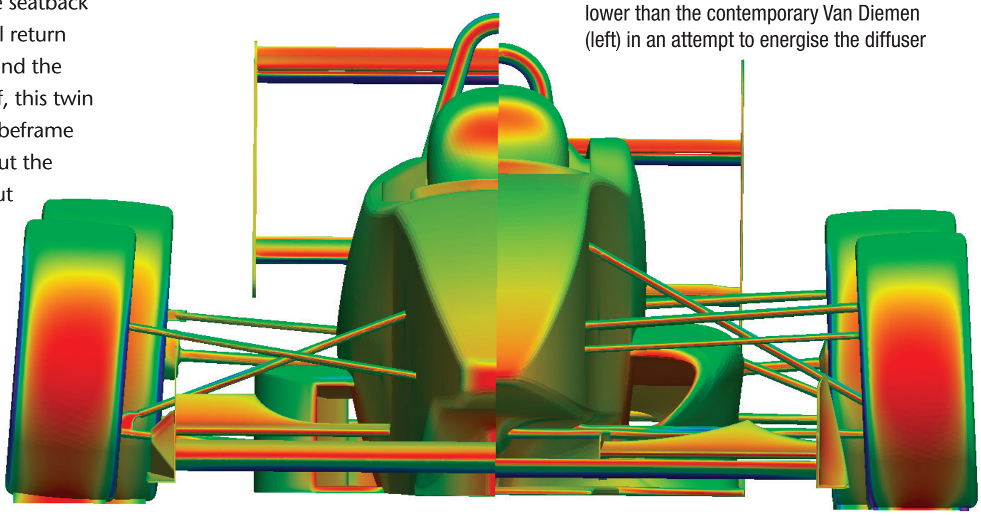
To this perimeter steel structure the inner carbon panels are bolted at the regulation 6″ centres. Outside of these panels the outer bodywork, in glass with an inlay of ballistic material, performs the role of the anti-intrusion panel. This has the added benefit of freeing up some cockpit space that the tubular diagonal members usually occupy as the composite panel can be contoured and moulded to provide the elbow and thigh room that the tubes encroach upon. Or, looking at it in another way, you can design a narrower chassis.

CARBON RADIATOR DUCTS

A similar carbon panel 'triangulates' the scuttle area and pedal box roof. Controversially, the dampers are attached directly to this via aluminium brackets. Finally, outboard of the anti-intrusion panels, the radiator ducts are in carbon and have additional hollow carbon bars bonded to their top and bottom surfaces to take side impact loading.

On the floor and seat back steel panels are welded in place continuously along the perimeter frame. The regulations permit this on the roll hoop structure, and on this car the seat back is also the roll hoop, seat back side frames and roll over hoop being integrated and formed from one continuous Ø1 3/8″ steel tube with multiple bends. A similar panel is mandatory on the floor, and here there is a limit of 1″ on any curvature. This is central to another feature of the car that raised eyebrows when it was first presented but which was perfectly legal at that time if one accepted the above definition of the rear roll hoop.

Retracing our steps for a moment, apart from the safety issues, one of the principal design goals was to improve – dramatically – on the existing aero performance of an FC car. This was also seen as one of the two biggest hurdles, the other being to manufacture the car. In the event, Ulrich was introduced to Robert Perry, who had extensive experience of CFD within the ▶



BELOW This CFD-generated shot shows how the Radon rear wing assembly (right) is much lower than the contemporary Van Diemen (left) in an attempt to energise the diffuser

motorsport industry as well as in aerospace. Perry had consulted on numerous high-level motorsport projects and had extensive experience with CFD (Computational Fluid Dynamics). He in turn introduced Miqdad Ali, an aerodynamicist with a broad range of experience on racing cars as well as in the automotive sector. Between them they handled the aerodynamic design and the CFD analysis.

WAKE INTERACTIONS

Perry's expertise was put to work using OpenFoam software as a basis. This is freeware, available on the net for download, and with the budget available was the only affordable solver. It can handle a steady state, incompressible flow, and can model porosity so radiator duct analysis is possible. He used OpenFoam's hexahedral mesher as a basis and best racecar practice on resolving wake interactions between objects, not just surface flow. Hex cells are less diffuse and offer superior streamwise resolution of vortex structures.

