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PART 2

PETER ELLERAY on chassis construction

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ABOVE All the major single-seater racing categories have now converged on carbon fibre composite construction, with Dallara's tender triumphing in IndyCar, as in so many other series (Photo: LAT USA)

SHEDDING NEW LIGHT ON A DARK ART

Peter Elleray completes his study of chassis construction methods, unravelling the mysteries surrounding carbon composite and looking at a controversial new car that might offer a glimpse of the future

IN PART 1 of this feature we took a look at some of the background to the status quo in racecar structural design. That status quo has resolved into a situation where the material and method of choice is normally moulded carbon composite construction. This now applies right across the spectrum down more or less to the entry-level formulae, where tubeframe construction is still the norm, and indeed is explicitly required in some categories such as Formula Ford.

We have seen that composite construction has become relatively less expensive and exotic as material costs have fallen and the depth of experience which the racecar industry can draw upon has expanded. At the same time the traditional pattern-mould-component process is still inherently labour intensive, and in areas where numerical machine tools can be used to replicate 3D CAD surfaces without hand work, material and machining costs are still relatively high.

As far as tubeframe design is concerned, the requirement to meet safety criteria that derive from those which have been applied on composite chassis for some time has meant that the tube content and fabrication requirements have increased quite significantly. Recent moves to mandate side impact protection have meant that in some cases the basic tubeframe has to be supplemented by composite 'ballistic' anti-intrusion panels, further increasing cost and complexity.

We will return to this theme later, but first it might be interesting to put a few numbers to the materials that we have been discussing. In general terms we usually quantify our fabricated structures, of whatever material content, by their strength, stiffness and weight. When we are discussing metals then this is relatively straightforward. Steel tubes of whatever grade will have a Young's Modulus – the ratio of stress to strain – of around 200 N/mm², and steel will have a density of around 7.86 g/cc. Aluminium sheet, in contrast, will have a modulus of around 70 N/mm² and a density of around 2.7 g/cc. So, the 'specific stiffness', the ratio of stress to weight, of each will be 200/7.86 = 25.44 (steel) and 70/2.7=25.92 (aluminium). The units don't make much sense but it is the ratio that we are interested in. And as we can

ABOVE & BELOW The racecar industry has learnt, sometimes painfully, that specialist knowledge is required to fully exploit the benefits of carbon fibre. This is the layup of TMG's Toyota TS030 sports prototype (Photos: TMG)

see, they are remarkably similar. So, we ought to be able to obtain similar stiffness in each material using a similar weight of material.

However, a structural steel such as T45 steel will have a UTS of 695 N/mm², whilst a lower grade of cold drawn seamless tube may not be much higher than 400 N/mm². The ratio of strength to weight will therefore vary between 88.4 and 50.9, in the above units. A chassis constructed from 4130 'chrome moly tube', a material beloved of many US constructors, will after heat treatment have a UTS of 1000 N/mm² and an impressive 'specific strength' of 127.2. Aluminium sheet such as L163, often used to create flat chassis panels in the 1970s, has a UTS of 380 N/mm², whilst a softer aluminium that can be formed – NS4 – has a UTS of 250 N/mm² in ½-hard form. The variation here then is between 140.7 and 92.6. We can see that these numbers overlap and that we can tailor various parts of our chassis to accept high or low loadings by varying the material type and thickness.

RIDDLE OF EARLY CARBON DISASTERS

When first introduced in the 1980s many racecar people still viewed carbon as some kind of super-stiff, high strength material and were most surprised when their first efforts popped out of the oven softer and less crash-resistant than the metallic structures they replaced. The numbers explain why.

At that time most tubs were constructed using a commercial grade of carbon prepreg known as T300 which is still widely used for bodywork and semi-structural applications but not so much in any chassis which is required to pass an FIA crash and load test regime. The 'headline' figures for T300 are a modulus of 230 N/mm², UTS of 3500 N/mm² and density of 1.6 g/cc, which at first glance would seem to imply the same stiffness as steel but with 3½ times the strength, at 20% of the weight. However, these figures do not take any account of the fact that any composite prepreg has a significant proportion of resin in its all-up weight which plays no significant part in either adding stiffness or strength, other than performing the vital role of stabilising the load-carrying carbon.