However nothing comes totally free and considerable pre- and post-processing was required. Perry was to write many custom scripts and modify the meshing to his own requirements so that a half car model of 20 million cells could be run on Radon's own linux workstations. Three machines were used, each with eight processors in the form of two Xeon Nehalem quad core CPUs, 1 TB disk space and 36 GB memory. CFD is very CPU intensive and a model of this size took about 12 hours to solve. All of the models used were symmetric, with the car running in straight line conditions. Rotating wheels were modelled. Because of the CPU time involved, many of the cases examined were 'deltas' between design values and not absolute values. The total investment was under $14000.

The aim was to both increase downforce and reduce drag, to create a linear aero feel and reduce sensitivity to ride height as well as pitch. In this regard particular attention was paid to behaviour under braking.

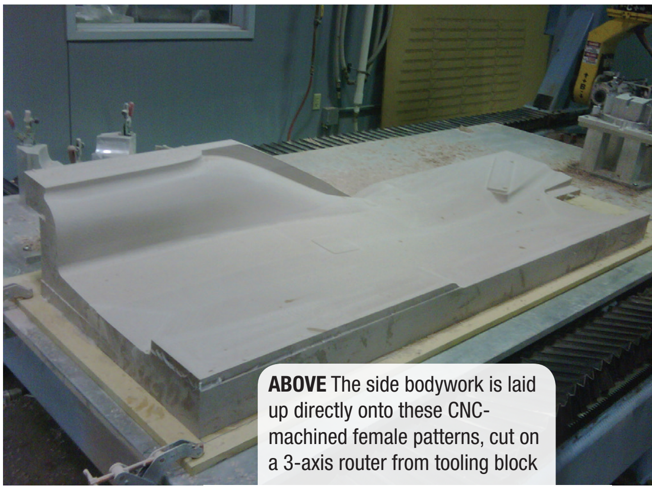
Those goals would be difficult to achieve when staying within the narrow confines of existing FC car architecture. What would be needed was a raised floor that would allow the air to cascade off the front wing and a boatnose under the footbox to channel that air back around the sidepods and through the rear coke bottle. There it could be used to energise the floor via the rear diffuser. By regulation FC cars already had sidepods that are only 900 mm wide, whereas a current F3 car measures 1300 mm in this area.

"The Radon raises the level of detail and execution well above that seen so far on this type of car"

The Van Diemen, being essentially a 20-year-old concept, had a flat floor which stretched from front bulkhead right back to the bellhousing. The frame regulations in force at the time that the Radon was being designed aimed to maintain the status quo by specifying that the floor's "curvature shall not exceed one inch" and maintain this tolerance over its full length as far back as the main roll hoop. Crucially there was no specification on any deviation from horizontal. In a separate section they went on to state that, "The use of 'ground effects' is limited. Deviation of the undertray may not exceed 2.54 cm (1") in the area between the rearmost point of the front tire to the front most point of the rear tire." Thus the rules themselves, perhaps unwittingly, differentiated the aerodynamic 'undertray' from the floor of the chassis.

In 2010 the RFR F2000/Formula Continental car – designed by Van Diemen designer Dave Baldwin and built by Van Diemen founder Ralph Firman – appeared with a fully raised nose. This was possible because a dummy floor, complete with vertical members at the front bulkhead, ran underneath the raised portion and shadowed it. When the car was looked at from underneath, it was flat; when looked at from above, there was a raised footbox and boatnose.

The Radon took a different approach, and for a very good reason. The fundamental problem with the full length dummy floor is that the ride height, and hence aero performance, is controlled by the point at which the front edge of the floor – the splitter – hits the track under heavy braking. On the RFR this is essentially the same as on a conventional Van Diemen. Radon's approach was to separate the chassis floor, the part which must have less than 1" of curvature between front bulkhead and rear roll hoop, from the underbody, which need only be flat to the rear of the front tyres. It does this by angling the chassis floor up as soon as it clears the driver's bum that rests upon it.



ABOVE The side bodywork is laid up directly onto these CNC-machined female patterns, cut on a 3-axis router from tooling block

BELOW The carbon radiator ducts also act as a side impact structure with carbon beams bonded top and bottom

As we have noted, there was no regulation in force to prevent this. A floor that had less than 1" of curvature but which was not parallel to the horizontal section behind the seatback, and hence the undertray, was perfectly legal. It was just that no one had ever read the regulations in this way before.

The geometry is such that to obtain the required footbox height, and accommodate the driver's torso, whilst still keeping his behind down on the undertray line, ▶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the roll hoop must be swept forwards – approximately to where a 45° seatback panel would normally intersect with the floor panel. This is exactly what the Radon chassis with its one-piece roll hoop/seatback frame achieves. The triangular space created below the seat is used to house a six (US) gallon Fuel Safe fuel cell. This 22-litre cell is slightly smaller than that in a Van Diemen but adequate for the typical SCCA 30-minute race.

The fuel cell compartment is closed on the bottom by an 1/8" thick aluminium floor that runs back to the bellhousing. If ballast is required this can be replaced by a steel panel. The rear is closed by a 1/8 thick aluminium bulkhead. Both of these parts, and the interior panels, are installed with fasteners on the 6" centres required by the regulations in place at the time.

Thus the car has a flat chassis floor to the

> ***"Composite construction is accessible and not ridiculously expensive if you approach it in the right way"***

main hoop, although it makes full use of the 1" tolerance allowed, and a flat undertray which is not in contact with that floor throughout its length. This need project no further forwards than the rear edge of the front tyre to comply with the regulations. Around 300-400 mm of splitter overhang are gained in doing this, which translates to a potential reduction in ride height of the order of 10 mm-15 mm. In a formula where there is no minimum pit lane ride height (unlike in the UK where a 40 mm block must be cleared), this gives significant aerodynamic advantages. Radon found that it had indeed made significant gains in underbody downforce – using the Van Diemen as a baseline – and had also achieved its goal of a large incremental gain in overall downforce for a modest reduction in drag whilst maintaining the aero balance.

One interesting aspect of the car is that both the rear beam wing and upper wing are lower than on the Van Diemen. This was done to improve the interaction with the diffuser and hence the floor. Extensions of the rear wing endplates which bring it down to the diffuser are employed to reduce drag and separate the tyre wake from the diffuser. These are curved. The regulations say that the width of this item must not increase behind the centreline of the tyre, which might be taken to imply that they must be straight. But the Radon's panels are the same width at the tyre centre as at the rear, although they curve inwards between these two points. This curvature is then used to flare the tunnel out forwards into the flat bottom and produce a wider throat.

The CFD work was backed up by fixed ground wind tunnel testing in the A1 Wind Tunnel in Charlotte, North Carolina. Fixed ground testing was employed because the only full-scale rolling road facility in the USA costs $4000/hr to hire. Using boundary layer suction but with the limitations of the fixed floor, back-to-back comparisons were obtained with the contemporary Van Diemen. Absolute values of lift and drag were relatively meaningless, so deltas and trends were focused upon. This work backed up the trends found with the CFD study.

RAISED EYEBROWS

Although the aero features on the car have resulted in raised eyebrows, it is the composite side panels which have created the most controversy. Ulrich is adamant that the prime motivation here was safety. He does not believe that he has effected any substantial gains in stiffness or reduction in weight by their usage.

The panels themselves are produced by Fiber Dynamics, which supplies all of the car's composites. This company is headed by founder Darrin Teeter, a self-taught composite engineer whose main business was in supplying the aviation sector. Fiber Dynamics parts can be found on Cessnas and other light aircraft. He has developed a process that uses resin transfer and is analogous to that developed in the UK by Lotus Cars some years ago. Thus the Radon parts are


ABOVE The car features miniature versions of the type of one-piece high-tensile steel hub that can be found on LMP cars or IndyCars. At the left is the splined rear tripod housing

not produced using conventional pre-preg materials, but with dry cloth. This reduces the base material cost and also allows a room temperature cure. In turn this means that lower temperature tooling can be used.