> *"The first carbon efforts often popped out of the oven softer and less crash-resistant than the metallic structures they replaced"*

A T300 prepreg sold in 200 g/m² form will typically have around 42% of its weight in resin. When the density of the resin (around 1.2 g/cc) is taken into account, this means that almost half of the volume of the 'composite' will be resin. The end result is that the actual 'weight' of our 200 gsm material will be about 350 gsm – 75% higher.

The situation with stiffness is also more complicated than the headline figure implies. We must first account for approximately half the material – by volume – being resin and having no significant stiffness in itself. We then need to consider the direction in which the fabric is draped. This is generally with the fibres at 0/90° to the direction in which the load will be applied, or +/-45°. In the first case only half the fibres are aligned and the other half of the material plays no significant part in adding stiffness. In the second case both sets of fibres add stiffness but off-axis, and the generally applied factor is only ¼.

To obtain the specific stiffness we can factor the weight (gsm) by the ratio of resin to carbon, and the stiffness by the ratio of working fibres. This would give a specific stiffness figure in the region of 41.7, with the modulus reducing to around 115 N/mm² and the density effectively 2.75 g/cc – very similar to aluminium in effective load-carrying material content but with a higher modulus and so stiffer. When the fibres are aligned at +/45 the figure drops to 21 – lower than either aluminium or steel. In order to avoid interlaminar shear it is generally agreed that it is not good practice to lay down too many ▶

layers back to back having the same ply orientation. The end result is that any layup will normally have a significant percentage of fibres not acting in the direction which would optimise their stiffness (or for that matter strength) and an average specific stiffness might be around 30 – not very much greater than steel or aluminium.

Whilst that may not have been fully appreciated in the early days, the situation was then compounded by looking at the specific strength, making the same corrections for density and UTS by the ratio of resin content and working fibres. For T300 the figure can drop to around 640 N/mm² at 0/90° and 300 N/mm² at +/-45° – still significantly higher than our metals. It was therefore tempting to use less material and hence the actual stiffness, which would be the product of specific stiffness and material content, was not always as high as expected or indeed as high as the aluminium chassis which they replaced. Prediction of weight was usually quite accurate in the early days, whilst analytical techniques for calculating stiffness were usually, sad to say, a country mile away. Hence some red faces.

In practice we obtain high stiffness in composite chassis by using a variety of different types of fibre and quite a lot of them – the requirement to absorb impact and static loads from the FIA tests usually determines how much material we need and the weight and stiffness follows from this. High-strength fibres such as T700 have similar modulus to T300 but with around 40% higher load-carrying capability. A high modulus fibre such as M46J has a slightly higher load-carrying capability than T300 but around twice the modulus.

We also use unidirectional fabrics, where all the fibres – usually of the high modulus type – are aligned in one direction, when we can then count on around 90% of the carbon working for us, at a high level of stiffness, in the direction we require. These are often used in traditionally weak areas such as the cockpit rim of an open single-seater or LMP 1½ seater. In fact, this use of composite can make the single most dramatic impact on increasing chassis stiffness that you can get and was sometimes used on aluminium ▶

> *"Any composite prepreg has a significant proportion of resin which plays no part in either adding stiffness or strength"*

ABOVE Hybrid construction employed as a last resort: when the shell-like carbon tub of the A9 Arrows proved woefully inadequate in torsion (all 28 kgs of it - see the hand-written figure on the inner skin), aluminium honeycomb panels were added to try to stabilise the laminates. The improvement was negligible: what was required was thicker carbon skins and a much thicker cockpit rim

tubs, most commonly of the aluminium honeycomb type, to stiffen and strengthen the base structure.

As we said in Part 1, the bottom line is that the stiffness and strength benefits are there to be had but they are not a given. In just the same way that it takes an understanding of load paths and sensible application of stress analysis to back up good engineering judgement and seat-of-the-pants intuitive design to produce an efficient spaceframe, it requires a certain amount of specialised knowledge to do the same for a composite tub.

Undeniably, this still comes at a cost and there are the other criteria that we investigated last time – crash repair, structural integrity, ease of modification – which mean that at the lower levels of motorsport and in particular, in club racing, a full carbon tub is not a viable option. At this point it should be noted that regardless of this quite a few 'home-built' carbon tubs have indeed appeared in club racing in recent years, some of them put together on a shoestring and in questionable circumstances as regards environment and processes. Some of them though are very good indeed and can show the 'professionals' a thing or two about cost control and efficient, intelligent use of limited resource, but there are also a few around that make you wince when you look inside and hope they are never tested in a crash… And that, perhaps, is one area that we are looking over our shoulders at when considering how we might progress in the future.