The side panels are moulded on tooling block patterns. The dry carbon cloth is laid down in a similar manner to that used with pre-preg and is vac bagged before the resin is introduced and the component cured. In contrast, the wing sections are produced in machined aluminium upper and lower moulds and employ foam cores. These expand when heat is applied to exert internal pressure and this helps to consolidate the ▶


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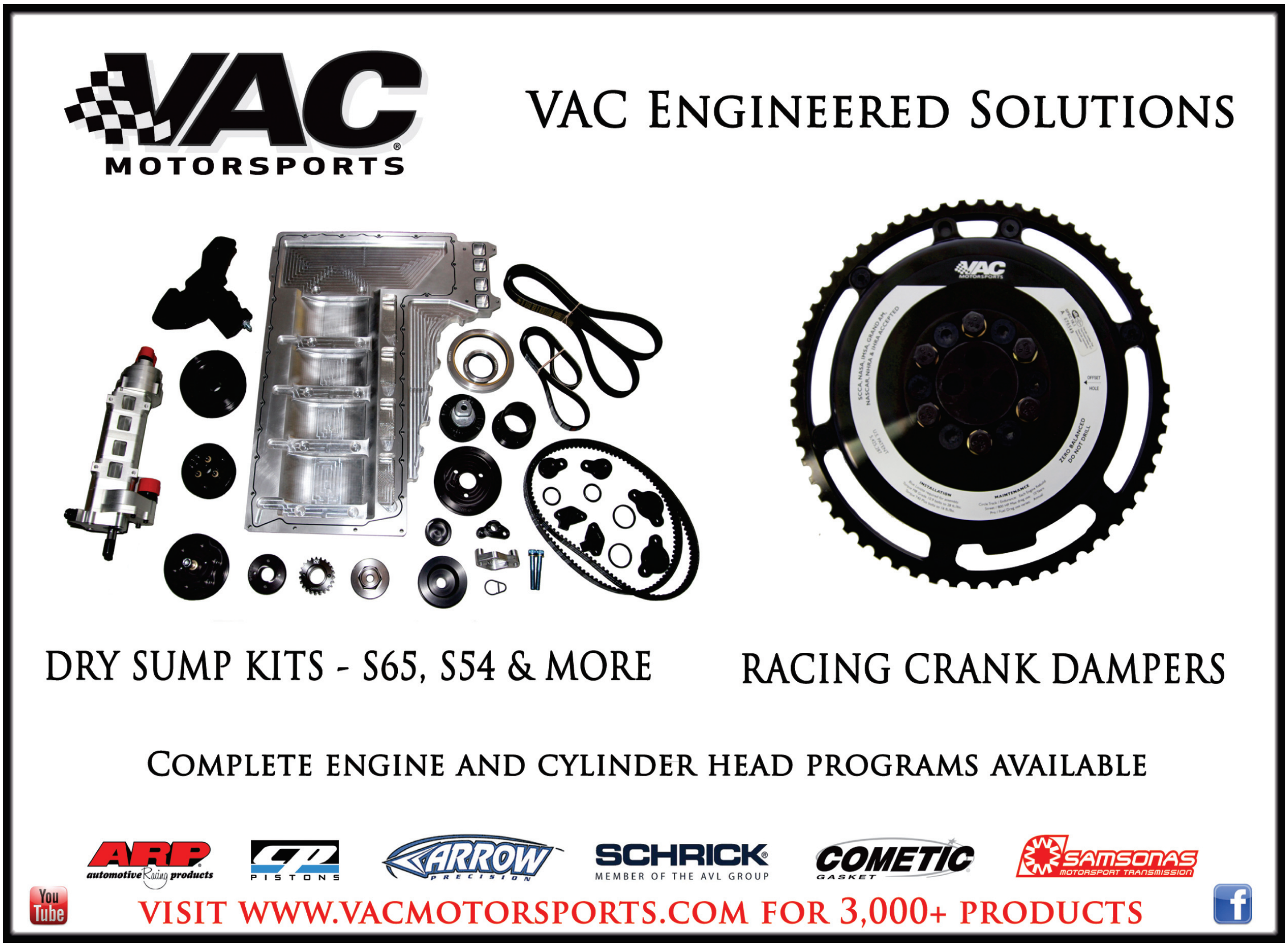
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ABOVE The Rn.10 testing. Where it will end up racing has yet to be decided

final skins. Carbon is not allowed in rear wing construction, so a mix of glass and uni-directional Kevlar is used. Internal spars are created by wrapping material around foam cores and inserting these between the skins before cure. Ironically, given the current price of carbon cloth, a carbon component would probably work out cheaper.