Although not generally known about in any great detail in Europe, there has existed in the USA for the past couple of seasons a car that competes in the US Formula Continental (FC) championship, the SCCA's version of what we used to call Formula Ford 2000 in the UK, which is worthy of study in this regard. Over here the cars that raced in the category eventually fell into the 750MC F4 championship (not to be confused with the new MSV F4 series), and some into the various Monoposto categories.

When we think of FF2000 we think tubeframe, GRP body, Ford Pinto engine and wings and slicks. So did everybody in FC until a car called the Radon appeared in 2011. The Radon uses a tubeframe chassis but lacks diagonal bracing. Instead it uses carbon 'anti-intrusion panels' to triangulate the chassis and these are bolted to the tubes at regulation 6" spacing. It also happens that some suspension elements are mounted directly to the composite panels and not to the steel tubeframe below. Inside, the frame and seat structure that incorporates inner side panels almost conceals the tube framework, whilst at the front, when the nosebox is removed, an aluminium bulkhead is used to mount suspension and master cylinders (and, indeed, the nosebox itself). So, again, there are no steel tubes on display, although they undoubtedly form the basis and primary load-bearing structure around which the car is built.

Unfortunately there has been a long-running debate, which might more accurately be described as a re-enactment of the civil war, about the legality of all of this within the basic tubeframe formula that the regulations are written around. It doesn't help that the car also uses a most creative interpretation ▶

ABOVE & BELOW Dark mutterings accompanied the introduction of composite technology to F1. A succession of incidents where cars 'exploded' in accidents, such as Martin Donnelly's shunt in a Lotus 102 at Jerez in 1990, did little to quell cynics' fears that the technology had not been fully conquered (Photos: LAT)

> **"** *Prediction of weight was usually quite accurate; analytical techniques for calculating stiffness were often a country mile away. Hence some red faces"*

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The science of friction **www.apracing.com** of a 'flat bottom', which in FC is not allowed to deviate from 'flat' by more than 1", to produce a stepped floor with approximately 6" of fresh air under the footbox. Those interested can follow the debate on www.apexspeed.com.