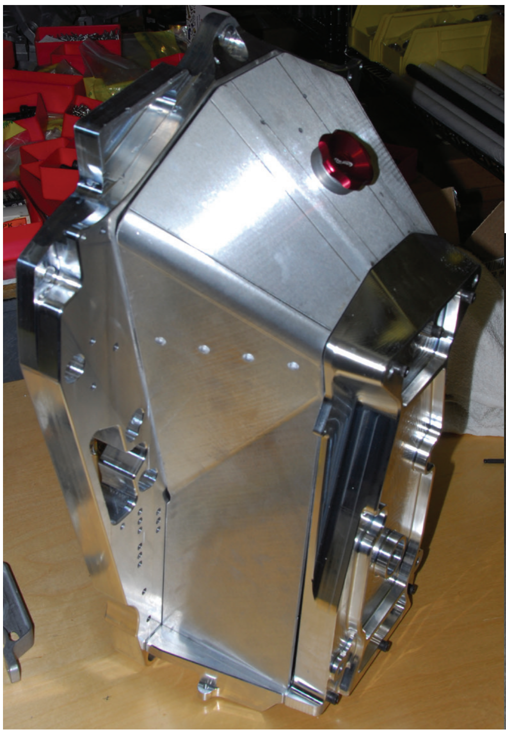
The potential problems with this method of construction might be expected to be dry areas where there has been no resin flow, and extra weight over and above pre-preg with its carefully-regulated resin content. In fact, resin is bled from the component during cure and neither has been an issue. No honeycomb is used in any of the composite panels, and no machined inserts, strength being obtained by tailoring the number of plies of cloth and their orientation. In the modern way, right up until the cloth is actually laid down, the process is completely digital, with Ulrich's CAD files being fed directly to a 3-axis router to create the patterns or tools.

IMPRESSIVE

As impressive are the machined components on the car. Most of the CNC machining is done in-house by Ulrich's company Technique Applied Science but the majority of the turned parts were made by Shawn McClure of HydroCam in nearby Concord, NH. Removing the composite nosebox reveals a machined aluminium front bulkhead which spigots onto the front of the perimeter frame tubes at the four corners. This is used to mount wishbones, rack, anti-roll bar and master cylinder reservoirs and the nosebox itself. The pedal box (see below) is also attached here. However, the most ambitious machining is in the engine bellhousing.

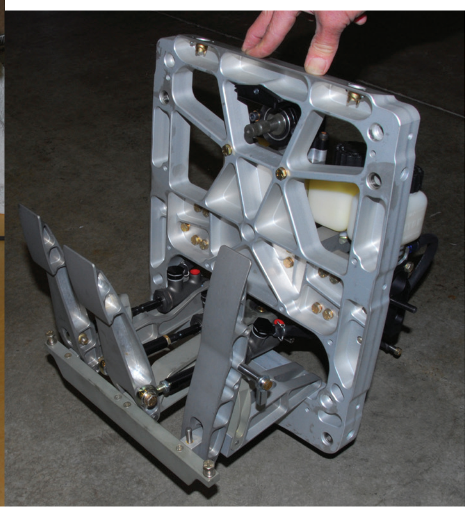
Although a conventional cast magnesium component has been designed, the initial batch of cars are all fitted with what Ulrich describes as his "preliminary solution". I can think of a lot of constructors who would be shouting long and loud about the same part as an example of the latest technology in action...

The bellhousing is fabricated from CNC-machined aluminium plates front and rear and is then covered by a 3/16 (5 mm) thick 6061-T6 aluminium skin. Fasteners are used to hold the parts together for welding but are removed and the holes welded up afterwards. There is no post-weld heat treat. The oil tank is integral, and the assembly incorporates a swirl pot and a couple of internal oil de-aeration features. There were some early problems with leakage which turned out to be through bad welds where there was a lack of penetration. This was in a difficult to reach area, and was overcome by adding a reinforcing gusset. Bellhousings repaired or built by the current welder haven't experienced any problems.



LEFT The fabricated bellhousing has complex machined bulkheads front and rear which are joined by a folded 5 mm aluminium skin to which they are then welded

BELOW The front bulkhead is another machined aluminium part that is multi-functional. This view shows the machined pedal assembly mounted to it



Interestingly, the cost of the fabricated bellhousing, including all the components and welding labour, is just under $1500, which compares reasonably well to a casting in small quantities.

The bellhousing also houses the rear rocker for the pullrod rear suspension. Ulrich schemed both pull and push rod options and opted for pulling primarily because it allowed a lower engine cover and tighter packaging in a critical area for airflow. The final decision was also driven by structural considerations when comparing pullrod versus pushrod angles and load paths.

Front suspension is conventional pushrod, with the lower wishbone picking up on brackets mounted centrally under the floor. It is the style of Formula One cars in the days before geometry went out of the window in the cause of aerodynamics.

The wheel hub is in one piece and machined from 4340 steel whilst the wheel bearing package is quite different to the contemporary Van Diemen. This has a separate hub and stub axle and uses a small diameter wheel nut in a bolted assembly which is surprisingly heavy.

The Radon assembly resembles a scaled down version of a current LMP car, Ulrich pointing out that it is also cheaper to make in this way. Whereas the Van Diemen (and a good few other production racecars down the years) use a road car twin row angular contact ball bearing, Radon has gone to the trouble of having a smaller, matched pair of bearings manufactured to a standard size but with ceramic balls. These are mounted back to back, spaced apart with a small gap to achieve a lighter package that gains stiffness back from the wider effective base between the two rows of balls. This assembly is mounted in an upright machined from 7075 aluminium.

Also of note on the front suspension is the T bar-style rack, a feature shared with the RFR and a difficult area to perfect as the 90° gear drive uses bevels which can be tricky to set up correctly.

Finally, there is a set of machined aluminium pedals that are in turn mounted to their own machined pivot bracket. The master cylinders, which are of the integrally pivoting spherical bearing type, are also mounted to this assembly, which can be moved back and forwards as a unit to suit different driver sizes.

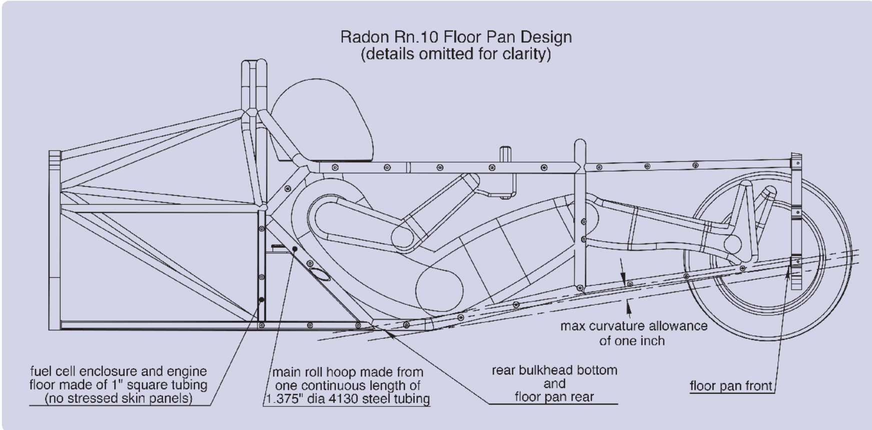
ENTRY-LEVEL INSPIRATION

There are many ideas on the Radon which would work well in Formula Continental and in other 'entry-level' formulae – even dreaded one-make series. The world has changed since the tubeframe regulations that essentially date back to the '70s were devised. Composite construction is accessible and not ridiculously expensive if you approach it in the right way. That 'right way' is essentially what Radon has done using simple structural panels that also provide a means of improving safety. The perimeter tubeframe is still an intrinsic part of the concept.

Similarly, modern CNC machining techniques, when allied to CAD design and file transfer, can produce complicated parts that would have been uneconomical – and probably impossible – to make 40 years ago. The Radon front bulkhead is a good example, yet there have been questions about its legality. Maybe it's time these sort of issues were looked at from first principles, instead of rewriting the last rewrite of the rule book?