BEST OF BOTH WORLDS

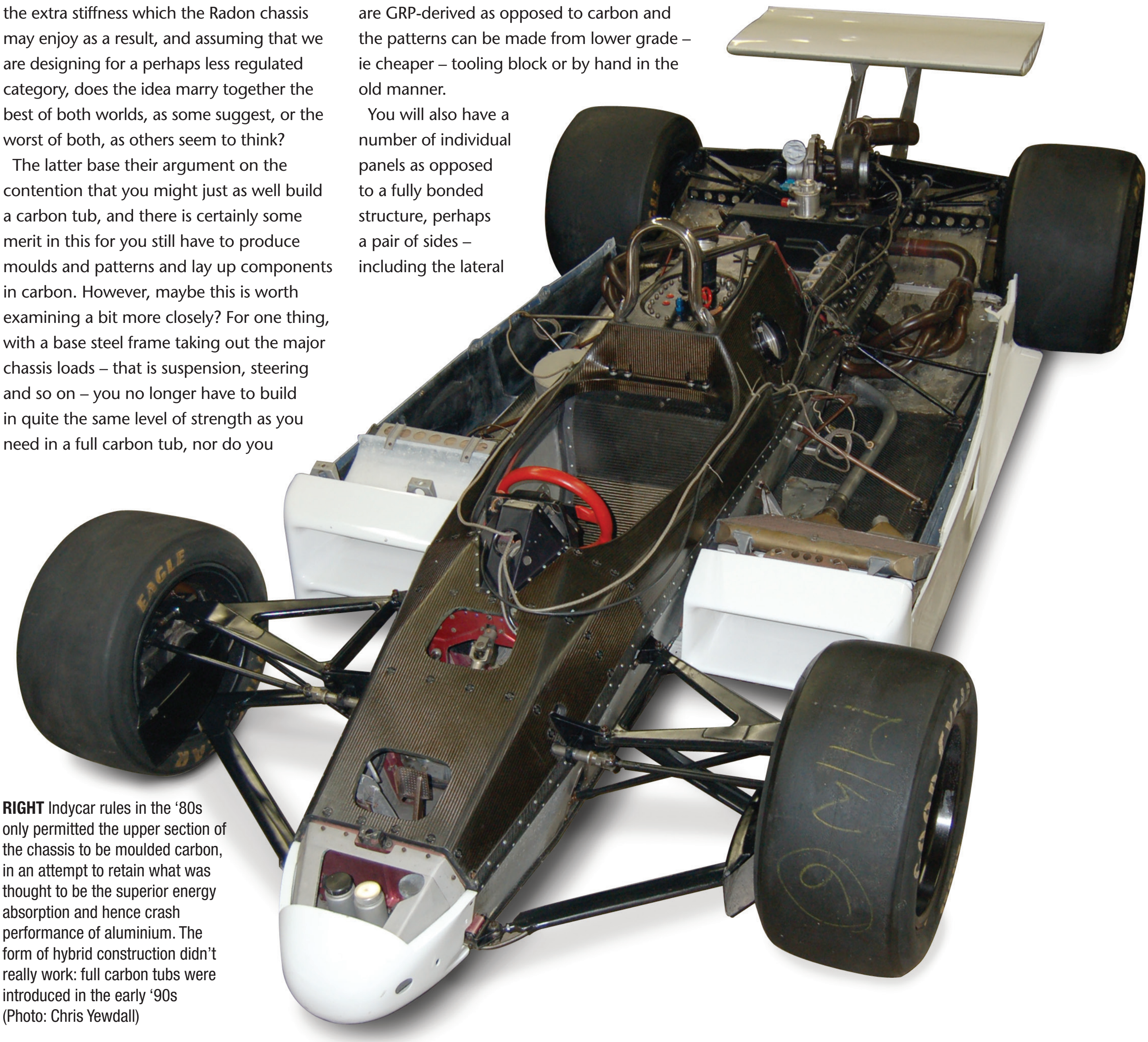
Although the whole Radon saga is fascinating in itself, the relevance here is what we might describe as its composite steel–carbon construction. Regardless of whether it conforms to the existing FC regulations – and the general consensus appears to be that it does not – the concept raises some interesting questions. Putting aside for one moment the concern that many in the SCCA have about the extra stiffness which the Radon chassis may enjoy as a result, and assuming that we are designing for a perhaps less regulated category, does the idea marry together the best of both worlds, as some suggest, or the worst of both, as others seem to think?

The latter base their argument on the contention that you might just as well build a carbon tub, and there is certainly some merit in this for you still have to produce moulds and patterns and lay up components in carbon. However, maybe this is worth examining a bit more closely? For one thing, with a base steel frame taking out the major chassis loads – that is suspension, steering and so on – you no longer have to build in quite the same level of strength as you need in a full carbon tub, nor do you need to go into anything like as much detail as regards insert design, manufacture and bonding. This is significant. On most carbon tubs these are one of the most persistent problem areas and when there is a 'shunt' they are usually one of the first to delaminate. From there your average club racer needs to put his car into specialist hands – or should do. But here the result is essentially a bent frame or lug or a bracket that has sheared off – no more difficult to repair than a true tubeframe design.

If you do not require the same level of strength then you can cook your composite panels at a lower temperature and maybe in an oven as opposed to an autoclave – another advantage of having no structural inserts. That in turn means that you can use tools that are GRP-derived as opposed to carbon and the patterns can be made from lower grade – ie cheaper – tooling block or by hand in the old manner.

You will also have a number of individual panels as opposed to a fully bonded structure, perhaps a pair of sides – including the lateral head protection structures – a scuttle, footbox floor and fuel tank top. So if you do damage them, replacement is a case of unbolting and replacing. If the base frame is stout enough that may well be all you need to do, but at the same time a number of diagonal tubes can be omitted from the frame and simplify its manufacture and save some weight. If this is starting to sound like the way a modern motorcycle is constructed, then maybe that is not such a bad thing.