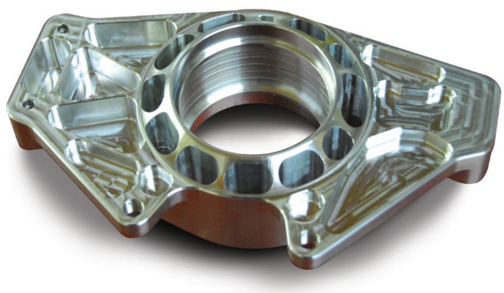
It's sad to have to relate that the end result of all of this effort and expenditure is a car that is currently deemed to be outside of the regulations as they have been rewritten for 2013. The project is not dead, but it is on hold until Radon has assessed what it will take to meet the SCCA's latest rule book. Whatever that turns out to be, Ulrich is adamant that he will not compromise the safety features built into the current version, which, after all, are now widely being adopted throughout motorsport in other categories.

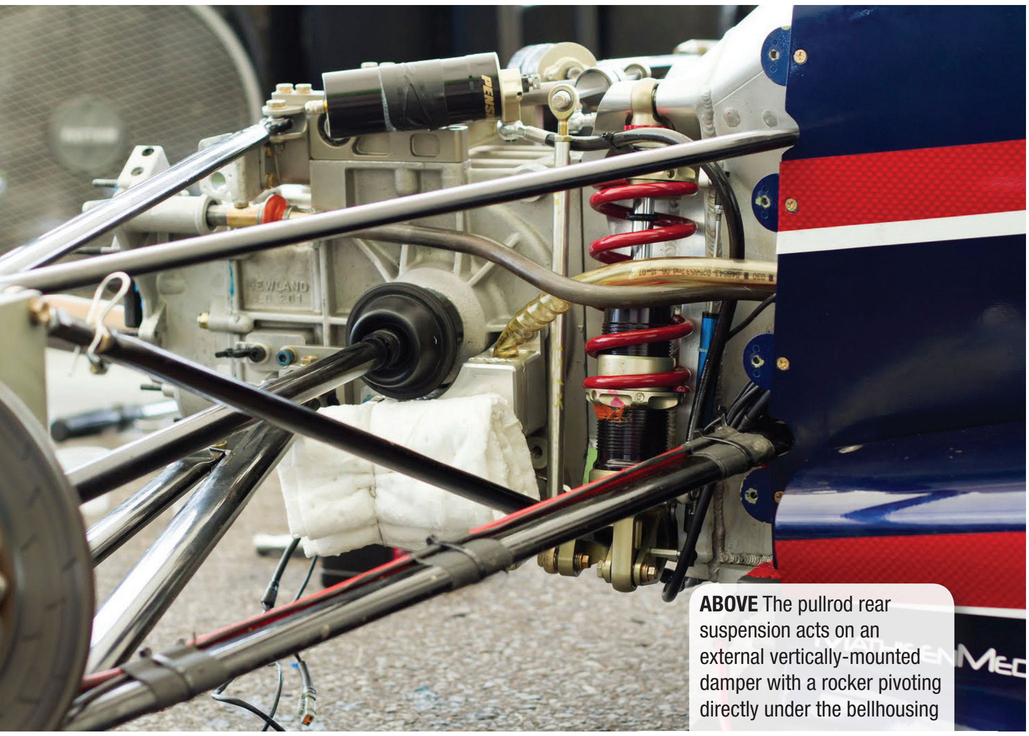
The concern is that in the regulation rewrite it has become more difficult to engineer workable solutions for side intrusion in particular, as well as redesigning other areas of the car to meet the new rule set. Under the new definition of the floor, for instance, the Radon's unique floor design is no longer legal, or even necessary as stepped floors are allowed, but the splitter must now be extended to the front bulkhead as on the RFR, and so in theory a revised car will have to run at a higher ride height. Until these issues are resolved the project, to quote Ulrich, is "mothballed"... RT



ABOVE How the raised nose is done. Remember that flat means flat, not parallel to the undertray...

BELOW Aluminium CNC-machined parts of this quality and complexity are to be found all over the car. This is a suspension upright, machined to take back-to-back bespoke deep groove ball bearings





ABOVE The pullrod rear suspension acts on an external vertically-mounted damper with a rocker pivoting directly under the bellhousing