These panels can of course perform the job of side impact protection – with appropriate use of Kevlar and dynema fibres – as well as being the outer bodywork. Some formulae already allow the use of a full composite nosebox on a tubeframe car ▶



RIGHT Indycar rules in the '80s only permitted the upper section of the chassis to be moulded carbon, in an attempt to retain what was thought to be the superior energy absorption and hence crash performance of aluminium. The form of hybrid construction didn't really work: full carbon tubs were introduced in the early '90s (Photo: Chris Yewdall)

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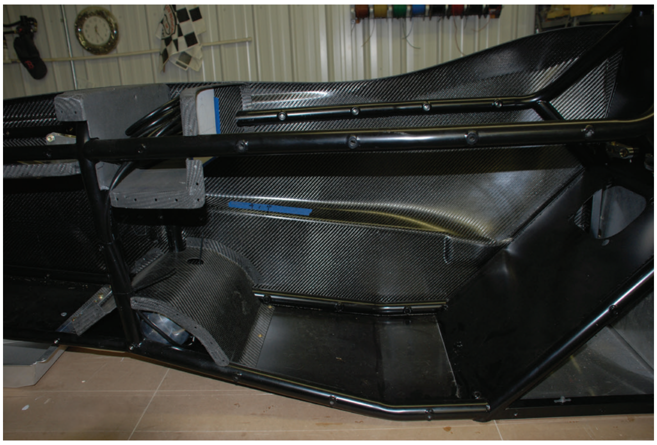
From left to right: Audi Sport head of engine technology Ulrich Baretzky, Caterham F1 performance director John Iley, Lord Paul Drayson of Drayson Racing, Motec commercial director Ross Buckingham and FIA technical director Bernard Niclot

– ironically including FC itself – and so what you have in effect is a semi-composite tub using a steel inner frame that does not in itself form a complete structure. When the two are joined, then you have your full structure.

A number of other details become less challenging. One of the hardest transitions on a composite tub carrying a non-structural engine is between rear bulkhead and engine frame. But here we have a framework that is essentially continuous across this joint, probably with detachable sections top and bottom to remove the motor. Another tricky area can be bolting the steel roll hoop to the carbon tub. This can often require substantial and heavy inserts. But here we are bolting it straight into steel bushes on the inner frame. If we are brave we can integrate it completely.



HYBRID HERESY?

It's a concept which gets more interesting the more you look into it, although the anti lobby may have a point when they say that such a compromise can't hope to match the weight of a composite tub. This is probably true, but if the formula is regulated to mandate the hybrid construction, it doesn't really matter. And we should be able

> *"Compromise is required at the regulatory level to kick-start the once buoyant single-seater racecar industry in the UK"*

LEFT & RIGHT The Radon Rn10 Formula Continental racer uses a tubeframe chassis but lacks diagonal bracing. Instead carbon anti-intrusion panels triangulate the chassis

to claw some of the deficit back by tailoring our composites to impact resistance and structural triangulation rather than an ability to handle high point loadings.

The concept most readily lends itself to formulae below F3, and could be applicable to both single-seater and two-seater categories, but one suspects that there might be some difficulty in getting regulations written for it that achieve the right balance between the amount of load, and work, the steel – ie heavy – section does and that which the composite part handles. In a competitive environment in which there are several manufacturers (which therefore rules out most modern championships…) there would be a natural tendency to migrate to a carbon tub with very little steel inside it.

ABOVE Radon Sport's controversial Rn10 FF2000 car was a clever attempt to bring improved safety to club racing, while making the cost of construction and repairs more affordable.

In some respects, with its anti-intrusion panels and crash-tested chassis, the latest Formula Ford and also the new Formula 4 are not that far away from this specification. Those are fitted to tubeframe chassis which are somewhat more substantial than their predecessors to meet FIA load test requirements, but the panels are still fitted in such a manner that they are not supposed to lend any stiffness to the structure. This is achieved by limiting the number of fasteners and their position. So this approach uses similar technology but does not really attempt to integrate the two materials into a structure. The Radon perhaps goes to the opposite extreme and has scored an own goal in the current legislative climate as a result.

Maybe it will be a case of pushing gently until the residual resistance – which is substantial – is overcome, or maybe it's a step too far outside of club racing. It would be a shame if that were to be the case, for one feels that in the current and foreseeable economic climate some sort of compromise is required at the regulatory level to kick-start the once buoyant single-seater racecar industry in the UK, which for many years had found a healthy market in the USA. FC still exists primarily on the back of the late 1990s family of Van Diemen tubeframe cars. To revive this it would need to be feasible for prospective manufacturers to build cost-competitive cars to a level of safety acceptable to the FIA and MSA that fall one step short of a full on, autoclaved, moulded and bonded carbon tub. Hybrid construction offers one possibility for that. RT